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Technical session 2g: Pile foundations (I): Piled rafts, bearing capacity, and analysis

Séances techniques 2g: Fondations sur pieux (I): Radier sur pieux, capacité portante et analyse

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1 INTRODUCTION

For the session, 32 papers were submitted and the papers cover a wide variety of topics which may generally be categorized under the following major areas:

- Analytical and Numerical Methods: new developments/improvements and parameter studies,
- Model tests: 1g-models, centrifuge model tests and shaking table tests,
- Full-scale tests: static and dynamic tests on full scale piles in different types of soils and back analyses,
- Case histories: analysis of settlement and load sharing behavior of piled raft foundations based on instrumentation data,
- Field penetration tests: New development and improvement of piles bearing capacity equations based on field penetration and boring tests.

The objectives, scopes and results presented by each paper are summarized in the following section. Discussion issues have been also indicated.

2 OVERVIEW OF THE PAPERS

2.1 *Analytical and Numerical Methods*

The papers under this category include new developments/improvements in the analytical and numerical methods and parameter studies using numerical methods.

V.F. Aleksandrovich et al. submitted the paper "On pile and piled raft footing settlement analysis". The paper presents analytical and numerical investigations to justify that the settlement of piled raft foundation is the sum of "solid block" settlement and individual piles "punching through" settlement. Accordingly, they have suggested a new approach for the analysis of the settlement. The proposed method was validated by comparing with finite element analysis. The comparative analysis indicated that the new approach estimates the settlement reasonably while the conventional "solid block" approach underestimates the settlement.

J.E. Bezerra et al. submitted the paper "Optimization concepts for the design of piled raft foundation systems". In this paper, comparative and parametric analysis of piled raft was carried out under general loading conditions. The paper explores the behavior of idealized piled raft situations in which the pile distribution is varied from case to case. The influences of positioning and number of piles in the group on the displacements of the system are observed by the simulations of some situations and configuration. The influences on the maximum and minimum pile loads, maximum and minimum displacements and maximum and minimum bending moments were investigated. The investigation results indicated that pile disposition and loading system affects the overall system. It has been observed that optimization of the positioning and the number of piles in the system provides a great economy for design.

A. M. Harraz et al. submitted the paper "Parameters controlling the capacity of axially loaded drilled shaft foundations in sand, gravel, and cobbles". Results of parameter studies were presented, which were conducted using finite element analysis on drilled shaft. The analyses were carried out to determine the important soil parameters controlling the axial pile capacity of drilled shaft. Two case studies were carried out. In the first case load test results conducted in coarse granular soils and cemented alluvial deposit were investigated. Here, the effects of the values of the angle of friction, angle of dilation and the coefficient of lateral earth pressure were investigated. In the second case, test results conducted in gravelly soil to evaluate the side friction between shaft and soil was analyzed. The effects of modulus of elasticity, side friction and coefficient of lateral earth pressure at rest were investigated. From the study it was found that the soil angle of internal friction, soil dilation angle, coefficient of friction between soil and shaft, and soil modulus of elasticity are the most important parameters controlling the behavior of axially loaded drilled shaft. Also, it was found that the ratio between the horizontal stresses and vertical stresses at failure is higher than the initial coefficient of lateral earth pressure at rest due to the high dilation behavior of SGC soils.

S. Karthigeyan et al. submitted the paper "Interaction between vertical and lateral loads on the response of piles in soft clays". The paper presents the results of 3d finite element analysis of a single pile installed in homogeneous soft clay under individual lateral load and combined vertical and lateral loads. In the finite element analysis the pile was considered as linear elastic and the soil as elasto-plastic material based on Drucker-Prager model with non-associated flow rule. The lateral deflection due to lateral load and combination of lateral and vertical load was investigated. Parametric study was conducted to determine the influences of method of loading, vertical load L/B ratio and pile-head fixity. The investigation indicated that when both vertical and lateral loads are simultaneously applied, the influence of vertical load on the lateral response of the pile is felt only at higher vertical load levels. When the vertical load is applied prior to lateral loads, the influence is noticed at all the load levels. Also, it was found out that the lateral capacities decrease and deflection increase under the presence of vertical loads in general and it is more prominent at higher vertical load levels. The influence of the vertical loads on the lateral response is felt only upto a certain limiting value of L/B for a specified lateral deflections and beyond this value, the piles can be designed as flexible piles under pure lateral load.

D. Milovic et al. submitted the paper "A pile loaded by horizontal force and moment – theoretical and field load test results". The paper discusses the use of in-situ test methods in solving problems related to the behavior of laterally loaded piles. A computer program was developed for the analysis based on finite difference method. Based on analyses of different cases of modulus variations, analytical relations were proposed for displacement, rotation, shear force and bending moment. Results obtained by the proposed method were compared with published results on field load tests. Comparison indicated that the calculated displacements agree well with measured values upto a certain load level (80 kN). However, for higher load level the difference becomes greater. Using the finite difference method, solutions were obtained in terms of non-dimensional coefficients for horizontal displacement, bending moments, rotation and shear forces. The proposed method requires only one soil parameter, namely the modulus of subgrade reaction. The capacity of the proposed method to design practice is evidenced by remarkable agreement between the predictions and published results on field load tests.

A. Noorzad et al. submitted the paper "Dynamic response of a single pile embedded in semi-infinite saturated poroelastic medium using hybrid element". The paper presents a systematic procedure for the dynamic behavior of single pile embedded in saturated semi-infinite poroelastic medium. In the presented model the pile is expressed as row of circular rigid discs, the so called radiation element, which represent the propagation of wave from pile foundation to the unbounded pile medium. The study focused on analytical solution to find out the radiation element stiffness and numerical method to obtain the pile stiffness. Such a combination allows the construction of more realistic simulations. The proposed approach was verified by comparing predictions with the solutions from rigorous methods developed previously. Parametric studies were carried out to investigate the influences of the soil type. Analyses results indicated that the proposed method is suitable to combine with FEM to drive more generally applicable and more computationally efficient solution. It was found that for saturated soil, modeling should be based on saturated poroelastic medium formulation. The results obtained are not reliable considering only one phase material. It is worthy to mention that the predictions of the model are in agreement with earlier results, while its simplicity offers a versatile alternative to rigorous solutions.

S. Perlo et al. submitted the paper "Analysis of laterally loaded micro piles groups using a hybrid method". The paper describes a numerical approach for predicting the behavior of axially and laterally loaded pile groups. A computer code was presented which uses a hybrid method and its ability to solve three dimensional problems as well as pile-soil-pile interaction is demonstrated through analyses of full-scale experiments on laterally loaded micro pile groups.

A. Wada submitted the paper "Bearing mechanism and pile foundation design". The aim of the paper was to investigate the bearing mechanism of pile from the review of large number of pile load tests conducted on cast in-situ concrete bored piles. The data is obtained from a large number of instrumented piles (over 40 piles). The bearing mechanism of piles was established through the analysis of the pile data. The pile adhesion factor and the neutral point of the negative skin friction were evaluated from the bearing mechanism. From the analyses, it was found out that skin friction is mobilized by the pile shaft displacement and its magnitude depends on the order of shaft displacement. Ultimate skin friction is observed at certain depth and this depth shifts downward with increasing pile load. The magnitude of the skin friction depends on pile length. When the pile length exceeds 30m, the skin friction is more that 95% of the bearing capacity of the pile.

J. O. Won et al. submitted the paper "Unified analysis considering pile groups and superstructures". In this paper a unified analysis procedure of pile foundations combined with superstructure was developed by considering the interactions and soil non-linearity. For verification, the method was compared with other computer codes which consider linear and non-linear soil behavior. A series of analysis have been conducted for pile foundations subjected to lateral loads at the pier top. In the non-linear analysis, it was found that the present method is capable of the predicting the behavior of a bridge pier in non-linear soils on the various loading conditions.

J. Yang et al. submitted the paper "End bearing capacity and end settlement of piles in sandy soils". In this paper, a new approach was presented for analysis of end bearing capacity and load settlement behavior of piles installed in sandy deposits based on existing spherical cavity expansion solutions. Based on the spherical cavity expansion theory, the finite strain theory and the energy conservation principle, mathematical relations were formulated for the pile end bearing capacity and load settlement behaviors in sand deposits. A practical framework was proposed to allow for the effects of stress and relative density of the soils and a relationship was suggested. The proposed method is verified using load test data. Comparison of predictions using the proposed method with load test results demonstrated that the proposed method can provide fairly accurate prediction of the end bearing capacity and settlement of piles in sand soils.

Generally, the progresses made in the area of numerical and analytical methods are appreciable. As indicated, the newly proposed methods were validated by comparing with finite elements and some with other rigorous methods. For example, as shown in figure 1, Noorzad et al. validated their method by comparing with rigorous methods. Here a question may be raised about how reliable is the other method in tackling a given geotechnical boundary value problem. So, to validate newly proposed methods it would rather be better if comparisons are made with measured results like for example by D. Milovic et al. in figure 2.

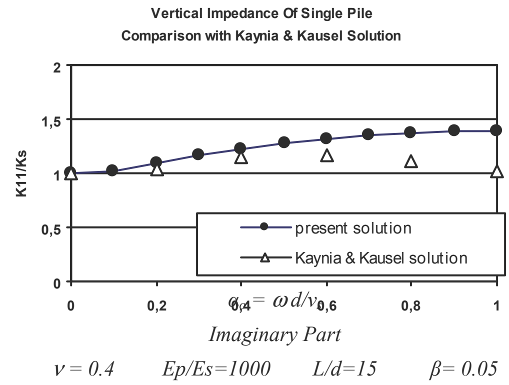


Figure 1 Comparison of new method with rigorous methods (Noorzad et al.)

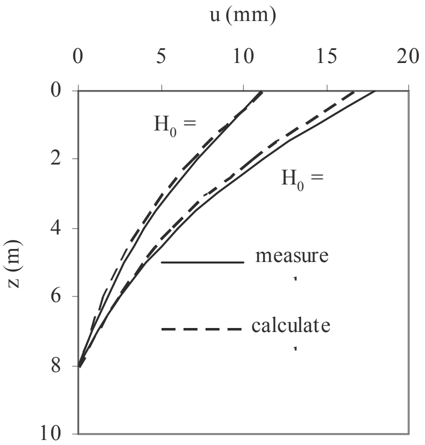
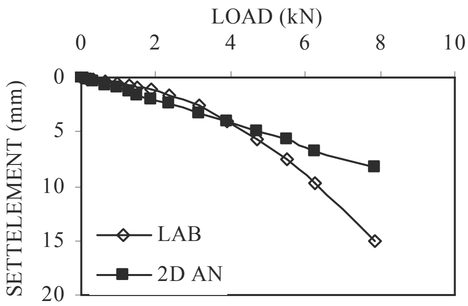
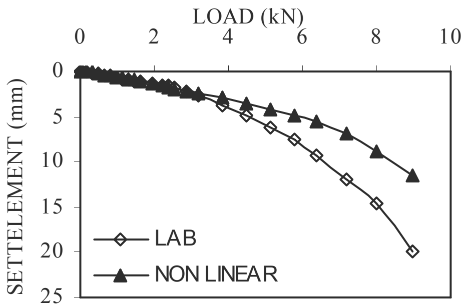


Figure 2 Calculated and measured values of horizontal displacement (D. Milovic et al.)

In some of the methods validated by comparing computed results with measured values, the differences observed were between 20% and 30%. For example, according to V. Balakumar et. al. the difference between measured and computed values of load-settlement curves are as shown in figure 3 for linear and non-linear analyses cases.



(a) linear analysis



(b) non-linear analysis

Figure 3 Comparison of load-settlement behavior (Balakumar et al.)

According to A. Bouafia et. al, the difference between measured and predicted lateral deflection of piles is as shown in figure 4. According to them about 20% variation was observed.

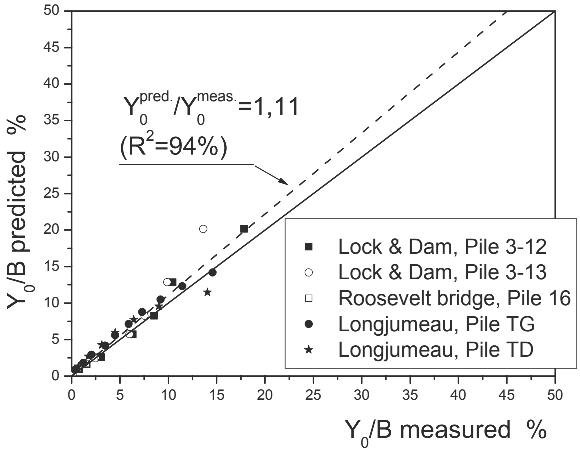


Figure 4 Comparison of predicted and measured deflections (A. Bouafia et al.)

According to R.Q. Countinho et. al., the maximum variation in measured and computed lateral deflection of pile is about 20% as shown in figure 5.

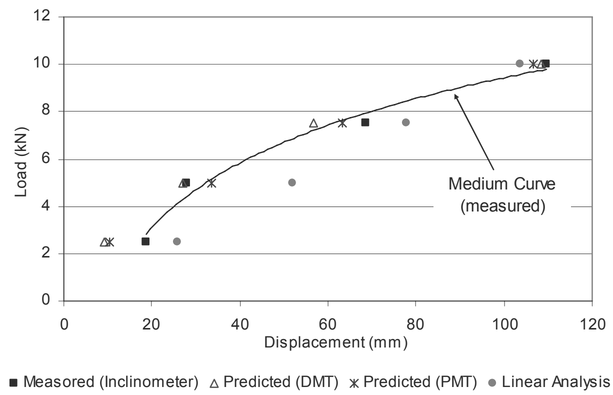


Figure 5 Predicted and measured displacements (Countinho et al.)

Here an issue may be raised for discussion regarding the limit to be considered to accept or not accept such comparisons, i.e. what should be the maximum acceptable difference between computed and measured values? In the finite element analysis (e.g. Balakumar et. al), it has been observed that the implementation of linear and non-linear soil models gives considerably different results. So, it is also very important to set a limit for which cases should be linear and non-linear soil models implemented.

2.2 *Model tests*

The papers presented under this section deal with 1g-model tests, Centrifuge model tests and shaking table tests. Brief descriptions of the papers are given below.

V. Balakumar et al. submitted the paper "Experimental and analytical study on the behavior of circular piled raft on sand". The objective of the research was to understand the load sharing and settlement reduction behavior of circular piled raft on sand using 1g-model test and linear and non-linear finite element analysis. In this regard, 1g-model tests were conducted on raft, piled raft and pile groups in medium sand. For the numerical analysis, the equivalent pier method was adopted. To validate the experimental results, an axis symmetric finite element analysis (both linear and non-linear) was carried out. From the model tests, it has been found out that the pile group of the piled raft takes much higher load than the free standing groups. The investigation indicated that the load sharing factor is much higher at the initial stage and then falls rapidly with settlement and tend to become more or less constant as the settlement increases. The influences of pile parameters such as length, diameter, and number of piles on load sharing and settlement reduction are brought out through the equivalent pier concept. Among the parameters investigated, the length of the pile highly influences the load sharing and settlement.

A. Boominathan et al. submitted the paper "Static and dynamic behavior of piles in clay". To investigate the bending behavior of single pile embedded in soft clay, static and dynamic load tests were carried out on model aluminum single pile. From the static test it was observed that the deflection occurs steadily with applied lateral loads for all piles. The maximum bending moment occurs at a depth of about 5 times the pile diameter from the ground level. From the dynamic test it was observed that the bending moment reaches the maximum at the fundamental frequency of the soil-pile system due to larger inertial force mobilized near resonance region. The dynamic bending moment towards the pile tip does not reach zero which indicates that even the lower part of the pile affect the pile head response to the inertia loads applied at the pile head. The depth of the maximum bending moment under dynamic load is about 2 times higher than that of the static case. This indicates that the active pile length is higher for dynamic load that necessitates the additional pile length required under dynamic load. The ratio of the maximum bending moment for static and dynamic cases indicated that the maximum bending moment for dynamic case is mobilized by about 2 times the maximum static bending moment for short piles and 3 to 4 times for long piles.

D. Chang et al. submitted the paper "Inertia and spreading load combinations of soil-pile-structure system during liquefaction induced lateral spreading in centrifuge tests". A series of dynamic centrifuge model experiment were performed to study the combination of inertia and lateral spreading soils loads on piles in liquefied and laterally spreading ground. Two of them included simple superstructures on pile groups embedded in gentle sloping soil profile with a clay crust overlying liquefiable loose sand overlying dense sand. In the tests, the superstructure inertia and cap inertia were obtained by accelerometer recordings. The system was shaken with series of scaled earthquake motions. As a result the non liquefiable crust spreads laterally down the slope on top of the liquefiable sand, imposing a large crust load on the pile foundation, which along with the inertial force from the super structure and the cap forms the main loads on the pile foundation during earth quake shaking and lateral spreading. The experimental results indicated that the peak shear force on the pile foundations could be reasonably estimated as the sum of the peak crust load and the peak inertia load. The fact that liquefaction results in relatively long period crust loads is an important considerations when evaluating whether inertial and lateral spreading loads will likely be inphase or not.

O. Jenck et al. submitted the paper "Experimental small scale analysis of a piled embankment". The model presents results obtained from physical model tests. Parametric studies were carried out based on physical model tests. The purpose of the investigation was to evaluate improvement of embankments under railways, roadways and industrial buildings using rigid piles.

R. Katzenbach et al. submitted the paper "Combined piled raft foundation subjected to lateral loads". In this paper results of model tests were presented which were carried out on piled-raft, raft and pile groups subjected to lateral load. In the study, horizontal loading tests were performed on small scale models of combined piled raft foundations, raft and pile groups. Dry sand was used and the sand is placed in the model container by "sand raining" technique. Half of the tests were conducted in loose sand and half of the tests were conducted in dense sand. During the tests, the raft settlement and horizontal displacements were measured with high resolution displacement transducers. The vertical movement of the sand surface was also observed using displacement transducers. The axial forces at the top and bottom, the lateral forces at the top and the bending moments with depth were measured. The test results indicated that the application of "sand raining" technique leads to reproducible densities of the model sand. Regarding the horizontal displacement, the test results indicated that for combined piled raft the values are dependent on the vertical load level. The displacement decreases with increasing vertical load level. For free standing pile groups, the lateral displacement relation is not dependent on the vertical load level. The test results indicated that the horizontal resistance of combined piled raft foundation is about 2.5 to 6 times higher than that of free standing pile groups. For small lateral displacements, the major part of the horizontal load is carried by the raft. With increasing displacements, the proportion of the load carried by the raft decreases. The load share between piles and raft leads to significantly smaller horizontal pile forces and bending moments of the piles of the combined piled raft foundation compared to the pile group. The distribution of the horizontal loads between the piles of combined piled raft foundation depends on the vertical load level. The settlements of combined piled raft foundation and free standing pile group depend on the vertical load level.

P. Kitiyodom et al. submitted the paper "Analysis of vertical and horizontal load tests on piled raft models in dry sand". In order to evaluate the reliability of a method developed by the authors for the analysis and design of piled raft foundation, comparative analysis was made between static centrifuge model test results and numerical analysis. The back analysis of the centrifuge model test results were carried out using a computer program called PRAB. Analysis of load settlement and load sharing behaviors indicated that for vertical loading, there are good agreements between the calculated and measured results. Even though the proposed method is simple, the out come of the analysis indicated that the method can be used with confidence as design tool for piled raft foundation subjected to vertical as well as horizontal loads.

L. W. Kong et al. submitted the paper "On the strength of gassy fine sand and model tests of pile foundation". In this paper the bearing capacity of piles was investigated in gassy sand soils. In order to demonstrate the influence of biogenetic gas on the shear strength of sand, suction controlled direct shear and triaxial tests were conducted under various suction and net stress. The shear strength equation for gassy soils was validated based on the test results. Then model tests were carried out on piles in sand with various matrix suction values. The pore water pressure and the pore air pressure were controlled independently. The penetration resistances of model piles were measured. In order to simulate the variation of dry density with gas release, consolidation tests were conducted by decreasing the pore air pressure gradually. The investigation results indicated that the ultimate bearing capacity of model piles is evidently influenced by the dry density and matrix suction of the sand and increase with increase of dry density and matrix suction. The investigation indicated that the baring capacity of piles in gassy sand will increase with gas release. However, the increasing amplitude of the ultimate bearing capacity is different at stage of gas release.

O. Kwon et al. submitted the paper "Load sharing ratio of raft in piled footing on granular soil by model tests". In this paper, results of parametric studies were presented, which were carried out to investigate the behavior of piled footing through model tests and numerical and analytical analysis. Model tests were carried out on piled raft, free standing pile group, single piles and raft and the influences of different parameters on the behavior of piled raft were investigated. The model tests were conducted using dry sand. The load settlement, group efficiency and load sharing ratio behaviors were studied experimentally and numerically. From the analysis it was concluded that the piles take major portion of the total load at the initial stage of loading but after yielding, considerable proportion of the total load is transferred by the raft. It was also observed that the group efficiency of piled footing is higher than that of a free standing pile group under all conditions, and it increases as the pile spacing becomes smaller, as the number of piles increases and as the density of soil becomes looser. The raft has considerable influence on the group efficiency in loose sand but not in dense sand. The load sharing ration of raft depends on the pile spacing, the pile length, relative density of sand and settlement levels. Comparison of experimental results with numerical and analytical methods indicated that the numerical analysis overestimate the results whereas the analytical method underestimate the model test results.

T. Matsumoto et al. submitted the paper "Influence of superstructure on behavior of model piled rafts in sand under shaking tests". The paper presents investigation of the influences of the height of the gravity center of superstructure on the behavior of model piled raft based on shaking table tests. For the investigation, model piled rafts with superstructures were constructed. The superstructures were constructed in such a way that the gravity center could be varied. Dry sand was used for the model test. A series of seismic tests and horizontal static tests were carried out. The test results indicated that the resonant frequency in decreased as the height of the gravity center of the super structure is increased. At a low input frequency, the behavior of the modeled piled raft having superstructure of low gravity center under seismic loading is similar to the behavior of the model piled raft subjected to static horizontal loading. Even if the horizontal response accelerations of the gravity centers of the superstructures are the same, the inclination of the raft, the shear forces and the bending moments of the piles are increased as the height of gravity center of the structure is increased. The results demonstrated the importance of the consideration of the height of the gravity center of the superstructures in seismic design of piled raft foundations.

Y. Suzuki et al. submitted the paper "Characteristics of lateral ground force acting on piles in laterally spreading soil". The objective of the paper is to describe the mechanism of lateral ground force acting on piles in laterally spreading soil based on shaking table tests and to examine the factors affecting the forces. Two series of shaking table tests, one with quay wall and the other with out, were conducted. A design earth quake was used as an input motion with maximum acceleration levels from 1.5 m/s^2 to 5 m/s^2. Acceleration and displacement of a structure and a quay wall, pile bending moment, and acceleration and pore water pressure in soils between piles, outside piles and near quay wall were measured. From the measured data, soil shear stress, shear strain, effective normal stress, relative displacement and relative velocity between piles and soils, and lateral ground force acting on the piles were evaluated and compared. From the investigations, it was found out that the lateral ground force acting on a pile in laterally spreading soil as well as in liquefied soil has the characteristics of solid ground due to decrease in excess pore water pressure and recovery of effective normal stress after liquefaction. The lateral ground force acting on a pile near a quay wall becomes 9 times larger than the maximum inertial force at a pile head in the laterally spreading soil.

A. Tejchman et al. submitted the paper "Model tests of piled raft foundation". In the paper, the results of model tests regarding interaction between piles, slab and subsoil for various numbers of piles and spacing are presented. For the model test, the soil used was fine quartz sand. Model tests were carried out on piled raft and pile groups. The load-settlement curves obtained from the model tests indicated that an increase of piles number under the raft caused an increased piles' contribution at the cost of raft which was restricting its interaction with the subsoil to the external area outside of the group of piles. The model tests performed allowed the determination of the piles and the slab contribution in transmission of loads for different number of piles and its sets. It was observed that the contribution of the raft decreases with increasing number of piles in the group. Based on the slab effectiveness coefficient it was found that the bearing capacity of piled raft is higher than the algebraic sum of the raft and pile group capacity working independently.

K. Tokimatsu et al. submitted the paper "Effects of pore pressure response around pile on horizontal subgrade reaction during liquefaction and lateral spreading in large shaking table tests". The objective was to investigate the variation of pore water pressure around a pile on p-y behavior during liquefaction and lateral spreading. For the model tests, the soil was constructed in three layers including top dense sand, liquefiable sand and an underlying dense gravelly layer. For some tests, the homogeneous liquefiable sand layer was used. An artificial ground motion, produced as a design earth quake, was used as an input base acceleration to the shaking table. To evaluate the effect of pore water pressure on p-y behavior, the displacements of the ground and pile were calculated from the double integration of accelerations and sub grade reaction from the double differentiation of bending moment with depth. The effect of pore pressure response on the sub grade reaction of the pile during liquefaction was investigated. From the tests it was observed that the increase in the horizontal sub grade reaction in the liquefied level ground is caused by the reduction in earth pressure on the extension side. The pore pressure reduction on the extension side is more remarkable in the soil outside the pile group than in side the pile group. When the ground moves down stream in the laterally spreading ground, the extension stress state accompanied by large dilation develops on the down stream side, with the compression stress state on the upstream side. When the ground moves upstream, the stress state developed on both sides of pile are considered to be unloading accompanied by small dilation.

As mentioned above, V. Balakumar et. al, O. Kwon et. al, and A. Tejchman et. al, presented 1g-model test results on vertically loaded piled raft foundation. As shown in figure 6 and figure 7, there observations were more or less similar.

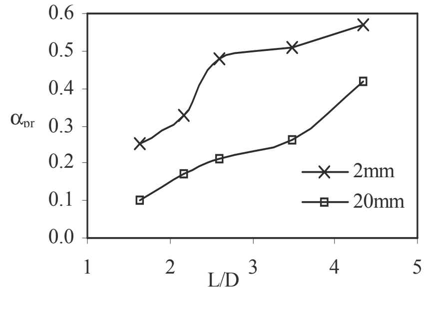


Figure 6 L/D Vs α_{pr} (Balakumar et al.)

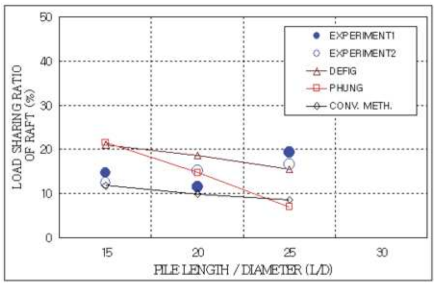


Figure 7 Comparison of load sharing ration along pile length (Kwon et al.)

R. Katzenbach et. al, P. Kitiyodom et. al, and T. Matsumoto et al. presented results of 1g-model tests, centrifuge model tests and shaking table tests on piled raft respectively. The objectives were to investigate the behavior of combined piled raft foundation under lateral load.

Katzenbach et al. conducted static 1g-model tests as shown in figure 8.

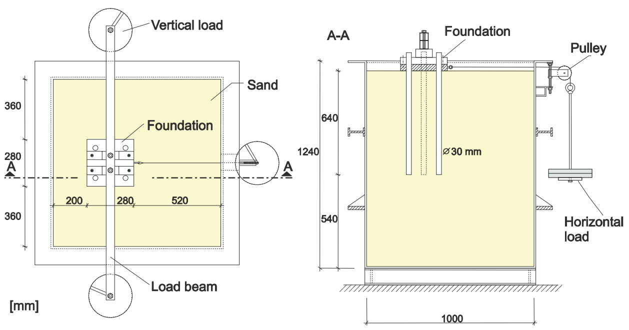


Figure 8 Plan view and section of test box with CPRF (Katzenbach et al.)

Kitiyodom et al. conducted centrifuge model tests as shown in figure 9.

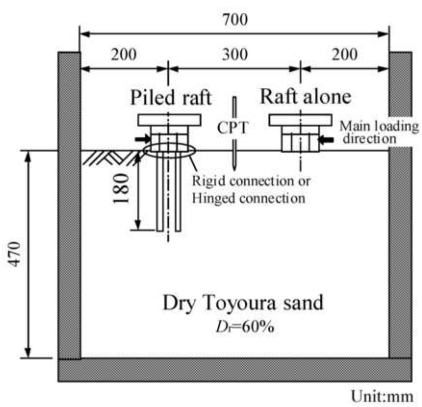


Figure 9 Schematic figure of centrifuge package (Kityodom et al.)

Matsumoto et al. conducted shaking table tests as shown in figure 10.

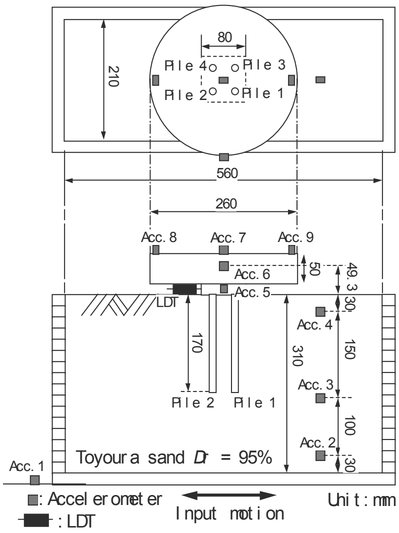


Figure 10 Test setup for seismic load test (Matsumoto et al.)

In order to investigate the effects of liquefaction and lateral spreading, D. Chang et al. and Y. Suzuki et al. conducted centrifuge model tests and shaking table tests respectively. The effects of laterally spreading is schematically indicated in figure 11.

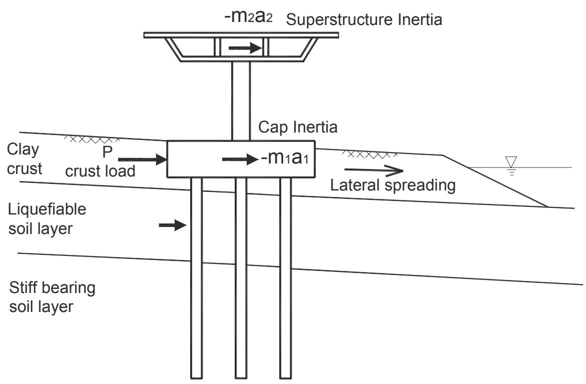


Figure 11 Schematic of pile-supported structure in laterally spreading ground (D. Chang et al.)

Generally, the data obtained from the model tests are very valuable. The results of the static 1g-model tests are useful to understand the load transfer and deformation behavior of combined piled raft foundations in sand and subjected to static horizontal loads. Such types of investigation results are very rare despite the large number of investigations conducted on vertically loaded piled raft foundation. However, the static 1g-model tests do not consider the effects of liquefaction and lateral spreading which are very important in earth quake areas. In fact, if liquefaction and lateral spreading are not expected, the dynamic load acting on pile may be modeled by an equivalent static horizontal load. Based on their static centrifuge tests in dry sand, Kitiyodom et al. supported this idea. On the other hand, if liquefaction and lateral spreading are expected, precautions must be taken in applying the results of static 1g-model tests and centrifuge model tests. Suzuki et al. mentioned that during Kobe earth quake in 1995, the lateral spreading force caused serious damage to the pile foundations. Therefore, for such cases, the lateral spreading test results from centrifuge model tests (e.g. Chang et al.) and Shaking table tests (e.g. Suzuki et al.) would rather be more appropriate.

Moreover, the shaking table tests by Matsumoto et al. considered the influence of height of gravity center of the superstructure which is very important in earth quake design. The 1g-model test and the centrifuge model test do not consider this parameter. So, it is important to investigate further and clarify the issue in how to incorporate the effect of this parameter by the other two tests. Or, it should be clarified, what the effect would be when this parameter is not considered.

In addition, the responses of combined piled raft foundation subjected to lateral load with the presence of vertical load are shown in figure 12. From the figure one can see that the lateral deflection decreases when the vertical load increases.

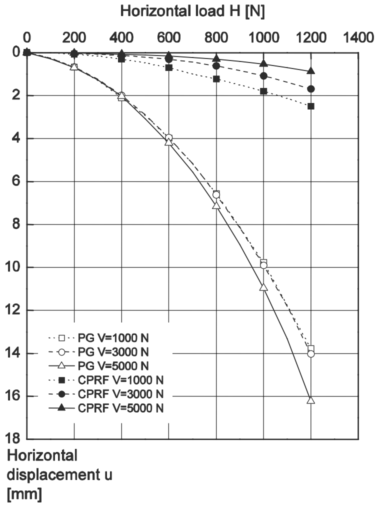


Figure 12 Horizontal displacement of CPRF and pile group in dense sand (Katzenbach et al.)

On the other hand the numerical analysis results presented by S. Karthigeyan et al. and J. O. Won et al., shown in figure-13 and figure 14 respectively, indicated that the lateral deflection increases when the vertical load increases.

The reasons for these two contradictory results shall be investigated further and explanations should be given.

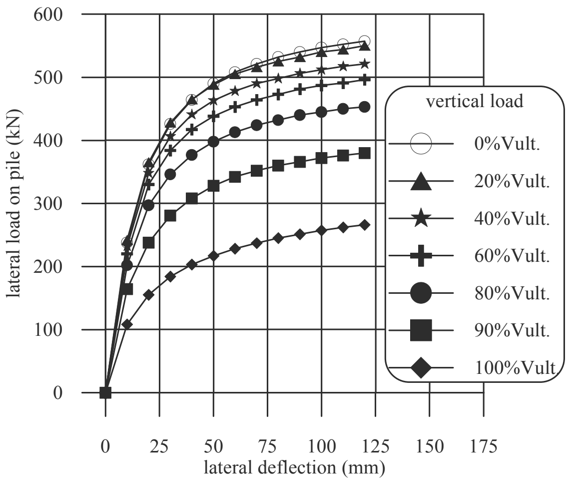


Figure 13 Lateral load-deflection relationship of free headed pile (Karthigeyen et al.)

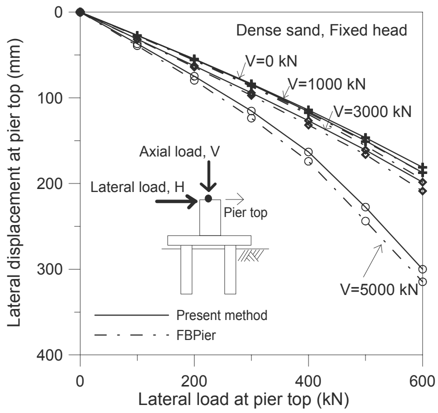


Figure 14 Load transfer curve (Won et al.)

2.3 *Full Scale Tests*

The papers under this category deal with full scale tests and back analysis of experimental results. The full scale tests and the back-analyses were used for different purpose. Some are used to establish analytical relation and verify. Some are used to evaluate the performance of field measurement techniques and some are used to solve actual project problems.

A. Bouafia et al. submitted the paper "Analysis of P-Y curves for single piles from prebored pressure meter test". To drive the p-y curves, results of sixteen full-scale horizontal pile loading tests in different soil conditions were analyzed. The bending moment and deflection curves were derive from the analyses of the test results. The procedure of constructing the p-y curves was validated by back computations of all the test piles. Computed deflections were found to be in good agreement with the experimental results. The analyses indicated that there exist fundamental relation between the p-y curve parameters and the lateral soil resistance. The important influence of the slenderness ratio and the pile soil compressibility on the p-y curves was demonstrated. Based on their relationships, hyperbolic functions were proposed to describe p-y curves for single piles. Validation procedure was undertaken by computing other case studies reported in the literature. Comparison of the predicted deflection and the measured deflection showed good agreement.

T.Y. Bui et al. submitted the paper "Back analysis of O-cell pile load test using FEM". In this paper a back analysis was carried out to evaluate the performance of Osterberg Cell pile load test. O-cell tests were conducted and the results were back analyzed using 3D finite element analysis. To compare equivalency of the O-cell test to conventional pile load test, a conventional load test result was simulated in the same finite element method. Comparison of the calculated pile load distribution and unit skin friction with measured values indicated that there is a close match. Comparisons of the O-cell test results, conventional load test results and finite element analysis indicated that generally there is very little difference between the computed and measured values. O-cell tests can provide a reasonable evaluation of the soil-pile interaction and equivalent pile top load-settlement curves. The end bearing load-movement curve obtained from an O-cell test gives a slightly stiffer load-movement response than that of conventional test due to shorter load transfer distance between the pile tip and the point of load application. Thus the end bearing of the O-cell test is mobilized much earlier as compared to that of conventional static pile load test. The equivalent pile top head-down load-movement curve of the O-cell test simulated by finite element method gives a slightly stiffer load-movement response and higher ultimate capacity than the conventional load test.

C. H. Chen et al. submitted the paper “Analysis for forced vibration test on a proto-type pile foundation in TSIP”. The objective was investigation of the ground vibrations induced by high-speed rail. Investigation was conducted on a prototype bridge. A bridge supported on four large diameter piles was built and a series of forced vibration tests were conducted on the pile foundation. For the forced vibration test, exciters which can generate harmonic force were mounted on the surface of the pier top. Sensors were used to monitor the decay of ground vibration with respect to distance. A maximum distance of 150m from the foundation center was considered for the observation. To express the attenuation of ground vibrations with respect to distance, the point load Raleigh wave model is adopted. Then a linear elastic finite element analysis was conducted. Test results indicated that the vertical responses are generally larger that the horizontal responses. The responses increase with frequency. The attenuation coefficient increases with respect to frequency. The analytical model adopted can effectively simulate the dynamic responses of the foundation and the surrounding soils. Predicted response fit quite well with those obtained from the field test. The forced vibration test conducted on the prototype pile foundation can be used to investigate the characteristics of the ground response induced by the vibration of the foundation system.

R.Q. Countinho et al. submitted the paper “Steel pile under lateral loading in a very soft clay deposit”. Experimental tests were conducted on laterally load steel piles driven into organic clay deposits. Analytical predictions of the horizontal displacements of piles top and estimations of the buckling loads of the steel pile in very soft soil were carried out using linear and non-linear finite element analyses. In the analysis the soil was modeled by p-y curves obtained from dilatometer and pressure meter tests. Comparison of measured and computed results indicated that the non-linear analyses results are very close to the measured values. Buckling load analysis indicated that the critical load is considerably sensitive to the effect of accidental displacements which decrease its value. As observed from the non linear analysis, lateral displacements reduce the vertical loading capacity drastically in soft clay deposits. The lateral displacements obtained through the non-linear analysis by using p-y curves are sufficiently in accordance with the results measured in the lateral loading tests.

K. M. Rollins et al. submitted the paper “Static and Dynamic Lateral response of a 15 pile group”. In this paper, to improve the understanding of the lateral resistance of pile groups, series of static and dynamic lateral load tests were conducted on full-scale pile groups in cohesive soils. A single pile test was also performed for comparison purposes. Compressive geotechnical investigation was carried out to define the soil profile and properties at the test site. Then, static and dynamic load tests were conducted on a single pile group and on single. Investigation results indicated that group interaction effects significantly reduced the lateral resistance of piles in the group for a given deflection relative to a single isolated pile. Reduction in the lateral resistance was a function of row with in the group rather than location with in the row. The front row piles carried the largest average load which was similar to single pile. The resistance decreased successively from second to third row, but then remained roughly similar for subsequent rows. It was found out that p-multiplier could adequately account for group effects. The load deflection curves suggest significant damping even with the presence of gaps around the piles.

2.4 *Case Histories*

The papers presented under this section discuss results of field measurements implemented for actual projects to monitor the performances of piled raft foundations.

S. Geffen et al. submitted the paper “Raft and piles foundation of a silo”. The paper presents the effect of time on the distribution of loads between raft and piles. It describes the study of an instrumented piled raft foundation in clay with bored piles arranged concentric circles. The piles were instrumented with strain gauges and pressure cells were fixed between the raft and the sub grade. Extensometers were placed between the raft and the pile heads in order to measure relative vertical displacements. Measurements were recorded continuously. The records helped to understand the mechanism of the interaction between pile-raft-soil. The measurements showed large changes in the load distribution between the piles and the raft in the early days, but remained stable for about two years. At the beginning, the load distribution between the raft and the piles was not according to the calculations or according to predictions, and changed frequently (figures 15 & 16). This indicates that to ensure safety and serviceability of constructions under difficult geotechnical conditions, the observational method is very important.

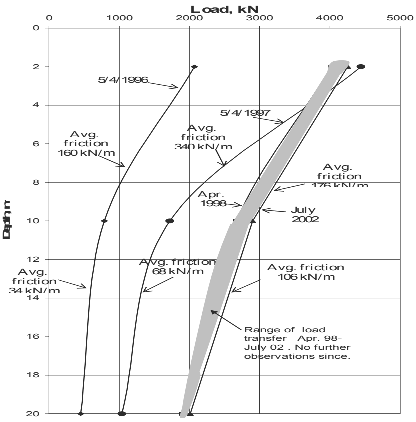
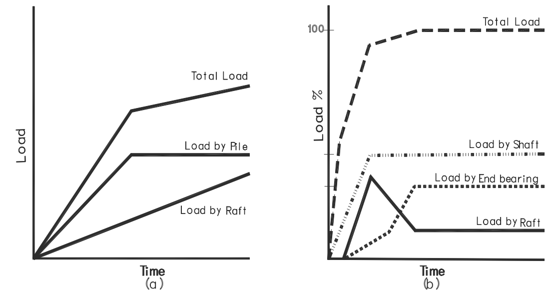


Figure 15 Load transfer pile/soil (Geffen et al.)



(a) classic (b) real

Figure 16 Load transfer – schematic model (Geffen et al.)

Y.C. Tan et al. submitted the paper “piled raft with different pile length for medium –rise buildings on very soft clay”. In this paper a design approach is presented in which the foundation of a medium-rise building is designed using skin friction pile of different length. An interactive design approach for piled raft foundation of 5-storey building is presented. The piled raft consists of piles with varying lengths. Longer piles are placed at the central portion of the building and progressively shorter piles towards the edge. In the design, the overall settlement behavior and the pile-soil-interaction were analyzed. A monitoring program was successfully carried out and the results show that the foundation system adopted show that the foundation system performed satisfactorily.

In the above mentioned project, in order to control the performance of a piled raft foundation system adopted for a 5-storey apartment building, the differential settlement and angular distortions were measured at different points. From the monitoring, it was observed that the measured values were with in the permissible limit. This shows that the foundation system adopted performs satisfactorily. This is again another very good example how observational method is essential to ensure the safety and serviceability of geotechnical projects.

2.5 *Field Penetration tests*

The papers presented under this section deal with the application of field penetration tests and boring tests to establish bearing capacity expressions.

V. T. Ganpule submitted the paper "Estimating geotechnical capacity of bored cast-in-situ piles from penetration resistance". The paper presents a semi-rational method of evaluation of the end bearing resistance and socket friction from the penetration energy required for developing borehole. A relationship was established for the penetration resistance ratio in terms of the energy required to advance 1 cm borehole using both chisel/bailer and auger system. Then a relation is proposed for the bearing resistance in terms of the penetration resistance. Theoretical comparisons were made with the dynamic pile formula and SPT-method. Field test data were used in validating the proposed method. From the comparison of the pile dynamic data and penetration resistance worked out, it can be seen that the method is fairly reliable for piles in weathered rock. In clay and sand, the method has good agreement with dynamic tests. However, it requires improvements using more data.

G. Hannink et al. submitted the paper "reduction of cone resistance caused by the installation of CFA piles". In this paper, comparisons were made between cone penetration test results conducted before and after the installation of continuous flight auger piles. The relevant articles in the Ditch code were verified by comparing results of cone penetration tests before and after installations of continuous flight auger piles. The verifications were done based on data from projects in the Netherlands. Investigation results indicated that the reduction of the cone resistance below certain depth (about 10m) appears to be significantly smaller than above that. This difference can be attributed to the decreasing effect of the installation towards and under the pile base. The results of the cone penetration tests made before and after the installation of continuous flight auger piles, show a large scatter in the calculated reduction factors. The installation effect is not constant around the pile, and decreased with increasing distance from the installed pile.

H.G. Vestberg et.al submitted the paper "Penetration resistance and the bearing capacity of small-diameter steel piles". The objective of the study was to improve the relationships between the penetration resistance of piles and their ultimate bearing capacity and examine the currently used allowable axial load capacity. Static loading tests were conducted to failure on a set of four 50mm diameter piles driven in stratified soil formation. From the investigation it was found that a relaxation of the current penetration resistance criterion is possible.

From the above mentioned works, it has been observed that bearing capacity expressions were suggested for piles. In fact the progress made is appreciable. However, since the expressions are sort of empirical relations, precautions shall be taken in the applications of the expressions for cases different from those the methods have been established for.

3 CONCLUSIONS

As it has been mentioned the papers submitted for this session span a wide variety of topics. Some of the papers present new developments and some are improvements in their respective area.

In the papers submitted in the areas of numerical analysis and analytical methods, new developments and improvements were presented. The methods were validated by back-analysis of model test results and full-scale test results conducted on pile rafts, pile group and single piles. In most cases, the comparison between measured and predicted values indicat good agreement. This shows that significant progress has been made in the area. However, there are issues which still need further clarification.

The papers in the area of model-test present investigation results conducted on pile rafts, pile group and single piles using 1g-model test, centrifuge model test and shaking table model tests. Influences of different parameters like pile length, number of piles, pile spacing and diameter of piles on the load-settlement and load sharing behaviors of pile-raft foundations subjected to lateral and vertical loads were investigated by different authors using 1g-model tests. The results obtained are very important to understand the performance mechanism and the soil-structure-interaction behavior of pile-raft foundations. In fact all the model tests were conducted in dry sands. This will limit the application of the experimental results to pile-raft foundations in clays or in general other types of soils. The data obtained from the centrifuge model test and shaking table tests are very useful to understand the influences of inertia forces and forces due to lateral spreading on piles in liquefiable soils.

The papers submitted in the area of full-scale tests present results of parametric studies on the bearing behavior of piles in different types of soils. Valuable data are presented in the papers.

Some papers were also submitted in the area of geotechnical case histories. The case studies include investigations of the performance of pile-raft foundations based on field instrumentations and performances of pier foundations in granular soils. The case studies conducted on pile-raft foundations indicate some discrepancy between measured and predicted values from theoretical models. This confirms that the observational method is very important in monitoring the performance of complex geotechnical projects like pile-raft foundations.

In the papers submitted in the area of bearing capacity estimations based on field penetration tests, new/improved relationships were formulated. Validation of existing methods and improvements were done based on penetration tests. The bearing mechanisms of piles were studied based on field load tests and penetration tests. The investigation results give better insight to the understanding of piles bearing mechanism and interpretation of penetration test results. This is a valuable contribution to the geotechnical practice. However, care shall be taken in applying the expressions for cases other that those being developed for.

REFERENCES

Alexandrovich, V.F., Barvashov, V.A., Bobyr, G.A., Fedorovsky, V.G., Kurillo, S.V., Skorohodov, A.G. 2005.
On pile and piled raft footing settlement analysis. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*

Balakumar, V., Kalaiarasi, V., Ilamparuthi, K. 2005. Experimental and analytical study on the behaviour of
circular piled raft on sand. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*

Bezerra, J.E., Cunha, R.P., Sales, M.M. 2005. Optimization concepts for the design of a piled raft foundation. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*

Boominathan, A., Ayothiraman, R. 2005. Static and dynamic bending behaviour of piles in clay. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*

Bouafia, A., Lachenani, A. 2005. Analysis of P-Y curves for single piles from prebored pressuremeter test. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Bui, T.Y., Li, Y., Tan, S.A., Leung, C.F. 2005. Back analysis of O-cell pile load test using FEM. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Chang, D., Boulanger, R.W., Kutter, B.L., Brandenberg, S.J. 2005. Inertial and spreading load combinations of soil-pilestructure system during liquefaction-induced lateral spreading in centrifuge tests. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Chen, C.-H., Ko, Y.-Y., Chu, H.-C. 2005. Analysis for forced vibration tests on a proto-type pile foundation in TSIP. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Coutinho, R.Q., Horowitz, B., Braga, J.M. 2005. Steel pile under lateral loading in a very soft clay deposit. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Ganpule, V.T. 2005. Estimating geotechnical capacity of bored cast-in-situ piles from penetration resistance. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Geffen, S., Birnbaum, I. 2005. Raft and piles foundation of a silo. *Proc. of 16th ISSMGE, Osaka, Japan.*
Hannink, G., van Tol, A.F. 2005. Reduction of the cone resistance caused by the installation of CFA piles. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Harraz, A.M., Houston, W.N., Houston, S.L., Walsh, K.D. 2005. Parameters controlling the capacity of axially loaded drilled shaft foundations in sand, gravel, and cobbles. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Jenck, O., Dias, D., Kastner, R. 2005. Experimental small scale analysis of a piled embankment. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Karthigeyan, S., Ramakrishna, V.V.G.S.T., Rajagopal, K. 2005. Interaction between vertical and lateral loads on the response of piles in soft clays. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Katzenbach, R., Turek, J. 2005. Combined Pile-Raft Foundation subjected to lateral loads. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Kitiyodom, P., Matsumoto, T., Horikoshi, K., Watanabe, T. 2005. Analyses of vertical and horizontal load tests on piled raft models in dry sand. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Kong, L.-W., Guo, A.-G., Chen, J.-B., Liu, G.-S. 2005. On strength property of gassy fine sand and model tests of pile foundation. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Kwon, O., Lee, S., Oh, S., Choi, Y. 2005. Load sharing ratio of raft in piled footing on granular soil by model test. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Matsumoto, T., Fukumura, K., Oki, A. 2005. Influence of superstructure on behaviour of model piled rafts in sand under shaking tests. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Milovic, D., Djogo, M. 2005. A pile loaded by horizontal force and moment – theoretical and field load test results. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Noorzad, A., Noorzad, A., Masoumi, H. 2005. Dynamic response of a single pile embedded in semi-infinite saturated poroelastic medium using hybrid elements. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Perlo, S., Frank, R., Degny, E., Estephan, R. 2005. Analysis of laterally loaded micropile groups using a hybrid method. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Rollins, K.M., Snyder, J.L., Broderick, R.D. 2005. Static and dynamic lateral response of a 15 pile group. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Suzuki, Y., Adachi, N. 2005. Characteristics of lateral ground force acting on piles in laterally spreading soil. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Tan, Y.C., Chow, C.M., Gue, S.S. 2005. Piled raft with different pile length for medium-rise buildings on very soft clay. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Tejchman, A., Gwizdała, K., Krasiński, A., Słabek, A. 2005. Model tests of piled raft foundation. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Tokimatsu, K., Suzuki, H. 2005. Effects of pore water pressure response around pile on horizontal subgrade reaction during liquefaction and lateral spreading in large shaking table tests. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Vestberg, G., Mann, G., Holtz, R.D. 2005. Penetration resistance and bearing capacity of small-diameter steel piles. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Wada, A. 2005. Bearing mechanism and pile foundation design. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Won, J.O., Jeong, S. 2005. Unified analysis considering pile groups and superstructures. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*
Yang, J., Tham, L.G., Lee, P.K.K., Yu, F. 2005. End-bearing capacity and tip settlement of piles in sandy soils. *Proc. of 16th ISSMGE Conf., Osaka, Japan.*