General Report of TC 212
Deep Foundations

Rapport général du TC 212
Fondations profondes

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ABSTRACT: This general report is prepared from the selected 62 papers of 18 ICSMGE which are related to the domain of studies for ISSMGE Technical Committee TC 212 – Deep Foundations. Paper IDs 1691~3105, which are presented during two sessions of TC 212 – Deep Foundations are from 26 member societies, which include Algeria (1), Argentina (1), Australia (6), Brazil (7), Bulgaria (1), Canada (3), China (2), Finland (2), Denmark (1), Egypt (3), France (4), Germany (1), Hungary (2), India (2), Iran (1), Italy (1), Japan (4), Korea (3), Mexico (1), Netherland (1), Poland (2), Russia (2), Thailand (1), UK (5), USA (4) and Vietnam (1). Value in parenthesis indicates number of papers from that particular member society. The subjects of these papers cover a variety of sub-themes like (i) foundation behaviour and performance (15), (ii) technologies for construction, rehabilitation and energy (6), (iii) analytical and numerical analyses on piles and pile-raft foundation (20), (iv) field measurements (5), (v) seismic hazard analysis (2), (vi) design methods and assessments (2), (vii) model testing, soil behaviours on soil-pile interactions (8), (viii) predictions from testing methods (4).

RÉSUMÉ : Ce rapport général est préparé à partir des 62 articles proposés au 18ème CIMSG concernant les Fondations profondes, le domaine du Comité Technique TC 212 de la SIMSG,. Les articles No. 1691 - 3105, qui sont présentés pendant les deux sessions du TC 212 - Fondation profondes, proviennent de 26 sociétés membres dont Algérie (1), Argentine (1), Australie (6), Brésil (7), Bulgarie (1), Canada (3), Chine (2), Finlande (2), Danemark (1), Egypte (3), France (4) Allemagne (1), Hongrie (2), Inde (2), Iran (1), Italie (1), Japon (4), Corée du Sud (3), Mexique (1), Pays-Bas (1), Pologne (2), Russie (2), Thaïlande (1), Royaume-Unis (5), Etats-Unis (4) et Vietnam (1). Les chiffres entre parenthèses montrent le nombre de papiers venant de chaque société membre. Les sujets des papiers couvrent plusieurs sous-thèmes comme (i) le comportement et les performances des fondations (15), (ii) les technologies de construction, réhabilitation et énergie (6), (iii) les analyses analytique et numérique des pieux et radiers sur pieux (20), (iv) les mesures in situ (5), (v) les risques sismiques (2), (vi) les méthodes de dimensionnement (2), (vii) la modélisation physique et le comportement des sols dans l'interaction sol-pieu (8), (viii) les prévisions à partir des essais (4).

KEYWORDS: pile, pile raft foundation, design, model test, in-situ measurements, construction, numerical and analytical methods.

1 INTRODUCTION

The 18th International Conference on Soil Mechanics and Geotechnical Engineering (18th ICSMGE) is being held at Paris, France during September 2 to 6, 2013 on the main theme 'Challenges and Innovations in Geotechnics'. Based on the main conference theme, two parallel technical sessions related to the sub-topic on 'Deep Foundations' are getting organized by the technical committee TC 212 – Deep Foundations of ISSMGE. Total sixty two (62) technical full length papers related to this sub-topic on deep foundations are grouped and distributed for the two parallel technical sessions.

The area of research and practice in the field of deep foundations is expanding day by day with new challenges and innovations in this area. All the technical papers for this sub-topic can be grouped into major three categories, viz. (i) field tests and monitoring of deep foundations, (ii) analytical and numerical methods for deep foundations and (iii) laboratory based tests including physical modelling of deep foundations. This conference is the best venue to share and exchange new innovations and difficulties in various countries for the subject matter on deep foundations. Papers received from twenty six (26) member societies of ISSMGE with wide range of research and practice data related to deep foundations will be extremely useful for the designers and practitioners worldwide.

2 REVIEW OF PAPERS

In this section, review of all 62 papers of the 18th ICSMGE, which are related to the topic of 'Deep Foundations' is carried out in the sequence of alphabetical order of authors' surname.

Allievi et al. discussed the process followed for designing the pile raft foundations of tall buildings by analyzing the governing limit states, assessing the geotechnical characterization of the soil deposits and using appropriate modelling techniques for studying the behaviour of the selected foundation system at different design phases. The piled raft was analysed using finite element software Oasys GSA 2010, where the superstructure, foundation and ground were modelled into a single soil – structure model. The effects of concrete in the raft and pile were considered since they influenced the long term behaviour of the foundation. It was observed that 50% of the total rat settlements occurred during construction.

Alnuiam et al. studied the performance of piled raft foundation systems under axial loads. 3D finite element model is established to analyze the piled raft foundation system installed in cohesionless soil with stiffness linearly increased with depth. The model was calibrated using geotechnical centrifuge test data. Conclusions are: The load carried by the piles is higher for a rigid raft ($K_f > 10$) due to the minimal interaction between the raft and subsoil compared to the perfectly flexible raft ($K_f < 0.01$). The spacing between piles can be used to evaluate the raft flexibility instead of its width (Eq. 2 in this paper). The load carried by piles increases as pile diameter increases. However, the rate of increase is higher for small size piles and diminishes as the pile diameter increases.

Ashlock and Fotouhi performed full-scale pile vibration test for steel HP piles installed to a depth of 6 m in a soft clay profile, with one pile being surrounded by a cement-deep-soil-mixed (CDSM) improved zone. Authors conducted multi-modal tests with vertical and coupled lateral-rocking vibrations using a shaker mounted on a rigid pile cap. It was observed that the improved soil zone significantly increased the stiffness of the measured vertical response, but had little effect on the lateral-rocking mode. Results of the forced vibration tests were analyzed using methods reported in the literature and it was found that the simplified model was able to capture the vertical response reasonably well in both the improved and native unimproved soil profiles along with the lateral response in unimproved soil.

Balakumar et al. developed a new design method for pile raft foundation in cohesionless soil for different densities. This design procedure constitutes two stages; First stage of design procedure regarding to determination of the optimum number of piles, pile length and diameter required to be placed in a strategic manner to produce the required settlement reduction along with the load shared by the pile group. Second stage of design procedure was developed a 3D model in ANSYS finite element analysis based software and performed an extensive parametric study. Authors were also performed 1g small scale model test on circular and square shaped pile raft foundation and concluded that that the equivalent pier theory could be used in combination with the pressuremeter test results to predict the load settlement and load sharing behavior of the piled raft foundation.

Basile described a practical analysis method for determining the response of piled rafts. Validity of the analysis was demonstrated through comparison with alternative numerical solutions and field measurements. The author suggests that the negligible computational costs make the analysis suitable not only for the design of piled rafts supporting high rise buildings (generally based on complex and expensive 3D FEM or FDM analyses) but also for that of bridges and ordinary buildings.

Basu et al. presented an approach using the variational principles of mechanics to analyze torsionally loaded piles in elastic soil. The total potential energy of the pile-soil system is minimized to obtain the differential equations governing the pile and soil displacements. The analysis explicitly takes into account the three-dimensional pile-soil interaction in multi-layered soil. The authors found that the soil layering does have an effect on the pile response, particularly for short, stubby piles with low slenderness ratio.

Berthelot et al. presented the necessary site investigations for continue flight auger piles in firm sites. The penetration in the grounds can be made only with a tool of specific attack extended by an experimental retractable point in the concreting. It also requires an important couple of rotation and the means of vertical pushes. These tests were implanted right adapted soils investigations highlight well the strong resistances and the very high modulus of this hard soil. They can validate the anchoring and help the specificities of each project to bring successful construction at the sites.

Bilfinger et al. adopted new approach to evaluate safety assessment of pile foundations which uses Bayesian inference to combine bearing capacity and field controls which may lead to economic design. Ultimate load prediction method was used for bearing capacity determination. Field controls methods were used to ensure pile settlement within limit. Bayesian inference which is statistical approach which consider local soil condition as variable and reported it in terms of equation. This approach provided sound justification to field operational rules that may lead to economical foundation solution while maintaining the same safety level as required by code.

Biswas and Manna conducted a comparative study on vertical vibration tests of full-scale single piles with three-dimensional FE analysis using Abaqus/CAE. The resonant frequency and amplitude obtained from 3D FE analysis were found compatible to field test results. The resonant frequencies are decreased with the increase of eccentric moments whereas the changes of resonant amplitudes are opposite. It increases gradually with the increase of eccentric moments, and stops below the ground water table.

Bouafia presented a practical method to construct the P-Y curves for analysis on lateral load-deflection behavior of single piles using data from pressuremeter test. Full-scale pile tests were conducted to validate the predictions. With the correlations between soil reaction modulus/resistance and pile/soil stiffness ratio via the parameters from PMT test, a step-by-step method was suggested to define the parameters of P-Y curves for single pile under in multi-layered soils. Formulations of the P-Y curves, methodology to construct the P-Y curve and the analytical features can be found in this paper.

Bretelle compared the French (Fascicule 62) and Australian (AS2159) approaches on pile design methodology and shows their difference with an example. French standard provides the relationship between measured characteristics and design parameters as well as a unique set of reduction factors on resistance. Australian standard leaves the choice to the engineers and defines different reduction factors on resistance depending on site geotechnical risk. The ways to account for pile testing is described is this paper with the example showing optimization opportunity when pile testing is undertaken on site.

Cannon described the high strain and low strain dynamic pile testing for assessing the foundation of Messa A Rail Bridge at Western Australia, which have caused a change in foundation type from bored pile foundation to a driven pile foundation. Cross – hole sonic logging (CSL) test was performed at the required site for testing the test pile statically in tension. However, during construction, serious problem with the constructability of the bored pile was detected by both high strain and low strain dynamic testing. Thus the bored pile was changed to a driven pile, after its integrity was tested using a Pile Integrity Tester. Hence, the dynamic pile testing confirmed the pile resistance, providing high level of confidence in the foundation.

Carvaldho and Albuquerque presented the test results of uplift behavior of bored piles in unsaturated sandy soil found in Southern central region of Brazil. Tests were conducted in on the campus of the University of São Paulo, located in the city of São Carlos on three bored piles having length of 10m and diameter of 0.35m, 0.4m and 0.5m respectively to ascertain load transfer mechanism to subsoil as well as ascertaining the applicability of the methods for calculating ultimate load that are available within the technical milieu. The ultimate loads (Q_{ult}) obtained on the three piles were 387kN, 440kN and 478kN respectively. The determination of the ultimate load using CPT demonstrates good results when the LCPC Method is adopted.

Christin et al. introduced the timber pile load test instrumentation with removable extensometer. As the timber piles become popularly used in France for retrofitting and reuse of all historical structures and sustainable development, the load test on such pile receives attentions. The authors present a research project “Pieux Bois” (2010-2013) to establish a database necessary for design methods on timber piles. The first pile loading test campaign was carried out in Rouen on piles instrumented with removable extensometers. Interesting results are discussed in this paper.

Dembicki et al. presented an analysis of raft foundation supporting the pylon of cable-stayed bridge in Rędzin. Important decision on the pile length was their shortening due to occurrence of confined aquifers which would cause soil liquefaction under the piles during installation. The decision could be undertaken after comprehensive numerical analyses as well as additional investigations of soil parameters. Load tests with measurement of the distribution of force along the piles with extensometers were found very useful, allowing the control of design assumptions. It was concluded that in-situ measurements with agreeable results from numerical analyses are the best proof of assumptions made in the design process.

EI – Sakhawy and Nassar investigated the behavior of soil – pile interaction during soil consolidation by performing several experimental tests for different conditions such as end bearing pile and floating tip pile for different soils at the tip of pile. From the test results authors concluded that;

1. The negative skin friction was developed along the pile shaft due to consolidation of the soil surrounding the pile under surcharge loads.
2. The neutral plane was moved closer to the tip of the pile with increase in the end bearing.
3. The depth of the neutral plane was increased with increase in the pile length.

Elsherbiny and El Naggar presented a 3D FE analysis using ABAQUS on helical piles for performance of the pile groups under axial compressive loads. Mohr-Coulomb plasticity model is used for soils, where numerical models are calibrated and verified using: full-scale load testing data of single piles; representative soil properties obtained from the borehole logs; and realistic modeling assumptions. It was found that the performance of a helical pile group in sand or clay is mainly affected by the pile-to-pile spacing. The practical range of inter-helix spacing (1D~3D) has negligible effect on the settlement ratio, R_s. The factor of safety could significantly affect R_s for piles in sand and has negligible effect for piles in clay. In general, R_s for helical piles with multiple helices spaced at a typical pile spacing of 3D is suggested to be 1.15 to 1.2 for both clay and sand.

Fakharian et al. adopted a numerical approach for studying the setup effects of a single pile embedded in layered soil strata by calculating the pile shaft resistance β – parameter. Authors adopted an axi-symmetric non – linear finite element scheme for simulating the cavity expansion which occurred due to pile driving followed by dissipation of pore water pressure and ageing. Finite element based numerical package ABAQUS was used for modelling the soil as elasto – perfectly plastic model. It was observed that an increase in the interface shear strength between pile – soil was considered to be the ageing component of the soil setup.

Goto et al. conducted model pile load tests on grouped piles in large tank of dry sand. 9 cylindrical model piles of 40mm diameter were tested under 50-200kPa load pressures. Test results were discussed at yielding point of the total load, tip stress distribution of the grouped piles, pressure distribution in the soil measured by the sensors and ground deformation after the loading tests. The authors suggested that the group pile of 2.5D spacing caused significant interactional effect between piles and it will behave as a block. In contrast, the piles in a pile group of 5.0D spacing was reported more independently.

Gusmão et al. presented main aspects of design, execution and control of shopping centre construction of 280,000 m2 area in Recife, Brazil. Geotechnical characterization revealed that soil consisted of silty clays. Static pile load tests were conducted on 400mm and 500mm diameter piles with allowable loads of 700 and 1,150 kN. The Van der Veen equation was used for extrapolating the results of the geotechnical rupture load for the load tests which may help in the design. It was found that as the number of sample increased standard deviation increases and probability density function around the mean decreases and the curve with flatter appearence can be observed. With increases in sample space, population dispersion is incorporated into sample and standard deviation was found to increase with increase in dispersion, reliability index decreases probability of failure was found to increase.

Gwizdala and Krasinski discussed the cases of bridge structures founded on driven displacement piles. It is pointed out that the general principles given by Eurocode 7 should aim at an unification of the methods for the calculation of bearing capacity of the pile. It would be important to create the international database with complete static and dynamic test results and the information regarding the soil resistances over the pile shaft and under the base referred to careful description of the subsoil and the in situ tests itself.

Haberfield described the design of piled raft for two buildings (Tall towers and Nakheel tower (1000m high)) in Dubai which is founded on weak carbonate rocks and a group of tall towers (up to 300 m high) founded in deep alluvial soil deposits based on serviceability condition to find out ground modulus based on various field testing adopted. To get accurate results pressuremeter, seismic crosshole test and Osterberg load cell test were used to evaluate the geotechnical properties of foundation material for two towers. Test result revealed that significant thickness of debris was found at the base of pile toe which made the elastic modulus estimation challenging and its estimation is made on unloading and reloading response of pile load test.

Hai and Dao performed two bidirectional loading tests on piles to determine pile capacities for the foundation of 12-story Sea Bank Building project in Da Nang City, Vietnam. Authors validated the capacities of pile with pile load test programme of the bidirectional O-cell test as it is the best suitable for the limited project. From the test results authors concluded that maximum upward movements were 3.3 and 7.4mm and maximum downward movements were 28mm and 49.3mm for the two tests, the maximum upward movement of pile head were 0.2 and 2.5 mm respectively and the shaft resistances above 30 m depth were not full mobilized.

Hamova et al. briefly described the effects of landslide of width in the top 55m, length 38m and depth 8 to 9m that occurred on main road and affected more than half of the roadway. From the analysis authors mentioned that ground water table raise, river erosion undermining the slope and the dynamic effects of transport were the main factors for slope instability. Authors designed and recommended cantilever retaining wall on driven pile foundation. Authors observed the proposed structure for period 2006 – 2012 and concluded that the landslide was successfully stabilized and new landslide deformations had not been established.

Herrmann et al. investigated the load-bearing behaviors of bored piles with different enlarged bases. According to DIN EN 1536, overboring of the bottom of drilled piles to increase the bearing resistance is permissible up to three times the pile diameter. To validate the supports of design specifications, model tests at a scale of 1:25 were performed. The tests showed that an enlargement contributes significantly. By the use of a reduction coefficient of 0.75 for the bearing resistance, covering the disturbance effects of the drilling the enlargement, the bearing resistance would be underestimated. The results were evaluated against the available results of large 1:1 drilled pile experiments.

Ishikura et al. discussed the technology of using surface stabilization and floating type deep mixing soil stabilization for acceptable settlement where the performance of piles on deep soft soil layers is maintained. Consolidation settlement properties and skin friction of model test of grouped piles were investigated. Two types of model tests and full scale FEM analysis were conducted. The full mobilization length of skin friction was found to be increased with elapsed time and it would converge to the constant value during the consolidation. Simple forms of the formulations are presented to calculate the skin friction of floating type column and equivalent conversion ratio defined as a ratio between the column length and the mobilized length for skin frictions.

Jeong and Cho studied the settlement behavior of piled raft foundations by 3D numerical analysis on case studies. Attention is given to the improved analytical method (YSPR) and interactive analysis considering raft flexibility and soil nonlinearity. It was found that the proposed method in present study is in good agreement with general trend of the field measurements. Conclusions are:. Proposed analytical method produces a considerably larger settlement than the results obtained by the conventional methods (GSRaft). The proposed method is shown to be capable of predicting the behavior of a large piled raft. Nonlinear load-transfer curve and flat-shell element can be used to improve the existing numerical methods.

Jung et al. introduced a new development of multiplexed Fiber-optic Bragg Grating (FBG) sensors to measure lateral pile displacements. With the pile displacement calculated under lateral load, the data were compared with the measured ones. Three optimization strategies—positioning sensors at regular intervals, positioning sensors at projected Gaussian points but not following the Gaussian rule, and positioning sensors exactly based on the Gaussian rule—were implemented. In both cases for the 1st and 2nd strategies, the measurement error decreases as the number of sensors increases. Moreover, positioning the sensors rigorously based on the Gaussian quadrature rule enhances the accuracy more than just using the Gaussian points.

Kaneda et al. presented the numerical simulation of field tests on bearing capacity of pile, raft, and piled raft foundations. The SYS Cam-clay model developed at Nagoya University was used. Material parameters were determined by laboratory tests considering the state of stress in the field. Agreeable results were found between predictions and field tests. Furthermore, it is found that the total bearing capacity of the raft and the piles is equal to that of the piled raft foundation. This was also confirmed via the simulations. The authors explained the reason of such phenomenon.

Kang et al. introduced the Fiber Reinforced Plastic (FRP) pile and applications. To improve axial and lateral load capacities, a Hybrid Concrete Filled FRP Pile (HCFFP) is suggested. The load-strain relation of CFFP was compared with finite element solutions. The confinement effect between FRP Pile and CFFP are shown. Load capacity of HCFFP member is increased if confining pressure and concrete strength are increased. In addition, the equations to predict the compressive and flexure strengths of the HCFFP member are proposed. It was confirmed that HCFFP is suitable to apply as the structural elements with the comparisons of CFFP member. It's suggested that the structural performance of connection between the segments of HCFFP, and constructability of HCFFP pile should be explored in the future for more practical applications.

Korff and Mair investigated the ground displacements related to deep excavations on a case study of North South Metro Line in Amsterdam. It was found that the response of buildings is governed by soil displacements resulting from the excavation. It is concluded that the surface displacement behind the wall is 0.3~1.0% of the excavation depth, if all construction works are included. The largest effect on the ground surface displacement (55~75%) can be attributed to the diaphragm wall construction, jet grout strut installation and construction of the roof and took in total about 4 years. The actual excavation stage caused only about 25-45% of the surface displacements. At larger excavation depths the influence zone is found significantly smaller than 2 times the excavation depth.

Lehtonen introduced the use of steel piles in retaining wall construction and energy transfer. Open section drilling for new micropile inventions is discussed. Drilled pile walls and energy transfer applications extend the use of drilled piles to sites where conventional piling is rarely seen as an option and where the drilled piles can be installed as hybrid structures, functioning as vertically loaded piles, or retaining structure, or a heating/cooling energy reservation system.

Levy and Richards confirmed that base suction may contribute significantly to footing performance. Field tests on full scale footings were carried. The suction developed is similar to physical model tests using centrifuge. The design uplift performance is not reached before the ultimate limit state displacement criterion set by UK design guidance. In the case where suctions did not develop, the uplift performance of the footings was extremely poor. Such a poor performance will require a re-evaluation of the use coarse granular material, when used in excavations bounded by London clay.

Look and Lacey implemented two land based test piles fitted with Osterberg cells for testing the shaft capacity of the sedimentary bedrock at the Gateway Bridge site. Based on the test data, the required magnitude of the input unconfined characteristic strength (UCS) of the rock were back calculated for various pile design methods. It was concluded by the authors that five of the examined methods produced results which matched the observed shaft capacities by adopting a design UCS value close to the UCS lower quartile "characteristic" value.

Lorenzo et al. described how to find out bearing capacity of piled raft foundation at ultimate stage which governs the design of PRs with a raft width between 6 to 14m using limit state approach. Author proposed the relation to find out ultimate bearing capacity of PR with the help of numerical model. To apply limit state method, floating piles behaviour is considered under ultimate or limiting capacity and design equation were presented. Global factor of safety considered in the design. Partial safety coefficient of resistant load was found out. Taylor series method was adopted to find bearing capacity of PR. This analysis is generalized method for the calculation for determining the bearing capacities of raft and pile groups separately.

Mayne and Woeller suggested a closed-form elastic continuum solution for upper and lower segment responses of bored piles subjected to bi-directional Osterberg load testing. Seismic piezocone tests (SCPTu) are used to provide data for assessing the capacity, while the shear wave velocity provides the fundamental stiffness for displacement analyses. A load test case study involving two levels of embedded O-cells for a large bridge in Charleston, South Carolina is presented to illustrate the approach. Results from the seismic piezocone testing provide the necessary input data to evaluate axial side and base resistances of the deep foundations, as well as the small-strain stiffness (G_{max}) needed for deformation analyses.

Mendoza et al. discussed the observations learned from Metro-Line 12 overpass in Mexico City soft clay. A pioneer foundation of footing or foundation slab with long skirts was used first time in the city. Geotechnical sensors and accelerometers were installed to monitor during the construction and long term operations as well as strong earthquakes A first earthquake of low intensity caused a sudden, reduced and transitory horizontal pressure decrease on the walls, but a rapid recovery of the sustained loads was observed. The Metro trains impose no significant changes in vertical pressure under the footing, nor on lateral pressures or pore water pressures on the sides of the perimeter walls.

Miller et al. discussed the applications of shaft grouting to improve pile foundation capacity in Georgia. Poor ground conditions and high loads were encountered and the deep bored piles were installed. Results from the strain gauges showed differences in the behaviour of the piles in different strata depending on the granular content of the material. It was found the shaft grouting improved the skin friction of the strata with a high sand and gravel content by a factor of 2.2~2.4. Some improvement was achieved in material with as little sand content (<10%). It was reported that the shaft grouting improved the load-displacement behaviour of the test pile with settlements reduced by approximately 50%.

Perälä presented a new technology called as polymer pillar. The product is patented and mainly made by injecting expanding high density geopolymer to a geotextile tube. It can be used as end bearing and/or friction piles with the dependence of soil conditions. While injected, the pillars volume expands fast, which will cause the surrounding soils displaced and compacted. Totally there have been over 500 projects so far. Some load tests and material tests are presented in this paper.

Poulos et al. performed pile load test for verifying the foundation design of a tower in South Korea. Four pile load test were performed on vertically loaded piles using the Osterberg cell method, while one was performed on a laterally loaded pile which were jacked against each other. Authors also carried out finite element analyses using the computer program PLAXIS for determining the effects of pile shape and quality of concrete which were used while conducting the pile load test. It was found that while pile load capacities were underestimated at over - break levels; they were overestimated during shaking, due to non – consideration of diameter of the pile during the analyses. It was concluded by the authors that non – uniformity of pile section and quality of concrete should be considered for accurate interpretation of pile load test data.

Powell and Skinner presented the data of tested piles on London clay which was located at Chattenden, northern Kent and was underlain by high plasticity London Clay to a depth of at least 44m. This paper presents testing of piles which is now in use onto the soil, pile tested at an age of up to 5 months, but mostly 2.5-3.5 months, by static incremental maintained load testing (ML). The Topic, RuFUS and RaPPER pile tests were undertaken using a combination of BRE load frames and a remotely operated hydraulic loading and control system. Through testing α (empirical factor for shaft resistance) was found out for different types of piles and reported and α will be incorporated in the design of pile capacity.

Puech and Benzaria presented an experimental study on the behaviour of piles under axial static load. Three mode of pile installation were considered: driving, boring, and screwing. Piles tested were instrumented with removable extensiometers and installed in the overconsolidated Franders clay. The results showed very high skin friction mobilized for driven pile (>150 kPa); that of bored pile and screwed pile are lower, 40 kPa and 60 kPa, respectively. The experimental results were finally compared to the prediction methods developed by Imperial College or recommended by French codes.

Ramadan et al. developed a model in PLAXIS 3D to study the importance of piled supporting system to the excavation adjacent to existing buildings in soft to medium clay. For the present study authors considered the excavation area as 10 x 10m and the foundation of adjacent building as three strip footings of length 10m and width 2m with 100kN/m^2 stress on the foundation level. From the analysis authors concluded that;

1. For stability number N_c = 4 the unsupported excavation was fail due to stress of the adjacent building.
2. Continuous pile wall support wall was decreased the lateral soil displacement between the foundation level of the adjacent building and the bottom of the excavation.

Ray and Wolf outlined the past history and present implementation of foundation design when subjected to seismic loading in Hungary as per Eurocode 8. Authors also used SAP 2000 finite element software for analyzing the influence of different support conditions on the bearing stresses of a superstructure on a typical reinforced concrete building. The building periods of the structure were computed using the Eurocode 8 formulae and modal analyses which considered fixed base and spring base supports, giving building periods of 0.85sec, 0.69sec and 0.79sec respectively. It was observed that foundations having spring base conditions reduced the bending moments near the base by 30%, with the reduction being less at the higher portion of the column. Moreover a decrease in fundamental period owing to different support conditions, resulted in an increase in magnitude of spectral ordinate and bending moment.

Rinaldi and Viguera performed pseudo-static load tests for evaluating the bearing capacity of large diameter piles. Authors showed that moderate loads, weighing between 10 to 20 tons, when dropped from a height of 10cm to 120cm, resulted in full mobilization of ultimate pile capacity. The loading generated a time controlled load which depended on the size and height of fall of the load, geometry and elastic properties of the elastomeric cushion which were included between the mass and top of the pile. It was concluded by the authors that pseudo-static methods allowed application of load increments in steps, repeatability of each loading step and simpler test setup, when compared to Statnamic tests.

Sakr and Nasr investigated the effects of inclined load on axial pile displacement and lateral pile response for single pile embedded in the level ground and near ground slope by conducting several experiments. Authors compared the results of single pile founded in the level ground with that in near ground slope and concluded that;

1. The ultimate axial and lateral load capacities of pile were decreased with increase in inclination of load with vertical.
2. The ultimate lateral load capacity of pile founded in dense sand subjected to inclined loads increased significantly with increase in slenderness ratio.
3. The lateral load capacity of pile was increased with increase in distance between pile head and slope crest for different densities of sand.

Salgado et al. proposed semi-analytical methods to calculate the response of laterally loaded piles with general-shape cross sections embedded in multilayered elastic soil. The method produces results with accuracy comparable with that of a 3D FE analysis but requires much less computational time. Analytical solutions for laterally loaded piles with rectangular and circular cross sections embedded in multilayered elastic media are obtained. The solutions for pile deflection, slope of the deflected curve, bending moment and shear force, are obtained iteratively and it depends on the rate at which the displacements in soil medium decreases with increasing distance from the pile.

Shulyatiev et al. described a new field test technique developed for the analysis of single pile and pile groups in Moscow International Business Center (MIBC) "Moskva-CITY" is a complex of 19 sky-scraper buildings. Authors were analyzed single pile and pile groups of length range 20 – 30m, diameter range 1.2 – 1.5m and spacing range 3 – 5m. Authors determined separately side resistance and tip resistance in the site by using that developed test technique and verified with analytical model developed in PAXIS 2D 8.2 software for single pile test data.

Silva et al. (a) proposed a method to mitigate risk in geotechnical constructions by using borings and pile load tests that enable the elaboration of bi and three-dimensional models, which gives assure that the correct analysis and evaluation of the associated risks to design and to the construction execution should be one of the targets of a Geotechnical Engineering. From the results authors concluded that the process of post-evaluation of the models developed in computer software requires geological/geotechnical experience of the region and knowledge of limitations and potential advantages of the computer software as the quantity of input attributes, working grid limit, interpolating devices and their limitations.

Silva et al. (b) proposed the use of SCCAP methodology to control the execution of CFA types foundation works which proposes formulations, routines and criteria for pile acceptance. To ensure quality and the design assumptions, the SCCAP routines introduces to the execution monitoring software for CFA piles the excavation quality control in real time and assure the execution piling process conditions for the piles to achieve the planned bearing capacity. Through SCCAP quality in the excavation can be assured whose results rely upon the bearing capacity and deformability through the decrease of the variability and the increase of reliability. SCCAP methodology also provides the stopping criteria for boring on the basis of statistical formulations.

Steenfelt and Schunk discussed the cavity remediation for piles underneath a cable stayed bridge. The cavity feature was pressure grouted and transfer of axial load across the cavity into Limestone was facilitated by insertion of grouted steel reinforcement assemblies. The success of the remedial measures was proven by carrying out an O-cell load test on the pile positioned over the maximum recorded depth of the cavity.

Szep and Ray predicted that soil – structure interaction could be better modelled using three dimensional geotechnical finite element packages where true soil – structure could be analyzed. The laterally loaded pile was analyzed using three numerical methods like (1) AXIS 10VM which is the fundamental structural design tool in Hungary, (2) GE04 and GE05 which are popular geotechnical codes and (3) PLAXIS and MIDAS GTS, which are 2D and 3D geotechnical finite element packages for ensuring realistic modelling of soil – structure interaction. Authors also used an optimization technique for translating the pile head displacements and rotations computed using finite element analyses to a small number of elasto – plastic subgrade springs, which could be used in various structural and geotechnical design software.

Teparaksa carried out damage assessment of the Bank of Thailand head office by means of finite element method for predicting its influence on the Tewavej Palace and Bangkhunphrom Palace with simulation of basement construction. The top down construction method was selected for basement construction and complete set of instrumentation was installed at the palaces, diaphragm wall and ground surface for monitoring the field performance during and after basement construction. The predicted wall movement obtained using finite element analysis agreed well with the field performance, and construction of basement was completed without affecting the stability of the palaces

Ter – Martirosyan et al. proposed a rheological equation based on modification of Maxwell rheological model to explain the shear deformations in partial saturated hardening – softening clay soil. Authors explained creep, relaxation and kinematic shear including decaying, stable and progressive creep, depending on shear stress intensity by using that proposed equation. Authors showed that in constant loading case that proposed equation described decaying, non-decaying and progressing soil creep as well as stress and shear strain relaxation processes in kinematic loading mode.

Tomisawa and Miura performed large-scale model experiments to suggest a design verification method for pile foundations combined with solidified improved columns with following suggestions. Specifications for solidified columns are related to ground conditions and the improvement depth depends on characteristic pile length $1/\beta$. The design horizontal subgrade reaction P_{HU} should be smaller than the passive earth pressure of composite ground for inner stability and column soundness. The allowable horizontal pile displacement in normal conditions and during storms and Level-1 earthquakes should be reduced to 0.5% of the pile diameter instead of 1% (or 15 mm) for natural ground.

Tsuha et al. conducted experiments for determining the influence of soil characteristics and configuration of helical blades on the uplift capacity of multi – helix anchors. The experiments included centrifuge tests on dry Fontainebleau sand and tension load tests executed out in a tropical soil at Sao Carlos in Brazil. The authors inferred that the efficiency of the second helix of helical anchors embedded in sand decreased with an increase in relative density of the sand and diameter of the helix. Further it was also found that uplift capacity of triple helix anchor with tapered helices were superior compared to those with cylindrical helices.

Van Tol et al. presented the results of a study of concealed safety factors by performing centrifuge tests on single pile and group piles. For studying the time effect authors loaded single pile in centrifuge test at 1, 10, 100,1000 minutes after installation and for pile group also were followed the same pattern and the centrifuge test was continued to operate from the start of installation until the final load test. Authors showed that the quantification of the effect and the determination of the impact of load variations and recommended to continue with research into pile group effects of displacement piles.

Wang et al. presented the aspects of design and construction of super-long bored pile foundation together with a brief description of bearing behaviors of super-long bored piles. Deep buried firm soils are usually selected as the bearing stratum. The authors suggests that the application of the double steel sleeves, design of the pile top, construction and measurement requirements are essential to the design of the field load test. Calculation should consider the synergism of the superstructure, soils and pile foundation. Inspection and controlling standards of super-long bored piles are stricter than those of ordinary piles.

Wong presented the results of two case studies on rock socketed pile design and pile load testing in Sydney region of Australia, in one site underlain by medium to high strength shale, dynamic pile load testing was carried out, and on another site underlain by high strength sandstone, Osterberg Cell (O-Cell) testing was carried out to validate the designs. Author concluded that better understanding of load-deformation characteristics of pile foundations would lead to more cost-effective designs.

Yanjing et al. proposed new methods for calculating rebound and recompression deformations by analyzing the data from the consolidation-rebound-recompression test of in-situ soil, bearing test, model experiment and field measurement test, which were based on the stress history of ground soil, loading and unloading conditions. Authors established a mathematical relation between rebound and recompression deformation. Form the analysis authors concluded that;

1. The progress of rebound deformation exhibits three – phase's characteristics, and the critical unloading ratio was used to determine the calculating depth of rebound deformation.
2. The recompression deformation was larger than rebound one and the increase proportion vary with different kinds of soil.
3. The recompression deformation of foundation soil was computed as two-phase mode.

Zaghouani et al. described some difficulties related to the execution of large diameter deep piles in soft soils during the construction of the bridge "Rades-La-Goulette" in Tunisia. First, drilling piles of 2-m diameter up to 100-m depth in soft clay met various problems that increased seriously the time previously expected. That induced the horizontal displacement of the borehole's wall toward its centre. Displacement was first estimated using finite element modeling. Calculations show that this problem would modify only the stress related to the lateral friction but not that at the pile's toe. Second, difficulties related to the concreting phase were also described. Some faults have been detected along the piles by sonic inspections. The paper describes the techniques adopted to repair these faults.

Zhang et al. reported the results of axial static load tests of both full-scale instrumented pile groups and single piles. The single pile settlement was found smaller than the corresponding pile group settlement at the same average load per pile when the load was relatively large. Group effect was more pronounced for piles with smaller L/B ratios, and the impact of the pile spacing is greater than that of the pile length. The load at the top of the corner piles was observed to be the largest, followed by side piles and then center piles.

3 SUMMARY

Deep foundation is a broad area of foundation engineering ranging from conventional pile foundation to modern combined pile-raft foundation. As expected, for this important topic huge number of papers were submitted and finally 62 papers have been selected which is distributed over two technical sessions of this technical committee TC 212 – Deep Foundations. The subject matters of these papers cover various sub-topics of deep foundations viz., foundation behaviour and performance, technologies for construction, rehabilitation and energy, analytical and numerical analyses on piles and pile-raft foundation, field measurements, seismic analysis of deep foundations, design methods and assessments, model testing, soil-pile interactions and predictions from testing methods in deep foundations. This general report summarizes the various latest developments in research and practice in the area of deep foundations.

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