Discussion Session 2.2 / Séance de Discussion 2.2

Recent developments in design and construction of pile foundations

Récentes mises au point dans le dimensionnement et l'exécution des fondations sur pieux

M.W.O'Neill – *Northwestern University, USA*
R.J. Finno – *Northwestern Universtiiy, USA*

ABSTRACT: Discussion session 2.2 of the XV International Conference on Soil Mechanics and Geotechnical Engineering, "Recent developments in design and construction of pile foundations" is summarized. Topics discussed at the session include the degree of uncertainty in prediction axial capacity of piles, cased CFA piles, soil-displacement screw piles, and future directions in practice and research of deep foundations.

RÉSUMÉ: Le séance de discussion 2.2 de la XV^{ème} conférence internationnale de méchanique des soils et de géotechnique est résumée ci-apres. Les sujets abordés lors de cette séance sout les suivants: le degré d'incertitude dans la prédiction de la capacité portante des pieux traditionnels, des pieux tubés et des pieux vissés, et les futurs développements dans la réalisation de la recherché sur les foundations profondes.

1 INTRODUCTION

Session 2.2 included fifty-two written contributions related to design and construction of deep foundations. This paper summarizes the topics of these papers, and provides a summary of the comments of the panelists and attendant discussion. Professor A. Saglamer was the moderator, Professor M. O'Neill was the discussion leader, Professor R. Jardine, Dr. M. Bustamante, and Professor A. Holeyman were the invited panelists, and Professor R. Finno was the session reporter.

2 SUMMARY OF TOPICS IN PROCEEDINGS

Professor O'Neill summarized the themes of the papers related to deep foundations presented in the Proceedings for this conference, as well as those presented in the XIV ICSMFE conference in 1997 and the Geo-Institute International Deep Foundation Congress (G-I IDFC) in 2002. As shown in Table 1, the most common topics were static pile capacity prediction, laterally loaded piles, pile construction methods/effects and verification technologies, pile capacity prediction from driving data (impact and vibro), piled raft analysis and design, static pile capacity in unusual soil/soil conditions, and pile foundation design/assessment philosophy and codes. The information in the table suggests that deep foundation engineering has become a mature discipline. There are several papers that essentially "discovered" procedures and information that have been available for a considerable amount of time. This observation implies that better exchange of information on deep foundations needs to be a goal of the ICSMGE.

3 PANELIST COMMENTS AND DISCUSSION

Professor Jardine questioned the philosophy of Terzaghi and Peck embodied in their 1967 textbook that theoretical refinements in dealing with pile problems were completely out of place because of the wide variety of soil conditions encountered in practice. He illustrated his contention of the need to theoretically assess and improve the reliability of pile design by presenting the results of a web-based prediction competition that was international in scope. He focused on the axial capacity of piles in marine sand driven at the Dunkirk test site as part of the GOPAL collaborative project, and showed that the results of the blind trials indicated that conventional prediction methods are not accurate. He summarized the results of selected recent research to show the importance of a fundamental approach to predicting axial capacity of driven piles in sand, including hypotheses for stress systems around piles, the effects of time on axial capacity, and cyclic loading effects.

Table 1. Paper topics in Session 2.2 and other recent conferences

Topic	XIV ICSMFE	XV ICSMGE	G-I IDFC	Total
Static pile capacity prediction	9	5	25	39
Laterally loaded piles	8	1	9	18
Pile construction methods (QA/QC)	4	1	13	18
Pile capacity prediction: drivng data	3	1	11	15
Piled raft analysis and design	6	4	4	14
Static pile capacity in unusual soil/rock	5	4	4	13
Pile design/assessment /codes	2	2	9	13
Micropile design	3	2	4	9
Static pile load-movement behavior	2	3	3	8
Pile capacity amelioration	3	2	3	8
Static pile soil-structure-interaction	6	1	1	8
Axially loaded pile group behavior	2	5	0	7
Use of piles for unusual structures	3	0	4	7
Dynamic pile-soil interaction analysis	0	3	3	6
Structural analysis/design of piles	0	1	5	6
Negative side resistance	1	3	1	5
Laterally loaded pile group analysis	0	2	3	5
Pile loading by ground movement	1	2	2	5
Pile testing methods	1	1	3	5
Characterization of geomaterials for pile design (case histories)	1	0	4	5
Underpinning and slide abatement	3	0	2	5
Piles in liquefying soils	1	1	1	3
Axial cyclic loading of piles	2	1	0	3
Pile foundations as heat exchangers	0	2	0	2
Loading rate and creep effects	0	1	1	2
Drilling slurry effects	0	1	1	2
Risk assessment methods	0	1	0	1
Scour around piles	0	0	1	1
Piles and the geo-environment	0	0	1	1

The radial effective stress against a pile after driving, σ'_{rs}, is an important factor in determining the axial capacity of piles. Jardine showed that the ratio of σ'_{rs} to tip resistance, q_b, is related to the normalized length of the pile, h/r, where h is the pile length and r is the pile radius. He showed that the limiting value of shear stress acting along the side of the pile is related to the radial effective stress and the critical state friction angle. Using a prediction method for driven offshore piles that accounts for these factors, he showed that the coefficient of variation in predicting the axial capacity of the piles at the Dunkirk test was reduced from 63% using the API design method to 23%.

He also presented axial load test results that showed the shaft resistance can vary by a factor of 5 for piles in sands when long enough periods are maintained between installation and axial loading. He attributed these gains to time-dependent increases in radial effective stress against the pile caused by creep effects. High tangential stresses are induced during driving and, with time, arching action reduces these with attendant increases in radial stress. These creep effects are independent of pile material. Similar time effects were not noted for tip resistance. While the pile was not subjected to sustained axial loads during the periods between installation and testing, Jardine believed that the same trends would hold if the piles were loaded during the quiescent period.

After briefly presenting results of cyclic loading tests performed at the Dunkirk test site, Jardine concluded that the standard methods to compute axial capacity in sands are not rooted in sound science or mechanics, and that confidence in the capacities predicted by these methods are not justified. He called for research to identify the basic behavior of piles.

Professor Bustamante discussed the performance of double rotary (cased) CFA piles in cohesive soils. He observed that although continuous flight auger piles have become a popular deep foundation alternative, possible sources of failure in sandy strata including shaft discontinuity, considerable upward soil transport, and loosening of the surrounding soil, have prompted drilling rig developers to design a new system that reduces these negative effects observed with the "classic" CFA pile. He summarized the installation technique wherein the casing tube and auger are rotated in different directions as the hole is advanced. Upon withdrawal during grouting, the casing and augur are rotated in the same direction. He described the performance of the double rotary piles relative to that of conventional CFA piles at a full-scale test on instrumented piles in marly clay. All piles were extracted after axial load testing and examination of the piles indicated relatively uniform cross-sections. Results of axial load tests indicated that the axial load at failure and stiffness were essentially the same for the CFA and double rotary CFA piles. This result suggests that the loosening in clays is negligible for the cased CFA.

Bustamante indicated that in his opinion major advantages of the cased CFA pile are that loosening in sands would be smaller than that associated with conventional CFA piles, that drilling is easier, and that the concrete volume would be smaller than that of a similar conventional CFA pile. He stated that 5 to 10% of concrete over-volume can be expected to occur in a cased CFA pile, as compared to 5 to 30% in a CFA pile. This improved performance comes at the price of about twice as much power required to install the cased CFA pile. This pile type should have application when piles are to be installed close to an adjacent building that may be adversely affected by ground movements arising from ground loss associated with pile installation.

Professor Holeyman described the installation and design of soil displacement screw piles in stiff, overconsolidated Boom clay. Specialized equipment is needed to install these piles because of the required high torque, high force and rpm requirements. Concrete consumption is monitored during installation. The resulting cross-sections of these piles are grooved, but nondestructive tests have been used successfully to verify the length and continuity of the as-built piles. He described a full-scale testing program designed to calibrate bearing capacity formulae with construction techniques. Five types of screw piles and a control concrete displacement pile were installed at the test section, and axial load tests were conducted. After testing, the piles were exposed to observe the as-built shape. He suggested that the advantages of these piles are that no spoil is generated, higher bearing capacities are obtained, and vibrations associated with installation are minimized.

He used the DeBeer formula and developed calibration factors for each of the screw piles based on the load test results. CPT tests were conducted at the location of each test pile. The average calibration factors were derived based on the average of the CPT results, rather than each CPT result correlated with each load test result. Applying the average calibration factors to the test piles at this site resulted in a coefficient of variation of 30% for the axial capacities of the test piles.

Professor Rollins presented the results of a number of full-scale lateral load tests on groups of piles installed in clay. At the ground line, the pile groups were free-headed and different pile-to-pile spacings were used for each group. He presented results that showed the p-multiplier effects advocated by Brown are a function of pile spacing within the group, and that the group effect would become negligible when the pile spacing exceeded 7 to 8 pile diameters.

Professor El Naggar described a study wherein p-y curves and the p-multiplier were used to evaluate numerically dynamic lateral responses of pile groups. The effects of rate of loading and group effects were discussed. The effects of frequency did not materially change the computed responses when frequency varied between 2 and 12 Hz.

The importance of installation effects on performance was emphasized throughout the session.

4 FUTURE DIRECTIONS

Professor O'Neill identified future directions in deep foundation practice, including the need to:

1. improve installation technologies,
2. improve subsurface characterization methods in soil and rock,
3. verify design methods in unfamiliar soils and for new pile technologies,
4. create viable public databases for load test results and costs,
5. improve data processing and visualization methods for integrity testing and subsurface characterization,
6. develop wireless instrumentation for in-pile monitoring of in-service piles, and,
7. develop more accurate and user-friendly software for analyzing piles and pile groups under foundation and soil loads.

He also discusses unresolved issues requiring additional research, including the need to:

1. improve understanding of the effects of pile installation on strength and deformation characteristics of soil and rock surrounding pile(s),
2. predict response of piles in liquefying soils,
3. develop appropriate structural design methods for driven and bored piles,
4. continue development of recommendations for reliability-based resistance factors,
5. resolve the uplift versus compression capacity issue in cohesionless soils,
6. continue study of the effects of nearby construction on existing piles, and,
7. develop a better understanding of group action of bored and augered piles in cohesionless soils, uplift loading and seismic loading.

Professor O'Neill summarized the session and thanked the panelists and audience participants prior to closing it.