STP923-EB/Nov. 1986

Summary

A symposium on Marine Geotechnology and Nearshore/Offshore Structures was held at Tongji University, Shanghai, People's Republic of China on 1-4 Nov. 1983. The symposium was under the sponsorship of ASTM Committee D-18 on Soil and Rock, Tongji University, Lehigh University (PA), and the Chinese Academy of Sciences. The financial support for the symposium was provided by the H. H. Liu Education Foundation of New York.

Approximately 30 papers were presented during the four-day symposium on recent research and experiences related to marine geotechnology, nearshore/offshore structures, and environmental conditions in the China Sea area. Approximately 110 individuals attended the symposium.

The object of this paper is to organize and briefly summarize the findings of each symposium contributor, to augment these results with the results of non-symposium researches, and to incorporate comments of attendees and manuscript reviewers to provide a balanced view. It is hoped that this summary will fulfill the needs and objectives of this symposium, namely, to identify tests and procedures that require standardization by ASTM as well as to identify research areas that require further investigation. A schematic organization of summary is presented in Fig. 1. The numbers attached to individual boxes correspond to respective sections in the summary.

A. General

1. Geology and Geography of Offshore China

China has a long coastline. Excluding the offshore island, the length of coastline in China is more than 18 000 km, ranking among the longest coastline countries in the world. The seas adjacent to China, the Bohai, Huanghai (Yellow Sea), East China Sea, and South China Sea are all the marginal seas of the Pacific Ocean, of which the Bohai is the interior sea of China. Four marginal seas link up each other and have a total sea area of 4.7 million km^2, half of the continental area of which the area of Bohai is 77 000 km^2, Huanghai is 380 000 km^2, the East China Sea is 770 000 km^2, and the South China Sea is 3.5 million km^2.

The Bohai is basically embraced by the continent and two peninsulas (Shandong Peninsula on the south and Liaodong Peninsula on the north). The Bohai Strait is the only outlet to the Huanghai. The Miaodao Islands are

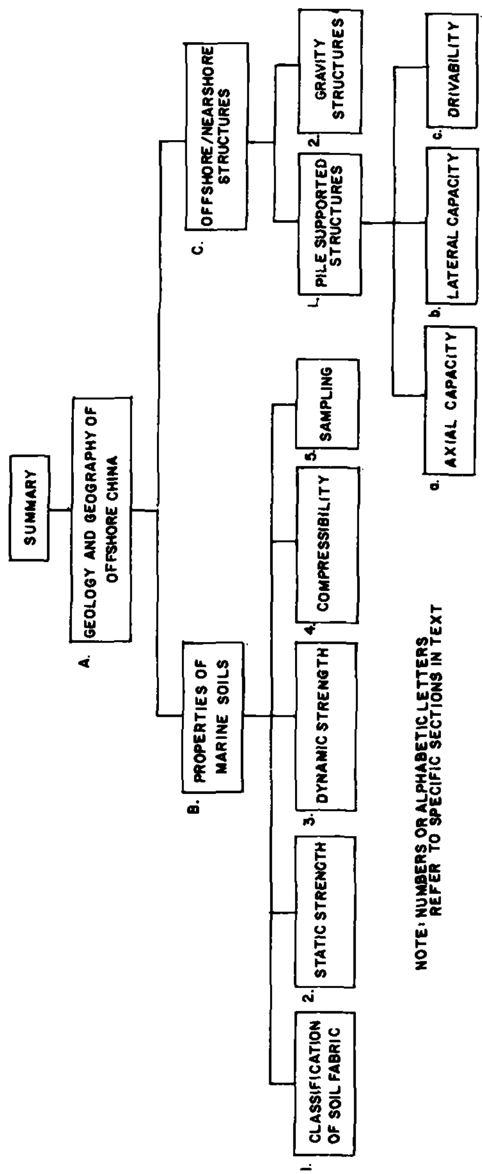

FIG. 1—*Organization of summary.*

in a significant place at the entrance of the Bohai. The Bohai is almost a sealed shallow sea with an average depth of 18 m. The Huanghai is a semi-sealed sea, located on the continental shelf; it is also a shallow sea and has an average depth of 44 m. The depth gradually increases from west to east where it has its greatest depth (140 m) adjacent to the Korean Peninsula. Even though the East China Sea is an open shallow sea compared with the two previously mentioned seas, it is much deeper with an average depth of 370 m. The seafloor west of the Wudao Isles-Taiwan line belongs to the continental shelf, whereas the seafloor east of that line is on the continental slope. The South China Sea touches Kwangdong, Fujian, and Taiwan Provinces in the north, extends south to the waters around the Zengmu Reef, and is a relatively complete deep sea basin. The average depth of its central part is 3000 m with some areas exceeding 4000 m. In sum, the continental shelf in the four marginal seas accounts for a large proportion. The seafloors of Bohai and Huanghai are wholly on the continental shelf, and the shelf proportion of the East China Sea and the South China Sea are two thirds and one half, respectively. The width of the continental shelf is over 100 sea miles for most cross sections.

China's coastline might be roughly divided into two types, sandy and rocky, with the Hangzhou Bay as the demarcation line. North of this line, the coast is mainly silt-mud. This coastal zone was formed by silt carried down by the Huanghe (Yellow River), Haihe, Liaohe, and so forth. South of the Hangzhou Bay, especially in the Zhejiang and Fujian Provinces, the mountain ranges run along the coast and close to it. The continuous pounding of the waves against this terrain has formed rocky jagged coastline favored with numerous islands and islets, and deep natural harbors.

A detailed discussion of the geology of offshore areas of East China is provided by Li and Xu in this volume.

B. Properties of Marine Soils

1. Classification of Marine Sediments

The source, composition, depositional environment, cementation, crushing behavior, micro-structure, and engineering performance are among the important considerations for classification of marine sediments. Various classification systems have been developed that incorporate various aspects of the above list. A classification of types of microstructure (microfabric) has been made for marine soils of China by Gao (1985). Based on this classification and physico-mechanical test data, Gao was able to demonstrate that the engineering properties of marine soils are closely related to their microstructure. A system has also been proposed by Noorany [*1*] based on looking at the source, composition and depositional environment of a sediment. In Noorany's system sediments are divided into three main groups: lithogenous, biogenous, and hydrogenous. Each group is then subdivided into different subgroups based on the composition and depositional environment. The proposed classification system is based both on marine geology and geotechnical engineering and can be considered an auxiliary to the Unified Soil Classification System. In contrast Dean et al. [*2*] proposed a descriptive classification scheme in which deep-sea, fine grained sediments are placed within a three component system of calcareous biogenic, siliceous-biogenic, and nonbiogenic components.

Classification schemes based on use of cone penetration tests have also been presented by a number of investigators. Senneset and Janbu [*3*] proposed a scheme using the results from a piezocone. Classification of sands, silt, and clay are based on an evaluation of point resistance versus a parameter B_q (ratio of pore pressure increase to point resistance minus overburden). Systems have also been proposed that correlate the relationship of cone point resistance q_c and the friction ration R_f with sediment classification. In these systems, based on theoretical considerations and empirical observations, sands are characterized by high cone point resistance and low friction ratio, and clays are characterized by low cone point resistance and high friction ratios. These systems typically classify sands, silts, and clays. Recent work by McNeilan and Bugno [*4*] have shown that data from silts plot predominantly within the zone identified as sand or noncohesive coarse grained soil on charts by Douglas and Olsen [*5*], and Schmertmann [*6*].

2. *Static Strength*

The strength and shearing resistance of sediments is the most important characteristic for engineering design or consideration of hazards. Varieties of test procedures (laboratory and in situ) and analytical models are used to describe strength and shearing resistance. Qian, Wang, and Guo presented a paper using the theory of rheology to solve various problems in soft clay engineering. In the first part of this paper, Lee's analogy method was used to solve a plate on a visco-elastic foundation for illustration. Second, this analogy method was extended to one-dimensional and axis-symmetrical consolidation problems taking account properties of the soil skeleton. Field measurements of foundation settlement of an oil tank and strength increase of a sand drain were compared with theoretical computations. In addition, this paper also used the visco-plastic theory to estimate the safety of a creeping wharf.

A brief summary of geotechnical properties of Shanghai soils along with engineering applications was presented by Gao et al. The summary included a general description of Shanghai soils, empirical formulas for compression index C_c, and studies of the coefficient of earth pressure at rest k_o. In addition, engineering applications included an evaluation of horizontal permeability, correlation of strength ratio and plasticity index, and application to oil tank foundation design.

3. Dynamic Strength

The primary difficulty with wave or seismic loading on a seabed sediment is that the induced stresses are transient, each peak lasting from only a fraction of a second to a few seconds. The response of the sediment to this type of loading is different from the response under a sustained load. One possible response is that the sediment progressively loses most of its strength or "liquefies" and flows under its own weight resulting in large permanent deformations. The other possibility is that the stiffness of the material decreases with cycles of loading as the amount of energy being dissipated per cycle increases (that is, damping).

Zhou and Zhou studied the influence of the initial stress state on the generation of dynamic pore-water pressure under uniform cyclic loading in saturated dense sands. It was found that dynamic pore pressure U_d developed because of pure densification and cyclic distortional volume change increases as the number of loading cycles increases and oscillates cyclically. The relationship between pore-pressure ratio and cyclic number ratio may be expressed by a logarithmic function, whereas the cyclic variation of pore-water pressure may be expressed approximately by a sine function. The relationship between the amplitude of pore pressure and the number of cycles to failure was also obtained.

4. Compressibility

A review of consolidation tests made on near-surface as well as deeper specimens indicates that the deep-sea deposits exhibit apparent overconsolidation in the upper layers of areas where erosion has not taken place. The depth of apparent overconsolidation ranges from 2 to 25 m.

The consolidation state of the sediments below this cap of apparent overconsolidated material is dependent on the sedimentation rate and the nature of the material. In areas of low sedimentation, such as the North Pacific, the sediment below the cap are normally consolidated. In contrast, for areas of high sedimentation, such as the Bermuda Ridge, the underlying sediment are sometimes underconsolidated possibly because of the presence of the cap restricting drainage (Chaney and Fang).

5. Sampling and In-Situ Testing

A systematic approach to offshore site investigation for foundation problems (depth less than 300 m) was presented by Richards and Zuidberg. Emphasis was placed on describing the composite parts of the drill ship, wireline sampling, and in-situ testing systems. The discussion of in-situ testing considered both stationary and moveable seabed systems. In the drill ship system, the various methods of reducing or preventing vertical motion of the drill string (that is, crown block heave compensator, traveling block heave compensator, seabed clamp, down-hole anchor, or inflatable packer) to improve drilling, sampling, and in-situ testing performance was evaluated. Sensors common to both wireline and seabed systems (that is, vane, cone, pressuremeter, and nuclear backscatter densitometer) were also discussed. Recently Richards and Zuidberg [*7*] have extended their work to include the requirements for in-situ sampling and testing for water depths exceeding 300 m.

The problem of recovered sample length consistent with the distance pushed for long stroke hydraulic push or piston samplers has been discussed by Holt and Ims [*8*]. They have demonstrated that the recovered sample lengths can be predicted to a high degree of accuracy by comparing the frictional resistance developed on the inside of the tubes with the soil bearing capacity as determined from cone penetrometer tests.

C. Offshore/Nearshore Structures

1. Pile Supported Structures

Axial Capacity—Feng and Liu found by model test and then by in-situ test of a miniature offshore oil drilling craft that adhesive force of marine clayey sediments to the embedded sides and bottom of a foundation is composed of three components: the adhesive and the suction forces on the bottom, and the friction force on all sides. Among them suction is the major factor and dominates the other two. The ultimate strength of the adhesive force depends on the boundary conditions of the mat and on the way it is lifted. The distribution of adhesion and suction varies with the rigidity of the mat.

A paper reviewing aspects of the development of piling in Shanghai soil was presented by Zai and Hu. They demonstrated, with test data in Shanghai and other places, that piles driven in soft soils will have considerable growth in capacity with time. In addition, the authors suggest that higher allowable capacity can be specified for single-piles, and the number of piles under a foundation can be cut down as compared with traditional practice. In addition they show that reducing the axial capacity of driven piles because of pre-boring is unwarranted.

Lateral Capability—Analysis used to predict lateral deflections, rotations and bending moments in the pile must consider: (1) boundary conditions imposed on the pile by the superstructure, (2) varying moments of inertia of the pile, (3) soil layers of different stiffness, (4) nonlinear stress-strain behavior of the soil, and (5) group effects [*9*].

The ground motion caused by earthquake loadings may cause the degradation in the stiffness and strength of the subsoil, and it may in turn degrade the lateral resistance of soil to pile deflection. A procedure for evaluation of the degradation in strength and lateral resistance by taking both the pore pressure and density into consideration was presented by Chen and Zheng. They discuss the dependence of the residual strength and the mobilized strength of offshore sands on the pore pressure induced by cyclic loadings with different density.

Gao, Chin, Ma, and Sun reported an in-situ experiment under lateral static cyclic and dynamic loadings, on a large sized steel pipe pile located along the Yangtze River in soft silty clay. In addition to the experimental work they also analyzed the pile-soil interaction behavior. In the analysis, the finite-element method and another simplified method were compared using different models of lateral soil stiffness. From the results of the tests as well as the analysis, a formulation of the *p-y* curves of the pile in soft clay under lateral loadings is suggested, and a simplified method of dynamic analysis taking into account the pile soil interaction was also proposed.

An in-depth discussion of the *p-y* method was presented by Reese and Wang. A principal feature of the *p-y* method is the solution of a nonlinear, fourth-order differential equation by finite-difference techniques. The soil is modelled by the use of a discrete mechanism (*p-y* curves), which relates the soil resistance to the pile deflection at various depths below the ground surface. The method was used to predict the response of a number of piles where experimental data were given in the technical literature. Results from experiments were compared with predictions. Comparisons were fair to excellent.

Drivability—Pile driving analysis (wave equation theory) assists in the drivability predictions and provides installation control possibilities. In addition, measured dynamic pile penetration during driving can also provide an indication of the static axial capacity of a driven pile (Höeq). Tang, Liu, and Shen presented a finite-difference solution of one-dimensional wave equation applied to the study of pile foundations of Bohai offshore platforms in North China. Piles were 90 to 110 cm outside diameter (OD) with variable wall thickness and 69 to 72 m in length. Driveability analysis and prediction of bearing capacity were made and compared with field driving records and static load tests with encouraging results.

Damage Evaluation—Ru-long, Yi, and Shu-jiang presented a case study of a deep-water pier in which it was observed that the piles were deformed and cracked. After a field investigation, it was found that (1) the damage of the pier structure was caused primarily by differential settlement and the effect of the lateral thrust of the soil was not important, (2) the differential settlement of the pier was produced mainly caused by the difference of the compression of soil between the front side and the rear side of the pier. Repair of the structure was proposed, which consisted of (1) installing vertical piles by jacking to replace all broken and unbroken batter piles and (2) ensuring all piles along the frontal platform of the pier to rest on the same bearing stratum.

2. *Gravity Structures*

Zhao, Dong, Zai, and Pei reported on soil models and presented tentative proposals for soil structure interaction problems (solid-rigid and nonrigid foundations) of offshore gravity platforms. Soil models found to be best suited for studying superstructure-foundation-soil interaction were linear elastic (finite layer element method), nonlinear elastic, and elastroplastic. In contrast the analysis of immediate, consolidation, and secondary settlements can be solved simultaneously using a viscoelastic (numerical-analytical method) model.

An analytical method for predicting the stresses, displacements, and pore pressures beneath a gravity structure under wave loading was described by Lee, Staunton, and White. The analysis is an application of the mechano-lattice technique, which considers linearized loading-unloading stress-strain relationships. The basic parameters of the analysis are the stiffness modulus and Poisson's ratio for both loading and unloading. A comparison was made between predicted and experimental (model) displacement and residual pore pressures. Pore pressures were 30% overestimated by the analysis but the incremental displacements were closely predicted.

References

[1] Noorany, I., "Classification of Marine Sediments," *Soil Mechanics Series*, Department of Civil Engineering, San Diego State University, San Diego, CA, 1983.

[2] Dean, W. E., Leinen, M., and Stow, D. A., "Classification of Deep-Sea Fine Grained Sediments," *Journal of Sedimentary Petrology*, Vol. 55, No. 2, March 1986, pp. 250-256.

[3] Senneset, K. and Janbu, N., "Shear Strength Parameters Obtained from Static Cone Penetration Tests," *Strength Testing of Marine Sediments: Laboratory and In-Situ Measurements, STP 883*, R. C. Chaney and K. R. Demars, Eds., American Society for Testing and Materials, Philadelphia, 1985, pp. 41-54.

[4] McNeilan, T. W. and Bugno, W. T., "Cone Penetration Test Results in Offshore California Silts," *Strength Testing of Marine Sediments: Laboratory and In-Situ Measurements, STP 883*, R. C. Chaney and K. R. Demars, Eds., American Society for Testing and Materials, Philadelphia, 1985, pp. 55-71.

[5] Douglas, B. J. and Olsen, R. S., "Soil Classification Using Electric Cone Penetrometer," *Proceedings of the Symposium on Cone Penetration Testing and Experience*, Geotechnical Engineering Division, American Society of Civil Engineers, New York, 1981.

[6] Schmertmann, J. H., "An Updated Correlation Between Relative Density D_r, and Fugro-Type Electric Cone Bearing, q_c," Contract Report DACW 29-76-M6646, Waterway Experimental Station, Vicksburg, MS, 1976.

[7] Richards, A. F. and Zuidberg, H., "In-Situ Testing and Sampling Offshore in Water Depths Exceeding 300 m," *Offshore Site Investigation*, Grahama and Trotman, London, 1985, pp. 129-163.

[8] Holt, J. R. and Ims, B. W., "The Phenomenon of Sample Tube Plubbing," *Strength Testing of Marine Sediments: Laboratory and In-Situ Measurements, STP 883*, R. C. Chaney and K. R. Demars, Eds., American Society for Testing and Materials, Philadelphia, 1985, pp. 166-174.

[9] Clausen, C. J. F., Aus, P. M., and Alemeland, "Analysis of the Pile Foundation System for a North Sea Drilling Platform," *Proceedings of the Offshore Structures*, Vol. 3, Boss '3, Cambridge, MA, 1982, pp. 95-103.

Ronald C. Chaney

Telonicher Marine Laboratory, Humboldt State University, Trinidad, CA 95570; editor.

Hsai Yang Fang

Lehigh University, Bethlehem, PA 18015; symposium, cochairman and editor.