TESTING AND CONSTITUTIVE MODELING OF BOMBAY HIGH MARINE SOIL WITH APPLICATION TO LATERALLY LOADED PILE

by

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Submitted in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY, DELHI

DECEMBER, 2005

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(Late) Shri. G. Velayudhan Pillai
Smt. K. Vilasini Amma

WIFE
Revati

and

CHILDREN
Akhil
Keertana

CERTIFICATE

This is to certify that the thesis entitled **"TESTING AND CONSTITUTIVE MODELLING OF BOMBAY HIGH MARINE SOIL WITH APPLICATION TO LATERALLY LOADED PILE"** being submitted by **Mr. Sanjaya Kumar V.** to the Indian Institute of Technology, Delhi is a record of bonafide research work carried out by him under our supervision and guidance. The thesis work, in our opinion has reached the standard, fulfilling the requirements for **DOCTOR OF PHILOSOPHY** degree. The research report and the results presented in this thesis have not been submitted, in part or full, to any other university or Institute, for the award of any degree or diploma.

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ACKNOWLEDGEMENT

I would like to express my sincere appreciation and deepest gratitude to my supervisors, (Dr.) K.G. Sharma, Professor and Head and (Dr.) A. Varadarajan, Former Dogra Chair Professor for their continuous support, encouragement, valuable suggestions and affection offered to me. They have been providing guidance, cooperation and kind help throughout the period of study.

My M.E Guide (Dr.) A. Sridharan, Honorary Professor at IISc, Bangalore, has been a constant source of inspiration for me ever since I joined IISc. I would like to record my sincere appreciation to him for all the things he has given me.

I am extremely grateful to Mr. V. Y. Salpekar (General Manager, Engg and Formerly Head of Engineering Technology Development) and Dr. A. Nanda (Senior Consultant, Geotechnical) of Engineers India Limited for the discussions, which we had regarding the subject topic and for the unflinching support they have given. I sincerely thank Mr. E. Ch. G. Reddy (Dy. General Manager and Formerly Head of Geotechnical Deptt.), Dr. M. Hariharan (General Manager, Offshore Projects and Formerly Head of Ocean Engg. Dept.) and Mr S.C. Sawhney (Former Head, Ocean Engg Department) for the encouragement and support given to me at all stages through out my study.

I take this opportunity to thank M/s ONGC (IEOT) for supplying the samples from Bombay High with out which the study could not have been conducted. Special thanks to Mr. Digvijay Kumar, Mr. Ravikumar and Mr. Ghanetkar of IEOT. Dr. Deepak Datye and Ms.Renuka Srivastava of ABAQUS Inc deserve special thanks.

I wish to acknowledge the help received from Prof. Manoj Datta, Prof K.S. Rao, Dr. G.V. Ramana and Dr. J. T. Shahu for their support and encouragement during the period of my study. I also wish to thank the staff of soil and rock laboratories, XRD and SEM laboratory, IIT Delhi for their cooperation especially, Mr. D.S. Gussain , Mr. Manoj Neelam, Mr. Munilal, Mr. Amarjeet and Mr. H.C. Sharma.

I would like to express gratitude to Mr R. Praveen Kumar, Former M Tech. student and currently research scholar at IIT Madras, for all the help he has given me. I would also like to thank my fellow research scholars Mr. Rakesh Kumar, Mr. Amit Sharma, Mr. Altaf Usmani and Mr. Ravi Shankar for all the help they have extended me. I would also like to thank all my colleagues in the Ocean Engineering Department of Engineers India Limited for whatsoever help they have done. Special thanks for Mr. Raj Tilak and Mr. Suman Ray.

At this hour I remember my Father (Late) Shri G. Velayudhan Pillai who expired on 3rd June 2003. It is he who moulded me in this fashion and he will continue to be my guide for the rest of my life. I also bow before my Mother, who in the same way as my Father, encourages, supports and guides me in this ongoing journey of life. Last but not the least, I am grateful to my wife Revati for her encouragement, support and patience all through the period of study. I am really indebted to my little ones, Akhil and Keertana who, during this period, always thought the only "holiday" destination of their father was IIT.

(Sanjaya Kumar V)

ABSTRACT

The crisis of energy is driving human mankind to explore oil and gas along with other non-conventional forms of energy to enhance their level of energy security. Even today oil and gas exploration takes the major share in new finds. The exploration of oil and gas, once restricted to the coastal areas has gone far into the ocean as the technology advanced. Since in the Indian scenario, the template type jacket structures with driven pipe piles are being designed, fabricated and installed for tapping the oil and gas resources, any improvement in the design of the facilities to be installed will not only improve the safety of the structure but also will economise the total project cost. For an optimal and safe design of the foundation system in the Bombay High region, an accurate determination of the soil parameters and improved analysis and design methods are needed. With this objective in mind the present study was planned.

As part of the present study, samples were taken from Bombay High region from the following depths in a bore hole: 9.10, 14.60, 22.20, 26.93, 28.43, 35.13 and 40.52m designated as BHE-9, BHE-14, BHE-22, BHE-26, BHE-28, BHE-35 and BHE-40 respectively. A series of tests were done at the IIT Delhi laboratory to study the behaviour of Bombay High Marine clay. First the classification and index properties were determined which showed that the clays differed mainly in the silt content. The clay mineralogy and structure determined using X-ray diffraction and scanning electron microscope also revealed the presence of needle like carbonate structures. The samples were remoulded and specimens were prepared using the slurry consolidation method for detailed triaxial testing. The preparation of one specimen by this method took around 21 to 30 days. The consolidation behaviour of all the

soils were determined by conducting isotropic consolidation tests which also lasted about 30 days for each soil. Subsequently 20 drained tests for five out of seven soil samples of 48 to 54 hours duration were conducted after consolidating the slurry consolidated sample to the required confining pressure in about 2 days. The drained stress-strain response and volumetric response of the soils were determined from these tests for four confining pressures namely 98.1, 196.2, 343.4 and 490.5 kPa. Consolidated undrained tests with pore water pressure measurement for the same above-mentioned confining pressures were also carried out for all the marine soils. The tests after the initial consolidation of about 2 days were sheared in a duration of about 4.5 hours. The undrained stress-strain response and the pore water pressure response were inferred from these tests.

Based on the detailed and elaborate testing, the seven soils could be broadly divided into two groups: Groupl and Group 2. The composition of Group 1 soils (BHE-9, BHE-14 and BHE-22) consisted of approximately equal percentage of clay, silt and sand, whereas Group 2 soils (BHE-26, BHE-28, BHE-35 and BHE-40) consisted of 65% silt with sand less than 5%. The consolidation behaviour showed that for the same range of pressure, the change in void ratio was greater for Group 1 soils even though the clay content was less with the exception of BHE-22. There was a similarity in the drained shear behaviour of all the soils. However large volumetric volumetric strains were noticed in Group 1 soils. The undrained response obtained from the test results presented an altogether different perspective. For Group 1 soils the response under all confining pressures the soils behaved like a normally consolidated clay with their typical nature of effective stress paths. However in the case of Group 2 soils, except for the lowest confinng pressure of 98.1 kPa,

considerable deviatoric hardening was noticed. This was also characterized by the change in the direction of the effective stress paths from left to right as the critical state line is approached. At the lowest confining pressure the behaviour was similar to that of a normally consolidated clay. The reason for this was the considerable amount of silt present in Group 2 soils as was also demonstrated in the case of Delhi and Swedish silts. However in all soils the amount of coarse content remained the same.

The strength envelope derived by plotting the results of both drained and undrained tests was unique for each of the soil studied. The angle of shearing resistance remained close to each other for all the soils except BHE-14. This behaviour is similar to that of a normally consolidated soil and is of practical importance. The existence of a unique water content- strength relationship and a unique water-content- effective stress at failure relationship were brought out and the similarity of these to the normally consolidated clay reinforces the practical significance of this study.

The behaviour of sand and clay has been extensively studied and is well understood. But the behaviour of silts and sand-silt-clay mixtures has hardly been investigated. The findings here on the soils of Bombay High area will significantly contribute to the understanding of these soils. Furthermore, these findings will be of great practical use for the analysis and design of offshore structures in the Bombay High region.

Having finalized the basic properties of the soils, the next step was to properly characterize the stress – strain – volume change behaviour and the stress-strain- pore water pressure behaviour. Two models, namely, modified Cam clay (MCC) and

modified Drucker-Prager (MDP) models were selected and predictions were carried out using the general purpose finite element software ABAQUS. The drained shear response was well predicted in both the models. The volumetric strains did not match at all in the MCC model while the range of volumetric stains was predicted in a reasonable manner by MDP model. Both the models predicted the undrained shear response in a satisfactory manner. The models could not predict the deviatoric hardening response for the Group 2 soils. Pore water pressure response were satisfactorily predicted for all the soils. However the initial part of the pore pressure response (upto 4 to 8% axial strain) has not been predicted very well.

Against the backdrop that the behaviour of sand-silt-clay mixture has hardly been studied an attempt has been made in the present research work to understand their behaviour. Perhaps, this is the first attempt made to depict the behaviour of these type of soils from Bombay High region. It is believed that this is a significant step and the models, notwithstanding the limitations, will have immense potential for use in the analysis and design of offshore structures in the Bombay High region.

A pile in an offshore environment if subjected to the environmental loading by waves, wind etc. essentially behaves in an undrained manner. All the analytical works on such piles are carried out using the total stress analysis with the undrained shear strength determined by unconsolidated undrained triaxial testing. This is partly because of the lower cost in terms of time and equipment involved in the on-board testing of samples and partly because the API recommended practice requires only these tests for the generation of p-y curves (to adequately represent the non-linear nature of the soil response for the full analysis involving soil-pile-structure

interaction). Although this has been accepted worldwide, one has to exercise caution in using the p-y curve approach for any site-specific application. The higher factor of safety taken for the environmental loads, the reserve strength due to aging of soil etc. often eclipses the other deficiencies in the well-established methods.

Therefore a three-dimensional analysis, which includes the undrained loading, is warranted till a correlation between the parameters used in industry and the standard methods is reached. In the present study, undrained effective stress three-dimensional analyses utilizing the modified Cam clay model and Modified Drucker-Prager model have been carried out. ABAQUS software has been used for the study. The soil continuum consisted of 20-noded brick coupled pore fluid- stress elements and the pile consisted of 20-noded stress elements. The slippage and gapping were also included in the analysis. The results obtained from the three-dimensional analyses showed broad similarities with the conventional approach obtained as per API recommended practice. However, the results from the conventional approach were found to be conservative.

The deflection pattern was almost similar in both the mehods of analysis. The maximum bending moment and shear force obtained from the API method was higher than the three-dimensional analysis. A proper assessment of the stresses and strain in the continuum was done through this analysis. There is a clear indication of bulging of the soil as is expected near the pile as shown by the direction of the accumulated plastic strains and the displacements at the end of the loading. The pore pressure behaviour has also been satisfactorily represented. As such, the realistic analysis of the type conducted herein, not only provides understanding of the laterally

loaded pile behaviour, but also gives scope for the evaluation and improvement in the existing design procedures.

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