THREE DIMENSIONAL LIQUEFACTION ANALYSIS OF OFFSHORE FOUNDATIONS

Hossein Ali Taiebat, B.Sc., M.E.S.

A thesis submitted for the
Degree of Doctor of Philosophy
Department of Civil Engineering
The University Of Sydney

March 1999
Dedicated to my dearest;

Giti & Dena
SYNOPSIS

This thesis presents numerical techniques which have been developed to analyse three dimensional problems in offshore engineering. In particular, the three dimensional liquefaction analysis of offshore foundations on granular soils is the main subject of the thesis.

The subject matter is broadly divided into four sections:

1) Development of an efficient method for the three dimensional elasto-plastic finite element analysis of consolidating soil through the use of a discrete Fourier representation of field quantities.

2) Validation of the three dimensional method through analyses of shallow offshore foundations subjected to three dimensional loading and investigation of the yield locus for foundations on purely cohesive soils.

3) Formulation of governing equations suitable for three dimensional liquefaction analyses of offshore foundations founded on granular soil, presentation of a method for liquefaction analyses, and application of the method in modified elastic liquefaction analyses of offshore foundations.

4) Application of a conventional elasto-plastic soil model in the liquefaction analyses of offshore foundations using the three dimensional finite element method.

The finite element method developed in this thesis provides a rigorous and efficient numerical tool for the analysis of geotechnical problems subjected to three dimensional loading. The efficiency of the numerical tool makes it possible to tackle some of the problems in geotechnical engineering which would otherwise need enormous computing time and thus would be impractical. The accuracy of the numerical scheme is demonstrated by solving the bearing capacity problem of shallow foundations subjected to three dimensional loading. The generalized governing equations and the numerical method for liquefaction analyses presented in this thesis provide a solid base
for the analysis of offshore foundations subjected to cyclic wave loading where they are founded on potentially liquefiable soil. The practicability of the numerical scheme is also demonstrated by a modified elastic liquefaction analysis of offshore foundations. The liquefaction phenomenon is redefined in the context of the conventional Mohr-Coulomb model, so that a relatively simple and practical model for elasto-plastic liquefaction analysis is presented.

The three dimensional finite element method together with the numerical scheme for liquefaction analysis and the elasto-plastic soil model provide a suitable practical engineering tool for exploring the responses of offshore foundations subjected to cyclic wave loading.
PREFACE

The candidate carried out the work described in this thesis during the period of his studies, 1995-1998, in the Department of Civil Engineering, the University of Sydney, under the supervision of Professor John P. Carter.

In accordance with the By-laws of the University of Sydney, a candidate shall state the sources from which his information is derived, the extent to which he has availed himself of the work of others, and the portion of the work which he claims as original. In this regard, the author claims originality for the entire work described in this thesis, less the information or ideas derived from the many references and sources which have been acknowledged in the text. In particular, originality of the following works is claimed:

The entire review of the current theoretical and experimental investigations of the liquefaction of granular soil and liquefaction analysis of offshore foundations, presented in Chapter 2.

The application of the discrete Fourier series in deriving a finite element formulation of consolidation and verification of the formulation and application of the method to the numerical examples, presented in Chapter 3.

The three dimensional finite element analyses of shallow foundations on cohesive soils, the presentation of the two and three dimensional yield locus for the foundations and the new bearing capacity equation suitable for foundations under combined three dimensional loading, the subjects of Chapter 4.

The development of the generalized governing equations for the stress-strain relationship of liquefiable soil, the presentation of a numerical scheme for liquefaction analysis, the application of the numerical method to modified elastic liquefaction analyses of offshore foundations, the entire investigation of the effects of various factors on the behaviour of the foundations, and the comparison of the results of analyses with the existing observed values, presented in Chapter 5.
The entire work on the elasto-plastic method for liquefaction analysis of offshore foundations and the application of the method to the numerical example considered in Chapter 6.

The entire studies on cyclic resistance of offshore foundations on granular soil, the investigation of the effects of various parameters on the cyclic responses of offshore foundations, and the presentation of a simple method for comparative studies, presented in Chapter 7.

The candidate used the powerful structure of the existing general finite element computer program of AFENA as the basis for his programming. However, incorporation of the discrete Fourier series and the pseudo force method in non-linear programming as well as the numerical scheme for liquefaction analysis into the finite element program are claimed to be original.
ACKNOWLEDGEMENTS

The work described in this thesis has been made possible through support and financial assistance provided to me during the course of study. I was the recipient of an Overseas Postgraduate Research Scholarship, a University Postgraduate Research Award, and the Centre for Geotechnical Research Scholarship, for which I am grateful.

I am indebted to many people for their interest and assistance during the course of this work. I have very much valued my time in the Department, I have learned a great deal and made some lifelong friends. In this regard, I would like to thank various members of the staff and the research students, in particular, Dr. David Airey, Associate Professor John C. Small, Dr. Tim Hull, Dr. Martin D. Liu, Mohammad K. Islam, Jiping Pan, Takashi Itakura, and Changxin Wang.

To Professor John P. Carter, the Head of the Department of Civil Engineering, I wish to express my deep gratitude and sincere thanks for his invaluable supervision, generous assistance, and continuous encouragement during my entire period of candidature.

Finally, the last four years would have been unbearably difficult without the continued support of my family. I cannot thank them enough for their love, understanding, sacrifices, and always being there for me. In appreciation of all that support, this thesis is dedicated to them.

March 1999                            H. A. Taiebat