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Theory and Application

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With 229 figures

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Foreword

Estimating foundation settlement of various structures is, in general, an important area of study in the field of geotechnical engineering. With the growth of metropolitan areas around the world and with scarcity of land, high rise building construction has become a necessity. In high rise building construction, it is important to evaluate the allowable bearing capacity and settlement of foundations for proper design and performance in the post-construction stage. Considering the nonhomogeneous, and anisotropic nature of subsoil, settlement calculation is truly a challenge for geotechnical engineering.

This text by Professor Xiangfu Chen is a welcome addition to scholars and practitioners in geotechnical engineering. It provides the state-of-the-art of settlement calculation procedures of deep foundations available in literature at this time for super high rise buildings that are built on raft foundations, raft foundations on floating piles, and raft foundations on end bearing piles as well as several case studies.

The book summarizes very well theories and application of the Winkler foundation model, elastic half space model, layered foundation model, double parameter elastic foundations models, cross-isotropic model, and nonlinear elastic model, along with the procedures to estimate sub-grade Poisson's ratio and elastic modulus which are essential parameters for estimating elastic settlement. It also has an excellent chapter on consolidation settlement.

I congratulate Professor Chen for the excellent work he has done in explaining the theoretical models and the field observations on settlement of foundations of structures. I sincerely trust that this will be a useful book for researchers and practicing engineers.

California State University Sacramento *Prof. Braja M. Das*

September 2009

Preface

Settlement calculation is one of the three major issues in foundation engineering and it has not yet been resolved completely. Especially settlement calculation of super high-rise buildings still remains the most difficult problem for engineers. Due to lack of practical settlement data, there is few systematic research result and rarer monograph to investigate this special problem.

This book summarizes the author's three decades of experiences and research results on deep foundation in design and construction of high-rise buildings. It presents a full coverage of settlement calculation issues theoretically with case studies, according to the characteristics and requirements of super high-rise buildings. It also brings forward the author's several original research results, which form a series of settlement calculation theory and application on high-rise buildings.

The book contributes to the problems of the constitutive model of soft soil, analysis of ground stress and deformation, the pile group effects and the behavior of super-long piles, settlement calculation methods in China and in the world.

The book focuses on settlement calculation of deep foundation of super high-rise buildings and its case studies. Based on the new Code for Design of Building Foundation in China and practical settlement data collected from more than 20 high-rise buildings, it for the first time deals with the effects of retaining structure in deep excavation on the settlement of the three kinds of deep foundations of high-rise buildings, i.e., box (raft) foundation, box (raft) foundation on floating piles, box (raft) foundation on end bearing piles. The calculation methods for the settlement of these foundations are proposed. A new design method for space-varying rigidity pile group with equal settlement has been invented and applied to high-rise buildings, based on the author's research results on the advantages of super-long piles on settlement control and that of short pile and middle length piles on bearing capacity. The method brings a new insight in the design theory of pile foundation. Other innovative studies are also covered in this book including the layered summation method for oblique stepped strata, and the integrated coefficient method of box foundation on sandy.

In the book, settlement data from super high-rise buildings in China and other countries are collected and analyzed, and special focus are given to the data of the Building of China Bank in Qingdao (designed by China Construction Beijing Design & Research Institute). The settlement calculation of finite element and Chinese methods (semi-theoretical & semi-empirical method) shows that the theoretical results are very close to the practical settlement data. After calculations and comparisons, several important results have been obtained, for example, the empirical settlement coefficient for strongly weathered granite in the Qingdao area is about 0.2; the adjustment coefficient of settlement calculation depth is 0.4. Other conclusions are also gained through analysis of the settlement data of Shanghai Jinmao Tower, Shanghai Senmao Building in China, Shenzhen Saige Plaza in China and Guangdong International Tower in Guangzhou China. The results can be considered as useful reference for project design and construction of super high-rise buildings.

The book is technical reference including technical experiences of typical practical projects, combining theoretical research with practical application, and design with construction.

This book is composed of 10 chapters. Chapter 1 mainly introduces the development of super high-rise buildings and deep foundation, and the international progress in settlement research. Chapter 2 presents six practical computing models for subsoil and the choice of calculation parameters. Chapter 3 deals with the mechanical issues in settlement calculations, i.e., space and plane analysis, contact pressure on the bottom of foundation, stress analysis in non-homogeneous and anisotropic subgrade. Chapter 4 covers the ground deformation theory, i.e., the compression characteristics of soil, the final settlement calculation, the calculation method of elasticity, the initial and consolidation settlement, the hypo-consolidation settlement, the settlement calculation of sand, the deformation theory of saturated soft soil, and the finite element solution of foundation settlement. Chapter 5 introduces the settlement calculation method of box (raft) foundation on super high-rise building, including simplified methods for settlement calculation, the calculation methods based on the national design codes, the settlement calculation of box (raft) foundation proposed by the author for the first time, taking into account the effect of the retaining structure in deep excavation on super high-rise buildings. This chapter also covers all the settlement calculation methods successfully applied to the box foundation of Qingdao Zhongyin Tower in Qingdao China (the highest building in Mainland China solely designed by Chinese, also the highest building in the world adopting box foundation), such as finite element method, settlement formulas considering the effect of retaining structure, the settlement calculation method for box foundation with effects of integrated coefficient, the spline function method for layered subsoil, the regional experience factor in the settlement calculation, with over five years of settlement data, and the analysis of the results. Since the author takes charge of the design of the project, the data in this case are reliable. There are also measured data and analysis results from the rock subgrade of Guangdong International Tower. Chapter 6 introduces the loading behavior and settlement calculation of super-long pile, i.e., settlement calculation of single pile and pile group, the empirical formula and simplified method of settlement calculation. Chapter 7 introduces the new design method for space-varying rigidity pile group with equal settlement, which has been proposed by the author. The design principle, design process and design parameters are also presented in this chapter. Chapter 8 is about the case study of Jinmao Tower and Senmao Tower, both in Shanghai China. Analysis and research of the settlement data of the diaphragm wall + super long floating piles + raft foundation shows the settlement characteristic of the foundation (for 50 meters plus long pile-raft foundation, the settlement is 60—100 mm). Analysis is also carried out on the effect of diaphragm wall with brace structures and load-bearing diaphragm walls in the settlement calculation. At the same time, the structure–foundation– subsoil interaction, the subsoil–pile interaction and the pile–subsoil–pile interaction is analyzed with the sub-domain method of spline function. Chapter 9 focuses on settlement of rock subgrade based on the data from Saige Plaza in Shenzhen China. Settlement computation of combined diaphragm wall + end pile + raft foundation in rock subgrade for super high-rise buildings is given in this chapter. In Chapter 10, the main innovative results (semi-theoretical & semi-empirical XFC method) and conclusions are summarized, and further subjects needed to be studied on settlement of super high-rise buildings are proposed.

The author sincerely gives his gratitude to the following organizations and experts. Without their support and help, this book would not have come to publication: Chinese Foundation for Excellence and Concern for the Grants, CPC Central Committee United Front Work Department and its Sixth Bureau, the State Council, the SASAC and its Group Work Department, the Ministry of of Housing & Urban-Rural Development Construction and its Science & Technology Division, China State Construction Engineering Corporation (CSCEC). The author is indebted to Tongji University, the author's Alma Mater and its leaders, to Professor Xueyuan Hou, the author's doctoral tutor, and to the colleagues at China Construction Beijing Design & Research Institute.

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The settlement calculation is a very complicated problem. The author believes that with the fast development of advanced technologies, and based on the evolution already accomplished, a complete solution to settlement calculation will be achieved with joint efforts of researchers across the world. Finaly, I wish to thank deeply Professor Braja M.Das for writing Foreword and making high evaluation in the book.

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Prof. Xiangfu Chen
November 2010

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