

The Engineering of Foundations

Rodrigo Salgado
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THE ENGINEERING OF FOUNDATIONS

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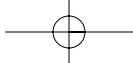
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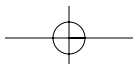
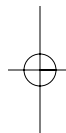
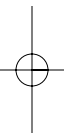
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To Mônica, for the unwavering support and encouragement.

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PREFACE

*I keep six honest serving-men
(They taught me all I knew)
Their names are What and Why and When
And How and Where and Who.*

Rudyard Kipling

Foundation engineering is the fascinating subject that deals with the safe and economical transfer to the ground of loads from structures of various types (such as buildings, bridges, and industrial facilities), functions, and sizes. Foundation engineers draw on their knowledge of mechanics, of how to measure or estimate various soil and rock properties, of how structures respond to foundation movements, and of basic economic concepts to determine the best, most economical foundations for these structures. Because of the need for knowledge from so many different fields, and because of the natural complexity of soils and rocks, many years of study and practice are required to master foundation engineering. This makes the writing of a foundation engineering text for senior undergraduate and first-year graduate students a challenging task.

Albert Einstein once suggested that things should be made simple, but no simpler. This certainly applies to foundation engineering and to a text on the subject. Due to the large scope of the subject, simplicity is desired so that all of the information, analyses, and techniques can be understood. The essence of knowledge, however, is to have it so that we can apply it. Oversimplification leads to spotty knowledge, which is hard to put to use in realistic practical problems. In this text, I attempt to present the subject of foundation engineering in a logical framework, in a natural sequence, and in as simple a presentation as possible. I emphasize conceptual understanding and avoid an oversimplistic treatment of soil. An example of this philosophy is how I treated one of the keys to the successful practice of foundation engineering: the estimation of soil parameters for use in calculations. In practice, these parameters are not given to us so that all we have to do is to plug them into an equation or two and arrive at an answer. Much of the work in foundation design resides in determining or estimating these parameters, and I have devoted significant attention to this.

STRUCTURE OF THE TEXT AND ANCILLARY MATERIAL

The book is organized into four parts and seventeen chapters. I have found in my teaching that having the subject divided in well-targeted chapters facilitates learning of the material. The first part is introductory. In it, I discuss foundation engineering

and foundation design in the context of civil engineering and civil engineering projects and discuss the different approaches to foundation design and the interaction of foundations and the structures they support. In the second part, I review the basics of soil and rock mechanics and how to determine soil and rock properties. The third part focuses on foundations in soil and rock. Foundation engineers must also contend with both temporary and permanent soil slopes and with excavations and retaining structures. These are addressed in the fourth and last part.

I have covered the construction of shallow foundations and the installation of deep foundations in more detail than is usually found in foundation engineering texts. It is important for engineers to understand what can and cannot be constructed in the field. It is also important, notably for deep foundations, to recognize the strong link between foundation response and installation techniques. On the analysis side, a derivation or at least an indication of how it is obtained accompanies each equation. Additionally, load and resistance factor design (LRFD) is an integral part of the book, as it is being increasingly adopted in the codes prepared by different organizations or promoted by their efforts (notably, in the United States, by the efforts of FHWA and AASHTO).

Three types of problems are proposed at the end of most chapters: conceptual, quantitative, and design. Conceptual problems are intended to test one's understanding of the topics. Quantitative problems are intended as relatively straightforward application of analyses and equations. Design problems simulate the types of decisions and calculations done in real problems, emphasizing how to start from information typically available in practice to arrive at intermediate or final results that are needed in design. Many of the examples and problems have been designed in a way that requires the solution to start at the same point as problems found in practice start, with the information typically collected from borings, penetration tests, and so on, from which stiffness or strength parameters of the soil or rock must be estimated.

The list of references is separated into cited references, references that are not cited but whose reading may benefit those with a deeper interest in a certain topic, and ASTM standards and procedures that are pertinent to each chapter.

The text web site contains a gallery with my photos and those of others who have agreed to let me post them. The gallery is organized according to the book chapters for easy consultation. The web site also contains other resources, including some programs and spreadsheets.

USE OF TEXT IN UNDERGRADUATE AND GRADUATE COURSES

Readers and instructors often find useful to know how the author of a text would use it in his own teaching. Typically, students taking a course in foundation engineering have already studied soil mechanics, and, in a few cases, rock mechanics and engineering geology as well. Therefore, chapters 2–6 are useful in the review of previously seen material in the foundation engineering courses. They contain some key concepts for the estimation of design values of soil shear strength and stiffness; thus, I refer to specific material in these chapters throughout the semester. Some of the material in chapters 2–6 is advanced. For example, strain analysis,

the Mohr circle of strains, and slip surfaces are treated in some detail. These are rarely covered in basic soil mechanics courses in the United States, and can be skipped without loss of continuity. However, I have found that the more curious undergraduate students benefit from having access to this material, and, in my opinion, graduate students should be exposed to it to have a deeper understanding of soil mechanics. I also use Chapters 2–6 in the soil mechanics courses I teach at Purdue University. Throughout the book, sections containing more challenging material are identified with an asterisk (*) so that both readers and instructors know they can skip them if more basic coverage of the subject is desired.

In my undergraduate foundation engineering course, I cover the following topics, in order:

1. Foundation engineering (Chapters 1 and 2)
2. Site exploration (Chapter 7)
3. Shallow foundations (Chapters 2, 8, 9, 10, and 11)
4. Deep foundations (Chapters 12–13)
5. Retaining structures (Chapter 16)
6. Slopes (Chapter 17)

In my graduate foundation engineering course, I cover the following topics (without skipping sections):

1. Foundation engineering (Chapter 1)
2. Foundation design (Chapter 2)
3. Site exploration (Chapter 7)
4. Shallow foundations (Chapters 8–11)
5. Deep foundations (Chapters 12–15)

It would be presumptuous of me to suggest a specific order. Each instructor feels comfortable with a different sequence that reflects the instructor's view of the subject and the specific needs of the students. The book was written to be flexible and to accommodate such needs.

ACKNOWLEDGMENTS

I was sitting in my office at Purdue University one day, when a nice gentleman knocked on my door and introduced himself as Thomas Casson of McGraw-Hill. I invited him to sit down, and, as soon as he did, he asked me whether I would like to write a book on foundation engineering for McGraw-Hill. This is how this book started. Tom's visit was timely, for after considering this for a while, I found that I was ready to write it. I felt that the progress of the underlying science and up-to-date design methods were not yet found in foundation engineering texts, and thus that there was a space that needed filling. I thank Tom for providing the spark and Suzanne Jeans and Bill Stenquist of McGraw-Hill for keeping it alive afterwards. Bill Stenquist believed in the project and in how I wanted to shape the book. I thank him for the support throughout the project. Jeff Lachina and Lori Kozey of Lachina Publishing Services made the book into a reality, and I appreciate the dedication and effort they put into it.

My interest in foundations and geotechnical engineering came about despite of myself, and those responsible deserve mention. As a young boy in Brazil, I spent more time on construction jobsites than on soccer fields (where, I have to admit, I many times wish I were). Both my grandfather, Paulo, and my father, Carlos, are civil engineers who owned their own civil engineering firms. As a result, there was plenty of opportunity for visits to construction sites that allowed a (very) early exposure to foundation engineering practice. I thank them, and my father in particular, for grounding me on the realities of construction before I ever saw any of the theory of design. My interest in reading and writing goes back to the devotion that my grandmother, Sueli, showed in instilling in me a love for books, for knowledge, and for language at an age of which I remember few things (one of which is getting pointed to this or that book and then discussing with her what I had liked or disliked in the various stories).

My good fortune continued in the work I did after graduation, which brought me in contact with things and with world-class people that continued to lift my interest in the subject. I have benefited from interactions with academic and professional colleagues in joint work, committee work, and other venues. In particular, James K. Mitchell and Michele Jamiolkowski were important examples of how effective the full integration of research, practice and education can be.

I am very grateful to Monica Prezzi and Dimitrios Loukidis. Their reviews of the manuscript were extremely helpful, and I appreciate the time and the dedication they devoted to this task. I thank Hoyoung Seo and Prasenjit Basu for helping me put together the solutions manual for the end-of-chapter problems. Sita Gentil helped with suggestions related to the cover design. Tanusree Chakraborty, Grace Abou-Jaoude, Umashankar Balunaini, and Dongwook Kim helped me with the preparation of some figures. Grace Abou-Jaoude and Umashankar Balunaini assisted with obtaining figure permissions. Tanusree Chakraborty, Umashankar Balunaini, and Dongwook Kim assisted with final proofreading. Antonio Carraro and Tejas Murthy assisted with some photos taken at Purdue University facilities. Antonio Carraro, Dimitrios Loukidis, and Monica Prezzi tested early versions of the manuscript in their courses at Colorado State University and Purdue University, and the feedback they provided was very complete and helpful. I tested the manuscript on the courses I teach at Purdue University, and received helpful comments and questions from graduate and undergraduate students, to whom I am thankful. In particular, I would like to mention Major Aaron Altwies of the United States Air Force and Ioannis Zevgolis, who provided me with comments on an early version of the manuscript, and Hoyoung Seo, Prasenjit Basu, and Umashankar Balunaini, who took the request for comments more seriously than I ever intended.

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Rodrigo Salgado
West Lafayette, IN

ABOUT THE AUTHOR



Rodrigo Salgado entered the Federal University of Rio Grande do Sul, Brazil, first as a chemical engineering major, then transferred to civil engineering. He graduated in 1986. After several years working first as a student intern, then as an engineer with a geotechnical specialty contractor and with PETROBRÁS, the Brazilian oil company, he came to the United States for graduate school. He obtained an MS in 1990 and a PhD in 1993 at the University of California, Berkeley. Immediately upon graduation, he joined the faculty at Purdue University, where he is today a professor. He has been a visiting scholar at the Technical University of Turin, a visiting professor at the University of Newcastle, and a Gledden Senior Fellow at the University of Western Australia. Professor Salgado is the recipient of numerous awards, including the Shamsheer Prakash Research Award in 2005 for the solutions of problems in geotechnical engineering using advanced analysis methods, the ASCE Casagrande Award in 1999 for his contributions in the fields of foundation engineering and earthquake engineering, and the ASCE Walter L. Huber Civil Engineering Research Prize in 2004 for his research on foundation engineering. He was an invited participant at the National Academy of Engineering Frontiers of Engineering Symposium in 2005. His research has been sponsored by, among others, NSF, FHWA, INDOT, and INTEL. He has served on ACI, ASCE, and ABMS technical committees.