Foundation Engineering Handbook

EDITED BY

Hans F. Winterkorn and Hsai-Yang Fang

FOUNDATION ENGINEERING HANDBOOK

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VNR VAN NOSTRAND REINHOLD COMPANY
New York / Cincinnati / Toronto / London / Melbourne

Van Nostrand Reinhold Company Regional Offices:
New York Cincinnati Chicago Millbrae Dallas

Van Nostrand Reinhold Company International Offices:
London Toronto Melbourne

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Library of Congress Catalog Card Number: 74-1066
ISBN: 0-442-29564-2

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Manufactured in the United States of America

Published by Van Nostrand Reinhold Company
450 West 33rd Street, New York, N.Y. 10001

Published simultaneously in Canada by Van Nostrand Reinhold Ltd.

15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging in Publication Data

Winterkorn, Hans Friedrich, 1905–
Foundation engineering handbook.

Includes bibliographies.
1. Foundations–Handbooks, manuals, etc. 2. Soil mechanics–Handbooks, manuals, etc. I. Fang, Hsai-Yang, joint author. II. Title.
TA775.W54 624'.15 74-1066
ISBN 0-442-29564-2

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PREFACE

A handbook should be a useful and dependable servant to its owner and user. In order to fill this role, handbooks in different fields must differ in accordance with the degree of complexity of the material systems involved and the extent—from qualitative to quantitative—to which fundamental parameters have been recognized, defined, and built into dependable theoretical structures. A handbook on foundation engineering must serve the dual purpose of, first, providing the best possible understanding of the nature and properties of soil and similar natural and artificial systems on which structural foundations are imposed, and second, presenting up-to-date information on the analysis, design, and construction of foundations for various purposes, including amelioration of deficient foundation soils, and indicating future developments that can reasonably be expected in the theory and art of foundation design.

Treatment in this book has been restricted to foundations on soil and similarly behaving soft and uncemented rock excluding those on hard rock, which present fundamentally different problems. The user of this book must keep in mind that soil data do not possess the same general validity as data for physically and chemically well-defined substances. Also, soil properties are usually of a complex nature and depend not only on composition but also on the mutual arrangement of the component phases, which itself is a function of previous history. Because of this, the numerical values of soil properties depend to a great extent on the method used in their determination and are actually defined by the method employed rather than by the name given to them. It is for this reason that standard methods are so important and should be followed in all prescribed detail, noting specifically when deviations occur for one reason or another.

Within the indicated framework, the authors have aimed to present clearly and concisely the basic principles and material parameters pertinent to each subject and to illustrate with practical examples the engineering application of these principles within the limitations set by the material parameters. Since no treatment can ever be exhaustive, the topics were carefully selected for their intrinsic importance as well as for the light their treatment would shed on topics that could not be dealt with in detail. Each selected topic was then matched with a recognized authority from industry, government, or education. Each contributed his knowledge and experience in developing this handbook. In spite of the large number of contributors, it has been attempted to give the book logical sequence and uniformity in both notations and symbols. The style and philosophy of the individual authors, however, have been retained as much as possible.

In order to enable the user to judge the range of validity of the mathematical formulations and methodologies for analysis and design, emphasis was placed on clear statements of the essence of the theoretical concepts employed and the simplifying assumption required for the mathematical treatment.

The primary purpose of this handbook is to serve the practicing engineer. However, its scope and its treatment of both theory and material parameters should also make it valuable to both the engineering teacher and student. They will find not only practical reference data and methodologies for analysis and design but also what amounts to rather complete texts not only of applied soil mechanics but also of important areas of transportation and ocean engineering, water resources systems, irrigation, and reclamation, to name just a few.

The editors express their thanks to all those who have generously given advice and encouragement in the preparation of this handbook. They are especially grateful to the contributors for their willingness and cooperation and to the publishers for their assistance and support in bringing the book to completion.

Thanks are also due to Miss Eleanor Nothelfer and Miss Phyllis Raudenbush for general aid in preparing the manuscripts and the index.

Hans F. Winterkorn
Hsai-Yang Fang

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1 SUBSURFACE EXPLORATIONS AND SAMPLING

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1.1 INTRODUCTION

The proper design of civil engineering structures requires adequate knowledge of subsurface conditions at the sites of the structures and, when structures are to consist of earth or rock fill materials, of subsurface conditions at possible sources of construction materials. The structures may be divided into three categories.

1. Structures for which the basic problem is the interaction of the structure and the surrounding ground. Such structures include foundations, retaining walls, bulkheads, tunnel linings, and buried pipes. The main point of interest is the load deflection characteristics of the interface.

2. Structures constructed of earth such as highway fills, earth and rockfill dams, bases and subbases for pavements, and backfill behind retaining walls. Besides the interaction of the earth structure with the adjacent ground, properties of the construction materials are required for determining the action of the earth structure itself.

3. Structures of natural earth and rock as natural slopes and cut slopes. In this case, knowledge of the properties of the natural materials is required.

In order to perform his design work properly, the engineer must have a good understanding of the problems encountered in making subsurface explorations and of the various tools available to make subsurface explorations. Specialists in soil and rock engineering and/or geology are required for planning, conducting, and supervising the programs of subsurface explorations.

The types of subsurface information required for design include, but are not limited to, the following:

1. Areal extent, depth, and thickness of each identifiable soil stratum, within a limited depth dependent on the size and nature of the structure, together with a description of the soil including its degree of density if cohesionless and degree of stiffness if cohesive.

2. Depth to top of rock and the character of the rock, including such items as lithology; areal extent, depth, and thickness of each stratum; strike, dip, and spacing of joints and bedding planes; presence of fault zones; and state of weathering or decomposition.

3. Location of groundwater and the presence and magnitude of artesian pressures.

4. Engineering properties of the soil and/or rock in situ such as permeability, compressibility, and shear strength.

The procedures for obtaining subsurface information may be divided into the two broad categories of indirect and direct methods. Indirect methods include: geologic mapping, aerial photography and topographic map interpretation, and the use of existing geological reports, maps, and soil surveys.

Direct methods comprise the following:

1. Field reconnaissance, including the examination of in situ materials in natural and man-made exposures such as river banks, escarpments, highway and railway cuts, quarries, and existing shafts and tunnels.

2. Soundings and probings.

3. Borings, test pits, trenches, shafts, and adits from which representative disturbed and/or undisturbed samples of the in situ materials may be obtained.

4. Simple field tests, such as the Standard Penetration Test (SPT) and the static cone penetration test, whose results have been correlated with engineering properties on a general basis.

5. Field tests such as the vane shear test, seepage and water pressure tests, plate bearing tests, the CBR test, and pile load tests, wherein the engineering properties of the in situ materials are measured directly.

It is the purpose of this chapter to present essential information for the complete range of subsurface explorations. Included are descriptions of the planning of an exploration program; indirect methods of exploration; drilling equipment and techniques; sampling equipment and techniques; field test procedures; and suggestions for reporting subsurface exploration information. A list of references is given at the end of the chapter.

1.2 PLANNING AN EXPLORATION PROGRAM

1. Purpose of Explorations and Phased Execution

The basic purpose of an exploration program is to provide the engineer with a knowledge of the subsurface conditions at the site of an engineering project. Normally, the explorations provide information required for the safe and economical design of a project and inform the construction engineer about the materials and conditions he will encounter in the field. At times, the explorations may be used to obtain information for the analysis of the failure of an engineering structure.

Explorations are normally accomplished in a phased sequence as follows:

1. Reconnaissance investigations.
2. Explorations for preliminary design.
3. Explorations for detailed design.
4. Explorations during construction.

Each phase of explorations together with the engineering done in that phase discloses problems which require further investigation in the next phase. Not all phases are required on all projects; the fourth phase generally is not necessary.

The number, type, location, size, and depth of the explorations are dependent upon the nature and size of the project and on the degree of complexity and critical nature of the subsurface conditions. A general rule of thumb is that the cost of the subsurface explorations for design should be in the range of 0.5 to 1.0 percent of the construction cost of the project. The lower percentage is for large projects and for projects with less critical subsurface conditions; the higher percentage is for smaller projects and for projects with critical subsurface conditions. About half the cost would be expended for explorations for preliminary design and about half for detailed design. A very much smaller amount of money would be expended for explorations in the reconnaissance investigation phase. No rule of thumb can be given for the cost of explorations during construction. Such explorations are used to investigate special problems which may arise during construction or to better delineate the materials in borrow areas or quarries in connection with the contractor's scheduling of his operations. Generally they are not required but, when used, their cost can vary widely from one project to another.

The combined cost of planning the subsurface explorations, supervising the explorations, laboratory testing, and reporting the results usually amounts to about the same cost as the explorations. In general, it is justifiable to spend additional money on explorations and related testing and engineering as long as the savings which can be effected in the project construction cost on the basis of the information obtained are significantly greater than the cost of the explorations plus related engineering work.

Local building codes often specify the minimum number of borings required for a given size and type of structure. In the case of a lightweight structure which is to be founded in an area of relatively uniform subsurface conditions this minimum number of borings generally will suffice and all borings may be completed during a single exploration program.

At times, because of deadlines set for completion of the engineering work, the argument is given that since the information from a full and proper exploration program will not be available in time for use in the design, the exploration program should be cut. In such cases, the much-preferred procedure is to proceed with the engineering on the basis of the best assumptions which can be made from the available subsurface information, but to continue with the full and proper program of explorations and testing. The information obtained will then either confirm the assumptions made to complete the engineering on time or indicate where changes in the design assumptions have to be made. Frequently, any modifications required by the changes indicated by the full exploration program can be made without undue difficulty and in a timely manner.

The sequence in which the explorations are to be performed is often left to the discretion of the drilling contractor. In such instances, the sequence will be governed by the ease of operation for the driller. Movement of the rigs between borings will be kept to a minimum; all borings in one area of the site may be drilled before those in another area are started. Often, it is not only advantageous but essential that the engineer designate the sequence of the explorations. If, for instance, the borings being drilled are intended to fill gaps in a geologic profile based on previous explorations, the information from a given boring could preclude the need for one or more other borings which had been programmed. The sequence may also be dictated by time limitations if the time available for design is short. It is not unusual for project design and laboratory testing to be concurrent with the explorations. Under these conditions, it may be necessary to obtain samples first from specific areas in order that testing may progress in a timely fashion. An example of this would be the case in which the borrow materials for an embankment dam had been selected on the basis of preliminary explorations and samples were required for detailed testing. In this situation, the explorations required to obtain the borrow samples might be done prior to or concurrent with additional foundation explorations.

2. Type and Number of Drilling Rigs

The types of rigs used will depend primarily on the type, size, and depth of the explorations; the location of the explorations, that is, whether they are onshore or offshore; the accessibility of the area to be explored; the types of rigs available in the area; and the terrain or sea conditions. The types of rigs used for exploration work and their applicability to various conditions are discussed in a subsequent section. The minimum number of rigs required to perform an exploration program is dependent on the time available for the execution of the program, the rate of advancement of the holes by the selected rigs, and the sequence of explorations. The estimated rate of advancement of the hole should include time allowances for equipment breakdowns, movement of the rigs from one location to another, and standby due to weather.

3. Types of Sampling Equipment

The sampling equipment to be used will depend on the type of information required and the characteristics of the materials to be sampled. If only classification of the soil strata is required, disturbed samples will suffice and samplers such as the split tube drive sampler may be used. If, on the other hand, the ultimate goal is the determination of the engineering properties of the soils by laboratory testing, more sophisticated equipment such as the thin wall tube and piston samplers will be required. The sizes and types of samplers will depend also upon such factors as the presence or absence of gravel; the maximum size of particle to be sampled; the type of material to be sampled, i.e., cohesionless or cohesive; the density of cohesionless materials; the consistency of cohesive materials; and the location of the material to be sampled with reference to the groundwater level. The types of samplers available and the specific conditions under which each may be used is discussed in detail in the paragraphs on samplers and sampling techniques.

1.3 RECONNAISSANCE INVESTIGATIONS

1. Purpose and Scope

The reconnaissance investigations provide information for prefeasibility studies and for planning the explorations for the succeeding phase, explorations for preliminary design. This program, for a localized project such as a building which is to be constructed on a preselected site, will be somewhat limited in scope. However, when a dam or highway project is under consideration, several alternative sites or alignments must be considered. The information obtained in this phase aids in the selection of the alternative sites or alignments for investigation. A large portion of the work during this phase falls into the category of research. Also included would be field reconnaissance by a geologist and a soils engineer plus such geophysical explorations and borings as are deemed essential.

2. Research

Any investigation begins with a thorough search for all existing information which could shed light on subsurface conditions at the site, including both old and recent topographic maps, geologic maps, aerial photographs, geologic and subsurface exploration reports and records of governmental agencies and private firms, university publications, and articles in engineering and geologic journals. The sources of these items vary from country to country and even between the political subdivisions of a country. One of the major sources of geologic and topographic information within the continental United States is the United States Geologic Survey (USGS). The types of information available from the USGS are discussed below. Other sources of information and a general description of the items provided by each plus a discussion of each of the different types of information and its use are also presented.

3. Topographic Maps

Various types of maps are useful in the planning of an exploration program. Topographic maps provide information on the accessibility of the site of the work and the terrain, both of which may exert a strong influence on the types of rigs used for the work. Topographic maps may also be used in much the same manner as aerial photographs. A knowledge of geomorphology often will permit a trained observer to surmise much about the geology of a site on the basis of the land forms and drainage patterns shown on the topographic maps. The maps do not have the detail of aerial photographs and, therefore, limit the capabilities of the observer. However, in the complete absence of aerial photographs or as an initial step, the use of the maps is worthwhile. The amount of information which can be derived from such maps also depends on the area involved and the amount of detail shown. General characteristics of the soil and/or rock are commonly revealed by the topography. Geomorphic soil forms such as coastal and flood plains, deltas, alluvial fans, terraces, dunes, eskers, drumlins, and other features are easily recognized. Swamp areas normally are designated directly on the maps and the drainage patterns of soils often give an indication of particle size and the degree of induration. In rock areas, structure is often revealed in such details as the course of a river or the slope of a hill. Under proper conditions, it is possible to determine structural features such as dip and strike, folding, faulting, and relative consistency.

The major source of topographic maps of the United States is the United States Geologic Survey (USGS). The USGS publishes a series of quadrangle maps, known as the National Topographic Map Series, which covers the United States and its territories and possessions. Each map covers a quadrangle area bounded by lines of latitude and longitude. Maps covering areas of 7.5′ of latitude by 7.5′ of longitude are plotted to scales of 1:24 000 and 1:31 680 for the continental United States; similar coverage of Puerto Rico is provided at scales of 1:20 000 and 1:30 000 and of the Virgin Islands at 1:24 000. Fifteen-minute maps of the continental United States are at 1:62 500; 30′ maps are at 1:125 000 and one-degree maps at 1:250 000. Maps of Alaska covering 15′ of latitude by 20′ to 30′ of longitude are available at 1:63 360; other maps of Alaska are also available at 1:250 000 and 1:1 000 000. Hawaii is partially covered by series of maps at 1:62 500 and 1:24 000. Some shaded-relief maps and metropolitan area maps are also published by the USGS. A complete list of all USGS maps is presented in the U.S. Geological Survey (1965) and the supplements thereto which are published monthly.

Topographic maps of the United States are also produced by the Army Map Service and the United States Coast and Geodetic Survey (USC&GS). The former are based on the United States Military Grid and are at scales of 1:25 000 for 7.5′ quadrangles; 1:50 000 for 15′ quadrangles; and 1:250 000 for 30′ quadrangles. Maps of larger areas are plotted at scales of 1:250 000 and 1:500 000. The USC&GS publishes aeronautical and coastline charts. The former are small-scale maps which are primarily used for those areas of the United States and its territories which have not been mapped on a large scale by the USGS. The coastline charts, plotted at scales from 1:10 000 to 1:80 000 are useful for offshore work.

Other sources of topographic information for the United States include the U.S. Army Corps of Engineers, which publishes topographic maps and charts of some rivers and adjacent shores plus the Great Lakes and their connecting waterways; the U.S. Forest Service, which publishes forest reserve maps; and the Hydrographic Office of the Department of the Navy, which publishes nautical and aeronautical charts.

The sources of maps for overseas work are varied. Two excellent sources of general information are the American Geographic Society maps, which cover a large portion of South and Central America, and the British Admiralty charts.

4. Geologic Maps

The major source of geologic maps and information within the United States is the USGS, which has published books, maps, and charts in various forms since 1879. One of the most useful series of these publications is the "Indexes to Geologic Mapping in the United States." This series comprises a map of each state on which are shown the areas for which geologic maps have been published. A color code is used to give the approximate scale of each map. A text on the sheet also gives the source of publication, scale, date, and author of each geologic map and a complete list of USGS reports on the state. The maps distributed by the USGS also include a geologic map of the United States at a scale of 1:2 500 000 and several other series of maps, the best known and most widely used of which are the (1) Folios of the Geologic Atlas of the United States; (2) Geologic Quadrangle Maps of the United States; and (3) Mineral Resources Maps and Charts. Each of the folios, which were published until 1945, consisted of a text describing the geologic history of the area covered and several quadrangle maps showing the topography, geology, underground structure, and mineral deposits of the area. Since 1945, the folios have been replaced by individual quadrangle maps. These maps often include structure sections, columnar sections, and other graphic geologic data, as well as descriptive material. The mineral resources maps include information on such detailed topics as the sand and gravel deposits of a state, the construction materials of a state, the geology of limited areas, and the location of possible sources of riprap.

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