Foundations
of
Bridges and Buildings

BY

HENRY S. JACOBY
Professor Emeritus of Bridge Engineering
Cornell University

AND

ROLAND P. DAVIS
Dean, College of Engineering
West Virginia University

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PREFACE TO THE THIRD EDITION

The many developments in the field of foundation engineering since 1925 have necessitated revision in practically all chapters; hence the book has been completely reset. The development of the field of soil mechanics has brought a new importance to foundation exploration work. Consequently this chapter, which in the first and second editions was placed at the end of the book, has been rewritten and made the first chapter.

The field of soil mechanics is too extensive to permit of full treatment in a general text on foundations of bridges and buildings, but some of the more important phenomena in this important field are given in the second chapter.

The following new material on piling is presented: proper hammer weights, new formulas for bearing capacity, added information on marine borers, lateral strength of piles, steel H-section piling, and design of sheet-piling installations.

New material on cofferdams and caissons include deep cofferdam construction, design of cofferdams, placing cylinder caissons by boring, deep concrete open caissons, compressed-air flotation caissons, the sand-island method of placing caissons, air locks and rules for working in compressed air.

Material has been added to the text on grouting. The use of boring machines for placing deep cylinder piers is described, as is also the subject of predraining foundations. The article on the obstruction offered by bridge piers to the flow of water has been amplified and an article added in the offset method of underpinning. Many additional changes will be found in the form of new paragraphs here and there throughout the book.

Acknowledgment is made to the following for the use of material and of illustrations: *Engineering News-Record, Civil Engineering,* Boston Society of Civil Engineers, American Railway Engineering Association, American Society for Testing Materials, Union Iron Works, Bethlehem Steel Company, United States Steel Corporation, Industrial Brownhoist Company, Portland Cement Association, Keystone Driller Company, Raymond Concrete Pile

Company, C. B. McCullough, Arthur Casagrande, Lazarus White, H. A. Mohr, Philip C. Rutledge and M. Juul Hvorslev.

The revision work of this edition was done by the junior author. He accepts responsibility for all new material, as well as for the many changes in the arrangement of material that appeared in previous editions.

R. P. Davis.

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PREFACE TO THE FIRST EDITION

In preparing this volume the aim of the authors has been to treat in a systematic manner the entire subject of foundations for bridges and buildings as represented by American engineering practice. Only occasional references are made to foreign practice. It was hoped, at first, to accomplish this task within the limits of about 300 pages, but, as the work progressed, it became evident that this could not be done without abbreviating the treatment of many topics so much as to become unsatisfactory. In many cases, space has been economized by inserting additional illustrations and reducing descriptions in the text.

A large proportion of space is devoted to piles and pile driving, since young engineers are more likely to obtain their early experience with pile foundations than with any other class of foundation construction. Many facts derived from experience are given to emphasize and illustrate the application of fundamental principles and to form a rational basis for that kind of judgment which is such an important element in an engineer's professional practice. The undesirable features of considerable pile driving in this country have been due as much to the assumption that the art of pile driving is so simple that the aid of science is not essential as to the attempt of some engineers to base the art upon theoretical rules which fail to take into account many practical factors of the problem. Another reason for extending the treatment is due to the recent introduction of concrete piles which will help to retain the dominant place that pile foundations have held heretofore among other classes of foundations.

The attention of engineering teachers is called to the arrangement of the topics in the first five chapters. Instead of combining the treatment of all kinds of piles in chapters on descriptions, equipment, driving, and bearing power, respectively, the subject is developed in accordance with pedagogical principles for the benefit of students who approach it without any previous knowledge of the subject. It is believed, however, that practicians will find this arrangement equally useful for their study and reference. The full discussion of the bearing power of timber piles before considering that of concrete piles, conforms also to the order of historical development.

The treatment of the pneumatic process and its application, to both bridges and buildings, is supplemented by a chapter on pneumatic-caisson practice by T. Kennard Thomson, an experienced consulting engineer who has specialized in foundation construction. The results of his experience and observation should be helpful to all engineers and contractors of lesser experience.

Three chapters on piers and abutments are incorporated in this work since courses of instruction in technical colleges frequently include these topics in masonry construction with foundations. During the past decade considerable improvements have been made in the design of piers and abutments by the introduction of new types, including hollow and arched forms, in order to reduce the loads upon foundation beds and to eliminate a large part of the lateral thrust of embankments, as well as to decrease the volume of masonry in some cases.

The limits of the volume precluded historical notes in connection with every class of foundation, but they are introduced in certain cases relating to new types of construction, or where the process of development indicates the features which are likely to persist in the future.

Since a subject embracing so many details of design and construction cannot be exhaustively treated in a single volume of convenient size to meet the needs of all practicians, a chapter has been added which contains a large number of carefully selected and classified references to the vast amount of illustrative material on foundations contained in engineering periodicals and the proceedings of engineering societies. It is hoped that young technical graduates will form the habit of consulting the articles referred to, making suitable abstracts, and filing them for future use. To compare the manner in which different designers have solved a given problem is a most valuable study.

Grateful acknowledgments for photographs are due to S. W. Bowen, A. S. Crane, A. O. Cunningham, Dravo Contracting Co., Lackawanna Steel Co., Ralph Modjeski, C. K. Mohler, J. H. Prior, J. R. Rablin, E. J. Schneider, H. E. Stevens, F. L. Thompson, and M. M. Upson; to J. Q. Barlow, J. D. Isaacs, and H. K. Seltzer for permission to reproduce drawings; to R. A. Cummings, *Engineering News*, *Engineering Record*, *Engineering and Contracting*, and *Railway Age Gazette* for permission to reprint illustrations; to C. W. Reinhardt for the excellent drawings from which a number of illustrations were reproduced; and to E. H. Connor, L. L. Davis, Walter Ferris, J. E. Greiner, H. Ibsen, A. R. Raymer, R. Trimble, and many other engineers who have kindly furnished information. Acknowledgment is made for several photographs on the half tones themselves, or their titles.

April 15, 1914.

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FOUNDATIONS OF BRIDGES AND BUILDINGS

CHAPTER I

SOIL EXPLORATIONS AND BEARING CAPACITY

1-1. Foundations. A structure usually consists of two parts, one of which is supported by the other, the upper part being known as the superstructure and the lower part as the substructure. In a bridge the superstructure is composed of the beams, girders, and trusses, together with the floor system and bracing which they carry, whereas the substructure consists of the piers and abutments, including their supporting bases.

The substructure frequently consists of two parts which differ more or less in form and character, the lower part being called the foundation, this supporting the rest of the structure. Sometimes the term "foundation" is used without regard to any substructure, as, for example, when it is applied to the independent structure which supports a machine.

The foundation of a structure may then be defined as that part of the structure which is usually placed below the surface of the ground and which distributes the load upon the earth beneath.

Foundations are divided into various classes. The simplest form is obtained by merely widening the base of a wall or pier, so as to distribute the load over sufficient area on the foundation bed of earth. Another form is known as a "spread footing," in which the bearing area of a wall or pier is enlarged either by reinforcing the concrete base with steel bars or by inserting one or more tiers of steel I-beams. Large buildings resting on poor bearing soil may have a spread or raft foundation in the form of a reinforced-concrete slab that covers the whole basement area.

Pile foundations consist of a base of concrete or of timber grillage, supported by piles which distribute the load to the earth through a considerable depth either by friction alone or by friction combined with bearing on the ends of the piles.

When the bottom of the foundation has to be located on a bed of firm material at a considerable depth below the surface of the ground, the classes of foundations are designated by the respective methods required to sink them into position.

Foundations built in open excavation, or in open wells, are used when the excavation can be made either in the dry or with no more interference by water than can be controlled by a reasonable amount of pumping.

Where open caissons are employed, the excavation is made through the water under ordinary atmospheric conditions; after the bottom is sealed by concrete, the rest of the foundation is built in the open air.

Pneumatic-caissons are those in which the excavation is made by working in compressed air in the chamber of the caisson, on the roof of which the concrete or masonry is built up in the open air during the process of sinking.

Many kinds of foundations also require the use of a temporary structure known as a "cofferdam," which excludes the water from the site of the foundation during its construction.

The kind of foundation to be adopted depends largely on the character of the soil at the site and also on the presence or absence of water. The above-noted general classes of foundations, and their subdivisions, are described and illustrated in the following chapters of this volume.

The science and art of foundation design and construction have lagged considerably behind the science and art of superstructure design and construction; and yet the difficulties encountered below the ground are much greater than those found above the ground level. The superstructure will be the same wherever built, but the substructure must be designed to fit the particular soil conditions obtaining at the site. Foundation failures are generally not due to structural defects within the substructure itself but rather to a yielding of the soil supporting the substructure. A moderate amount of uniform settlement may be permissible, but differential settlement—a varying settlement in different parts of the structure—may lead to serious consequences by producing excessive stresses in the structural elements and by causing unsightly cracking.

In studying any foundation problem, the first step should be an investigation of the soil conditions, in order (*a*) to provide the necessary data by which the engineer may determine the most economical type of substructure and its proportions and (*b*) to furnish the contractor with the necessary information for carrying on construction work with maximum speed and economy. The investigation will include an exploration survey to determine the general nature and thicknesses of the several strata penetrated, as well as laboratory and field tests for bearing capacity determinations.

1-2. Need of Subsurface Explorations. Because of the general lack of proper investigation of subsurface conditions, underground work is still the biggest gamble in both engineering and construction. Adequate explorations are often omitted because of the time and cost involved. Innumerable examples demonstrate that this is false economy, for the cost of exploration is frequently less than the expense involved in merely revising the plans of the structure, without considering the unnecessary cost of the structure due to lack of proper information. Inadequate foundation investigations invariably result in greatly increased costs, and sometimes even in the loss of the structure itself.

In one instance a bridge pier was built on the surface of hardpan in a river bed. No examination was made on account of the swift current. Without warning the pier sank out of sight, causing the loss of two adjacent spans and a number of lives. On making an investigation afterward, it was found that the hardpan was only a thin stratum overlying a deep layer of soft clay.

In another example a bridge abutment which was founded on 60-ft. timber piles settled slowly until it reached a maximum of 3 ft. Exploration showed that the settlement was due to a 10-ft. layer of peat 35 ft. below the surface, which apparently was flowing under the superimposed load.

In placing the foundation for a building in New York City in which steel-cylinder piles (Art. 7-8) were used, a great deal of trouble was experienced because of the presence of buried stone-filled cribs. The actual conditions were not known previous to construction, as exploratory work was not permitted inside the existing building. The preliminary investigations were limited to a few core-drill holes through the sidewalk outside of the property lines.

Pile driving was started by using 12-in. pipe with shell thicknesses of $\frac{3}{8}$ and $\frac{1}{2}$ in., but with these thicknesses from 25 to 45 per cent of the piles were ruined in attempting to force the same through the cribs. Better results were obtained when the shell thicknesses were increased to $\frac{3}{4}$ and $\frac{7}{8}$ in., although in one spot the use of piles had to be abandoned, a timbered open pit being substituted.

The Washington Monument, designed for a height of 600 ft., was built on a deposit of good bearing material consisting of closely compacted sand and gravel, the base being 80 ft. square. Started