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FOUNDATIONS

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Frontispiece. Failure of a foundation of an otherwise strongly built framed building after an earthquake in Japan.

FOUNDATIONS

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and

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Preface

No book of this size can possibly provide all the information necessary to design the foundations for any type of building. This has not been the intention.

The author has been more concerned with explaining the principles, and illustrating the balance of forces when the weight of a building is superimposed on the widely-varying geological strata of the earth's surface.

An introduction is given to the study of rocks and soils and methods of testing them, with a guide to the interpretation of test results.

Various types of foundation, and their applications, are described. Only simple design methods which illustrate the principles are given, but references are given for the further study of more complex examples. The emphasis has been on giving a wide outline of the subject, and, to use an apt metaphor, in providing a firm foundation on which to build!

Forewarned is forearmed, and the reader should recognize when the foundation problem is not a straightforward one. In such cases, special care in testing the soil and seeking the right solution is necessary.

Good practice in building construction is suggested for work below ground, in order to ensure stability and the control of moisture. This is necessary so that the principles can be related to the complex operations carried out on building sites in sequence. With a clear understanding of why and how a satisfactory solution to a constructional problem has been evolved, the more capable designer is well equipped to solve new problems as they arise.

V.C.L.

Acknowledgement

I am indebted to a number of people who have provided information and help over a long period. It is impossible to list everyone. Some have provided information indirectly through their books and other publications, or lectures, and might even be surprised to see their names here.

I apologize in advance to anyone who recognizes a phrase, or illustration which they originated and which I have used inadvertently without acknowledgement. In the technical field, a pioneer's research soon becomes the standard method, and this is also true in the educational field. Everyone draws on the work of his predecessors, and so progress goes on. The important thing is to collect the experience of others, add one's own to it and pass it on by some form of record, in this case a book, so that the knowledge is not lost, and further progress can be made by those who study it.

All the authors and publications mentioned in the lists of references have been of great value to me in my research for this book and will provide further sources of information for readers studying the subject more deeply.

Dr. Smith of the Dept. of Engineering, Bristol University and members of the staff of Messrs. Clarke, Nicholls and Marcel's Bristol office have helped check my methods of design and calculation in the examples given, for which I am grateful.

Picture acknowledgements

Frontispiece	Robin Phillips, Bristol
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Contents

List of Symbols	x
Introduction	xiii
SECTION ONE: THE SITE INVESTIGATION	
1. The site survey	3
2. Rocks and soils	5
3. Sampling and site testing	21
4. Laboratory tests on soils	39
SECTION TWO: THE FOUNDATION	
5. Principles of foundations	53
6. Selection of foundation type	61
7. Piles and piling	71
8. Retaining walls	97
9. Some special problems in foundation design	119
10. Preparing the site for foundations	129
11. Materials for foundations	145
Appendix : Examples of the design of simple foundations	149
Bibliography	157
Index	158

List of symbols

(Symbols mostly conform with B.S. 1991, Part 4)

A_s	Area of steel
B	Breadth of foundation
b	Breadth of wall
c	cohesion of soil at a given depth
c_u	cohesion — from undrained triaxial test
c_{cu}	cohesion — from consolidated undrained triaxial test
c_d	cohesion — from drained triaxial test
c_w	wall adhesion
c_o	cohesion at zero normal load
$\bar{c}$	average cohesion of soil
D	depth of foot of foundation below ground level
d	effective depth
E	Young's modulus
e	eccentricity
F	factor of safety
f	force
ff	frictional force
g	gramme
H	freestanding height of wall
h_w	vertical distance from bottom of foundation to ground water level
I	moment of inertia
k	kilo (1000)
K_a	Coefficient of active earth pressure (non-cohesive soils)
K_A	Coefficient of active earth pressure (cohesive soils)
K_p	Coefficient of passive earth resistance
$\bar{K}_s$	Coefficient of skin friction for piles
la	lever arm of reinforced concrete section
L	Length of foundation
LI	Liquidity Index of cohesive soils
LL	Liquid Limit of cohesive soils
M	bending moment
MR	moment of resistance
m	metre
m/c	moisture content
mm	millimetre
N	number of blows in a standard penetration test

N	Newton (a standard force equal to $1 \text{ kg} \times 1 \text{ m/s}^2$ acceleration)
O	Sum of perimeters of reinforcing bars in tension in a section of reinforced concrete
P	applied load or pressure
PI	Plasticity Index of cohesive soils
PL	Plastic Limit of cohesive soils
P_a	total active soil pressure
P_{an}	total active soil pressure normal to wall
P_p	passive earth resistance
P_{cb}	permissible compressive stress in concrete
P_{ct}	permissible tensile stress in concrete
P_{st}	permissible tensile stress in reinforcement steel
Q	maximum shear force
q	shear stress per unit area
q_a	allowable bearing capacity per unit area
q_s	safe bearing capacity per unit area
q_f	ultimate bearing capacity per unit area (failure stress)
R	resultant force
R_v	vertical component of resultant force
R_h	horizontal component of resultant force
t	tonne (metric)
V	volume
W	weight, concentrated
w	distributed weight or load per unit length or area
Z	modulus of section
z	vertical distance measured behind a retaining wall from base to top of retained soil.

Greek alphabet symbols

β (beta)	Inclination of a slope
γ (gamma)	density, bulk
γ_d	density of dry soil
γ_m	density of moist soil
γ'	density of saturated soil (submerged below water table)
γ_w	density of water
Δ (delta)	settlement
δ (delta)	angle of wall friction
μ (mu)	micro
π (pi)	3.142
ρ (rho)	settlement
Σ (sigma)	the sum of
ϕ (phi)	angle of internal friction
Ω (omega)	load factor

Introduction

Foundation design in the past has always been very much a matter of inspired guesswork on a background of past experience. Ancient methods were pathetically crude. Winchester cathedral was built originally on a foundation of short oak piles and bundles of wattles in a bed of peat but has survived on this for 750 years due to the preservative qualities of the peat. On the other hand, the famous Campanile at Pisa began to lean almost as soon as it was built and now has a dangerous overhang of 4.2 m out of plumb at the top. Today there would be no problem in rectifying this, but as long as it stays up, Pisa does not want to lose its greatest attraction to tourists; and all the engineers who see it as a challenge are constantly frustrated!

There was little scientific interest in the study of foundations until the spread of rational thought processes in France in the late 18th century led to the development by Coulomb of his theory of earth pressures against retaining walls. However, not until 100 years later was there a fresh surge of interest. This was due mostly to the problems arising from the construction of large commercial buildings on difficult sites, as in Chicago, where three “firsts” are claimed. The Borden Block (1880) is held to be the first building with independent footings taken down to sound strata below through a considerable depth of soft clay. The Montauk building (1882), 10 storeys high, was the first to use a steel grillage foundation, and the Stock Exchange building (1894) became the first to use large diameter concrete piles (eight wells were sunk to limestone bedrock and filled with concrete). As the height of structures soared, the need for more accurate methods of assessment for building foundations grew. Not until 1925, with the publication of “*Erdbaumechanik*” by Terzaghi, the father of modern soil mechanics, were scientific principles and methods made available to designers for the analysis and testing of soils, to establish their bearing capacity, settlement, and probable manner of failure.

A major step forward in this country was the establishment in 1930 of the D.S.I.R. Laboratory for research into soil mechanics. Since then, many international scientists have entered the field and important conferences on soil mechanics have taken place: at Harvard 1936, Rotterdam 1948, Zurich and Lausanne 1953, London

1957, Paris 1961 and Toronto 1965. There is now an International Society of Soil Mechanics and Foundation Engineering. The work of the Road Research Laboratory at Harmondsworth, Middlesex, has also been important in this field.

Today, we have many methods of checking the subsoil which were not available a few years ago, but test results can still only give us a very rough guide to the underlying strata, its strength and its probable performance under load. We can reduce the factor of safety (really a factor of ignorance), and build up a wide range of confirmatory evidence from all the means available, but there must always be a risk of some undetected weakness. This is a warning not to place implicit trust in the careful laboratory test, or in expensive site loading tests, but to use their results in the light of experience as useful aids to decision making in foundation design.

From the foregoing it will be apparent that there are two sides to foundation design:

(1) *Exploration of the site* to decide:

- (a) if it is suitable to build on
- (b) what the load-bearing capacity of the soil is likely to be
- (c) where the best practical place to build the foundations is to be found (if, of course, there is room for choice).

(2) *The selection and design of the type of foundation*, necessary to take the load from the superstructure of the building and distribute it sufficiently to avoid overloading the soil; or in some cases, to anchor the building down.