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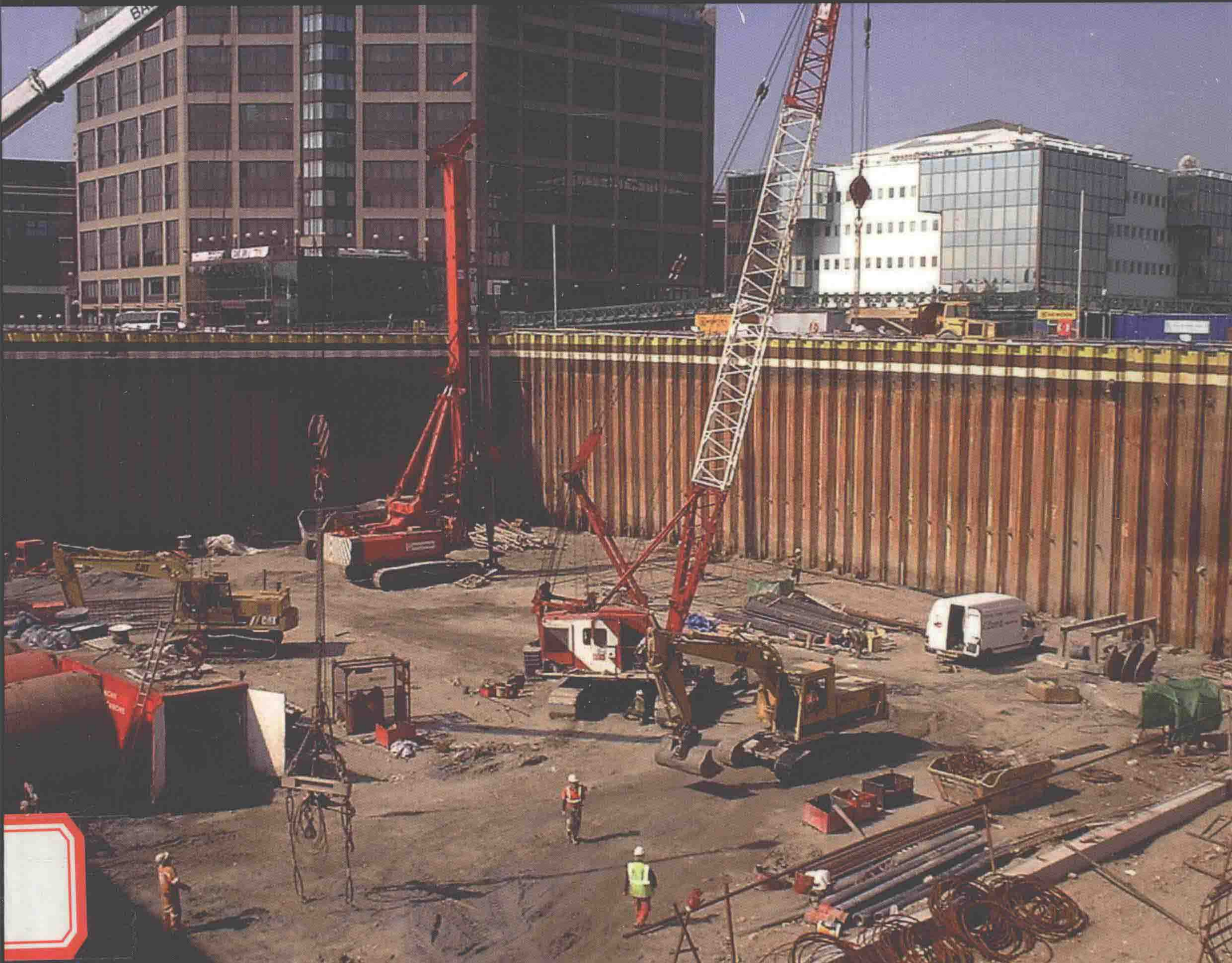

John Atkinson

Fundamentals of

Ground Engineering

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Geology and Engineering

Ground engineering combines geology and engineering. Normally ground engineers have first degrees in geology or in civil engineering and many have a post-graduate degree in engineering geology or geotechnical engineering.

During their first degrees, geologists are trained to observe the ground and the fossils and structures in it and draw inferences about the history of planet Earth. They make use of chemistry, botany, zoology and so on. They relate their observations to engineering performance largely through empirical correlations and transforms. During their first degrees, civil engineers are trained to make measurements of strength and stiffness of materials, steel, concrete and soil, and to predict the performance of structures. They make use of physics, mechanics and mathematics and use theories such as elasticity and plasticity to represent ground behaviour.

Each discipline has a complementary role to play in ground engineering. Geotechnical engineers should know enough geology to be able to communicate with geologists; geologists should know enough physics and mathematics to be able to communicate with geotechnical engineers.

There are several books on engineering geology that give largely empirical relationships between the geological history of the ground and its engineering behaviour and the behaviour of structures and excavations. This book describes the physical theories for the strength and stiffness of the ground and the analyses that are routinely used by engineers to predict the behaviour of slopes, foundations, and other structures in the ground.

These basic theories apply strictly to the behaviour of materials made of unbonded grains, which is a very good approximation for soil. The ground is taken to be elastic or plastic and frictional or cohesive and analyses satisfy the basic requirements of equilibrium and compatibility. Although natural soils may behave a little differently, their behaviour still closely follows the theories in this book. The outcomes should be designs that are safe, serviceable, economic, sustainable and buildable and the fundamental analyses make use of the basic theories in this book.

How to Use This Book

This book is not meant to be read from the first page to the last like a novel. The best way to use it is to select a topic for study and find what it says here. Then go to a book, or books, that deal with the topic in more detail but make sure that what you find there agrees with the simple basic theories of mechanics and the analyses that are in this book. Study is like navigating a city road map; there are many routes to the destination but at each turn you should know exactly where you are.

The book is not a collection of lecture notes although it covers the core geotechnical engineering content of typical undergraduate courses in civil engineering and post-graduate courses in geotechnical engineering and engineering geology. It is not a design guide although it includes some charts and analyses that are useful for design of geotechnical works. It is a summary, with few words but plenty of diagrams, of the fundamental theories and analyses that underpin all geotechnical engineering.

Things to Do

Geotechnical engineers should be familiar with fundamental principles and theories—most of them are relatively simple applications of basic mechanics to the behaviour of granular materials. But it is not enough to be able to do the mathematics; geotechnical engineers need to have an understanding of geology, knowledge of soil behaviour and a feel for what are reasonable numbers.

The photographs have been chosen to illustrate the general features of routine geotechnical engineering practice and they do not necessarily show state-of-the-art field and laboratory investigations and geotechnical works. Readers should search for other pictures or, better still, see the real thing.

At the end of most chapters there are suggestions for things to do to illustrate the principles in the chapter. Most do not require special equipment and can be done at home using kitchen equipment and samples commonly found in the home and garden. Schools once taught science students how to make simple test equipment and do simple experiments and that was part of a physics course. It is a good skill for an engineer to have.

Further Reading

This book should be used together with other books that students and engineers may already have or which their teachers and mentors recommend but deliberately there are very few specific references.

There are many long and expensive books on engineering geology, soil mechanics and geotechnical engineering. Some focus on theories and others on applications; many are at best unclear. They give advice that can appear to be conflicting or even wrong and it is difficult to recommend any one book or collection of books for further study.

Whatever your favourite book may say and whatever your teacher or mentor may say it ought to have a basis in physics and mechanics. Geotechnical engineering is a practical science with a theoretical basis; it is not a creative art and certainly not magic.

Acknowledgements

I have long thought that there was a need for a short and easily read book that set out the basic theories of geotechnical engineering. This book is influenced by Tony Waltham's *Foundations of Engineering Geology* but, because of the nature of the subject, it has a somewhat different style and approach.

Tony Moore, my editor, at Taylor & Francis has chased me for this book for several years and I am grateful to him for his persistence. Thanks are due to friends and colleagues who read and commented on drafts and to the printers and publishers who pieced together my drafts into the one page per topic format.

Many of the photographs are my own; I am grateful to Tony Waltham, David Norbury, Marcus Matthews, Richard Levine, Chris Eccles (TerraConsult), Bill Grose (Arup Geotechnics), George Tuckwell (RSK), Darren Ward (In Situ), Bill Howard (Griffin Soils Group) and Andrew Smith, Alex Booer and Helen Chow (Coffey Geotechnics) for additional photographs.

Units

In the SI system used in this book the basic units of measurement are

Length	m			
Time	s			
Force	N	multiples	kiloNewton	1 kN = 10^3 N
			megaNewton	1 MN = 10^6 N

Some useful derived units are

Velocity	m/s
Acceleration	m/s^2
Stress (pressure)	kN/m^2 = kiloPascal = kPa
Unit weight	kN/m^3

Unit force (1 N) gives unit mass (1 kg) unit acceleration (1 m/s^2). The acceleration due to the Earth's gravity is $g = 9.81$ m/s^2; hence, the force due to a mass of 1 kg at rest on Earth is 9.81 N. (*Note*: there are about 10 apples in 1 kg so a stationary apple applies a force of about 1 N acting vertically downwards.)

Symbols

(The symbols in this book may differ from those in other books and technical papers.)

σ	total normal stress
u	pore pressure
σ'	effective normal stress
$\tau = \tau'$	total and effective shear stress

In some books effective normal stress is denoted as $\bar{\sigma}$. In most books there is no distinction between total and effective shear stress and τ' is not used.

One dimensional and shear tests:

τ'	shear stress
σ'	normal stress
γ	shear strain
ε_v	volumetric strain = normal strain

Axisymmetric and triaxial tests:

$q' = (\sigma'_a - \sigma'_r)$	deviatoric stress
$p' = \frac{1}{3}(\sigma'_a + 2\sigma'_r)$	mean normal stress
$\varepsilon_s = \frac{2}{3}(\varepsilon_a - \varepsilon_r)$	shear strain
$\varepsilon_v = \varepsilon_a + 2\varepsilon_r$	volumetric strain

Plane strain ($\varepsilon = 0$ out of the page):

$t' = \frac{1}{2}(\sigma'_v - \sigma'_h)$;

$s' = \frac{1}{2}(\sigma'_v + \sigma'_h)$

$\varepsilon_\gamma = (\varepsilon_v - \varepsilon_h)$;

$\varepsilon_{vol} = (\varepsilon_v + \varepsilon_h)$

Superscripts for strains:

e	elastic
p	plastic
c	creep

Subscripts for states:

0	initial state (i.e. τ'_0)
c	critical state (i.e. τ'_c)
p	peak state (i.e. τ'_p)
y	yield stress (i.e. σ'_y)
m	limiting stress ratio (i.e. $\tan\phi'_m$)
r	residual (i.e. $\tan\phi'_r$)

Subscripts for axes:

v, h	vertical and horizontal
a, r	axial and radial

A	area; activity; parameter for peak state power-law envelope
B	breadth or width
C	compliance
C_c	slope of the normal compression line
C_α	creep parameter
C_s	slope of a swelling and recompression line
D	depth
D_r	relative density
D_w	depth of water
E	work done by external loads
E	Young's modulus (E' for effective stress; E_u for undrained loading)
F	load on a foundation
F_a	axial force
F_n	normal force
F_s	shear force
F_s	factor of safety
G	shear modulus (G' for effective stress; G_u for undrained loading)
G_o	shear modulus at very small strain

G_s	specific gravity of soil grains
H_c	critical height (of a slope)
H	height or thickness; maximum drainage path; hardening parameter $\delta\tau'_y/\delta\gamma^p$
I_L	liquidity index
I_P	plasticity index
I_σ	influence coefficient for stress
I_ρ	influence coefficient for settlement
J	stiffness modulus that couples shear and volumetric parameters
K′	bulk modulus
K_0	coefficient of earth pressure at rest
K_a	coefficient of active earth pressure
K_p	coefficient of passive earth pressure
L	length
L_f	load factor
M′	one-dimensional modulus
N_s	stability number (for undrained slopes)
N_f	number of flow channels (in a flownet)
N_d	number of equipotential drops (in a flownet)
N	normal force
N_c, N_γ, N_q	bearing capacity factors
P	potential $= z + u/\gamma_w$
P_a	force due to active pressure
P_p	force due to passive pressure
P_w	force due to free water pressure
Q	flow (volume); pile load
Q_b	pile base resistance
Q_s	pile shaft resistance
R	radius
R_o	overconsolidation ratio $= \sigma'_m/\sigma'$
R_y	yield stress ratio $= \sigma'_y/\sigma'$
S	stiffness: degree of saturation
S_σ	state parameter $= \sigma'/\sigma'_c$
S_w	state parameter $= w_\lambda - w_\Gamma$

T	shear force; surface tension force
T_v	$= c_v t/H^2 =$ time factor for one-dimensional consolidation
U	force due to pore pressures
U_t	average degree of consolidation after time t
V	volume; velocity (of seepage)
V_w	volume of water
V_s	volume of soil grains
W	weight; work dissipated by interval stresses
W_w	weight of water
W_s	weight of soil grains
a	acceleration
b	thickness or width: parameter for peak state power-law envelope
c'	cohesion intercept in Mohr–Coulomb failure criterion
c_v	coefficient of consolidation for one-dimensional consolidation
e	voids ratio; eccentricity
e_0	voids ratio of normally consolidated soil at $\sigma' = 1.0$ kPa
e_κ	voids ratio of overconsolidated soil at $\sigma' = 1.0$ kPa
e_Γ	voids ratio of soil on the critical state line at $\sigma' = 1.0$ kPa
h_w	height of water in standpipe
i	slope angle; hydraulic gradient
i_c	critical slope angle; critical hydraulic gradient
k	coefficient of permeability
m	mass
m_v	coefficient of compressibility for one-dimensional compression
m, n	slope stability numbers (for drained slopes)
p'_m	maximum past stress
p_w	free water pressure
q	bearing pressure; rate of seepage
q_c	bearing capacity
q_n	net bearing pressure
q_a	allowable bearing pressure
r	radius

r_u	pore pressure coefficient = u/σ'_v
s	length along a flowline
s_u	undrained strength
t	time
u	pore pressure
u_a	pore air pressure
u_w	pore water pressure
u_∞	long-term steady-state pore pressure
u_0	initial steady-state pore pressure
$\bar{u}$	excess pore pressure
v	specific volume
v_κ	specific volume of overconsolidated soil at p′ = 1.0 kPa
w	water content
w_L	liquid limit
w_P	plastic limit
w_λ	$w + C_c \log \sigma'$
w_Γ	water content of soil on the critical state line at p′ = 1.0 kPa
Γ	specific volume of soil on the critical state line at p′ = 1.0 kPa
Δ	large increment of ....
M	slope of CSL projected to q′:p′ plane
N	specific volume of normally consolidated soil at p′ = 1.0 kPa
Σ	sum of ....
α	factor for undrained shear stress on pile shaft
γ	unit weight
γ_d	dry unit weight
γ_w	unit weight of water (= 9.81 kN/m^3)
δ	small increment of ....
δ'	angle of friction between structure and soil
η	stress ratio q′/p′
κ	slope of swelling and recompression line
λ	slope of normal compression and critical state lines
ν	Poisson's ratio (ν' for drained loading, ν_u = 1/2 for undrained loading)

ρ	settlement
ρ_c	consolidation settlement
ρ_i	initial settlement
ρ_t	settlement at time t
ρ_∞	final consolidation settlement
ρ_a	allowable settlement
ρ	density
ρ_d	dry density
ϕ'	angle of friction
ϕ'_c	critical state angle of friction
ϕ'_p	peak angle of friction
ϕ'_m	mobilised angle of friction
ϕ'_r	residual angle of friction
ψ	angle of dilation
τ, τ'	total and effective shear stress (usually with a subscript)
σ, σ'	total and effective normal stress (usually with a subscript)

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