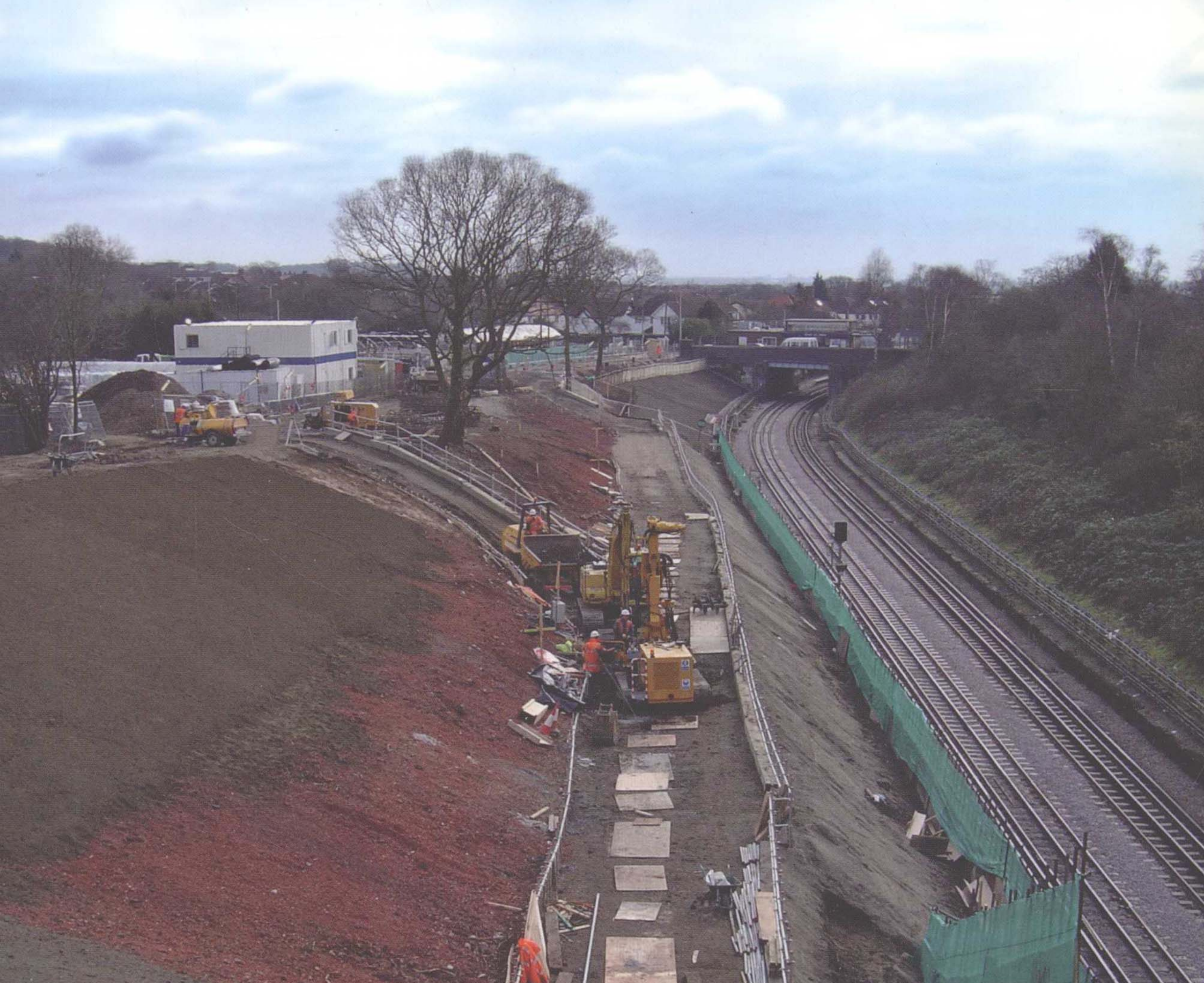
THIRD EDITION

Soil Mechanics

CONCEPTS AND APPLICATIONS



WILLIAM POWRIE

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General symbols

Note: Simple dimensions (*A* for cross-sectional area, *D* or *d* for depth or diameter, *H* for height, *R* for radius and so on) and symbols used as arbitrary constants are not included. Subscripts are not listed where their meaning is clear (for example, crit for critical, max for maximum, ult for ultimate). Effective stresses and effective stress parameters are denoted in the text by a prime (′).

A	Air content of unsaturated soil (Section 1.5); Activity (Section 1.11); A soil parameter used in the description of creep (Section 5.17)
A_c	Projected area of cone in cone penetration test (Section 11.3.2)
A_n	Fourier series coefficient (Section 4.8)
$A_{\rm n}$	Area of shaft of cone penetrometer
B	$\Delta u/\Delta\sigma_c$ in undrained isotropic loading (Chapter 5)
B_q	Pore pressure ratio in cone penetration test (Section 11.3.2)
C	Tunnel cover (depth of crown below ground surface) (Section 9.11)
C	Parameter used in analysis of shallow foundations (Section 8.5)
C_c	Compression index: slope of one-dimensional normal compression line on a graph of e against $\log_{10} \sigma'_v$
C_s	Swelling index: slope of one dimensional unload/reload lines on a graph of e against $\log_{10} \sigma'_v$
C_N	Correction factor applied to SPT blowcount (Section 11.3.1)
D	Drag force (Section 1.8)
D_{10} etc.	Largest particle size in smallest 10% etc. of particles by mass
E	Young's modulus. Subscripts may be used as follows: *h* (horizontal); *v* (vertical); *u* (undrained)
E'_0	One-dimensional stiffness modulus
E^*	Rate of increase of Young's modulus with depth
E	Horizontal side force in slope stability analysis (Section 8.10)
EI	Bending stiffness of a retaining wall
E_r	Young's modulus of raft foundation
E_s	Young's modulus of soil
F	Shear force
F	Prop load (propped retaining wall)
F	Factor of safety. A subscript may be used to indicate how the factor of safety is applied: see Section 9.4.

F_r	Normalized friction ratio in cone penetration test
F_s	Factor of safety applied to soil strength
G	Shear modulus
G^*	Modified shear modulus in the presence of shear/volumetric coupling (Section 6.10); Rate of increase of shear modulus with depth (Section 9.8)
G_s	Relative density (= ρ_s/ρ_w) of soil grains (also known as the grain specific gravity)
H	Rating on mineral hardness scale (Chapter 1)
H	Horizontal load or force
H	Overall head drop (for example, across flownet)
H	Slope of Hvorslev surface on a graph of q against p'
H	Hydraulic head at the radius of influence in a well pumping test
H	Limiting lateral load on a pile (Section 8.9)
I_D	Density index
I_L	Liquidity index
I_P	Plasticity index (= $w_{LL} - w_{PL}$)
I_ρ, I_σ	Influence factor for settlement and stress respectively (Chapter 6)
J	Parameter related to shear/volumetric coupling (Section 6.10)
K	Intrinsic permeability (Chapter 3)
K	Earth pressure coefficient, σ'_h/σ'_v. Subscripts may be used as follows: a (to denote active conditions); p (passive conditions); i (prior to excavation in front of a diaphragm-type retaining wall); 0 (*in situ* stress state in the ground); nc (for a normally consolidated clay); oc (for an overconsolidated clay)
K	Elastic bulk modulus (subscript u denotes undrained)
K^*	Modified bulk modulus in the presence of shear/volumetric coupling (Section 6.10)
K_{ac}, K_{pc}	Multipliers applied to τ_u in the calculation of active and passive total pressures respectively (undrained shear strength model)
K_T	Total stress earth pressure coefficient, σ_h/σ_v (Section 7.10)
L_0	Distance of influence of a dewatering system idealized as a pumped well
LF	Tunnel load factor (Section 9.11)
M	Bending moment. Subscripts may be used as follows: des (to denote the design bending moment); le (retaining wall bending moment calculated from a limit equilibrium analysis); p or ult (fully plastic or ultimate bending moment of beam or retaining wall)
M	Moment
M	Mobilization factor on soil strength
M'_0	Constrained or one-dimensional modulus
N	Normal force, for example, on rupture surface or soil/structure interface
N	SPT blowcount
N_k	Cone factor relating q_c and τ_u (Section 11.3.2)
N_1	SPT blowcount normalized to a vertical effective stress of 100 kPa (Section 11.3.1)
N_{60}	Corrected SPT blowcount, for an energy ratio of 60% (Section 11.3.1)

N_1, N_2, N_3	Interblock normal forces, mechanism analysis for shallow foundation (Section 10.9)
N_F, N_H	Number of flowtubes and potential drops respectively in a flownet
N_c	Basic bearing capacity factor: undrained shear strength analysis
N_p	Value of v at $\ln p' = 0$ on isotropic normal compression line on a graph of v against $\ln p'$ (Chapter 5)
N_q	Basic bearing capacity factor: frictional soil strength analysis
$N\gamma$	Term in bearing capacity equation to account for self-weight effects
OCR	Overconsolidation ratio
P	Prop load; tensile strength of reinforcement strip (reinforced soil retaining wall)
Q	Ram load in triaxial test (Chapter 5)
Q	Equivalent toe force in simplified stress analysis for unpropped retaining wall
Q_t	Normalized cone resistance in cone penetration test
R	Proportional settlement ρ/ρ_{ult}
R	Resultant force, for example, on rupture surface or soil/structure interface
R	Dimensionless flexibility number $R = m\rho$ (Section 9.8)
R	Depth of tunnel axis below ground level (Section 9.11)
R_r, R_z	Degree of consolidation due to radial and vertical flow alone, respectively (Section 4.9)
R_0	Radius of influence of a pumped well
S, S_r	Saturation ratio
s	Slope of graph; drain spacing (Section 4.9); sensitivity (Section 5.15)
s	Surface settlement due to tunnelling (Section 9.11)
T	Total shear resistance of soil/pile interface (Section 2.11)
T	Shear force, for example, on rupture surface or soil/structure interface
T	Surface tension at air/water interface
T	Dimensionless time factor $c_v t/d^2$ in consolidation problems
T	Anchor load (anchored retaining wall)
T	Torque
TC	Tunnel stability number at collapse (Section 9.11)
T_{des}	Design anchor load (anchored retaining wall)
T_r	Dimensionless time factor for radial consolidation $c_{hv}t/r^2_w$
T_v	Torque due to shear stress on vertical surfaces in shear vane test (Section 11.3.4)
U	Coefficient of uniformity $= D_{60}/D_{10}$
U	Average excess pore water pressure (consolidation problems)
U	Force, for example, on rupture surface or soil/structure interface due to pore water pressure
U_e	Pore water suction at air entry
U_r, U_z	Average excess pore water pressure if drainage were by radial flow or vertical flow alone, respectively (Section 4.9)
V	Volume (total)
V	Electrical potential difference (voltage) (Section 3.19.5)

V	Vertical load or force
V_a	Volume of air voids in soil specimen
V_{tunnel}	Nominal volume of tunnel (Section 9.11)
V_s	Volume of soil solids in soil specimen
V_t	Total volume occupied by a soil specimen
V_{ti}	Total volume of triaxial test specimen as prepared (Chapter 5)
V_{to}	Total volume of triaxial test specimen at start of shear test (Chapter 5)
V_v	Volume of voids in soil specimen
V_w	Volume of water in soil specimen
V_L	Volume loss in tunnelling (Section 9.11)
W	Weight of a block of soil
W	Mass of falling weight used in heavy tamping (Section 11.5)
W_c	Set of collapse loads for a structure (in plastic analysis)
W_t	Total weight of a soil specimen
X	Vertical side force in slope stability analysis (Section 8.11)
Z	Coefficient of curvature = $(D_{30})^2/(D_{60} \cdot D_{10})$
Z	Reference depth in a Newmark chart analysis (Chapter 6)
a	Acceleration (Section 11.4)
a	Area ratio A_n/A_c in cone penetration test (Section 11.3.2)
av	Subscript indicating the average value of a parameter
b	Parameter defining the intermediate principal stress (Section 5.10)
c	Subscript denoting the initial state
c'	Intersection with τ -axis of extrapolated straight line joining peak strength states on a graph of τ against σ'
C_{hv}, C_v	Consolidation coefficient for vertical compression due to horizontal flow, and vertical compression due to vertical flow, respectively
crit	Subscript denoting a critical condition
current	Subscript indicating the current value of a parameter
d	Equivalent particle size (Section 1.8.1)
d	Prefix denoting infinitesimally small increment (for example, of stress, strain or length)
d	Half depth of oedometer test specimen (maximum drainage path length)
d_c, d_c^*	Depth factors (bearing capacity analysis)
d_q, $d\gamma$	Depth factors (bearing capacity analysis)
ds	Subscript indicating parameter measured in direct shear
e	Void ratio
f	Subscript used to denote 'final' conditions at the end of a test
f	Frequency
fc	Sleeve friction (stress) in cone penetration test (Section 11.3.2)
ft	Corrected sleeve friction (stress) in CPT
f_1	Parameter relating undrained shear strength to SPT blowcount (Section 11.3.1)
g	Acceleration due to Earth's gravity (= 9.81 m/s^2)
g	Constant used to define Hvorslev surface (Section 5.13)

h	Total or excess head, height of specimen in shearbox test
h	Subscript: horizontal
h_c	Critical height of backfill in analysis of compaction stresses behind a retaining wall (Section 7.10)
h_{crit}	Critical hydraulic head drop across an element of soil at fluidization
h_e	Excess head (consolidation analysis)
h_i	Height of triaxial test specimen as prepared (Chapter 5)
h_0	Height of triaxial test specimen at start of shear test (Chapter 5)
h_0	Initial depth of block of soil in analysis of settlement due to change in water content (Section 1.13); initial height of soil specimen in shearbox test; drawdown at a line of ejector wells analysed as a pumped slot (Section 4.7.3)
h_w	Head in a pumped or equivalent well
i	Hydraulic gradient: subscripts x, y or z may be used to indicate the direction
i	Parameter quantifying width of settlement trough due to tunnelling (Section 9.11)
i	Subscript denoting an initial state (the pre-excavation state in the case of an *in situ* retaining wall)
i_{crit}	Critical hydraulic gradient across an element of soil at fluidization
i_e	Electrical potential (voltage) gradient (Section 3.19.5)
k	Permeability used in Darcy's Law. Subscripts may be used as follows: h (horizontal); v (vertical); x, y or z (x-, y- or z-direction), t (transformed Section); i or f (at start or end of a permeability test)
k_e	Electro-osmotic permeability (Section 3.19.5)
l	Limit of range of a Fourier series (Section 4.8)
l	Length of part of a slip surface (Sections 8.11 and 10.9)
m	Soil stiffness parameter (Section 9.8); Rate of increase of soil Young's modulus with depth (Section 11.4)
m	A soil parameter used in the description of creep (Section 5.17)
m	Subscript denoting model (Section 11.4)
m_a	Mass of air in soil specimen
m_s	Mass of soil solids in soil specimen
m_t	Mass of tin or container
m_w	Mass of water in soil specimen
max	Subscript indicating the maximum value of a parameter
n	Porosity
n	Overconsolidation ratio based on vertical effective stresses
n	Number of 'squares' of Newmark chart covered by a loaded area (Chapter 6)
n	Centrifuge model scale factor (Section 11.4)
n_p	Overconsolidation ratio based on average effective stresses
p, p'	Average principal total and effective stress, respectively: $p = \{\sigma_1 + \sigma_2 + \sigma_3\}/3$
p'_0	Maximum previous value of p'; value of p' at tip of current yield locus (Chapter 5)
p_u, p'_u	Lateral load capacity (per metre depth) of a pile (Section 8.9)
p	Subscript denoting prototype (Section 11.4)

p	Cavity pressure in pressuremeter test (Section 11.3.3)
p_b	Passive side earth pressure (Section 9.8)
p'_e	Equivalent consolidation pressure: value of p' on isotropic normal compression line at current specific volume (Chapter 5)
p_L	Extrapolated 'limit pressure' in analysis of the plastic phase of the pressuremeter test (Section 11.3.3)
p_p	Cavity pressure at onset of plastic behaviour in pressuremeter test (Section 11.3.3)
ps	Subscript indicating parameter measured in plane strain
q	Deviator stress
q	Volumetric flowrate
q	Surface surcharge or line load
q_c	Measured cone resistance (stress) (Section 11.3.2)
q_t	Corrected cone resistance
r	Wall roughness angle
r_e	Radius of an equivalent well used to represent an excavation
r_p	Radius of plastic zone in the soil around a pressuremeter (Section 11.3.3)
r_u	Pore pressure ratio, $r_u = u/\gamma z$
r_γ	Reduction factor (bearing capacity analysis)
s	Average total stress $(\sigma_1 + \sigma_3)/2$: locates centre of Mohr circle on a-axis
s	$[(1+\sin\psi)\sin\phi'_{peak}]/(1+\sin\phi'_{peak})$ (Section 11.3.3)
s_c, s_c^*	Shape factors (bearing capacity analysis)
s_q, s_y	Shape factors (bearing capacity analysis)
s'	Average effective stress $(\sigma'_1 + \sigma'_3)/2$: locates centre of Mohr circle on σ'-axis
t	Time
t	Radius of Mohr circle of stress, $t = (\sigma'_1 - \sigma'_3)/2 = (\sigma_1 - \sigma_3)/2$
t_b, t_m	Parameters used in analysis of shallow foundations (Section 8.5)
t_r	Thickness of a raft foundation
t_x	Reference point on time axis used to determine consolidation coefficient c_v from oedometer test data
u	Pore water pressure
u	Subscript: undrained
u_e	Excess pore water pressure (consolidation analysis)
u_{ed}	Excess pore water pressure at mid-depth of an oedometer test specimen of total depth $2d$ (Chapter 4)
u_2	Pore water pressure measured in cone penetration test
ult	Subscript denoting the ultimate value of a parameter (for example, settlement)
v	Specific volume
v	Particle settlement velocity (Section 1.8); velocity of relative sliding (Section 10.9)
v	Subscript: vertical
v, v_D	Darcy seepage velocity. Subscripts x, y or z may be used to indicate the direction
v_0	Reference velocity for mechanism analysis (Section 10.9)

v_κ	Intersection of unload/reload line with $lnp' = 0$ axis
v_{true}	True average fluid seepage velocity
w	Water content
w	Weight of a soil element (Sections 8.10 and 9.11)
w_{LL}, w_{PL}	Water content at liquid limit and plastic limit, respectively
x	Relative horizontal movement in shearbox test
y	Upward movement of shearbox lid
y_c	Outward movement of cavity wall in pressuremeter test (Section 11.3.3)
y_{rp}	Outward displacement of soil at the plastic radius r_p in a pressuremeter test (Section 11.3.3)
z	Depth coordinate
z_c	Critical layer thickness for compaction of soil behind a retaining wall (Section 7.10)
z_0	Depth of tunnel axis below ground level (Section 9.11)
z_p	Depth of pivot point below formation level (unpropped embedded retaining wall)
Γ	Value of v at $lnp' = 0$ on critical state line on a graph of v against $\ln p'$ (Chapter 5)
Δ	Prefix denoting increment (for example, of stress, strain or length)
Δ	Angle used in Mohr circle constructions for stress analyses (Chapter 10)
Δ	Multipropped wall flexibility parameter (Chapter 9)
M	Slope of critical state line on a graph of q against p'
ψ	$v - v_c$ (Section 5.20)
ΔV_{tc}, ΔV_{tq}	Volume change of triaxial test specimen during consolidation and shear, respectively (Chapter 5)
Δy, Δz	Width and depth, respectively, of reinforced soil retaining wall facing panel
$\Delta p_{u/r, max}$	Maximum reduction in cavity pressure in a pressuremeter test that can be applied without causing plastic behaviour in unloading (Section 11.3.3)
α	Transformation factor for flownet in a soil with anisotropic permeability (Chapter 3)
α	A soil parameter used in the description of creep (Section 5.17)
α	Angle of inclination of slip surface to the horizontal (Section 8.11)
α	Term applied to one of the two characteristic directions, along which the full strength of the soil is mobilized (Chapter 10)
α	Retained height ratio h/H of a retaining wall (Section 9.8)
α	Soil/wall adhesion reduction factor
β	Angle between flowline and the normal to an interface with a soil of different permeability
β	Term applied to one of the two characteristic directions, along which the full strength of the soil is mobilized (Chapter 10)
β	Slope angle
β	Parameter quantifying the depth to the anchor for an anchored retaining wall (Section 9.8)
γ	Engineering shear strain
γ	Unit weight ($= \rho g$)

γ_{dry}	Unit weight of soil at the same void ratio but zero water content
γ_f	Unit weight of permeant fluid (Section 3.3)
γ_{sat}	Unit weight of soil when saturated
γ_w	Unit weight of water
δ	Soil/wall interface friction angle
δ	Strength mobilized along a discontinuity (Chapter 10)
δ	Prefix denoting increment (for example, of stress, strain or length)
δ	Displacement
δ_{mob}	Mobilized soil/wall interface friction angle
ε	Direct strain. Subscripts may be used to indicate the direction as follows: h (horizontal); v (vertical); r (radial); θ (circumferential)
ε_c	Cavity strain in pressuremeter test (Section 11.3.3)
ε_q	Triaxial shear strain $\varepsilon_q = (2/3)(\varepsilon_v - \varepsilon_h)$
ε_{vol}	Volumetric strain
ε_1, ε_3	Major and minor principal strains, respectively
ε	Electro-kinetic or zeta potential
η	Stress ratio q/p'
η_f	Dynamic viscosity
θ	Rotation of stress path on a graph of q against p'
θ	Rotation of principal stress directions; included angle in a fan zone (Chapter 10)
κ	Slope of idealized unload/reload lines on a graph of v against $\ln p'$
κ_o	Slope of idealized unload/reload lines on a graph of v against $\ln\sigma'_v$
λ	Slope of critical state line and of one-dimensional and isotropic normal compression lines on a graph of v against $\ln p$
λ	Load factor in structural design
λ_0	Slope of one-dimensional normal compression line on a graph of v against $\ln\sigma'_v$
μ	Coefficient of friction
ν_r	Poisson's ratio of raft foundation
ν_s	Poisson's ratio of soil
ν	Poisson's ratio
ν_u	Undrained Poisson's ratio
ρ	Mass density. Subscripts may be used as follows: b (for the overall or bulk density of a soil); s (for the density of the soil grains); w (for the density of water = 1000 kg/m at 4°C)
ρ	Settlement
ρ	Wall flexibility H/EI; a subscript c may be used to denote a critical value
ρ	Cavity radius in pressuremeter test (Section 11.3.3); a subscript 0 may be used to denote the initial value
ρ	Parameter used in analysis of shallow foundations (Section 8.5)
σ, σ'	Total and effective stress, respectively. Subscripts may be used to indicate the direction as follows: a (axial, in a triaxial test); h (horizontal); h0 (horizontal, *in situ*); v (vertical); v0 (vertical, maximum previous); r (radial); θ (circumferential); n (normal)

σ_c	Cell pressure in a triaxial test
σ_f, σ'_f	Normal total and effective stress (respectively) on a shallow foundation at failure
σ_0, σ'_0	Normal total and effective stress (respectively), acting on either side of a shallow foundation at failure
σ_{xx}, σ'_{xx}	Total and effective stresses on the plane whose normal is in the x direction, acting in the x direction
$\sigma_1, \sigma_2, \sigma_3$,	Major, intermediate and minor principal total stress, respectively
$\sigma'_1, \sigma'_2, \sigma'_3$	Major, intermediate and minor principal effective stress, respectively
σ_T	Tunnel support pressure (Section 9.11)
σ_{CT}	Tunnel support pressure required just to prevent collapse (Section 9.11)
σ_{uc}	Unconfined compressive strength
τ	Shear stress
τ_c	Shear stress at cavity wall in pressuremeter test (Section 11.3.3)
τ_u	Undrained shear strength
$\tau_{u,\,design}$	Design value of undrained shear strength
τ_w	Shear strength mobilized on soil/wall interface
τ_{xy}	Shear stress on the plane whose normal is in the x direction, acting in the y direction
φ'	Soil strength or angle of shearing resistance (effective angle of friction)
φ'_{crit}	Critical state strength
φ'_{design}	Design strength
φ'_{mob}	Mobilized strength
φ'_{peak}	Peak strength
φ'_{tgt}	Slope of best-fit straight line joining peak strength states on a graph of τ against σ'
φ'_w	True friction angle between soil grain and wall materials
φ'_μ	True friction angle of soil grain material
x	Parameter used in the description of unsaturated soil behaviour (Section 5.19)
ψ	Angle of dilation
ω	Angular velocity; angle of retaining wall batter (Chapter 10)
0	Subscript denoting an initial state (at $t = 0$), a value at $x = 0$ or $z = 0$, or the initial *in situ* state in the ground

Preface

My original aims in writing this book were

- To encourage students of soil mechanics to develop an understanding of fundamental concepts, in contrast to the formula-driven approach used by some other authors
- To help students build a framework of basic ideas robust and adaptable enough to support and accommodate the more complex problems and analytical procedures that confront the practising geotechnical engineer
- To illustrate, with reference to real case histories, that the sensible application of simple ideas and methods can give perfectly acceptable engineering solutions to many classes of geotechnical problem
- To avoid the unnecessary use of mathematics
- To cover in a single text, the soil mechanics and geotechnical engineering topics usually included in typical MEng-level university courses in civil engineering and related subjects, without too much in the way of additional clutter

However,

- Civil engineers must be numerate, and possess a reasonable degree of mathematical ability—they must be able to do sums
- Different lecturers will have different views on the content of a core syllabus in the soil mechanics/geotechnical engineering subject area
- Some material may not be suitable for formal presentation in lectures, but is nonetheless essential background reading

Thus, while perhaps 80% of the book is undoubtedly core material at MEng level, some sections are useful background, some sections might be covered in some courses but not in others, and one or two sections (for example, Section 4.8) are almost certainly for reference only.

I have not in general marked the non-core sections in the text, not least because (as indicated above) different teachers will have their own ideas about what does and does not constitute core material. Instead, I have tried to ensure that separable topics and subtopics are covered in separate sections and subsections, with clear and unambiguous titles and subtitles. This should enable a university lecturer to draw up a bespoke reading schedule, appropriate to his or her own course.

The book is based on the undergraduate courses in soil mechanics and geotechnical engineering that I helped to develop initially at King's and Queen Mary and Westfield Colleges (University of London) and more recently at the University of Southampton.

While the basic principles have not changed, the subject has developed over this time and expectations in engineering education have evolved; the last perhaps most clearly evidenced by a master's level degree (MEng) having become the norm for students aspiring towards chartered engineer status.

Our undergraduate course structure in soil mechanics and geotechnical engineering at Southampton has likewise evolved over the years, as a result of advances in research, practice, and the availability of computational tools, and is now as follows.

Year of study	*Chapters in the book*
Year 1:	Chapter 1, within courses on engineering geology and/or civil and environmental engineering materials
Year 2:	Chapter 2 up to and including Section 2.11; Chapter 3 up to and including Section 3.16; Chapter 4 up to and including parts of Section 4.7 (Section 4.8 is covered in parallel in the mathematics course on differential equations); Chapter 5 up to and including Section 5.13; Chapter 6 up to and including Section 6.5; and an introduction to retaining walls, foundations and slopes covering Sections 7.1 to 7.8, 8.1 to 8.4, and 8.10.
Year 3:	Retaining walls, foundations and slopes in more detail, that is, the parts of Chapters 7 and 8 not covered in the second year and Sections 9.1 to 9.10.
Year 4 (options):	Advanced foundations (Sections 10.1 to 10.5), modelling and *in situ* testing (Sections 11.3 and 11.4) and construction dewatering (Sections 3.17 to 3.19)

The material is, of course (along with Chapter 11), used and developed in design and individual projects in all years of the degree programme. Some of the early chapters are structured around the standard laboratory tests used to investigate a particular class of soil behaviour. These are Chapter 2 (the shearbox test; friction), Chapter 4 (the oedometer test; one-dimensional compression and consolidation) and Chapter 5 (the triaxial test; more general aspects of soil behaviour). This approach is not new, but by no means is it universal. In my experience, the integration of the material covered in lectures with laboratory work by means of coursework assignments in which laboratory test results are used in an appropriate geotechnical engineering calculation is thoroughly beneficial.

The order in which the material is presented is based on the belief that students need time to assimilate new concepts, and that too many new ideas should not be introduced all at once. This may have led to the division of what might be seen as a single topic (for example, soil strength or retaining walls) between two chapters. Where this occurs, the topic is initially addressed at a fairly basic level, with more detailed or advanced coverage reserved for a later stage.

For example, while some authors deal with both the shearbox test and the triaxial test under the same heading (such as 'laboratory testing of soils' or 'soil strength'), I have covered them separately. This is because the shearbox serves as a relatively straightforward introduction to the behaviour of soils at failure in terms of simple stress and volumetric parameters, and to the concept of a critical state. The triaxial test introduces more general stress states, the difference between isotropic compression and shear, the generation of pore water pressures in undrained tests, and the behaviour of clay soils before and after yield. Similarly, I have endeavoured to establish the basic principles of earth pressures and collapse calculations with reference to relatively simple retaining walls in Chapter 7, before addressing more complex earth retaining structures in Chapter 9 and soil/wall friction more rigorously in Chapter 10. This is reflected in our course structure at Southampton.

The book assumes a knowledge of basic engineering mechanics (equilibrium of forces and moments, elastic and plastic material behaviour, Mohr circles of stress and strain and so on). Also, it is intended to be followed in sequence. Where necessary, a qualitative description of an aspect of soil behaviour that has not yet been covered is given to allow the development of a fuller understanding of another. For example, the generation of excess pore water pressures during shear is mentioned qualitatively in Chapter 2 to explain the need for drained shear box tests on clay soils to be carried out slowly. For the more experienced reader, it is hoped that the section and subsection headings are sufficiently descriptive to enable the required information to be extracted with the minimum of effort.

In preparing the third edition of this book, I have:

- Added an introduction to suction/water content/permeability relationships for unsaturated soils (Section 3.20)
- Improved the introduction to behavioural models for sands (Sections 5.20 and 5.21) and added a section on repeated or cyclic loading effects (Section 5.22)
- Reorganised material to give a more coherent and up to date coverage of gravity and embedded retaining walls (Chapters 7 and 9)
- Added an introduction to the use of laterally loaded piles for slope stabilization (Section 8.12)
- Improved the development of bearing capacity factors and interaction diagrams for shallow foundations subjected to inclined and eccentric loads (Sections 10.1 to 10.5)
- Added new material on site investigation (Sections 11.1 and 11.2)
- Made general updates to reflect changes in the interpretation of knowledge or design guidance
- Added some more worked examples and further sample questions at the ends of chapters
- Made the text broadly consistent with the design philosophy espoused in the most recent version of EC7. EC7 has changed significantly since the second edition of this book. It is now quite a confusing document, and may well be changed again before too long. For this reason, and because this book is concerned with fundamental principles that do not change, I have kept references to codes of practice to a minimum

More than 60 worked examples and case studies are now included within the text, with more than 90 further questions at the end of each chapter. Many of these are based on end-of-year examination questions I have set at King's College, Queen Mary and Westfield College or the University of Southampton, and I am grateful to those institutions for their permission to use these problems in this book. Some were provided by my colleagues Dr A. Zervos, Dr R.H. Bassett, Professor J.B. Burland, Dr M.R. Cooper, Dr N.W.M. John, Dr J.A. Smethurst and Dr R.N. Taylor, to whom I would also like to express my thanks. I apologise for any that I have inadvertently 'borrowed'.

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