9TH EDITION

Smith's Elements of Soil Mechanics

Ian Smith

with website

WILEY Blackwell

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About the Author

Ian Smith is Head of the School of Engineering and the Built Environment at Edinburgh Napier University. He has taught Geotechnical Engineering at the university for nearly 20 years, having spent some years beforehand working in the site investigation industry. He is an authority on the use of Eurocode 7 in geotechnical design and has instructed designers and academics in the use of the code throughout the UK, Europe and in China.

Preface

When I wrote the 8th Edition of this book in 2005, only Part 1 of Eurocode 7 had been published. In that Edition, I illustrated how geotechnical design to the new Eurocode was to be carried out and the feedback that I received indicated that readers found my approaches easy to follow. Between 2007 and 2010, Part 2 of the code and both UK National Annexes to the code were published and much of the new material in this 9th Edition has been developed around the now complete set of documents.

To help the reader fully understand the stages of a Eurocode 7 design, I have rearranged the sequence of chapters in the book and written two new chapters around the complete design process: Chapter 5 describes the design methods (aligning to Eurocode 7 Part 1) and Chapter 6 describes the ground investigation aspects (aligning to Part 2). The specific design methods to be used for various geotechnical structures are described in the later chapters, which cover retaining walls, shallow and deep foundations and slopes. The early chapters of the book cover the fundamentals of the behaviour of soils.

I have provided many worked examples throughout the book that illustrate the principles of soil mechanics and the geotechnical design processes. To help the reader further, I have produced a suite of spreadsheets and documents to accompany the book that match up against many of the worked examples. These can be used to better understand the analysis being adopted in the examples, which are particularly beneficial to understanding the Eurocode 7 design examples. In addition, I have produced the solutions to the exercises at the end of the chapters as a series of portable document format (pdf) files. All of these files can be freely downloaded from www.wiley.com/go/smith/soil

Whilst the full content of both parts of Eurocode 7 has driven the bulk of the new material in this edition, I have also updated other aspects of the text throughout. This was done in recognition that some aspects of the book had become dated as a result of the introduction of new methods and standards. Furthermore, the format of the book has been improved to aid readability and thus help the reader in understanding the material. All in all, I believe that I have produced a valuable and very up-to-date textbook on soil mechanics from which the learning of the subject should be made easier.

I must thank my colleagues Dr Daniel Barreto and Dr John McDougall for their advice on the revisions I have made to the sections on shear strength and unsaturated soils.

Notation Index

The following is a list of the more important symbols used in the text.

A	Area, pore pressure coefficient
A'	Effective foundation area
A_b	Area of base of pile
A_s	Area of surface of embedded length of pile shaft
B	Width, diameter, pore pressure coefficient, foundation width
B'	Effective foundation width
C	Cohesive force, constant
C_a	Area ratio
C_C	Compression index, soil compressibility
C_N	SPT Correction factor
C_r	Static cone resistance
C_s	Constant of compressibility
C_u	Uniformity coefficient
C_v	Void fluid compressibility
D	Diameter, depth factor, foundation depth, embedded length of pile
D_W	Depth of groundwater table
D_r	Relative density
D_1, D_2	Cutting shoe diameters
D_{10}	Effective particle size
E	Modulus of elasticity, efficiency of pile group
E_d	Eurocode 7 design value of effect of actions
$E_{dst;d}$	Eurocode 7 design value of effect of destabilising actions
$E_{stb;d}$	Eurocode 7 design value of effect of stabilising actions
E_M	Pressuremeter modulus
E_r	SPT Energy ratio
F	Factor of safety
F_b	Factor of safety on pile base resistance
$F_{c;d}$	Eurocode 7 design axial compression load on a pile
F_d	Eurocode 7 design value of an action
F_{rep}	Eurocode 7 representative value of an action
F_s	Factor of safety on pile shaft resistance
$G_{dst;d}$	Eurocode 7 design value of destabilising permanent vertical action (uplift)
G_s	Particle specific gravity
$G_{stb;d}$	Eurocode 7 design value of stabilising permanent vertical action (uplift)
$G'_{stb;d}$	Eurocode 7 design value of stabilising permanent vertical action (heave)
GWL	Groundwater level
H	Thickness, height, horizontal load
I	Index, moment of inertia
I_D	Density index

I_L	Liquidity index
I_P	Plasticity index
I_σ	Vertical stress influence factor
K	Factor, ratio of σ_3/σ_1
K_a	Coefficient of active earth pressure
K_0	Coefficient of earth pressure at rest
K_p	Coefficient of passive earth pressure
K_s	Pile constant
L	Length
L′	Effective foundation length
M	Moment, slope projection of critical state line, mass, mobilisation factor
M_s	Mass of solids
M_w	Mass of water
MCV	Moisture condition value
N	Number, stability number, specific volume for ln p′ = 0 (one-dimensional consolidation), uncorrected blow count in SPT
N_{60}	Number of blows from the SPT corrected to energy losses
$(N_1)_{60}$	Number of blows from the SPT corrected to energy losses and normalised for effective vertical overburden stress
N_c, N_q, N_γ	Bearing capacity coefficients
P	Force
P_a	Thrust due to active earth pressure
P_p	Thrust due to passive earth pressure
P_w	Thrust due to water or seepage forces
Q	Total quantity of flow in time t
Q_b	Ultimate soil strength at pile base
Q_s	Ultimate soil strength around pile shaft
Q_u	Ultimate load carrying capacity of pile
R	Radius, reaction
$R_{b;cal}$	Eurocode 7 calculated value of pile base resistance
$R_{b;k}$	Eurocode 7 characteristic value of pile base resistance
R_c	Eurocode 7 compressive resistance of ground against a pile at ultimate limit state
$R_{c;cal}$	Eurocode 7 calculated value of R_c
$R_{c;d}$	Eurocode 7 design value of R_c
$R_{c;k}$	Eurocode 7 characteristic value of R_c
$R_{c;m}$	Eurocode 7 measured value of R_c
R_d	Eurocode 7 design resisting force
R_o	Overconsolidation ratio (one-dimensional)
R_p	Overconsolidation ratio (isotropic)
$R_{s;cal}$	Eurocode 7 calculated value of pile shaft resistance
$R_{s;k}$	Eurocode 7 characteristic value of pile shaft resistance
S	Vane shear strength
$S_{dst;d}$	Eurocode 7 design value of destabilising seepage force
S_r	Degree of saturation
S_t	Sensitivity
T	Time factor, tangential force, surface tension, torque
T_d	Eurocode 7 design value of total shearing resistance around structure
U	Average degree of consolidation
U_z	Degree of consolidation at a point at depth z
V	Volume, vertical load
V_a	Volume of air
$V_{dst;d}$	Eurocode 7 design value of destabilising vertical action on a structure

V_s	Volume of solids
V_v	Volume of voids
V_w	Volume of water
W	Weight
W_s	Weight of solids
W_w	Weight of water
X_d	Eurocode 7 design value of a material property
X_k	Eurocode 7 representative value of a material property
Z	Section modulus
a	Area, intercept of MCV calibration line with w axis
b	Width, slope of MCV calibration line
c	Unit cohesion
c'	Unit cohesion with respect to effective stresses
c_b	Undisturbed soil shear strength at pile base
c'_d	Eurocode 7 design value of effective cohesion
c_r	Residual value of cohesion
c_u	Undrained unit cohesion
c_u	Average undrained shear strength of soil
$c_{u;d}$	Eurocode 7 design value of undrained shear strength
c_v	Coefficient of consolidation
c_w	Unit cohesion between wall and soil
d	Pile penetration, pile diameter
d_c, d_q, d_γ	Depth factors
e	Void ratio, eccentricity
f_s	Ultimate skin friction for piles
g	Gravitational acceleration
h	Hydrostatic head, height
h_c	Capillary rise, tension crack depth
h_e	Equivalent height of soil
h_w	Excess head
i	Hydraulic gradient
i_c	Critical hydraulic gradient
i_c, i_q, i_γ	Inclination factors
k	Coefficient of permeability
l	Length
m	Stability coefficient
m_B, m_L	Eurocode 7 load inclination factor parameters
m_v	Coefficient of volume compressibility
n	Porosity, stability coefficient
p	Pressure, mean pressure
p_a	Active earth pressure
p_c	Preconsolidation pressure (one-dimensional)
p'_e	Equivalent consolidation pressure (isotropic)
p_{LM}	Pressuremeter limit pressure
p_0	Earth pressure at rest
p'_m	Preconsolidation pressure (isotropic)
p'_o	Effective overburden pressure
p_p	Passive earth pressure
q	Unit quantity of flow, deviator stress, uniform surcharge, bearing pressure
q_a	Allowable bearing pressure
q_u	Ultimate bearing capacity

$q_{u\,net}$	Net ultimate bearing capacity
r	Radius, radial distance, finite difference constant
r_u	Pore pressure ratio
s	Suction value of soil, stress parameter
s_c, s_q, s_γ	Shape factors
s_w	Corrected drawdown in pumping well
t	Time, stress parameter
u, u_w	Pore water pressure
u_a	Pore air pressure, pore pressure due to σ_3 in a saturated soil
u_d	Pore pressure due to $(\sigma_1 - \sigma_3)$ in a saturated soil
$u_{dst;d}$	Eurocode 7 design value of destabilising total pore water pressure
u_i	Initial pore water pressure
v	Velocity, specific volume
w	Water, or moisture, content
w_L	Liquid limit
w_P	Plastic limit
w_s	Shrinkage limit
x	Horizontal distance
y	Vertical, or horizontal, distance
z	Vertical distance, depth
z_a	Depth of investigation points
z_o	Depth of tension crack
z_w	Depth below water table
α	Angle, pile adhesion factor
β	Slope angle
Γ	Eurocode 7 over-design factor, specific volume at ln $P' = 0$
γ	Unit weight (weight density)
γ'	Submerged, buoyant or effective unit weight (effective weight density)
γ_A	Eurocode 7 partial factor: accidental action – unfavourable
γ_b	Bulk unit weight (bulk weight density), Eurocode 7 partial factor: pile base resistance
γ'_c	Eurocode 7 partial factor: effective cohesion
γ_{cu}	Eurocode 7 partial factor: undrained shear strength
γ_d	Dry unit weight (dry weight density)
γ_F	Eurocode 7 partial factor for an action
$\gamma_{G;dst}$	Eurocode 7 partial factor: EQU permanent action – destabilising
$\gamma_{G;stb}$	Eurocode 7 partial factor: EQU permanent action – stabilising
$\gamma_{G;fav}$	Eurocode 7 partial factor: GEO permanent action – favourable
$\gamma_{G;unfav}$	Eurocode 7 partial factor: GEO permanent action – unfavourable
γ_M	Eurocode 7 partial factor for a soil parameter
γ_Q	Eurocode 7 partial factor: variable action – unfavourable
γ_{qu}	Eurocode 7 partial factor: unconfined compressive strength
γ_R	Eurocode 7 partial factor for a resistance
γ_{Re}	Eurocode 7 partial factor: earth resistance
γ_{Rh}	Eurocode 7 partial factor: sliding resistance
γ_{Rv}	Eurocode 7 partial factor: bearing resistance
γ_s	Eurocode 7 partial factor: pile shaft resistance
γ_{sat}	Saturated unit weight (saturated weight density)
γ_t	Eurocode 7 partial factor: pile total resistance
γ_w	Unit weight of water (weight density of water)
γ_γ	Eurocode 7 partial factor: weight density
γ'_ϕ	Eurocode 7 partial factor: angle of shearing resistance

δ	Ground–structure interface friction angle
ε	Strain
θ	Angle subtended at centre of slip circle
κ	Slope of swelling line
λ	Slope of normal consolidation line
μ	Settlement coefficient, one micron
ν	Poisson's ratio
ξ_1, ξ_2	Eurocode 7 correlation factors to evaluate results of static pile load tests
ξ_3, ξ_4	Eurocode 7 correlation factors to derive pile resistance from ground investigation results
ρ	Density, settlement
ρ'	Submerged, buoyant or effective density
ρ_b	Bulk density
ρ_c	Consolidation settlement
ρ_d	Dry density
ρ_i	Immediate settlement
ρ_{sat}	Saturated density
ρ_w	Density of water
σ	Total normal stress
σ'	Effective normal stress
σ_a, σ'_a	Total, effective axial stress
σ'_e	Equivalent consolidation pressure (one-dimensional)
σ_r, σ'_r	Total, effective radial stress
$\sigma_{stb;d}$	Eurocode 7 design value of stabilising total vertical stress
$\underline{\sigma'_v}$	Effective overburden pressure
$\overline{\sigma'_v}$	Average effective overburden pressure
σ_1, σ_2, σ_3	Total major, intermediate and minor stress
σ'_1, σ'_2, σ'_3	Effective major, intermediate and minor stress
τ	Shear stress
ϕ_u	Angle of shearing resistance with respect to total stresses (=0)
ϕ'	Angle of shearing resistance with respect to effective stresses
ϕ_{cv}	Critical state, or constant volume, angle of shearing resistance
$\phi_{cv;d}$	Design value of critical state angle of shearing resistance
ϕ'_d	Design value of ϕ'
ψ	Angle of back of wall to horizontal

About the Companion Website

The book's companion website www.wiley.com/go/smith/soil provides you with resources and downloads to further your understanding of the fundamentals of soil mechanics and the use of Eurocode 7:

- A suite of editable spreadsheets which map onto the worked examples in the book, showing how they are solved.
- Solutions to the end-of-chapter exercises, including the full workings.
- Convenient tables with useful data and formulae.

Contents

Chapter 1

Classification and Physical Properties of Soils

In the field of civil engineering, nearly all projects are built on to, or into, the ground. Whether the project is a structure, a roadway, a tunnel, or a bridge, the nature of the soil at that location is of great importance to the civil engineer. *Geotechnical engineering* is the term given to the branch of engineering that is concerned with aspects pertaining to the ground. Soil mechanics is the subject within this branch that looks at the behaviour of soils in civil engineering.

Geotechnical engineers are not the only professionals interested in the ground; soil physicists, agricultural engineers, farmers and gardeners all take an interest in the types of soil with which they are working. These workers, however, concern themselves mostly with the organic topsoils found at the soil surface. In contrast, geotechnical engineers are mainly interested in the engineering soils found beneath the topsoil. It is the engineering properties and behaviour of these soils which are their concern.

1.1 Agricultural and engineering soil

If an excavation is made through previously undisturbed ground the following materials are usually encountered (Fig. 1.1).

Topsoil

A layer of organic soil, usually not more than 500 mm thick, in which humus (highly organic partly decomposed vegetable matter) is often found.

Subsoil

The portion of the Earth's crust affected by current weathering, and lying between the topsoil and the unweathered soil below.

Hardpan

In humid climates humic acid can be formed by rainwater causing decomposition of humus. This acid leaches out iron and alumina oxides down into the lower layers where they act as cementation agents to form a hard, rock-like material. Hardpan is difficult to excavate and, as it does not soften when wet, has a high resistance to normal soil drilling methods. A hardpan layer is sometimes found at the junction of the topsoil and the subsoil.

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