

# Introduction to SOIL MECHANICS



Béla Bodó & Colin Jones

WILEY Blackwell



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This edition first published 2013 © 2013 by John Wiley & Sons, Ltd

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John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom.

*Editorial Offices*

9600 Garsington Road, Oxford, OX4 2DQ, United Kingdom.

The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom.

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*Library of Congress Cataloging-in-Publication Data*

Bodo, Bela, (Engineer)

Introduction to soil mechanics / Bela Bodo, Colin Jones.

pages cm

Includes bibliographical references and index.

ISBN 978-0-470-65943-4 (pbk. : alk. paper) - ISBN 978-1-118-55387-9 (emobi) -

ISBN 978-1-118-55388-6 (epub) - ISBN 978-1-118-55389-3 (epdf) 1. Soil mechanics. I. Title.

TA710.B617 2013

624.1'5136-dc23

2012040913

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Cover image courtesy of Shutterstock.com

Cover design by Steve Thompson

Set in 9/11.5pt Interstate-Light by SPI Publisher Services, Pondicherry, India

Printed and bound in Malaysia by Vivar Printing Sdn Bhd

# **Introduction to Soil Mechanics**

### **About the companion website**

This book's companion website is at [www.wiley.com/go/bodo/soilmechanics](http://www.wiley.com/go/bodo/soilmechanics) and offers invaluable resources for students and lecturers:

- Supplementary problems
- Solutions to supplementary problems



[www.wiley.com/go/bodo/soilmechanics](http://www.wiley.com/go/bodo/soilmechanics)

# Preface

This book is intended to introduce the subject to students studying for BTEC Higher National Certificate/Diploma in Civil Engineering and Building Studies or for a Degree in Civil Engineering. It should also be practical reference to Architects, Geologists, Structural and Geotechnical Technicians.

The primary aim is to provide a clear understanding of the basic concepts of Soil Mechanics. We endeavoured to avoid the temptation of over-elaboration by providing excessively detailed text, unnecessary at this early stage of technical studies.

The purpose of this publication is threefold:

1. To introduce the student to the basics of soil mechanics.
2. To facilitate further advanced study.
3. To provide reference information.

In order to satisfy the above requirements, the concepts of the subject are defined concisely, aided by diagrams, charts, graphs, tables and worked examples as necessary.

The text may appear to be excessively analytical at first sight, but all formulas are derived in terms of basic mathematics, except for a few requiring complicated theory, for those interested in working from first principles. They can be applied however, without reference to the derivation. The expressions are numbered and referred to throughout the text.

There are numerous worked examples on each topic as well as supplementary problems. All examples and problems are solved, many of them interrelated so that solutions can be compared and verified by means of several methods.

Some soil testing procedures are outlined only, as there are a number of excellent, detailed, specialized books and laboratory manuals available to cover this part of the subject.

There is some emphasis on the units employed and on the difference between mass and weight. This subject is discussed in Appendix A.

Béla Bodó and Colin Jones

# Dedication

*"I dedicate this book to my late wife Dorie."*

Béla Bodó

# Acknowledgments

We wish to express our appreciation to Mr. Norman Seward, Senior Lecturer in Civil Engineering at the University of Wales College, Newport for his technical advice as to the presentation of the subject.

We are also grateful to Mr. Gregory Williams for his help in the production of this book.

We would like to thank ELE International for their support in providing product images.

# List of Symbols

## Chapter 1

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$CBR$	California bearing ratio
$C_r$	Relative compaction
$D_r$	Relative Density
$e$	Voids ratio
$G_s$	Specific gravity
$k$	CBR Load-ring factor
$M$	Total Mass of sample
$m$	Moisture (water) content
$m_o$	Optimum moisture content
$M_s$	Mass of solids
$M_w$	Mass of water
$n$	Porosity
$P$	CBR applied force
$P_a$	Percentage of air voids
$Q$	CBR Load gauge reading
$S_r$	Degree of saturation
$V$	Total volume of sample
$V_a$	Volume of air
$V_c$	Volume of calibrating cylinder
$V_s$	Volume of solids
$V_v$	Volume of voids
$V_w$	Volume of water
$W$	Total weight of sample
$W_s$	Weight of solids
$W_w$	Weight of water
$\delta$	CBR Penetration distance (delta)
$\gamma$	Bulk weight density (Gamma)
$\gamma'$	Submerged weight density
$\gamma_d$	Dry Weight density
$\gamma_d$	Dry Unit weight to be achieved by compaction
$\gamma_s$	Weight density of solids
$\gamma_{sat}$	Saturated weight density
$\rho$	Bulk mass density
$\rho_d$	Dry mass density
$\rho_{sat}$	Saturated mass density
$\rho'$	Submerged mass density
$\rho_s$	Mass density of solids



## Chapter 2

$C_d$	Correction for dispersing agent
$C_m$	Meniscus correction
$D$	Equivalent particle diameter
$D_{10}$	Effective size of a particle
$f$	Specific Volume change
$H$	Height from the top of the bulb to surface
$h_b$	Length of bulb
$H_R$	Height of centre of bulb to surface
LI	Liquidity index
LL	Liquid limit
$M_p$	Mass passing the $n^{\text{th}}$ sieve
$M_r$	Mass retained on the $n^{\text{th}}$ sieve
$m_T$	Temperature correction
$N$	Number of blows
PI	Plasticity index
PL	Plastic limit
$P_n$	Percentage of soil passing the $n^{\text{th}}$ sieve
$R$	Mixing ratio
$R'_h$	Recorded hydrometer reading
$R_h$	Corrected hydrometer reading
RI	Relative consistence index
SL	Shrinkage limit
$T$	Temperature
$t$	Time
$U$	Uniformity coefficient
$u$	Velocity of sedimentation
$V_b$	Volume of hydrometer bulb
$V_o$	Volume of over-dried specimen
$\approx$	Volume at SL
$x$	Magnitude of linear shrinkage or swelling
$Z$	Saturation limit
$\eta$	Dynamic viscosity <eta>

## Chapter 3

$A$	Cross-sectional area of specimen
$a$	Cross-sectional area of standpipe
$A_s$	Cross-sectional area of solids in specimen
$A_v$	Cross-sectional area of voids in specimen
EPL	Equipotential line
FL	Flow Line
$F_s$	Factor of safety
GL	Ground level
GWL	Groundwater level (Water Table)

$h$	Head loss
$H_T$	Total head at $x$
$H_x$	Head loss to point $x$
$h_x$	Pressure head at $x$
$i$	Hydraulic gradient
$i_{av}$	Average hydraulic gradient
$i_c$	Critical hydraulic gradient
$i_e$	Exit gradient
$k$	Coefficient of permeability
$L$	Length of flow path
$N_e$	Number of squares (head drops)
$N_f$	Number of flow channels
$N_x$	Number of head drops to point $x$
$P$	Hydrostatic force
$Q$	Flowrate
$q$	Quantity of flow in time ( $t$ )
$R$	Radius of influence
$r$	Radius to observation well
$r_o$	Radius of central well
$S$	Seepage force
$u_x$	Seepage pore pressure at $x$
$\Delta h$	Head Loss between equipotential line
$v$	Discharge velocity
$v_s$	Seepage velocity

## Chapter 4

---

$I$	Influence factor
$n$	Number of elements on the Newmark chart
$Q$	Concentrated point load
$q$	Uniformly distributed load (UDL)
$r$	Radius
$z$	Depth
$\sigma$	Horizontal pressure
$\sigma_v$	Vertical pressure
$\tau$	Shear stress

## Chapter 5

---

$dh$	Total deformation of specimen of thickness $h$
$h_A$	Artesian pressure head
$h_c$	Capillary head
$h_s$	Seepage pressure head
$i_c$	Critical hydraulic gradient
$m_E$	Equilibrium moisture content
$m_o$	Optimum moisture content
pF	Soil suction index
PI	Plasticity index
$S_r$	Degree of saturation

$S_s$	Soil suction
$T$	Surface tension
$u$	Pore pressure
$u_{cs}$	Pore pressure in the capillary fringe
$u_h$	Static pore pressure at depth $h$
$u_s$	Seepage pore pressure
$z_c$	Critical depth for piping
$\Delta u$	Small change in $u$
$\Delta \gamma$	Change in unit weight
$\Delta \sigma$	Small change in $\sigma$
$\Delta \sigma'$	Small change in $\sigma'$
$\delta$	Deformation of specimen at time $t$
$\sigma$	Total pressure
$\sigma'$	Effective pressure
$\sigma_A$	Artesian pressure

## Chapter 6

$A$	Pore pressure coefficient
$\bar{A}$	Pore pressure coefficient
$B$	Pore pressure coefficient
$c$	Cohesion
$c_u$	Undrained shear strength
CD	Consolidated-drained test
CU	Consolidated-undrained test
ESP	Effective stress path
NCC	Normally consolidated clay
$n$	Proving ring constant
OCC	Over consolidated clay
$p$ & $q$	Stress path coordinates
$p_f$ & $q_f$	Stress path coordinates at failure
QU	Quick-undrained test
$r_x$	Force dial reading at $x$
TSP	Total stress path
UU	Unconsolidated-undrained test
$x$	Strain gauge reading
$\Delta u_d$	Change in pore pressure due to $\Delta \sigma_d$
$\Delta u_c$	Change in pore pressure due to $\Delta \sigma_c$
$\Delta \sigma_c$	Change in cell pressure
$\Delta \sigma_d$	Change in the deviator stress
$\varepsilon$	Strain at $x$
$\phi$	Angle of friction
$\sigma_n$	Normal pressure
$\sigma_x$	Deviator stress at $x$
$\sigma_u$	Unconfined compression strength
$\tau$	Shear stress
$\tau_f$	Shear stress at failure
$\tau_p$	Shear stress on a plain
$\tau_m$	Maximum shear stress

## Chapter 7

---

$A_c$	Area indicating completed consolidation
$A_t$	Area under an isochrone
$a_v$	Coefficient of compressibility
$C_\alpha$	Coefficient of Secondary settlement () to consolidation
$C_c$	Compression index
$C_v$	Coefficient of consolidation
$D_x$	Dial reading at stage $x$
$dH_i$	Initial settlement
$E$	Modulus of elasticity
$e_0$	Initial voids ratio
$e_f$	Final voids ratio
$e_s$	Voids ratio after swelling
$e_x$	Voids ratio at stage $x$
$H$	Layer thickness
$H_0$	Flow path
$h_x$	Height of specimen at stage $x$
$I_p$	Influence factor
$k$	Coefficient of permeability
$m_v$	Coefficient of volume change
OCR	Overconsolidation ratio
$q$	Bearing pressure
$T_v$	Time factor
$t$	Time
$U$	Average degree of consolidation
$U_z$	Degree of consolidation
$u$	Pore pressure at time $t$
$u_0$	Initial pore pressure
$\Delta H$	Long-term consolidation settlement
$\Delta\sigma'$	Effective consolidating pressure
$\delta$	Depth factor (Delta)
$\infty$	Poisson's ratio ( $M_y$ )
$\sigma'_x$	Effective pressure at stage $x$

## Chapter 8

---

$c_u$	Unconfined compression strength
$c_w$	Adhesion between soil and wall
$e$	Eccentricity
$F_\phi$	Factor of safety in terms of friction angle
$f_{\max}$	Maximum compressive stress
$f_{\min}$	Minimum compressive stress
$F_s$	Factor of safety
$H$	Height of wall
$H_0$	Height of unsupported clay
$K$	Coefficient of lateral pressure

$K_o$	Coefficient of earth pressure at rest
$K_a$	Coefficient of active earth pressure
$K_f$	Coefficient of earth pressure at failure
$K_p$	Coefficient of passive earth pressure
$L$	Length of slip surface
$M_{\max}$	Maximum bending moment
$M_o$	Overturning moment
$M_R$	Resisting moment
$P_a$	Active force
$P_p$	Passive force
$P_w$	Force of water in tension crack
$R$	Force on wedge
$T$	Tension force in tie rod
$z_c$	Pile penetration
$z_o$	Depth of tension crack
$\delta$	Angle of wall friction
$\phi'_m$	Mobilised friction
$\mu$	Coefficient of friction
$\sigma_a$	Active earth pressure
$\sigma_c$	Cell pressure in triaxial test
$\sigma_d$	Deviator stress in triaxial test
$\sigma_p$	Passive earth pressure
$\sigma'_a$	Effective active earth pressure
$\sigma'_p$	Effective passive earth pressure
$\bar{\sigma}$	Average pressure
$\tau_f$	Shear stress at failure

## Chapter 9

$\bar{c}_u$	Average undrained shear strength
$A_e$	End bearing area
$A_s$	Surface area of pile
$B$	Width of footing
$c$	Cohesion
$F_o$	Overall factor of safety
$F_s$	Factor of safety
$K_s$	Average coefficient of earth pressure
$l$	Length of pile
$N$	Number of SPT blows
$n$	Number of piles
$N'$	Corrected value of $N$
$N_c$	Bearing capacity factors
$N_q$	
$N_\gamma$	
$P$	Failure load on pile
$Q$	Design working load
$Q_a$	Allowable carrying capacity of pile
$Q_{ag}$	Allowable carrying capacity of pile group

$Q_e$	End bearing resistance
$Q_f$	Negative skin friction
$Q_s$	Shaft resistance
$Q_u$	Ultimate carrying capacity of pile
$Q_{ug}$	Ultimate carrying capacity of pile group
$q_n$	Net ultimate bearing capacity
$q_s$	Safe bearing capacity
$q_{sn}$	Safe net bearing capacity
$q_u$	Ultimate bearing capacity
SPT	Standard penetration test
$W_p$	Weight of pile
$\alpha$	Adhesion factor (Alpha)
$\delta$	Angle of friction between soil and pile (Delta)
$\eta$	Efficiency of pile group (Eta)
$\phi$	Angle of friction
$\sigma$	Safe bearing pressure of footing
$\sigma_n$	Net bearing pressure of footing
$\bar{\sigma}'_o$	Average effective overburden pressure
$\sigma'_o$	Effective overburden pressure

## Chapter 10

---

$c_u$	Shear strength
$F$	Friction force
$F_c$	Factor of safety with respect to cohesion
$F_s$	Factor of safety
$F_\phi$	Factor of safety with respect to friction
$L$	Length of slip surface
$M_D$	Disturbing moment
$M_R$	Resisting moment
$N$	Normal (or radial) component of $W$
$N_c$	Stability number
$R$	Radius of slip circle
$r_u$	Pore pressure ratio
$S$	Shear force
$T$	Tangential component of $W$
$W$	Weight

## Chapter 11

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The comprehensive list of symbols for EC7 is given in *Eurocode 7. Geotechnical design Part 1: General rule*. Only some of the symbols, applied in this book, are reproduced here:

$E_d$	Design value of the effect of actions
$E_{dst;d}$	Design value of the effect of destabilizing action
$E_{stb;d}$	Design value of the effect of stabilizing action
$F_d$	Design value of an action
$F_{rep}$	Representative value of an action
$F_s$	Factor of safety

---

$G_{dst;d}$	Design value of destabilising permanent action
$G_{stb;d}$	Design value of stabilising permanent action
$Q_{dst;d}$	Design value of destabilising variable action
$R_d$	Design value of resistance action
$S_{dst;d}$	Design value of destabilising seepage force
$T_d$	Design value of total shear resistance
$U_{dst;d}$	Design value of destabilising pore water pressure
$V_{dst;d}$	Design value of destabilising vertical action
$X_d$	Design value of a material property
$X_k$	Characteristics value of a material property
$\gamma_G$	Partial factor for a permanent action
$\gamma_{G;dist}$	Partial factor for a destabilising action
$\gamma_{G;stb}$	Partial factor for a stabilising action
$\gamma_m$	Partial factor for soil parameters (material property)
$\gamma_Q$	Partial factor for a variable action
$\gamma_{R;h}$	Partial factor for sliding resistance

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