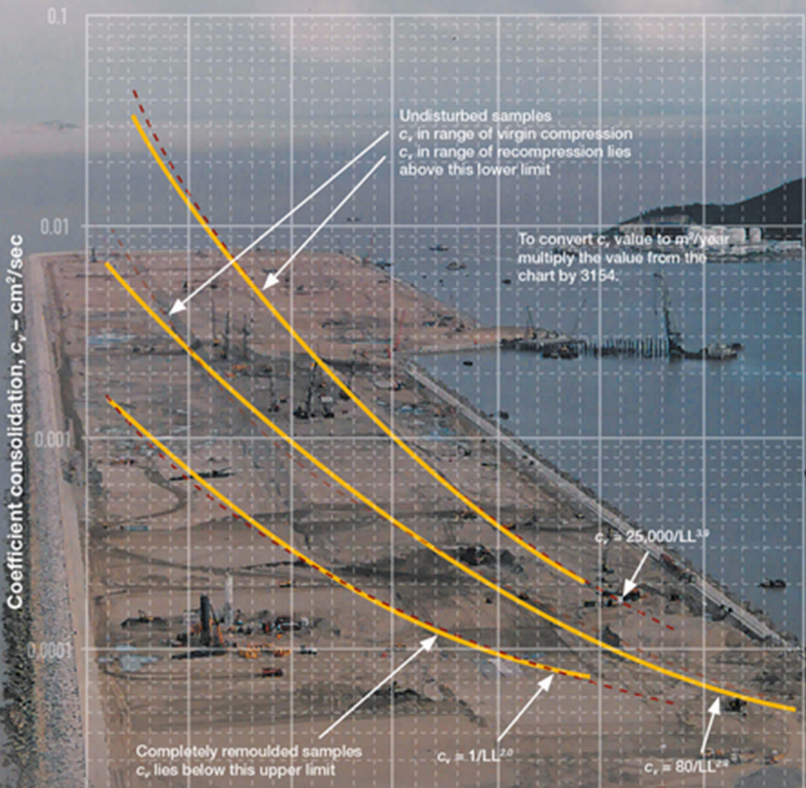
SOIL PROPERTIES AND THEIR CORRELATIONS

SECOND EDITION



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Contents

Preface

The aims of this book are to provide a summary and discussion of commonly used soil engineering properties and to give correlations of various engineering properties.

The book includes:

- a compendium of published correlations;
- discussions of the reliability, accuracy and usefulness of the various correlations;
- practical advice on how soil properties are used in the assessment and design of geotechnical problems, including basic concepts, and limitations on their use that need to be considered; and
- descriptions of the measurement of soil properties, and how results are affected by the method of measurement and the expertise of technicians carrying out the testing.

A consideration in describing the various properties has been an awareness by the authors that many geotechnical engineers and engineering geologists have little, if any, hands-on experience of laboratory testing, and are often unaware of the procedures used to obtain the various soil properties and of the effects of poor or inappropriate practice.

The properties are also described in relation to their use in geotechnical analysis, in a way that we hope will give students and younger engineers an in-depth appreciation of the appropriate use of each property and the pitfalls to avoid, and should also provide a useful reminder to more experienced professionals.

Many soil correlations were established in the early decades of soil mechanics, with there being no need to repeat the work once correlations had been established and verified by sufficient researchers. As a consequence, the correlations given in this book span a wide range of time, a few as far back as the 1930s, but we have also presented more recent work where this adds useful information. However, our intention in selecting correlations is to present those that will be of wide practical application, and the book is not intended as a research review. To aid their use in spreadsheet calculations, we have derived mathematical expressions to fit many of the correlations that were originally given only graphically. We have also tried to keep the work independent of national design codes, but it inevitably contains references to practices that are more prevalent in the English-speaking world. Where references are made to classification systems and associated codes we have, where possible, included references to both UK and US practice.

We envisage and recommend that correlations be used in two ways: firstly, to obtain values of a property that has not been measured; and secondly, to provide additional values where some direct measurements of the property have been made. In the first case, where no values of a particular property have been directly measured, the values obtained from correlations should be viewed with caution and treated as preliminary, especially where the property value is critical to the predicted performance of a design. Where correlations are used in combination with direct measurements to provide supplementary values, the accuracy and reliability of the correlations can usually be verified, fine-tuning the correlation if necessary, which may allow the values obtained by correlation to be viewed with more confidence.

While every care has been taken in the preparation of this book, with the very large amount of information that has been assembled it is possible that some errors have occurred; users should satisfy themselves that the information presented is correct. The authors can take no responsibility for consequences resulting from any errors in the book. The views expressed about the reliability and accuracy of correlations, typical values and other published information are based on the authors' own experience and may not accord with those of other geotechnical specialists.

Acknowledgements

In creating a compendium of published correlations, we had to seek permission from many authors around the globe; for her role in this important and painstaking task, the authors would like to thank Carol Clark. Bringing together such a large number of disparate items of information from many sources also involved a great deal of checking, and our thanks go to ex-colleagues Jason Williams and Max Lundie for their checking of some of the work, and especially to Mark Campbell who read through the entire script, noting errors and giving many helpful suggestions.

List of Symbols

Symbol	Name of variable	Typical units (SI)*
α	A scaling factor for estimating footing settlements from plate bearing test results.	D
α	A factor for estimating values of coefficient of volume compressibility from static cone test results.	D
α	Adhesion factor, for pile calculations.	D
α	A factor used to estimate the pull-out resistance of a soil reinforcement grid.	D
Δp	A distance above or below the A-line on a standard plasticity chart.	%
θ	Angle of a plane, from the direction of maximum principle stress, on which stresses act.	Degrees
μ	Viscosity of permeant for general seepage calculations.	$kN.s/m^2$
ν	Poisson's ratio.	D
π	Ratio of the circumference of a circle to its diameter (≈3.14159).	D
ρ	Settlement.	m, mm
σ	Direct stress.	kPa (kN/m^2)
σ'	Effective direct stress.	kPa (kN/m^2)

$\sigma_1, \sigma_2, \sigma_3$	Maximum, intermediate and minimum principal stresses.	kPa (kN/m^2)
σ_n	Effective earth pressure, used in soil nail calculations.	kPa (kN/m^2)
σ_v, σ'_v	Vertical stress, or overburden pressure, in total and effective stress terms, respectively.	kPa (kN/m^2)
τ	Shear stress.	kPa (kN/m^2)
γ	Bulk density of soil.	kN/m^3
γ_d	Dry density of soil.	kN/m^3
γ_{dmax}	Maximum dry density, for relative density calculations.	kN/m^3
γ_{dmin}	Minimum dry density, for relative density calculations.	kN/m^3
γ_p	Density of permeant for general seepage equation.	kN/m^4
γ_{sub}	Submerged density of soil.	kN/m^3
γ_w	Density of water.	kN/m^3
φ	Angle of shearing resistance (general, or in total stress terms).	Degrees
φ'	Effective stress angle of shearing resistance.	Degrees
φ_d	Drained angle of shearing resistance.	Degrees
φ_r	Residual angle of shearing resistance (general).	Degrees
a	Air voids content of soil.	%
a	Component of influence factor I_c for estimating settlements of footings on sands.	D
A	Area (nominal) of soil water flow.	m^2
A	A correction factor for rod energy ratio in the standard penetration test.	D
A	Percentage passing a 2.4 mm sieve, used in the calculation of suitability index.	%
A	A constant used in the estimation of swelling potential from plasticity index.	D
A_c	Activity value (of a clay).	D
A_p	End area of penetration cone in a 1standard penetration test.	mm^2
A_s	End area of penetration cone in a dynamic probe.	mm^2

a_v	Coefficient of compressibility. (See also m_v, coefficient of volume compressibility.)	m^2/MN
b	Component of influence factor I_c for estimating settlements of footings on sands.	D
B	Footing width.	m
B	A constant used in the estimation of swelling potential from plasticity index.	D
c	Shape factor in general seepage calculations.	D
c	Cohesion.	kPa (kN/m^2)
C	Percentage finer than 0.002 mm, used in the calculation of activity for a clay.	D
c'	Effective stress cohesion.	kPa (kN/m^2)
C_1	Constant used in Hazen's formula to estimate the coefficient of permeability.	D
CBR	California Bearing Ratio.	%
C_c	Coefficient of curvature (coefficient of grading).	D
C_c, C_r	Compression index, recompression index, respectively.	D
c_d	Drained cohesion.	kPa (kN/m^2)
CI	Consistency index.	%
C_N	Correction factor for overburden pressure, applied to SPT N-values.	D
c_u	Undrained cohesion, shear strength.	kPa (kN/m^2)
C_u	Coefficient of uniformity.	D
c_v	Coefficient of consolidation.	cm^2/s, $m^2/year$
C_α	Secondary compression index.	$(\log_{10} \text{time})^{-1}$
$C_{\alpha\varepsilon}$, C'	Modified secondary compression index (sometimes referred to simply as the secondary compression index).	$(\log_{10} \text{time})^{-1}$
d	Maximum length of drainage path in consolidation calculations.	m
D	Depth of foundation (when calculating allowable bearing pressures on sands).	m
D_{10}	The 10% particle size, also called the effective size.	mm (or µm)
D_{30}, D_{60}	The 30% and 60% particle sizes, respectively.	mm (or µm)

D_n	The particle size at which $n\%$ of the material is finer. See also D_{10}, D_{30}, D_{60}.	mm (or μm)
D_r	Relative density (of granular soils).	D
D_s	An effective particle size for permeability estimates, usually taken as D_{10}.	mm
e	Voids ratio.	D
e	The natural number, approximately 2.718.	D
E	Young's modulus (also called the elastic modulus).	kPa, MPa
e_1, e_2	Initial and final voids ratios in consolidation testing.	D
E_d	Deformation modulus (also called the constrained modulus).	kPa, MPa
e_{max}	Maximum voids ratio, for relative density calculations.	D
e_{min}	Minimum voids ratio, for relative density calculations.	D
ER_r	Rod energy ratio in standard penetration test.	D
F	The percentage passing the 75 μm sieve, used in the calculation of AASHTO classification group index.	%
f_l, f_s, f_t	Shape, layer thicknes and time factors, respectively, for estimating settlements of footings on sands.	D
F_p	Drop distance of monkey (falling hammer) in a dynamic probe.	mm
F_s	Drop distance of monkey (falling hammer) in a standard penetration test.	mm
G	Shear modulus.	kPa, MPa
G_s	Specific gravity of soil solids	D
h	Thickness of specimen in consolidation testing.	mm
H	Thickness of a compressible layer in consolidation testing.	m
i	Hydraulic gradient in soil water flow.	D
I_c	Influence factor for estimation of settlements of footings on sands.	D

I_r	Rigidity index, used in rate-of-settlement estimates based on static piezocone test results.	D
I_r	Swell index, used in the estimation of swelling pressure.	D
k	Coefficient of permeability.	m/s, m/year
K	A constant used in the estimation of swelling potential from plasticity index.	D
K_0	Coefficient of earth pressure at rest.	D
K_d	Depth factor for allowable bearing pressures on sands.	D
K_s	Earth pressure coefficient use in driven pile calculations.	D
L	Footing length.	m
LI	Liquidity index.	%
LL	Liquid limit.	%
m	Moisture (water) content of soil.	%
M_p	Mass of monkey (falling hammer) in a dynamic probe.	kg
M_s	Mass of monkey (falling hammer) in a standard penetration test.	kg
m_v	Coefficient of volume compressibility. (See also a_v, coefficient of compressibility.)	m^2/MN
n	Porosity of soil.	D
n	A factor used to estimate undrained shear strength from consistency index or liquidity index.	D
N	SPT *N*-value; blows of standard hammer to drive the SPT sampler or cone 300 mm.	Blows
N_1	SPT *N*-value corrected for overburden pressure.	Blows
$N_{1(60)}$	SPT *N*-value corrected for overburden pressure and to a rod energy ratio of 60%.	Blows
N_{60}	SPT *N*-value corrected for rod energy ratio, ER_r. (the "60" refers to standardisation to 60% rod energy.)	Blows
$N_{corrected}$	SPT *N*-value corrected for silts and fine sands below the groundwater table.	Blows

N_k	A factor used in the estimation of undrained shear strength from static cone tip resistance.	D
O_{40}, O_{80}	Pore diameters at which 40% and 80% of the pores are finer	mm, µm
OCR	Overconsolidation ratio.	D
p	Previous maximum overburden pressure, used in estimating settlements of footings on sands.	D
p_1, p_2	Initial and final pressures used in a stage of consolidation testing.	kPa (kN/m^2)
PI	Plasticity index.	%
PL	Plastic limit.	%
PM	Plasticity modulus.	%
P_p	Penetration for each blow count in a dynamic probe.	mm
P_s	Penetration for each blow count in a standard penetration test.	mm
q	Quantity of flow of water through soil per unit time.	m^3/s, m^3/year
q	Bearing pressure.	kPa (kN/m^2)
q_a	Allowable bearing pressure.	MPa (MN/m^2)
q_c	Measured cone resistance (pressure) in static cone tests.	kPa (kN/m^2)
q_u	Ultimate bearing capacity.	kPa (kN/m^2)
R	Component of influence factor f_t for estimating settlements of footings on sands.	D
S	Degree of saturation.	%
S	Swelling potential.	%
s, s_u	Undrained shear strength.	kPa (kN/m^2)
S_t	Sensitivity	D
SL	Shrinkage limit.	%
t	Time, used in calculations or rates of consolidation and secondary compression.	s, years
t_1, t_2	Start and end times for secondary compression calculations.	s, years
T_v	Basic time factor, used in calculations or rates of consolidation.	D

u	Pore water pressure.	kPa (kN/m^2)
U	Degree of consolidation.	D
v	Nominal velocity of flow of water through soil.	m/s, m/year
v_t	True velocity of flow of water through soil.	m/s, m/year
W_{LW}	Weighted liquid limit, used in the estimation of swelling potential.	%
W_w	Weight of water (in the model soil sample).	g
Y	Rate of frost heave.	mm/day

* D = dimensionless; % values are also essentially dimensionless.

List of Property Values and Correlations in the Tables and Figures

	Index properties			Density			Compressibility			Strength		Specialised					Probe testing		
Table	Grading	Moisture content	Plasticity/ consistency limits	Density	Relative density	Permeability	Total settlement (m_v, C_c and settlement of sands)	Rate of settlement (c_v)	Coefficients of secondary compression	Shear strength	California Bearing Ratio	Shrinkage and swelling characteristics	Frost susceptibility	Susceptibility to combustion	Stresses at soil-structure interfaces	Soil classification	Standard penetration test	Dynamic cone tests	Static cone tests
3.1				✓															
3.2				✓												✓			
3.3				✓												✓			
3.4					✓												✓		
3.5																	✓		
3.6																	✓		
3.7																	✓		
4.1						✓													
5.1							✓									✓			
5.2							✓												
5.3								✓								✓			
5.4							✓		✓							✓			
5.5							✓									✓			✓
6.1										✓						✓			
6.2			✓							✓									
6.3										✓						✓			
6.4					✓					✓						✓			
6.5										✓						✓			
7.1											✓								
7.2			✓								✓					✓			
8.1												✓							
8.2			✓																
8.3												✓							
8.4			✓									✓							
8.5			✓									✓							
8.6	✓		✓									✓							
8.7	✓		✓									✓							
9.1	✓		✓										✓						
9.2													✓			✓			
11.1															✓	✓			
11.2															✓	✓			
A1																✓			
A2																✓			
A3																✓			
A4																✓			
A5																✓			
A6																✓			
A7																✓			
A8																✓			
B1																			✓

	Index properties			Density			Compressibility			Strength		Specialised					Probe testing		
Figure	Grading	Moisture content	Plasticity/consistency limits	Density	Relative density	Permeability	Total settlement (m_v, C_c and settlement of sands)	Rate of settlement (c_v)	Coefficients of secondary compression	Shear strength	California Bearing Ratio	Shrinkage and swelling characteristics	Frost susceptibility	Susceptibility to combustion	Stresses at soil-structure interfaces	Soil classification	Standard penetration test	Dynamic cone tests	Static cone tests
1.13										✓									
2.1	✓															✓			
2.2	✓																		
2.4			✓																
2.5			✓													✓			
3.1				✓															
3.2		✓		✓															
3.4		✓	✓	✓															
3.5		✓		✓															
3.6																	✓		
3.7					✓														✓
3.8																	✓		✓
4.1						✓										✓			
4.2	✓					✓													
5.3			✓				✓										✓		
5.4							✓												
5.5							✓												
5.6								✓											
5.7			✓					✓											
5.9		✓							✓										
5.10		✓							✓										
5.11							✓										✓		
5.12							✓										✓		
5.13							✓										✓		
5.14							✓										✓		
5.15							✓	✓											✓
6.4			✓							✓									
6.5			✓							✓									
6.6			✓							✓									
6.7			✓							✓									
6.8			✓							✓									
6.9										✓							✓		
6.10			✓							✓							✓		
6.11			✓							✓									
6.12				✓	✓					✓						✓			
6.13					✓					✓							✓		
6.14					✓					✓									
7.1		✓	✓								✓								
7.2		✓									✓								
7.3	✓		✓								✓								

	Index properties			Density			Compressibility			Strength		Specialised					Probe testing		
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7.4			✓	✓							✓								
7.5		✓		✓							✓								
7.6											✓					✓			
7.7											✓					✓			
7.8											✓								
8.1			✓									✓							
8.2	✓		✓									✓							
8.4	✓		✓									✓							
8.5			✓									✓							
9.3	✓												✓						
9.4	✓												✓						
9.5	✓												✓			✓			
10.1														✓					
11.1										✓					✓				
11.2										✓					✓				
11.3			✓												✓				
11.4			✓												✓				
A1			✓													✓			
A2			✓													✓			
B8																✓			✓