

# Contents

<i>Preface</i>	viii
<i>Acknowledgements</i>	x
<i>Introduction</i>	xi
<i>Symbols</i>	xiii
<b>1 Properties of Unsaturated Soils</b>	1
1.1 Nature and genesis of unsaturated soils	1
1.2 Soil variables	3
1.3 Particle properties	7
1.4 Phase properties and interactions	9
1.5 Soil structure	22
1.6 Experimental techniques for examining pore size distribution	23
1.7 Pore size distribution	25
1.8 Conclusions	32
<b>2 Suction Measurement and Control</b>	34
2.1 Introduction	34
2.2 Techniques for measurement of suction	35
2.3 Control of suction in laboratory tests	52
2.4 Conclusions	56
<b>3 Laboratory Techniques</b>	57
3.1 Introduction	57
3.2 Material selection and specimen preparation	58
3.3 Experimental techniques for volume change and strength measurements	64
3.4 Essential measurements	69
3.5 Further details of triaxial and stress path testing techniques	71
3.6 Conclusions	85
<b>4 Background to the Stresses, Strains, Strength, Volume Change and Modelling of Unsaturated Soil</b>	87
4.1 Introduction	87

4.2	Stresses in soils	88
4.3	Strains in soils	90
4.4	Constitutive modelling	92
4.5	Critical state framework for saturated soils	98
4.6	The constitutive Barcelona Basic Model for unsaturated soils	107
4.7	Extended constitutive and elasto-plastic critical state frameworks for unsaturated soils	112
4.8	Concluding remarks	123
5	Thermodynamics of Soil Systems	127
5.1	Introduction	127
5.2	Outline of thermodynamic principles and systems	128
5.3	Introduction to equilibrium and meta-stable equilibrium	129
5.4	Variables of state	130
5.5	Extensive and intensive variables	131
5.6	The laws of thermodynamics	131
5.7	Thermodynamic potentials	135
5.8	Thermodynamic potentials in practice	138
5.9	Conjugate thermodynamic pairings	142
5.10	Influence of a gravitational field	144
5.11	Concluding remarks	145
6	Equilibrium Analysis and Assumptions in Triaxial Testing	147
6.1	Introduction	147
6.2	The minimum principles for the potentials	147
6.3	Isotropic loading conditions	149
6.4	Anisotropic loading conditions	152
6.5	Work input and the thermodynamic potential	155
6.6	The thermodynamic potential and axis translation	156
6.7	The thermodynamic potential and an aggregated soil structure	157
6.8	Conclusions	158
7	Enthalpy and Equilibrium Stress Conditions in Unsaturated Soils	160
7.1	Introduction	160
7.2	Role of enthalpy	160
7.3	Enthalpy and Terzaghi's effective stress for saturated soils	162
7.4	Enthalpy of unsaturated soils	163
7.5	The significance of $\alpha$	167
7.6	Stress state in unsaturated soils	171
7.7	Alternative equilibrium analysis	172
7.8	Graphical representation of stress state in unsaturated soils	173
7.9	Stress state variables and conjugate volumetric variables	174
7.10	Hysteresis, collapse and discontinuities in soil behaviour	176
7.11	Conclusions	179
8	Shear Strength and Compression Characteristics of Unsaturated Soils	180
8.1	Introduction	180

8.2	Shear strength and critical state characteristics of unsaturated soils	181
8.3	Equivalent strength parameters	200
8.4	Compression and critical state characteristics of unsaturated kaolin	200
8.5	Modelling of unsaturated kaolin	206
8.6	Structure, variables and parameters	208
8.7	Conclusions	210
9	Work Input, Conjugate Variables and Load-Deformation Behaviour of Unsaturated Soils	213
9.1	Introduction	213
9.2	Work input under triaxial stress conditions	213
9.3	Components of the deviator stress	218
9.4	Work input to unsaturated soils	218
9.5	Analysis of the mobilised stress ratios	220
9.6	Continuity relationships between strain-increments	221
9.7	Stress state variables and conjugate volumetric and strain-increment variables	223
9.8	The meaning and interpretation of stresses and strains	224
9.9	Analysis of triaxial experimental data on kaolin	232
9.10	Conclusions	251
	<i>References</i>	254
	<i>Index</i>	273