Developments in Geotechnical Engineering 30

MECHANICS OF PARTICULATE MATERIALS

THE PRINCIPLES

by

JAROSLAV FEDA

Institute of Theoretical and Applied Mechanics
of the Czechoslovak Academy of Sciences, Prague

ELSEVIER SCIENTIFIC PUBLISHING COMPANY

Amsterdam • Oxford • New York • 1982

UNIVERSITA' D. STUDI DI TRENTO
BIBLIOTECA

CONTENTS

Preface 9

List of symbols 13

Chapter 1 **Introductory considerations** 19

1.1 Particulate materials 19
1.1.1 Definition 19
1.1.2 Particulate state of matter 23
1.1.3 General considerations concerning the structure of particulate materials 27
1.2 Phenomenological and structural approach to the mechanics of particulate materials 36
1.3 Characteristics of the principal trends in the mechanics of particulate materials 39
1.3.1 Phenomenological approach from the engineering standpoint 40
1.3.2 Phenomenological approach from the standpoint of continuum mechanics 42
1.3.3 Structural approach 45

Chapter 2 **Some descriptive properties of particulate materials** 48

2.1 Size, shape and composition of elementary particles 48
2.2 Methods of dispersion analysis 55
2.3 The grain-size curve 65
2.4 Unit weight and density 74
2.5 Water content and the degree of saturation 75
2.6 Size and distribution of pores 77
2.7 Surface activity of solid particles 79

Chapter 3 **Bonding between solid particles and the interaction of phases** 85

3.1 Solid phase bonds 85
3.2 Liquid and gaseous phase bonds 87
3.3 Bonds between solid particles 88
3.3.1 Long-range and short-range forces 88
3.3.2 Friction bonds 95
3.3.3 Brittle bonds 102
3.3.4 Ductile bonds 104
3.3.5 Conclusion 105
3.4 The principle of effective stresses 107

Chapter 4 **Structure of particulate materials and its models** 115

4.1 Rheological models 115
4.2 Real structure of particulate materials 118
4.2.1 Particulate materials with isometric particles 118
4.2.2 Particulate materials with elongated and platy particles 128
4.2.3 Particulate materials with particles of diverse shapes and sizes 140
4.2.4 Elementary and higher structural units 141
4.3 Structure of sets of spheres and its effect on the mechanical behaviour of such sets 143
4.3.1 Regular (deterministic) sets 144
4.3.2 Statistical sets 157
4.4 Models formed of platy particles 169
4.5 Differences in the behaviour of a real and a model particulate material . . . 172
4.6 Structural metastability 178

Chapter 5 **Measurements and examples of the mechanical behaviour of particulate materials**. 185

5.1 Oedometer 186
5.2 Shear box 193
5.3 Simple shear apparatus 208
5.4 Triaxial apparatus 213
5.5 Apparatuses to produce a general state of stress in the sample 226
5.6 Other instruments 237
5.7 Uniaxial and hydrostatic compression 239
5.7.1 The mechanism of compression 240
5.7.2 Uniaxial compression 250
5.7.3 Hydrostatic compression 253
5.8 Some experimental findings 256
5.8.1 Dilatancy 256
5.8.2 Inherent and induced anisotropy 257
5.8.3 Strength 262
5.8.3.1 Types of Mohr envelopes 266
5.8.3.2 Experimental verification of the criteria of failure 268
5.8.4 Coaxiality of the stress tensor, strain tensor and the strain increment tensor 274
5.8.5 Effect of the stress path 275
5.8.6 Effect of the stress level 277
5.8.7 Some other effects 278

Chapter 6 **Time-independent constitutive relations for particulate materials** 281

6.1 Introduction 281
6.2 Finite (pseudoelastic) equations 285
6.2.1 Isotropic materials 285
6.2.2 Anisotropic materials 288
6.2.3 Higher-order elasticity theory 291
6.3 Incremental (plastic) equations 293
6.3.1 Introduction 293
6.3.2 Energy conception 296
6.3.3 Application of the theory of dilatant behaviour 299
6.3.4 Axiomatic approach 300

6.3.5 Theory with anisotropic and kinematic hardening 307
6.3.6 Relations between the failure surface, the yield surface and the surface of plastic potential 311
6.3.6.1 $F \equiv Y \equiv P$ 312
6.3.6.2 $F \neq Y \equiv P$ 313
6.3.6.3 $F \equiv Y \neq P$ 314
6.3.6.4 $F \neq Y \neq P$ 314
6.3.6.5 The hybrid theories 315
6.3.6.6 Conclusion 316
6.4 Special stress-strain relations 318
6.5 Conclusion 319

Chapter 7 **Consolidation and creep of particulate materials** 323

7.1 Introduction 323
7.2 Creep 325
7.2.1 Creep stages 325
7.2.2 The Boltzmann-Volterra theory of hereditary creep 328
7.2.3 The engineering concept of creep 336
7.2.4 The rate process theory and the macrostructural theory 343
7.2.5 Long-term strength and viscosity of particulate materials 348
7.3 Consolidation of two-phase systems 353
7.3.1 Methods of solution 353
7.3.2 Review of rheological models used in the consolidation theory 358

Chapter 8 **Some aspects of the mechanical behaviour of particulate materials** 363

8.1 Shear strength of some particulate materials 363
8.1.1 Introduction 363
8.1.2 Granular food-stuff 363
8.1.3 Rockfill 367
8.1.4 Rocks 371
8.2 Crushing of grains 378
8.3 Loading with periodic unloading 384
8.4 Cemented particulate materials 387
8.5 Relation between descriptive and mechanical properties of particulate materials 395

Bibliography 399

Author index 433

Subject index 442