

Underground Excavations in Rock

E. Hoek

D.Sc (Eng)

Principal, Golder Associates,
224 West 8th Avenue, Vancouver V5Y 1N5, Canada

E.T. Brown

Ph.D

London University Professor of Rock Mechanics,
Imperial College of Science and Technology,
South Kensington, London SW7 2BP, England

The Institution of Mining and Metallurgy, London

1980



Contents

	Page
Chapter 1: Planning considerations	
Introduction	7
•Types of underground excavation	8
Underground excavation design	9
Bibliography on underground excavations	12
Chapter 1 references	13
Chapter 2: Classification of rock masses	
Introduction	14
•Terzaghi's rock load classification	14
•Classifications by Stini and Lauffer	18
•Deere's Rock Quality Designation (RQD)	18
Influence of clay seams and fault gouge	20
CSIR classification of jointed rock masses	22
NGI Tunnelling Quality Index	27
Discussion on rock mass classification systems	34
Chapter 2 references	36
Chapter 3: Geological data collection	
Introduction	38
Study of regional geology	38
Engineering geological maps and plans	40
Mapping surface outcrops	40
Geophysical exploration	43
Diamond drilling for sub-surface exploration	45
Index testing of core	52
Core logging and core photography	55
Core storage	55
Exploratory adits and shafts	57
Chapter 3 references	59
Chapter 4: Graphical presentation of geological data	
Introduction	61
Equal area and equal angle projections	61
Stereographic projection of a plane and its pole	63
Definition of geological terms	63
Construction of stereographic nets	65
Construction of a great circle to represent a plane	72
Determination of the line of intersection of two planes	73
Relationship between true and apparent dip	74
Plotting and analysis of field measurements	75
Computer processing of structural data	79
Sources of error in structural data collection	79
Isometric drawings of structural planes	79
Use of demonstration models in underground excavation design	84
Chapter 4 references	86
Chapter 5: <u>Stresses around underground excavations</u>	
Introduction	87
-Components of stress	87
-Two dimensional state of stress	90
-In situ state of stress <i>at home</i>	93
- Stress distributions around single excavations	101
- Stresses around a circular excavation	103
Calculation of stresses around other excavation shapes	108
Stresses around multiple excavations	112
Three-dimensional pillar stress problems	122

	Page
Stress shadows	124
Influence of inclination upon pillar stresses	125
Influence of gravity	125
Chapter 5 references	127
Chapter 6: Strength of rock and rock masses	
Introduction	131
Brittle and ductile behaviour	133
Laboratory testing of intact rock samples	134
An empirical failure criterion for rock	137
Survey of triaxial test data on intact rock specimens	140
Simplifying assumptions	150
Anisotropic rock strength	157
Strength of rock with multiple discontinuities	163
Strength of heavily jointed rock masses	166
Use of rock mass classifications for rock strength prediction	171
Deformability of rock masses	173
Approximate equations defining the strength of intact rock and heavily jointed rock masses	175
Chapter 6 references	178
Chapter 7: Underground excavation failure mechanisms	
Introduction	183
Structurally controlled instability	183
Computer analysis of structurally controlled instability	191
Optimum orientation and shape of excavations in jointed rock	194
Influence of excavation size upon structurally controlled instability	197
Influence of in situ stress on structurally controlled instability	199
Pillar failure	200
Fracture propagation in rock surrounding a circular tunnel	211
Sidewall failure in square tunnels	217
Influence of excavation shape and in situ stress ratio	221
An example of excavation shape optimisation	223
Excavation shape changes to improve stability	230
Influence of a fault on excavation stability	232
Buckling of slabs parallel to excavation boundaries	234
Excavations in horizontally bedded rock	235
Stiffness, energy and stability	236
Chapter 7 references	241
Chapter 8: <u>Underground excavation support design</u>	
Introduction	244
Support of wedges or blocks which are free to fall	246
Support of wedges or blocks which are free to slide	247
Rock-support interaction analysis	248
Summary of rock-support interaction equations	258
Examples of rock-support interaction analysis	270
Discussion on rock-support interaction analysis	285
Use of rock mass classifications for estimating support	286
Comparison of underground excavation support predictions	298
Pre-reinforcement of rock masses	312
Suggestions for estimating support requirements	319
Additional reading	321
Chapter 8 references	325

	Page
Chapter 9: Rockbolts, shotcrete and mesh	
Introduction	329
Organization of a rockbolting programme	329
Review of typical rockbolt systems	332
Rockbolt installation	342
Wire mesh	351
Shotcrete	353
Mix design	355
Engineering properties of shotcrete	360
Placement of shotcrete	360
Fibre reinforced shotcrete	363
Chapter 9 references	365
Chapter 10: Blasting in underground excavations	
Introduction	367
Basic mechanics of explosive rock breaking	367
Creation of a free face	368
Rock damage	370
Smooth blasting and presplitting	372
Design of blasting patterns	377
Damage to adjacent underground excavations	378
Conclusions	380
Chapter 10 references	381
Chapter 11: Instrumentation	
Introduction	382
Objectives of underground instrumentation	382
Common inadequacies in instrumentation programmes	382
Instrumentation for the collection of design data	384
Monitoring of underground excavations during construction	389
Monitoring of underground excavations after construction	393
Monitoring of trial excavations	393
Conclusion	394
Chapter 11 references	395
Appendix 1: Bibliography on large underground excavations	397
Appendix 2: Isometric drawing charts	449
Appendix 3: Stresses around single openings	467
Appendix 4: Two-dimensional boundary element stress analysis	493
Appendix 5: Determination of material constants	513
Appendix 6: Underground wedge analysis	517
Appendix 7: Conversion factors	523
Index	525