

The shear strength of rock joints with special reference to dam foundations

by

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ABSTRACT

Introduction

The stability along joint planes is one of the most important characteristics of a rock mass forming the foundation of a concrete dam. The shear strength of discontinuities within the foundation rock is probably the most important characteristic.

Objectives and Purpose of the study

The objectives of this research project were to determine and to analyse the shear strength of joints in a number of rock types, sampled at different locations, and to link these strengths to the condition in the foundations of dams and, in particular, the condition of the surfaces of the rock joints. The information so obtained can then serve as a databank for the design of new dams and for the evaluation of the safety of existing dams.

Stages of investigation

The study was carried out in four identifiable phases. The first phase that took place during 1992 and 1993 was a literature study in order to determine the shear strength characteristics of different rock types world-wide and in southern Africa. The literature study was updated during 2002/3. During this stage a visit was undertaken to the UK, Norway and the USA to study shear apparatus and the rock testing methods in these countries. The second phase was to determine the shear strength characteristics of important southern African rock types. During the period 1993 to 1995 the shear apparatus and surface-scanning device to be used in the third stage were designed and constructed. The third phase (1994 to 1999) comprised of direct shear tests on NX-size borehole core samples and the testing and characterisation of large shear surfaces. The last phase (1999 to 2003) consisted of updating the literature survey and compilation of the thesis.

Several delays were encountered mainly due to the following reasons: (a) the late delivery of the large shearbox and subsequent problems with the computer controlling the shearbox, (b) resignation of the technician working full-time on the project and (c) illness of the researcher during 1996.

It was impossible to determine the true peak and residual shear strength due to practical limitations. As discussed in chapter four the peak values are therefore approximated by

determining the “maximum post-peak” strength, whilst residual values were approximated by “minimum post-peak” values.

Format of the thesis

The text of the thesis starts by stating the problems to be investigated, followed by Chapter two containing the findings of a literature study. Chapter three describes the experimental stage of the study: the methods used and a description of the equipment. Chapter four contains the presentation and discussion of the results. This is followed by Chapter five showing a classification of shear strength using a geotechnical characterization of the joint surface followed by Chapters six and seven with the conclusions, recommendations and references. The Compact Disc (CD) contains the appendices (reports, graphs and photo's) in electronic format.

Results

A literature study on the test methods and shear strength characteristics of different rock types was conducted. It was found that although shear strength characteristics of rock material have been investigated on a regular basis for civil and other engineering applications, this information is not readily available to the engineering community at large for safety use in dams. It is often regarded as confidential information by clients and filed for possible use against claims. This document is probably the most comprehensive source of shear strength characteristics of southern African rock types available today.

This report describes the shear strength characteristics of quartzite, shale, sandstone, dolerite, mudstone, granite, rhyolite and tillite. Chapter four describes each of these rock types in detail. These rock types were selected because they cover a very large portion of the surface area of southern Africa, and as such, many dams and other civil engineering structures have been built on them.

Emphasis was placed on the shear strength parameters of joints, especially the angle of friction. Two types of joints are recognised in nature: (a) joints with no or little fill material where the shear strength is determined by the characteristics of the rock material and (b) joints with fill material where the shear strength is determined by the characteristics of the fill material. The major part of this research concentrated on joints with no or little fill material listed under (a).

The three major characteristics determining the shear strength parameters of this type of joint are (i) the base shear strength of the rock material, (ii) the roughness profile along the joint surface and (iii) the hardness of the material on the joint surface.

The basic shear strength parameters of the different rock materials were determined as part of the determination of rock material characteristics. The basic angle of friction obtained for the different materials corresponds very well to those published in the literature. The values for cohesion obtained through testing is zero to very small.

As part of this research project, a laser-scanning device was developed. This device measure the x, y and z co-ordinates on a rock joint surface on a grid pattern. This information can be analyzed with software on a computer to produce a contour diagram of the joint surface area. From this contour diagram, joint roughness profiles were obtained. These, as well as profiles obtained with a carpenter's comb, were compared visually, with an overlay, to typical roughness profiles as published by Barton (1977).

The relationship between joint roughness coefficient (JRC) and shear displacement was investigated during this study. The influence of high normal stresses were not taken into consideration as testing was limited to normal stresses with a maximum of 1 MPa. An exponential regression was fitted to the points plotted. After a cumulative shear displacement of more than 2,0 meter will be required to smooth the joint surface as a result of friction. It was found that after a shear displacement of 2,0 meters the friction angle was equal to the residual friction angle.

Conclusions

This study provides a guide to shear strength characteristics of several important rock types in southern Africa for planning and preliminary design of dams. It is probably the most comprehensive document describing the rock material, the testing procedure, and the shear strength characteristics of so many rock types in southern Africa.

This research project was the first attempt to determine the shear strength characteristics of joints in southern African rock types with a large shear apparatus.

This study also contributes to the knowledge on shear strength of southern African rocks, in particular on (i) the sampling and preparation of specimens for testing in the large shear apparatus, (ii) the measurement of the roughness of the joint surfaces and (iii) the testing procedure and (iv) interpretation and application of friction angle as design parameter in the analysis of stability of dam foundations. The shear strength characteristics of the rock joints of southern African rocks are described joints were classified using a geotechnical description of the joint surface. Geotechnical parameters include rock type, roughness, hardness, and a description of fill joint material was used in the classification. This classification is a first attempt to use these parameters and further work still needs to be done in this regard.

Further research

It is recommended that a project be initiated to investigate the shear strength of southern African rock types in further detail. Such an investigation can build on the knowledge obtained in this investigation. It is important to keep the variables such as rock type, weathering, and hardness to a minimum to investigate influence of joint roughness. An appropriate rock type to start with could be mudstone from the Qeduzisi Dam area near Ladysmith. This is a relative soft rock with smooth joints that gave low shear strength results during testing. These results of this study could be confirmed. The investigation could then be extended to other rock types once the influence of roughness has been established.

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CONTENTS

1. Introduction and motivation
 - 1.1 Objectives of the study
 - 1.2 Motivation
 - 1.3 The history of the study conducted
 - 1.4 Outline of the thesis

2. The shear strength of joints in rock
 - 2.1 Introduction
 - 2.2 Discontinuities in rock
 - 2.3 Principals of shear
 - 2.4 Shear strength of planar joint surfaces in rock
 - 2.5 Shear strength of rough surfaces in rock
 - 2.6 Determination of joint wall hardness
 - 2.7 Joint matching
 - 2.8 Infilling of joints
 - 2.9 Shear strength equations

3. The experimental stage of the study
 - 3.1 Rock types tested
 - 3.2 Apparatus used in testing
 - 3.2.1 Shear boxes
 - 3.2.2 Laser apparatus
 - 3.3 Tests methods
 - 3.3.1 Testing basic friction angles with small shear box
 - 3.3.2 Testing shear strength with the large shear box
 - 3.3.2.1 Phase 1 testing
 - 3.3.2.2 Phase 2 testing
 - 3.3.2.3 Shear strength of joints in Granite - Phase 3

4. Results of the investigation

4.1 Basic friction angle

4.2 Shear strength of rock types tested

4.3 Maximum post-peak shear strength – Phase 1

4.3.1 Basalt

4.3.2 Dolerite

4.3.3 Granite

4.3.4 Sandstone

4.3.5 Mudstone

4.4 Minimum post-peak shear strength - Phase 2

4.4.1 Basalt

4.4.2 Dolerite

4.4.3 Granite

4.4.4 Sandstone

4.4.5 Mudstone

4.5 Shear strength of joints in Granite - Phase 3

4.5.1 Granite 1C

4.5.2 Granite 2C

4.5.3 Granite 3C

4.6 Discussion of test results

4.6.1 Discussion of test results of Phase 1 and 2

4.6.2 Discussion of test results of Phase 3

4.7 Relationships investigated

4.7.1 The relationship between shear displacement and joint roughness

4.7.2 The relationship between friction angle and joint roughness

4.7.3 Field estimate of shear strength of joint surfaces in rock

4.7.4 The influence of true cohesion, rock bridging and waviness on shear strength.

4.8 Further research and conclusion.



5. Classification of shear strength of joints in rock

5.1 Introduction

5.2 Classification of joints according to this study

5.2.1 Classification of joint wall compressive strength

5.2.2 Classification of roughness profiles

5.3 Shear strength classification based on roughness and hardness of joint surfaces

5.3.1 Joints in hard rock filled with clayey material of more than 2mm thickness

5.3.2 Joints in hard to very hard rock with stained surfaces

5.3.3 Smooth, planar bedding joints with unweathered surfaces in moderately hard rock.

5.3.4 Rough planar tectonic unweathered joint surfaces in hard rock

5.3.5 Rough irregular tectonic joints in unweathered hard rock

5.4 Proposed classification of joints according to roughness and hardness

5.5 Application in shear strength in the design of concrete dam foundations

6. Conclusions and recommendations

7. References

Appendices

LIST OF FIGURES

		Page
Figure 2.1	A slab of rock resting on another rock separated by a natural joint tilted at an angle θ with the horizontal. (After Cutnell and Johnson, 2000)	..... 2.5
Figure 2.2	A free body diagram for a slab of rock when it is on the verge of sliding. (After Cutnell and Johnson, 2000)	..... 2.6
Figure 2.3	Continuous rupturing and reforming surfaces of contact areas as surfaces move across each other. (After Cutnell and Johnson, 2000)	..... 2.7
Figure 2.4	Schematic representation of displacement and stresses on joint planes.	..... 2.8
Figure 2.5	Shear stress vs. displacement, illustrating peak and residual strength.	..... 2.9
Figure 2.6	Graph of shear stress vs. normal stress illustrating angle of friction and cohesion.	..... 2.10
Figure 2.7	Saw-tooth asperity roughness by Patton	..... 2.11
Figure 2.8	Shear strength envelope by Patton	..... 2.12
Figure 2.9	Typical roughness profiles (After Barton and Choubey, 1977)	..... 2.14
Figure 2.10(a)	Geometrical scale effects in joint roughness.(After Rengers, 1970)	..... 2.15
Figure 2.10(b)	Inclination (i) vs. measured distance (D) (After Rengers, 1970)	..... 2.15
Figure 2.11	The relationship between Schmidt hardness and the uniaxial compressive strength of rock (After Deere and Miller 1966 as reported by Barton and Choubey, 1977)	..... 2.20
Figure 3.1	Location where samples of rock material with joints were taken	..... 3.1
Figure 3.2	The modified soil shear box for shear testing of NX-size rock core samples	..... 3.4

Figure 3.3	The large shear testing machine	.....	3.5
Figure 3.4	Schematic sketch of large shear testing machine (side view)	.....	3.5
Figure 3.5	Schematic sketch of large shear testing machine (front view)	.....	3.6
Figure 3.6	Bottom half of shear box assembly with test specimen	.....	3.8
Figure 3.7	The laser scanning device	.....	3.10
Figure 3.8	Carpenter's comb on rough joint surface	.....	3.13
Figure 3.9	Rock sample with associated joint surface tied, up with wire ready to be cast	.....	3.14
Figure 4.1	Shear load vs. shear displacement – showing where readings were taken	.....	4.3
Figure 4.2	Horizontal displacement vs. vertical displacement showing dip angle	.....	4.3
Figure 4.3	Shear stress vs. normal stress -Phase 1 of shearing for Basalt 2 and 3	.....	4.5
Figure 4.4	Shear stress vs. normal stress -Phase 1 of shearing (dry) of Dolerite 1	.....	4.6
Figure 4.5	Shear stress vs. normal stress - Phase 1 of shearing (dry) Granite	.....	4.7
Figure 4.6	Shear stress vs. normal stress - Phase 1 of shearing (dry) Sandstone	.....	4.8
Figure 4.7	Shear stress vs. normal stress-phase 1 of shearing (dry) Mudstone	.....	4.9
Figure 4.8	Shear stress vs. normal stress-Phases 2A and 2B of shearing Basalt 1, 2 and 3	.....	4.10
Figure 4.9	Shear stress vs. normal stress -Phases 2A and 2B of shearing (dry and submerged) of Dolerite 1 & 3	.....	4.12
Figure 4.10	Shear stress vs. normal stress -Phases 2A and 2B of shearing (dry and submerged) Granite	.....	4.14
Figure 4.11	Shear stress vs. normal stress -Phases 2A and 2B of shearing (dry and submerged) Sandstone	.....	4.15

Figure 4.12	Shear stress vs. normal stress -Phases 2A and 2B of shearing (dry and submerged) Mudstone	.....	4.17
Figure 4.13	Shear stress vs. normal stress for Granite 1C	.....	4.19
Figure 4.14	Shear stress vs. normal stress for Granite 2C	.....	4.20
Figure 4.15	Shear stress vs. normal stress for Granite 3C	.....	4.22
Figure 4.16	The theoretical relationship between joint roughness coefficient and shear displacement	.....	4.30
Figure 4.17	Relationship between JRC and cumulative shear displacement	.....	4.31
Figure 4.18	Graph of JRC vs. friction angle	.....	4.32
Figure 4.19	Chart for the estimation of portion of peak friction angle (i) due to surface characteristics, for $\sigma_n = 1$ MPa	.....	4.34

LIST OF TABLES

	Pg	
Table 2. 1	Parameters controlling the shear strength of infilled discontinuities (After De Toledo et al, 1993)	2.2
Table 2. 2	Descriptive classification of Rock Joints (After Barton and Choubey, 1977)	2.1
Table 2.3	Basic friction angles of various unweathered rocks (After Barton and Choubey, 1977)	2.22
Table 3. 1	Selected rock types (large rock samples) tested with the large shear box	3.1
Table 3.2	Granite specimens tested during the third phase of the investigation	3.18
Table 4.1	Basic friction angles and cohesion of various unweathered rocks obtained from flat surfaces of important Southern African rock types.	4.1
Table 4.2	Specimens tested during the first and second phases of testing	4.2
Table 4.3	Shear strength parameters of basalt as determined during test Phase 1	4.5
Table 4.4	Friction angle and apparent cohesion for Dolerite 1	4.6
Table 4.5	Shear strength parameters of Granite as determined during Phase 1	4.7
Table 4.6	Shear strength parameters of sandstone as determined during Phase 1	4.8
Table 4.7	Shear strength parameters of mudstone as determined during phase 1	4.9
Table 4.8	Shear strength parameters of Basalt as determined during test Phases 2A and 2B	4.11
Table 4.9	Friction angles and apparent cohesion for Dolerite	4.12
Table 4.10	Shear strength parameters of Granite as determined during Phases 2A and 2B	4.14
Table 4.11	Shear strength parameters of Sandstone as determined during phase 1	4.16

Table 4.12	Shear strength parameters of Mudstone	.....	4.17
Table 4.13	Results of shear testing on Granite 1C	.....	4.19
Table 4.14	Results of shear testing on Granite 2C	.....	4.21
Table 4.15	Shear stress vs. normal stress for Granite 3C	.....	4.22
Table 4.16	Friction angles for rock types as calculated with the Barton and Choubey (1977) empirical equation for shear strength at normal stress $\sigma_n = 1000$ kPa	.....	4.24
Table 4.17	Difference between the calculated peak and tested residual friction angles for rock types tested during Phase 2. (Calculated peak friction angle = 100 %)	.....	4.25
Table 4.18	Difference between dry and saturated friction angles	.....	4.26
Table 4.19	Friction angles for Granite as calculated with the Barton and Choubey (1977) empirical equation for shear strength at normal stress $\sigma_n = 100$ kPa	.....	4.27
Table 4.20	Difference between the calculated peak and residual friction angles for Granite tested during Phase 3 (Percentages calculated in relation to calculated peak)	.....	4.28
Table 4.21	Difference between dry and saturated friction angles of Granite samples tested	.....	4.29
Table 4.22	Estimation of <i>i</i> value contribution to angle of friction	.....	4.33
Table 5.1	Classification of intact rock strength (Deere and Miller, 1966)	.....	5.3
Table 5.2	Friction angle of clay filled joints in hard rock (Dolerite)	.....	5.4
Table 5.3	Friction angles of joints in hard rock to very hard rock with stained joint surfaces (Granite 2C)	.....	5.6
Table 5.4	Friction angle of smooth, planar bedding joints with unweathered surfaces in moderately hard rock (Mudstone)	.....	5.7
Table 5.5	Friction angle of rough planar, tectonic, unweathered surfaces in hard rock (Granite 1C)	.....	5.8
Table 5.6	Friction angle of rough, irregular, tectonic joints in		



	unweathered hard rock (Basalt)	.....	5.9
Table 5.7	Friction angles of rough, irregular, tectonic joints in unweathered hard rock (Dolerite)	.....	5.10
Table 5.8	Classification of joints according to roughness and hardness of joint surfaces.	.....	5.11



LIST OF SYMBOLS AND ACRONYMS

- A = cross-sectional area (m^2)
c = cohesion (kPa, MPa)
d = diameter (m)
 E_t = Tangent modulus (GPa)
 E_{av} = Average modulus (GPa)
 E_{sec} = Secant Modulus (GPa)
g = acceleration due to gravity ($9,81 \text{ ms}^{-2}$)
l = length (m)
m = meter (m)
N = Newton
 ν = Poisson's ratio
 ρ = density (kg/m^3)
 γ = unit weight (kN/m^3)
 σ = normal stress (MPa)
 τ = shear stress (MPa)
 ϕ = friction angle (degrees)
 ϕ_b = basic friction angle (degrees)
 ϕ_r = residual friction angle (degrees)
- ISRM = International Society for Rock Mechanics
JCS = Joint wall compressive strength (MPa)
JRC = Joint roughness coefficient
PLSI = Point load strength index
SHI = Shear strength index
UCS = Uniaxial compressive strength (MPa)
XRD = X-ray diffraction