EXECUTIVE SUMMARY

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:

(a) 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 of the foundations 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, and

(b) to determine the characteristics of a number of southern African rock types to serve as preliminary design parameters to allow safer and more economical designs for the foundations of concrete dam walls.

Stages of investigation

The study was carried out in four identifiable phases. The first phase that took place during 1992 and 1993 was to do a literature study in order to determine the engineering characteristics of different rock types world-wide and in southern Africa. 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 general 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 shear tests on NX-size borehole core samples (base shear and direct shear) and the testing and characterisation of large shear surfaces. The last phase (1999 to 2000) was used to compile the report.

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.

Format of the report

The text of the report start by stating the problems to be investigated followed in Chapter two by the findings of a literature study. Chapter three describes the determination of the engineering characteristics: methods and equipment, and Chapter four the presentation and discussion of results. This is followed in Chapter five by a description of the estimation of shear strength using a geotechnical characterization of the joint surface followed in Chapters six, seven and eight by conclusions, recommendations and references.

The Compact Disc (CD) contains the appendixes in electronic form as reports, graphs and photo's.

Results

A comprehensive literature study on test methods and engineering characteristics of different rock types was conducted. It was found that although engineering 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. It is often regarded as confidential information by clients and filed for possible use in claims situations. This document is probably the most comprehensive source of engineering characteristics of southern African rock types available today.

This report describes the strength, deformation and general characteristics of quartzite, shale, sandstone, dolerite, mudstone, granite, rhyolite and tillite. Chapter 4 describes each of these rock types in detail. The results are too comprehensive to describe here. 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 (a) joints with no or little fill material.

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 base shear strength parameters of the different rock materials were determined as part of the determination of rock material characteristics. The 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 and built in association with the Department of Civil Engineering of the University of Natal. This device measure 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 with typical roughness profiles as published by Barton.

Because of the importance of joint roughness in connection with the shear strength of joints, a further attempt was made to obtain a method of quantifying this phenomenon. The volume of material (asperities) above the lowest point on a joint surface was determined for each specimen tested with the large shear apparatus. The volume was then divided by the surface area of the specimen to obtain a value called the volume-area ratio. This was then correlated to the shear strength (in particular to the angle of friction) of a joint plane. Although no good correlation could be found, it is believed that this ratio could be a method of expressing joint roughness. Further investigation will be needed to verify this.

Conclusions

This study provides a useful guide to engineering parameters of several important rock types in southern Africa for planning and preliminary design purposes. It is probably the most comprehensive document describing the rock material, the testing procedure, and the engineering 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. The shear strength characteristics of the rock joints of southern African rocks are described and an attempt was made to classify joints using a geotechnical description of the joint surface. Geotechnical parameters include rock type, roughness, hardness, and description of fill joint material. The joint fill material could be a clay or secondary mineral like smectite, it could be staining or it could be clean. This classification is a first attempt and further work still needs to be done in this regard.

Recommendations

It is recommended that a project be initiated to investigate the shear strength of southern African rock types in further detail in a systematic manner. 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 be kept 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 should be confirmed. This could then be extended to other rock types once the influence of roughness has been established.

Acknowledgement

The author whishes to express his gratitude to the Water Research Commission for funding this project and hope that the report will contribute to dams and other civil engineering structures be built more cost effectively and safely.

It could be noted that this project was the first project at a Technikon to be funded by the Water Research Commission. As such it contributed to the building of capacity at the Department of Civil Engineering at Technikon Pretoria: Two technicians had the opportunity to gain experience in testing rock specimen on the newly built shear apparatus belonging to the Department of Water Affairs and Forestry. Staff of the above-mentioned department were trained on the use and procedures of the machine. The researcher had the opportunity to gain experience and knowledge on many aspects of rock mechanics with the emphases on shear strength. This abundant source of information established during the project will lead to publication in of articles in scientific and engineering journals.

LIST OF CONTENTS.

page

Acknowledgements ii

Executive Summary iv

List of Contents viii

List of Tables xiii

List of Figures xviii

List of Symbols/Acronyms xxi

Definition of terms xxii

List of Appendices xxiv

1. Introduction

1.1 Motivation and objectives. 1.1

1.2 Engineering characteristics investigated during this study. 1.2

1.2.1 Engineering characteristics of rock materials. 1.2

1.2.2 Shear properties of joints in rock. 1.3

1.3 The history of the study conducted. 1.3

1.4 Outline of the report. 1.5

2. Review of the related literature

2.1 Introduction 2.1

2.2 Literature study on testing procedures for engineering characteristics of rock material. 2.1

2.3 Shear strength of discontinuities in rock. 2.2

2.3.1 Types of discontinuities in rock. 2.2

2.3.2 Factors influencing the shear strength of rock joints 2.5

2.4 Review of equipment for direct shear testing of large specimens (testing machines). 2.9

2.4.1 Norwegian Geotechnical Institute's apparatus. 2.9

2.4.2 US Bureau of Reclamation's apparatus. 2.9

2.4.3 US Army Corps of Engineer's apparatus. 2.10

2.4.4 Imperial College's apparatus. 2.10

2.5 Review of shear strength assessment method by Barton and others 2.11
2.5.1 Introduction 2.11
2.5.2 Measurement of the hardness of joint surfaces. 2.13
2.5.3 Review of measurement of the roughness of joint surfaces. 2.16
(a) Joint Roughness Coefficient (JRC). 2.16
(b) Physical roughness measurement by Pegram and Pennington. 2.19
2.5.4 Scale effects 2.19
2.5.5 The empirical equation of shear strength 2.20

2.6 Literature study on the engineering characteristics of southern African rocks
2.6.1 Strength properties of rock material 2.22
(a) Uniaxial compressive strength (UCS)
(i) Uniaxial compressive strength 2.22
(ii) Point load strength index (PLSI) 2.23
(b) Triaxial compressive strength 2.23
(c) Tensile strength 2.24
(i) Direct tensile strength 2.24
(ii) Indirect tensile strength (Brazilian method) 2.24
(d) Shear strength. 2.25
(i) Base shear strength 2.25
(ii) Shear strength of joints (Peak and Residual) 2.25
(iii) Punch shear strength (Intact shear strength) 2.26

2.6.2 Deformation properties of rock material
(a) E-modulus (Young's modulus) 2.26
(b) Poisson's ratio 2.27
2.6.3 Other general rock properties 2.28
(a) Hardness (Schmidt hammer) 2.28
(b) Abrasiveness 2.28
(c) Seismic wave velocity 2.29

(d) Water absorption 2.29
(e) Porosity 2.29
(f) Density 2.30
(g) Swelling (Free swell) 2.30
(h) Slake durability 2.31
2.6.4 Petrographic description of rocks. 2.31

3. Determination of engineering characteristics during this study: methods and equipment

3.1 Introduction 3.1
3.2 Strength properties of rock materials
3.2.1 Uniaxial compressive strength 3.1
3.2.2 Triaxial compressive strength 3.2
3.2.3 Tensile strength 3.3
3.2.4 Shear strength 3.4
3.2.4.1 The small shear box 3.4
3.2.4.2 Large shear box of the Department of Water Affairs and Forestry 3.5
3.2.4.3 Laser scanning device to measure joint roughness 3.12
3.2.4.4 Alternative method of determining joint roughness 3.15
3.2.5 Punch shear strength. 3.16
3.3 Deformation properties of rock materials 3.16
3.4 Other engineering rock properties 3.16

4. Presentation and discussion of results

4.1 Rock types investigated 4.1
4.2 Presentation of results 4.3
4.3 Discussion of rock material characteristics 4.4
4.3.1 Quartzite of the Cape Supergroup 4.4
4.3.2 Shale of the Cape Supergroup 4.9
4.3.3 Sandstone of the Cape Supergroup 4.11
4.3.4 Dolerite: post-Karoo 4.13
4.3.5 Mudstone of the Karoo Supergroup 4.18
4.3.6 Shale of the Ventersdorp Supergroup 4.22

4.3.7 Sandstone of the Ventersdorp Supergroup 4.20
4.3.8 Granite of the Basement Complex 4.22
4.3.9 Sandstone of the Karoo Supergroup 4.26
4.3.10 Siltstone of the Karoo Supergroup 4.28
4.3.11 Rhyolite of the Karoo Supergroup 4.30
4.3.12 Tillite of the Karoo Supergroup 4.31

4.4 Correlation of some rock properties 4.32
4.4.1 The relation of uniaxial compressive strength and point load strength 4.32
4.4.2 The relation between Schmidt hammer hardness and uniaxial compressive strength 4.33
4.4.3 The relation between punch shear strength and uniaxial compressive strength 4.34
4.4.4 The relation between modulus of elasticity and uniaxial compressive strength 4.35
4.4.5 The relation between punch shear strength and Brazilian tensile strength. 4.35
4.4.6 The relation between density and seismic wave velocity 4.36
4.4.7 The relation between punch shear strength and cohesion of triaxial testing 4.37
4.4.8 Conclusion 4.37

4.5 Results of shear testing on large shear apparatus 4.38
4.5.1 Phases of testing and testing procedure 4.38
4.5.2 Data analysis 4.39
4.5.3 Rock types tested 4.40
4.5.2.1 Basalt 4.41
4.5.2.2 Dolerite 4.43
4.5.2.3 Granite 4.45
4.5.2.4 Sandstone 4.51
4.5.2.5 Mudstone 4.53

4.7 Determination of hardness and roughness of joint surfaces tested in the large shear apparatus 4.55
4.7.1 Hardness of joint surfaces 4.55
4.7.2 Determination of roughness of joint surfaces 4.56
4.7.3 Correlation of joint roughness, hardness and shear strength 4.59
4.8 Discussion of testing and results of Phase 2 4.61
4.9 Discussion of testing and results of Phase 3 4.65

5. Estimation of shear strength using a geotechnical characterisation of the joint surface
5.1 Introduction 5.1
5.2 Joint surface parameters 5.1
5.3 The theory of shear strength of joints in rock. 5.2
5.4 Classification of joint surfaces for the determination of shear strength 5.3
5.4.1 Joint surfaces in hard rock. 5.3
5.4.2 Joints with staining on hard and rough joints. 5.4
5.4.3 Joints in rock with fill material present 5.5
5.5 Application of shear strength in the design of concrete dam foundations 5.6
5.6 Guidelines for the use of information contained in this report 5.6

6. Conclusions 6.1

7. Recommendations 7.1

8. References 8.1

9. Appendixes **see: Compact Disc**

LIST OF TABLES

Table 2.1 Parameters controlling the shear strength of infilled discontinuities (After De Toledo et al, 1993)

Table 2.2 Basic friction angles of various unweathered rocks. (After Barton and Choubey, 1977)

Table 2.3. Descriptive classification of Rock Joints (After Barton and Choubey, 1977)

Table 2.4 Roughness descriptors by Pegram and Pennington (1996)

Table 2.5 Rock types described in the literature.

Table 2.6 Uniaxial compressive strengths of selected southern African rock types.

Table 2.7 Point load strength index of selected southern African rock types.

Table 2.8 Triaxial compressive strengths of selected southern African rock types.

Table 2.9 Direct tensile strength of selected southern African rock types.

Table 2.10 Indirect tensile strength of selected southern African rock types.

Table 2.11 Basic shear strength of selected southern African rock types.

Table 2.12 Punch shear strength of selected southern African rock types.

Table 2.13 E-moduli of selected southern African rock types.

Table 2.14 Poisson's ratios of selected southern African rock types.

Table 2.15 Schmidt hammer hardnesses of selected southern African rocks.

Table 2.16 Abrasiveness of selected southern African rocks.

Table 2.17 Seismic wave velocities of selected southern African rocks.

Table 2.18 Water absorption capacities of selected southern African rocks.

Table 2.19 Porosity of selected southern African rocks.

Table 2.20 Densities of selected southern African rocks.

Table 2.21 Swelling properties of selected southern African rocks.

Table 2.22 Slake durability properties of selected southern African rocks.

Table 4.1 Selected southern African rock types tested for engineering characteristics.

Table 4.2 Selected rock types (large block samples) tested with the large shear box.

Table 4.3 Characteristics of selected specimens of Quartzite (1A) of the Cape Supergroup.

Table 4.4 Characteristics of selected specimens of Quartzite (1B) of the Cape Supergroup.

Table 4.5 Characteristics of selected specimens of Quartzite (8A) of the Cape Supergroup.

Table 4.6 Characteristics of selected specimens of Quartzite (8B) of the Cape Supergroup.

Table 4.7 Characteristics of selected specimens of Shale (2A) of the Cape Supergroup.

Table 4.8 Characteristics of selected specimens of Sandstone (2B) of the Cape Supergroup.

Table 4.9 Characteristics of selected specimens of fine grained Dolerite (3A)

Table 4.10 Characteristics of selected specimens of coarse grained Dolerite (3B)

Table 4.11 Characteristics of selected specimens of coarse grained Dolerite (5D)

Table 4.12 Friction angle of selected specimen of post Karoo Dolerite (similar to Dolerite 3A).

Table 4.13 Characteristics of selected specimen of Mudstone (3C) of the Cape Supergroup.

Table 4.14 Friction angle of selected test specimens of Mudstone of the Karoo Supergroup (similar to Mudstone 3C).

Table 4.15 Characteristics of selected specimen of Shale (4A) of the Ventersdorp Supergroup

Table 4.16 Characteristics of selected specimen of Sandstone (4B) of the Ventersdorp Supergroup.

Table 4.17 Characteristics of selected specimen of Granite (5A) of the Basement Complex.

Table 4.18 Friction angles of selected specimens of Granite of the Basement Complex (similar to Granite 5A).

Table 4.19 Characteristics of selected specimen of Sandstone (5B) of the Karoo Supergroup.

Table 4.20 Characteristics of selected specimen of Siltstone (5C) of the Karoo Supergroup.

Table 4.21 Characteristics of selected specimen of Rhyolite (6A) of the Karoo Supergroup.

Table 4.22 Characteristics of selected specimen of Tillite (7A) of the Karoo Supergroup.

Table 4.23 Specimens tested during the first and second phases of testing.

Table 4.24 Granite specimens tested during the third phase of the investigation.

Table 4.25 Shear strength parameters of basalt as determined during test Phases 2A and 2B.

Table 4.26 Friction angles and apparent cohesion for Dolerite as determined by this study.

Table 4.27 Shear strength parameters of Granite as determined during phases 2A and 2B.

Table 4.28 Results of shear testing on Granite 1C.

Table 4.29 Results of shear testing on Granite 2C.

Table 4.30 Results of shear testing on Granite 3C.

Table 4.31 Shear strength parameters of Sandstone as determined by this study.

Table 4.32 Shear strength parameters of Mudstone as determined by this study.

Table 4.33 Hardness of joint surfaces determined by Schmidt hammer and expresses in terms of uniaxial compressive strength.

Table 4.34 Measured joint roughness coefficient (JRC) for large samples tested.

Table 4.35 Calculated roughness index for large samples tested during Phase 2.

Table 4.36 Shear strength parameters for samples tested in the large shear apparatus during Phases 2.

Table 4.37 Friction angle for rock types as calculated with the Barton and Choubey (1977) empirical equation for shear strength at normal stress equal to 1000kPa.

Table 4.38 Difference between the calculated and tested residual friction angles for rock types tested during Phase 2.

Table 4.39 Difference between dry and saturated friction angles.

Table 4.40 Friction angles for granite as calculated with the Barton and Choubey (1977) empirical equation for shear strength at normal stress equal to 1000kPa.

Table 4.41 Difference between the calculated and tested residual friction angles for rock types tested during Phase 3.

Table 4.42 Difference between dry and saturated friction angles of granite specimens tested.

Table 5.1 Friction angle characteristics of Granite 1C.

Table 5.2 Friction angle characteristics of Granite 2C.

Table 5.3 Comparison of basic, calculated peak, measured maximum residual and measured saturated maximum friction angles of some rock types tested.

LIST OF FIGURES

Figure 2.1 Shear stress vs. normal stress illustrating peak and residual shear strength.

Figure 2.2 Shear stress vs. normal stress illustrating friction angle and apparent cohesion.

Figure 2.3 The relationship between Schmidt hardness and the uniaxial compressive strength of rock. (After Miller 1965 as reported by Barton and Choubey, 1977)

Figure 2.4 Typical roughness profiles (After Barton and Choubey, 1977)

Figure 3.1 Farnell test press used for testing of rock specimens.

Figure 3.2 Point load test apparatus.

Figure 3.3 The triaxial cell or Hoek cell used to determine the triaxial strength of intact rock specimens.

Figure 3.4 Brazilian tensile test apparatus.

Figure 3.5 The modified soil shearbox for shear testing of NX-size rock core samples.

Figure 3.6 The large shear testing machine.

Figure 3.7 Schematic sketch of large shear testing machine (side view).

Figure 3.8 Schematic sketch of large shear box (front view).

Figure 3.9 Bottom half of shearbox assembly with test specimen.

Figure 3.10 Rock sample with associated joint surface tied up with wire ready to be cast.

Figure 3.11 The laser scanning device.

Figure 3.12 Carpenters comb on rough joint surface.

Figure 3.13 Punch shear apparatus.

Figure 3.14 The Schmidt hammer.

Figure 4.1 Location where samples of rock material were taken.

Figure 4.2 Correlation of point load strength vs uniaxial compressive strength.

Figure 4.3 Correlation of Schmidt rebound number vs uniaxial compressive strength.

Figure 4.4 Correlation of punch shear strength vs uniaxial compressive strength.

Figure 4.5 Correlation of tangent modules vs uniaxial compressive strength.

Figure 4.6 Correlation of punch shear strength vs tensile strength.

Figure 4.7 Correlation of density vs seismic wave velocity.

Figure 4.8 Correlation of punch shear strength vs triaxial cohesion.

Figure 4.9 Shear stress vs normal stress of Basalt - Phases 2A and 2B of shearing of Basalt 1, 2 & 3.

Figure 4.10 Shear stress vs normal stress of Dolerite - Phases 2A and 2B of shearing of Dolerite 1 & 3.

Figure 4.11 Shear stress vs normal stress of Granite – Phases 2A and 2B of shearing (dry and submerged).

Figure 4.12 Shear stress vs normal stress observations for Granite 1C.

Figure 4.13 Shear stress vs. normal stress observations for Granite 2C.

Figure 4.14 Shear stress vs. normal stress observations for Granite 3C.

Figure 4.15 Shear stress vs. normal stress observations for Sandstone - Phases 2A and 2B of shearing (dry and saturated).

Figure 4.16 Shear stress vs. normal stress of Mudstone - Phases 2A and 2B of shearing (dry and saturated).

Figure 4.17 A comparison between profiles along the centreline of specimen determined by (a) the laser apparatus vs. (b) the carpenters comb and (c) roughness profile by Barton and Choubey.

Figure 4.18 Correlation of friction angle to effective roughness.

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 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 = base 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

DEFINITION OF TERMS

Average modulus (Eav) = The average modulus is the Young's modulus measured at the linear portion of the axial stress-strain curve.

Base friction angle (ϕb) = The base friction angle is the friction angle of rock material measured on a artificial saw cut joint in arock specimen.

Density (ρ) = Density is defined as the mass of a specimen divided by its volume and is usually expressed in g/cm^3 (ml) or kg/m^3.

Effective normal stress (σn) = Effective normal stress is the total stress level acting on a joint surface in the field minus the hydrostatic pressure.

Friction angle (ϕ) = Friction angle is the angle in degrees at which an object on an inclined surface is just stable.

Joint wall compressive strength (JCS) = Joint wall compressive strength is the strength of rock material at the surface of a joint plane, in terms of uniaxial compressive strength in MPa.

Joint roughness coefficient (JRC) = Joint roughness coefficient is a number developed by Barton and Choubey (1977) describing the roughness of a joint surface.

Normal stress (σ) = Normal stress is defined by a force acting on a determined surface area.

Peak shear strength (ϕ_p) = Peak shear strength represent the maximum shear resistance.

Poisson's ratio (ν) = Poisson's ratio is the ratio of the slope of the axial stress-strain curve to the slope of the diametric stress-strain curve.

Punch shear strength = Punch shear strength is the shear resistance to punch.

Residual friction angle (ϕr) = The residual friction angle is the friction angle parameter at the residual shear strength after substantial movement along the joint plane has taken place.

Secant Modulus (E_{sec}) = Secant Young's modulus (E_{sec}), is usually measured from zero stress to some fixed percentage of the ultimate strength, generally 50%.

Shear strength (τ) = Shear stress is a combination of the angle of friction and the cohesion, given by the Mohr Coulomb expression $\tau = c + \sigma n \tan \phi$.

Tangent modulus (Et) = Tangent Young's modulus (E_t), is measured at a stress level which is usually some fixed percentage of the ultimate strength.

Uniaxial compressive strength (UCS) = The uniaxial compressive strength is the strength of a rock specimen two and a half to three times the diameter in length broken in compression, expressed in MPa.

LIST OF APPENDICES

Appendix A & B – Basic shear strength: Test results (Software: Corel Quattro Pro 8)

Appendix C & D – Shear strength on small specimens: Test results (Software: Corel Quattro Pro 8).

Appendix E - Shear strength on large specimens: Test results of Phase 1 Graphs of shear load vs. shear displacement (Software: MS Word 97).

Appendix F - Shear strength on large specimens: Test results of Phase 1 Graphs of normal stress vs. shear stress. (Software: Corel Quattro Pro 8).

Appendix G - Shear strength on large specimens: Test results of Phase 2A and 2B. Graphs of shear load vs. shear displacement (Software: MS Word 97).

Appendix H - Shear strength on large specimens: Test results of Phase 2A and 2B. Graphs of normal stress vs. shear stress. (Software: Corel Quattro Pro 8).

Appendix I - Shear strength on large specimens: Test results of Phase 2A and 2B. Tables and graphs of normal stress vs. shear stress. (Software: MS Exell 97).

Appendix J - Shear strength on large specimens: Test results of Phase 3A and 3B. Graphs of shear load vs. shear displacement (Software: MS Word 97).

Appendix K - Shear strength on large specimens: Test results of Phase 3A and 3B. Tables and graphs of normal stress vs. shear stress. (Software: MS Exell 97).

Appendix L - Shear strength on large specimens: Plates of shear surfaces. (Software: MS Word 97).

Appendix M - Shear strength on large specimens: Topography of shear surfaces of Phases 2A, 2B, 3A and 3B. (Software: Microstation).

Appendix N - Shear strength on large specimens: Roughness profiles of shear surfaces of Phases 2A, 2B, 3A and 3B. (Software: Microstation).

Appendix O – Principal stress diagrams for the determination of triaxial compressive strength of some southern African rock types. (Software: Corel Quattro Pro 8).

Appendix P – Stress strain diagrams for the determination of youngs modulus and poissons ration of some southern African rock types. (Software: Corel Quattro Pro 8).

Appendix Q – Test report on microscopic identification of rock samples. Department of Geology, University of Pretoria. January 1994. (Software: MS Word 97).

Appendix R – Test report on porosity and slake durability of rock samples. Geological Survey, Pretoria, December 1993. (Software: MS Word 97).

Appendix S – Test report on free swell strain tests. EMATEC, CSIR Report. November, 1993. (Software: MS Word 97).

Appendix T – Test report on Los Angelas abrasion testing on coarse aggregate. SABS Report. May 1996. (Software: MS Word 97).