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

by

André Johan Geertsema

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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. Sa 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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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 = 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