CHAPTER FIVE

CLASSIFICATION OF SHEAR STRENGTH OF JOINTS IN ROCK

5.1 Introduction

The shear strength of joint surfaces in a rock mass is a difficult parameter to determine. Several researchers, including Amadei and Seab (1990), Barton and Choubey (1977), Goodman (1976), Nicholson (1983) and others have investigated this problem. The shear strength parameters of joints in a rock mass are affected by a number of factors as described in chapter two. To simulate these factors in a laboratory is virtually impossible and in this study only the most important factors have been considered.

Geotechnical characteristics of joint surfaces in a rock mass can be described in terms of hardness, roughness filling and water considerations. Sampling and testing of these joints is difficult and time consuming. Design engineers usually need an estimate of the shear strength of joints early during the design stage of a structure in a rock mass. If the shear strength could be linked to a geotechnical description of the joints, then a first estimate of the shear strength could be made which would satisfy the immediate need of the design engineer. This research concentrated on classifying joints in order to estimate the shear strength of joints at the early stage of an investigation. The findings are discussed in this chapter. This chapter contributes to the existing knowledge of shear strength by describing the results of shear tests on a number of southern African rock types tested on the large shear machine described in chapter four. The rock types used for the investigation were Basalt, Dolerite, Granite, Mudstone and Sandstone.

The major factors influencing shear strength are:

(i)   hardness of the joint surface

(ii)   roughness of the joint surface

(iii)   the influence of water

(iv)   the effects of joint fill material

An attempt was made to estimate the shear strength parameters by describing geotechnical properties of the joint surface, including hardness, roughness, joint fill material present and the presence of water. These factors were correlated with the shear strengths measured during large scale shear testing.

A correlation between the calculated peak angle of friction and the tested angle of friction was made for each of the rock types tested. The method described by Barton and Choubey (1977) for calculating the empirical relation of shear strength of joints in rock is as follows:

$$\tau = \sigma_n \tan \left[JRC \log_{10} (JCS/\sigma_n) + \phi_b \right]$$

where τ =   peak shear strength (kPa)

σ_n =   effective normal stress (kPa)

JRC =   joint roughness coefficient

JCS =   joint wall compressive strength (kPa)

ϕ_b =   basic friction angle (obtained from residual shear tests on flat unweathered rock surfaces) (degrees)

From this relation it is apparent that there are three important factors determining the shear strength of joints in rock.

They are:

(i)   the basic friction angle of the rock material

(ii)   the joint roughness (JRC)

(iii)   the joint wall compressive strengths (JCS)

The following portion of the formula used above can express the contribution of roughness and hardness of the joint surface to the peak friction angle:

$$[JRC \log_{10} (JCS/\sigma_n)]$$

5.2 Classification of joints according to this study

In order to classify joint surface characteristics it was necessary to investigate work done on unconfined compressive strength (Deere and Miller,1966), joint wall compressive strength (Barton and Choubey, 1977) and joint roughness (Barton and Choubey, 1977).

5.2.1 Classification of joint wall compressive strength

The value of the joint wall compressive strength (JCS) is of fundamental importance in the determination of rock slope stability since it is largely the thin layer of rock adjacent to the joint wall that controls the shear strength. This parameter can be determined using a Schmidt Hammer. The relationship between the Schmidt rebound number and the unconfined compressive strength is discussed in chapter two of this thesis. The UCS is used if the joint wall has no alteration. Miller (1965) found a reasonable correlation between the rebound number and unconfined compressive strength. The unconfined compressive strength (UCS) classification of rock material by Deere is displayed in Table 5.1.(Deere and Miller,1966)

Rock classification	Unconfined compressive strength (UCS)	Rock type
Very weak rock	1 – 25 MPa	-
Weak rock	25 – 50 MPa	-
Moderately hard rock	50 – 100 MPa	Mudstone, Sandstone
Hard rock	100 – 200 MPa	Basalt
Very hard rock	> 200 MPa	Dolerite, Granite

Table 5.1 **Classification of intact rock strength (Deere and Miller, 1966)**

5.2.2 Classification of roughness profiles

The roughness profile is another fundamental parameter in the determination of shear strength. Table 2.4 (after Barton and Choubey, 1977) of roughness profiles with associated JRC values was used as guide to 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 2 mm thickness

In the case where joints are filled with a secondary mineral or soft fill material, the peak shear strength cannot be determined by the empirical formula of Barton and Choubey (1977).

Joint description

During the testing programme a Dolerite sample was tested. The Dolerite material was hard and the joint filled with completely weathered (residual) doleritic material. The joint fill material was more than 2mm thick.

Test results

The results are illustrated in Table 5.2 below.

Characteristic	Dolerite (Phase 2)
Measured dry min. post-peak friction angle	17,0°
Measured saturated min. post-peak friction angle	14,9°

Table 5. 2   **Friction angles of clay filled joint in hard rock (dolerite)**

Discussion of results

In this case the joint fill material (a 2 mm thick layer of clay) resulted in a maximum post-peak friction angle much lower than the basic friction angle of the rock. The basic friction angle is 36°. The measured maximum post-peak friction angle was tested as 17,0° and the saturated post-peak friction angle as 14,9°.

Conclusion

For filled joints in moderate to hard rock or joints in soft rock, the following conclusions can be made:

(i)   the basic friction angle of the rock material is **not** the minimum friction angle of a filled joint.

(ii)   the dry minimum post-peak friction angle is much lower than the basic.

(iii)   the angle of friction is affected negatively by the presence of water if the infill consists of clay.

5.3.2 Joints in hard to very hard rock with stained joint surfaces

Joint description

Joints in granite (Granite 2C) were tested. These joints were in hard to very hard rock and the joint surfaces were stained, presumably with iron staining.

Test results

The results of empirical calculations as well as test results are shown in Table 5.3.

Characteristic	Empirical value Peak	Tested value
Basic friction angle		31°
$JRC \log_{10} (JCS/\sigma_n)$	12°	
Peak or max. p-p angle of friction	43°	35,2°
Min. post-peak angle of friction		31,8°
Min. post-peak angle of friction (saturated)		29,8°

Table 5. 3   **Friction angles of joints in hard to very hard rock with stained joint surfaces (Granite 2C)**

Conclusions

The following conclusions could be made for unfilled joints and joints that are lightly stained in hard rock:

(i)   the basic friction angle is the minimum friction angle of a particular joint

(ii)   the contribution of the roughness and hardness of the joint can be added to the basic friction angle to obtain a design parameter.

(iii)   the angle of friction is not significantly affected negatively by the presence of water.

(i)   the max. post-peak is considerably lower than the calculated peak.

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

Joint description

Joints consisted of smooth planar bedding joints with unweathered surfaces in a moderately hard mudstone.

Results

The results of empirical calculations as well as test results are shown in Table 5.4.

Characteristic	Empirical value	Tested value
Basic friction angle		31°
$JRC \log_{10}(JCS/\sigma_n)$	4,5°	
Max. post-peak angle of friction	35,5°	34,9°
Min. post-peak angle of friction (saturated)		16,8°

Table 5.4   **Friction angle of smooth, planar, bedding joints with unweathered surfaces in moderately hard rock (Mudstone)**

The tested angle of friction of the three samples is between 37,0° and 32,8° with an average of 34,9°. The calculated peak friction angle is between 35,3° and 35,8° with an average of 35.5°. There is a difference of less than one degree between the calculated and the tested value of the peak friction angle.

There is a marked difference between the angle of friction determined under dry conditions and that of under saturated conditions. For Mudstone 1 the difference is 10°. For Mudstone 1 and 2 the difference is even greater namely 22° and 22,4° respectively.

The influence of water on the shear strength (angle of friction) of mudstone was larger than expected and this phenomenon should be taken into consideration in the design of dams on mudstone.

Conclusions

(i)   The empirical formula developed by Barton and Choubey (1977) to calculate peak angle of friction was found to be applicable to the rock type tested in this case under dry conditions.

(i)   The influence of water on the shear strength (angle of friction) of mudstone was larger than expected and this phenomenon should be taken into consideration in the design of dams on mudstone.

5.3.4 Rough, planar, unweathered surfaces in hard rock

In a rock mass where joint surfaces are characterised by moderate to high joint roughness coefficient values (JRC above 6 according to Barton and Choubey, 1977) and high joint wall compressive strength values (UCS above 100 MPa), the shear strength is determined by these characteristics. The peak shear strength can be calculated using Barton and Choubey's empirical formula (1977). In essence the peak angle of friction consists of the basic friction angle plus the contribution of the hardness and roughness.

Joint description

Unweathered joints in hard rock (Granite) were investigated. The joints were rough and planar.

Results

Results are shown in Table 5.5.

Characteristic	Empirical value By Barton	Tested value
Basic friction angle	-	31°
JRC $\log_{10}$ (JCS/σ_n)	10°	-
Max. post-peak angle of friction	41°	43,1°
Min. post-peak angle of friction	-	37,0°
Min post-peak angle of friction (saturated)	-	27,5°

Table 5.5 **Friction angle of rough, planar, tectonic, unweathered surfaces in hard rock (Granite 1C)**

Discussion of results

The tested maximum post-peak and calculated peak friction angle for the specimen are almost the same. The effect of water is that the friction angle under saturated conditions is about 10° lower than under dry conditions.

Conclusion

(i)   In hard rock with relatively rough surfaces the calculated peak friction angle is much the same as the tested maximum post-peak value.

(ii)   The influence of water on the angle of friction is relative large, in this case almost 10°.

5.3.5 Rough, irregular joints in unweathered hard rock (Basalt, Dolerite)

Two hard to very hard rock types were investigated that had rough, irregular joints. Basalt has a unconfined compressive strength in the order of 160 MPa and Dolerite 260 MPa.

Joint description

The joint surfaces of Basalt samples tested were rough, irregular with a JRC of between 6 and 10. The Schmidt rebound number was between 53 and 57. The joint surfaces of Dolerite samples tested were rough, irregular with a JRC of between 4 and 8. The Schmidt rebound number was between 46 and 51.

Results

Tables 5.6 and 5.7 are summaries of the results of Basalt and Dolerite respectively.

Characteristic	Empirical value By Barton	Tested value
Basic friction angle	-	35 - 38°
$JRC \log_{10} (JCS/\sigma_n)$	14°	-
Max. post-peak angle of friction (dry)	49°	44,0°
Min. post-peak angle of friction (saturated)	-	42°

Table 5.6   **Friction angle of rough, irregular, joints in unweathered hard rock (Basalt)**

Characteristic	Empirical value By Barton	Tested value
Basic friction angle	-	36°
$JRC \log_{10} (JCS/\sigma_n)$	11°	-
Max. post-peak angle of friction (dry)	47°	52,6°
Min. post-peak angle of friction (saturated)	-	43,6°

Table 5.7   **Friction angles of rough, irregular, joints in unweathered hard rock (Dolerite)**

Discussion of results

The peak calculated and tested maximum post-peak values of angle of friction are very high namely 49° and 44° for Basalt and 47° and 52,6° for Dolerite respectively. The minimum post-peak friction angles for both rock types are also very high namely 42° and 43,6° respectively.

Conclusions

(i)   The peak shear strength of joints in rock with rough and hard joint surfaces are very high.

(ii)   The minimum post-peak shear strength under saturated conditions are also very high. Water has little effect on the friction angle of hard and rough joints.

5.4 Proposed classification of joints according to roughness and hardness.

Table 5.8 is a proposed classification of joints according to roughness and hardness as determined during this study.

Joint description	Peak angle of friction Calculated	Max. post-peak angle of friction Tested	Min. post-peak angle of friction Saturated
1. Joint in hard rock filled with clayey material of 2mm thickness	-	-	14,9°
2. Joints in hard rock with stained surfaces	43°	35,2°	29,8°
3. Smooth, planar, bedding joints with unweathered surface	35,5°	34,9°	16,8°
4. Rough, planar, joints with unweathered surfaces	41°	43,1°	27,5°
5. Rough, irregular, with unweathered surfaces	46- 49°	44 – 52,6°	42 – 43,6°

Table 5.8   **Classification of joints according to roughness and hardness of joint surfaces.**

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

In the design of the stability of a concrete dam foundation the design must include parameters for even the worst possible situations. This includes joint sets with unfavourable dip, full water uplift pressure acting on joint surfaces and the maximum force on the concrete structure as a result of water in the reservoir at maximum overflow conditions.

Important parameters used in the design of concrete dam foundations include the following:
- the orientation of important joint sets in the rock foundation
- the shear strength of joints in the rock mass
- the direction and magnitude of the forces acting on the rock foundation as a result of:
  (i)   the concrete structure
  (ii)   the water in the reservoir

(iii)   the uplift pressure of the water

(iv)   external forces (e.g. Seismic)

Instability can occur as a result of sliding of the concrete structure along an unfavourable joint set with insufficient shear strength or rotation of the concrete structure around the toe of the structure. The design of every structure including the foundation as part of the structure should be treated separately and investigated in detail.