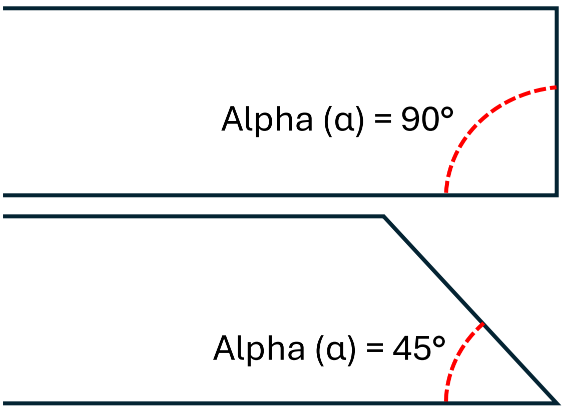
FREQUENTLY ASKED QUESTIONS – LOP PRACTITIONER'S GUIDELINES FOR SAMPLING AND LABORATORY TESTING FOR OPEN PIT OPERATIONS: ISRM R3 TO R6

Direct Shear

Could you provide a straightforward diagram illustrating the acceptable alpha angle range for a sample undergoing direct shear testing?

The preferred alpha angle (α) range for samples undergoing direct shear testing is typically between 45° and 90°. The alpha angle is the apparent dip angle of a discontinuity measured relative to the core axis, as shown in the figure below. It is important to consider the alpha angle of samples because it can influence the failure behaviour of the sample. An alpha angle below this range may introduce tensile stress that could lead to premature failure or chipping of the sample. Samples with small alpha angles can also prove difficult to mount in the testing apparatus without damaging the sample.



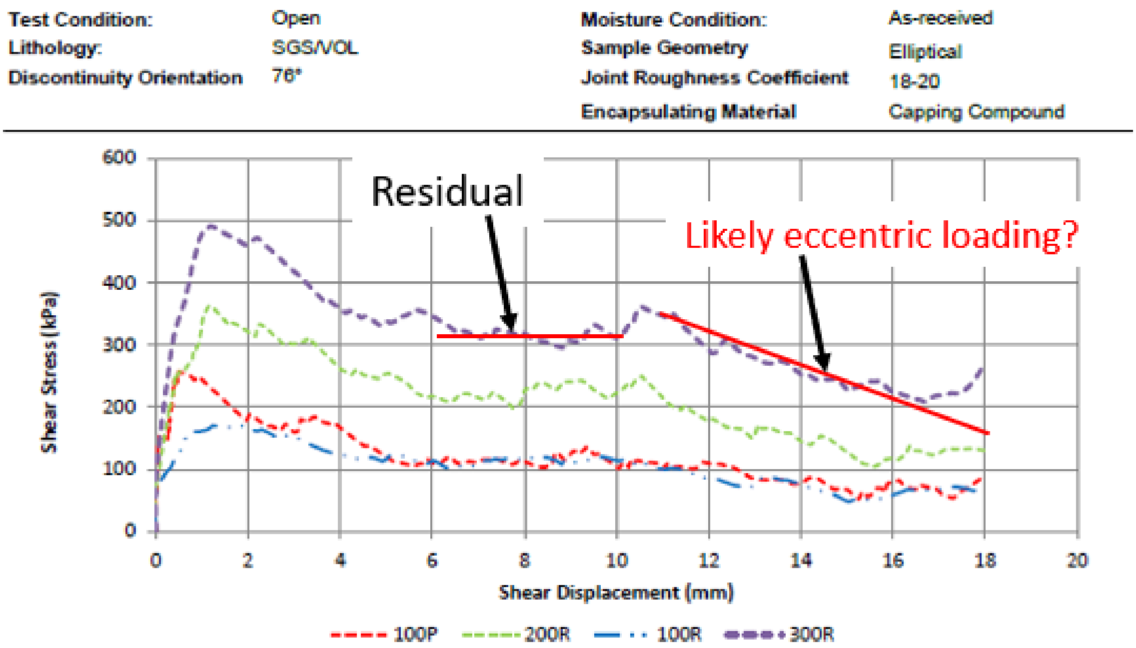
What are the main physical limitations associated with large displacements in a testing apparatus?

Testing with large shear displacements can lead to erroneous data, potentially due to sample tilting, eccentric loading, or contact between the metal shear box and the sample or encapsulating material. Therefore, caution is advised when conducting tests with significant displacement.

The ISRM recommends that shear displacements of 5% to 10% of the discontinuity length are sufficient (Muralha et al. 2014), and this guideline should be used as a reference. For example, for a 63 mm core sample, a 6 mm displacement should provide the required information.

Some practitioners argue for larger displacements, claiming they offer a clearer representation of peak and residual shear strengths. However, the impact of eccentric loading was demonstrated in slides 52 and 53 of the webinar on direct shear testing. Slide 52, reproduced below, shows that after 10 mm of shear displacement, the specimen tilted, causing eccentric loading for the remainder of the test. Again, caution is advised when conducting and interpreting tests with significant displacement.

WSP Canada Inc.
840 Howe Street, Suite 1000, Vancouver, BC
V6Z 2S9 Canada
T: (604) 685-9381



In terms of physical limitations, some testing apparatuses, such as shear boxes, are designed with a finite travel range which restricts the extent of large displacements. The webinar suggests that testing a sample 2 to 3 times with the same normal load may provide an option for obtaining the residual shear strength when the recommended length of testing is insufficient to clearly define the residual shear stress.

For multi-stage direct shear tests, is the same quantity of specimens necessary?

Single stage testing is preferable; however, single stage testing requires more specimens than multi-stage testing, which can be difficult to collect.

In a multi-stage test, a single specimen can be tested at multiple normal stresses. Because a minimum of three to five different normal stresses are required to define a strength envelope from direct shear testing (ASTM 2016), single stage testing would require a minimum of three to five different specimens that have similar discontinuity and rock properties. In contrast, with multi-stage testing, three to five different normal stresses can be applied to a single specimen (MacDonald et al. 2023).

Multi-stage tests are suitable for infilled joints or joints that are relatively smooth. In both cases the difference between peak and residual strengths is minor and the results less influenced by the testing method. Multi-stage testing is also typically used when it is difficult to collect several samples with similar discontinuity and rock properties, and it can be more efficient and cost-effective than single-stage testing (MacDonald et al. 2023).

However, an important consideration in multi-stage testing is that repeated shearing can significantly deteriorate the discontinuity surface during subsequent loading stages, potentially distorting or impacting the shear strength results. The ASTM (2016) standard recommends that each subsequent multi-stage be completed using a higher normal stress.

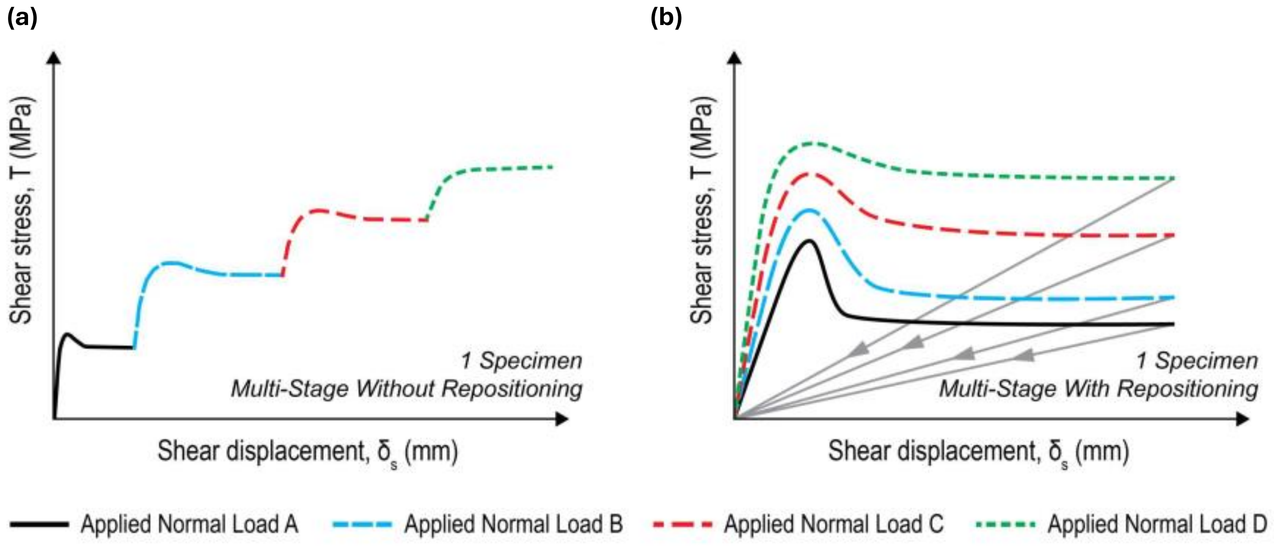
When documenting the roughness of a discontinuity set, how should the average roughness be calculated?

When reporting the roughness of a discontinuity set, it is generally recommended to calculate the average as the median roughness value of the discontinuities comprising the set. Additionally, it is important to indicate the direction of testing in relation to the observed roughness (i.e., whether following along or going against it), when the surface roughness exhibits a clear orientation.

When analyzing the stress versus displacement graph for a multi-stage test, how is the endpoint of each stage determined?

Similarly to a single-stage test, the endpoint of each stage is determined to be where the ultimate (residual) shear strength of a sample is reached (ASTM 2016).

In multi-stage testing, subsequent stages can be completed either without repositioning the sample to zero displacement after each residual shear stress is reached (left figure below) or with repositioning the sample to zero displacement (right figure below). Each stage is considered complete once the residual strength has been reached.



Source: MacDonald et al. 2023.

Direct Shear test methods for (a) multi-stage without repositioning and (b) multi-stage with repositioning

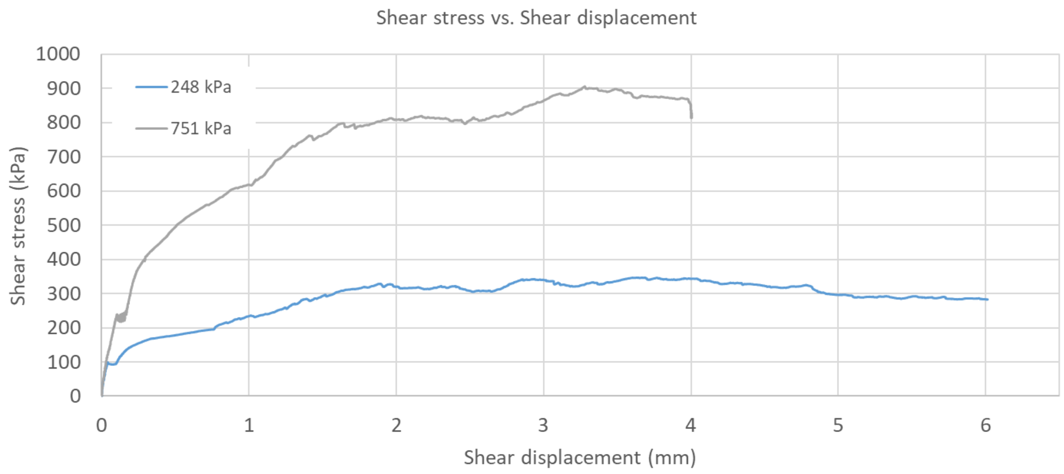
Where should you select the peak strength in a shear stress versus shear displacement graph?

Where should the peak shear stress be selected: a) after the initial inflection of the curve, or b) the highest value in the shear stress curve? This is a good topic for discussion which is dependent on several factors and requires engineering judgement.

The ISRM defines peak shear strength as the *"highest recorded shear stress corresponding to a specific initial apparent normal stress, after which the shear load decreases until ultimate or residual shear loads are reached"* (Muralha et al. 2014). It is important to note that this ultimate value is characterized by the absence of dilation or contraction with increasing shear displacement.

However, relying solely on the highest shear value can be misleading. The specimen may shear over the first asperity and get stuck at the next, even though it has already sheared. Additionally, the condition described in the ISRM guidelines (Muralha et al. 2014) may not be clearly developed.

Some laboratories use the shear stress obtained after the initial inflection of the curve, arguing that debris from shearing could impact the shear stress results. In the example below, for the specimen tested at 751 kPa normal stress, which shear stress should be considered for representing the peak shear strength? Additional information would likely be required, such as inspecting the conditions of the joint surface after testing, to evaluate what factors might have caused the observed shear displacement behaviour and confirm whether the test was valid.



The same question applies to the direct shear test results shown in the example below, for a specimen tested at 199 kPa normal stress. Perhaps, for this latter example, considering a shear stress of about 120 kPa would be more representative than the maximum recorded stress of 230 kPa, to err on the side of caution.

What is the Hencher correction?

There are two Hencher corrections:

i. Surface correction (Hencher and Richards 1989)
ii. Dilation correction (Hencher and Richards 2015)

The surface corrections proposed by Hencher and Richards (1989) or King et al. (2016) are commonly applied to the direct shear test results.

The dilation correction proposed by Hencher and Richards (2015) should be considered for rough to very rough discontinuity surfaces. It is not commonly applied to smooth surfaces.

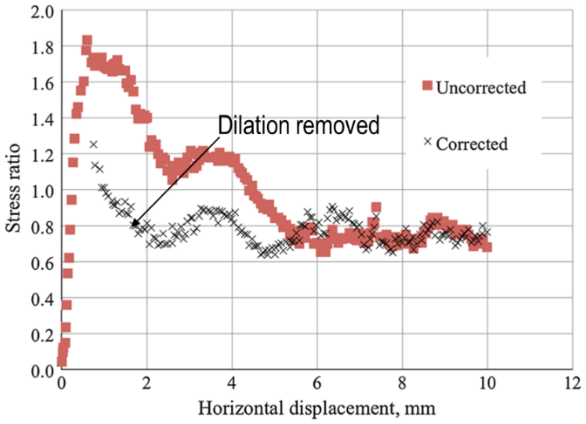
Surface correction (Hencher and Richards 1989)

Since the area of the surface being sheared changes throughout the duration of a test, the resulting pressures applied to the sample change slightly during the test. Therefore, a correction needs to be applied to the normal stress for accurate interpretation of results. Hencher and Richards (1989) proposed equations for the correction of circular or elliptical areas. These equations are presented in Appendix A of the webinar on direct shear testing.

It should be noted that the surface area correction is <u>not</u> a requirement of the ISRM and ASTM standards and may need to be specified separately when commissioning testing.

<u>Dilation correction</u> (Hencher and Richards 2015)

The dilation correction aims to remove the influence of dilation when interpreting test results. It is recognized that joints can dilate at relatively low normal loads as the asperities of the discontinuity interact during shear testing. This dilation tends to increase the force required to continue shearing, thereby increasing the shear stress observed during testing, as illustrated below.



Variations in roughness on different samples can lead to a wide range of shear strengths. This correction method removes the effect on strength of volumetric changes from dilation and reconsiders the testing surface as an effectively planar surface with natural rock texture, allowing the full effect of the rock mineralogy to be interpreted (Hencher 1995).

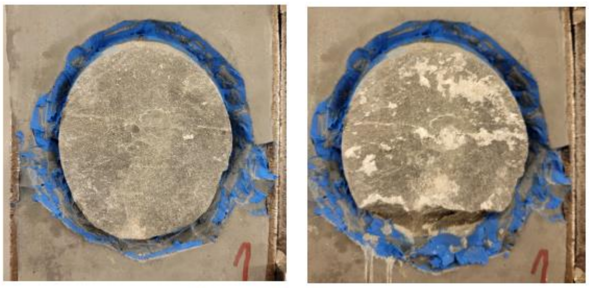
The dilation correction is carried out by adjusting the shear stress (τ) and normal stress (σ) using the following equations, where *i* is the incremental dilation angle (Hencher 2015):

$$\tau_i = (\tau * \cos i - \sigma * \sin i) \cos i$$

$$\sigma_i = (\sigma * \cos i + \tau * \sin i) \cos i$$

When developing shear strength envelopes, are most of the decisions based on the analysis of the shear stress versus shear displacement graphs, or do they rely on examining the samples and photographs?

Both approaches are required and recommended. Physical inspection of the specimens after testing is essential. When this is not possible, it is advisable to request that photographs be taken before and after testing from both the upper and lower portions of the discontinuity surfaces. This will allow verification of, for instance, whether there was significant specimen deterioration or chipping of the sample, as illustrated below. In addition, photographs can help to understand anomalous test results, such as large jumps in the shear stress from sliding or shearing of asperities.



Top Surface Before / After Shear

Once the examination of the specimens and photographs is completed, the analysis of the shear stress versus shear displacement graphs should be undertaken. This analysis will help verify, for instance, that the shear displacements were not large enough to cause tilting of the specimen and, consequently, load eccentricity.

Documenting the characteristics of the sample before testing is essential to aid in the interpretation process and provide valuable context to the test results. Understanding the surface shape, roughness, condition, and infill characteristics of discontinuities helps with interpreting similarities or differences within a set of data. For example, in a case where direct shear testing was conducted on seven joint samples where three samples have a planar, smooth surface and four samples have a rough, undulating surface, the samples may need to be classified and considered separately when interpreting the data.

Is there a significant impact on the results if the test is performed on a remolded sample?

Tests on remolded specimens are not performed on strong rocks (i.e., UCS > 25 MPa).

For a discontinuity in extremely weak to weak rock (UCS < 15 MPa), for instance, for clay gouge fault material, remolded samples can be considered. It is important to understand that the direct shear results from these samples would provide the lower bound of the residual shear strength.

When testing remolded samples for weak rocks, it should be noted that:

- Remolding a sample will disrupt the natural structure and matrix of the rock, leading to lower shear strength compared to an intact sample.
- Remolded samples tend to be more homogeneous than natural, intact rock samples. This homogeneity may result in more uniform, but potentially less representative, shear strengths.
- Remolding will alter the particle size distribution of the rock.
- The process of remolding can alter the water content of the sample.

References

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