A new tool for the field characterization of joint surfaces

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ABSTRACT: Laser profilometers exist for obtaining very accurate two and three dimensional profiles of joint surfaces. The application of this technology is not commonly applied to the collection of field data on discontinuity surface roughness. Rugged and portable field devices are not commonly used and the value of the possible field data that can be collected has not been well recognised. This paper reviews commonly used field techniques for assessing discontinuity roughness, discusses the value of this data and presents a new laser profilometer design for field application.

1 INTRODUCTION

Understanding the properties of discontinuities is important to many areas of rock engineering. The most obvious application is for estimating the frictional properties of a discontinuity for slope stability applications. Other applications include estimating the overall rock mass strength and for estimating permeability properties of the fractures for flow predictions. The approach taken for estimating the properties of discontinuities varies with the engineering application.

In engineering applications where discontinuity and rock mass properties are highly variable, requiring large amounts of data and time to obtain representative average properties, very subjective descriptions of discontinuities are often used to estimate the properties. In engineering applications such as slope stability design, where potential failures can occur on a single feature or set of discontinuities, quantitative measurements of discontinuity properties can often be measured and linked to lab testing and back analysis of case histories.

This paper presents a new laser profilometer developed for measuring a 15 cm long profile on a discontinuity surface. This device is designed for field use and is a portable and easily used. Before describing this device, current methods of characterising and measuring discontinuity surface properties are first presented.

2 APPROACHES FOR DESCRIBING DISCONTINUITY SURFACES

The description or measurement of discontinuity surfaces is conducted to obtain estimates of the friction properties of the surface, to provide input for estimating the overall properties of a rock mass (including rock mass strength), and to estimate the permeability of the discontinuities and the rock mass. The assessment of the surface roughness of a discontinuity can be broken into general approaches which include subjective descriptions and qualitative measurements. A review of these general approaches highlights the importance of developing a simple and accurate field technique for measurement of discontinuity roughness.

2.1 *Subjective discontinuity descriptions used for rock mass classification*

Rock mass classification systems are designed to provide an estimate of the overall rock mass strength and general elastic properties. Approximately 30% of the overall assessment of rock strength is dependent upon the description of the surface character of the discontinuities (Milne et al., 1998). Discontinuity surface properties include: discontinuity aperture, infilling (residual friction value), roughness and waviness.

The different rock mass classification systems use different terminology and discontinuity properties for assessing the discontinuity condition. The most commonly used systems and their discontinuity descriptions are discussed in the following sections.

2.1.1 *RMR_{76} classification descriptions for discontinuity surface profiles*

Descriptions and categories used to assess discontinuity conditions have evolved in the RMR classification systems. The discontinuity descriptions for the commonly used 1976 system (RMR_{76}) combine surface roughness, aperture and infilling in a general description summarized in Table 1.

Table 1. Joint or discontinuity description for the RMR_{76} classification system (After Bieniawski, 1976)

Joint Description	Rating
Very Rough, not continuous, no separation – hard joint wall rock	25
Slightly rough surfaces, separation <1mm – hard joint wall rock	20
Slightly rough surfaces, separation < 1mm – soft joint wall rock	12
Slickensided or gouge, < 5mm thick or open 1 – 5mm	6
Soft gouge > 5mm thick or joints open > 5mm	0

It is interesting to note that only the roughness of the joint surface is mentioned and that no mention is made of the scale at which the roughness is being described. The discontinuity roughness is only broken into two categories; slightly rough and very rough. Slickensided (sometimes referred to as polished) reflects a smaller scale of roughness that is more easily detected by touch than assessed by a visual roughness.

2.1.2 *RMR_{89} classification descriptions for discontinuity surface profiles*

The RMR_{89} classification system has a more rigorous assessment of discontinuity conditions. Table 2 summarizes the discontinuity condition categories. In this version of the RMR system, roughness is broken into 4 categories of roughness (from very rough to smooth) and can be described at a smaller scale as either slickensided or not slickensided.

Table 2. Joint or discontinuity description for the RMR_{89} classification system (After Bieniawski, 1989)

Parameter	Ratings				
Discontinuity Length	< 1m	1-3m	3-10m	10-20m	>20m
	6	4	2	1	0
Separation (Aperture)	None	<0.1mm	0.1-1.0mm	1.5mm	>5mm
	6	5	4	1	0
Roughness	Very Rough	Rough	Slightly Rough	Smooth	Slickensided
	6	5	3	1	0
Infilling (Gouge)	None	<5mm	>5mm	<5mm	>5mm
	6	4	2	2	0
Weathering	Unweathered	Slightly Weathered	Moderately Weathered	Highly Weathered	Decomposed
	6	5	4	1	0

2.1.3 *Q classification descriptions for discontinuity surface profiles*

The Rock Quality Q system, developed in 1974 (Barton et al.), follows a more rigorous approach for categorising discontinuity surface profile conditions than most classification systems. The joint assessment is made at 3 scales of roughness; planar – wavy, rough – smooth and slickensided or polished or not slickensided or polished. Table 3 summarises the categories.

Table 3. Joint or discontinuity description for the Q classification system (After Barton et al., 1974)

Description	Rating
Discontinuous joints	4.0
Rough undulating	3.0
Smooth undulating	2.0
Slickensided undulating	1.5
Rough planar	1.5
Smooth planar	1.0
Slickensided planar	0.5

The roughness categories can also be broken into the scales of roughness they describe:

- Large scale roughness, wavy to planar 1.0 to 2.0
- Small scale roughness, rough to smooth 1.0 to 1.5
- Very small scale or tactile roughness, slickensided or not slickensided 0.5 to 1.0

The assigned ratings given in Table 3 are obtained by multiplying together the ratings assigned to the three scales of roughness.

2.1.4 *MRMR classification descriptions for discontinuity surface profiles*

The MRMR (Mining Rock Mass Rating) was developed by Laubscher as a mining adaptation of the RMR system. It describes discontinuities in a more rigorous fashion, as shown in Table 4 and appears to borrow some of the approaches used in the Q classification system. The rating values in this classification system are expressed as a per cent and are multiplied together to obtain an overall rating value. The discontinuity categories are assessed for various water conditions to account for the increased potential for slip along discontinuities under wetter / higher water pressure conditions. It is of interest to note that in this classification system, the discontinuity character is also assessed at 3 scales of roughness; large and small scale irregularities and polished or not polished surface conditions. The roughness assessment is determined by multiplying the large and small scale roughness values, expressed as a per cent, with assessments for infilling and alteration.

2.1.5 *GSI classification descriptions for discontinuity surface profiles*

The GSI classification system looks at two scales of roughness (Table 5). Small scale roughness is divided into categories of very rough, rough and smooth and the very small scale, or tactile scale is divided into slickensided or not slickensided. The assigned ratings to these values are very approximate and they tend to vary with the degree of jointing. The discontinuity description rating is added to the discontinuity spacing assessment to obtain the GSI value.

Table 4. Joint or discontinuity description for the MRMR classification system (After Laubscher, 1990)

Parameter	Description		Dry Conditions	Wet Conditions: Moist	Wet Conditions: Moderate Pressure	Wet Conditions: Severe Pressure
Large scale irregularities	Wavy	Multi-directional	100%	100%	95%	90%
		Uni-directional	95% 90%	95% 90%	90% 85%	80% 75%
	Curved		89% 80%	85% 75%	80% 70%	70% 60%
	Straight		79% 70%	74% 65%	60%	40%
Small scale irregularities or roughness	Very rough		100%	100%	95%	90%
	Striated or rough		99% 85%	99% 85%	80%	70%
	Smooth		84% 60%	80% 55%	60%	50%
	Polished		59% 50%	50% 40%	30%	20%

Table 5. Joint or discontinuity description for the GSI classification system (After Hoek et al, 1995)

Joint Description	Rating
Very Good, very rough, unweathered surface	~ 40 to 50
Good, Rough, slightly weathered iron stained surface	~ 30 to 40
Fair, smooth, moderately weathered or altered surfaces	~ 10 to 20
Poor, slickensided highly weathered surfaces	~ 10 to 20
Very Poor, slickensided highly weathered with soft clay coatings or infillings	~ 0 to 10

2.2 *Approaches for qualitative assessments of discontinuity profiles or roughness*

The Joint Roughness Coefficient (JRC) is probably the most commonly used approach for quantifying the roughness of a joint profile. The JRC value can be related to the peak angle of friction based on the following equation from Barton and Choubey, (1977).

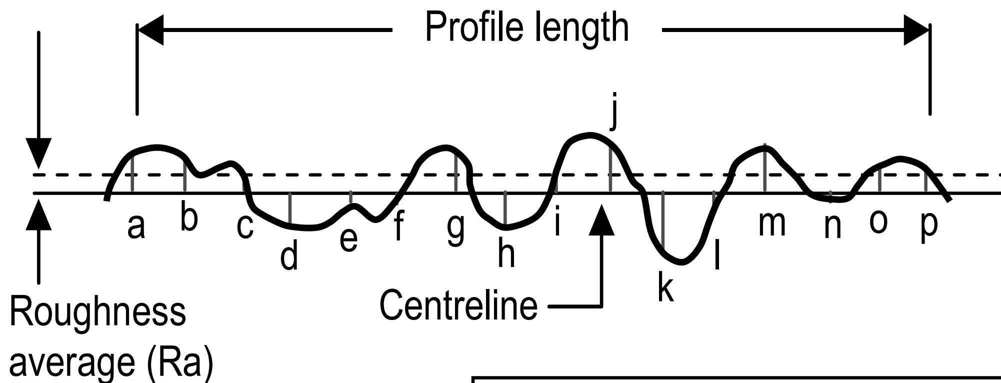
$$\phi_p = \phi_r + JRC(\log_{10} \frac{JCS}{\sigma_n}) \qquad (1)$$

Where $\boldsymbol{\phi_p}$ = Peak friction angle, $\boldsymbol{\phi_r}$ = residual or basic angle of friction, JCS is the joint compressive strength and σ_n it the normal stress on the discontinuity surface.

JRC values provide a qualitative estimate of the joint roughness properties, usually at a scale of 10 cm. Techniques exist for relating the JRC value to discontinuity permeability, angle of friction on a surface at any scale, and has also been related to other discontinuity and rock mass properties (Bandis, 1980; Makarut and Gutierrez, 1996; Nguyen and Selvadurai, 1998). The attractiveness of the JRC factor is it provides a quantitative measure of discontinuity profile properties, however, the estimation of JRC often relies on standard profiles whose use can be quite subjective.

Another measure of surface roughness, Ra, is calculated by first determining an average straight profile to represent the surface trace. The distances above and below the profile are calculated and the average distance, Ra, is determined by averaging the absolute distances to the average profile, as shown in Figure 1.

Substantial work has been done with other approaches for quantifying discontinuity roughness including roughness based on fractals (Seidel and Haberfield, 1995; Lee et al., 1990; Turk et al., 1987; Carr and Warriner, 1987)



$$Ra = \frac{y_a + y_b + y_c + \ldots + y_n}{n}$$

Figure 1. Average roughness, Ra. (After Hebert, 2004)

3 FIELD MEASUREMENT METHODS FOR ASSESSING DISCONTINUITY PROFILES

Laboratory measurement techniques for assessing discontinuity surfaces can be quite detailed and sophisticated. They range from the casting of discontinuity surfaces for repeated testing to developing 3-D surface profiles for analysis and comparison to laboratory testing. Field measurements of discontinuity profiles are not commonly conducted and are not usually as sophisticated as laboratory methods. Some of the commonly used methods are discussed.

3.1 *Discontinuity Mapping*

Discontinuity mapping consists of simply placing a base line along the side of a discontinuity surface. A base line tape is set up close to the discontinuity surface and the distance to the discontinuity surface and the base line is measured at frequent regular distances along the joint surface. The technique can provide a detailed 2-dimensional representation of the discontinuity, however the approach is very time consuming and is seldom applied in the field. A simpler approach is to approximate the maximum amplitude along the joint discontinuity profile (Figure 2). This value can be related to the discontinuity JRC value (Bandis, 1980).

3.2 *Rangers' Method*

The Rengers Method of quantifying discontinuity roughness consists of taking multiple orientation measurements on a joint surface using different sized discs. The variability in orientation is a function of the roughness or irregularity of the discontinuity surface at different scales, as measured by different sized discs (Feckers and Rengers, 1971).

3.3 *Profile comb*

A profile or carpenter comb is a simple, easily used device for recording the 2 – D profile of a short (15cm) profile length on a discontinuity surface. This inexpensive device is easily used and can be compared to standard JRC profiles or can be traced to obtain a hard copy of the profile. Its application for rock mass classification is summarised in Milne et al., (1991). Figure 3 shows the field application of the device.

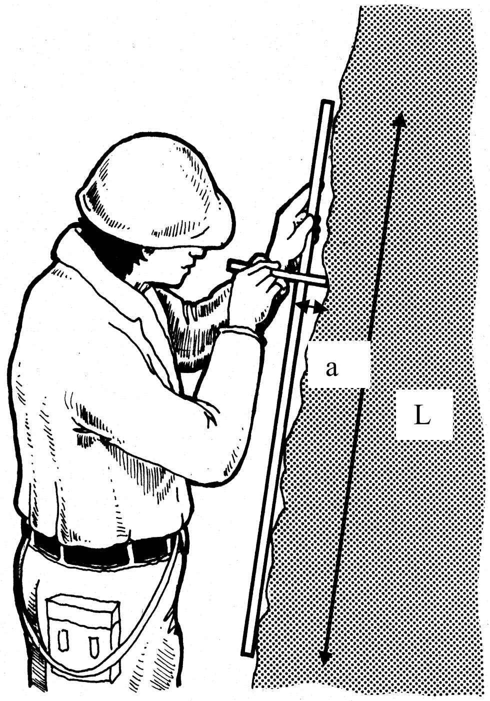


Figure 2. Maximum amplitude measuring technique used for estimating joint roughness (Milne at al., 1991)

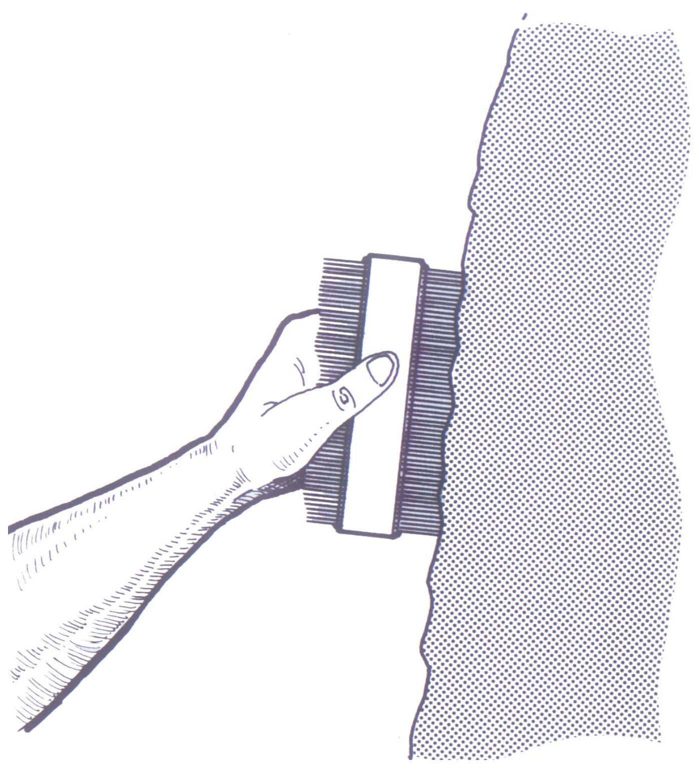


Figure 3. Application of a profile comb for recording discontinuity profile roughness (From Milne et al., 1991).

3.4 *Shadow Profilometer*

Shadow profilometer techniques, as well as other photogrametry techniques, have been applied to measuring discontinuity roughness profiles. Photogrametry methods are usually done at a fairly large scale and involve locating points on a discontinuity surface to produce a contour of the joint surface. Shadow profilometer techniques have been used to obtain a profile of the joint surface corresponding to the shadow produced by a light source at a 45° angle to the discontinuity surface (Franklin et al., 1988) (Maerz et al., 1990) (Milne et al., 1992). The profile produced by the shadow can be photographed and compared to typical JRC curves, as shown in Figure 4. Based on this visual comparison, the user assigns a JRC value.

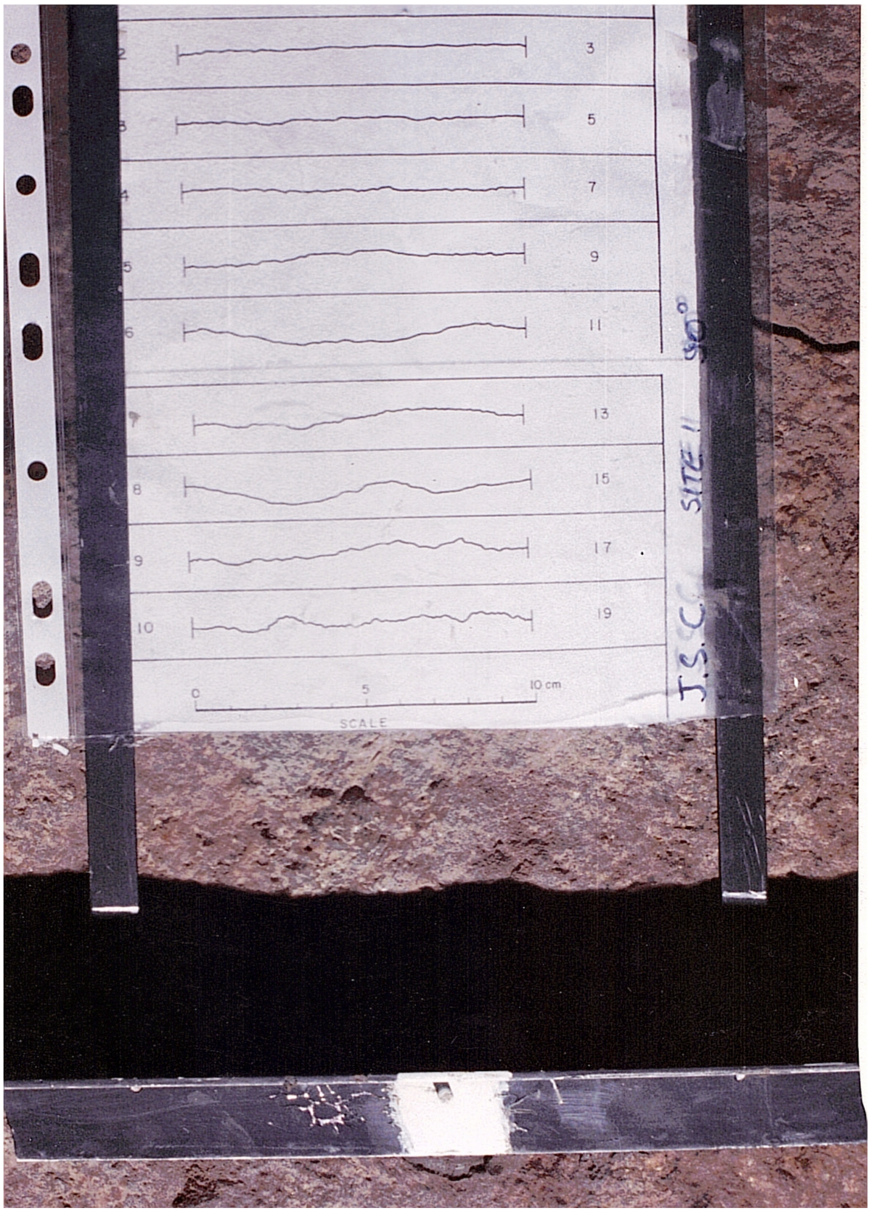


Figure 4. Shadow profile of a joint surface with a JRC chart shown for assessing the JRC value (From Milne, 1988).

4 FIELD PROFILOMETER

Techniques exist for detailed analytical assessments of discontinuity profiles. These techniques are suited for use in conjunction with lab based 2-D and 3-D profilometers. Field techniques for recording discontinuity profiles are either time consuming to use or do not record profile data in a digital format.

A laser profilometer has been developed at the University of Saskatchewan for field use. The light weight unit is shown in Figure 5. The laser measures the amplitude on the profile and a potentiometer measures the distance along the profile. A DI-710 series data logger by DATAQ instruments, in conjunction with a disk memory card, are used for saving acquired field data. Software to upload field data onto a PC comes with the data logger. Black and Decker VPX batteries operate the LRP remotely or the system may be connected directly to a 120 volt AC outlet.

The wenglor CP08MHT80 laser is a class 2 laser and has a working range of 30 mm to 80 mm. The resolution of the unit on speed mode is 12 µm. At a working distance of 30 mm the light spot size is 0.5 mm x 1 mm and increases to 1 mm x 2 mm at a working distance of 80 mm. Larger beam widths will average finer vertical variations reducing resolution of the unit. As this is a field tool with an operator controlling the horizontal travel, the accuracy and resolution is dependent on the rate of traverse. The accuracy and resolution improves with slower and smoother traverses across the sample. To date the greatest error in precision has been found to be caused by the user, allowing the sample of the profilometer to slip while making several passes over a single profile.

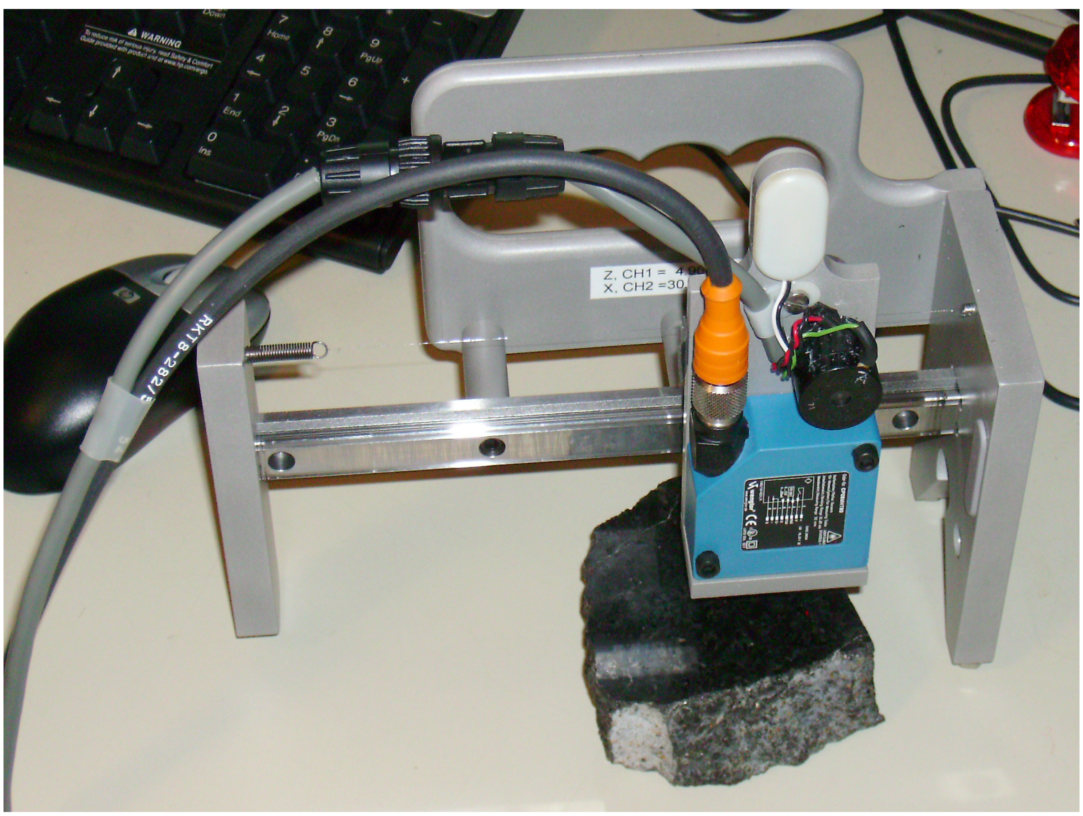


Figure 5. Portable laser profilometer developed at the University of Saskatchewan.

A typical profile created by the laser profilometer is shown in Figure 6. The sample shows the repeatability of the profilometer, as a traverse is run from one end of the joint to the other, then back again (i.e., returning to its starting position). Also shown is the Ra value calculated for this surface, which is -2.8 mm.

One problem that has been found with the prototype field profilometer is the inaccuracy of measuring vertical steps of greater that 1 cm. The laser uses a single detector for recording the reflection of the laser and on certain surfaces it is not accurate when vertical profiles are to the side the detector is on. To record the vertical step the profiler needs to be turned 180 degrees and the traverse needs to be rerecorded.

4.1 *Future improvements to the current unit*

A protective housing needs to be placed to cover open wires connected to the potentiometer and the potentiometer itself on the profiler. The current design allows for the storage of the profiler and accessories in a waterproof case. However it does not allow for the case to be closed and sealed during field use. This creates a problem with portability if one is looking to walk around profiling rock surfaces. To remediate the problem the team will consider drilling a hole in the waterproof case and allow for a connection of the wires on the outside of the case close to the handle to allow for portability while in use. The team will also be considering other configurations for storing the circuit board, data logger and batteries to allow a more user friendly experience by creating easier access to all commonly used plug-ins inside the case. The final step is to create a user friendly macro to allow for easy upload of the data into a template spreadsheet and the automatic generation of roughness parameters such as JRC and Ra. The ability to overcome the afore-noted difficulty in profiling vertical steps could be addressed by using a higher-end laser.

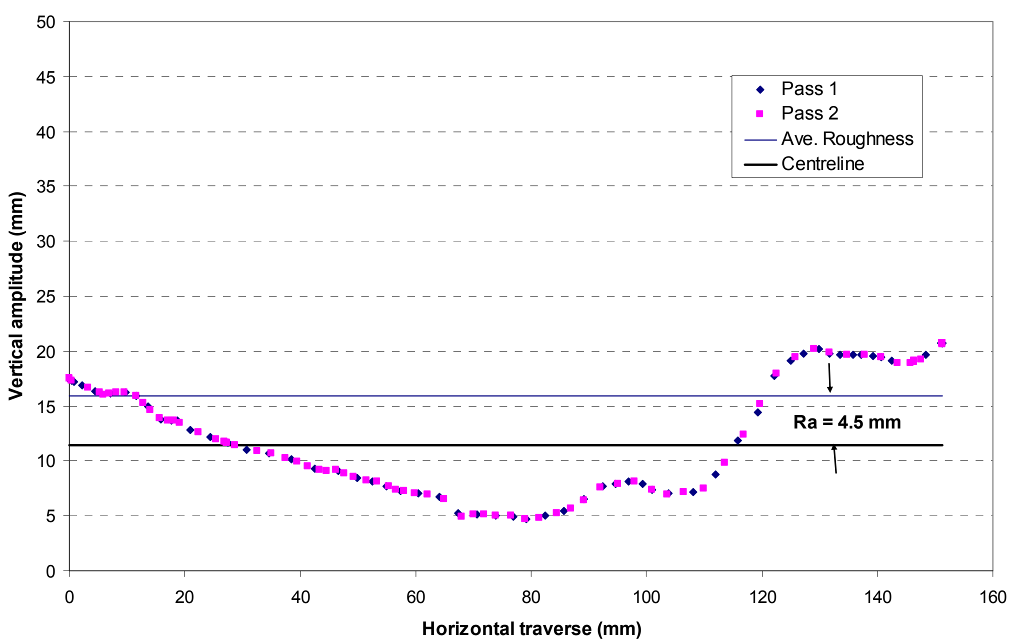


Figure 6: Sample joint surface profile generated using the portable laser profilometer.

5 CONCLUSIONS

There is a large gap between the quality of field data that is commonly collected compared to our ability to measure, record and quantify discontinuity profile conditions in the lab. Due to the highly variable nature of discontinuity conditions, field techniques are needed for easily measuring and recording large numbers of joint profiles to improve our understanding of the importance and variability of this rock mass property.

Rock mass classification systems are the most commonly used approach quantifying behaviour and strength properties of a rock mass. Discontinuity condition is an important part of classification and improved methods of quantifying this parameter, in the field, will improve rock engineering design. These improved methods will also be useful in petroleum engineering and greenhouse gas sequestration operations because these depend on characterization of the frictional strength and hydraulic properties of fractures, both of which are strongly influenced by joint roughness.

The newly developed profilometer can easily be used, in conjunction with field mapping / line mapping studies, to obtain discontinuity profiles. These profiles are recorded in digital format and can be analysed to obtain different measures of discontinuity roughness. It is ideally suited for use with core logging projects where the unit can be mounted to quickly scan core samples of joint surfaces. Current methods of assessing discontinuity surface conditions of either rough, smooth or polished can be greatly improved with measurements.

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