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Issues related to stability design of very high spoil dumps

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ABSTRACT: As spoil dumps get higher, particularly in strip mining where most overburden is placed in-pit, consequences of slope failure become disproportionately greater.

Current understanding of the shearing behaviour of spoil for stability design has involved a combination of laboratory-scale diagnostic testing and engineering judgment. This is a relatively empirical approach that provides a linear shear strength envelope for materials known to exhibit non-linear behaviour, particularly under high confining stresses. A shortcoming to the diagnostic testing is that oversize particles are usually scalped to accommodate the device capacity. The influence of prototype-size particles on the geomechanical behaviour of mine spoil is not truly captured.

In response to concerns about overestimating the shear strength and stability of high spoil dumps, and current plans for coal mine dumps to exceed 400 m in height, there is a need to rationally define the stress-strain behaviour of more characteristic spoil masses under representative compressive and shearing loads.

A Large Direct Shear Machine (LDSM) has been designed at The University of Newcastle to generate reliable stress-strain data on large samples of coal measures spoil (0.72 m x 0.72 m x 0.6 m) subjected to loads representative of very high dumps (~3.5 MPa). This paper reviews current methods for predicting shear strength parameters in the context of very high spoil dumps, and presents an overview of the design considerations of the DSM.

INTRODUCTION

Following the global economic crisis in 2009, the Australian economy sustained growth as a consequence of continued coal exports. Over the next decade or so, the demand for Australia's coal is expected to increase significantly in response to the projected needs of China and India.

The aim of any open pit coal mine design is to provide the steepest possible excavation configuration that is commensurate with stability, safety and financial requirements. The economic depth for open cut coal mining, expressed as the 'strip ratio', is based on the unit revenue of the coal and the cost to recover it. The increased demand for Australia's largest export is seeing the nation's coal producers secure significant price rises for the commodity. The flow-on effect is that deeper coal reserves previously regarded unprofitable due to high stripping ratios are now being developed, with mine owners relying on experience-based models to establish stability design criteria for pit slopes.

For high-value commodities such as coking-coal, economic depths in excess of 275 m are currently underway in Australian coal mines, with plans to progress to 350 m or more. This translates to mine spoil dumps potentially reaching heights of up to 450 m. Current experience-based understanding of mine spoil stability behaviour falls well short of this, by about 330 m. Furthermore, civil engineering experience with rockfill dams is that current experience-based models overestimate strength under higher stress regimes.

Mine owners have relied on geotechnical practitioners for advice on geotechnical risks that could impact on the success of long-term mine plans. Since current methods are believed to overestimate the stability of very high spoil dumps to an unknown degree, and the consequences are potentially catastrophic, risks to mine owners cannot be evaluated and due diligence reviews may find that legal, financial and operational risks to the business are unacceptable.

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In the context of very high spoil dumps, the uncertainty associated with current strength models can only be reduced by simulating field-scale conditions in the laboratory.

LIMITATIONS WITH CURRENT DESIGN STRENGTHS

Empirical shear strength envelopes

Linear envelope - BMA Coal strength framework

The Australian coal mining geotechnical community currently uses either totally empirical strength models or simple models based on extremely small test specimens. The BMA Coal strength framework was described in 2004 by Simmons and McManus, and represents almost two decades of extensive in-house research and collaboration with CSIRO on dragline-scale dumps. It is based on laboratory tests with empirical adjustments using back analyses of several large spoil dump failures.

The framework provides a visual-tactile method for identifying any type of spoil into one of four categories. Spoil category identification is based on the assessment of five geological attributes, comprising predominant particle size, consistency, structure, plasticity and age.

Table 1 - Spoil Categories and Attributes (after Simmons and McManus, 2004)

CATEGORY		1	2	3	4
Description Attributes	**Weighting** *(excl. Age)*	Fine-grained clay-rich high plasticity	Fine-grained low plasticity with larger clasts	Larger clasts with fine matrix, low plasticity	Large blocks, minor fines, minor slaking
Predominant Particle Size	3/31=**9.7%** *(11.6%)*	Clay	Sand	Gravel	Cobbles
Consistency: cohesive cohesionless	7/31=**22.6%** *(26.9%)*	Soft to Firm Loose	Stiff Med. Dense	Hard Dense	XLS+ rock Very Dense
Structure	7/31=**22.6%** *(26.9%)*	Matrix only	Matrix supported	Framework supported	Framework only
Liquid Limit	9/31=**29.0%** *(34.6%)*	High (>50)	Intermediate (35 – 50)	Low (20 – 35)	Not Plastic (<20)
Age	5/31=**16.1%**	0 - 2y	2 - 10y	10 - 30y	>30y

The 'structure' attribute is a fabric-related parameter, where larger particles represent the 'framework', and finer particles the 'matrix' (Figure 1). Simmons and McManus (2004) describe the framework as the larger sized fraction that is relatively stiff and transmits most of the forces within the spoil mass when in particle-to-particle contact. Comparably, they describe the matrix as the finer-sized component that fills the void spaces between framework particles. Framework-abundant spoils are said to be stronger and less compressible than matrix-abundant spoils.

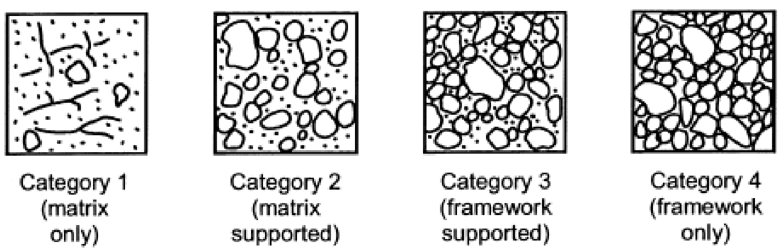


Figure 1 - Spoil structure attribute to be used with Table 1 (after Simmons and McManus, 2004)

For each category of spoil, shear strength parameters for three potential strength mobilization modes are provided, including unsaturated, saturated and remoulded conditions.

Table 2 - Shear Strength Parameters for Categories and Mobilisation Modes (after Simmons and McManus, 2004)

(Parameter standard deviations in italicised parentheses)

Category	Unsaturated			Saturated			Remoulded
	γ (kN/m³)	c' (kPa)	ϕ' (deg)	γ (kN/m³)	c' (kPa)	ϕ' (deg)	c'=0 kPa, ϕ' (deg)
1	18 *(1)*	20 *(10)*	25 *(2.5)*	20 *(1)*	0 *(0)*	18 *(3)*	18 *(1.5)*
2	18 *(1)*	30 *(15)*	28 *(3)*	20 *(1)*	15 *(7.5)*	23 *(2.5)*	18 *(1.5)*
3	18 *(1)*	50 *(15)*	30 *(2)*	20 *(1)*	20 *(10)*	25 *(2.5)*	18 *(1.5)*
4	18 *(1)*	50 *(15)*	35 *(2.5)*	20 *(1)*	0 *(0)*	30 *(1.5)*	28 *(2)*

The peak strength parameters cohesion c' and friction angle ϕ' are based on a linear fit to data obtained from laboratory tests simulating stresses experienced in 60-90 m high spoil dumps (Figure 2). The method has been validated in practice by back-analysis of instability and successful design of spoil dumps up to 120 m high. The linear Mohr-Coulomb shear strength envelope is expressed as:

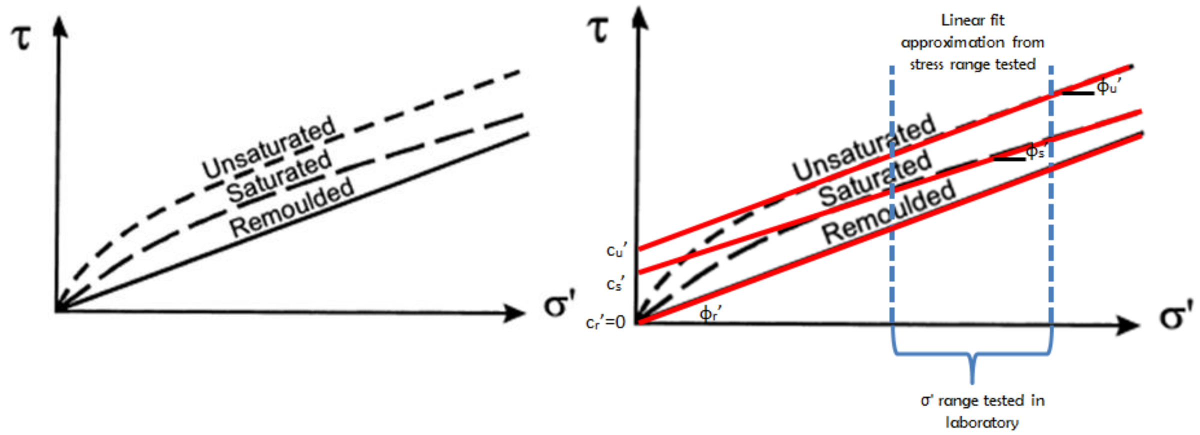


Figure 2 - (a) Three conceptual strength modes for spoil as described by Simmons and McManus (2004); and (b) modified to explain the linear shear strength approximation adopted in the framework

It is generally accepted that the frictional strength of mine spoil is strongly dependent on the magnitude of confining stress. A fundamental shortcoming of the BMA strength framework is that it cannot be extrapolated to cover the stress states expected in very high dumps. This is because the framework is based on a Mohr-Coulomb linear fit for data within a defined stress range, and mine spoil shear strength behaviour is distinctly non-linear. Extrapolation of the framework will overestimate the stability of very high spoil dumps to an unknown degree, and with plans for coal mine spoil dumps to exceed 400 m there is a need to investigate the shearing behaviour of representative spoil masses at field stress conditions.

Similarly, extrapolation of the framework to the low stress range will significantly underestimate the frictional strength for low spoil slopes (<30 m high), with the actual available shear strength considerably less than that estimated (Figure 3). It is a common occurrence for the lower excavated slope within a dragline spoil dump to sit at batters steeper than repose angle for short periods of time. Simmons and McManus (2004) suggest that, in addition to the effects of matric suction, the non-linear shear strength envelope helps explain this phenomenon.

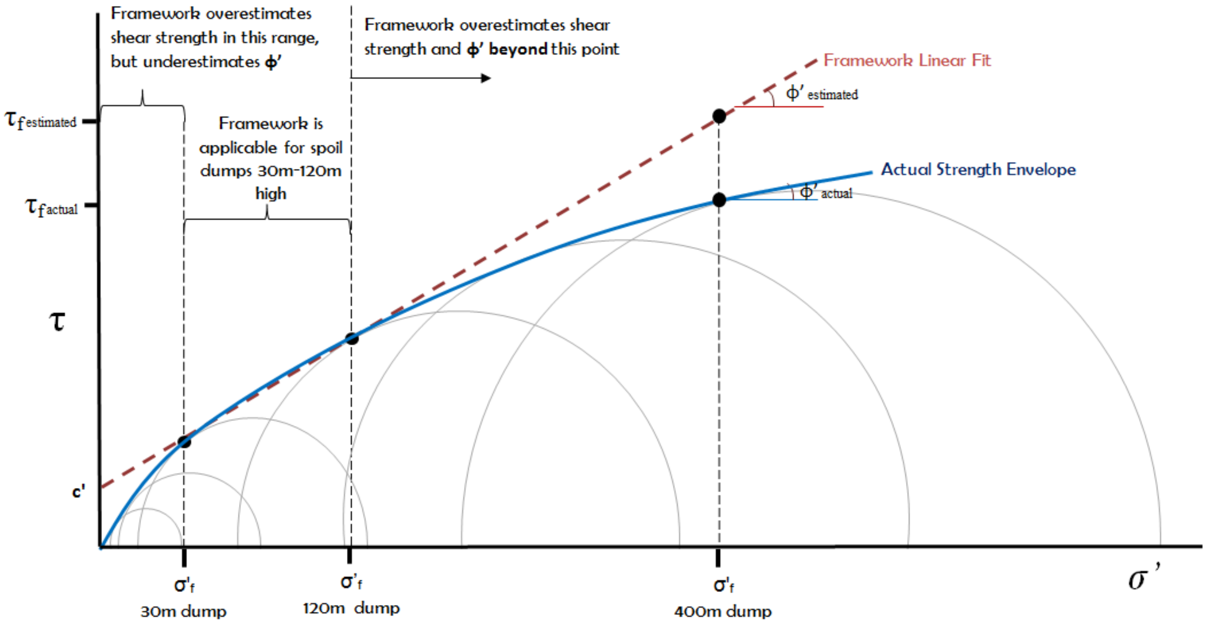


Figure 3 - Mohr diagram showing framework linear fit with respect to actual strength envelope (not to scale)

Non-linear failure envelopes

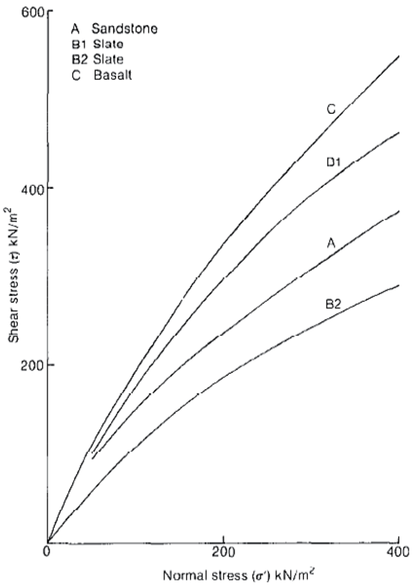
For decades, civil engineers have used non-linear failure envelopes to define the shearing behaviour of granular materials, particularly in relation to rock fill dam design. A number of studies have used power-law relationships to explain the dilatant behaviour of compacted rock fills at low effective stress, and reduced dilation due to particle crushing as stress increases.

Leps (1970) examined rock fill triaxial data obtained from over 20 dam construction projects and demonstrated a marked increase in friction angle ϕ' with decreasing confining pressure. Included in the data were test results from large apparatus capable of handling 1m diameter samples with a maximum particle size of 200 mm, at confining stresses up to 3.9 MPa. Barton and Kjaernsli (1981) developed a power-law criterion to model this data, and established a number of simple index tests that could be used to estimate the peak drained friction angle ϕ' of rock fill. Recommendations from the Barton and Kjaernsli study have strong merit for rock-fill projects using the types of rock-fills tested in the study; i.e. predominantly rocks with high to very high substance strength. However, its applicability to coal measures spoil of comparatively low substance strength is not well founded.

Charles and Watts (1980) modelled a power-law relationship to describe triaxial data obtained for rock fills of igneous, sedimentary and metamorphic origin, with varied substance strength and shape. In contrast to the aforementioned large-sample-high-stress studies, Charles and Watts placed a much higher importance on the stability of rock fill at comparatively low stresses. Samples with a maximum particle size of 38mm and specimen diameter of 230 mm were tested over the low stress range considered critical for lower-slope stability. It was proposed that over a limited stress range (40 kPa to 400 kPa) the shear strength of rock fill is given below, where constants A and b are dependent on rock type (Figure 4).

$$\tau = A\,(\sigma')^{b} \qquad (1)$$

The Charles and Watts study is applicable to rock fill embankments up to 50 m high, and covers the majority of rock types considered suitable for dam embankments. However, a number of limitations exist in the context of very high mine spoil dump design. The first is the stress range; 400 kPa is equivalent to a small spoil dump; and the equation cannot be extrapolated out to cover the higher stress range. The second is that the rock fills tested are heavily compacted well-graded samples; in contrast to mine spoil dumps that are placed in a loose state, with highly variable gradation as a result of parent rock type and mining processes. The third is that the samples were scalped to meet apparatus constraints; the deficiencies of which will be discussed later.



Rock type	A	b
A. Sandstone	6·8	0·67
B1. Slate	5·3	0·75
B2. Slate	3·0	0·77
C. Basalt	4·4	0·81

Figure 4 - Shear strength for rock fills at low confining pressures, and rock fill constants (Charles and Watts, 1980)

A CSIRO study (Mallett, *et al.*, 1983) performed direct shear tests on weak pit floor material at South Blackwater coal mine, and modelled best-fit linear and non-linear relationships to describe its strength envelope (Figure 5). The material was block-sampled from a clay-filled shear zone, hence not quantitatively comparable to the shear strength of mine spoil; however it is included in this paper for a number of reasons. It demonstrates the difference in frictional strength between the models for the low stress range, as is the case for a typical spoil. In addition it shows agreement for both strength models within the stress range tested in the laboratory; and infers that accurate shear strength models can only be achieved by testing representative size samples at the stress range of interest. In the case of very high spoil dumps, this translates to testing large samples at very high confining stresses.

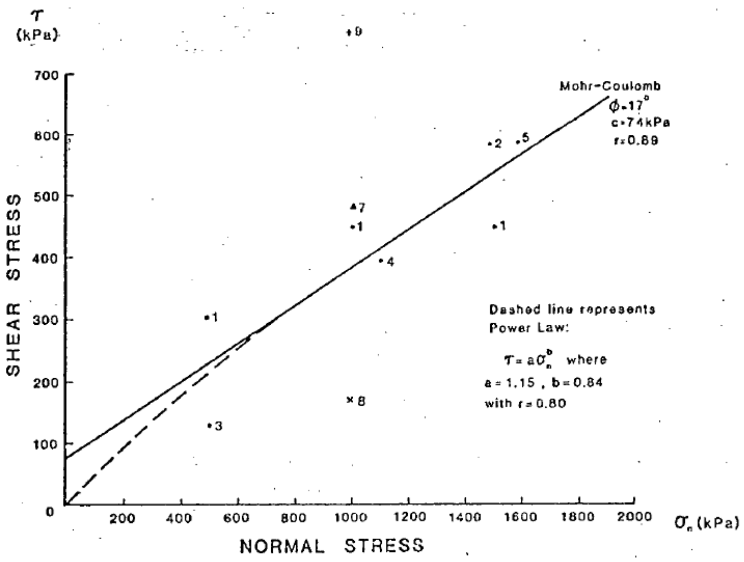


Figure 5 - Direct shear test results conducted on discontinuity material in a pit floor (Mallett, *et al.*, 1983)

Scale effects of laboratory testing

The application of laboratory data to spoil dump stability design has been used with caution for decades. This is partly attributed to the highly variable nature of mine spoil, consisting of large rocks and boulders and some fines at placement; but more so due to the inability of standard laboratory tests to account for this variability by testing full-scale samples at as-dumped grading and porosity, and at loads representative of field conditions.

It is widely accepted that the presence of large rocks and boulders strongly influences the shearing behaviour of rock fill. A decrease in frictional strength with increasing particle size is well established, particularly at low confining stresses. Vallerga *et al.* (1957) found this relationship to be non-existent for particles less than 5 mm. Barton and Kjaernsli (1981) attribute this to the higher propensity for larger rock fragments to undergo particle crushing than are smaller particles, as they are more likely to contain planes of weakness than are sands or fine gravels. However, limitations of standard laboratory apparatus are such that the shear strength of only the finer fraction of spoil can be measured. Application of such results to slope design will result in an overestimation of shear strength and stability.

By way of explanation, a standard laboratory direct shear box can test 60 mm x 60 mm samples, of maximum particle size equivalent to fine gravel, and maximum normal stress up to 2.7 MPa. For testing coarse materials such as rock-fill, a direct shear box capable of handling larger samples (300 mm x 300 mm) is becoming common-place in geotechnical laboratories, and can test coarse gravels at normal stresses up to 1 MPa. However, this is still not of sufficient size to handle the cobble and boulder size particles typical of coal mine spoil.

The overestimation of shear strength when testing only the fine fraction of spoil is demonstrated in Figure 6. Direct shear test results conducted at the University of Newcastle for a typical category 2U spoil (according to Table 1) are compared with the geotechnical parameters implicit in the BMA Coal strength framework. A category 2 spoil predominantly consists of fine-grained low-plasticity material (sand) with larger clasts, is stiff/medium dense and matrix supported. The 'U' refers to the unsaturated strength mobilisation mode (Table 2, Figure 2). The dimension of direct shear test sample was 100 mm x 100 mm with a maximum particle size less than 4.75 mm. The BMA Coal strength framework is based on a number of shear strength investigations, including large-sample direct shear tests with size of 1 m x 0.75 m and validated by field slope performance data for dumps up to 120 m high.

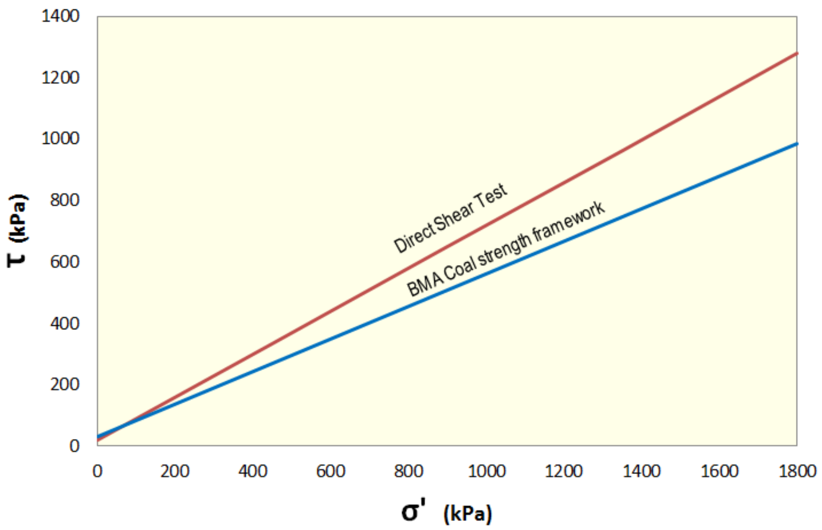


Figure 6 - Overestimation of shear strength due to scalping

Groundwater effects

The destabilizing role that water has on the soft rock spoil dumps of coal mines is widely recognized but difficult to evaluate.

Coal measures rocks are prone to physical and chemical deterioration with changes in moisture content, resulting in slaking and softening and a reduction in shear strength. Water pressure can have both positive and negative effects on slope stability; depending on the stress states within the spoil mass, the moisture content, and time-scale considered. Negative pore water pressure (suction) is usually implicit where low spoil slopes are observed to sit at batters steeper than repose angle for short periods of time. Conversely, positive water pressure reduces shear strength by pushing grains apart and reducing their intergranular friction.

It is widely accepted that water pressures must be considered in stability analysis. The civil engineering field often couples piezometer data with seepage analysis to establish the phreatic surface level and flow paths through a slope. However, water pressures are not easily ascertained in spoil materials. The logistical and practical difficulties associated with the installation of piezometers in spoil materials are many and varied, and often incur significant project costs. Voids are problematic for drilling equipment, commonly resulting in hole collapse, production disruptions and equipment damage.

Current understanding of water behaviour in strip mine spoils has not advanced far beyond the conclusions drawn by Gonano (1980, after Boyd, 1976), in that groundwater tends to occupy the basal 3 to 5 m of the spoil foundation, draining through the slope to the level at which water ponds externally. The BMA Coal strength framework employs a similar model, based on observations of spoil dumps in the Bowen Basin. It assumes that the phreatic surface is no more than 5 m above the foundation and reduces to the down-slope toe; with saturated spoil material underlying the phreatic surface.

The inherent uncertainties with groundwater behaviour in spoil dumps characterized by the strength framework are increased to an unknown degree in the context of very high spoil dumps. In particular, the extent of saturation and associated reduction in shear strength within the basal layer are significant to spoil dump stability, as large-scale deep-seated failure mechanisms commonly develop along this plane of weakness.

There is some conjecture around the potential for mine spoil to achieve effective saturation under the confining loads characteristic of very high spoil dumps. Preliminary studies at the University of Newcastle suggest that, although strongly dependent on field moisture content, this could be the case. It was found that for a typical category 2 spoil subjected to confining loads of 3.5 MPa, compression-induced saturation could develop at moisture contents greater than 11%. The field moisture content at the time of sampling ranged between 10 and 11%, following several weeks without rain. The results warrant further investigation into compression-induced saturation, which will likely be a key stability consideration for very high spoil dumps.

RESOLVING UNCERTAINTIES ASSOCIATED WITH STRENGTH FRAMEWORKS

Current knowledge of mine spoil shearing behaviour falls well short of that of soil mechanics for several reasons. The first is due to the significant costs and time associated with the design, construction and operation of equipment large enough to test characteristic spoil samples at field stress conditions. And secondly, the BMA Coal strength framework has worked well for nearly a decade, and its limitations are only starting to emerge with the prospect of deeper mines being developed.

The University of Newcastle is currently undertaking research to update and extend the BMA Coal strength framework to include very high spoil dumps. Of key importance is the ability to measure the stress-strain behaviour of characteristic spoil masses under field stress conditions.

Estimation of stress states for very high dumps

The maximum confining stress required to simulate conditions within a 400 m high spoil slope has been estimated for the two commonly observed large-scale failure mechanisms for spoil dumps; a deep seated multi-wedge mechanism, and a multi-wedge rill mechanism (Figure 7).

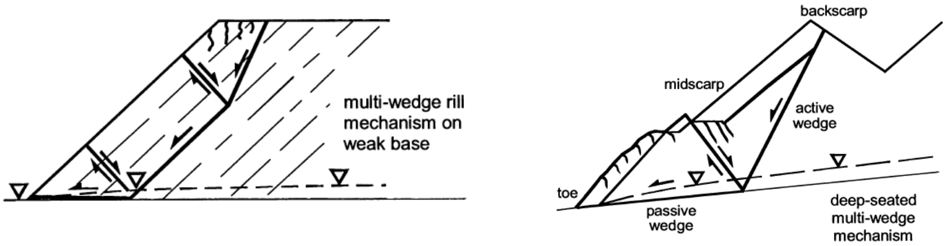


Figure 7 - Large-scale failure mechanisms for spoil dumps (Simmons and McManus 2004)

The slope geometry was simplified to rill angle (37°) for a total slope height of 400 m; the base of which was assumed saturated to a maximum of 5 m above the foundation floor. A weak remoulded basal layer occupying the lower 2 m was also assumed. Limit equilibrium analyses explored the effects that foundation inclination and back-scarp location had on the stress distributions through the spoil mass and associated Factor of Safety. The Sarma method for non-vertical slices was used to divide the failure surface into boundaries considered most appropriate for capturing the anisotropic strength state characteristic of mine spoil (after Simmons and McManus, 2004). This method is based on the principle of limiting equilibrium and the method of slices, and calculates the critical horizontal acceleration required to bring the mass of the spoil slope bound by the failure surface to a state of limiting equilibrium (of forces and moments).

The following observations were made in the analyses:

- The deep-seated multi-wedge failure mechanism developed the highest normal stresses within the spoil mass, occurring on the base of the passive wedge.
- Enlarging the failure surface geometry by moving the backscarp away from the slope crest increased the maximum normal stress within the spoil mass. However, this also increased the Factor of Safety against failure occurring.
- Increasing the foundation inclination had the opposite effect, reducing the Factor of Safety and the maximum normal stress within the dump.

The analyses suggested that, for a marginally stable 400 m high spoil dump, the maximum normal stress acting on the base of the passive wedge could range between 3.1 and 3.4 MPa, depending on foundation inclination. Figure 8 shows an example 2D limit equilibrium analysis for a 400 m spoil dump of simplified geometry. This analysis was performed using the Galena code software (Clover Technology, 2012) and the Sarma method for non-vertical slices.

Furthermore, Mohr analysis using the BMA Coal strength framework parameters, and extrapolating to confining stresses equivalent to 400 m of spoil weight, suggests normal and shear stresses at failure are unlikely to exceed 3.5 and 2.1 MPa respectively. It is recognized that extrapolation will overestimate the shear strength to an unknown degree; however is useful in establishing the upper-bound of stress required for discussion.

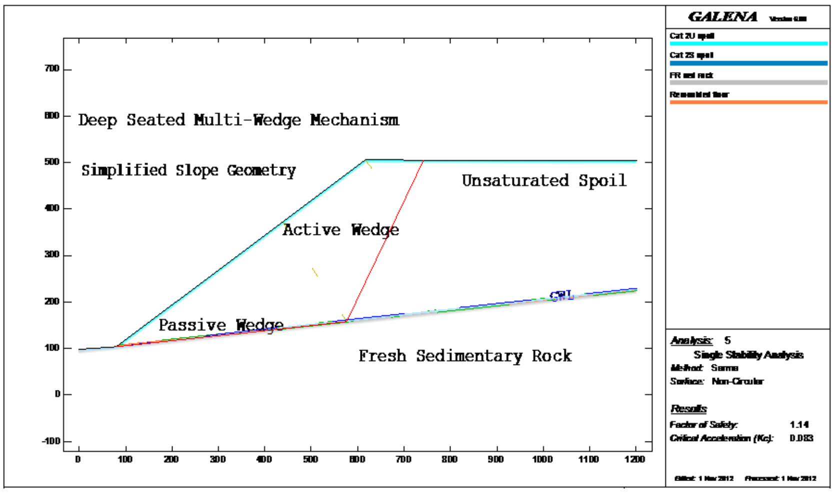


Figure 8 - Example 2D limit equilibrium analysis of a simplified geometry for a 400 m spoil dump

Field-scale test apparatus

To the authors' knowledge, few testing machines exist worldwide that can meet the large-sample-high-stress requirements for shear strength testing of representative spoil masses at field stress conditions.

A large direct shear test frame was constructed to test then-representative spoil masses as part of a CSIRO study into the stability of spoil piles (Mallett, *et al.*, 1983). At the time of the study, spoil dumps rarely surpassed 90 m in height. The apparatus could handle large samples (1 m x 0.75 m x 0.67 m) and test at consolidating and shearing loads of 1.3 MPa.

It is understood that a large-scale-high-stress triaxial device exists at the IDIEM Laboratory of the Universidad de Chile in Santiago. The apparatus can test samples 2 m x 1 m in diameter, with maximum particle size of 203 mm at confining pressures up to 2.5 MPa. The apparatus has been used to characterize the geotechnical properties of very high waste dumps in the copper mines of Codelco, Andina Division (CAD) in Chile. The waste rock tested by Linero *et al.* (2006) is classified as 'hard-rock', consisting of porphyry and granodiorite of high substance strength. To the author's knowledge, the apparatus has not been used to perform shear strength studies on the 'soft-rock' coal mine spoils.

In comparison, it is evident that the CSIRO apparatus falls short of the required design stress of 3.5 MPa for very high dumps. Furthermore, logistical limitations prevent the use of the IDIEM Laboratory device for shear strength investigations into coal measures spoil at the University of Newcastle.

Large direct shear machine

Overview

A large direct shear machine (LDSM) has been designed at the University of Newcastle as part of a postgraduate research project. Construction of the LDSM commenced in mid-2012, and is expected to be fully operational by 2013. The design criteria for the LDSM were:

- To be capable of handling large (full-scale) spoil samples;
- To have sufficient hydraulic capacity to simulate field loading conditions estimated for very high spoil dumps (minimum of 3.5 MPa and 2.1 MPa for normal and shearing loads respectively);
- To maintain constant normal load whilst also minimising tilt of the top plate;
- To apply a constant rate of horizontal displacement;
- To be as rigid as possible to prevent sample rotation and minimise side-wall deflection, whilst also minimising friction losses;
- To be able to conduct wet (inundated) and dry tests.

Figure 9 shows the schematic of large direct shear machine.

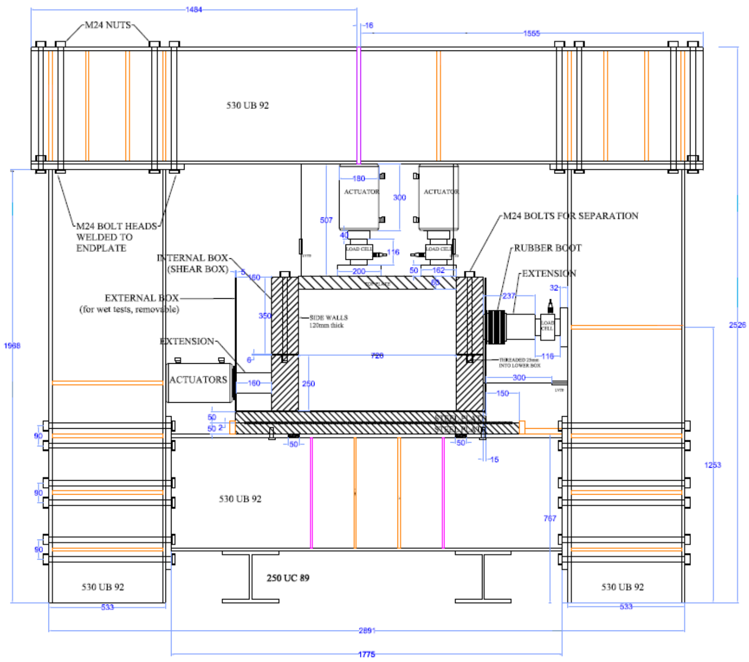


Figure 9 - Large direct shear machine

The dimensions of the internal shear box are as large as possible within budget constraints such that 3.5 MPa confining pressure can be imposed on the shear plane. The initial research proposal indicated that a 1 m x 1 m shear box would suitably handle the large samples required. However, budget limitations have restricted the size to 0.72 m x 0.72 m.

The internal shear box consists of a 350 mm-high upper box, and a 250 mm-high lower box. The sidewalls consist of 120 mm thick solid steel (250 grade); designed to minimise deflection and associated volume changes under the very-high expected loads. High-tensile strength (Grade 8.8) 30 mm-diameter threaded rods join the sidewalls such that the boxes can be disassembled between tests if required. Removable water-proof walls (external box) encase the internal box, and enable inundated or 'wet' tests to be conducted.

The internal shear box is mounted in a large self-reacting stand-alone frame, fabricated from over 26 lineal metres of 530 mm-deep universal beams. The frame is window-shaped and has the dimensions of 3 m x 1.2 m x 2.5 m (l x w x h), and reinforced with over 100 steel plates up to 16 mm thick. During testing, the LDSM will weigh more than 8 t.

Some scalping will be necessary to accommodate the sample size. With a maximum sample height of 600 mm, and likely to reduce to 450-500 mm following the application of confining load, a maximum particle size between 65 mm and 100 mm is anticipated. Note that this is based on the recommendations from test methods developed for smaller apparatus. A new test method will be devised for the LDSM, which will set out the nominal maximum particle size, subject to machine trials.

The confining and shearing forces will be applied via a number of 100 t double-acting hydraulic actuators. Considerations to controlling tilt of the top-plate led to the strategic placement of three actuators such that corrections for displacement could be individually applied during consolidation, whilst still maintaining a common constant load between them. The three cylinders can deliver a maximum consolidating stress of up to 5.7 MPa to the shear plane; however will be restricted to 3.5 MPa in initial stages of testing. Two cylinders acting in the horizontal direction can transfer up to 3.7 MPa stress to the shear plane, however it is anticipated that the peak shear stress is unlikely to exceed 2.1 MPa.

Loads will be measured via five load cells; three positioned in series with the actuators applying the confining loads; and two opposing the horizontal actuators. Horizontal and vertical displacements will be measured via transducers located as close to the shear plane as possible.

The LDSM allows for 150 mm of horizontal travel; equivalent to approximately 21% horizontal strain. Small scale direct shear tests on the spoil intended to be tested in the LDSM indicated that a peak shear stress was generally reached between 10 and 15% horizontal strain. The available 21% allows for any potential scale effects, and for post-peak stress-strain behaviour to be observed. The nominal rates of displacement will vary for the category of spoil tested and the saturation condition; and will be determined from full-scale consolidation tests on the LDSM.

For comparison purposes, Figure 10 shows the internal shear box of large direct shear machine and a standard size shear box inset.

Figure 10 - Scale comparison: Internal shear box of large direct shear machine, with a standard size shear box inset

LDSM outputs

It is anticipated that the proposed LDSM will provide peak shear strength data for coal mine spoils subjected to a wide range of confining loads, particularly those representative of very high dumps. The widest possible range of coal measures spoil types will be tested at various moisture contents in keeping with the strength mobilisation modes outlined in the BMA Coal strength framework.

The framework is used with confidence to characterize coal measures spoil dumps up to 120 m high. The LDSM data will be used to generate the full-scale stress-strain data required to extend the BMA Coal strength framework to reliably assess the stability for spoil dumps up to 400 m high.

Additionally, the LDSM will allow for scale effects to be measured. Although some scalping will be necessary to accommodate its capacity, it is expected that the stress-strain data can be calibrated by back-analysis of existing very-high coal mine spoil dumps.

CONCLUSIONS

The uncertainties associated with the application of current shear strength models to very high coal measures spoil dumps have been presented, and scale-effects inherent to standard laboratory testing of mine spoils have been discussed. These shortcomings can only be overcome by the construction of a purpose built machine capable of simulating field-scale conditions; however access limitations prevent the use of existing large-sample-high-stress machines for testing Australian coal measures spoils. A large direct shear machine (LDSM) has been designed at the University of Newcastle as part of a postgraduate research project. It is anticipated that the LDSM will provide reliable stress-strain data for full-scale samples of spoil subjected to loads representative of very high dumps. The data will be used to update and extend the BMA Coal strength framework to cover these higher stress ranges.

ACKNOWLEDGEMENTS

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