Scale-effect considerations for shear strength assessment of coal mine spoil

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Coal mine spoil dumps commonly exceed 250m. There are plans to construct spoil dumps more than 400m high.

The scale effect on shear strength suggests there is a minimum test specimen size, and minimum test normal stress that is technically acceptable for simulating a shear failure surface within a high dump constructed of mine spoil.

Practicing engineers are reluctant to apply shear strength parameters determined from standard laboratory testing due to uncertainty regarding the significance of scale effects.

How do we determine shear strengths for modelling the stability of high dumps?
SO DOC... YOU'RE SAYING THE SPOIL IS EXCEPTIONALLY STRONG, EVEN THOUGH IT NEVER STANDS UP AT MORE THAN 30°?

WELL, IF THAT'S WHAT THE DATA SAYS, IT MUST BE RIGHT...

THANKS DOC. MANAGEMENT WILL BE SO PLEASED!

ABSOLUTELY !!!

IF WE EXTRAPOLATE THE DATA BY SEVERAL ORDERS OF MAGNITUDE, THE RESULTS INDICATE THAT YOU CAN BUILD YOUR SPOIL DUMPS 2 KILOMETERS HIGH WITH SLOPE ANGLES OF 80°!!

Max $\sigma_n =$ 1MPa
1. DOES SIZE MATTER?

To what degree can the grading of a spoil sample be down-scaled to comply with device limitations, so that the influence of prototype-sized particles on shear strength is not anomalous?

2. DOES STRESS MATTER?

Normal stress limits of test apparatus. Can the failure envelope developed from small-scale tests be reliably extrapolated out to the much higher stress ranges to simulate field conditions for dumps of modern and future heights (>350m)?
What has been used until now?

- Spoil-specific strength testing is rarely performed
- For 2+ decades shear strength estimation for spoil dumps has been based on published guidelines such as the BMA Coal (BMAC) strength framework (Simmons & McManus, 2004).
  - Linear Mohr-Coulomb strengths
  - Small-scale tests that simulated stresses for dumps 60-90m high
  - Test data adjusted by back-analysis of failed dumps up to 120m high
  - Verified in practice for dumps 30-120m high

- What about high dumps?
  - For rockfill dam design there is a broad acceptance of curvilinear shear strength envelopes
  - If this was true for coal mine spoil, extrapolation of linear strength envelopes to cover the stress range for high dumps may overestimate shear strength to an unknown degree
BMAC shear strength framework

Spoil structure control ranking (Category)

Shear strength defined as linear Mohr-Coulomb Failure Envelopes After Simmons and McManus (1995, 2004)

\[ \tau = \sigma_n' \tan \phi' + c' \]
Instability Mechanisms

Mechanisms (b) and (c) → $\sigma'_n$ acting on the critical failure surface is large

BMAC shear strength framework
1970’s & 1980’s

Spoil dumps rarely exceeded 90m in height

Max $\sigma_n \leq 1\text{MPa}$
Fast forward to dumps of modern times
High dump example > 350m

>120m
Max $\sigma_n >> 1$MPa

No reliable design information

$\leq 120$m
Max $\sigma_n \leq 1$MPa

Reliable design information from the ’70s & ’80s

≤120m
Max $\sigma_n \leq 1$MPa

No reliable design information
Standard-sized Direct Shear Machine (DSM)

60-100mm

Max $\sigma_n \sim 1\text{MPa}$
Scalping Mine Spoil to fit Shear Box
Scale Effect - Normal Stress

\( \tau \) overestimation

\( \tau \)

Extrapolated linear envelope

Actual strength envelope?

BMAC framework

\( c' \)

\( c' = 0 \)

30m

120m

400m

Dump height or \( \sigma'_n \)

Standard shear box
Resolving Limitations – Full Scale Testing

• A **Large Direct Shear Machine** at the University of Newcastle was custom-built to test large samples of spoil at field stresses
  – Specimen Dimension 720mm x 720mm x 600mm
  – Normal Stress Range 0 – 4600kPa

• Significance of scale effects evaluated by comparing shear strength data measured by DSMs of various sizes:
  – Small (60-100mm)
  – Medium (300mm)
  – Large (720mm)

• Test Materials
  – Consistently graded, fine-grained dry silica sand (calibration)
  – Permian coal mine spoil containing fine and coarse grained particles in a range of different proportions
Large Direct Shear Machine

Standard Box Size
Sand Test Results – Shear Strength

All Shear Box Sizes, different stress ranges

\[ \sigma'_n = 0-1250 \text{kPa} \] (standard lab stress range)

\[ \sigma'_n = 0-3400 \text{kPa} \] (wide stress range)
Sand Test Results – Secant Friction Angle

All Shear Box Sizes, different stress ranges

- $\sigma'_n$ = 0-1250kPa (standard lab stress range)
  - $\phi'_s$ unchanged with increasing $\sigma'_n$ for all DSM sizes

- $\sigma'_n$ = 0-3400kPa (wide stress range)
  - $\phi'_s$ unchanged with increasing $\sigma'_n$ for all DSM sizes
Test material – Permian Mine Spoil

Samples dominated by siltstone and fine to medium grained sandstone. Minor amounts of claystone, shale, tuff, laminite and conglomerate.

Category 2 spoil (BMAC framework)
Mine Spoil Test Results – Secant Friction Angle

All Shear Box Sizes, different stress ranges

$\sigma'_n = 250$-1100kPa (standard lab stress range)

$\sigma'_n = 250$-4600kPa (wide stress range)

Systematic decrease in $\phi'_s$ with increasing $\sigma'_n$ for small DSMs

For LDSM - Systematic decrease in $\phi'_s$ with increasing $\sigma'_n$ for Zones 1 and 3 of trilinear envelope
Mine Spoil Test Results – Shear Strength

All Shear Box Sizes

\( \sigma'_n = 250-1100 \text{kPa} \) (standard lab stress range)

\[ \begin{align*}
\sigma'_n &\quad \tau \\
0 &\quad 0 \\
200 &\quad 200 \\
400 &\quad 400 \\
600 &\quad 600 \\
800 &\quad 800 \\
1000 &\quad 1000 \\
\end{align*} \]
Extrapolated failure envelopes from 100mm and 300mm DSMs compared with actual 720mm LDSM data

→ Shear strength overestimated by small DSMs

$\sigma'_n = 250-4600\text{kPa (wide stress range)}$
Conclusions

• For coal mine spoils, scale effects are significant in the context of dumps of modern and future heights
  – Size of the specimen tested → **SIZE DOES MATTER !**
  – Normal stress → **STRESS DOES MATTER !**

• Adoption of shear strength parameters measured by standard-sized DSMs will overestimate the shear strength of spoil dumps with height-equivalent stress ranges of 450kPa-4600kPa

• Scale effects are material-type dependent
Thank You for Listening - Questions?

Big John Timelapse