Design Shear Strengths for Mine Spoil

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Prior State of Practice

BMA Coal Spoil Categorisation Process (Simmons and McManus, 2004)

- Shear Stress at full yield ($\tau$)
- Unsaturated
- Saturated
- Remoulded

Saturated state is possibly reversible
Remoulded state is NOT reversible

Effective Normal Stress ($\sigma'$)
Prior State of Practice

BMA Coal Spoil Categorisation Process (Simmons and McManus, 2004)
**Prior State of Practice**

BMA Coal Spoil Categorisation Process (Simmons and McManus, 2004)

<table>
<thead>
<tr>
<th>Category</th>
<th>(a) Unsaturated</th>
<th>(b) Saturated</th>
<th>(c) Basal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\gamma$ (kN/m³)</td>
<td>$c'$ (kPa)</td>
<td>$\phi'$ (deg)</td>
</tr>
<tr>
<td>1</td>
<td>18</td>
<td>20</td>
<td>25</td>
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<tr>
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<td>10</td>
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</tbody>
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... and a Quick Reminder about Origins

Prior State of Practice

BMA Coal Spoil Categorisation Process (Simmons and McManus, 2004)

FOS = 1.19

Non-vertical slices: Sarma Method

“ill-defined zone”
Prior State of Practice

BMA Coal Spoil Categorisation Process (Simmons and McManus, 2004)

FOS = 1.13

Non-vertical slices: Sarma Method

Dump stability is controlled by strength of spoil that becomes saturated or remoulded

"ill-defined zone"
Spoil Materials Tested with LDSM

1. Typical 2yr Exposed Fresh Permian (MAC CD)  [Cat. 2.5]
2. Typical 1mo Exposed Fresh Permian (MAC RX)  [Cat. 2.5]
3. “Vintage” (10yr+) Exposed Fine-Grained Permian (MAC VP)  [Cat. 2]
4. Fresh Permian Non-Slaking (ROL FP-NS)  [Cat. 2]
5. Fresh Permian Slaking (ROL FP-S)  [Cat. 2]
6. Weathered Tertiary Volcanics (ROL WTV)  [Cat. 1]
C20019: Unit Weights from LDSM

UNSATURATED UNIT WEIGHT IS HIGHER THAN BMAC PARAMETERS

![Graph showing the relationship between saturated unit weight ($\gamma_b$) and effective stress ($\sigma'$). The graph compares different datasets including MAC CD & RX, MAC VP, ROL FP-NS, ROL FP-S, and ROL WTV. The data points and lines indicate a general trend where $\gamma_b$ increases as $\sigma'$ increases.](image)
SATURATED UNIT WEIGHT IS HIGHER THAN BMAC PARAMETERS
C20019: MAC CD Unsaturated

Mt Arthur Coal CD Spoil Unsaturated

- LDSM Tests
- BMAC Cat.3U
- BMAC Cat.2.5U
- BMAC Cat.2U

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C20019: MAC RX Unsaturated

Mt Arthur Coal RX Spoil Unsaturated

Peak shear stress (kPa) vs Normal stress (kPa)

- LDSM Tests
- BMAC Cat.3U
- BMAC Cat.2.5U
- BMAC Cat.2U

- 453, 295
- 1522, 857
- 2560, 1636
- 3610, 2531
- 4605, 2973

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Mt Arthur Coal Vintage Permian Spoil Inundated

- LDSM Tests
- BMAC Cat.2S
- BMAC Cat.1.5S
- BMAC Cat.1S

Peak shear stress (kPa) vs. Normal Stress (kPa)

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C20019: ROL FP-NS Unsaturated

Rolleston Fresh Permian Non-Slaking Spoil Unsaturated

Peak shear stress (kPa)

Normal Stress (kPa)

LDSM Tests
BMAC Cat.3U
BMAC Cat.2.5U
BMAC Cat.2U

0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

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C20019: ROL FP-NS Inundated

Rolleston Fresh Permian Non-Slaking Spoil Inundated

![Graph showing the relationship between Normal Stress (kPa) and Peak Shear Stress (kPa). The graph includes data points and lines for LDSM Tests, BMAC Cat.3S, BMAC Cat.2.5S, and BMAC Cat.2S.]

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C20019: ROL FP-S Unsaturated

Rolleston Fresh Permian Slaking Spoil Unsaturated

- LDSM Tests
- BMAC Cat.2U
- BMAC Cat.1.5U
- BMAC Cat.1U

Peak shear stress (kPa) vs Normal Stress (kPa)

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C20019: ROL FP-S Inundated

Rolleston Fresh Permian Slaking Spoil Inundated

- LDSM Tests
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C20019: ROL WTV Unsaturated

Rolleston Weathered Tertiary Volcanics Spoil Unsaturated

- LDSM Tests
- BMAC Cat.2U
- BMAC Cat.1.5U
- BMAC Cat.1U

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BOHOGS  9 May 2017 Peak Downs Mine
C20019: ROL WTV Inundated

Rolleston Weathered Tertiary Volcanics Spoil Inundated

- LDSM Tests
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- BMAC Cat.1.5S
- BMAC Cat.1S

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Summary Characteristics MAC Spoils

MAC CD & RX
lithic sandstone/siltstone, alluvial floodplain, UCS 5-25+ MPa, degradation on exposure, low slake/swell/dispersion, LL~28%

_Fits with BMAC Categorisation process, linear envelope but possible strength enhancement for \( \sigma'_n > 2500 \text{ kPa} \)_

MAC VP
carb mudstone, alluvial offbank, UCS 5-10 MPa, degradation on exposure, low slake, high swell, low dispersion, LL~38%

_Unsaturated fits with BMAC Cats, but Saturated does not follow, and difference is attributable to clay content in rock_
Summary Characteristics ROL Spoils

ROL FP-NS & FP-S
lithic sandstone/siltstone, alluvial floodplain, UCS 2-5 MPa, degradation on exposure, FP-S breaks down readily and is much more slake-prone, LL~44%

Unsat FP-NS fits, but Unsat FP-S does not. Saturated does not fit: the huge difference is attributable to particle strength/friability

ROL WTV
weathered Tertiary volcanics: sesquioxide clays, UCS 0.5-2 MPa, shrink-swell fissures but no degradation on exposure, high slake, high swell, low dispersion, LL~57%

Doesn’t fit BMAC Categorisation process but was supposed-to
Models for Spoil Moisture Conditions

Simmons & McManus (2004): conceptual models based on limited drilling and observations going back to 1970’s UDC-CSIRO research at Goonyella & South Blackwater

Phreatic Surface height ≤ 5m above floor of dump

Perched Water Tables of very limited height on old running surfaces
Smith et al 1995: Spoil Moisture Conditions

Hydrostratigraphic Model:
- Spoil texture
- Dump structure
- Hydrological factors

Spoil texture:
- “soil-like”/“rock-like”? (channelised flow)
- cohesionless/cohesive?
- slake-prone

Developed as part of BC *Interim* Waste Dump Design Guidelines
Wunsch et al 1996: Spoil Moisture Conditions

Hydrogeological Model:
- based on observed structure formed by mining sequence
- investigated with wells and insitu flow tests
- also examined spoil settlement over time

Kentucky: rehabilitated landform built from surcharged coal mine spoil

DEEP INFILTRATION BASIN

final landform surface
haulroad & truck dump
dragline dump
dragline bench & pad
cast carpet

“hollow” fill

SHALE

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Three-Zone Moisture Condition Model

- **Upper Zone:** can gain some water from rainfall, and will lose water to evaporation and percolation, ≤ 20% infiltrates
- **Middle Zone:** transmits water, undergoes minimal changes
- **Lower Zone:** a phreatic aquifer with a water table, a capillary zone, and an unsaturated zone
Lower Zone:
Deep, Structured, with a Saturated Base

- Exists only when basal spoil is saturated by water re-entering the mine void after spoil dumping
- Saturated spoil state at rock floor contact, with a phreatic surface and positive water pressure
- Capillary zone above phreatic surface: saturated but with negative water pressure (suction)
- Unsaturated transition zone with suction increase and degree of saturation decrease with height
- Capillary zone thickness varies:
  - ≤ 0.3m (Cats.3-4, “rock-like”)
  - 0.3m – 1m (Cat.2, “soil-like”, non-cohesive)
  - 1m – 10m (Cat.1, “soil-like”, cohesive).
Summary and Conclusions

BMAC Strengths may be reliably used for spoils that satisfy additional criteria:

- Rock material strengths: UCS ≥ 5 MPa
- Plasticity limitations: LL < 35%
- Slaking behaviour limited: Coffey Test low slake/swell, low-moderate dispersion

No compelling evidence for strength envelope curvature, and compelling evidence for material transitions under higher dump stresses, requires cutoff at c’=0, φ’=45°

C20019 Report: recommendations for stability analysis

BMAC treatment of groundwater and stability analysis methodology remain valid but still require care and thought.
Acknowledgements

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• John Brett

... and a final Comment: