Settlement and shear strength of uncemented coal mine overburden materials placed loose under dry and wet conditions

Tassement et résistance au cisaillement de matériaux de couverture non cimentés extraits de mines de charbon et mis en dépôt en vrac dans des conditions sèches et humides

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ABSTRACT: The overburden materials in the coalfields of South East Queensland, Australia, are dominated by essentially uncemented rocks, which rapidly break down on excavation to extract coal. On excavation, these uncemented materials bulk up to a very loose density. On end-dumping by haul truck in spoil piles, these loose materials then undergo three forms of settlement: that due to their self-weight, "collapse" settlement on wetting-up by rainfall, and settlement due to degradation on exposure to weather, resulting in a substantial increase in density. Due to their lack of cementation, these overburden materials degrade rapidly on exposure to the weather, leading to significant settlement, followed by some reversal on re-agglomeration and swell. Collapse and weathering-induced settlements, both being associated with exposure to water, occur simultaneously on wetting-up. Wetting-up also causes a substantial reduction in the shear strength of the materials. The paper quantifies the settlement and shear strength of uncemented overburden materials excavated on open pit mining in the coalfields of South East Queensland.

RÉSUMÉ: Les matériaux de couverture dans les bassins miniers du Sud-Est du Queensland, en Australie, sont principalement constitués par des roches non cimentées, qui se décomposent rapidement lors de l'excavation pour extraire le charbon. Lors de l'excavation, ces matériaux non cimentés sont mis en dépôt en vrac dans un état très lâche (très faible densité). Après mise en dépôt par des camions dans des zones de stockage, ces matériaux subissent trois formes de tassement : celui résultant de leur poids propre, le tassement d'"effondrement" résultant du mouillage par la pluie et le tassement dû à la dégradation lié à l'exposition au climat. Ces tassements entraînent une augmentation substantielle de la densité. En raison de leur non cimentation, l'exposition au climat entraîne une dégradation rapide de ces matériaux de couverture, se traduisant par des tassements significatifs, suivis par des processus de reformation d'agrégats et de gonflement. Les tassements résultant du phénomène d'effondrement et des dégradations dues au climat, tous deux liés à l'exposition à l'eau, se développent simultanément lors du mouillage. Le mouillage entraîne aussi une réduction significative de la résistance au cisaillement des matériaux. La communication présente une quantification du tassement et de la résistance au cisaillement de ces matériaux de couverture excavés dans les mines à ciel ouvert des bassins miniers du sud-est du Queensland.

KEYWORDS: coal mine, compression, degradation, dry, overburden materials, settlement, shear strength, wet.

MOTS CLES : mine de charbon, compression, dégradation, sec, matériaux de couverture, tassement, résistance au cisaillement, humide

1 INTRODUCTION

The net bulking of coal mine overburden materials from their *in situ* state on open cut mining results in an increased volume required to accommodate the excavated spoil. Knowing the bulking and subsequent self-weight, collapse and degradation-induced settlement of the spoil over time is important for estimating the storage volume required in mined-out pits and in out-of-pit piles.

The majority of the self-weight settlement occurs during placement ((Naderian *et al.*, 1996), with only a residual 20%, or so, occurring after the end of construction. Collapse settlement on wetting-up of the placed spoil by rainfall and/or groundwater infiltration requires just sufficient wetting-up to saturate the micro-cracks that occur at highly-stressed particle contacts. On collapse of these particle contacts, the coarse-grained particles break down, creating multiple, less-stressed particle contacts. Further wetting-up of the spoil then essentially fills the pores between the broken particles, without leading to significant further settlement.

Uncemented coal mine overburden materials bulk-up substantially on excavation, but also settle significantly due to their self-weight or the height of spoil, "collapse" on wetting-up, and degradation on exposure to weather cycles. Uncemented weathered rock spoil sampled from Jeebropilly Coal Mine in the Ipswich Coalfields of South East Queensland, Australia is characterised and its shear strength, compression under loading, and degradation due to exposure to weather cycles are described. Laboratory testing was carried out on scalped specimens at the as-sampled gravimetric moisture content (that is, "dry") and in a water bath (that is, "wet"), which highlighted the high potential for this material to slake and disperse, and to collapse and breakdown, on wetting-up.

2 SAMPLING OF JEEBROPILLY WEATHERED ROCK

The uncemented weathered rock overburden found in the depth range from about 5 to 20 m in an open pit at Jeebropilly Coal Mine was sampled from haul truck dumps. It was shaken through a 19 mm sieve fitted to the top of a 20 litre bucket. The sample passing 19 mm (-19 mm) and the +19 mm oversize were both weighed, and the oversize was photographed for later estimation of its particle size distribution.

3 SPOIL CHARACTERISATION

The characterisation testing of the Jeebropilly weathered rock was broadly carried out in accordance with AS 1289. The as-sampled gravimetric moisture content of the -19 mm scalped Jeebropilly weathered rock was 14.9%, and the Liquid and Plastic limits of the -0.0425 mm fraction were 71.0% and 21.0%, respectively, giving a Plasticity Index of 50.0% and indicating a Unified Soil Classification of CH (Clay of High

Plasticity). Note that the as-sampled moisture state was drier than the Plastic limit. In the as-sampled moisture state, the -2.36 mm scalped sample had a total suction, measured using a WP4 Dewpoint Potential Meter, of 4,320 kPa. The specific gravity of the solids, measured using a helium pcynometer, was 2.60.

The electrical conductivity (EC) and pH of a 5 (deionised water) to 1 (-2.36 mm scalped, dry solids) paste of Jeebropilly weathered rock were 356 µS/cm and 4.0, respectively. From the measured EC, corrected to 25^{o}C, and the relationship between EC and osmotic suction (after U.S.D.A. 1954), an as-sampled osmotic suction of 10 kPa was obtained, and a matric suction of 4,310 kPa was obtained by subtraction from the measured total suction. The Emerson Class Number of the Jeebropilly weathered rock was 1, implying that the material slakes and disperses completely, and had a high potential for breakdown and erosion.

Mg^{2+} is the dominant cation in the Jeebropilly weathered rock, and its high cation exchange capacity (CEC) of 16 cmol(+)/kg and sodium adsorption ratio (SAR) of 0.76 suggest a relatively high clay content, low permeability, limited structure, the potential for compaction under trafficking, and the potential for internal erosion.

The particle size distribution curves obtained from photographs using SplitDesktop (http://www.spliteng.com/split-desktop/) or by dry sieving after air-drying of the -19 mm scalped Jeebropilly weathered rock are shown in Figure 1, together with the scalped curves obtained by the removal of the oversize, for use in the various laboratory tests.

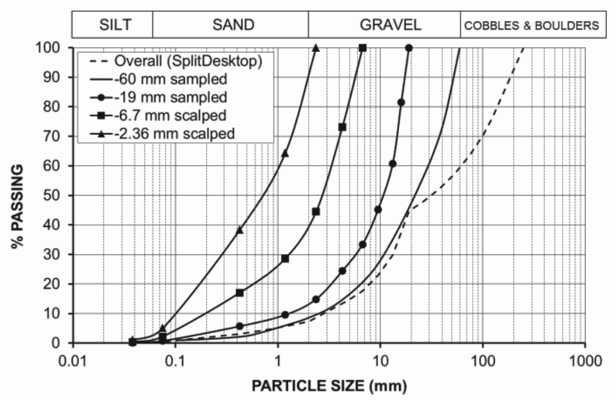

Figure 1. Particle size distribution curves of Jeebropilly weathered rock overall, and scalped for use in various laboratory tests.

The particle size distribution curves obtained for the -19 mm scalped Jeebropilly weathered rock by dry sieving after air-drying or 60^{o}C oven-drying, by wet sieving using tap water without or with dispersant added, and by hydrometer analysis in deionised water without or with dispersant added, are shown in Figure 2.

It is clear from Figure 2 that Jeebropilly weathered rock is extremely prone to breakdown in the presence of water, dominated by the gravel fraction breaking down to sand-size, with no appreciable generation of silt and clay fines. The results of the hydrometer analyses suggest that the fines content is less than 10% by mass, and that the clay content is negligible. However, it is likely that the intrinsic particle size does contain appreciable silt and clay fines, and that these would require more energy to be released than is applied in the standard test procedure. The effect of adding dispersant is minor.

Laboratory Standard compaction testing of -19 mm scalped Jeebropilly weathered rock indicated a low Maximum Dry Density (MDD) of only 1.52 t/m^3, at an Optimum (gravimetric) Moisture Content (OMC) of 19.0%, close to the Plastic Limit of the material. At the MDD and OMC, the material has a high porosity of 0.42 and a low degree of saturation of 69%.

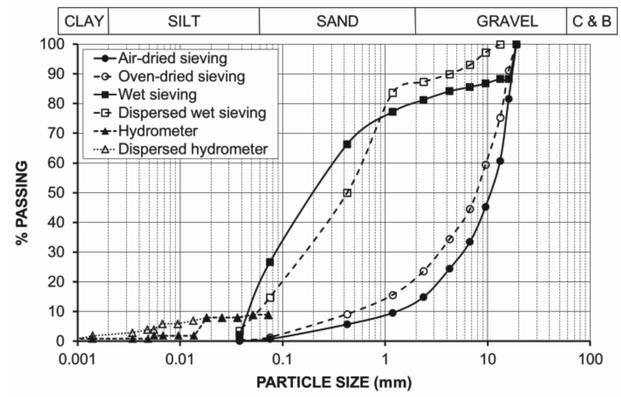

Figure 2. Particle size distribution curves of -19 mm scalped Jeebropilly weathered rock obtained with different pre-treatments and testing methods.

4 SHEAR STRENGTH

Shear strength testing of loosely-placed, -2.36 mm scalped Jeebropilly weathered rock, at its as-sampled gravimetric moisture content of 14.8% (that is, tested "dry") or tested in a water bath (that is, tested "wet"), was carried out in a 60 mm direct shear box. It demonstrated that the shear strength envelopes obtained were not substantially dependent on the shearing rate over the range from 0.01 mm/min to 1 mm/min; implying that drained conditions existed over this range.

On testing dry, the loose-placed dry density of the Jeebropilly weathered rock averaged 0.908 t/m^3. This increased to an average 1.226 t/m^3 after 24-hour compression under a normal stress of 500 kPa, and to an average 1.370 t/m^3 (75% of MDD) after shearing. Compression increased the average degree of saturation from the loose-placed value of 20.7 to 34.4% and 36.9% after shearing, as the average porosity decreased from 0.650, to 0.528 to 0.510, respectively.

On testing wet, the loose-placed dry density of the Jeebropilly weathered rock averaged 0.991 t/m^3. This increased to an average 1.351 t/m^3 after 24-hour compression under a normal stress of 150 kPa, and to an average 1.445 t/m^3 (82% of MDD) after shearing. Compression decreased the average gravimetric moisture content from the loose-placed value of 70.4 to 35.5% and 34.3% after shearing, as the average porosity decreased from 0.647, to 0.480 to 0.471, respectively.

The shear strength parameters obtained for -2.36 mm scalped Jeebropilly weathered rock are summarised in Table 1, in terms of apparent cohesion and friction angle, and friction angle only (assuming zero cohesion). These values are in broad agreement with those recommended for comparable coal mine spoil materials (Simmons 1995).

Shear strength testing of -2.36 mm scalped Jeebropilly weathered rock was also carried out in a 300 mm direct shear box at a shearing rate of 1 mm/min. The shear strengths obtained from the 60 mm and 300 mm direct shear box testing at a shearing rate of 1 mm/min are compared in Figure 3. The results from the smaller shear box cover a far greater range between dry and wet conditions than those from the 300 mm shear box, and appear more plausible.

Table 1. Shear strength parameters for Jeebropilly weathered rock.

State	*Dry*	*Wet*
Apparent cohesion (kPa)	29	6.0
Apparent friction angle (deg.)	27.2	19.5
Friction only angle (deg.)	35.2	22.0

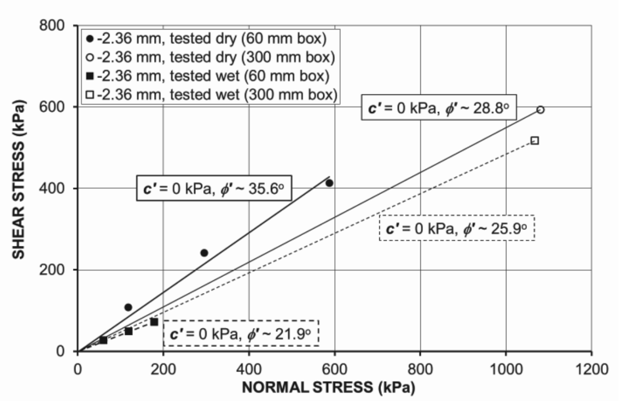

Figure 3. Comparison of friction only strength envelopes for 60 mm and 300 mm direct shear testing of -2.36 mm scalped Jeebropilly weathered rock.

5 COMPRESSION UNDER LOADING

Staged, and single-stage creep, compression testing of loosely-placed, -2.36 mm Jeebropilly weathered rock, at its as-sampled gravimetric moisture content (that is, tested "dry") or tested in a water bath (that is, tested "wet"), was carried out in a 76 mm diameter oedometer. The compression curves for the staged testing under dry and wet conditions are shown in Figure 4, indicating Compression Indices C_c of 0.408 and 0.271, respectively.

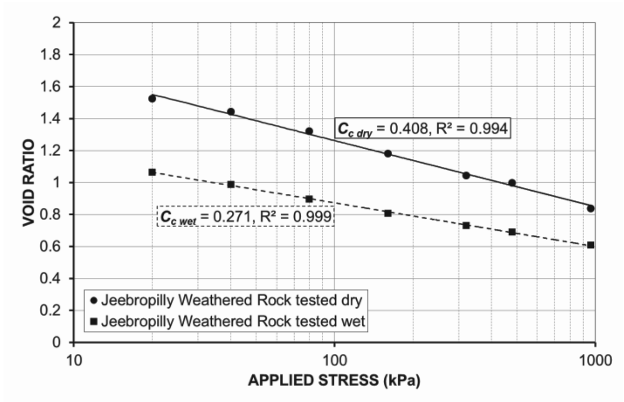

Figure 4. Compression curves for staged testing of loose-placed, -2.36 mm scalped Jeebropilly weathered rock under dry and wet conditions.

The % settlement (relative to the initial loose height) versus $\log_{10}$ time plot for a loosely-placed specimen tested dry under a single-stage creep loading of 500 kPa, over 14 days, shown in Figure 5, indicates a self-weight settlement rate of 4.5%/$\log_{10}$ cycle of time, and a creep settlement rate of 0.5%/$\log_{10}$ cycle of time.

From the staged testing under wet conditions and the creep testing under dry conditions, coefficient of consolidation c_v values may be calculated as a function of void ratio e, as shown in Figure 6. It is noteworthy that the data point from the single-stage creep test carried out under dry conditions lines up with the trendline for the data points from the staged testing under wet conditions. The "dry" specimen, tested at its as-sampled gravimetric moisture content of 14.8% (initial degree of saturation of 24.7%), achieved a degree of saturation of 40.0% by the end of the test. The relatively high final degree of saturation for the dry test goes some way towards explaining why the dry data point lines up with the wet trendline.

From the calculated coefficient of consolidation c_v and coefficient of volume decrease m_v values, the saturated hydraulic conductivity k_v values may be calculated from Equation (1).

$$k_v = c_v . m_v . \gamma_w \quad (1)$$

where γ_w is the unit weight of water = 9.81 kN.m^3. The resulting k_v values are plotted in Figure 7, which demonstrate the low permeability of wet -2.36 mm scalped Jeebropilly weathered rock, even in a relatively loose state.

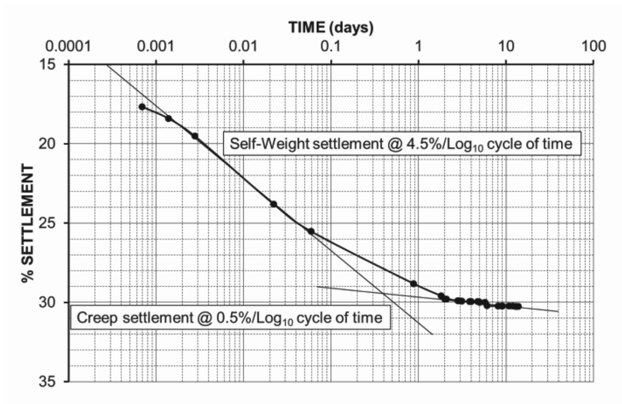

Figure 5. Single-stage creep loading of loose-placed, dry, -2.36 mm scalped Jeebropilly weathered rock under 500 kPa for 14 days.

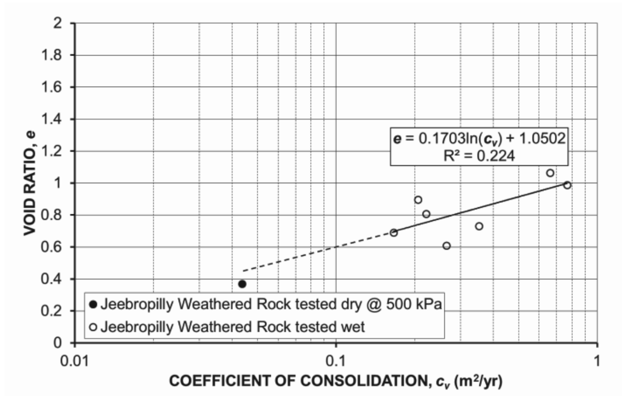

Figure 6. Coefficient of consolidation for loose-placed, -2.36 mm scalped Jeebropilly weathered rock under wet and dry conditions.

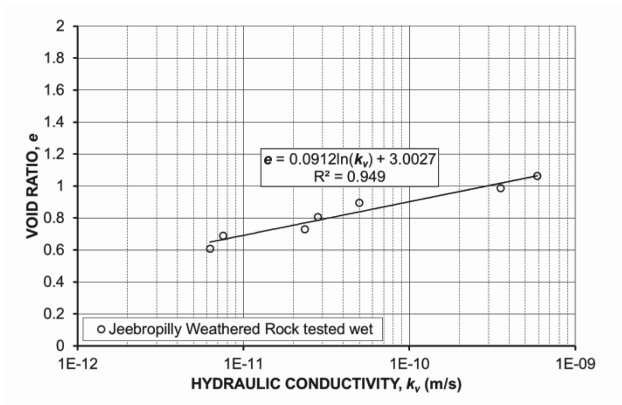

Figure 7. Hydraulic conductivity for loose-placed, -2.36 mm scalped Jeebropilly weathered rock under wet conditions.

6 DEGRADATION ON EXPOSURE

Jeebropilly weathered rock scalped to -19 mm was loose-placed to a nominal depth of 100 mm in a Perspex tray measuring

600 mm square by 150 mm deep and left exposed to the weather for 35 days, during which time it experienced wetting by a number of rainfall events totalling 113 mm, with desiccation between these rainfall events. The rainfall was recorded, the net settlement of the surface was measured regularly at nine points over the area of the specimen, and sub-samples were taken at the same time intervals for air-drying and dry sieving to determine the change in the particle size distribution.

The specimen underwent major particle breakdown, followed by re-agglomeration on desiccation crusting, as shown visually in Figure 8. Changes in particle size distribution during the course of the degradation test are shown in Figure 9. Figure 10 shows the cumulative rainfall and average net % settlement relative to the initial specimen height with time during the degradation test. Both Figures 9 and 10 clearly show the effects of the initial major particle breakdown and subsequent re-agglomeration, leading to reversals in the particle size distribution curves and average net % settlement.

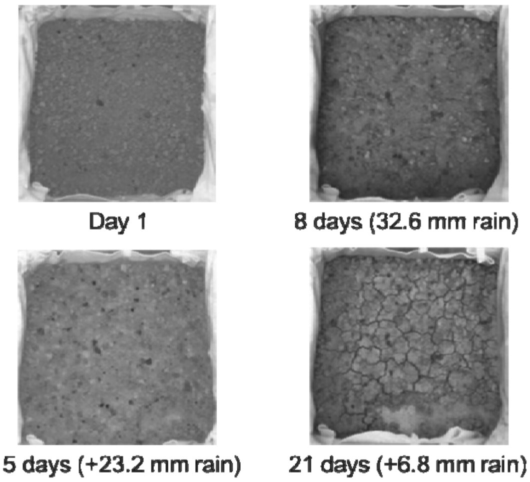

Figure 8. Photographs of major particle breakdown and re-agglomeration on crusting during degradation test on loose-placed, -19 mm scalped Jeebropilly weathered rock.

7 COMBINED SETTLEMENT OF JEEBROPILLY WEATHERED ROCK

Based on the results of the laboratory testing, the self-weight settlement of initially relatively dry, loose-dumped, uncemented Jeebropilly weathered rock spoil under 500 kPa (equivalent to a spoil pile height of about 30 m) could amount to about 15% of the initial spoil height, of 6% (20% of this) would likely occur post-construction. Wetting-up of loose-dumped, uncemented Jeebropilly weathered rock spoil could cause collapse settlement of a further 15% of the initial spoil height. Degradation-induced settlement of loose, uncemented Jeebropilly weathered rock spoil could be 15 to 25% of the initial height, although this might only occur to limited depth. Overall, the combined settlement of a 30 m high pile of loose-dumped, uncemented Jeebropilly weathered rock spoil, also subjected to collapse and degradation on wetting-up, could be up to 36 to 46% of the initial loose spoil height.

Coal mine open pits up to 500 m deep are being planned in the Hunter Valley Coalfields of New South Wales, Australia, which would result in spoil piles up to 600 m high. These could settle about 40% of the initial loose spoil height, resulting in a net bulking of the order of 12% relative to the initial *in situ* dry density of about 1.87 t/m^3.

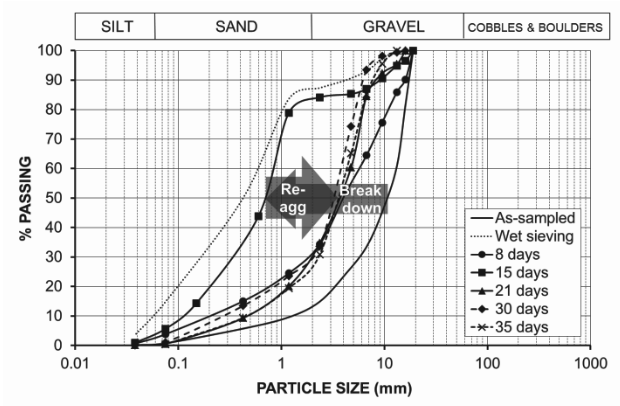

Figure 9. Changes in particle size distribution curves with time during degradation test on loose-placed, -19 mm scalped Jeebropilly weathered rock.

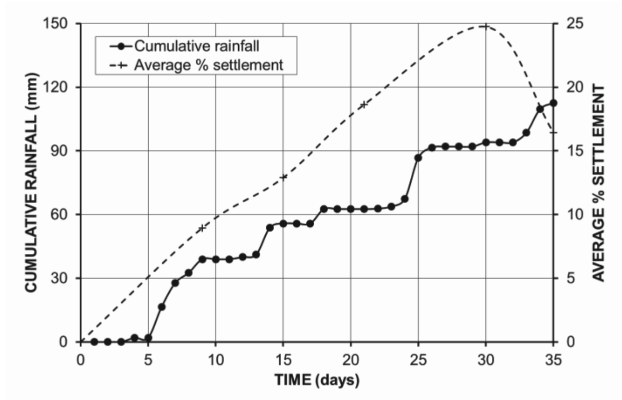

Figure 10. Cumulative rainfall and average net % settlement relative to the initial specimen height with time during degradation test on loose-placed, -19 mm Jeebropilly weathered rock.

8 CONCLUSION

The laboratory testing of uncemented Jeebropilly weathered rock spoil has identified and quantified the components of settlement on loading under dry and wet conditions, and on wetting-up alone. These are substantial and reduce, to a relatively modest amount, the initial considerable bulking on excavation and loose-dumping of the overburden in spoil piles. The final dry density of a high spoil pile of uncemented weathered rock spoil could eventually approach that achieved by laboratory Standard compaction of the material.

9 ACKNOWLEDGEMENTS

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10 REFERENCES

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