Mudstone Depressurisation behaviour in an open pit coal mine, Indonesia

Geneviève Marchand[1], John Waterhouse[2], Joseph Crisostomo[3]

[1,2] Golder Associates Ltd Pty, Level 2 1 Havelock Street, West Perth, WA, 6005, Australia,
[1]gmarchand@golder.com.au, [2]jwaterhouse@golder.com.au
[3]PT Adaro Indonesia, Menara Karya, 22nd-23rd Floor, Jl. HR Rasuna Said Block X-5 Kav. 1—2, Jakarta 12950, Indonesia, joseph@ptadaro.com

Abstract The Tutupan open pit mine, Indonesia, follows major coal seams for at least 15 km. The mudstones and sandstones in the coal-bearing sequence exhibit low strengths and the bedding dips vary from flat to steep. The final pit depth may be at least 300 m. A key issue in slope design is understanding the depressurisation behaviour of the mudstone units (some >20 m thick) within the high wall and parts of the low wall. Recent data interpretations have shown that unit thickness and unloading of the mudstones as well as dewatering of adjacent sandstone units all affect the depressurisation rate.

Key Words depressurisation, mudstone, pore pressure, open pit, coal, slope stability

Introduction

Mining and export of sub-bituminous coals at Tutupan, South Kalimantan, Indonesia began in the mid-1990s. The Tutupan open pit follows major groups of Miocene coal seams with a total thickness of at least 100 m for approximately 15 km in a geologically complex sequence. Coal seams vary in thickness along strike, and are interbeded with fine-grained sandstones, mudstones and carbonaceous mudstones, which generally exhibit low strength (Waterhouse et al. 2008). Bedding dips vary considerably along strike, and in one part of the mine, steepen progressively from 20° to more than 65° within 400 m. The projected final pit is likely to be at least 300 m deep, depending on global coal price, geotechnical analysis and design constraints.

Slope stability analyses at Tutupan have always integrated hydrogeology into the geotechnical engineering. As mining has developed and the understanding of the groundwater system has evolved, slope designs have been progressively optimised, resulting in important savings in excavation cost or reduced risk of slope failure. A key issue for slope design is understanding the depressurisation behaviour of the mudstone units (which range in thickness from a few metres to many tens of metres) within the high wall and part of the low wall. In some areas, the slope design is greatly affected by mudstone pore pressures and steeper slopes would allow considerable savings in mining costs and waste dump size. This paper addresses the influence of mining and dewatering on mudstone depressurisation.

Background and Observations

Although some mudstone units can be as thin as 1 m, others can, in combination, form most or all of the high wall. A typical cross-section of the Tutupan mine and its mining history from 2000 to 2010 is shown in Figure 1. The sequence has not been deeply buried (maybe 2,000 m). There is therefore a significantly greater degree of consolidation in the lowest mudstones, beneath the main coal seam, than in those several hundred metres higher in the sequence. The weakest mudstones are found in the mine high wall in the northern part of the pit.

Thin mudstone units, even in the low wall where they are the most consolidated, have been shown to depressurise quickly in response to dewatering of adjacent sandstones. However, difficulties in achieving depressurisation of thicker mudstones, particularly in the high wall, have always been a concern to slope design. Reduction in pore pressure in slopes may occur as a result of three mechanisms (Read and Stacey 2009):

- Groundwater flow away from the zone in question;
- Increase in total porosity, caused by deformation and expansion of the rock, as a result of striping the overlying material (lithostatic unloading or relaxation); and
- Increase in total porosity caused by expansion of the rock mass as a result of drainage and removal of water from the overlying rock (hydrostatic unloading).

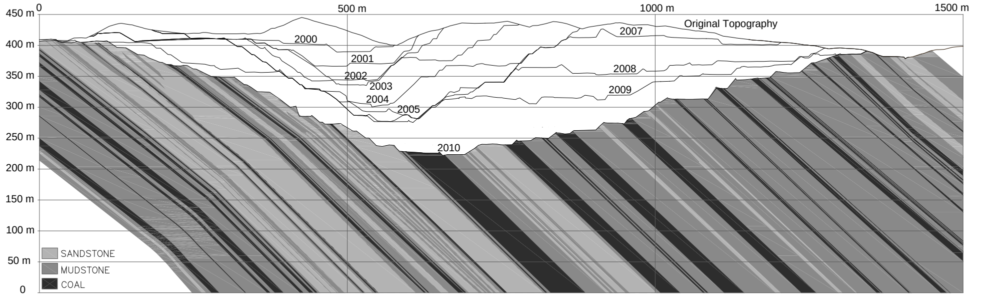


Figure 1 Typical Tutupan cross-section viewed north, with a mudstone-dominated high wall and multiple thin mudstone units in the upper part of the low wall and mining history from 2000 to 2010

Lithostatic unloading is considered to be the most effective depressurisation technique of the three in clayey material (Sullivan 2007). In the low permeability mudstones found at Tutupan, an increase in total porosity (by unloading) is believed to be the only mechanism which could reduce the pore pressures significantly in the context of slope design and at rates that match the rapid vertical rates of mining. From experience, the thinner mudstone units (< than 20 m) generally depressurise quickly with lithostatic and hydrostatic unloading, and in response to drainage of adjacent sandstone aquifers. They are therefore less of a challenge in slope design. Subsequent efforts were put in place to understand the depressurisation behaviour of thick mudstone units (> 20 m), largely targeting high wall design.

Pore pressure measurement system

Since 2004, more than 250 vibrating wire (VW) sensors have been installed in the low and high walls at Tutupan in depth ranges relevant to mining and potential failure zones. The mudstone pore pressure trends with time were interpreted by taking into account:

- the position of the sensor within the unit
- the thickness of the unit
- the presence or absence of known thin sandstone beds within the unit
- unloading by mining above and along strike; and
- the position of the mudstone within the sedimentary sequence.

In addition to interpreting the general depressurisation behaviour, the data have been analysed with respect to depressurisation with varying depth within particular units, the delay of depressurisation response and the rate of depressurisation.

Results

All VW sensors located within areas of mining showed lower pore pressure than the pre-mining values. It was concluded that unloading by mining had an effect on the pore pressure in thick mudstone units regardless of the depth, the thickness and the properties of the unit. Following unloading, the pore pressure within high wall mudstone units typically decrease to values equivalent to the elevation of the unit where it is exposed up-dip in that high wall.

Mining along strike from mudstone piezometers

In Figure 2, pore pressures started declining in June 2007 but mining in the area of the VW sensors only occurred between April and July 2008. The pore pressure decline shown in Figure 2 appears to be related to depressurisation due to mining of the same unit 200 m along strike from an elevation of 110 m down to 50 m from June 2007 to January 2008. Prior to the start of mining above the unit the pore pressures had already fallen below the final elevation of the unit expose in the high wall of 70 m. Therefore, mining above the unit did not further reduce the pore pressures.

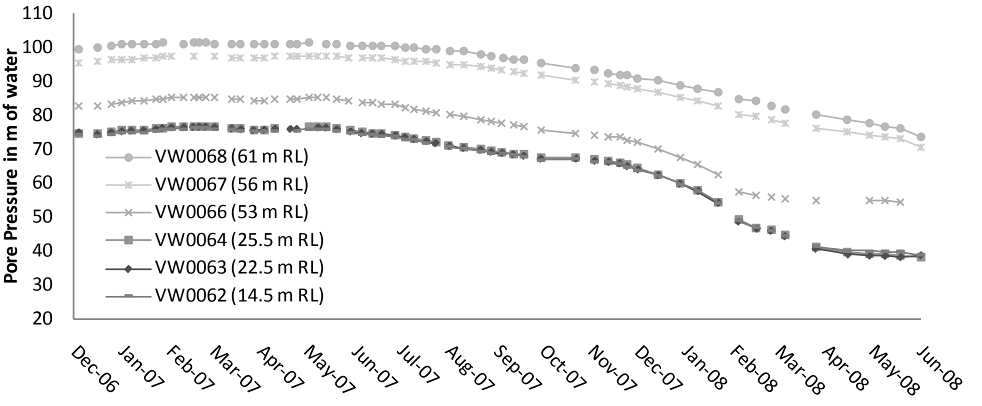


Figure 2 *Decline in pore pressure with mining along strike*

Depressurisation behaviour with depth (and lag time)

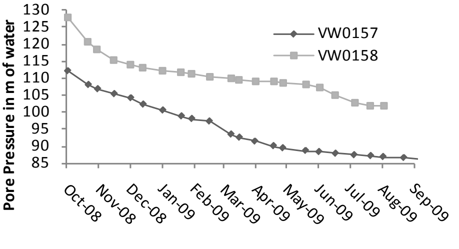
Although all mudstones with VW sensors have been shown to depressurise with unloading, the rate of depressurisation was affected by the depth to which each VW sensor was located within a unit. Figure 3a shows the lag time and the difference in head within the same unit following unloading. Mining of the unit ended in October 2008 to an elevation of 100 m. The VW sensor locations within the unit are shown in Figure 3b. Both VW sensors show an immediate and quick depressurisation response. However, the deeper sensor depressurisation rate slowed down earlier.

Depressurisation with thickness and with varying mudstone properties

The VW sensors presented in Figure 2 were installed at different depths within the same mudstone unit above and below a coal seam. The mudstone unit below the coal seam (VW0062 to VW0064) showed equivalent pore pressure to the coal and depressurised simultaneously. The VW sensors located in the mudstone unit above the coal (VW0066 to VW0068) had different pore pressures and different depressurisation behaviour, indicating that depressurisation does not always occur simultaneously through an entire unit. Furthermore, it confirms the variability in the depressurisation behaviour of the mudstone units, which could be attributed to different hydraulic properties, such as secondary permeability, presence or absence of thin sand zones, etc.

Drainage of adjacent sandstone and coal units

In general, dewatering of sandstone units within the low wall has caused a decline in pore pressure within the thick mudstone unit located immediately behind the sandstones. A trial dewatering involving the dewatering of a coal seam caused an immediate response within the adjacent mudstone unit (Figure 4). This decline in pore pressure was too small to be used in slope design.



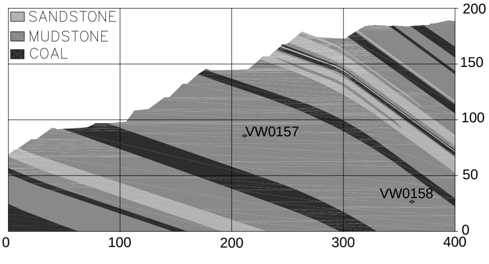


Figure 3 *a) Decline in pore pressure with depth following unloading b) VW sensor locations*

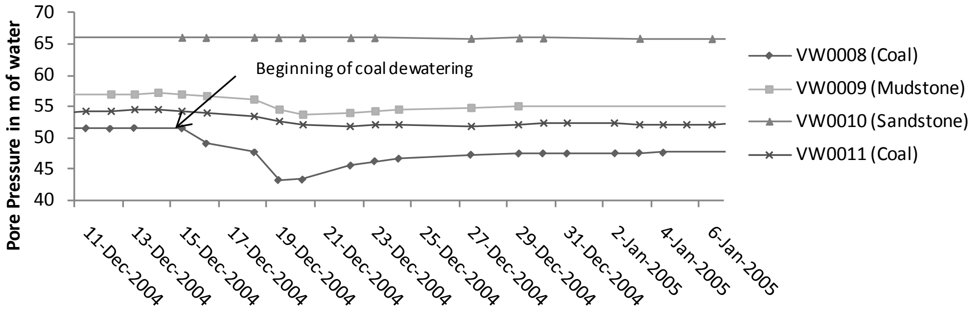


Figure 4 *Decline in pore pressure with dewatering of adjacent coal unit*

Conclusions

Four main conclusions have been drawn:

1. Unloading of mudstone units through mining has an immediate effect on the pore pressure close to the excavated face regardless of the thickness and properties of the unit. Depressurisation responses develop either directly beneath the unloaded zone and up to 200 m laterally.
2. Depressurisation occurs at distance away from the excavated face within a unit when unloading through mining or intensive dewatering.
3. The mudstone units (high in the sequence) show lower strengths and permeability and are less responsive than the deeper mudstones to depressurisation by means other than unloading.
4. Unloading through drainage of adjacent units reduces the pore pressures in thick mudstones:
   - Intensive dewatering of thick sandstone units reduces pore pressure in the portion of the mudstone adjacent to the dewatered sandstone.
   - Drainage of thin interbeds of coal and sandstone had a minor effect on pore pressure.

Although the pore pressure decreases with unloading, the rate of depressurisation is not necessarily sufficient to be used in the slope design. Based on the data available, it appears that mining above and along strike as well as intensive dewatering of adjacent permeable units are the two mechanisms that can cause mudstone depressurisation at a rate sufficient to steepen design slopes.

The data interpretation also showed that the mudstone units lower in the sequence have higher permeabilities than those higher in the sequence. Although it is doubtful that there are large differences in the primary permeabilities in the different mudstones, it is possible that the apparent difference is related to greater fracturing in the deeper and stronger rock units providing some secondary permeabilities.

Acknowledgements

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