An Integration of Hydrogeology and Geotechnical Engineering for the Design of the Tutupan Coal Mine T100 Low Wall, South Kalimantan, Indonesia

John Waterhouse [a)], Joseph Crisostomo [b)], David Nolan [c)], Dr Anthony Dutton [c)]

[a)] Golder Associates, 1 Havelock Street, Perth, WA 6019 Australia, email jwaterhouse@golder.com.au
[b)] PT Adaro Indonesia, Suite 704, World Trade Centre, Jl. Jend Sudirman Kav. 29-31,Jakarta 12920, Indonesia
[c)] Golder Associates, 611 Coronation Drive, Toowong, Q'ld 4064, Australia

Abstract

Mining of the Miocene sub-bituminous coals at Tutupan began in the mid-1990s. There was a general plan for 20 years of open pit mining along a strike length of some 15 km from 3-4 major groups of coal seams in a geologically complex sequence.

The coal deposit is notable for the low sulphur and low ash contents of the coal and for the thickness (up to about 50 m) of the deepest economic seam, which also has the best coal quality (lowest moisture content). The deposit differs from most others being mined in the region in that the bedding dips vary considerably (from about 20^0 to at least 60^0), and the material strengths are generally lower than others.

In common with many mining projects, a final mine plan was not available at the start of mining, as development began early to provide cash flow, and it was not until 2004 that an economically-based plan confirmed a likely full depth of mining to about 300 m. As the world price of coal increases, economics, subject also to geotechnical analysis and design constraints, may allow deeper mining.

Unusually for mining projects, Golder Associates and PT. Adaro have maintained continuity of most key senior technical staff on the project from the pre-mining studies to the present day. This has facilitated a progressively improved understanding of the geology and the stability issues and allowed good integration of groundwater manangement and slope design with logistical issues associated with the mining.

A key issue for successful mining is management of the stability of the low wall, with individual batters not to be steeper than bedding and the overall slope angle having a huge effect on mining costs. The potential saving in excavation costs is many millions of dollars per kilometre strike length per degree of steepening.

The geotechnical study (which is ongoing) has always involved a combination of experienced hydrogeologists working in an integral manner with geotechnical engineers and engineering geologists. As a consequence, all slope designs, failure analyses and investigations have included a detailed hydrogeological consideration.

Optimum slopes for the low wall can be achieved by depressurising the major sandstone units in the upper part of the low wall stratigraphy. Dewatering of the sandstone units has been shown to reduce pore pressures in the intervening mudstones provided that they are not more than 10-20 m thick. The thick mudstones that form the deeper part of the low wall are not amenable to depressurisation at rates that are useful in the context of the mining rates at Tutupan. Stability analyses suggest the mudstones should deform sufficiently to relieve some of the pre-mining pore pressure.

Careful integration of hydrogeology into the geotechnical engineering study is allowing progressive optimisation of the slope designs, assisted by depressurisation within sandstones by pumping wells and free-flowing drainholes. Future separation of clean groundwater from turbid surface runoff should minimise the issues associated with mine water discharges to the natural environment.

Key words: dewatering, depressurisation, coal, groundwater, open pit, slope stability

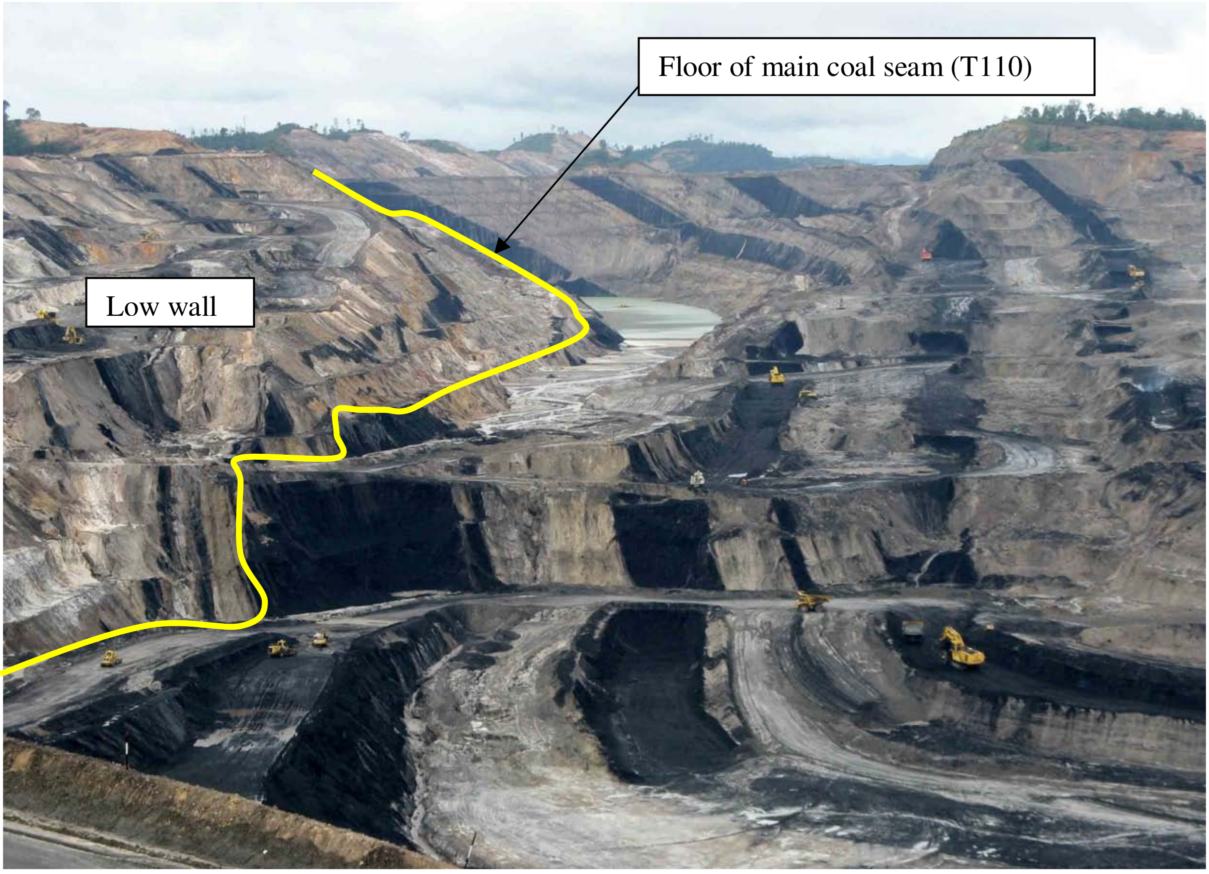
Introduction

This paper describes hydrogeological aspects of the low wall slope stability and the associated design study for the Tutupan coal mine, which is located in South Kalimantan, Indonesia. Coal has been mined since 1997 from an open pit operation over a length of some 15 km with a current maximum depth of about 180 m. The economically attractive coal seams total at least 100 m in thickness although seams vary in thickness and relative importance along the mine. All coal seams are interbedded with fine-grained sandstones, mudstones and carbonaceous mudstones.

In 2007, 36 million tonnes of coal was mined at Tutupan, making it one of the largest coal mines in Indonesia. The geological setting is different from many other Kalimantan coal mines with which Golder Associates has experience in that the material strengths are lower (for example, some sandstones have practically no cohesion) and the bedding dips vary considerably. In one part of the mine, bedding steepens progressively from about 20^0 to about 65^0 along only 400 m of strike length.

The development of an understanding of the issues controlling slope stability at this mine has required a combination of geological, geotechnical and hydrogeological studies that have been greatly helped by an unusual continuity of professional staffing over at least ten years.
This paper addresses the T100 low wall which, when fully developed, will extend as the final slope in the southern part of the mine – some 10 km of the likely final mine length of about 20 km. Design investigations have concentrated on a 6 km section where the mine may reach a depth of 300 m+.

Figure 1 *Tutupan Coal Mine to North, showing main seams and, at left, the low wall sequence*



Structural aspects
Important structural features include:

- variable bedding dips (from 20^0 to 60^0 over short distances);
- variable scale folding, some of which is not immediately obvious;
- bedding shears of extremely low strength generally associated with the roof and floor of coal seams;
- some mudstones contain numerous slickensided surfaces due to the strain associated with folding; and
- a few steeply dipping faults with strikes oblique to bedding strike.

Groundwater before mining
Prior to mining, groundwater elevations in the coal deposit probably reflected groundwater movement to the east, downdip, with some upward discharge to local stream beds. The distribution of heads was complex at the scale of the mine, but now heads are dominated locally by the open pit.
Pre-mining groundwater heads were at an approximate elevation of RL 90 m. Pore pressures at the currently planned mine depth of 300 m (RL -204 m) were equivalent to nearly 3 MPa prior to mining. This pore pressure is greater than the unconfined compressive strength of many of the rock materials.

Geotechnical issues
Slope depressurisation in the Tutupan low wall should be clearly distinguished from typical mine dewatering. The mine is not being dewatered in a conventional sense. Dewatering at Tutupan is aimed almost entirely at reducing pore pressures in order to achieve the maximum slope angles that are judged acceptable. The low wall sandstones can be drained with free-flowing drainholes and pumped wells. However, the sandstones are interbedded with less permeable coals seams and mudstones, the pore pressures of which need to be reduced but for which dewatering, i.e. draining, is neither necessary nor practicable.

Failure mechanisms
Most low wall failures to date have been single bench failures due to either planar sliding along undercut bedding or small scale active-passive wedge failures involving bedding shears.
Potential overall slope low wall failures involve a large-scale active-passive wedge mechanism. The upper portion of the slope slides down a bedding shear(s) with rock mass shearing and / or buckling in the lower portion of the slope. Two multi-bench low wall failures have occurred to date.
The potential overall slope failure mechanisms are sensitive to the pore pressure within the slope. Depressurisation is only practical in the sandstones and thin mudstone beds that comprise the lower portion of the slope. Mining has removed these units in the upper portion of the slope exposing thick mudstone beds that cannot be quickly depressurised.

Groundwater management
Two trial dewatering wells were constructed in the late 1990s and demonstrated that:

- a sand-free well design could be achieved at the remote location of the mine (with specialist water well drillers) and the fineness of the aquifer sands (typically 0.1-0.4 mm);
- the mudstones acted as barriers to drawdown at the time and distance scales of the testing; and
- that the sands were hydraulically continuous at a scale of hundreds of metres.

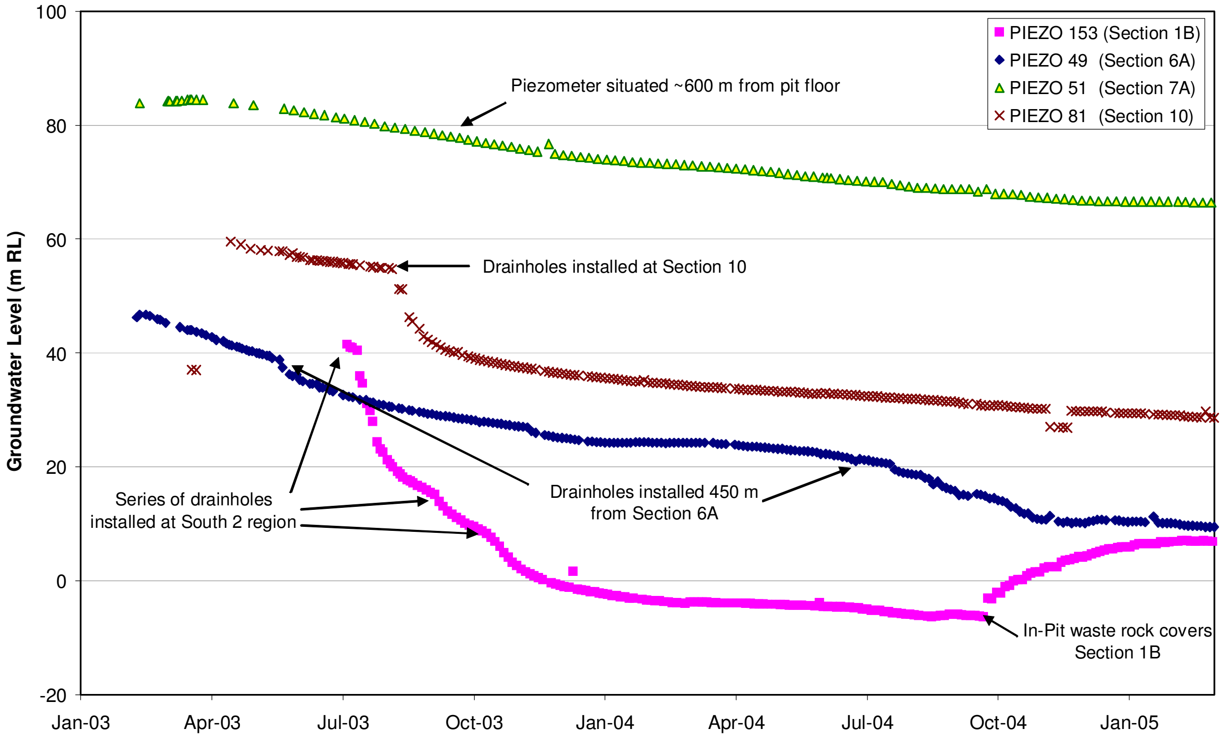
In parallel with the piezometer installations in the low wall, a programme of angled drainhole installation was initiated by Adaro with depths up to 150 m, cased with 50 mm PVC with machined slots of 0.5 mm aperture. These drainholes have produced artesian flows at rates up to 100-200 L/s.

Effects of drainholes
The results show that the sequence of interbedded sandstones has good connectivity along strike at a scale of kilometres and that the exact positions of drainholes is not critical to the outcome. Drawdown rates of 4-6 metres per month can be achieved as required to balance mining rates.
Data show drawdown of approximately 1-2 m/month in sands not directly drained by drainholes, suggesting that there is leakage through the mudstones at a rate sufficient to start depleting groundwater in deeper sand aquifers. This reduction in heads caused by diffuse leakage does not occur at a rate sufficient to match expected vertical mining rates as high as 4-5 m/month.
The aquifer system was conceptualised as having good along strike connectivity, with small but significant leakage across the mudstones. Tutupan is a classic example of leaky strip aquifers.

Future groundwater management
The groundwater management can be summarised as follows:

1. installation of drainholes to the extent that mining activity allows, aiming to depressurise the upper part of the low wall sequence, but not achieving head reductions beyond the collar elevations, i.e. no deeper than the pit floor and lagging behind mining;
2. installation of in-pit wells to dewater the deeper parts of the low wall aquifer sequence and, as the mine deepens towards 300 m depth, to reduce heads to levels below the final floor; and
3. monitoring of pressures along the established lines of section and adjust (mainly increase) drainage and pumping rates as required to achieve depressurisation goals.

Figure 2 *Typical piezometer results showing effects of installation and blockage of drainholes*



Discussion

The long term geotechnical studies of the Tutupan low wall provide a good example of the benefits of a proper integration of geology, hydrogeology and geotechnical engineering.

One of the most important facets of the entire study has been the realisation that it has required years of site experience to develop a sufficient understanding of the stratigraphy, hydrogeology, structural geology and material properties of the main units to analyse the slope stability in a realistic way.

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