Experience-based approaches to coal mine groundwater evaluation in Kalimantan, Indonesia

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Abstract

Large, open-cut coal mines in Indonesia extend up to hundreds of metres below the water table. Seams are tens of metres thick, hosted in clay/mudstone and sand/sandstone sequences. Bedding dips range from flat to near-vertical and mine stability is strongly influenced by groundwater pressure and bedding dip.

Complex hydrogeological testing is not always warranted when making initial evaluations of mine feasibility and slope design. Adjacent surface water and the stratigraphy, structure and bedding dips are much more important than hydraulic parameters.

The authors advocate using experience-based judgement as far as practicable for pre-feasibility studies and initial mine design.

Introduction

Indonesia is developing many large and shallow coal deposits at a large scale with production rates in the range 10-50+ Mtpa. Often mine development precedes conventional feasibility testing. Nonetheless, design parameters such as provisional slope angles are required and dewatering and depressurisation approaches need to be decided conceptually at least.

Field testing, including test pumping, dewatering trials and so forth are often precluded by logistical difficulties prior to mine development. In particular, access for drilling rigs can be challenging and the range of equipment that is available for test well construction is often limited.

Successful coal mine development in Indonesia usually requires an integration of hydrogeology and geotechnical engineering. Whilst dewatering is important, management of groundwater pressures in high walls and low walls is critical to slope stability. Perhaps the most common issue is the combination of failures both to measure groundwater pressures to check that they correspond to slope design assumptions and to implement measures to reduce those pressures or change the slope design.

Many coal mines have been developed over the last 20 years or so and the authors and colleagues have worked on many pre-mining investigations and ongoing operational advisory roles.

Geological and hydrogeological background.

The coal deposits in Indonesia are mostly, if not all Miocene in age and sub-bituminous in rank. Typically they occur as multiple seams, of which many are tens of metres thick. Bedding dips vary from sub-horizontal to sub-vertical from deposit to deposit. Larger deposits may exhibit changes in bedding dip of 30-40 degrees over distances as short as one kilometre.

The deposits occur in sedimentary sequences that are typically dominated by clays and mudstones of low to moderate strength with interbeds of sand/sandstone and coal seams. The relative proportions of sandstone and mudstone vary considerably within some deposits, the variability usually increasing for deposits with longer development along-strike.

Sandstones are typically aquifers with potential well yields of several to tens of litres/second. Mudstone units are typically aquitards with such low hydraulic conductivity that the authors do not belief conventional depressurisation measures are realistic. Coal units drain freely but are not sufficiently conductive to be regarded as aquifers.

Units of each lithology, if thicker than 20 m or so, tend to extend for many kilometres. Demonstrated strike lengths for individual major coal seams or aquifer zones often exceed ten kilometres.

Groundwater conditions – general comments

Most coal mines in Indonesia extend below the water table. Some mines have nearby surface water, either in perennial or ephemeral streams with potential for active recharge to the groundwater system behind the mine walls. Dewatering discharges need settlement ponds prior to the release of water to the environment. These ponds may cause recharge.

Figures 1 and 2 show diagrammatic examples that are typical of Indonesian coal deposit hydrogeological settings. These diagrams show typical low wall and high wall geometry, although many mines have lower bedding dips. The presence of surface water that can provide active recharge along bedding to units beneath floors is one critical factor with potential to cause floor instability. Figure 1 illustrates the increase in pore water pressure with depth below the water for a hydrostatic case. This diagram is derived from the basic relationship $P = \rho g H$, where

P = pressure (kPa)

ρ = specific gravity of groundwater (1.0 for in most Kalimantan deposits)

g = acceleration due to gravity (9.8)

H = depth below water table (m).

At its simplest this relationship means that the pressure 10 m below the water table is 100 kPa, and 100m below the water table is 1000 kPa (or 1 MPa). A typical misunderstanding is to state that groundwater pressures increase or develop behind the walls as mining progresses: rather, mining develops into areas where higher pre-mining groundwater pressures have been preserved. The groundwater conditions for a small deposit of only 1-2 km extent along strike can be predicted reasonably with only a few drillholes and piezometers. Mines with strike lengths in excess of 5 km typically exhibit major changes in the relative proportions of sandstone and mudstone.

Requirements for groundwater solutions

Preliminary studies (scoping studies) for new deposits are followed by various combinations of prefeasibility and feasibility studies. In reality, pressures for rapid mine development can result in conventional, bankable feasibility studies not being completed. Full hydraulic testing often cannot realistically be undertaken but solutions for early mine development are nonetheless required. Operational advice is often needed, frequently in response to emerging groundwater-related issues.For larger, long-life mines,detailed dewatering and depressurisation design is important, and should be integrated with geotechnical engineering and slope design.

Common hydrogeological elements

Low permeability mudstones are always present, both above and below the coal seams. Multiple coal seams are common. The coals are permeable enough to drain when exposed but flows large enough to need consistent pumping have never been observed by the authors. Sandstones are common both above and below the coal seams and tend to be the only aquifers from which water can be pumped in useful quanitities. The sandstones range from uncemented porous media to fractured rocks with secondary porosity and permeability.Thin mudstones, varying approximately in the range 2-20 m thick, have been observed to depressurise in response to dewatering of adjacent sandstones and coal seams. Thick mudstones tend to depressurise slowly relative to vertical mining rates and depressurise in response to unloading by mining off overlying material (Marchand et al, 2010). Low walls and nearly flat floors may fail if underlying sandstones occur and are not depressurised.

Wet season rains tend to produce only small (1-3 m) seasonal variations in groundwater level. Head distributions can become complex after mining has commenced, particularly in steeply-dipping situations. This complexity can be caused by the great contrast in hydraulic conductivity between the main lithologies (mudstone and sandstone), which imparts strong anisotropy to the typical coal-bearing sequence. Typically, hydraulic conductivity along the bedding direction will be many orders of magnitude greater than across the bedding by virtue of the mudstone interbeds. No new site should be *assumed* to conform with these general comments.

Groundwater-related issues

The main groundwater related issues are those associated with slope stability and groundwater pressure (Waterhouse, et al., 2008). Anecdotal information suggests that floor failures may occur at depths of only a few tens of metres below the water table as a consequence of low strength materials combined with shallow sandstone aquifers. Such failures may therefore occur within a year of mining unless groundwater pressures are understood and managed. Dewatering is typically required not only to control inflows (which may be dominated by surface runoff anyway) but to reduce heads and contribute to the depressurisation of mudstones.

Realistic approaches to investigations and to groundwater management during mining

Key aspects, apart from understanding the hydrological setting, the geology and the mining plans (which will be incomplete and will change), include the following. What is the likely range of mining depths below the water table versus time of mining, i.e. what will be the highest potential pore pressures behind and beneath the walls and floor? How close is the nearest sandstone aquifer to the base of the main seam to be mined, i.e. are upward heads likely to threaten floor stability unless the unit is depressurised? Are there any major cross-cutting faults known to the client's geological or mining staff? Major groundwater inflows associated with any faulting in these mines have not been observed by the authors or their colleagues. What is the groundwater quality (if water is to be discharged, an environmental permit of some sort will be required) and is there likely to be an acid generation issue? Are the dips steep (say greater than 15-20 degrees) or flat (less than 10 degrees).

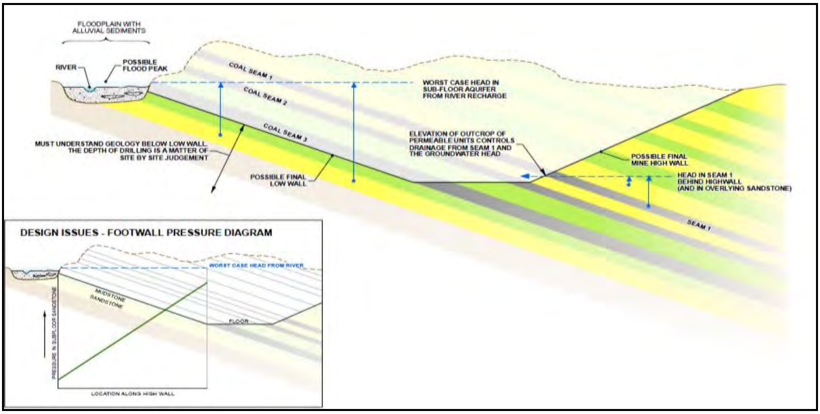

Figure 1*: Schematic diagram of mine with surface water adjacent to low wall perimeter*

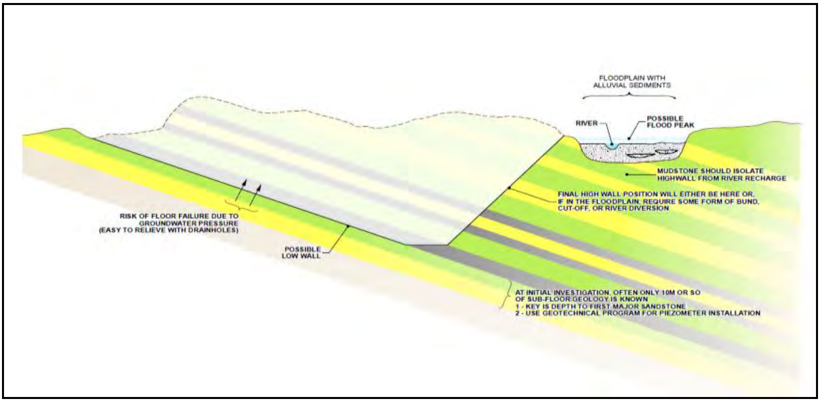

Figure 2: *Schematic diagram of mine with surface water adjacent to high wall perimeter*

Are coals and sandstones hydraulically connected to a river, its floodplain sediments or to the sea? If the surface water is on the low wall side, then surface water may be hydraulically connected along the bedding to footwall sandstones, which may be important to management of slope stability for the pit low wall. Typically, pumping sandstone units is effective in dewatering with good along-strike transmissivity. Drawdowns typically do not propagate across mudstone units in the short term, although leakage through the mudstones does occur at a time scale of months to years with heads declining more slowly than the vertical rate of mining.

Suggested aspects of studies at new deposits

It is best, in the authors' opinion, to adopt a restrained approach that takes careful account of the geology (i.e. stratigraphy and structure) in parallel with geotechnical issues and the plan by which the mine will develop. It is not worth testing mudstone permeability. It is not worth testing coal permeability. It is important to understand the geometry, permeability and transmissivity of any sandstone aquifers that may need dewatering. Initial testing of sandstone aquifers can use slugs in 50 mm piezometers and maybe recovery testing after wells are purged for water sampling. A further simple option is airlift pumping followed by recovery measurements. For a rigorous bankable feasibility study, test pumping with multiple piezometers may be necessary. Testing using packers is not often worth the effort in these deposits for initial assessments.

If the mine is near the coast or near a river, monitoring groundwater heads/pressures in parallel with monitoring river flood levels or the tidal fluctuation can be an excellent test and demonstrate whether mine slope design and dewatering design must or need not take these nearby surface waters into account. Given that most mines take some time to work up to their full rate of mining, the first 1-2 years give a good opportunity to monitor the hydrogeological effects of mining, to study the geology in exposures instead of correlating between boreholes and to trial dewatering wells and wall drainholes as appropriate. This approach allows deferral of complicated test work (such as long term test pumping), by using experience-based judgements to predict the early behaviour of the mine.

Conclusions

Experience-based approaches can be used for coal mine hydrogeological design investigations in typical Indonesian coal deposits. Detailed hydraulic testing of all units is not necessarily required but a clear understanding of the coal deposit's stratigraphic and structural setting is critical. Early operational data can be used to design dewatering and depressurisation systems that should be an integral part of slope design studies. Knowledge of the behaviour in mining environments of the commonly occurring sedimentary units can be used to optimise investigation activities and costs and to accommodate practical limitations on early investigations.

References

Marchand, G., Waterhouse, J. and Crisostomo, J., 2010. Mudstone Depressurisation behaviour in an open pit coal mine, Indonesia. Proceedings of the International Mine Water Association conference “Mine Water and Innovative Thinking”, Sydney, Nova Scotia.

Waterhouse, J., Crisostomo, J., Nolan, D. and Dutton, A., 2008. An Integration of Hydrogeology and Geotechnical Engineering for the Design of the Tutupan Coal Mine T100 Low Wall, South Kalimantan, Indonesia. Proceedings of the 10th International Mine Water Association Congress “Mine Water and the Environment”, Karlovy Vary, Czech Republic.