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Geotechnical Challenges of Brownfield Sites for Use as Landfill

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ABSTRACT

This paper looks at the geotechnical challenges associated with siting a landfill at a brownfield site in south east Queensland. In particular, the geotechnical issues encountered at former quarry and mine voids and underground coal workings, when endeavouring to ascertain the maximum airspace at a proposed landfill site, will be considered. Geotechnical features will include highwall stability, managing the risk of subsidence of underground mine workings, dealing with residual waste materials such as carbonaceous material, tailings, spoil etc. and the management of spontaneous combustion of former coal workings and coal rejects. 3D conceptual models of underground workings and photogrammetry surveys of highwalls used to assist in the assessment of geotechnical risks are presented. Key emphasis will be given to the assessment of the stability of selected landfill lining systems for both basal lining and final closure, as innovation in this area can be key to maximising airspace and enhancing asset value. Critical factors affecting the performance of landfill lining/capping systems will also be discussed.

Keywords: landfill, geosynthetic lining systems, mine working, design, airspace, geotechnical

1 INTRODUCTION

This paper presents the geotechnical challenges associated with the use of brownfield sites as landfill in south east Queensland. Owing to the mining history of this region the brownfield sites utilised for landfill are typically existing voids formed as part of the extractive industry process, generally coal mining or rock quarrying. Legacy geotechnically significant features arising from these industries can include former underground tunnels and adits, remnant highwalls, stockpiles of coal rejects and other challenging materials. The geotechnical challenges associated with managing such features is heightened by uncertainty surrounding the accuracy of site development records, the variability of '*in situ'* material and often the presence of large volumes of water in the former open pits. This paper presents some approaches to these geotechnical challenges as well as the geotechnical challenges encountered when designing landfill lining systems for such conditions in a cost effective manner. This paper is not intended to provide an exhaustive overview of all geotechnical assessments or investigations required for the development of a landfill site in such environments. It is acknowledged that site history or geological and hydrogeological settings should also be considered, among other considerations.

2 BACKGROUND AND CONTEXT

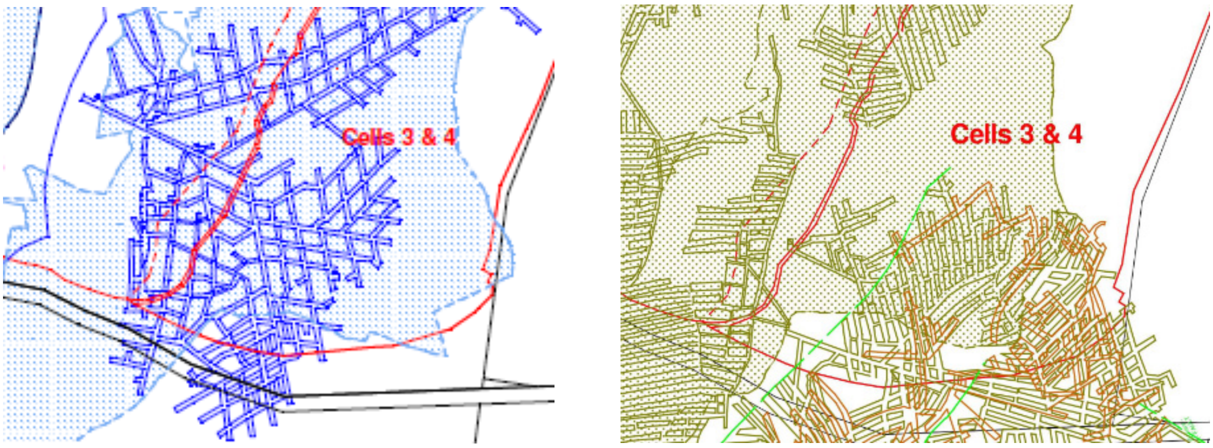
The volumetric capacity of a landfill to accept waste, known as its airspace, together with the cost of developing this airspace, is a key indicator of the value of a landfill site to a waste management company. Maximising the airspace at a site requires an appreciation of the geotechnical constraints, which will invariably differ from site to site, and the ability to develop innovative and safe designs. The geotechnical analysis presented in this paper centres on former coal mines and quarries where consideration of highwalls and the optimisation of airspace is required.

The Queensland landfill guidelines require landfill designs to be based on a geotechnically stable subgrade. The guidelines do not provide prescriptive standards and require a risk based approach for the development and operation of landfill sites. This requires innovation on the part of the landfill designer to develop a cost effective liner system which maximises airspace by taking advantage of the geotechnical constraints. The maintenance of a risk register during the development of the design is an appropriate and necessary measure to ensure that risks are safely mitigated to the extent practical, and that the operator is informed of any residual risks once the design is completed.

3 GEOTECHNICAL CONSIDERATIONS

3.1 Former underground workings

Coal mines contain a complex history of underground and open cut mining activities, and often subsequent partial backfilling of the open cut voids with a wide range of material types, including overburden spoil, coal rejects and wet coal fines (tailings). It is necessary to review and interpret as-constructed plans of the former workings to develop an understanding of their potential impact on the proposed landfill. Typical plans of former mine workings are shown in Figure 1.



(a) (b)

Figure 1. Mine Workings Plan (a) Seam 1; and (b) Seam 2

Review of historical plans for this site indicated that underground mining was undertaken in six coal seams underlying the site. The mining method utilised was board and pillar, a method that typically removes around 50% of the coal seam. Many of these workings were later removed by open cut mining, but some workings still remained at depth under the footprint of the proposed landfill. Following the open cut mining, there was a complex history of backfilling of the pit voids with material from a range of sources and with differing geotechnical characteristics. The variability of this backfill and the uncontrolled compaction required conservative assumptions for the material properties in the analyses undertaken at the site. Backfilled material also included carbonaceous materials and consideration of the risks of spontaneous combustion of these materials was required, including the development of a spontaneous combustion management plan.

The coal seams exploited by past mining operations at the site ranged in thickness between 1.5 and 4 metres. A 3D model of the site was prepared to allow for a better understanding of the former mining works. A screenshot of the model is provided in Figure 2, with the proposed landfill cell shown at the top of the figure, and the various seams (5) shown beneath the cell.

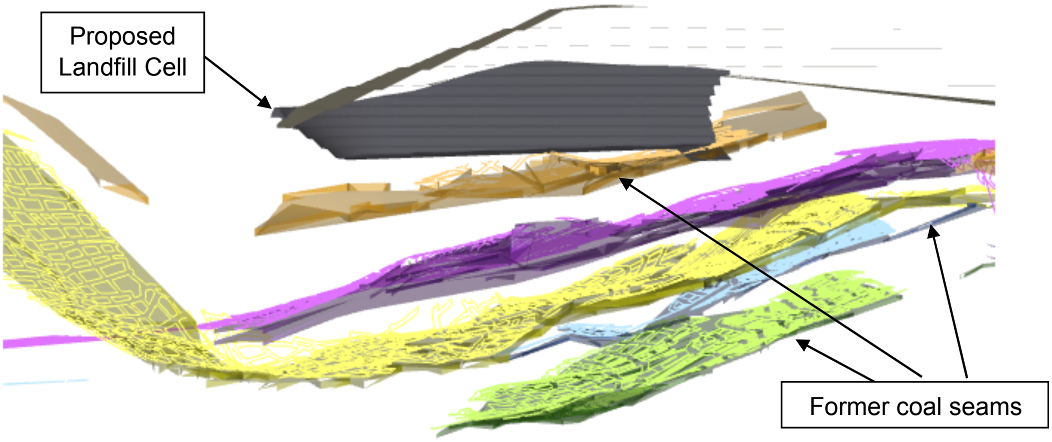


Figure 2. Cross-section of concept design and final profile (looking west) with underlying coal seams / workings

The development of the 3D model enabled the preparation of critical cross-sections of the site showing the relationship between the underground workings and the proposed landfill. Figure 3 shows an example cross section through the 3D model.

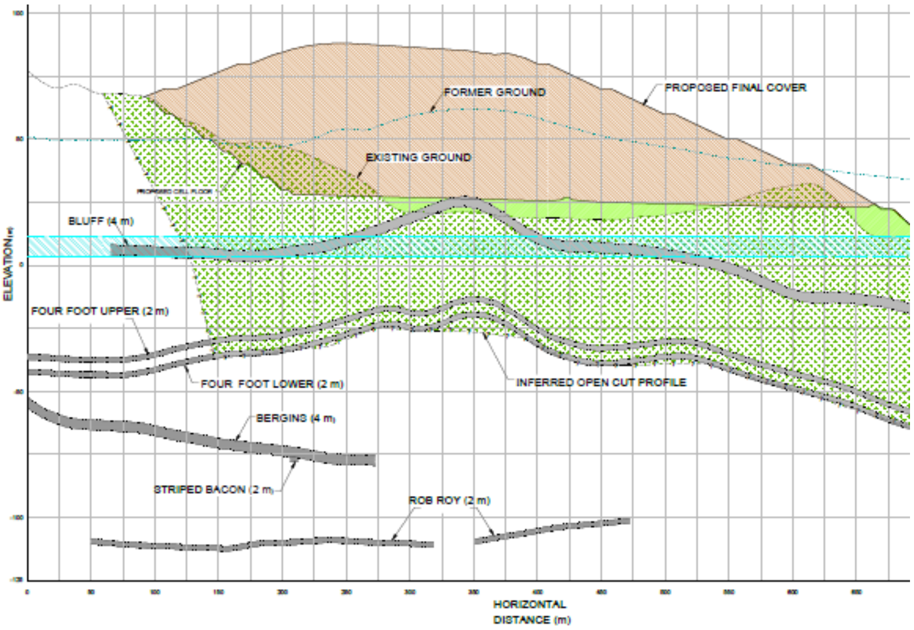


Figure 3. Cross section (looking north) of concept landfill design and underground workings

The 3D model was used to estimate the cut and fill requirements to develop the site, and to consider the potential for differential settlement. Figure 3 also includes the existing ground surface profile, pre-mining ground profile, approximate extent of open cut mining and the groundwater table.

3.2 Subsidence Potential due to Collapse of Underground Workings

The potential for subsidence of the proposed cell floors associated with pillar crushing or collapse of relict underground workings was considered, with reference to rock mechanics expertise and literature, for example, the National Coal Board (NCB) of the United Kingdom empirical method for prediction of surface subsidence. Analysis indicated a very low risk of subsidence associated with the upper seam, as it had been larger removed by open cut mining. Assessment of the subsidence associated with collapse of the seam closest to the bottom of the landfill, which was separated from the cell floor by between 65 m and 100 m, indicated that the worst case amount of subsidence at the landfill floor was limited to between 100 mm and 300 mm. If the underground workings were to collapse, the volume of the collapsed material would increase due to bulking and the upward propagation of the collapse would be arrested (or 'choked') when the void space has been completely filled by the bulked material. A number of areas were selected as worst case scenarios where total void volume as a proportion of the total seam volume was at its greatest. Based on the selected analytical method for prediction of surface subsidence, and assuming total catastrophic collapse of all of the coal pillars in the second deepest workings directly below the edge of proposed cell, the maximum predicted surface subsidence was calculated to be in the order of 300 mm. However, given width to height ratios of the pillars, such a catastrophic collapse was considered to be highly unlikely. If collapse of a small number of pillars were to occur, it was considered more likely that the load would be redistributed to the surrounding pillars and the remainder of the workings would remain stable. In this scenario, the maximum surface subsidence resulting from the localised pillar collapse was estimated to be in the order of 100 mm. The workings in these lower seams, based on analysis, were not considered to pose a subsidence risk to the proposed cell floor.

3.3 Settlement Modelling

Landfills require a firm subgrade to reduce the risk of subsidence limiting the effectiveness of the liner system. Based on the available information, the landfill cell floor was to be formed by cut and fill of the existing irregular ground surface. The assessment of subsidence was therefore necessary to ensure that the liner system was not subject to excessive strain. The cell was also partly underlain by mine spoil that was placed in the old open cut void more than 20 years ago. The spoil comprises a mixture of ‘overburden waste rock’ and ‘coal mine spoil’ from the open cut mining operation. It was considered that the overburden waste rock would originally have consisted mainly of slightly weathered to fresh sedimentary rocks, including sandstone and shale of medium to high strength. Some degradation would have occurred in this material over time so the materials were likely to include extremely to distinctly weathered sandstone, shale, claystone and basalt in the mix. The coal mine spoil was carbonaceous shale, tailings and reject coal, which was also likely to have degraded over time.

A numerical model (PLAXIS) was used to assess the settlements using appropriate parameters, including site specific stiffness parameters. Figure 4 presents a representative analysis undertaken along a cross section of the site, showing the calculated settlements distribution.

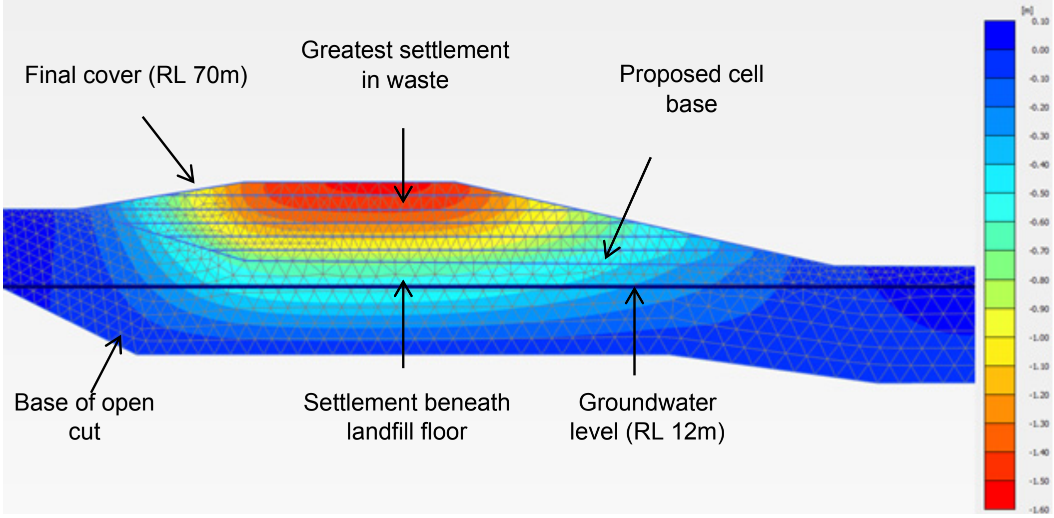


Figure 4. Graphic representation of the calculated settlements along site cross section

Based on the results of the analyses, the settlement (immediate, consolidation and long term creep) along the base of the cells was estimated to be vary between 300 mm and 900 mm, with the peak settlement located under the greatest height of landfill waste and thickest underlying mine waste spoil depth.

4 LANDFILL LINING SYSTEM DESIGN CONSIDERATIONS

4.1 Risk assessments

Assessing geotechnical risks should be undertaken in a phased manner to ensure that risks are documented and addressed appropriately. The first stage of such an assessment may involve a desktop study to identify potential risks and their relevance to the project. The second stage may involve intrusive or non-intrusive investigation of issues to further improve understanding of the risks. Further stages involve the development of a preliminary approach to mitigate the risk of geotechnical failure and optimise the airspace at the site. The risks should consider mitigation measures for both the design and operational stages, with the client being advised of how risks have been mitigated and whether residual risks exist.

4.2 Interaction between subgrade and lining system

Based on the geotechnical conditions a lining system needs to be developed that does not undergo excessive and unacceptable strain. In the case of former coal mines, such strain may be induced or enhanced by subsidence arising from poorly backfilled materials or the failure of underground workings. In the case of a former quarry or highwall with a near vertical lining system, the strain may be induced by settlement of the waste mass against a steep wall lining system, or by differential settlement of the subgrade adjacent to the highwall or steep wall lining system. A number of key considerations and approaches are presented by Jones and Dixon (2003) and these form a good basis for understanding risks and taking them into account in the design. It is not appropriate to undertake stability analysis of the subgrade and lining system in isolation, as the interaction between them can be interdependent. Geotechnical modelling of the subgrade in conjunction with the liner system and waste loads may be necessary on a site by site basis to decide whether reinforcement of the lining system or subgrade is required.

4.3 Lining System Materials

Effective landfill lining systems typically consist of a combination of natural (clay, gravel etc.) and geosynthetic (geomembrane, geosynthetic clay liner (GCL), geotextiles, geocomposites, geogrids etc.) materials. Composite lining systems are more and more common and generally comprise a geomembrane with an underlying low permeability material such as compacted clay or a GCL. The non-prescriptive risk based approach required by the Queensland Landfill Guidelines allows for the certifying engineer to use discretion in selecting the most appropriate lining system, which must provide long term performance of the barrier and drainage elements of the lining system. Selecting the appropriate lining system, often balancing risk (environmental and geotechnical) against airspace, requires an appreciation of how individual components interact with the subgrade, each other and the overlying waste material.

4.4 Seepage and the influence of groundwater

Landfill lining systems are not impermeable and designers need to estimate the potential seepage through the lining system to assess the risk to the surrounding environment. Rowe et al (2004) presents a number of methods of estimating the seepage including factors for singular or composite lining systems. Further work by Chappel et al (2012) and Giroud and Wallace (2016) go on to consider the effect of wrinkles on seepage through the composite lining systems. Poor design, construction and quality control of the lining system could have direct implications on construction and operational costs if the groundwater levels are not well understood. In the case of the example presented long term groundwater monitoring of the area post mining gave confidence to the positioning of the cell floor around 5 metres above the recovered groundwater level. Dewatering of the former mine and quarry pits during the operational stage may result in depression of groundwater table, which may rebound post closure. Recharge of the groundwater table over time, or the impact of seasonal changes in the groundwater table due to regional factors, could lead to heaving of the lining system in the early stage of construction and initial waste placement. Such elevated groundwater levels may result in construction delays, reconstruction the lining system, or the need for long term dewatering beneath the lining system. Where dewatering is not undertaken, there is a risk of excess leachate generation due to inward seepage of the rebounding groundwater. This would lead to additional leachate management costs. The value of airspace below the long term predicted groundwater table therefore requires careful consideration.

4.5 Stability of highwalls

In former mines and quarries, the stability of highwalls and the landfill lining systems need careful consideration. A need to balance a stable and effective lining system against a desire to maximise airspace can lead to oversights by an inexperienced designer. Safety in design requires careful consideration of the health and safety risks introduced by steep wall lining systems during construction and operations, particularly next to a highwall. Figure 5 shows how photogrammetry helps the designer to develop a digital terrain model (DTM) and identify and measure key geotechnical features such as faults, toppling and rock wedges.

4.6 Steep wall lining systems

Identification of geotechnical features is necessary to ensure that they can be considered when designing the lining system, as the quality of the quarry face or highwall will affect the constructability and integrity of the lining system. Stabilisation of the rock face will often be required and the overall stability of any steep wall lining system needs to be considered. Dixon and Jones (2003) provide examples of some steep slope lining systems for use for steep slope batters. Most steep wall lining systems are constructed in lifts, due to the need to provide a stabilising buttress against the liner to ensure stability of the lining system. The buttress can be a waste material in a ‘Christmas tree’ lining system where clay is used without geomembrane, however the low stiffness of municipal solid waste can present issues in this regard and an additional layer may need to be introduced between the lining system and waste material. Geosynthetic barrier systems introduce a whole raft of other complications such as constructability, safety and long term performance issues for a steep lining system.

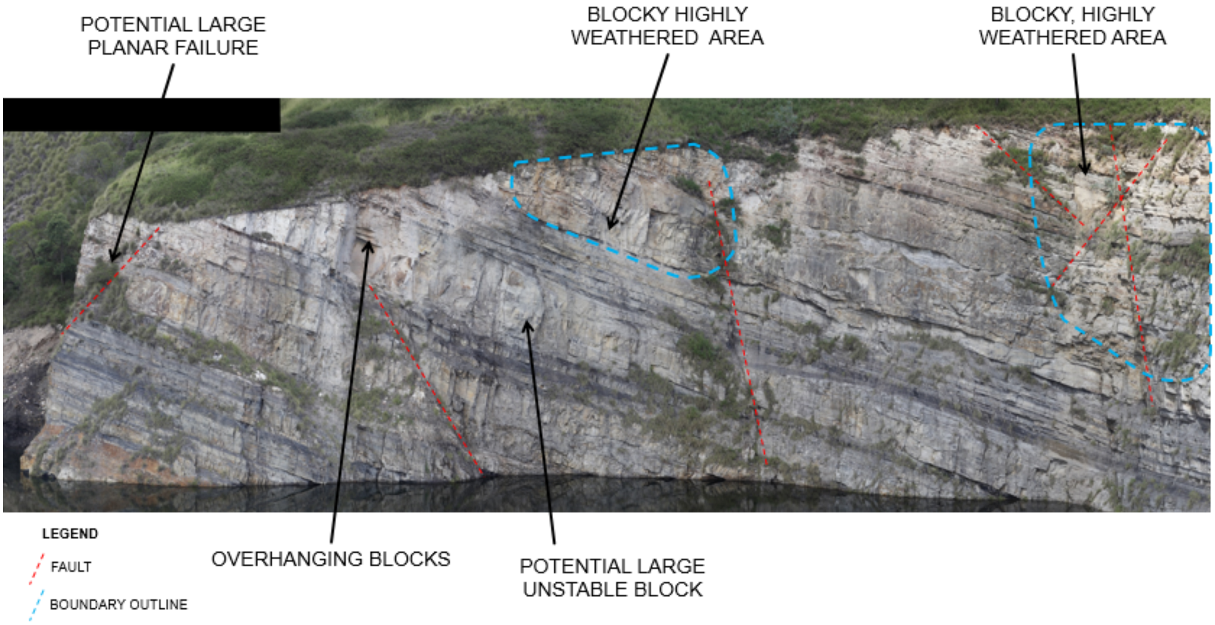

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Figure 5. Photogrammetry of highwall showing some potential failure mechanisms

4.7 Effect of waste settlement on lining system

Settlement of waste has the potential to induce large strains on lining systems, in particular side wall or sloped liners. The strain can be managed through the introduction of an intermediary material between the waste and the barrier system. In the case of steep wall lining systems, the intermediary material could be a preferential sliding layer or a material of high stiffness, with the selection of the material depending on a range of factors.

4.8 Capping Interface Stability Analysis

A desire to maximise airspace can lead to over steepened external waste batters. When developing the capping system design, the risk of veneer failure of the capping system requires careful consideration by a landfill designer. Jones and Dixon (2003) presents an overview of the risks associated with poorly designed capping systems and an approach to assessing interface stability of the various lining systems. This approach has been developed by others including Koerner and Soong (2005) to include temporary loads and forces, including construction effects. The selection of interface strength values is a critical component during the design stage of the capping system. While consultants can benefit from an internal database of interface strength values, these values should be verified during construction. It is essential to assess the actual interface values based on the proposed capping materials. Additional consideration must be given to site specific factors such as settlement of waste, gas collection systems and stormwater management. The effect of seepage in a capping system needs to be carefully considered in conjunction with the cap stormwater management system, as the two are inter-related. The need for veneer reinforcement in the capping system should be considered by the designer on a site specific basis for the long term stability of the lining system and post closure maintenance requirements.

5 CONCLUSION

The appreciation of geotechnical risks is a fundamental part of landfill design. The variability of sites requires an understanding of a range of issues that may affect failures or present opportunities to increase airspace. The range of geotechnical challenges presented in this paper require the input of a range of specialists to provide the best outcome. The process of copying and pasting the previous design is not acceptable, nor is it in the best interest of the site owner.

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