

Backfilled Quarry Development with Inbuilt Landfill Gas Solution

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ABSTRACT

A basalt quarry north east of Melbourne operated for over 30 years from the mid-1960s. Rock extraction occurred to a depth of approximately 28 m below ground level with dewatering. Since operations ceased in 1999, the quarry has been progressively backfilled with variably compacted 'clean fill' until 2017 and the groundwater level allowed to rebound close to its former level. Potential development of the land, for residential or mixed land use, triggered geotechnical and environmental investigations with the objective of identifying and managing below ground issues to support a planning rezoning process. Based on the investigation results, some of the key considerations for future development of the site were settlement of the backfilled quarry, foundation system options across the filled quarry extent and management of landfill gas. Development time, future ongoing management pressures and the need for large scale ground improvement, led to the consideration of a landfill gas control barrier integrated within the engineered fill ground solution, and an on-site trial. This paper provides the findings from the surcharge trial to date to combine the reduction in time to achieve an acceptable settlement of the fill and the management of entrapped landfill gas.

Keywords: landfill, settlement, gas, redevelopment, ground improvement, trial

1 INTRODUCTION

A 45-hectare parcel of land north east of Melbourne operated as a basalt quarry for over 30 years from the mid-1960s. The quarry footprint covers approximately 25 hectares, of which nearly 20 hectares is within the site boundary. Rock extraction had continued to a depth of approximately 28 m below ground level and was made possible through dewatering the local area. Between 1999 and 2017 the quarry has been progressively backfilled with variably compacted, but largely uncontrolled 'clean fill' and the groundwater level allowed to rebound unevenly but close to its former pre-quarry operations level.

Potential development of the land (currently zoned 'Industrial 1 Zone') for residential or mixed land use, triggered geotechnical and environmental investigations, with the objective of identifying and managing below ground issues and supporting a rezoning process, which includes completing an environmental audit.

Based on the investigation results, the key considerations for future development of the site were settlement of the uncontrolled backfill, foundation system options across the filled quarry extent and management of landfill gas. While individual solutions to these issues could be applied, including the use of surcharging to shorten settlement time of the uncontrolled fill, backfilling the remaining extent of the quarry footprint with engineered fill to design surface and installing a vapour barrier, several factors drove the design of a combined engineered solution and implementation of a trial.

This paper focuses specifically on the findings and solutions within the quarry footprint area of the site.

2 BACKGROUND

Due to the long history of quarrying and subsequent backfilling at the site, review of historical documents, including aerial photographs, and previous environmental and geotechnical investigation reports provided important data collected prior to and during the backfilling process. This information was supplemented by additional combined geotechnical and environmental investigations, over a period of two years, to infill and further minimise data gaps. Investigation included cone penetration testing (CPT), drilling of boreholes and their conversion to wells, installation and sampling of groundwater and landfill gas bore, test pitting, contaminant and geotechnical analysis.

The site is underlain by Quaternary Newer Volcanics basalt, of which at least four lava flows were quarried down to within 2 m of the base of the unit. Groundwater flows through this unit. The basalt, approximately 30 m thick, is underlain by an equivalent of the Tertiary Werribee Formation. This 5 m to 6 m thick layer of sandy clays, sands and gravels contains a confined aquifer and overlies Silurian siltstone. An influent creek runs along the western and southern boundaries of the site.

2.1 Environmental Issues

While the site was considered to be backfilled with 'clean fill' and there was no evidence of putrescible waste, past Environmental Protection Authority Victoria (EPA) inspections noted uncontrolled dumping of building rubble, confirmed when concrete rubble was encountered during a recent site investigation. In 2001, EPA granted approval for the site to accept Coode Island Silt (CIS), which is either a potential or actual acid sulfate soil (ASS). The EPA stipulated that it was disposed below the rebounding water table within the quarry, at that time. Based on

this information the following issues required consideration in formation of a development solution:

- Fill materials – potentially contaminated imported soils, presence of building rubble and other anthropogenic materials - contaminants within the imported fill potentially could impact future site users and/or leach to groundwater.
- Fill materials – ASS producing sulfuric acid and hydrogen sulfide, if placed above water table / exposed to air.
- Groundwater – potentially impacted by contaminants within the fill
- Landfill gas – presence of organic matter within fill biodegrading to produce methane and carbon dioxide – requirement for landfill gas risk assessment and potential engineered solution for site development.

2.2 Geotechnical Issues

The prolonged history of quarrying and backfilling practices has led to multiple snapshots of information at specific times from different sources and for different outcomes. Additional site investigation was undertaken to refine the understanding of the following geotechnical issues encountered:

- Quarry footprint extent – the lateral extent of the quarry changed over time, with voids being filled while other areas were still being quarried. The understanding of its extent is extremely important for the design and construction of any future development.
- Benching – the sides of the quarry were benched with access ramps / haul roads. Benches varied in width, length, relative height and near vertical slope of the quarry wall.
- Quarry floor – the base of the quarried surface was variable, with two deeper 'pondage' areas.
- Fill materials – the acceptance of varied soils (clay, silt, gravel, boulders) with different properties leads to differential settlement and varied response to moisture, plus building rubble and biodegradation of timber. The localised presence of imported Coode Island Silt adds a compressible soil type. It was reported that CIS was deposited close to the liquid limit, with rubble added to the soft sediment for trafficking.
- Fill placement – it is understood that while some compaction of fill layers occurred, formal compaction and moisture conditioning of material was not general practice. Filling by tipping from the benches of the quarry and edges of the quarry occurred during quarrying, and from the edge of the quarry later, during backfilling period.
- Groundwater – water level affected by rebound from dewatering and potential creek water ingress. Highly variable levels measured within fill with shallow water levels limiting ground improvement options.

3 DEVELOPMENT

Over the investigation period, the development drivers changed. Time, cost, full scale versus staged development, environmental assessment and audit, requirements for rezoning, proposed mixed land use, future ongoing management pressures and the need for large-scale ground improvement, all played roles in the direction of development planning progress. The potential to manage both environmental and geotechnical site issues with combined engineering solutions, rather than dealing with each issue separately, allowed the projected development timeline to be reduced.

For the purposes of the project objective, the end use is assumed to be mixed use with low density residential (access to surface soils) and open space.

4 KEY SOLUTIONS

The key issues were considered to be high total and differential settlement and potential ongoing landfill gas management. Various solutions were assessed over time, a selection of which are described below.

4.1 Ground Improvement

The ability to construct buildings and infrastructure on the filled quarry area relies on preventing or limiting settlement of the structures. A piled option had previously been investigated but was deemed costly, with potential problems associated with deflection of piles on quarry walls, impenetrable waste and punching through the base of basalt. An alternate option to improve the properties of the existing ground was considered. Ground improvement could enable construction on shallow foundations by the reduction of long term settlement. While there are a number of different methods the following was considered for adoption.

4.1.1 Surcharging

Ground improvement through surcharging was considered an option to reduce settlements to acceptable levels but differential settlement potentially remains an issue, particularly across the boundary between filled profile and natural ground outside the quarry extent. This was proposed to be accommodated through planning and engineered solutions. Surcharging can take considerable time and requires large volumes of material to be imported to site. A moveable surcharge that covers only part of the area was preferred but relies on the settlement being reduced over a shortened period. Given the heterogeneity of the existing backfill materials and variability of past compaction, shown through the CPT data, the rate of settlement was estimated and modelled but was deemed to have a low level of accuracy and a trial was considered to be essential.

4.1.2 Wick drains

Wick drains, also known as prefabricated vertical drains, were considered and included in the trial as they have a number of advantages:

1. They allow any excess pore pressures to dissipate more quickly and accelerate settlements
2. They accelerate equilibration of the groundwater levels within the fill and accelerate hydro-compaction
3. They allow the rapid release of landfill gas pockets both during installation and post settlement

Wick drains are installed in a grid pattern. Drainage, storage and management of significant volumes of expelled (and potentially contaminated) porewater is required to be considered.

4.2 Engineered Fill Finished Level

The level of backfill at the time of the investigation, relative to proposed future development masterplan levels, required approximately 3.5 m of additional engineered fill to be placed. The reasons for this were:

- To raise the ground level to match the ground level outside of the quarry footprint, allowing drainage and civil design (with consideration for additional settlement).
- The existing fill is not currently a suitable geotechnical founding material for future development (uncompacted).
- A verified clean fill cap is likely to be required by the EPA appointed Auditor for low density residential use due to contaminant impacts in existing fill.
- Provision of a low permeability clay cap (see landfill gas – Section 4.3).

While it is possible that some materials present on site could be utilised as engineered fill, the majority of the required volume of material would need to be imported, meeting both geotechnical and environmental specifications.

Optimally, a clay-rich fill would form a low permeability, 2 m thick layer over which a non-reactive fill material, such as mudstone is placed in the upper 1.5 m to reduce the ground surface shrink-swell seasonal reactivity.

4.3 Landfill Gas

Landfill gas investigation at the site to date has measured elevated methane and carbon dioxide concentrations within the quarry extent, with lower concentrations outside the quarry; inferring that the quarry fill is the source of methane generation. Measured flow rates were generally low and the Gas Screening Level calculated within the quarry area, determined a Characteristic Gas Situation 2 (low risk) in accordance with BS 8485:2015. A combination of engineered gas protection measures

are typically integrated into residential floor slabs with under-floor ventilation and a gas impenetrable membrane. An alternate passive venting system option at depth creates a pathway for gas to disperse beneath a low permeability clay layer, providing one engineering measure across the site, with limited risk of damage during construction or over the life of the development. While the option may not necessarily mitigate all of the requirements for engineering measures within individual dwellings, it can significantly reduce the measures.

5 PROPOSED COMBINED SOLUTION

The proposed solution integrated the required ground improvement and need to raise ground level with the management of landfill gas.

The following sequence of elements which integrate to form the combined solution are presented:

5.1 Subgrade preparation

Preparatory earthworks are required to form a compacted earth mound (Figure 1). The aim is to raise the existing backfilled ground surface at the centre of the loaded area, ensuring a fall of 4% from the centre to the perimeter of the area when placed. This allows for a conservative minimum 1% fall to be retained following long term settlement. The gradient is required to ensure flow through the subsequent permeable layer for the pore water and then the landfill gas, albeit in different directions.

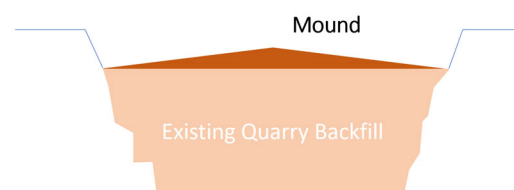


Figure 1. Indicative mound preparation (exaggerated)

5.2 Wick drain installation

Wick drains are installed through the mound material and the underlying existing backfill to the base of the quarry (Figure 2) providing a pathway for water and gas to travel to the surface in addition to equilibrating the groundwater level within the quarry backfill. A grid was proposed across the development area, to be determined based on required settlement timeframes. The investigation encountered construction debris in the fill, which was anticipated to cause early refusal for wick drain installation. Pre-drilling was incorporated into the conceptual methodology, but was found during construction not to be required. The top of each wick drain integrated into the permeable layer. Monitoring equipment such as extensometers, vibrating wire piezometers and settlement plates are installed at this stage to allow monitoring of settlement and pore pressures over time.

5.3 Permeable Layer

The permeable layer, installed over the mound, is required to ensure flow of expelled porewater (via wick drains) to the perimeter and also ensures landfill gas can migrate up gradient to venting infrastructure.

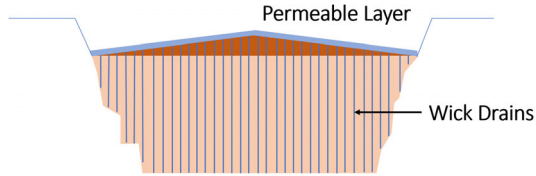


Figure 2. Indicative wick drain and dual purpose permeable layer (exaggerated)

The permeable layer is made up from two elements as described below.

5.3.1 Gravel

A 350 mm layer of gravel is placed across the mound surface with each wick drain exiting into the gravel layer. Flooding of this gravel layer must be prevented.

5.3.2 Piping and Geotextile Layer

Vertical gas piping infrastructure (Figure 3) is installed through the gravel layer at this time, positioned towards the highest point of the mound to allow venting of the rising landfill gas with sufficient grade to avoid landfill gas entrapment. Lateral drainage pipes at the perimeter of the permeable layer are installed to divert water to sump locations. A non-woven geotextile layer is installed over the gravel to prevent fines from subsequent engineered fill material migrating into the gravel layer, which could reduce the hydraulic conductivity of the drainage layer.

5.4 Engineered Fill

The engineered fill layer is made up of two sub-layers, both to be placed and compacted as per guidelines for earthworks (AS 3798-1996). The lower layer forms a low permeability layer at least 2 m thick to inhibit migration of landfill gas and is to be constructed using suitable clays. The upper layer provides a geotechnically suitable low-reactive subgrade on which residential development can be founded (Figure 3).

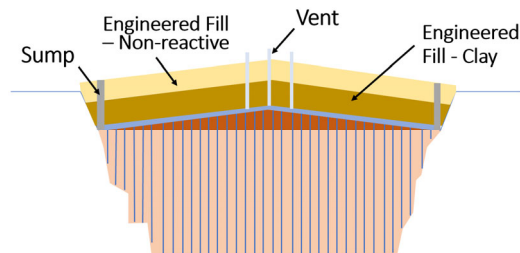


Figure 3. Indicative engineered fill layers (exaggerated)

At this stage sumps will need to be constructed around the perimeter to collect porewater and any surface water ingress, which can be pumped to surface, and managed. These sumps may be utilised within the future development.

5.5 Surcharge

To accelerate settlement of the existing fill, placement of surcharge material is required over the engineered fill layer. The height and volume of surcharge required for the development is governed by the desired rates of settlement and associated development timeframes, allowing for primary consolidation, secondary compression (creep) and, hydro-compaction. A 6 m high surcharge load (Figure 4) was originally anticipated to be in place for 1.5 to 2.5 years depending on the depth of the quarry and adopted settlement tolerances.

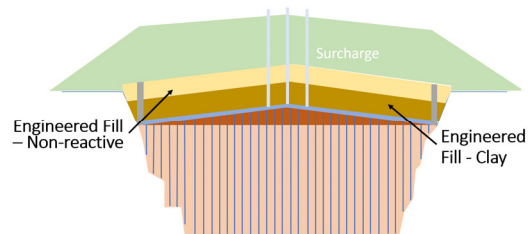


Figure 4. Indicative surcharge (exaggerated)

The gradients and volumes of fill layers and surcharge required to implement the solution across the entire quarry extent at one time was likely economically and practically unfeasible. Typically, development on this scale occurs in stages. By dividing the site into stages, a 'rolling' or movable surcharge could be re-used across the staged areas over time. Development of initial porewater drainage and ongoing gas venting infrastructure would be required per stage, taking into account the timeframes for settlement per stage and effects on the adjacent / subsequent stage. Additionally, design and preparation of the permeable layer 4% fall will need to consider each development stage and the quarry development as a whole.

The conceptual solution was presented to the site EPA appointed environmental auditor to ensure that the proposed solution was reasonable, with respect to obtaining regulatory approval in the future. The preliminary review confirmed that the sequence of works appeared reasonable, subject to further investigation and monitoring, including conducting a trial.

6 SOLUTION TRIALLED

The focus of the trial was to demonstrate that the magnitude and timeframe for settlement modelled was realistic for the purposes of planning future development, while also testing the conceptual integrated solution.

The conceptual solution was applied on a reduced scale. A 50 m by 50 m trial area was selected over the deepest area of the quarry, partially across a former 'pondage' area backfilled with compressible Coode Island Silt early in the backfilling history of the quarry.

6.1 Subgrade Preparation

Available on-site material most recently used to form a working platform in an alternate portion of the site was used for subgrade preparation. The 4% gradient mound was constructed to the furthest extent of the proposed surcharge batter footprint and density testing confirmed the specified compaction parameters. At this time, swale drains were also excavated around the perimeter of the surcharge extent to capture runoff from the trial area and also to prevent surface run off from the rest of the site affecting the trial. This was designed to drain to a peripheral stormwater pond outside of the area so as not to potentially impact trial measurements. Unfortunately, this failed at various times.

6.2 Wick Drains

Wick drains were installed on a grid pattern at 1.5 m spacing. The filled quarry level at the trial pad stands approximately 3.5 m below surrounding ground level therefore fill was anticipated to be approximately 24.5 m thick. During the installation it was ascertained that pre-drilling was not required. Of the 1140 wicks installed, 99 were replacements for wick drains that refused on shallow solid inclusions within fill, or the baseplate (which fixes the base of the wick drain at the installed depth) refused to hold (potentially caused by a void). 60% of wick drains were installed to 24.5 m depth or greater. Gas and water were noted to be expelled from some of the wick drains on completion of installation. This was most likely linked to pockets of gas being released.

6.3 Permeable Layer

The gravel layer was installed with the associated drainage pipes. These were linked to two separate areas of connected leachate collection tanks (IBCs) with the purpose of measuring the volumes of porewater expelled during settlement. In the trial the geotextile layer was installed wrapped under the outer edge of the gravel layer and perimeter drainage pipe, to ensure the drainage pipe retained its position once the surcharge had been applied. During each monitoring event the volume of porewater was measured, with tank content pumped to a distant managed storage pond when required.

6.4 Surcharge

Monitoring of settlement, from the top of the mound layer below the gravel layer was the focus of the trial. As the engineered fill layer was not required for the surcharge trial, this layer was replaced with 3 m additional surcharge material. In total a 9 m high layer of surcharge material, totalling approximately 40,000 m³, was added to the trial area, with 1V:2H to 1V:2.5H batters and a ramp for plant access. The

import and placement of fill was conducted over one month and was built up in stages, filling the southern side of the trial area by a few metres, followed by the northern area, for each stage. This occurred over a longer period than originally anticipated and modelled. However, the time period adopted can be considered potentially more realistic of future site development.

The full surcharge load remained in place for three months upon which the primary consolidation was mostly completed, after which the top 6 m of surcharge was removed, replicating the removal to the top of engineered fill level of the conceptual solution. Unloading was conducted over a period of four weeks.

6.5 Monitoring

The monitoring equipment was installed within the 50 m by 50 m trial area and consisted of:

- Two vibrating wire piezometers each recording porewater pressure at two depths.
- Two extensometers, each with a plate magnet and three spider magnets positioned at various depth intervals.
- Five settlement plates.

Baseline monitoring occurred on installation of the permeable layer. The frequency of monitoring was initially weekly, dropping to fortnightly during the final month of the full surcharge load period, with additional monitoring during the rebound period, during and following unloading. Monitoring reduced to monthly and then every two months after unloading and as settlement reduced.

7 FINDINGS

7.1 Settlement

The total settlement measured over the period to date is between 522 mm and 625 mm, including the period in which the site was surcharged (refer Figure 5).

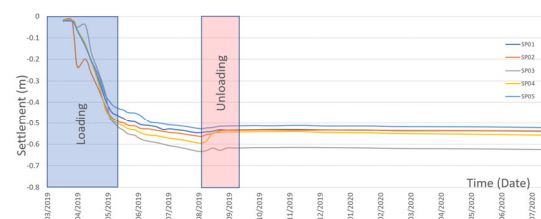


Figure 5. Trial settlement plate results

This is in the order of 2.8% of fill depth. As expected, this is greater than the 1% to 1.5% measured in similar quarry environments in engineered fill without surcharge (Colls et al 2010). Given the variable groundwater level at the site, the upper 5 m of fill has the potential to settle through hydro-consolidation prior to and during surcharging, as the water level equilibrates. Hydro-consolidation is documented to contribute settlement of between 3% and 6% of fill

depth of non-engineered stiff clay fills and fill with low levels of compaction (Waddell and Wong 2005) (Charles and Watts 2002)

Upon unloading, a rebound of up to 150 mm occurred followed by settlement over the subsequent period of six months of typically about or less than 5 mm (Figure 5) prior to flooding.

Heavy rainfall combined with a pump failure resulted in flooding, saturating the fill, entering the wick drains and imposing additional load not anticipated nor modelled. This has impacted and slightly increased the recently measured settlements and possibly initiated hydro-compaction of the fill above the water table.

Extensometers confirmed the settlement at the targeted depths was apportioned relative to those depths, with no significant variations in responses which could be attributed to different fill types, such as Coode Island Silt.

7.2 Porewater

Porewater was expelled via wick drains and drained through the permeable layer to the perimeter drain and collection tanks, as anticipated. The volume of porewater expelled is proportional to settlement. Initial high levels of settlement resulted in high volumes of porewater being collected. During the loading event issues with measuring the volume of porewater were encountered.

Vibrating wire piezometers, measuring porewater pressure, were severed during earthworks. Rectification works were successful in repairing three of the four inputs. The remaining readings from both upper and lower sensors showed that the pore water pressures stabilised once the surcharge was removed albeit at a higher level than prior to surcharge.

7.3 Gas

No venting infrastructure was installed to monitor gas flow or concentrations during the trial. However, landfill gas was noted to be expelled during wick drain installation, potentially penetrating pockets of gas trapped by layers of clay or other low permeability materials in the fill. Landfill gas will be monitored at a later stage.

8 CONCLUSION

The ground improvement trial confirmed that installation of wick drains and surcharging together are effective ground improvement techniques for use on this site to accelerate fill settlements and provide a pathway to displace landfill gas within the quarry fill. The period of primary consolidation (and hydro-consolidation) was shorter than predicted for the adopted wick drain spacing and will mostly occur over a three month period. The ability of wick drains to accelerate rebound of the groundwater table within the quarry fill also speeds up the process of any collapse settlement.

Variability of settlement results across settlement plates and extensometers is indicative of the potential for considerable differential settlement. The trial results aid the ability to build in contingency for differential settlement in the calculations for percentage fall of the preparatory earthworks mound at its surface. This will ensure a flow gradient is retained post loading in the dual purpose permeable layer.

A 2 m low permeability clay-rich barrier over the permeable layer provides a gas protection measure, which will prevent or at least greatly inhibit gas migrating into future dwellings above. The dwellings might still require a reduced landfill gas engineered mitigation measure below the foundations, depending on the EPA-appointed Auditor decision. The top of this clay-rich engineered layer is at least 2 m below the typical civil and residential construction works at or above the original site ground level, together with associated services, reducing likelihood of a breach of the gas protection measure. Basements and swimming pools are likely to be precluded. Further landfill gas monitoring is required to confirm the Characteristic Gas Situation for the environmental audit.

9 ACKNOWLEDGEMENTS

We acknowledge the input and support of our client in the preparation of this paper. The project is confidential at this time.

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