

# Brown gold: redevelopment of former quarry and landfill sites

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## ABSTRACT

This paper presents a discussion of key geotechnical considerations and challenges associated with the rehabilitation and redevelopment of former quarry and landfill sites, including open quarry pits to be backfilled with imported engineered fill and former quarry pits that are already backfilled with uncontrolled fill materials where it is not practical to remove the landfill/uncontrolled fill materials as part of the rehabilitation/redevelopment. Geotechnical considerations and challenges that are discussed include the importance of communication with regulatory authorities throughout planning, design and handover, the challenges associated with geotechnical investigation of former landfill sites, the availability of materials from onsite sources or importation for use as engineered fill, requirements for assessing and monitoring ground settlement and the importance of quality assurance (e.g. Level 1 inspection and testing) during rehabilitation/redevelopment earthworks. Development outcomes ranging from public open space to residential or commercial development are also discussed.

*Keywords:* quarry, landfill, brownfields development

## 1 INTRODUCTION

The practical challenges and costs associated with the redevelopment of former brownfield quarry and landfill sites have historically limited their development potential. However, as Melbourne's population and land value increase, former quarry and landfill sites are increasingly being targeted by a range of public and private developers, with potential associated benefits for community amenity and the sustainable reuse of in situ materials (e.g. stockpiles of uncontrolled fill).

This paper presents a discussion of key geotechnical considerations and challenges associated with the rehabilitation and redevelopment of former quarry and landfill sites, based on the authors' experience across a range of Melbourne sites over the past 20 years. Each site typically presents a unique set of challenges but for ease of description the following simplified groupings have been adopted in this paper:

- Open quarry pits, or pits with a shallow depth of uncontrolled fill that can be removed to expose natural subgrade materials, where there is the opportunity to control the nature of the backfill materials to target a specific development outcome.
- Former quarry pits that are already backfilled (typically with uncontrolled fill materials ranging from soil and rock to municipal waste), where it is not practical to remove and replace the backfill and the nature of the existing conditions and the potential for ground improvement will govern the geotechnical approach for development.

Development outcomes ranging from public open space to residential or commercial development are also discussed.

Whilst land contamination issues are a key aspect of the potential development of former quarry and

landfill sites given there is typically a requirement to complete an Environmental Audit, these issues are not discussed in detail in this paper which focusses on geotechnical considerations in particular the settlement characteristics of filled sites and the resulting implications for development.

## 2 FEASIBILITY AND CONCEPT PLANNING

Developing a ground model that relates the expected ground conditions to the type of development proposal and a remediation strategy that clearly communicates how the land may be developed is critical to the conceptual planning of quarry/landfill developments and to inform feasibility or due diligence assessments. However, feasibility assessment will not be limited to geotechnical considerations and related factors such as the likely site value pre- and post-development (likely influenced by the site location), the level of community support for development, and any environmental or planning restrictions on the type of development (including Earth Resources Regulation – the Victorian Mining Regulator – Work Authority or rehabilitation requirements) will need to be considered by the relevant specialists.

Quarry or landfill developments will often require rezoning to be carried out before development can begin in earnest and a key early challenge for the project team can be in balancing the need to obtain sufficient baseline geotechnical information to support planning applications with project budgets that may be limited until there is confidence that planning approval will be granted. There is therefore typically an initial desktop or non-intrusive phase of assessment where available information about the site history and likely geotechnical requirements for development are subject to preliminary evaluation.

Key geotechnical characteristics to be considered in the initial assessment of quarry and landfill sites for development include but are not limited to:

- The depth and extent of the former quarry pit(s), e.g. a relatively shallow, wide pit or a relatively deep, narrow pit.
- The geological setting e.g. a hard rock/basalt quarry, a soft rock/siltstone/brickworks quarry, or a sand quarry.
- The depth to groundwater and whether ponded water is present within the pit.
- The nature of any backfill materials within the pit (e.g. whether they were placed as controlled or uncontrolled fill and the type of waste materials likely to be present) and whether it is practical to remove them as part of the proposed development.
- The history of development, e.g. the timing of quarry extraction and backfilling.
- The extent of natural ground or generally undisturbed areas outside the former quarry pit(s), which if present offer the potential for conventional development to offset the challenges associated with the quarry pit(s). The respective characteristics of different parts of the site should be considered in planning the type of development proposed.
- The surface topography, which can be particularly important for former landfill sites if they are mounded to facilitate surface water runoff and are subject to restrictions on levelling earthworks to avoid exposing waste.
- For former landfill sites, the presence of surface, side or base liners that may restrict development.
- The availability of earthworks materials, e.g. whether material stockpiles or potential borrow areas are available onsite or imported fill materials are required.
- The presence of buildings or underground structures such as tunnels associated with quarry or other operations that may affect development in areas outside the pit(s).

The following broad categories of development are considered in this paper:

- Public open space, i.e. parkland and sports fields, which generally have a high tolerance for ongoing settlement. However, there may be associated buildings (e.g. sports pavilions) and infrastructure such as light towers that have a low settlement tolerance and there may be some types of sports fields that have a relatively low settlement tolerance, for example synthetic surfaces and sports fields for elite use.
- Low-rise residential development, i.e. 1-2 storey residential buildings which could potentially be supported on shallow footings founding in suitably engineered fill materials.
- Medium to high rise development, i.e. buildings of more than about 3 storeys for which it is unlikely that fill materials are a suitable founding stratum, and where piled footings founding in natural materials below fill are likely to be required.
- Infrastructure such as roads and underground services associated with the above broad development categories.

The geotechnical challenges associated with former quarry and landfill sites mean the planning process is typically more complex than for other greenfield and brownfield sites. Early engagement with Council or other planning authorities to clearly communicate the geotechnical challenges and the proposed redevelopment strategy in the context of the site-specific geotechnical characteristics can be beneficial to provide Council with confidence that development is feasible. Consideration may need to be given to establishing an owners' corporation to manage public assets such as road reserves to assuage Council concerns in relation to asset management and maintenance. There may also be more onerous bonding and maintenance period requirements for assets that will eventually be transferred to Council ownership in consideration of the potential for ongoing settlement. It is also critical that development details (e.g. final surface levels and the general type of development proposed) are established early as there may be limited scope to make adjustments once bulk earthworks or other development works commence.

The following sections of this paper provide more detailed discussion of the key geotechnical considerations and challenges as they relate to open quarry pits (where the development can influence the backfill materials) and former quarry pits that are already backfilled.

### 3 OPEN QUARRY PITS

#### 3.1 General

The key distinction made in this paper with respect to open quarry pits is that there is the opportunity for the geotechnical design of earthworks strategies (backfill) to accommodate the proposed development.

The design of backfill earthworks should consider the Australian Standard AS3798 (2007) 'Guidelines on earthworks for commercial and residential developments', noting that AS3798 (2007) provides guidance on minimum considerations and not explicit requirements. Reference to the Standard is not a substitute for a technical specification that sets out the *specific* requirements for a *specific* development at a *specific* site. It is critical that the geotechnical design of earthworks takes the site-specific geotechnical characteristics and nature of the proposed development into consideration.

In this paper, 'controlled fill' (also referred to as engineered or structural fill) is used to refer to fill placed with engineering supervision in accordance with a specification developed in accordance with the guidance in AS3798 (2007). For controlled fill it is important that the specification is in place prior to the commencement of earthworks so that compliance with the specified requirements can be assessed. Fill materials placed without engineering supervision or where there are no records of the engineering supervision having been undertaken are considered 'uncontrolled fill' materials.

If low-rise residential development is proposed and requires a site classification in accordance with AS2870 (2011) 'Residential slabs and footings', reclassification (from Class P) cannot take place unless the fill is controlled. However, there may be circumstances where the effort to place controlled fill is not justified by the proposed end use, for example the development of parkland may not require the use of controlled fill (potentially with the exception of near surface zones).

A key distinction between controlled and uncontrolled fill materials is that the specified requirements for controlled fill materials and associated records of compliance provide a technical basis for estimating the future engineering performance of the fill based on reasonably consistent and predictable material properties. Whilst the specific material requirements are critical for a specific development proposal, if the nature of the development changes the presence of controlled fill materials still provides a basis for assessing the likely ground response. If the fill is uncontrolled or if the specified requirements are overly broad, the potential for variability makes it difficult to assess the likely engineering performance of the fill.

### 3.2 Geotechnical design of backfill

Geotechnical issues to be considered in the design of backfill earthworks include:

- The required engineering performance of the fill platform, including where relevant to the development proposal:
  - The timing and magnitude of settlement of the fill platform.
  - The reactivity of the fill (i.e. shrink/swell movement due to seasonal moisture content changes).
  - The potential for differential settlement at the interface between filled areas and areas that have not been filled.
  - The ability of the backfill to support the proposed structures (i.e. the bearing capacity of the backfill).
  - The suitability of the fill as subgrade for pavements, and as the zone in which future trenching and excavation works (e.g. for underground services and building footings) will occur.
  - Aesthetic considerations for the completed backfill surface.
- The nature and strength of the subgrade material at the base of the pit, including whether water (from groundwater or surface water inflow) is present and whether there are existing uncontrolled fill materials within the pit that need to be removed before backfilling can commence.
- The geotechnical properties of the materials to be used as backfill (e.g. particle size distribution/grading, clay content and plasticity). These properties will affect the engineering performance of the backfill.
- The availability and cost of site-won or imported backfill materials and whether processing of the materials is required.

- The target level of compaction and moisture content during the placement of backfill. In general terms, the higher the level of compaction achieved during backfilling, the smaller the amount of settlement once backfilling has been completed. The fine fraction of backfill should be placed and compacted at a moisture content that is close to its optimum moisture content for Standard compaction (SOMC). Fill that is poorly compacted or placed significantly dry of SOMC has an increased risk of collapse settlement as it becomes saturated (e.g. due to recovering groundwater levels).
- The level of engineering supervision (including survey control and monitoring of the performance of the backfill) during and after the backfilling earthworks, i.e. Level 1 inspection and testing or Level 2 sampling and testing as set out in AS3798 (2007).
- The potential impact of groundwater on construction processes and the long-term performance of the fill. There is the potential for groundwater levels to change as a result of backfilling.
- The stability of quarry pit batter slopes.

For deep controlled filling in former quarry pits it is typical to adopt different zones or types of fill at different elevations within the pit to accommodate the potential variability in fill sources and to address issues such as groundwater control in the base of the pit and aesthetic requirements near the final surface. In general, at least three distinct vertical zones may be required within the backfill platform, including:

- A zone of open-graded backfill at the base of the quarry pit to help control water inflow.
- A zone of 'general' backfill placed over the open-graded fill zone (with a geotextile separation layer between these zones).
- A surface zone of nominally 'higher quality' fill (e.g. fill with stricter controls on grading and compaction) to help bridge over variability in the nominally 'lower quality' general fill as well as to provide suitable material for surface development works.

Colls et al (2010) provides an example of the zoning approach used during the backfilling of the former Niddrie quarry (refer Figure 1). Charles (2008) provides several useful case studies relevant to deep controlled fill sites and approaches for estimating settlement. However, given the potential for variability in the fill materials actually used as well as the methods for placing fill and the level of compaction achieved, settlement monitoring (e.g. via survey of settlement monitoring plates or other monitoring instruments installed at different depths within the fill platform) and interpretation of the monitoring data are usually required to assess the settlement performance with respect to initial estimates. Given the rapid rate at which site conditions can change during bulk earthworks, survey control of the extent and thickness of approved subgrade and controlled fill cells is also a key component in quality control to provide

confirmation that there is vertical and horizontal overlap between controlled fill cells.



Figure 1. The former Niddrie quarry prior to redevelopment (top, c.2001) and in November 2019 (bottom)

### 3.3 Geotechnical investigation

Intrusive geotechnical investigation for open quarry pits may be limited to test pits or boreholes to assess the nature of potential borrow materials and likely processing requirements, the thickness and extent of uncontrolled fill to be removed, and groundwater considerations. Other information such as historical aerial photographs (including photogrammetry) and quarry records if available can assist to provide site conditions information.

Where Level 1 inspection and testing by a geotechnical inspection and testing authority (GITA) is specified, a completion report should provide confirmation that the specified requirements have been met but may still not be sufficient to inform design development. Once the backfill earthworks are completed, there will usually be a requirement for additional geotechnical investigation (e.g. boreholes for in situ testing to assess the strength of the fill) to inform design works. If the specification was developed for the eventual development proposal and the earthworks complied with the specification, the post earthworks investigation should predominantly be a confirmatory exercise e.g. to confirm the site classification in conjunction with a review of relevant engineering records and the results of settlement monitoring. Where reclassification of controlled fill is required it will usually be necessary for the GITA to provide the reclassification.

### 3.4 Common issues for development of open quarry pits

Common geotechnical issues observed in bulk controlled earthworks projects that are relevant to the backfilling and development of open quarry pits in general include the following:

- Where a significant volume of imported fill is required the availability and cost of suitable

imported fill materials can present significant project risks, as they depend on market factors and the geographic location of the destination site with respect to potential source sites. Where imported fill materials are required it is important that the development strategy and specification are developed recognising the likely commercially available fill materials.

- Inadequate specification or the lack of a specification leading to unsatisfactory performance, e.g. excessive swelling of high plasticity clay compacted significantly dry of SOMC. The development of a specification that is targeted at the specific site conditions and development proposal is a key factor in successful bulk earthworks.
- Misinterpretation of the requirements of Level 1 inspection and testing, which AS3798 (2007) defines as the presence of the GITA at all times during earthworks activities. Periodic visits to undertake compliance tests represent Level 2 sampling and testing. However, there appear to be differences in the industry in how the requirements of Level 1 are interpreted.
- Responsibility for engineering quality control. There is the potential for a conflict of interest if the earthworks contractor is responsible for their own quality control (e.g. via engagement of the GITA). The authors see it as important that the Principal or owner of the development is responsible for engaging independent engineering quality control.
- Difficulties in achieving compaction against steep pit walls. Quarry pit walls especially in hard rock quarries can be near vertical and it can be difficult achieving consistent and adequate compaction in the zone adjacent to the wall leading to excessive total and differential settlement. It may be necessary to reduce the pit slope (particularly near the finished surface level) to reduce the potential for differential settlement across this interface.

## 4 BACKFILLED QUARRY PITS

### 4.1 General

The key distinction made in this paper with respect to backfilled quarry pits is that the backfill materials are already present and must be accommodated in the proposed development works (i.e. not removed and replaced with controlled fill). Where backfill materials are already present (and placed by others) they typically represent uncontrolled fill.

The potential for significant ongoing total and differential settlement of uncontrolled fill materials is usually the key geotechnical consideration when assessing redevelopment options for these sites. Differential settlement is generally a maximum at the interface between fill and natural ground materials and hence it is important to define the boundary of the backfilled former quarry pit. There are significant risks associated with attempting to support buildings or infrastructure with a low settlement tolerance directly on uncontrolled fill, as illustrated by the Yarraville sinking village case study from the early

1970s presented in Dahlhaus (1991), and buildings with low tolerance for total or differential settlement are typically piled. However, there are numerous public open space parks and sports ovals built over backfilled former quarry pit (and gully fill landfills) in Melbourne as well as commercial or public buildings (e.g. Altona Gates and Northcote Plaza shopping centres and Footscray Technical School), low-rise residential developments (Bouazza & Avelle, 2006) and medium to high rise buildings including the piled multi-level car park at the Tooronga Village and townhouse development in Cavanagh Street, Cheltenham. Provided that development is planned in recognition of the specific geotechnical challenges then development is technically feasible. However, where linear infrastructure such as roads and services will be constructed over uncontrolled fill materials there should be an expectation of ongoing ground settlement which may require ground improvement to reduce but not eliminate the magnitude of post-construction settlement, and needs to be communicated at an early stage to the developer and relevant planning authority (e.g. Council).

For former landfills, the age of the landfill and whether it is lined are key development considerations. Modern landfills (refer EPA Victoria, 2015) are typically constructed with low permeability side and base liners and have a surface capping of low permeability materials. These features can restrict their development potential as it may not be permitted to alter the capping or penetrate the base liner (for example) with pile foundations. However, older landfills (including older unlicensed landfills) typically do not have base or side liners. Where a capping layer is present above older landfills it is usually practical to reinstate the cap or otherwise provide satisfactory environmental provisions around pile penetrations. Note that mounding of the surface cap to help with surface water runoff, and restrictions on earthworks such as excavation into waste materials below the cap, can pose challenges for achieving surface grades conducive for development.

Environmental considerations are critical to the development of backfilled quarry pits but are not addressed in detail in this paper.

#### **4.2 Site characterisation and settlement**

The geotechnical characterisation of backfilled quarry pits can be challenging as there are usually few (if any) records of the backfill materials used and it can be challenging to identify the footprint of the former quarry pit once it is backfilled. Landfill materials and the cap also typically extend beyond the perimeter of the former quarry pit.

Key information sources to assist in the characterisation of backfilled quarry pits include historical aerial photographs, survey and quarry plans including photogrammetric mapping, as well as landfill licence documents where relevant and available, and information from more conventional geotechnical and geophysical investigation

techniques. Where landfill waste with a capping layer is present it is important to assess the thickness and nature of the cap (which may more accurately be called a layer of cover soil with minor or no waste rather than a formal engineered cap as would be constructed over a modern landfill).

Key challenges for geotechnical and geophysical investigation techniques include the following:

- Health and safety risks including the potential to encounter landfill gas and explosive/flammable atmospheres as well as contaminated soils, leachate or groundwater.
- Obstructions or materials such as wire can be encountered during drilling which can cause damage to the investigation equipment (e.g. broken drill rods) and delays to investigations whilst boreholes are relocated and redrilled.
- Where relevant, requirements to limit disturbance to the landfill cap and reinstate penetrations through the cap.
- Difficulty in interpreting geophysical results in variable backfill materials.

The amount and rate of settlement depends on a number of factors including the depth of the backfill materials and their composition (including any waste materials present), the age of the backfill and the type of plant and methodology used to initially place and compact the backfill materials. Furthermore, if additional fill is placed over existing uncontrolled backfill materials, additional settlement will occur.

In general terms, the settlement that occurs comprises primary settlement in response to the application of a new load (e.g. the weight of additional fill), and secondary or creep settlement that occurs in the absence of any new loads (e.g. due to the decomposition of putrescible materials in the landfill and consolidation of the fill under its self-weight). Secondary or creep settlement is usually the main concern, assuming that ground improvement works such as fill surcharging and/or dynamic compaction are undertaken prior to the commencement of building works to address issues associated with primary settlement (i.e. the settlement behaviour of the landfill is monitored and assessed during ground improvement works, which are designed to 'build-out' the additional primary settlement before construction of permanent structures commences – this process may take one to two years or longer).

Ground improvement works will not eliminate secondary settlement. However, monitoring of landfill settlement behaviour during preparatory works provides the opportunity to assess the rate of secondary settlement. Ground improvement works can also assist in building a 'bridging layer' of relatively well-compacted fill near the ground surface which can help reduce the potential for differential settlement due to secondary settlement in the underlying landfill materials.

The magnitude and rate of primary and creep settlement is difficult to predict in advance and usually requires the performance of a monitored field

trial (e.g. trial embankment, refer Figure 2). Yuen & Styles (2000) provide some useful settlement data for landfill materials placed in a former sand quarry in the southeast suburbs of Melbourne.



Figure 2. An example of a surcharge trial pad constructed to help assess settlement rates

#### 4.3 Common issues for development of backfilled quarry pits

Common issues observed in the development of backfilled former quarry pits include the following:

- Health and safety risks, e.g. the potential to encounter landfill gases and contaminated soils, leachate and groundwater.
- Inability to identify and classify uncontrolled backfill materials, or a lack of communication/knowledge transfer about the presence of uncontrolled fill leading to inappropriate development. Ideally, a single developer should oversee development from start to finish to manage risks rather than selling allotments to a third party to develop. If uncontrolled backfill materials are present, it is important they are identified as such in geotechnical investigations. This may require review of historical aerial photographs or other information sources. It is also important to recognise that placing a surface layer or layers of controlled fill does not allow for reclassification of a site in accordance with AS2870 (2011).
- Obstructions to piling or other construction activities may be present within the backfill materials. The presence of steep former pit wall slopes is also important as piling near these slopes can result in significant pile breakage or loss of verticality. Trial piling works can assist.
- Where piling in fill subject to ongoing settlement is required, due consideration of downdrag/negative friction loads is required.
- The ground support conditions and requirements for working platform construction need to be carefully considered.
- Unrealistic expectations about the benefits of ground improvement, i.e. ground improvement work such as surcharging, deep dynamic compaction, impact rolling.
- Difficulties with maintaining the integrity of monitoring equipment during trials, e.g. damage to settlement monitoring plates during trial embankment construction, or difficulty identifying a stable reference point for survey monitoring on large landfill sites.

## 5 OTHER CONSIDERATIONS

This paper focuses on the commonly encountered situation(s) where the quarry and/or landfill activities have made no prior plans for end of life redevelopment. Planning for future redevelopment whilst quarrying is still underway (or has not yet commenced) presents significant opportunities for sustainable and more cost-effective redevelopment at the end of the quarry or landfill life.

## 6 CONCLUSION

The redevelopment of former quarry and landfill brownfields sites offers benefits for community amenity and the sustainable reuse of geo-materials. Given the complexity of these sites, the geotechnical considerations as discussed in this paper are critical to the early development of a site and development specific strategy for redevelopment. It may not be practical to rectify poorly planned or poorly performed development works (e.g. excessive settlement of deep fill) and such adverse outcomes would increase the difficulty in obtaining regulatory approval for new projects.

Communicating the key geotechnical issues and the strategy to address risks to stakeholders including the developer and relevant regulatory authorities such as Council is also critical to progressing this type of redevelopment and providing regulators with confidence that redevelopment is feasible.

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