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Sustainable design for construction and operation of a storage area for filter press bauxite residue in a desert environment

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Abstract

Bauxite residue produced via the Bayer process is of a high pH and as such is typically considered to pose a significant risk to the environment. Accordingly, storage facilities for bauxite residue are typically designed and constructed to incorporate a low permeability liner system. A concept design was developed by others based on conventional compacted clay liners and large perimeter embankments.

The region did not possess the materials typically required for construction of a low permeability liner system (i.e. clay and water), so a revised design was developed which resulted in a more sustainable solution by substantially reducing construction costs, required resources and greenhouse gas emissions associated with material transport. This included reduced earthworks requirements, maximising the use of site won materials, minimising the need to import water and crushed rock, and eliminating the need to import clay.

Specialist accelerated durability testing was conducted on the proposed liner materials to ensure the liner system would perform satisfactorily under the anticipated extreme exposure conditions, including a highly alkaline environment.

Due to the risk of residue dusting, a laboratory-based dust suppression study was undertaken during the design stage to help understand dust suppression requirements for the facility in this hot, dry and windy environment.

In addition, in an effort to reduce the risk of dust generation, the facility was designed to facilitate progressive rehabilitation, using site won materials excavated to construct the baseliner of the facility. This limits the exposed area of residue and the associated risk of dust generation..

Keywords: *bauxite residue, dry stack, filter press, geosynthetics, alumina, sustainable dust suppression*

1 Introduction

Bauxite residue (BR) produced from alumina refining via the Bayer process is of a high pH and as such, is typically considered to pose a significant risk to the environment. Accordingly, storage facilities for BR are typically designed and constructed to incorporate a low permeability liner system. Depending on site specific requirements related to managing risk to the environment, this may comprise a geomembrane and compacted clay composite liner system.

Construction of low permeability liner systems of this nature in a remote desert environment poses challenges as materials typically used for their construction (e.g. clay and water) are not locally available.

This paper presents a summary of select aspects of a design developed for a facility used to store BR at a remote desert site for a new refinery operation.

The facility has now been constructed and has commenced operations.

2 Site conditions

The BR storage facility is located in a remote desert environment more than 30 km from the coast and the alumina refinery. At the time of design and construction, the surrounding areas were undeveloped, however, these areas are zoned for future industrial development. The site location experiences a hot arid climate with mean evaporation of approximately 2,500 mm/yr and mean precipitation of approximately 67 mm/yr which produces characteristic desert terrains and summer temperatures in excess of 50°C. Subsurface conditions at the site typically comprise a 1 to 7+m thick layer of dune sand (poorly graded sand and poorly graded sand with silt) underlain by highly weathered sandstone or siltstone.

3 Refinery process and residue characteristics

The refinery produces alumina based on the Bayer process from imported bauxite. The BR is subjected to the filter press process to remove liquid which produces a solid residue cake.

The BR placed in the facility is characterised as a low or intermediate plasticity silt on the Casagrande Chart based on the Unified Soil Classification System. Based on testing undertaken, the material has a standard optimum moisture content (SOMC) of approximately 30% and standard maximum dry density of approximately 1.55 t/m^3 (Standards Australia 2003) and after filter press is produced by the refinery at a moisture content of up to approximately SOMC + 4%. The results of testing for particle size distribution by laser diffraction indicates the BR typically comprises approximately 5% sand, 68% silt and sand and 27% clay sized particles.

4 Operational philosophy

The produced BR is transported to the residue storage area by covered road trucks as a solid before being placed and compacted in the storage area using conventional earthmoving techniques to form a ‘dry stack’. The design included requirements related to the minimum dry density ratio (DDR) for placed material to ensure stability of the stack. Based on the outcomes of geotechnical assessments, a minimum requirement of 95% of maximum DDR (modified) was adopted for BR placed around the perimeter of the facility with a reduced requirement applying to the remainder of the facility. Depending on the delivered moisture content of the BR, this was expected to require some drying of the BR and the design was prepared to provide allowance for some drying prior to compaction of the BR to enable the BR to be compacted in a manner which achieves the target DDR.

To help maximise opportunity for drying and limit leachate generation potential, filling of the BR is undertaken in near horizontal layers across the entire surface area of the facility (i.e. ‘bottom to top filling’ rather than filling to target profile from ‘end to end’).

It is noted that a concept design was developed by others based on large perimeter embankments to be constructed using site won fill. Subsequent to this, WSP was engaged to prepare a design for construction and developed the 'dry stack’ approach that was adopted for the works. This dry stack approach resulted in a reduction of infill required for the work by approximately 90% compared with the concept design.

The facility design was prepared such that runoff from the BR stack was captured via a lined drainage network and stored onsite in lined storage ponds for re-use as a dust suppressant.

5 Baseliner design and material selection

In response to the high pH characteristics of the BR and requirements related to managing risk to the environment, a composite liner with overlying leachate collection system was selected to be adopted. Conventionally, such lining systems typically employ the use of a geomembrane, compacted clay liner and gravel leachate collection layer with cushion geotextile. It is noted that:

- A reliable clay source within the country was not able to be identified.

- The identified crushed rock source was greater than 40 km distance from site.
- Water for construction was required to be hauled a distance of approximately 30 km.

In response to costs and sustainability negative impacts associated with importing clay and gravel to the site, alternative materials were considered.

This resulted in the adoption of the following liner system profile (from bottom up):

- Prepared select subgrade.
- Geosynthetic clay liner (GCL).
- High-density polyethylene (HDPE) geomembrane.
- Leachate collection/protection layer comprising:
  - 500 mm thickness layer of site won dune sand.
  - Network of small diameter HDPE pipes with fine gravel surround to act as filter to the surrounding dune sand.

The adopted liner system design performance was assessed using Giroud & Wallace (2016), to be similar to the liner system that had been prepared in the concept design that had regulatory approval.

The leachate collection/protection layer design resulted in a greater than 98% reduction in the volume of crushed rock required for the works (approximately 150,000 m^3). Rock available at or nearby to the site was not considered to be sufficiently durable to suit this application.

In response to the challenging elevated pH exposure conditions and work undertaken previously (publications include Gassner et al. (2008), Gassner & Scheirs (2010) and Du Preez et al. (2014) etc.), a program of specialist durability testing was undertaken on samples of candidate products considered for use as GCL and geomembrane in the works using a process liquor sample provided by the owner. As outlined by Webb (2022), the results of this testing indicated significant variability in the expected performance of candidate GCL and geomembrane products in contact with the BR with a number of the candidate products (for both material types) considered unsuitable, which reinforced the need for testing of this type for this application.

The leachate collection/protection layer was designed to serve three purposes:

1. To act as a relatively high permeability drainage layer which helps limit hydraulic head on the underlying liner system and enables this liquid to drain to designated low points (sumps) in the liner system where it can be extracted.
2. To act as a liner protection layer to help reduce the risk of damage to the liner system during BR placement and compaction. Site won sand was sampled, tested and assessed based on results of laboratory testing for particle size distribution as suitable for placement directly on the geomembrane without the need for additional a cushion layer. It is noted geotextile materials were not expected to be sufficiently durable in the anticipated high pH exposure conditions.
3. Confine the GCL until the BR is placed over the liner system.

Deployment of a GCL over a dry sandy subgrade posed challenges associated with ensuring hydration of the bentonite within GCL due to the lack of moisture present in the subgrade and the ability of poorly graded sand to retain moisture. Pre-hydration with ‘fresh’ water is considered important as the durability testing for this project confirmed that hydration with the BR liquid results in reduced osmotic swelling of the bentonite and a significantly higher coefficient of permeability compared with hydration with ‘fresh’ water.

In this instance, pre-hydration requirements were developed by undertaking field trials with moisture conditioned subgrade material of various site won sources to understand which subgrade materials would help retain and release sufficient moisture to promote GCL hydration. Based on the outcomes of this, subgrade preparation requirements were developed which included subgrade material and moisture conditioning requirements immediately prior to GCL and geomembrane deployment. In addition, the design required the protection layer be placed within 48 hours of GCL deployment to ensure the GCL was confined soon after deployment and relatively early in the hydration process.

The designed baseliner system significantly limited the need to import materials compared with the use of materials more typically used in composite baseliner construction (e.g. clay and gravel) which significantly reduced construction costs (reportedly to be millions of dollars) and greenhouse gas emissions associated with material transport. The incorporation of the GCL in the design in lieu of 1 m thickness compacted clay liner helped significantly limit water demand and greenhouse gas emissions (by approximately 90% or 85,000 t of CO_2 equivalent based on an indicative assessment) for this component of construction. The greenhouse gas emission estimates were undertaken using an approach similar to that outlined in Athanassopoulous & Vamos (2012) and considering information included in Koerner et al. (2019) which included allowance for emissions associated with:

- GCL:
  - Bentonite mining.
  - Geotextile and GCL production emissions.
  - International shipping and transport from manufacturer factory to site (assumed 14,000 km by cargo ship plus 50 km by road at either end).
  - Deployment of GCL.
- Clay:
  - Excavation at source.
  - Haul from nominal source 160 km from site.
  - Placement, moisture conditioning and compaction.

Similar to outcomes reported in Athanassopoulous & Vamos (2012), the primary factors driving the carbon footprint comparison are distances between the clay source and site and GCL plant, site and equipment used for this transport. It is noted that the estimate does not consider greenhouse gas emissions associated with water transport to site so actual savings from the works are expected to be greater than estimated due to the GCL option requiring less water than compacted clay.

6 Dust suppression

Considering the characteristics of the BR and climatic conditions at the site, dust generation was identified as a risk to operations. In response to this the following was undertaken:

- A dust suppression study was undertaken to help understand dust emission risk and dust suppression requirements for the site.
- The design was prepared to facilitate progressive rehabilitation of the stack to limit the area of BR exposed to dust.

The following subsections describe these in further detail.

6.1 Dust suppression study

The dust suppression study included the following activities:

- Wind tunnel testing using samples of BR to measure total suspended particles and assess the risk of dust generation from the residue in various conditions. This included at different moisture contents, different wind speeds, disturbed and compacted BR and after using different dust suppressant liquids including BR 'leachate', refinery waste liquid (from refinery acid neutralising process) and sea water. The outcomes of this indicated disturbed and dry BR posed an increased risk of dust generation than BR compacted to a smooth and uniform surface. In response to this, operations controls were developed to limit dust generation potential (and associated dust suppression requirements) which included smooth drum rolling of BR surface after compaction.

- Air drying column testing under simulated summer and winter climatic conditions and generation of soil water retention curve for BR to help understand the expected time frame for drying of placed BR and therefore expected required frequency for application of dust suppressants.
- A water balance study using simulated climate conditions based on historical information to estimate:
  - Estimated dust suppression frequency for each month (for different liquids) and for potential upset conditions (e.g. sandstorms).
  - Probabilistic dust suppression liquid demand.
  - Equipment/fleet requirements for dust suppression activities.

The outcomes of the study were able to be used to select a dust suppression fleet and strategy for facility operation that limited requirements for importing water to site by maximising the use of refinery waste liquids, thus providing a more sustainable solution than disposal at an alternate location (likely to sewer). Based on the results of chemical testing, the characteristics of the refinery waste liquids were assessed as not posing an increased risk to the environment compacted with BR and BR 'leachate'.

The laboratory dust suppression study helped demonstrate that the refinery waste liquid performs better as a dust suppressant compared to sea water, forming a crust on the dried residue surface. As such, neutralised slurry is preferentially used as a dust suppressant in operations, with sea water only used when neutralised slurry is unavailable. This helps deliver a more sustainable operation by limiting vehicle movements and associated greenhouse gas emissions and costs as all water is required to be transported to site by truck.

6.2 Rehabilitation design

Rehabilitation of the facility was designed to comprise capping using a geomembrane and cover soil layer. To help limit the exposed area of BR on the stack during operations, the facility was designed such that rehabilitation of the site slopes could be undertaken in stages as filling progressed. This was undertaken by including benches at nominal 5 m vertical increments in the stack side slopes which the geomembrane could be anchored in, enabling rehabilitation to be completed bench by bench. Similar to the baseliner protection layer, the design was prepared to ensure site won material could be used as the cover soil layer.

Progressive rehabilitation in this manner required the incorporation of measures to ensure stormwater that had been in contact with the BR (impacted runoff) would not discharge to the environment over the capped surface. This required a network of drains to be designed and constructed on each bench to divert impacted stormwater to a designated runoff pond.

This progressive approach for rehabilitation of side slopes limits the area of exposed BR during operations which, based on the outcomes of the dust suppression study described in Section 6.1, helps reduce dust emission potential for the facility.

7 Conclusion

By applying the measures described in this paper, a design was able to be prepared for a BR storage facility in remote desert environment which resulted in a more sustainable solution by substantially reducing construction costs, resources and greenhouse gas emissions associated with construction and operation. This included limiting the requirement for earthworks, maximising the use of site won materials and refinery waste products, minimising the need to import water and crushed rock, and eliminating the need to import clay.

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