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DESIGN AND CONSTRUCTION OF LINING SYSTEM FOR A COKE LANDFILL

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ABSTRACT

This paper presents the salient features of the design and construction of the lining system for a coke landfill, with a maximum height of 30 m, which was to be constructed on foundation strata which comprised a 5.0 – 9.0 m thick layer coke fill underlain by clay with thickness of up to 30 m. The bottom lining system comprises a geosynthetic clay liner, an HDPE geomembrane and a geocomposite leachate collection system. The effects of ground conditions on the integrity of the bottom lining system were evaluated and excessive localized differential settlements was identified as the significant risk. Hence it was decided to provide a reinforced soil pad below the lining system, to smoothen any abrupt changes in settlement profile. The final design for the reinforced soil pad included three reinforcement layers – a polypropylene biaxial geogrid-nonwoven composite at the bottom and two layers of polypropylene biaxial geogrid.

1. INTRODUCTION

The project comprised the design and construction of the bottom lining system for a coke storage/disposal facility. The coke is a predominantly carbonaceous granular material which is a byproduct of the process of upgrading bitumen recovered from oil sands. In order to prevent any contamination of the soil and ground water, it was required to provide a lining system comprising an impervious barrier and a leachate collection system at the base of the landfill. The ground at the site comprised a layer of coke fill with variable thickness and a deep deposit of clay. In view of the significantly high stresses imposed by the landfill and foundation strata comprising uncontrolled coke fill and thick clay layer, geotechnical considerations of stability and settlement and its impact on the long-term integrity of the lining system became important considerations in the design of the lining system. This paper describes details of geotechnical evaluation and the presents details of the solution adopted to ensure the long-term integrity of the lining system.

2. DIMENSIONS OF THE LANDFILL

A plan of the proposed landfill are shown in figure 1. The landfill has a footprint of about 350 m x 140 m and a maximum height of about 30 m. The cross-section has a trapezoidal shape along the longer dimension and a triangular shape along the shorter dimension. The steepest side slope is 3.3H:1V. The coke is a granular material with particle size ranging from that of fine sand to coarse gravel. The material has a bulk density of approximately 1000 kg/m^3 and permeability in the range of 1 x 10^{-3} to 1 x 10^{-5} m/s.

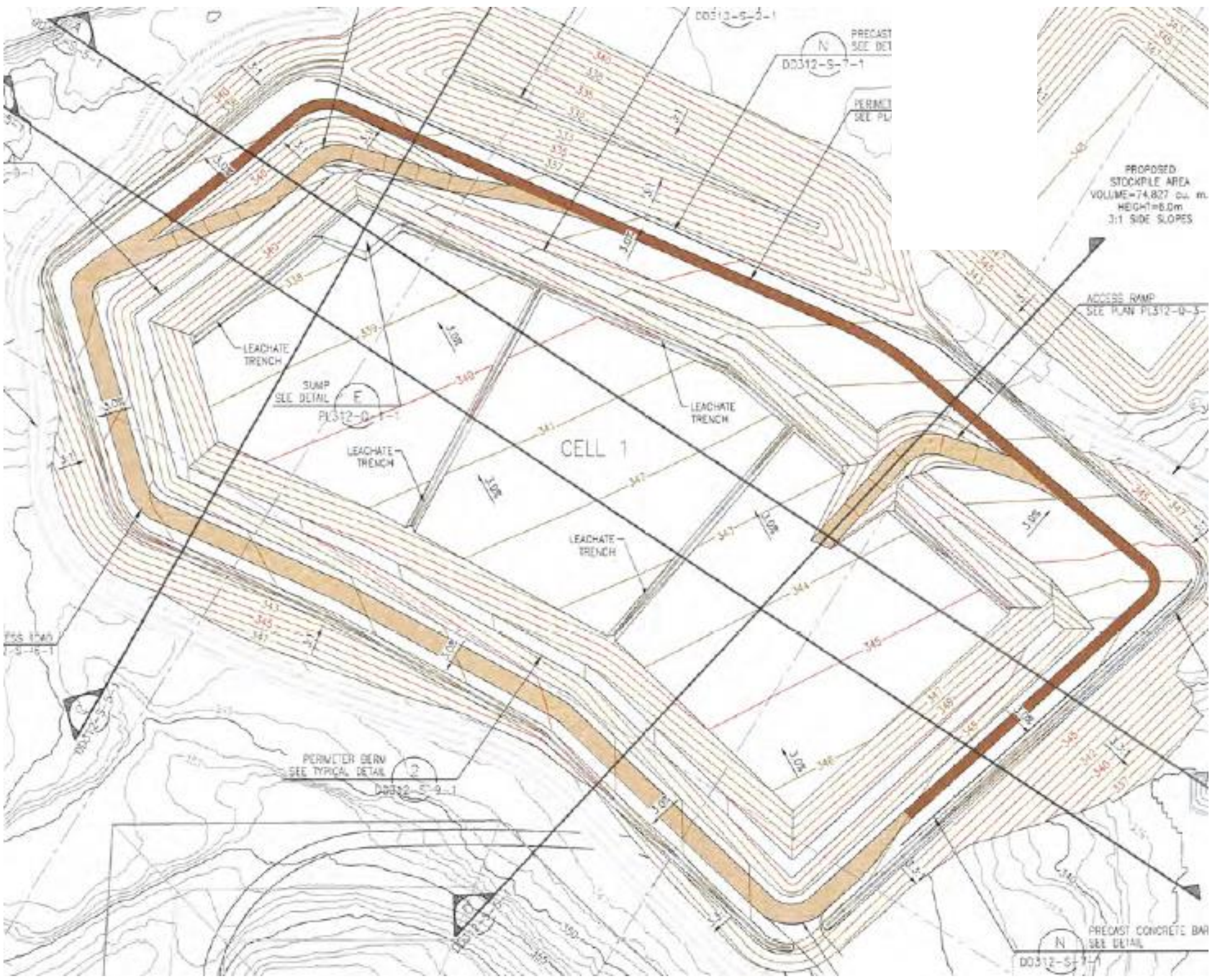

Figure 1. Plan and representative cross-sections of the coke landfill

3. GROUND CONDITIONS

Results of four boreholes drilled at the location to depths ranging from 29.5 to 41.0 m below the existing ground level, show that the strata at the site comprise coke fill underlain by clay with occasional layer of silt stone, clay shale, sand etc. The uppermost stratum is coke fill with thickness ranging from 0 to 13.0 m. At most of the locations, the thickness of coke layer is in the range of 5 – 9 m. However, at a few locations, this layer is not present and at some other locations, the layer is indicated to be thicker. The material is black in color, with a loose consistency and is dry to damp. The clay is typically brown to dark brown in color, with medium to high plasticity, with some silt and traces of sand. Standard penetration test blow counts at most locations has a value between 15 and 45 indicating a consistency typically ranging from very stiff to hard. At some locations blow counts are in the range of 9 to 14 (stiff consistency).

The highest elevation of the ground water table was reported to be 10 m below the existing ground surface and the lowest elevation 33 m below the existing ground surface.

4. COMPOSITION OF THE LINING SYSTEM

The bottom lining system proposed for the landfill comprised a geosynthetic clay liner, a high density polyethylene geomembrane and a geocomposite leachate collection system. The geosynthetic clay liner consisted of a layer of sodium bentonite between two nonwoven geotextiles which are needle-punched together. The geomembrane was a 1.5 mm thick high density polyethylene geomembrane.

5. GEOTECHNICAL DESIGN OF THE LINING SYSTEM

5.1 Geotechnical Design Considerations

The first step in the design was to identify the various modes of failure of the lining system or the ground. The following potential failure modes were identified:

- Foundation extrusion
- Bearing capacity failure of the ground
- Global stability
- Liquefaction of coke fill
- Excessive differential settlement of the lining system

5.2 Lateral squeezing of Clay Stratum

Lateral squeezing or extrusion is the failure of a clay layer by lateral plastic flow from beneath loaded areas. This is a potential mechanism when a plastic clay stratum is subjected to vertical loads and the dimensions of the loaded are much larger in comparison to the thickness of the clay layer. Lateral squeeze is a possibility when the ratio of the applied vertical stress to the undrained shear strength of the clay is greater than three (Berg et al. 2009).

In the present case, the maximum height of the landfill is 30 m and the unit weight of the coke is 1000 kg/m^3. Hence, the maximum vertical stress at the base is 294 kPa. At most locations, the clay has a consistency ranging from very stiff to hard and hence the undrained shear strength of clay may be expected to be greater than 100 kPa. Hence, the ratio of vertical stress to undrained shear strength is likely to be less than 3 and hence lateral squeeze of the clay strata is unlikely.

5.3 Bearing Failure of the Ground

Since, the plan dimensions of the landfill are 350 m x 140 m, the foundation may be considered as a flexible raft of same size placed at the ground surface, i.e. with zero embedment. The ground may be approximated as a two layer system, comprising a sand layer (coke) underlain by clay. The bearing capacity of a flexible raft on two layer soil was evaluated using the approach described by Das (2011).

The following data were considered in the calculations:

- Dimensions of the raft foundation : 350 m x 140 m
- Depth of embedment below ground surface : 0
- Average thickness of coke fill layer : 7 m
- Properties of the coke fill layer
  - Effective cohesion (c′) : 0
  - Effective peak angle of shearing resistance (ϕ′) : 28°
  - Bulk unit weight : 10 kN/m^3
- Undrained shear strength of clay : 150 kPa

The ultimate bearing capacity was estimated to be 835 kPa and with a factor of safety of 2.5, the safe bearing capacity works out to be 334 kPa.

The maximum vertical stress at the base of the landfill is about 295 kPa and since the cross-section along the width is triangular, the maximum vertical stress would be applied only in the centre portion, with stress reducing to zero at the edges. Hence, it can be concluded that bearing failure of the ground is unlikely.

5.4 Global Stability

The global stability of the landfill-ground system was analyzed by evaluating the factor of safety along numerous potential failure surfaces passing through the landfill and the ground. Stability analysis was done using the program ReSSA (3.0). Calculations showed that the lowest factor of safety of 1.36 was obtained for relatively shallow slip surfaces passing through the coke (as would be expected for a slope comprising granular material for which effective cohesion is zero). Deep seated failure surfaces gave a factor of safety greater than 1.5. Hence, it was concluded that deep seated slip failures passing thorough the foundation strata were unlikely.

5.5 Liquefaction

Loose saturated granular materials are potentially liquefiable. In the present case, the coke fill layer, the upper-most foundation stratum is a loose granular material and hence is likely to densify during earthquake. However, the material is not saturated and the highest elevation of the ground water table was indicated to be below the bottom of this layer. Therefore the risk of the liquefaction of the loose coke fill layer was not considered to be significant.

5.6 Differential Settlement

Due to the vertical stress imposed by the landfill, some settlement of the ground surface can be expected. The settlement would be partly due to the compression of the loose coke fill layer and the consolidation of the clay layer. The liner system would tend to follow the settlement profile of the ground. If the settlement is uniform, no additional stresses are imposed on the liner. However, the settlements are likely to be non-uniform because of the following reasons:

- Since the vertical stresses are maximum at the centre of the landfill and zero at the edges, a dish-shaped settlement profile with maximum settlement at the centre and minimum along the edges could be expected.
- Differences in thickness of the coke fill layer and also the sequence and thickness of the clay strata could result in variations in settlement.

As long as the variations in settlement are gradual, the geosynthetic clay liner and the HDPE geomembrane liner could adapt to the settlement without significant distress. However, abrupt localized changes in settlement profile could induce distress in the liner. HDPE geomembranes have very high elongation at break when subjected to a uniaxial state of stress (greater than 400 % and higher), whereas under biaxial state of stress they may fail at elongations as low as 25 % (Koerner, 2005). Therefore, integrity of geomembranes could be affected by abrupt localized changes in the settlement profile. Hence, it may be surmised that most significant threat to the integrity of the liner system is an abrupt change in the settlement profile caused by localized high settlements.

6. REINFORCED SOIL PAD

Geosynthetic reinforcement is extensively used to minimize the effects of localized differential settlements in many applications- pavements, rail roads, embankments etc. Tensile inclusions would be helpful in spanning over weak spots, voids etc. and smoothening out the settlement profile. Therefore it was decided to provide a reinforced soil pad below the lining system to function as a bridging layer. Since the objective is to span over loose pockets and weak spots in the ground, the geosynthetic reinforcement should have approximately equal strength in both directions, have high tensile stiffness and possess excellent chemical resistance. Based on these considerations, a polypropylene punched and drawn geogrid with integral nodes was selected as the most suitable type of reinforcement.

To ensure adequate stiffness, a 1000 mm thick soil pad reinforced with three layers of reinforcement was provided. The first layer was placed at the bottom of the pad, second at a distance of 300 mm from the bottom and third at a distance of 600 mm from bottom. For the bottom most layer, a biaxial geogrid composite (TE-BXC30) - a polypropylene punched and drawn geogrid bonded to a nonwoven geotextile – was selected to enable it to function as a separator also. For the other two layers, TE-BX30 biaxial geogrid was selected. The biaxial geogrid has an ultimate tensile strength of 31 kN/m in both directions. The lining system adopted for the site is shown in figure 2.

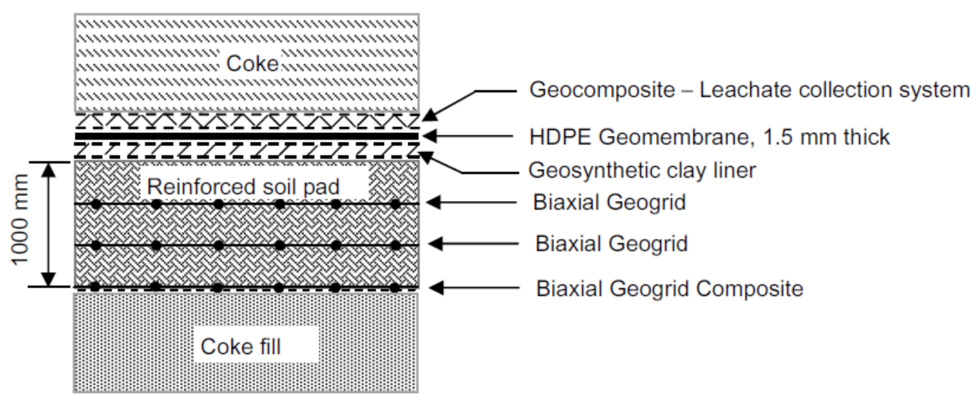

Figure 2. Components of the Lining system

Photographs illustrating the construction of the liner system are shown in figure 3.

Figure 3. Construction of the Liner System

7. CONCLUSIONS

The effect of ground conditions on the long-term stability and integrity of the bottom lining system for a coke landfill was investigated. The potential failure mechanisms leading to geotechnical failure were identified as lateral extrusion of foundation clay, bearing failure, global stability, liquefaction and excessive differential settlement. Evaluation showed that lateral extrusion, bearing failure, deep seated slip failure and liquefaction of the coke fill did not pose a significant risk. Excessive differential settlements in the form of abrupt changes in the settlement profile due to localized soft pockets and weak spots was evaluated as posing significant risk for the long-term integrity of the lining system. To mitigate any potential impact of excessive localized differential settlement, a 1000 mm thick reinforced soil pad was proposed below the lining system. The design finally adopted for the site comprised two layers of polypropylene punched and drawn biaxial geogrids and one layer of biaxial geogrid composite.

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