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Integration of geosynthetics in reclaiming an oil sands tailings pond

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Abstract. Global mining operations produce significant amounts of soil waste referred to as tailings. In oil sands mining, a portion of the deposited tailings is extremely soft and is primarily in a fluid state with solid contents (by weight) ranging between 30% and 40%. As part of reclaiming its Pond 5 oil sands tailings pond, Suncor constructed an engineered "floating" cover on top of the soft tailings deposits between 2010 and 2017 over an area spanning approximately 200 hectares to provide trafficability for limited construction equipment. This initial cover consisted of two layers of geosynthetics overlain by 2 m of petroleum coke. After construction of the initial cover, Vertical Strip Drains (VSDs) were installed through the majority of the capped area to enhance the consolidation rate of the underlying soft tailings. Additional coke has been placed on top of the initial coke cover to a total thickness of 4 m to 6 m. Previous publications have discussed the cover design, installation details of the geosynthetics, installation and performance of the VSDs, and performance of the cover. This paper presents the geosynthetics design, inspection of the geosynthetics post cover construction, and an update on the performance of the coke cover.

1 Introduction

Tailings are waste materials from mining once valuable minerals or metals are extracted from ore. In oil sands mining, a portion of the tailings is extremely soft and is primarily in a fluid state. The oil sands soft tailings, if untreated, can take centuries to consolidate to a normally consolidated soil due to its particular composition and significant thickness in the tailings ponds. Engineering measures are required to enhance the tailings consolidation and establish a trafficable surface for tailings pond capping and reclamation.

Suncor's Pond 5, located north of Fort McMurray, Alberta, Canada, is a soft tailings impoundment. The soft tailings are up to 50 m thick, have shear strengths as low as 0.1 kPa, and cover an area of approximately 200 hectares. To reclaim the pond, Suncor constructed a floating engineered cover consisting of, from bottom to top, a layer of High-Strength Woven Geotextile (HSWG), a layer of biaxial geogrid, and 2 m of petroleum coke (byproduct from the bitumen extraction process) above the soft tailings. The initial cover was constructed in winter seasons when a minimum thickness of frozen tailings was achieved. The engineered

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cover then served as a platform for equipment to install VSDs to enhance the consolidation rate of the soft tailings. Additional coke has been placed on top of the initial 2 m coke, and the coke cover has been raised to 4 m and then to 6 m thickness by 2023, which facilitates tailings consolidation and improves the stiffness of the engineered cover in support of closure activities.

Mills (2011) documented the geotextile's fabrication process, seaming challenges, testing methods, and installation along the road network. Pollock et al. (2010), Abusaid et al. (2011 & 2021), and Zhang et al. (2022) discussed the tailings properties, cover design, construction, and performance. This paper presents an overview of the geosynthetic design and results of the post-construction inspection of the geosynthetics, and an update on the performance of the coke cover.

2 Design

2.1 Overview

The design and construction of the cover followed a road network and cell method, as shown in Figure 1. The road network allowed access from different sides of the pond compared to a full-frontal advance from one side of the pond. Also, the road and cell placement method reduced the risk of soft tailings squeezing out and creating a mud wave towards the dyke which might have occurred with a full-frontal advance. Figure 2 shows a typical road design cross section with petroleum coke overlying two layers of geosynthetics. The coke material and the geosynthetic considerations are addressed in the subsequent sections.

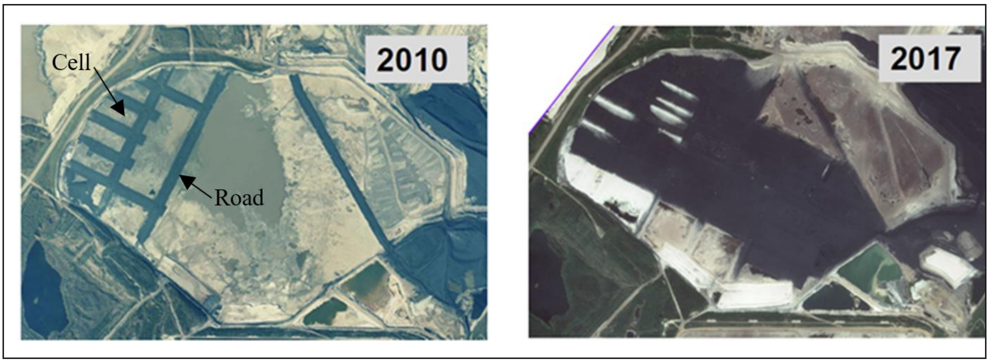

Fig. 1. Coke cover with part of the road network in 2010 and the completed 2 m cover in 2017

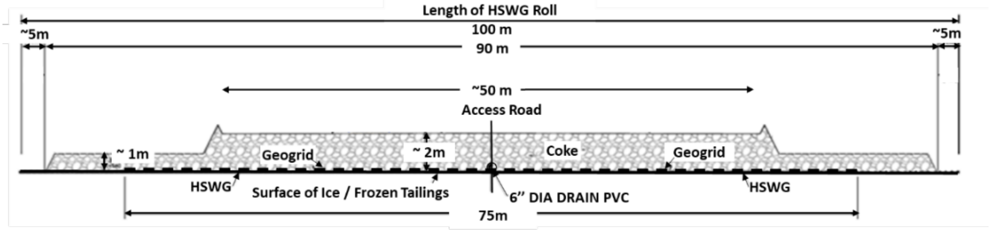

Fig. 2. Typical cross-section of a 2 m thick coke road

2.2 Coke

Coke mainly consists of carbon and is the solid residue from the bitumen extraction process. It has a wide range of particle sizes but is generally well-graded sandy gravel (in size) with less than 5% fines. Coke particles have entrapped air pockets from the formation process which makes it a lightweight material. The measured specific gravity ranges from 1.2 to 1.5 depending on the amount of entrapped air in the coke particles. Coke is a cohesionless material with measured friction angles higher than 40°. Given its lightweight, high friction angle, and availability at Suncor's mine site, coke was selected as the capping material to cover the Pond 5 soft tailings.

2.3 Necessity of Geotextile

The bulk density of the upper soft tailings at Pond 5 is comparable to the density of the coke particles. The soft tailings would infiltrate into the voids between the coke particles if the coke layer were directly placed above the soft tailings. A layer of geotextile was necessary below the coke to separate it from the underlying tailings and prevent the intrusion of tailings in order to maintain a floating cover. In addition, geotextile is required to reinforce the coke cover to provide sufficient bearing capacity to carry equipment during coke placement and VSD installation.

2.4 Selection of Geosynthetics

The coke cover design addressed two main failure modes for different equipment at various stages of the project: the ultimate limit state with rupture of the geosynthetics; and the serviceability limit state. Two-dimensional Fast Lagrangian Analysis of Continua (FLAC) deformation modelling was conducted to predict the tensile forces in the geosynthetics and the deformation of the cover under equipment loading. The ultimate limit state design adopted a Factor of Safety of 1.5 for the predicted tensile forces in geosynthetics. Given the complex dynamic methodology required to make accurate and reliable deformation predictions, the serviceability limit state only referred to the predicted deformation as guidance and mainly relied on the observations of the cover during trials and construction. During the FLAC modelling, the three-dimensional equipment loads were converted to equivalent two-dimensional loads at the depth of the geosynthetic layers using theoretical elastic solutions. A Dynamic Impact Factor (DIF) of 2 was applied to static loads to empirically account for different operating modes imposed by the actual dynamic loading as the haul trucks travel on the coke cover. For VSD installation equipment, a DIF of 1.0 was used for VSD equipment given its low travel speed. Figure 3 presents an example of the model setup and output of FLAC models.

The FLAC modelling results indicated that a minimum tensile strength of 82.5 kN/m was required for the coke cover to carry a 40-ton haul truck during coke placement. The selected HSWG has a strength of 105 kN/m in the Machine Direction (MD) and 155 kN/m in the Cross-Machine Direction (CMD). The seam between the adjacent HSWG rolls has a tensile strength of 82.5 kN/m, which governs the tensile strength of the HSWG panels. Any failure of the geosynthetics could be catastrophic during construction and could have resulted in the loss of life and equipment. Given the geosynthetic placement is conducted in the coldest winter months over ice, a biaxial geogrid with a tensile strength of 30 kN/m was selected to be placed above the HSWG for additional support to account for imperfection in the seams. The geogrid also provided additional tensile strength to reduce the required coke thickness to 2 m and assisted in resisting tear propagation of the HSWG following VSD perforations.

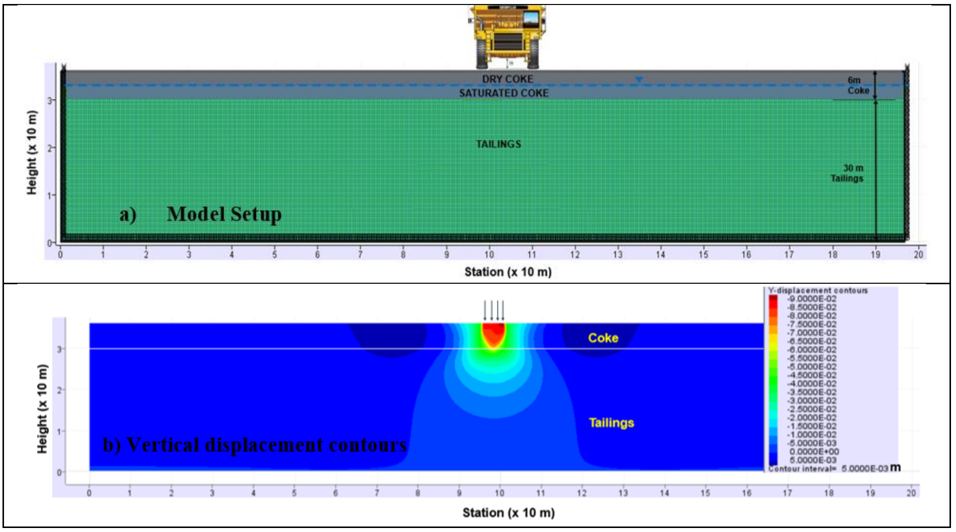

Fig. 3. Model setup and vertical displacement output from a recent FLAC model

2.5 Strain compatibility

The strain compatibility between the HSWG and the geogrid can directly influence the load distribution, coke cover deformation characteristics, and overall performance of the cover. The strain to rupture for the HSWG was measured to be about 13% to 14% in the MD and about 9% to 10% in the CMD. The geogrid used at Pond 5 was reported by supplier to have a rupture strain of about 11% to 12%, with post-peak strengths at or near the peak strength up to a strain of about 13%. It was concluded that the HSWG and the geogrids demonstrated overall strain compatibility. In addition, the expected strain in the geosynthetics is well below the strain at failure for both the HSWG and the geogrids.

2.6 Impact of VSD installation on geosynthetics

To minimize the strength reduction in the geosynthetics due to perforations from the VSD installation, the layout of the VSD locations and the selection of equipment and installation methods were established based on Koerner et al. 1987 and Koerner 2012 and input from the geosynthetic suppliers. The VSD spacing was in a 2 m triangular pattern and the VSDs were laid out at 13 degrees to the MD to maximize the gap between perforated strands as recommended by the vendor. Additionally, the VSDs were installed using a hydraulically driven mandrel that minimized the ripping of the HSWG and limited the size of the holes. Under these conditions, it was estimated that HSWG retained 75% of its strength and the geogrid retained 95% of its strength after VSD installation.

2.7 Placement of Geosynthetics

For the road network, HSWG panels (22.5 m by 100 m) were laid out across the roads in the MD on top of the frozen tailings and stitched between adjacent panels in a heated trailer on site, as shown in Figure 4. Each panel consisted of five rolls of HSWG (4.5 m by 100 m) which were seamed along the length of the roll in the vendor's factory. The biaxial geogrid (3.85 m by 75 m) was overlaid directly above the geotextile and parallel to rolls of HSWG, as shown in Figure 2. A 0.5 m of coke layer was initially proposed to be placed between the HSWG and geogrid layer to utilize higher interface friction angles, however it was ruled out due to construction challenges and safety concerns. A 1 m overlap was implemented between adjacent geogrid rolls. The roads were anchored to the surrounding dykes and beaches, which rely on the friction developed between the HSWG and the overlying fill. Figure 5 shows the road construction with the coke being placed above the geosynthetics.

Fig. 4. Heated trailer and the sewing machine in the trailer

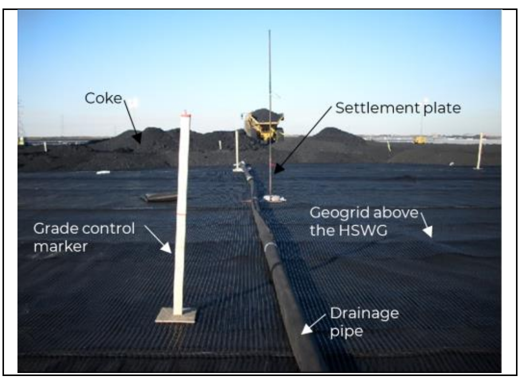

Fig. 5. Construction of coke cover above frozen tailings

For the cell layout, the width of the cells was equal to the length of the HSWG rolls for the ease of HSWG deployment. For cell infill, the HSWG panels were 13.5 m wide and 160 m long and consisted of three 4.5 m wide rolls stitched together in the factory. The adjacent panels were seamed along the 160 m edges in the field. As shown in Figure 6, the geogrid rolls (3.85 m by 75 m) were deployed perpendicular to the HSWG panels to create an equivalent strength in both directions, which eliminated limitations on travel direction for the VSD equipment to install VSDs. The geosynthetics in the cells were anchored to the adjacent roads, i.e., placed over 1 m of coke, with at least 2 m of coke placed above the geosynthetics, as shown in Figure 6. This approach utilized the high interface friction angle between coke and geosynthetics, as opposed to the friction between two geosynthetic layers.

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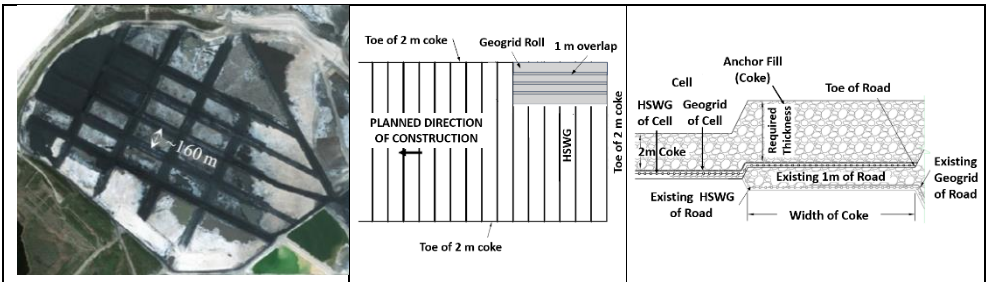

a) Cell layout | b) Geosynthetic layout in cells | c) Anchor to the road

Fig. 6. Geosynthetics in cells

3 Construction

3.1 Field Trials

Field trials, with the support of FLAC analyses, were conducted prior to full-scale operation. The field trials were intended to determine the allowable equipment size and speed, lift thickness, and allowable distance away from the leading edge for the haul trucks. In 2009, Suncor conducted two field trials to support the design and construction of the full-scale 2 m of coke cover. The Phase One trial was conducted on a tailings sand beach at Pond 5 which was more competent than the foundation conditions for the full-scale operation. The Phase 2 trial was conducted on the soft tailings of Pond 5 which was more representative of the foundation conditions for the full-scale operation. The trials proved the feasibility of the coke cover at Pond 5 and provided insights into the design and construction. A detailed discussion of these trials is presented by Caldwell et al. (2010). During later stages of the design and construction, several more field trials were conducted to evaluate the request for changes to equipment size and speed and offset to the leading edge of coke placement. Some of the field trials are documented by Abusaid et al. (2021).

3.2 Inspection

For the geosynthetic placement, the HSWG was mainly deployed and unrolled using amphibious machines above the frozen tailings, while helicopters were occasionally used to speed up the deployment. Geogrid was towed by amphibious machines and unrolled by manual labour. The details about the placement and the connection between adjacent rolls/ panels of the geosynthetics are discussed by Abusaid et al. (2011). The sewing development and installation preparation for the HSWG are documented by Mills (2011).

Field quality control and quality assurance (QC/QA) were carried out during the deployment of the geosynthetics. Defects, including factory weaving defects, seaming defects, and rips/tears were marked and repaired according to the specified repair procedures incorporating industry standards and design specifications.

The geosynthetics were inspected several times as part of other investigation programs after the installation, which confirmed the integrity of the geosynthetics and the filtering functionality of HSWG. In July 2010, a test pit was excavated along a road in the pond through the coke to expose the geosynthetics, as shown in Figure 7. The geosynthetics and the seams between the HSWG were observed to be intact. In September 2018, four test pits were excavated using hydrovac to expose the geosynthetics above the soft tailings near the pond edge. The geosynthetics were intact with no evidence of tearing and tailings intrusion, as shown in Figure 7.

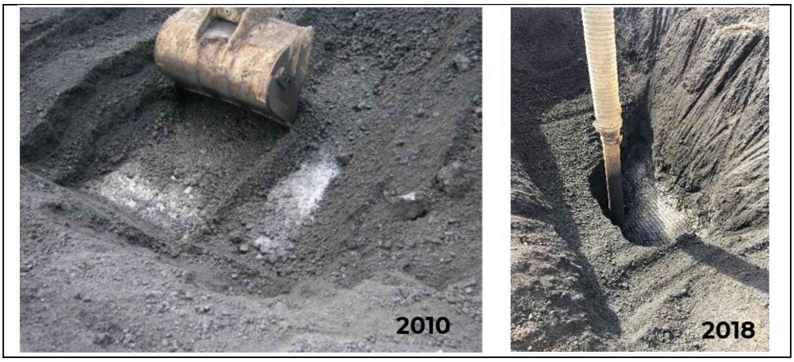

Fig. 7. Exposed geosynthetics in 2010 and 2018

In addition, a sampling program is conducted annually to collect continuous samples at multiple locations within the pond using piston samplers. No evidence of tailings intrusion into the coke has been observed, as shown in Figure 8, which confirms the filtering function of the HSWG.

Fig. 8. Sample showing the interface between coke and soft tailings

4 Performance of the coke cover

The design and construction of the coke cover were carried out through close collaboration with Suncor and the vendors. The performance of the coke cover has been closely monitored and documented during field trials and full-scale construction. During the 2 m of coke cover construction, significant road surface deflection (a road surface wave) was observed during dynamic loading from haul truck traffic, as shown in Figure 9. The deformation was elastic, with the road subsiding when haul trucks passed by and rebounding back afterwards. Cracks developed on the road surface, and road surface maintenance was carried out as required. With increasing the coke thickness to 6 m, negligible surface deflection was noticed from haul truck traffic, even with loaded haul trucks weighing more than 100 tons driving on the coke cover. In general, the deformation and integrity of the coke cover continue to be in satisfactory condition since the coke cover construction, as discussed by Abusaid et al. (2011 & 2021).

Fig. 9. Road surface with evident deflection and cracks under the load of a moving 100-ton haul truck

The long term performance of the geosynthetics in the coke cover was assessed using FLAC undrained deformation modelling. The density and shear strength profiles of the soft tailings 50 years after VSD installation were estimated using FLAC consolidation models. The predicted surface deformations of a 6 m coke cover under a 100-ton haul truck were well within acceptable limits without the geosynthetics due to the underlying tailings becoming more soil-like. The manufacturer and existing literature suggested that the geosynthetics can maintain their functionality for over 50 years, since they are resistant to biological degradation, as well as naturally occurring chemicals, alkalis, and acids. Therefore, the coke cover will no longer need geosynthetics for stability, before the geosynthetics have reached their end of service life. The performance of the coke cover is considered to be acceptable in the long term.

5 Summary

Geosynthetics, consisting of HSWG and geogrid, are an integral component of the engineered coke cover to cap the soft tailings at Suncor's Pond 5. The HSWG separates the coke layer from the underlying fluid soft tailings to maintain a "floating" cover and provides reinforcement to the cover system for equipment to conduct capping and closure activities. A biaxial geogrid product with a compatible strain at maximum tensile force was used to provide additional bearing capacity to reduce the required initial coke thickness and reduce the potential of tear propagation of the HSWG during VSD perforations. The perforation of the geosynthetics due to VSD installation was addressed in the design.

The coke cover at Pond 5 followed the road and cell approach, and the length of the HSWG roll was considered in sizing the roads and cells. There are two design criteria for the coke cover: ultimate limit state with the rupture of the geosynthetics and serviceability limit state for trafficability. The design utilized FLAC deformation modelling and heavily relied on the performance during field trials and full-scale production. The geosynthetics were rigorously inspected post-installation, which confirmed the integrity of the geosynthetic and filtering functionality of the HSWG. The coke cover has performed well for the construction activities during the past 13 years. It is also expected that the coke cover will continue to be trafficable for future closure activities, and the performance of the cover will be monitored and evaluated regularly.

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