LANDFILL CONSTRUCTION OVER PEAT DEPOSITS - A CASE HISTORY

Te-Yang Soong, Ph.D., P.E.
CTI and Associates, Inc., Brighton, Michigan USA

Rich Paajanen, P.E.
Waste Management of Michigan, Inc., Orion, Michigan USA

Xuede Qian, Ph.D.
Michigan Department of Environmental Quality, Lansing, Michigan USA

ABSTRACT

Construction of a new disposal cell over a fully saturated organic peat deposit was performed at a municipal solid waste (MSW) landfill. Preliminary calculations indicated that the total settlement can be up to 2.4 m in the deepest portion at the end of the 30-year post-closure period.

To ensure liner integrity and positive drainage of the cell subgrade, a soil stockpile surcharging (or “pre-loading”) prior to cell construction was proposed by the design engineers. The approach aimed to achieve pre-construction settlement exceeding 50% of the total anticipated settlement, whereas the remaining settlement was to be accommodated by a steepened cell floor design. To facilitate stockpile construction, a high strength geotextile reinforcement layer was selected and installed immediately above the fully saturated peat soils.

A rheological model was established prior to stockpile construction to provide a preliminary estimate of the total peat settlement under the full waste load so that the stockpile could be properly sized. During and after stockpile construction, field monitoring was conducted to examine the site-specific settlement behavior. The monitored results were used to validate and calibrate the previously established rheological model. Once the model was successfully calibrated, the total anticipated liner settlement under full waste loading was recalculated and, subsequently, the desired pre-construction settlement target was reset.

The stockpile was successfully constructed over the high strength geosynthetic reinforcement layer. Approximately 50% of the total anticipated settlement was accomplished before the initiation of liner construction. Cell construction was also successfully completed and certified at a later time.

BACKGROUND

Foundation soils below the proposed landfill expansion area consist of a complex combination of glacial outwash deposits underlain by glacial till. The outwash deposits consist of interlensing sequences of sands, silts, and clays with varying thickness and aerial extent across the cell development area. Since there is no continuous deposit of soft subsurface layers in the local geology, it was concluded that deep-seated foundational instability is very unlikely beneath the development area.
There existed, however, an organic peat deposit beneath a portion of the proposed landfill expansion area (maximum depth exceeding 6 meters) that required additional consideration. As depicted by the contours of peat deposit thickness shown in Figure 1, most of the peat deposit ranged in thickness from 1.5 to 3.0 meters, beginning at or near the ground surface. Note that portions of the peat deposit were removed and replaced with sand backfill during previous cell construction (to the east and south of the existing peat deposit shown as the dashed contour lines in Figure 1).

Since the groundwater level at the proposed expansion area is very close to the existing ground surface, a significant amount of structural fill above the existing ground was required to provide a certain isolation distance between the groundwater and the proposed liner system.

![Figure 1 – Peat Deposit Thickness Contours Prior to Surface Removal](image)

It would have been ideal if the in-situ peat material could have been completely removed. However, such an operation would have required the design and installation of major earth retaining structures and would have been extremely costly and time consuming. Moreover, complete removal of the in-situ peat material might have had an adverse impact on the stability of the existing landfill, and might have disturbed other pertinent landfill infrastructures (leachate forcemain, electrical conduit, etc.).
Considering the above factors, the engineering team recommended to restrict peat removal to only those areas and depths that would result in a stable and safe excavation using standard earth-moving equipment. It was estimated that the peat deposit could be safely reduced to a relatively small area. See the shaded area shown in Figure 1 for the approximate outline of the remaining peat deposit.

To ensure the integrity of the liner system and positive leachate drainage over the remaining peat material, the engineering team decided to address the peat settlement issue on two fronts: (1) surcharge (i.e., “pre-load”) the remaining peat area until at least 50 percent of the total anticipated settlement is achieved and (2) design the cell floor grade with an increased slope to ensure an adequate floor grade (min. 2%) at the completion of total settlement.

CONSTRUCTION ACTIVITIES

Surface Peat Removal

The surface peat removal was successfully conducted by the earth work contractor. As indicated in Figure 2, the contractor used an excavator to remove the surface peat soil until suitable in-situ sandy soil was encountered. Note that the peat material to be left in place was flagged as a “not-to-disturb” area and properly buffered to ensure that the earth removing process was safely executed.
Selection and Installation of Geosynthetic Reinforcement Layer

The remaining, fully saturated, peat soil has an extremely low California Bearing Ratio (CBR) value, therefore, posed a great safety concern for the construction equipment/personnel. Calculations indicated that a relatively thick (≥ 450 mm) and continuous soil “bridging” layer would be necessary to uniformly distribute equipment loading and reduce the stress at the peat surface to prevent localized bearing capacity failures and allow for further construction activities.

To facilitate the construction of the bridging layer and the subsequent structural fill, the design engineers recommended a high strength woven geotextile to be installed immediately above the peat surface. The reinforcing geotextile would provide not only an adequate separation between the structural soil fill and the underlying peat material, it would also, when properly installed and tensioned, provide additional bearing strength to the peat soil to allow for the placement of the soil bridging layer. After examining the literature and consulting with various geotextile manufacturers, Mirafi Geolon® HP665 woven polypropylene geotextile was selected for the project. See Table 1 for the material specifications of the high strength geotextile.

<table>
<thead>
<tr>
<th>Property</th>
<th>Minimum Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide-width tensile strength</td>
<td></td>
</tr>
<tr>
<td>Machine (warp) direction</td>
<td></td>
</tr>
<tr>
<td>5% strain</td>
<td>17.5 kN/m</td>
</tr>
<tr>
<td>Ultimate</td>
<td>70.0 kN/m</td>
</tr>
<tr>
<td>Cross-machine (fill) direction</td>
<td></td>
</tr>
<tr>
<td>5% strain</td>
<td>N/A</td>
</tr>
<tr>
<td>Ultimate</td>
<td>96.4 kN/m</td>
</tr>
<tr>
<td>Seam strength</td>
<td>52.5 kN/m</td>
</tr>
<tr>
<td>Flow rate</td>
<td>813 liters/min/m²</td>
</tr>
</tbody>
</table>

Prior to the placement of the reinforcing geotextile, a small wide-track dozer (maximum 20 kPa ground pressure) was used for subgrade preparation. No dump truck traffic was allowed in the remaining peat area until the high strength geotextile and the overlying 450 mm sand bridging layer had been placed. Trees and brush that might damage the overlying geotextile were removed. However, smaller vegetative cover species (e.g., grass and reeds) were left in place to provide additional support matting. Any ruts and depressions exceeding 150 mm in depth were backfilled with sand.

The high strength geotextile panels were deployed and positioned per the designed panel layout. The geotextile was manually pulled taut to remove wrinkles. The deployed geotextile panels were sewn together with flat seams (all seams facing up, see upper left corner of Figure 3). Every stitch was inspected for quality and continuity. Installation of the reinforcing geotextile layer, including panel placement and seaming, was successfully completed above the remaining peat material. Figure 3 shows the completed reinforcing layer installed immediately above the remaining peat material.
Following the completion of geotextile deployment, a 450-mm sand blanket was placed over the geotextile in one complete lift. Small dump trucks (five cubic meters) or partially loaded larger trucks (10-15 cubic meters) were utilized to end-dump the initial sand fill adjacent to, but not directly on, the geotextile. After end-dumping the sand fill material, small dozers were used to spread and compact the sand fill material. A minimum sand thickness of 450 mm between construction equipment and the geotextile was maintained at all times to avoid overstressing the underlain peat material and damaging the geotextile. A specific sequence of sand placement (i.e., a “fingered” pattern) was carefully followed to ensure uniform surcharging loading on the peat material and constant tensioning in the geotextile.

The constructed sand blanket not only acted as the “bridging layer” for subsequent construction activities, but also provided an additional drainage path for the expelled consolidation water to shed away from the surcharging area.

A stockpile consisting of earthen structural fill was constructed over the remaining peat deposit area to “pre-load” the peat material. The designed stockpile was approximately 6 m high, which yielded an approximate surcharge stress of 120 kPa. The structural fill material was placed and spread using equipment and techniques that would not compromise foundation stability. The first 900-mm structural fill materials were compacted only by tracking in place with dozers to avoid over compaction/stressing. Structural fill materials over the first 900-mm layer was constructed in 300-mm loose lifts and were compacted to 90% modified Proctor maximum dry density.
The engineering team was consulted on a daily basis to ensure the loading rate did not exceed a safe limit determined by the actual piezometer readings. The entire stockpile construction took place over a period of approximately 1 month.

FIELD VALIDATION OF SETTLEMENT-PREDICTION METHOD

The difficulty and inability to apply conventional settlement-prediction methods such as Terzaghi’s consolidation theory [1] to peat materials is well documented in the literature [2, 3, 4]. The primary reason for such difficulty is the relatively large secondary compression that occurs in peat material in comparison with inorganic clays. Moreover, the rate-dependency of the secondary compression of peat material needs to be properly included for an accurate settlement prediction.

As a result, various approaches have been recommended by researchers to characterize the compression behavior of peat materials. Edil and Mochtar [2] have recommended the use of a simple rheological model that considers both of the above-mentioned issues. The model has successfully described both laboratory and field settlement data for peat and other organic soils. Therefore, it was considered representative for peat materials in general and was used by the project team to predict the total settlement of the subject peat deposit due to future surcharging and waste loadings.

Rheological Model Description

The rheological model shown in Figure 4 has given satisfactory results in describing the one-dimensional compression of peat materials under given stress increments [2]. When the model is subjected to a stress increment ($\Delta \sigma$), the time-dependent strain, $\varepsilon(t)$, can be described using Eq. (1).

\[
\varepsilon(t) = \Delta \sigma \left[ a + b \left( 1 - e^{-\left(\frac{\lambda}{b} \right) t} \right) \right]
\]

Where

- $a$ = primary compressibility
- $b$ = secondary compressibility
- $\lambda/b$ = rate factor for secondary compression

Figure 4 – Rheological Model for Peat Compression
Master curves that characterize the non-linearity of parameters “a” and “b” (stress-dependent) and the rate-dependency of secondary compression (i.e., “\(\lambda/b\)”) of peat soils were developed by Edil and Mochtar (1984). The master curves given by Edil and Mochtar (1984) were generated based on a wide range of peat and organic soils. They are considered representative for peat materials in general and were used by the engineers to estimate the total anticipated settlement of peat deposits at the end of the landfill’s 30-year postclosure period. The model, along with the master curves, was also used to set the “target” amount of settlement that the pre-loading process should achieve.

Field Measurements

Settlement cells were installed at the surface of the peat deposit to measure both the surcharge stress and the corresponding settlement of the peat. The field monitoring was conducted for a period of approximately 6 weeks.

Results obtained from the field measurements were fitted into the model [i.e., Eq. (1)] to determine the parameters “a”, “b” and “\(\lambda/b\)” under each loading increment (i.e., \(\Delta\sigma\)) for each measurement location. Results of the model fitting (in solid lines), in terms of settlement versus time, are shown in Figure 5. As seen in the figure, the proposed rheological model did provide a satisfactory simulation of the stress- and time-dependent behavior of the peat deposit in the proposed construction area.

![Figure 5 - Results of the Model Fitting (Solid Lines)](image)

The respective parameters “a”, “b” and “\(\lambda/b\)” that yield the modeled behavior shown in Figure 5 were superimposed on the corresponding master curves reported in the literature [2] to examine the validity of using the literature “master curves” for prediction of settlement under future waste loadings. See Figures 6, 7 and 8 for parameters “a”, “b” and “\(\lambda/b\)”, respectively.

As seen in Figures 6 and 7, both primary and secondary compressibility values (“a” and “b”) are dispersed over the range of measured stress. They are, however, in good agreement with the range of literature values. Similar observations/conclusions can be made regarding the rate factor for secondary compression (“\(\lambda/b\)”) in comparison with the literature value (Figure 8).
Figure 6 – Primary Compressibility vs. Stress (field monitored results vs. literature values)

Figure 7 – Secondary Compressibility vs. Stress (field monitored results vs. literature values)
Figure 8 – Dependency of Rate Factor for Secondary Compression on Average Strain Rate  
(field monitored results vs. literature values)

It was concluded by the engineering team that the master curves for parameters “a”, “b” and “λ/b” presented by Edil and Mochtar (1984) are representative of the project-specific peat deposit and it is appropriate to use the master curves to predict the long-term settlement of the peat deposit under the anticipated waste loading conditions.

SETTLEMENT PREDICTIONS

Two points (Points “A” and “B” in Figure 9) along the most critical segment perpendicular to the leachate removal header pipe were selected for peat settlement analysis. To properly include the “rate-dependent” nature of peat compression into the analysis, the waste loadings were applied incrementally. Table 1 tabulates the location-specific information for Points “A” and “B” for the settlement analyses.

As listed in Table 2, the analysis assumed a total of 12 waste loading increments over a period of 3 years. After the full waste height is reached, a 30-year “post-closure” period was added to the settlement calculations using 1-year time increments. Note that the incremental waste loadings were added to an existing stress level of 120 kPa to properly reflect the impact of the peat pre-loading process in the future settlement prediction. While actual loading increments may differ somewhat from these assumptions, the amount of total settlement should not be materially different.
Table 2 – Required Site-specific Information for Settlement Analyses

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Point “A”</th>
<th>Point “B”</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste thickness</td>
<td>33.0</td>
<td>31.1</td>
<td>m</td>
</tr>
<tr>
<td>Waste unit weight</td>
<td>10.2</td>
<td>10.2</td>
<td>kN/m³</td>
</tr>
<tr>
<td>Total waste loading</td>
<td>336.6</td>
<td>317.2</td>
<td>kPa</td>
</tr>
<tr>
<td>Assumed total waste filling time</td>
<td>3.0</td>
<td>3.0</td>
<td>years</td>
</tr>
<tr>
<td>Duration between waste load increments, (\Delta t)</td>
<td>0.25</td>
<td>0.25</td>
<td>year</td>
</tr>
<tr>
<td>No. of waste loading increments</td>
<td>12</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>Level of waste stress increment, (\Delta \sigma)</td>
<td>28.1</td>
<td>26.4</td>
<td>kPa</td>
</tr>
<tr>
<td>Thickness of peat material (after surface removal)</td>
<td>4.88</td>
<td>2.44</td>
<td>m</td>
</tr>
</tbody>
</table>

The afore-mentioned, literature value based, stress-dependent parameters “a”, “b” and the rate-dependent parameter “\(\lambda/b\)” were incorporated in the future peat settlement prediction model as the incremental waste loading progressed. Spreadsheet programs were created and used for the prediction of total peat settlement at Points “A” and “B”. The results of settlement prediction model are presented in Figure 10. Note that the maximum expected settlement will occur in approximately 15 years from the start of waste of filling.

As seen in Figure 10, the total values of anticipated settlement of the peat deposit are 1.55 and 0.76 m for Points “A” and “B”, respectively. With a minimum 7.3% designed liner slope over the remaining peat deposit area, a minimum 2% slope in the direction perpendicular to the leachate removal header pipe will be ensured at the end of the landfill post-closure period.
CONCLUSION

Pre-loading by stockpile surcharging was performed over the peat deposit area to induce consolidation and densification. Since the surcharging was conducted prior to the commencement of liner construction, it induced pre-liner-construction settlement of the peat material, thereby reducing post-liner construction settlement.

Field monitoring for both surcharge pressure and settlement was conducted during the pre-loading period. This field data provided an opportunity to validate the adequacy of applying the rheological model in predicting the site-specific peat settlement behavior.

Once the appropriateness of applying the model was validated, the total settlement due to future waste loading was determined. The results were used to determine the target surcharge settlement amount (50% of the total amount). As for addressing the remaining (i.e., post-construction) settlement, an increased cell floor slope (minimum 7.3%) was designed and constructed to ensure that the post-settlement cell floor grade will be greater than 2%.

This innovative engineering approach to addressing the peat deposit beneath the solid waste disposal area provided many benefits. These benefits included a substantial construction cost and time savings. Furthermore, this method prevented the potential stability problem of the existing landfill cells located immediately adjacent to the peat deposit. Complete peat removal under saturated ground conditions would have created a significant risk to the basal stability and liner integrity of the adjacent disposal cells. Ultimately, the engineering team developed a plan that provided a timely, cost effective, environmentally protective, and regulatory compliant solution to this specific peat deposit challenge.
REFERENCES


