CONSTRUCTION OF A DEEP SOIL-BENTONITE CUT-OFF WALL AT THE MSW LANDFILL OF ST-THOMAS, QUEBEC

Luc Demers, Tecsult inc., Montreal, Quebec, Canada
Ronald Anderson, Tecsult inc., Montreal, Quebec, Canada
Claude Robitaille, Tecsult inc., Montreal, Quebec, Canada
Romeo Ciubotariu, Tecsult inc., Montreal, Quebec, Canada

ABSTRACT
A soil-bentonite cut-off wall nearly 2.6 km long with an average depth of 35 m has been constructed in 2004 around an existing municipal solid waste (MSW) landfill cell at St-Thomas, Quebec. The works have been successfully carried out without trench stability problems from a working platform constructed at a level of at least 2.5 m above groundwater table. This paper presents the existing geotechnical and hydrogeological site conditions and the design considerations that led to the choice of a soil-bentonite cut-off wall, a description of the works and the results of the quality control program.

RÉSUMÉ
Un écran d'étanchéité en sol-bentonite de près de 2,6 km de longueur et ayant une profondeur moyenne de 35 m a été construit en 2004 au périmètre d'une cellule d'enfouissement de déchets ménagers à St-Thomas, Québec. Les travaux ont été complétés avec succès, sans problème de stabilité de parois à partir d'une plate-forme de travail construite à un niveau se situant à au moins 2,5 m au-dessus de la nappe phréatique. Cet article présente les conditions géotechniques et hydrogéologiques du site ainsi que les éléments de conception qui ont amené le choix d’un écran d’étanchéité en sol-bentonite, une description des travaux de construction de l’écran et les résultats du programme de contrôle de la qualité.

1. INTRODUCTION
The municipal solid waste (MSW) landfill of St-Thomas is located about 65 km north-east of Montreal, in the Lanaudière region, Quebec, Canada (Figure 1). The landfill site was in operation for more than 25 years and it comprises four already closed cells (C-1, C-2A, C-2B and C-2C) and one cell which is still in operation (C-3). So far, landfilling operations on the site were mainly conducted above ground level and no leachate control was required according to the existing regulation (the conditions of the site favour natural attenuation). In order to meet upcoming landfilling regulations, the construction of a deep (35 m) cut-off wall around cell C-3 was planned (perimeter of nearly 2 400 m). In the perspective of a future extension of the MSW site, a portion of this cut-off wall is planned to be part of a larger cut-off that will surround a new cell (C-4), which will incorporate the footprint of cell C-3 (Figure 2).

2. SITE CONDITIONS
2.1 Stratigraphy
The numerous investigation campaigns conducted on the site of future cell C-4 lead to the identification of four main overburden stratigraphic units. From the surface, the stratigraphic sequence is:
- Stratified deltaic deposits formed of sandy alluviums becoming silty with depth;
Figure 2: Key plan of the site

- Transition deposits formed of a succession of sand, silt and clay beds;
- Marine deposits formed of a silty clay;
- Glacial deposits covered by fluvio-glacial deposits in place.

The thickness of the deltaic deposits varies between 17 and 29 m throughout the site. The upper part of these deposits corresponds to an uniform fine sand and is classified as a «SP» or a «SP-SM» according to USCS. The lower part of the deposits comprises a higher fine content and is classified as a «SM».

The thickness of the transition inter-bedded deposits found underneath this first layer varies between 6 and 15 m. Despite the vertical heterogeneity of this stratigraphic unit, its upper part could be globally considered as a sandy silt «ML» while its lower part corresponds to a low plasticity inorganic clay «CL».

The underlying marine deposits consist of a homogeneous silty clay typical of the Champlain Sea. The top of this stratigraphic unit is located at a depth of between 27 and 39 m from the surface and is characterized by a regular slope oriented toward the south-east part of cell C-4. The base of the marine deposits is situated between 66 and 82 m depth. These cohesive deposits are generally classified as high plasticity inorganic clays «CH», except in some places in the upper part of the deposits where the classification corresponds to low plasticity inorganic clays «CL».

Glacial and fluvio-glacial materials (granular soils) constitute the deepest overburden unit present on the site. Bedrock is found between 70 and 94 m of depth. The slope of its surface is similar to the one of the marine deposits.

2.2 Hydrogeology

Three distinct hydrogeological units are present in the overburden: an unconfined (surface) aquifer, an aquitard and a confined (deep) aquifer. The surface aquifer is mainly located in the deltaic deposits and reaches the upper part of the transition deposits. Figure 3 presents the piezometric map observed for the surface aquifer before the beginning of the cut-off wall construction (May 2004, during high groundwater period). The underneath marine deposits correspond to the aquitard, which has a hydraulic conductivity of $4 \times 10^{-7}$ cm/s or less and a thickness of about 40 m. The deep aquifer is located in the glacial and fluvio-glacial deposits and in the fractured part of the bedrock. The piezometric levels observed in this confined aquifer are situated between 5 and 7 m below ground level.

Figure 3: Piezometric map of the surface aquifer observed in May 2004

3. DESIGN CONSIDERATIONS

3.1 Analyses of the cut-off wall construction techniques

Before the selection of a particular technique for the construction of the cut-off wall, a thorough literature review of the available and proven techniques was carried out. For almost all construction techniques identified at this stage (deep soil mixing, jet grouting, vibrating beam,
trench is vertically excavated down to the depth required for the support of the walls of the trench until backfilling. Consequently, it is very difficult to predict which leads to great uncertainties in the evaluation of the trench stability.

With the SB technique, there were concerns of potential trench stability problems considering the depth of the cut-off wall and consequent length and duration of maintaining an open trench. The stability of the trench was evaluated based on groundwater level, shear strength of the soils, depth of the trench, level of the bentonite slurry in the trench and the in-trench density of the slurry. However, the latter parameter is time dependent and influenced by many factors such as the initial properties of the slurry, the characteristics of the native soils, the method and equipment of excavation and the precipitations. The in-trench density of the slurry is consequently very difficult to predict which leads to great uncertainties in the evaluation of the trench stability.

A CB cut-off wall is built by panels using a much denser slurry (bentonite with cement and water) which results in significantly fewer trench stability problems. However, the CB technique was considered feasible and was selected as the preferred method of construction for the cut-off wall at the site mainly for economical reason. The CB cut-off wall (with a cement that includes additives such as fly ash or slag in order to obtain a particularly low hydraulic conductivity) was maintained as an alternative technique in case of difficulties with the SB solution.

3.2 General description of the SB cut-off wall technique

The construction of a SB cut-off wall is carried out in two steps: 1) the excavation of a trench filled with bentonite slurry and 2) the preparation and placement of the low permeability SB backfill. At first, the trench (typically 0.6 to 1.5 m wide) is excavated along the alignment of the cut-off wall. As the soils are excavated, bentonite slurry is pumped into the trench. The hydrostatic pressure of this fluid, which comprises around 6 % bentonite, ensures the support of the walls of the trench until backfilling. The trench is vertically excavated down to the depth required in order to obtain a minimum penetration (generally at least 1 m) into an impervious stratum to ensure a proper key-in of the cut-off wall. The SB backfill is then gradually placed into the trench. Because of its higher density, the SB backfill pushes and replaces the bentonite slurry to form the impervious cut-off wall.

The SB backfill is generally constituted of the excavated soils, bentonite slurry and dry bentonite. At times, a part of the excavated material is replaced by borrow materials to obtain a more appropriate grain size distribution of the SB. The preparation of the SB backfill is usually conducted along the trench on the ground surface but could also be carried out on a fixed remote mixing pad. The mixing operations of the SB backfill are conducted by repeated actions of dozers until the mix is homogeneous and the proper consistency (paste) is reached. The prepared SB backfill is then pushed or dumped into the trench at the point where the backfill rises to the ground surface. The SB cut-off wall construction technique is characterized by a continuous process of excavation, preparation and placement of SB backfill.

3.3 Design of the cut-off wall

The depth of the top of the marine homogeneous silty clay to key-in the cut-off wall was determined by a total of 33 piezocene soundings conducted along the alignment of the trench. Considering the continuity (readings at 1 cm intervals), the accuracy of the investigation method and the regularity of the stratigraphy, the key-in depth was fixed at the 1.0 m minimum value required by the regulation. In addition, the presence of an average of about 3.5 m of silty clay inter-bedded by thin seams of silt and sand in the lower part of the transition deposits can be considered as a form of additional security for the key-in.

Laboratory tests were conducted on representative samples of the soils to be excavated in order to evaluate the optimal composition of the SB mix and its probable properties. The laboratory tests conducted include: grain size analyses, permeability tests, water content determination, slump tests, Atterberg limits and consolidation tests. The main design criteria for the SB backfill mix were the following:

- A) Rather stiff SB backfill (a slump in the range of 50 to 100 mm as determined for fresh concrete);
- B) Hydraulic conductivity as low as possible (10⁸ cm/s);
- C) Maximum reuse of the excavated soils;
- D) Minimum bentonite addition;
- E) Use of low cost borrow materials if required.

The criterion A) was defined in order to decrease the risk of trench instability; a rather stiff SB backfill would position itself with a relatively steep slope into the trench and would consequently reduce the length and duration of the open trench. The criterion B) was established in order to limit as much as possible the groundwater infiltration into the future cell C-4 that will be seated at depths varying from 25 to 30 m (thus avoiding high costs of leachate treatment). Criteria C) D) and E) were defined mostly for economical considerations.

The hydraulic conductivity obtained for 8 different SB mixes comprising 0 to 3 % of added bentonite (total dry weight) varies from 1.8x10⁻⁸ to 4.3x10⁻⁷ cm/s. A well graded sand (corresponding to screened stone residue) available in large quantity and at relatively low cost was identified as a promising borrow material to stiffen the SB mix and to improve its gradation without increasing the required amount of bentonite for a given hydraulic conductivity. The laboratory tests suggest the optimum SB mix would comprise about 20 % of this borrow material and at least 2 % of bentonite.

Chemical compatibility tests were also conducted to verify the long term performance of the SB backfill in contact with the site leachate. Those tests consist in permeability measurements using site leachate as permeation fluid. The evolution of the hydraulic conductivity was observed.
until the sample has been permeated by a volume of leachate equal to at least twice the pore volume in the sample. No increase of the hydraulic conductivity was observed and it was consequently concluded that the SB backfill will not be affected by contact with the site leachate.

3.4 Cut-off wall specifications

General SB cut-off wall specifications found in the literature (USEPA (1998), USACE (1998), Geo-Con (2003) and Geo-Solutions (2003)) were considered in the establishment of the specifications for this project. Adaptations were made to take into consideration the specific site conditions and the project needs, mainly for the SB backfill preparation. A grading envelope was imposed for the grain size distribution of the SB backfill. The fines content (material smaller than 0.080 mm) was required to be in the range of 30 to 50 %. The minimum percentage imposed for the coarser fraction of the SB backfill gradation curve implies the inclusion of borrow material into the mix. These specifications contribute to obtain more easily a rather stiff SB backfill without disadvantageously increasing the hydraulic conductivity and without much higher costs. For flexibility reasons, the slump acceptable range for the evaluation of the SB backfill consistency was fixed to 50 to 150 mm.

Excluding the bentonite quantity blended via the slurry, a minimum addition of 2 % of dry bentonite into the SB backfill was required. In addition, a criterion was fixed for the hydraulic conductivity of the SB backfill; 6x10⁻⁸ cm/s or less. To avoid potential chemical compatibility discrepancies for SB backfill mixes prepared with different bentonites, the dry bentonite to blend into the SB backfill was required to be the same as those used for the samples tested for chemical compatibility.

For reason of space limitations for some segments of the cut-off wall and for better quality control, a remote mixing pad consisting in a concrete slab was imposed for the preparation of the soil-bentonite backfill.

4. DESCRIPTION OF THE WORKS

4.1 General

After the mobilization of the equipment, the excavation of the trench was carried out from May 17th to October 28th 2004. The works begun at point A as shown on Figure 2 and progressed counter-clockwise. The works ended with the completion of the SB backfill placement on November 9th 2004, before the beginning of the cold winter period.

The cut-off wall built around cell C-3 is 2 397 m long and its depth varies between 32.0 and 38.3 m (average of 34.9 m). Considering the good progress of the works observed at the end of September, it was decided to construct an additional segment of cut-off wall that would be part of the cut-off wall which will entirely surround the projected cell C-4. This additional segment is 170 m long and is located at the North-West corner of cell C-3 as shown on Figure 2. The total area of the cut-off wall thus constructed in 2004 was 89 300 m².

4.2 Working platform

Ahead of the excavation, a horizontal working platform was constructed by a backfill made of compacted sand from the site. This platform was 20 m wide (5 and 15 m on each side of the centreline of the cut-off wall) and built at elevation 23.5 m (at least 2.5 m above groundwater table).

4.3 Bentonite slurry preparation

The preparation of the bentonite slurry was conducted with two high velocity mixers which allow a proper dispersion of the powder bentonite into the water. Groundwater pumped up gradient of cell C-3 was used for the preparation of the slurry. The Bara-Kade 90 and Hydro-Gel bentonites were added to the water in a proportion of about 5 %. The prepared slurry was stocked in two basins of nearly 500 m³ capacity constructed above ground away from the trench. A system including pipes and pumps allowed the supply of fresh slurry into the trench and to the SB mixing pad according to needs.

The fresh bentonite slurry was controlled twice a day. The average density and apparent viscosity (according to API RP13B-1 Standard) were 1 033 kg/m³ and 39.4 s respectively.

4.4 Trench excavation

The upper part of the trench was first excavated with a Koehring (1266 D) long reach backhoe equipped with a 1 m wide bucket. Despite the fact that this equipment had the capacity to excavate up to 19.6 m deep, it was generally operated to excavate up to depths of no more than 17 m. The excavation was afterwards completed by three 150 metric tons LS 518 Link-Belt crawler cranes. The cranes were equipped with 1 m wide clamshells and 4.0 m of opening. The working method with these equipments consisted in an alternation of primary and secondary panels. The method can be described as follow:

- A primary panel is first excavated;
- A few metres ahead, another primary panel is then excavated;
- Afterwards, the secondary panel, corresponding to the soils left in place in between the primary panels, is also excavated.

The excavation conducted with the cranes begun at the depth reached by the backhoe and ended at the prescribed depth of the cut-off wall. Generally the lengths of the primary and secondary panels were respectively 4.0 and 3.0 m.

The excavation was conducted entirely in the presence of bentonite slurry maintained at a level close to the surface to allow a proper support of the walls of the trench. The horizontality of the working platform and the use of wire suspended clamshell ensured the verticality of the trench. The continuity of the cut-off wall at the location of corners
was ensured by excavating overlaps and by an appropriate panels' arrangement. The continuity of the cut-off wall at the connection between the starting and ending points was ensured by the excavation of the SB backfill initially placed over a 4.0 m horizontal distance for the total depth of the cut-off wall.

The depth of each completed panel was verified by soundings with a weighted tape (weight of 1.3 to 2 kg attached to a tape graduated at 1 cm intervals). The conformity of the theoretical depth of the cut-off wall based on piezocone soundings was verified by visual examination of the soils excavated on the bottom of the trench at the beginning of the works and by samples collected at every three panels (10 to 11 m intervals). When collected, all of those samples were examined and identification tests (fines content and Atterberg limits) were conducted on nearly 50 of them. These verifications validated the stratigraphic interpretation of piezocone soundings and confirmed that the required key-in depth was reached.

The excavated soils were disposed beside the working platform and later on loaded by a backhoe, transported by off-road trucks and stockpiled near the SB mixing pad.

4.5 Soil-bentonite backfill preparation and backfilling

The SB backfill was mixed by the continuous operation of two bulldozers (D8 and D6 types) on a 40 x 75 m concrete slab. Dosage of each SB batch was achieved by bags of bentonite (3 000 lbs size) and by loader buckets count for different types of soils included into the mix. These different types of soil correspond to: 1) the sandy soils excavated by the long reach backhoe, 2) the silty and clayey soils excavated by the cranes and 3) the borrow material. Distinctive stockpiles were created for each type of material near the mixing pad.

At least 2 % of powder bentonite (based on dry weight of constituents) was blended into the SB backfill mix and supplementary bentonite was included with the slurry (fresh) added in order the facilitate mixing and to obtain the desired consistency (slump).

After its preparation, the SB backfill was pushed by the bulldozer and the loader on one extremity of the SB mixing pad or on the adjacent storage pad (surface of 1 875 m² made of 0-56 mm crushed stone). Following the reception of acceptable results tests for the slump and the fines content for each SB batch prepared, the authorization of loading the material for transport and backfilling was given. Typically, at the same time, one SB batch was in preparation, one was being loaded and another one was in standby for fines content determination.

In addition to slump test and fines content determination, numerous other tests were conducted on SB backfill samples collected on the mixing pad: complete grain size analyses (114), water content (382), Atterberg limits (113), density (111) and hydraulic conductivity (119). A summary of the test results on SB backfill is presented in Table 1. The specified range for the slump was respected for all the tests and only 5 SB batches (out of 266 prepared) presented a lack of fines and were consequently modified prior to backfilling in order to meet the minimum value of 30 %. Figure 4 presents the grain size distribution curves of the SB backfill (maximum, minimum and mean values). The average hydraulic conductivity (5.2x10^{-8} cm/s) is satisfactory with respect to the specified maximum value of 6x10^{-8} cm/s. Permeability tests were conducted in triaxial cell with a hydraulic gradient between 15 and 20 and under a confining stress of 50 kPa in accordance with ASTM Standard D 5084.

### Table 1: Summary of the properties of the soil-bentonite backfill

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump (mm)</td>
<td>103</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>Water content (%)</td>
<td>26.5</td>
<td>24.0</td>
<td>32.2</td>
</tr>
<tr>
<td>Liquid limit (%)</td>
<td>25</td>
<td>22</td>
<td>33</td>
</tr>
<tr>
<td>Plastic limit (%)</td>
<td>19</td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td>Plasticity index (%)</td>
<td>5.3</td>
<td>3.0</td>
<td>14</td>
</tr>
<tr>
<td>Liquidity index</td>
<td>1.4</td>
<td>0.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Dry density (kg/m³)</td>
<td>1 552</td>
<td>1 451</td>
<td>1 609</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>1 962</td>
<td>1 878</td>
<td>2 000</td>
</tr>
<tr>
<td>Hydraulic conductivity (x10⁻⁸ cm/s)</td>
<td>5.2</td>
<td>1.5</td>
<td>10</td>
</tr>
</tbody>
</table>

![Figure 4: Grain size distribution curves of the soil-bentonite backfill](image-url)
where backfill rises to the ground surface (above the slurry level).

In order to avoid potential segregation of SB in backfilling, no free dropping of the SB backfill through the slurry was permitted and a particular method was required for the initial placement of the backfill. For the start-up of the works, the excavation begun with the long reach backhoe by profiling a lead-in trench of about 2H:1V over a horizontal distance of 45 m. From this point on, the excavation of the trench was conducted over its full depth. Beside the 2H:1V lead-in trench, the backfill was then placed by lowering the SB to the bottom of the trench with a small crane equipped with a clamshell. When the SB backfill into the trench reached the toe of the 2H:1V slope, the SB backfill was dumped on the surface at the crest of the slope. At the end of the works, when the connection was made between the starting and ending points, the SB backfill previously placed in June stood vertically over the total depth of the cut-off wall.

The profile of the SB backfill into the trench was determined at the beginning and at the end of every working day. The soundings were conducted along the trench centreline at 10 m intervals with a weighted tape. The global slope of the SB backfill into the trench was observed to vary from 6H:1V to 14H:1V with an average of 9H:1V. Figure 5 presents a typical longitudinal section of the cut-off wall during construction.

4.6 Bottom of the trench and toe of the backfill cleaning

Soundings of the bottom of the trench were conducted at the beginning and at the end of every working day as for the profile of the SB backfill into the trench. The comparison of the soundings made at the beginning of the day with the soundings made at the end of the previous working day allowed the detection of the accumulation of some material at the bottom of the trench and on the lower part of the SB backfill slope. These accumulations of material were only associated to sedimentation of some sand in suspension in the slurry (no collapse of the walls of the trench was observed throughout the work period) and occurred mainly over the weekend while no works were conducted most of the time. Before subsequent backfilling, the sediments accumulated were excavated with a crane equipped with a clamshell. The removal of the totality of the sediment was ensured by visual inspection of excavated material and a control of the depth of excavation.

4.7 Trench stability and in-trench slurry control

No significant trench stability problems were observed during the works. Only non damaging minor surface sloughing occurred at the place of two small leachate resurgences observed at the junction of the working platform and the landfill cell. The open trench had an average length of 510 m and reached a maximum length of 620 m. The corresponding time of opening was in average 35 days and reached a maximum of 41 days.

For the control of the in-trench slurry, two representative samples were collected twice a day. One sample was collected at around 1 m from the surface and another one at about 1 m from the bottom of the trench. The samples were tested for apparent viscosity, density and sand content (according to API RP13B-1 Standard). The apparent viscosity generally varies between 37 and 42 s (average of 40 s) while the sand content varies from few percentages to more than 20 %. The weekly mean density of the in-trench slurry is presented in Figure 6. This figure also presents by the error bar the range of discrete density values for each week which are comprised between 1 070 and 1 380 kg/m$^3$.

Considering the occurrence of sedimentation and the observation of sand content and density exceeding the specified values (15 % and 1 360 kg/m$^3$ respectively), cleaning operation of the in-trench slurry was required. Essentially, the in-trench slurry was cleaned by desanding it with cyclones. Difficulties associated to pumping such a dense and viscous fluid, especially with a preferable deep intake, limited the cleaning operations. More efforts were allowed to make sure the removal of sediment material was effectively completed (as mentioned in section 4.6).

4.8 Protective cap construction

In order to protect the cut-off wall from desiccation and from detrimental effects of freeze/thaw cycles, a protection cap was gradually placed over the SB backfill. It consists of a 1 m high dike made of sand from the site.

5. CONCLUSIONS

A segment of approximately 2.6 km of SB cut-off wall with an average depth of 35 m was constructed around a MSW landfill cell within time schedule. The works have been successfully conducted without trench stability problems. According to quality control results, the cut-off wall is expected to be effective and to fulfill its role. The planned excavation and dewatering works needed for C-4 landfill cell operation should give the possibility to evaluate its global performance.

6. ACKNOWLEDGEMENTS

The authors would like to acknowledge Dépôt Rive-Nord inc., the owner of the landfill site, for the authorization to publish this paper.

References


Figure 5: Typical longitudinal section of the cut-off wall during construction (vertical exaggeration: 2x)

Figure 6: Variation of the density of the in-trench slurry

Sea to Sky Geotechnique 2006


U.S. Army Corps of Engineers (1998) Soil-Bentonite Slurry Trench for HTRW Projects, UFGS-02260A.
