LANDSLIDE AT THE JAKUSEVEC LANDFILL

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ABSTRACT: The dumpsite remediation at the Jakusevec Landfill is performed by relocating old waste onto rehabilitated cells which bottom is comprised of the liner (clay and textured geomembrane) above which the protective geotextile, drainage gravel and filter geotextile are placed. In August 2002 a locally contained slide was noticed at a section of the rehabilitated landfill formed at the bottom of the relocated waste slope surface. In order to establish what caused the slide, laboratory shear tests at the fully saturated clay/geomembrane interface were carried out, as well as field investigations regarding the construction of three wells in the area of large displacements. Furthermore, back analyses were also carried out which have established waste and bottom liner shear strength parameters for the safety factors of approximately 1.0. Based on the results of investigation works and performed analyses, it has been established that the slide occurred due to a decrease in the waste and bottom liner shear strength. In the end, recommendations are given for designing and construction that would reduce the risk of similar slides at landfills.

1 INTRODUCTION

Jakusevec serves as a main disposal site for municipal and other types of waste from the wider area of Zagreb, the capital of Croatia. Back in 1965 people started uncontrollably depositing waste at this location and approx. 7.5 million m^3 of waste has been deposited to date.

The landfill is located at the distance of some 6 km away from the centre of Zagreb and only 400 m from the nearest Jakusevec village. It is located along the river Sava, whereas downstream, only 3 km away, there is an area designated as the future water supply reserves for Zagreb and its surroundings.

Considering the geological and hydrological conditions in the underground, it may be stated that the landfill is located in a very unfavorable position. The initial field investigations and water quality testing have shown that groundwater in immediate vicinity of the landfill is polluted (Mayer & Markovac, 1992), but far less than it was expected. It was concluded that well fields had not been exposed to pollution at that point. However, considering that the construction of some hydrotechnical structures (Hydropower plant Drenje) has been planned for the future, as well as the need for increasing water quantities for Zagreb water supply, the groundwater regime may change and with it the influence the landfill has on groundwater quality.

For these reasons the need for the dumpsite remediation had been recognized back in 1980s, but began as late as 1995 on an experimental field the size of approx. 6 ha. Figure 1 shows the dumpsite remediation stages, with the experimental field marked as Cell 1, including phase development for the rest of the dumpsite.

Dumpsite remediation was sped up after Cell 1 had been completed, so from 1999 to date each subsequent cell (cells 2-4) was constructed in the period of 12 months by relocating old waste onto rehabilitated cells. At the same time new waste was transported to the landfill and was also deposited at this part of the dumpsite. Hazardous waste found in the old waste was separated because its disposal at the Jakusevec landfill is not allowed. Relocation of old waste onto rehabilitated cells was completed in September 2003. Final cover system works for these cells remain to be completed. They commenced in June the same year.

Cells 5 and 6 have been proposed for waste disposal in the future, from 2005 onwards. Considering the volume of waste intake and the estimated annual waste amounts delivered to the landfill, the proposed Jakusevec landfill service time is until 2017.

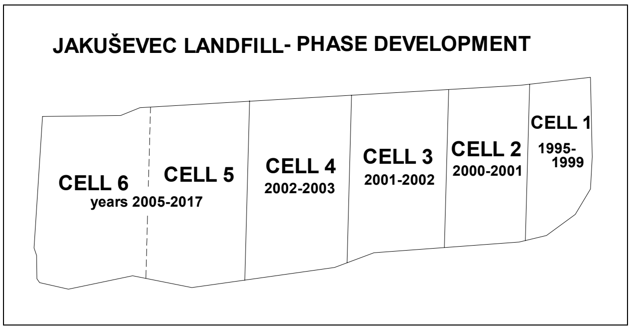

Figure 1. Landfill phase development

Along with the construction of the landfill body itself, service facilities have been or will be constructed around it and will have the following function: environmental protection (leachate treatment plant, intervention pumping system, monitoring), waste recycling and reduction of waste amounts to be deposited (recycling yard, composting plant, construction waste recycling plant) and utilization of waste's energy (gas station).

2 DESCRIPTION OF THE LANDFILL AND SLIDE

2.1 *Landfill Description*

The area onto which waste is deposited is divided into 6 cells with surface areas of 6 to 9 ha, the entire landfill surface area being approx. 57 ha. The landfill length is approx. 1400 m and the maximum width approx. 450 m.

Typical landfill cross-section is shown in Figure 2. Waste is deposited at the inclination of 1V:2.85H to the height of approx. 45 m from the surrounding terrain surface, and at the inclination of 5% from that elevation point onwards. Approx. 8 m high perimeter berm is constructed at the toe of deposited waste. Bottom liner and leachate drainage system layers are placed under the waste and are sloped at 1% towards perimeter berms. The slope in the longitudinal direction towards drainpipes that collect leachate is at 2.5%. The final cover system is constructed, as well as the surface water control berms.

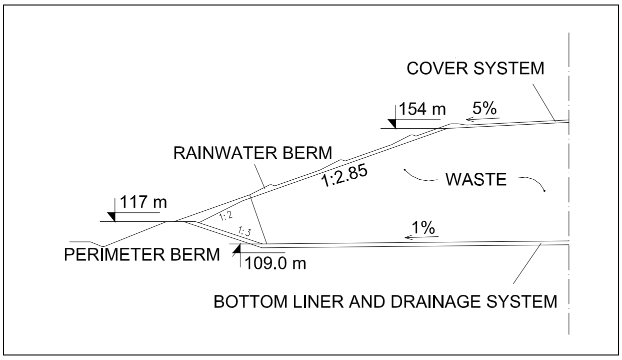

Figure 2. Typical transversal cross-section

Bottom liner detail is shown in Figure 3. The bottom liner is made of clay and textured geomembrane, above which protective geotextile, leachate collection drainage layer and filter geotextile are placed.

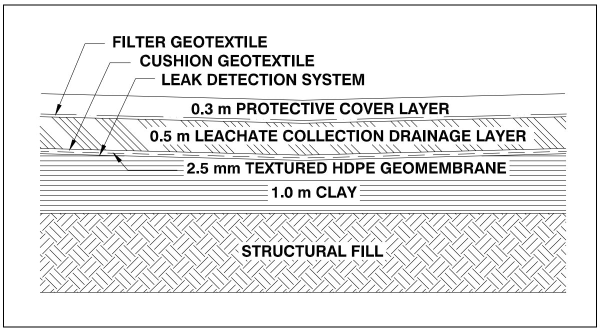

Figure 3. Liner and leachate collection system – detail

The bottom liner is built up of clay of high plasticity with the following properties: w_L=55 %, I_p=30 % and w_{opt}=20 %.

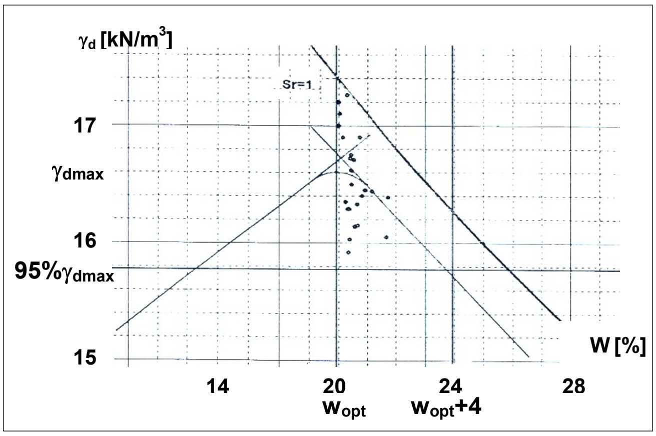

Figure 4. Compaction curve with bottom liner clay control test results

Control test results and clay compaction curve indicate that the moisture content of placed clay is within limits from w_{opt} to w_{opt}+4%, as shown in Figure 4. It must be kept in mind, that the shearing resistance and soil permeability are extremely sensitive to the compaction conditions (Mitchell et al., 1990). Although the design specification could be made according to the methodology proposed by Daniel and Benson (1990), stringent control of some parameters (compactive effort, molding moisture content) should be done during construction to achieve the desired goal.

Final landfill cover system is made of artificial materials: gas drain composite, GCL and water drain composite for rainfall water drainage; and natural materials: 0.85 m thick protective soil layer and 0.15 m thick humus layer.

2.2 *Landfill Failure*

In August 2002 a locally contained slide was noticed at the south side of cell 3 at the bottom of the deposited waste slope. A slide position scheme on the landfill layout plan is shown in Figure 5. Old waste was deposited at this location after it had been relocated onto the rehabilitated cell in a very short period of time of approx. one year. At the moment the slide appeared, waste had been deposited up to the elevation of approx. 150 m a.s.l., i.e. approx. 4 m below the designed elevation.

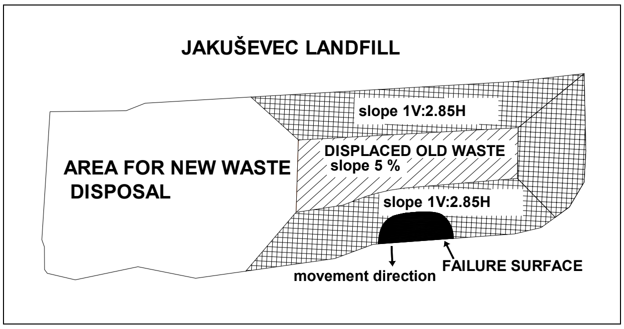

Figure 5. Position of the slide at the landfill

No indications of the slide (fissures, deformations etc.) were visible before it actually appeared that might have pointed out to a stability failure, and at the moment the displacement occurred, which was at night and in a short time, there was no one at the site.

Clear edges of the slide were not fully pronounced due to high plastic properties of waste but it was possible to determine the slide-affected area with great accuracy based on fissures created in the zone of large displacements and based on the topographical survey. The slide is approx. 52 m long and 140 m wide (Figure 6). It has spread over estimated 100.000 m^3 of waste.

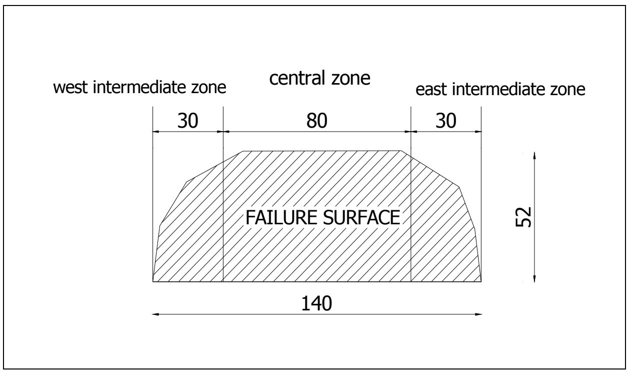

Figure 6. Slide zones

Considering the extent of deformations, the slide area may be divided into *peripheral (intermediate) zones*, where no significant waste displacements occurred and the bottom liner geosynthetics only wrinkled up (see Fig. 7), and the *central zone*, where all major displacements occurred, of both waste as well as of all bottom liner materials (see Fig. 8).

Figure 7. Deformations in the intermediate zone

Figure 8. Deformations in the central zone

The detail of the perimeter berm constructed in accordance with the design is shown in Figure 9, whereas material deformations in the central zone of the slide are shown on the perimeter berm detail in Figure 10. Maximum horizontal waste displacement in the central slide zone is approx. 8 m.

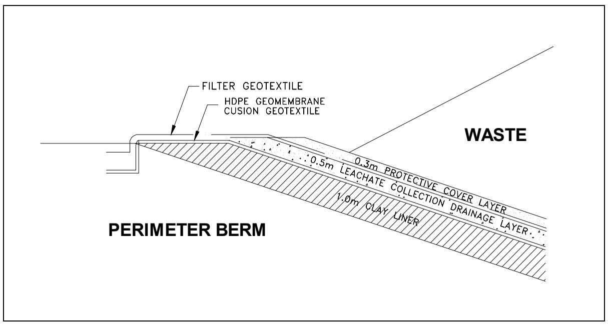

Figure 9. Perimeter berm detail constructed as designed

It was noticed by visual inspection at the bottom edge of the slide (perimeter berm crest) that the slide has developed at the interface between the clay liner and the berm. In this section the geomembrane is deformed along with the drainage gravel, and filter and protective geotextile (Fig. 10). Furthermore, it has been assumed that the slip plane has affected the clay liner right underneath the geomembrane, except at the top of the perimeter berm (Fig. 10) where the slip plane has also affected the soil underneath the clay liner.

It should also be mentioned that, after the slide occurred, leachate from the slide-affected area was not noticed to drain outside the waste body, i.e. it was not reaching the leachate drainage system shaft located on the outer side of the perimeter berm. It has been concluded that the drainpipe connection with drainage at the inner toe of the perimeter berm has been damaged during the displacement of bottom liner materials.

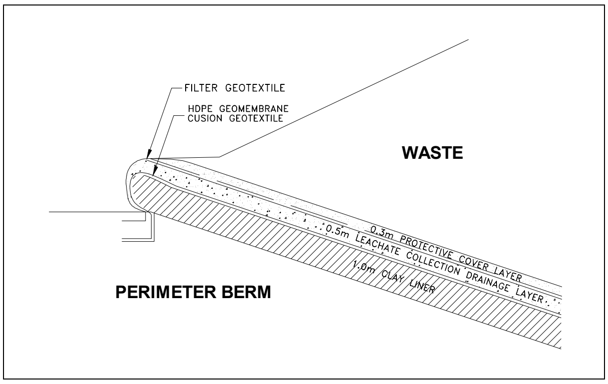

Figure 10. Perimeter berm scheme in the central zone of the slide

3 INVESTIGATION WORKS

Additional laboratory testing and field investigations were carried out after the slide occurred on the south side of cell 3.

3.1 *Additional Laboratory Testing*

Since it has been assumed that the slide occurred mostly at the clay/textured geomembrane interface, additional shear strength laboratory testing for this particular interface was carried out for specific materials placed into the Jakusevec landfill bottom liner.

It is a well known fact that shear strength of this particular interface decreases as the clay moisture content increases, so fully saturated clay was put into the direct shear test box with the moisture content of approx. w=28%. Samples were consolidated 24 hours prior to shearing under the same load as during shearing.

The following shear strength parameters were obtained by additional laboratory testing of the fully saturated clay/textured geomembrane interface: $c=0$ kN/m^2, $\phi=9°$. As expected, these parameters are lower than the ones obtained during prior testing of the same materials, where the tested clay had lower moisture content.

3.2 *Additional Field Investigations*

Three wells were constructed at the lowest position of the bottom liner (at the inner berm toe near the leachate drainpipe). The purpose of these investigations was to establish by visual inspection the waste content and properties; the level of leachate inside the waste; as well as the impact of water pumping inside one well on the level of leachate inside other two wells. Location of those wells is shown in Figure 11.

The performed field investigations have established the following:

- According to content and properties, the waste deposited in the slide area does not differ from the waste deposited at other parts of the landfill. Larger quantities of old inert waste have been deposited, soil and construction materials, along with municipal waste.
- According to initial measurements carried out in September, the measured level of leachate from the top of the clay liner was as follows: 1.1 m for WELL1, 0.7 m for WELL2 and 11.5 m for WELL3.
- By pumping water from one well, the water level did not change in other wells.
- After water from the pumps had been pumped, further measurements were carried out up until December 2002, which have indicated that leachate remains inside the leachate drainage gravel layer.

Varying water levels measured in the wells, suggest that perched leachate (Koerner & Soong, 2000) may exist within the waste. This has also been confirmed by a test where pumping water form one well does not influence the water level in other wells. Leachate lenses have been created probably because, along with municipal waste, larger amounts of low-permeability earthen materials are also deposited at this section of the landfill.

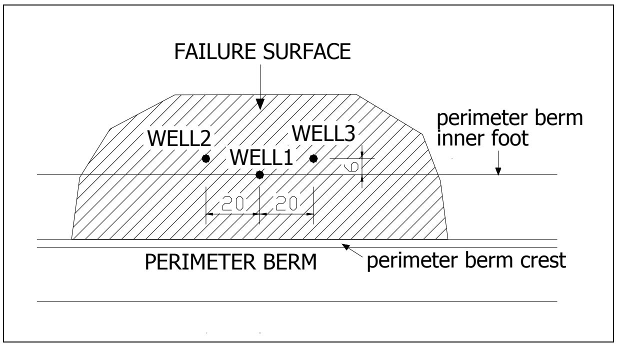

Figure 11. Location of wells

4 STABILITY ANALYSES

Stability analyses of the deposited waste slopes have also been carried out within the demanding Jakusevec landfill remediation project. In the process, a lot of attention has been paid to the selection of the shear strength parameters of materials.

4.1 *Designed Material Properties Applied in Previously Performed Stability Analyses*

Waste shear strength parameters c=19 kN/m^2 and ϕ=24° have been selected in accordance with data from technical literature. These parameters are in keeping with recommended values cited by Jesberger and Kockel (1991) and are within the area of recommended design parameters according to Singh and Murphy (1990), Gabr and Valero (1995), and Sanchez-Alciturri et al. (1995). An estimated waste weight of γ=13 kPa has been selected since larger amounts of inert waste (soil and construction waste) have also been deposited at the dumpsite over a number of years, along with municipal waste.

Bottom liner and leachate collection system shear strength parameters, c=0 kN/m^2, ϕ=12°, have been verified by laboratory testing of all inner and interface shear strengths carried out on specific placed materials. The lowest shear strength was found to be at the clay/textured geomembrane interface, where shear strength residual parameters of c= 0 kN/m^2, ϕ=13° were obtained for the placed clay of required moisture content (w_{opt} to w_{opt}+4%).

Satisfactory safety factors for sliding have been obtained in back analyses for all estimated external loads and abovementioned material properties.

4.2 *Establishing What May Have Caused the Slide by Back Analyses*

In order to determine possible causes of the slide, a series of back analyses was carried out subsequently using SLOPE/W program and Spencer's method. General model used in calculations is shown in Figure 12.

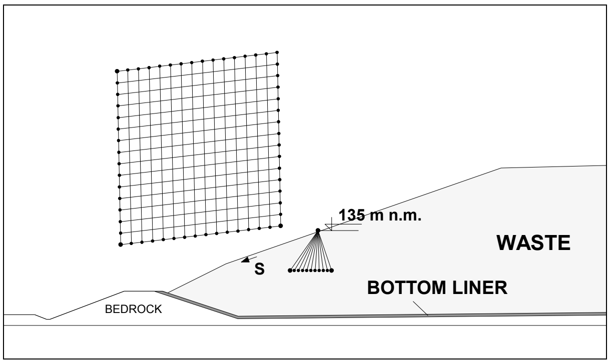

Figure 12. General model used in back analyses

By selecting material parameters in accordance with Chapter 4.1 (waste - c=19 kN/m^2 and ϕ=24°, bottom liner - c=0 kN/m^2, ϕ=12°), the obtained safety factor is FS=1.78. Input parameters (shear strength of materials) had to be reduced or additional external load applied in order to obtain safety factors approximately equal to 1.0 by back analyses for the purpose of establishing what may have caused the slide.

One of the possible reasons for the loss of stability is the fact that actual waste parameters were lower than the ones designed in accordance with technical literature. Waste shear strength parameters were therefore reduced in back analyses in order to determine which parameters attain the safety factor approx. equal to 1.0.

It is possible that shear strength parameters somehow decreased in the bottom liner if the clay moisture content increased for some reason. Control tests were carried out right after the clay liner was placed, so it is possible that the clay surface layer had somehow gotten wet before clay was covered by geomembrane. Furthermore, as was the case with some other landfills around the world, water might have been extruded from clay during consolidation as a consequence of filling the cell with waste too rapidly, or water might have accumulated underneath the geomembrane surface at the interface with clay as a consequence of the geomembrane heating.

Subsequent laboratory testing described in chapter 3.1 has shown that the shear strength parameters for fully saturated clay obtained at the clay/textured geomembrane interface are c=0 kN/m^2, ϕ=9°. However, a satisfactory safety factor FS=1.70 is obtained for these bottom liner parameters and for the waste parameters selected in accordance with technical literature (c=19 kN/m^2 and ϕ=24°).

In accordance with the data from technical literature (Gisbert et al., 1996), shear strength parameters for fully saturated clay at the clay/textured geomembrane may assume values very close to zero. Because of the suggestions made in technical literature and the possibility that the actual parameters at the clay/geomembrane interface at the landfill were lower than the ones obtained by testing in a laboratory, some analyses have been performed for extreme conditions where no shear strength at the clay/textured geomembrane interface was assumed.

Finally, over the entire landfill area as well as in some sections of the slide, leachate was noticed to be leaking out of deposited waste in some places. That is why one part of back analyses has been performed for the applied seepage force inside the waste. Seepage force was presented as stationary water flow inside a layer 2.0 m high from the slope surface.

4.3 *Discussion*

The following has been concluded based on performed stability analyses:

- *Waste parameter values are lower than values adopted from technical literature*

According to technical literature data for waste strength parameters (c=19 kN/m^2 and ϕ=24°), safety factor is approx. 1.0 only when the bottom liner has no shear strength either at the bottom of the cell or at the perimeter berm (c=0 kN/m^2, ϕ=0°).

It is impossible for the bottom liner materials at the perimeter berm to have no interface shear resistance, which has been confirmed by mutual displacements of all bottom liner materials detected during on-site inspection.

The calculations which are therefore more realistic are those where the bottom liner parameters at the perimeter berm confirmed by prior laboratory testing (c=0 kN/m^2, ϕ=12°) or slightly lower than that (c=0 kN/m^2, ϕ=10°) are applied, whereas only the cell bottom is taken to have no bottom liner shear resistance (c=0 kN/m^2, ϕ=0°). Back analyses have indicated that waste shear strength parameter values, which in these cases cause slides, are 35 % (c=11.4 kN/m^2 and ϕ=14.4°) to 45% (c=10.5 kN/m^2 and ϕ=13.2°) lower when compared to expected parameter values.

By taking into account the performed calculations, it has been concluded that waste parameter values are lower than values adopted from technical literature, a possible reason for this being insufficient waste compaction level.

- *It is likely that the bottom liner shear strength was reduced*

When the bottom liner shear strength parameters are selected according to laboratory results (c=0 kN/m^2, ϕ=12° and c=0 kN/m^2, ϕ=9°), slip failure plane runs almost entirely through the waste and does not spread over to the bottom of the cell (Fig. 13).

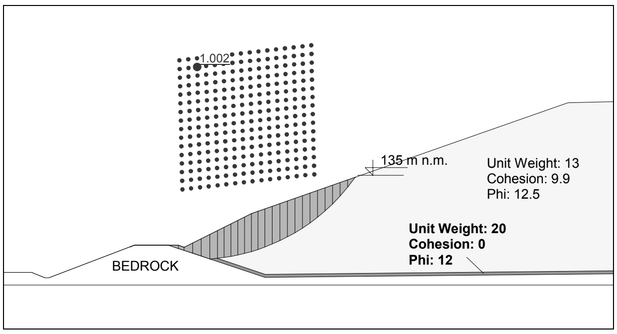

Figure 13. Back stability analysis where the slip plane does not spread over to the bottom liner

Due to large displacements of the bottom liner materials but mostly due to the fact that the drainpipe connection with drainage at the inner perimeter berm toe was damaged, it may be concluded that the actual slip plane spread over to the bottom liner at the bottom of the cell. The same result has been obtained in back analyses where no bottom liner shear resistance at the cell bottom (c=0 kN/m^2, ϕ=0°) was applied, whereas bottom liner parameters at the perimeter berm were in keeping with prior laboratory testing or were just slightly lower (c=0 kN/m^2, ϕ=12^o or ϕ=10°).

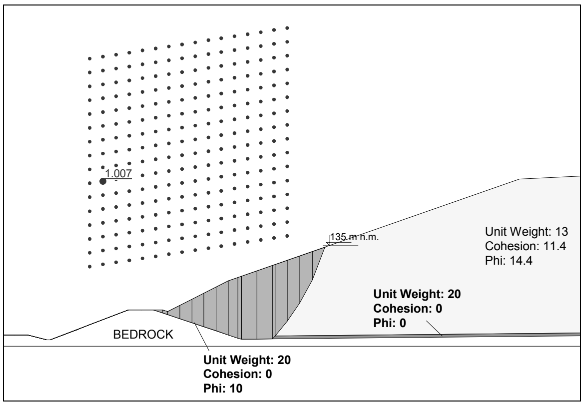

Figure 14. Back stability analysis where the slip plane spreads over to the bottom liner

- *The slide has most likely been caused by a combination of two things: reduced waste and bottom liner shear strength*

Back analyses have proved that for the factor of safety of approx. 1.0 it is necessary to apply waste strength parameters lower than parameters adopted form technical literature. Furthermore, when lower shear strength parameters of the bottom liner are applied, the obtained result is that the slip plane passes through the bottom of the slide which, by all accounts, seems to be its true form. It may therefore be concluded that the slide has most likely been caused by a combination of reduced shear strength parameters of waste and bottom liner.

- *The effect seepage force has on slope stability is a minor one*

Seepage force has no significant impact upon slope stability. Back analyses that have applied the same bottom liner strength parameters have yielded 5% lower waste strength parameters when applying the seepage force, in comparison to the analyses where seepage force was not applied.

5 REHABILITATION

Since the existing slide had to be rehabilitated in the simplest, fastest and most cost-effective way possible, a rehabilitation method that does not require waste relocation on a larger scale has been considered.

It is assumed that the displacements created during sliding caused damage to the bottom liner geomembrane. Since a 1.0.m thick clay liner has been placed underneath the geomembrane, and under the clay liner a clay material fill 3.0 to 4.0 m thick, it has been concluded that these layers provide adequate protection barrier with regards to the leachate inflow to the underground, and that there is no need to repair the damage made to the geomembrane. Furthermore, it has been decided that a 1 mm thick textured LLDPE geomembrane will be placed along the GCL as an additional liner inside the landfill cover system, not proposed at other landfill slopes, in order to bring infiltration of the rainfall water into the waste to a minimum.

After it was established that, from an environmental point of view, an acceptable rehabilitation does not require waste relocation, it has been proposed that the rehabilitation include the construction of a retaining structure at the bottom of the deposited waste slope that would secure its stability. Calculations have been carried out that have shown that such rehabilitation will provide satisfactory stability factors. Thus, safety factors ranging from 1.32 to 1.70 for reduced waste and bottom liner shear strength parameters (parameters that, during back analyses of slide causes, yielded safety factors approx. equal to 1.0) are obtained for the final rehabilitation stage. Stability analyses for all rehabilitation stages and earthquake loads have also been carried out, and it has been established that the risk form slope sliding is low enough. Cross-section through the central slide zone is shown in Figure 14.

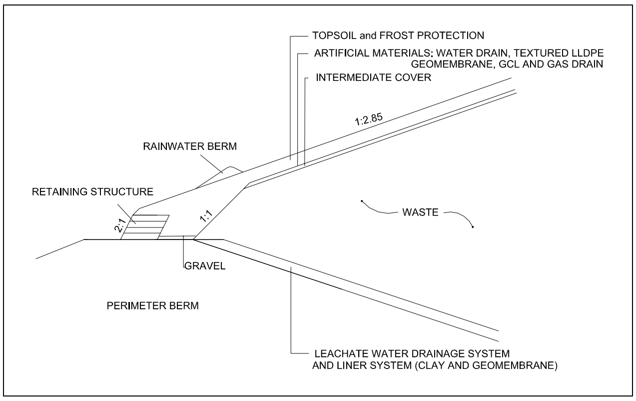

Figure 14. Cross-section of the rehabilitated landfill section

A retaining structure made of reinforced soil consisting of well-graded gravel material and geonet will be constructed at the toe of the berm. The retaining structure width is 3.0 m, its maximum height 2.0 m, with the front surface sloped at 2V:1H.

6 CONCLUSION

Experiences gained at the Jakusevec municipal waste landfill, i.e. gained while analyzing the slide at one section of the landfill, should be put to use in order to avoid similar occurrences while designing, but also while managing entire remediation projects of future landfills. The following issues should be particularly pointed out:

- It is essential to perform adequate laboratory testing of all materials to be placed into a landfill. Sample preparation and testing must, to the highest degree possible, simulate the actual in-situ conditions for all construction stages.
- Material properties obtained through laboratory testing should be critically examined and only then used as input parameters for the stability analyses. Calculations should be performed in order to secure the deposited waste slope stability for all anticipated loads and adequate site conditions.
- Waste properties should be selected very carefully in keeping with the regulations and experiences from technical literature, for the waste content and age that best correspond to waste at an actual landfill.
- Shear strength decreases at the clay/geomembrane interface when the clay moisture content increases. One should make sure that clay has all the properties required by the design right before clay is covered with geomembrane, and therefore the time of taking clay samples for control tests should be coordinated accordingly. Since geomembrane tends to heat up when directly exposed to the sun, thus causing water to accumulate underneath its surface at the interface with clay, it is best to place the drainage system materials as soon as possible. Furthermore, one should take into account clay consolidation conditions with regards to this particular interface and the possible extrusion of water from clay as a result of sudden loads.
- Defective construction of a landfill may be pivotal in jeopardizing the deposited waste slope stability because the achieved material properties unquestionably depend on the construction method. That is why a good construction control at the site is equally important as the quality of a design itself.

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