LESSONS LEARNED FROM A LANDFILL SLOPE FAILURE INVOLVING GEOSYTNTHETICS

By: Virginia L. Wilson
Environmental Engineer
Ohio Environmental Protection Agency
Division of Solid & Infectious Waste
Northeast District Office, 2110 E. Aurora Rd.
Twinsburg, OH, 44087
Telephone: 1/330-963-1180, Telefax: 1/330-487-0769
E-mail: virginia.wilson@epa.state.oh.us

W.Douglas Evans
Environmental Engineer
Ohio Environmental Protection Agency
Division of Solid & Infectious Waste Management
Central Office, 122 South Front St.
Columbus OH, 43216
Telephone: 1/614-728-5371 Telefax: 1/614-728-5315
E-mail: doug.evans@epa.state.oh.us

and

Timothy D. Stark
Professor of Civil Engineering
University of Illinois at Urbana-Champaign
Urbana, IL 61801
Telephone: 1/217-333-7394, Telefax: 1/217-333-9464
e-mail: t-stark1@uiuc.edu

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E-mail: doug.evans@epa.state.oh.us

and

Timothy D. Stark
Professor of Civil Engineering
University of Illinois at Urbana-Champaign
Urbana, IL 61801
Telephone: 1/217-333-7394, Telefax: 1/217-333-9464
e-mail: t-stark1@uiuc.edu

ABSTRACT:

This paper describes a recent slope failure in a municipal solid waste containment facility. The interim slope failure involves sliding primarily along the geomembrane/compacted clay liner interface in a composite liner system. Some of the lessons learned from this case history include: (i) pore-water pressures induced by

leachate recirculation and/or surface infiltration can adversely affect slope stability and should be included in stability analyses, (ii) failure to successfully manage surface runoff can result in the buildup of piezometric pressures, (iii) leachate recirculation using vertical wells can cause differential settlement that can facilitate ponding and infiltration of surface water, (iv) a stability evaluation of interim slopes should be conducted even though it may not be required by regulations, and (v) state-of-practice interface testing and stability analyses could have been used to predict this failure.

I INTRODUCTION

An interim slope failure is used to illustrate the importance of (i) pore-water pressures induced by leachate recirculation and/or surface infiltration on slope stability, (ii) differential settlement due to leachate recirculation via vertical wells on surface runoff, (iii) slope stability and the resulting damage that can be caused to an underlying geomembrane by slope instability, and (iv) evaluating the stability of interim slopes. This slope failure occurred in the State of Ohio and provides valuable lessons for the design and construction of composite liner systems, the recirculation of leachate, surface water management, and the stability of interim slopes at waste containment facilities.

The Geneva Landfill is located near Geneva, Ohio which is approximately 70 kilometers (45 miles) northeast of Cleveland along Lake Erie. The landfill is located on a 35 ha (86.5 acres) parcel of property and receives approximately 90,000 tonnes (100,000 tons) of municipal solid waste per year. Landfilling activities initiated at this site in 1977 and a permit to expand the landfill was approved on 6 May 1991. The lateral expansion involved construction of a new disposal area adjacent to the existing landfill. Cell 2 of the lateral expansion was constructed first and began accepting waste in 1994 (see Figure 1). Cell 1, was constructed during the spring and summer of 1997. A composite liner system and a leachate collection and removal system underlie both placement areas. On 3 October 1996 the landfill owner/operator received authorization to begin recirculating leachate back into the waste through vertical wells and a pipe network embedded in Cell 2. A slope failure occurred during placement of the soil drainage layer in Cell 1 in August 1997. The failure caused extensive damage to the geomembrane in the lateral expansion area.

II. BACKGROUND

Figure 1 shows a plan view of the landfill expansion, which is designed in such a way, that the two cells slope towards each other. Therefore, the middle of the combined cells is the lowest point between Cells 1 and 2. Leachate collection sumps are located in both cells (see Figure 1) with a low permeability soil berm separating the cells. The composite liner system at the facility in the area of the failure consists of, from the bottom up:

- a 0.9 m (3 foot) thick compacted clay liner (CCL),
- a smooth 1.5 mm (60 mil) thick high density polyethylene (HDPE) geomembrane,
- a geonet,
- a non-woven geotextile, and
- a 0.3 m (12 inch) thick protective sand layer.

The cell floor, and thus the geomembrane, is sloped at a minimum of 2% towards the sump to promote leachate flow. The composite bottom liner system on the 1 Vertical:2.5

Horizontal, i.e. 40%, side slopes is similar, except the geonet was heat bonded to two geotextiles. Figure 2 presents a generalized cross-section through Cell 2 (see Figure 1 for location). The low permeability cell separation berm separating the two cells is shown and was underlain by the composite liner system. This cross-section also shows the proposed final configuration of Cell 2 and the leachate recirculation system.

The cell separation berm is underlain by a smooth 1.5 mm (60 mil) thick HDPE geomembrane, which is underlain by the CCL. The cell separation berm consists of compacted clayey soils. The slopes of the cell separation berm are 1 Vertical:2 Horizontal and rise to a height of 1.8 m (6 feet) above the geomembrane. The crest width of the berm is a minimum of 4.6 m (15 feet). A smooth 1.5 mm (60 mil) thick HDPE geomembrane "flap" was extrusion welded to the smooth HDPE geomembrane of the permanent liner system that underlies the cell separation berm. The geomembrane flap extends 1.2 m (4 feet) up the 1 Vertical:2 Horizontal side slope of the cell separation berm that faces the active placement area (Cell 2). The geomembrane flap was installed to limit leachate migration through the cell separation berm during construction of the lateral expansion. At a height of 1.2 m (4 feet) the geomembrane was anchored in the cell separation berm. Therefore, the upper 0.6 m (2 feet) of the separation berm-facing Cell 2 and the cell separation berm side slope facing the lateral expansion (Cell 1) were not covered by a geomembrane. The southern edge of the cell separation berm was located approximately 3 m (10 feet) north of the extent of Cell 2. The smooth geomembrane for the permanent liner system extended underneath the cell separation berm to within 0.3 to 0.6 m (1-2 feet) of the northern edge of the berm. To join or tie the geomembranes from Cell 2 and Cell 1 together, the northern 0.3 to 0.6 m (1-2 feet) of the cell separation berm had to be excavated to expose the two geomembranes prior to welding.

III. INTERSECTION OF CELLS 1 AND 2

Figure 3 presents a detailed cross-section at the intersection between Cells 1 and 2 just prior to the failure. It is important to note that the soil fill shown in Figure 3 was placed on the 1V:3H waste slope in an effort to control the continual leachate outbreaks that occurred along the toe of the waste slope. Initially, a 0.6 m (2 ft) thick lift of soil was placed over the slope toe in an unsuccessful attempt to control the leachate outbreaks. Several subsequent 0.6 m (2 ft) thick lifts of soil were also placed in unsuccessful attempts to control the leachate outbreaks. Finally, an approximately 3 m (10 ft) thick lift of soil was placed over the toe. The soil fill then extended into Cell 1 the distance shown by the line at approximately a 1V:2H slope. The abundance and magnitude of the outbreaks were probably attributable to leachate recirculation, surface water infiltration, and the lowest portion of the cell being along the toe of the interim waste slope. In addition, the permanent sump is located at the northeastern end of the cell separation berm (see Figure 1) and thus a large distance away from the location of cross-section B-B'. Therefore, it was concluded that leachate was building up behind the low permeability cell separation berm and causing the leachate outbreaks.

In order to combine or “tie-in” the composite liner systems of Cells 1 and 2, it was necessary to remove a substantial portion of the soil fill that extended into Cell 1 and some of the cell separation berm (see Figure 4). The geomembrane from Cell 2 that had to be exposed prior to the welding of the Cell 1 and Cell 2 geomembranes was located under the cell separation berm. As a result, the soil fill was excavated so that the northern portion of the cell separation berm was excavated to expose the Cell 2 geomembrane. The slope above the cell separation berm was excavated in 0.9 to 1.5 m (3 to 5 foot) high terraces (see Figures 5 and 6). The removal of the soil fill from Cell 1 decreased the normal stress acting on the geomembrane/CCL interface and the buttressing affect provided to the soil fill at the slope toe. Figure 7 shows an overview of Cells 1 and 2 and the interim slope failure, which is subsequently described in detail.

It is important to note that the stability of the terraced excavation/interim slope was never analyzed. The placement of the soil fill was not anticipated in the permitting process and thus the potential for instability was not recognized during construction. It is also important to note that some of the soil from the excavation was placed or dumped along the crest of the terraced slope (see Figure 8). This excavated soil loaded the slope with additional driving force and effectively dammed or trapped some surface water runoff at the top of the terraced slope. Figure 8 shows a close up view of the excavated soil to the right of the post-failure tension cracks. The saturated nature of the soil fill is evident even after some desiccation cracking had developed.

IV. FAILURE AND REMEDIAL MEASURES

Between the close of business on 17 August 1997 and the start of business on 18 August 1997 a block of the soil fill, some waste, and the temporary cell separation berm from Cell 2 translated laterally 4 to 6 m (15 to 20 feet) into Cell 1. The sump for Cell 1 near the intersection of the two cells can be seen in the foreground of Figure 7. The sump for Cell 2 is located near the tires in the foreground but hidden by the overlying waste. The access area/road for the landfill is evident by the vehicles in the background of Figure

7 and is shown in Figure 1 on the west side of Cells 1 and 2. Figure 7 also shows the cohesionless drainage layer being placed in Cell 1, the displaced soil/waste from Cell 2, and the damaged geomembrane at the toe of the failed slope. The slope failure is approximately 92 m (300 feet) long, 6 m (20 feet) high, and involved about 91,680 m^3 (120,000 cubic yards).

Figure 9 shows the tension that was induced in the geomembrane at the top of the slope due to the slide movement. To investigate the damage to the composite liner system a significant portion of the soil fill had to be excavated. The wrinkled and torn geomembrane (Figures 6 and 10) indicated that the failure plane occurred at the interface between the compacted clay liner and the smooth geomembrane. However, it is also probable that some of the damage was due to the saturated soil fill slumping or bulging into Cell 1. Figure 10 shows the removal of the slide debris, i.e. soil fill and waste, and the resulting damage to the 1.5 mm (60 mil) thick HDPE geomembrane from the failure. Repair to the facility consisted of removing the soil fill, waste, and damaged geomembrane and replacing the damaged portions of the composite liner system.

V. LEACHATE RECIRCULATION SYSTEM

The leachate recirculation system consists of 4 vertical wells connecting multiple hubs of horizontal trenches. The four vertical wells are located about every 30 m (100 feet) horizontally from the cell separation berm (see Figure 1) throughout Cell 2. Each vertical recharge well has two hubs that connect to eight horizontal trenches that are filled with high permeability material, such as sand and/or tire chips (Figure 2). The trenches from the four vertical wells cover the majority of the cell floor to distribute the leachate.

The lowest or deepest hubs are located approximately 9 m (30 feet) above the composite liner system.

Discussions with landfill personnel indicate that leachate generation increased dramatically during and after rain events. This increase is thought to be the result of surface water infiltrating the recirculation system. Surface water run on in the recirculation area was increased by filling activities, the haul road, and the adjacent landfill slopes. This probably contributed to increased infiltration around the recharge wells. It will be recommended that facilities that use leachate recirculation actively promote surface runoff so large quantities of water do not infiltrate the waste and contribute to slope instability.

Field observations suggest that the increase in leachate was influenced by surface water infiltrating in and around the vertical wells and flowing to the bottom of the wells. It is anticipated that liquids left the bottom of the vertical wells and flowed to the bottom of the waste, i.e. top of the geomembrane. The presence of the geomembrane and the 2% slope of the cell floor allowed the leachate to flow to and build up behind the low permeability cell separation berm. This was verified by a manhole located on the west side of Cell 2, furthest away from the sump. After a rain event, 0.9 to 1.5 m (three to five feet) of leachate usually would be present in the bottom of the manhole. It is anticipated that this buildup of leachate behind the cell separation berm resulted in the leachate outbreaks on the soil fill slopes in Cell 2. The slope failure occurred during or shortly after a large rainfall, which probably induced a large buildup of leachate behind the cell separation berm. Additionally, saturated conditions may have existed, and still may exist, at the bottom of the landfill due to the effectiveness of horizontal trench A (lower level) as compared to horizontal trench B (upper level) at diffusing fluids from the recirculation system.

The buildup of leachate behind the low permeability cell separation berm adversely affected the stability of the slope toe in at least two ways: (i) increasing the waste and soil fill unit weights from a moist to a saturated value and (ii) increasing the horizontal pressure on the back of the cell separation berm. It is possible that the earth pressure due to the saturated waste, the fluid pressure due to the buildup of leachate acting along the back of the cell separation berm, the additional driving force applied by placement of some of the excavated soil at the top of the slope, and the removal of the toe buttress for the saturated soil fill caused sliding to occur along the CCL/smooth geomembrane interface and/or slumping of the soil fill. This allowed the soil fill and waste to move into Cell 1 and damage the geomembrane.

Initially the buildup of leachate in the waste did not influence the CCL/smooth geomembrane interface because the geomembrane contained the leachate. As a result, the sliding analysis of the slope toe that should have been conducted for this case should not have modeled the leachate acting on the CCL/smooth geomembrane interface. However, the analysis should have modeled the saturated unit weight of the waste and the fluid pressure acting on the back of the cell separation berm due to the leachate buildup. Of course, a site-specific value of shear strength for the CCL/smooth geomembrane interface should be used in the analysis.

The sliding analysis that could have been prepared is similar to that performed for an earth retaining structure. The analysis divides the shear resistance along the interface by the horizontal component of the earth and fluid pressures to estimate the factor of safety against sliding. The minimum factor of safety can be determined using Coulomb's (1776) earth-pressure theory and varying the failure surface through the waste to estimate the maximum horizontal pressure acting on the cell separation berm. Some slope stability software also can conduct this analysis by assigning an appropriate phreatic surface for the leachate level, creating a horizontal failure surface along the critical interface, adding weight at the top of the slope, removing the buttress to the soil fill and thus reducing the normal stress on the critical interface, and searching for the critical inclination of the failure surface through the waste.

VI CONCLUSIONS

This paper presents a recent case history of slope instability in a municipal solid waste containment facility. The following lessons can be drawn from this case history:

1. Excessive piezometric pressures may be generated by leachate recirculation leading to slope instability. A stability analysis should be conducted for this condition with the fluid pressures properly modeled. If a geomembrane is installed below the waste, the piezometric pressures only influence the materials and geosynthetic interfaces above the geomembrane. Therefore, piezometric pressures should not be applied to the interfaces below the geomembrane, e.g. the CCL/geomembrane interface, in the stability analysis. However, the resulting earth and fluid pressures should be applied to the slope toe.

2. Piezometric or seepage analyses should be conducted to assess the size and frequency of leachate outbreaks during normal and erratic leachate generation periods. Techniques for managing leachate outbreaks that do not adversely affect slope stability should be developed. Slopes at waste containment facilities should be regularly inspected for saturated areas and these areas should be treated accordingly.

3. Failure to successfully manage surface water can result in saturated conditions and piezometric pressures that can cause slope instability. This may be especially relevant in the areas of leachate recirculation wells. Additional settlement may occur around these leachate recirculation wells due to increased waste degradation that may hinder surface runoff and increase infiltration. This unexpected increase in infiltration could adversely influence slope stability.

4. The stability of interim or temporary waste slopes and stability during special circumstances arising from construction and operation activities, e.g. leachate recirculation, may represent the most critical condition that will occur at a waste containment facility and as such should be analyzed accordingly.

5. State-of-practice limit equilibrium stability analyses and interface test results could have been used to predict this failure. As a result, it is recommended that state-of-practice testing and analyses and a suitable factor of safety be used when geosynthetics are involved.

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Figure Captions:

Figure 1. Plan view and cell layout at Geneva landfill.

Figure 2. Cross section A-A' in Cell 2

Figure 3. Cross section B-B' in toe area showing soil fill to reduce leachate outbreaks

Figure 4. Cross section B-B' in toe area showing excavation of soil fill

Figure 5. Cross section B-B' at toe area showing estimate failure surface

Figure 6. Terraces in soil fill and wrinkles in smooth geomembrane at toe of the slope failure

Figure 7. Excavated soil fill placed at the top of the slope Note: Excavated soil fill to the right of the tension cracks.

Figure 8. Overview of interim slope. Note: The photograph was taken from the top of the east slope, slightly south of the leachate riser pipes (see Figure 1). Cell 2 is on the left of the photograph and Cell 1 is on the center-right part of the photograph.

Figure 9. Tension induced in geomembrane at the top of the slope due to failure

Figure 10. Observed damage to geomembrane after waste removal

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The sump for Cell 1 is located to the right, i.e. north, of the tires.