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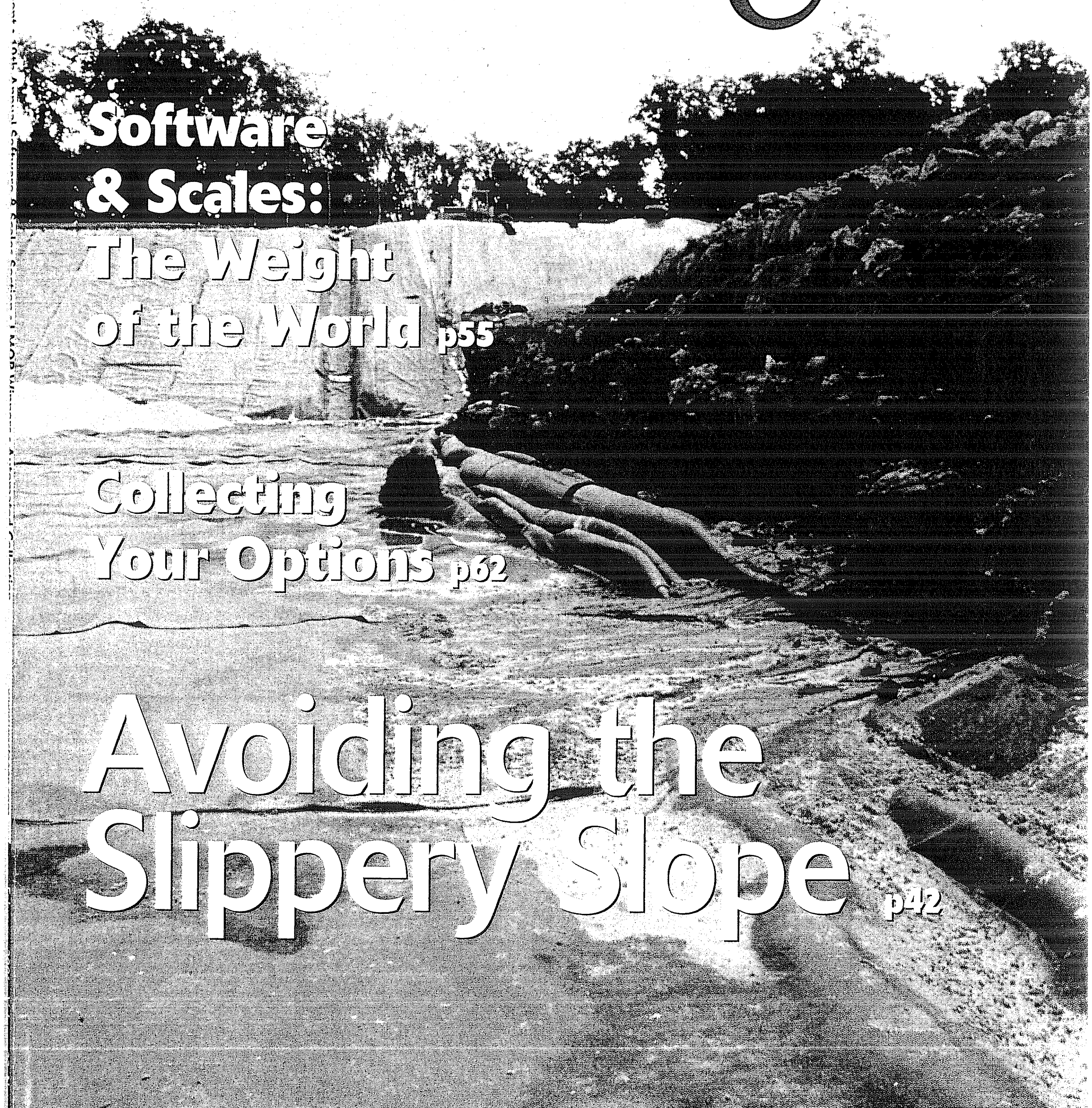

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Avoiding the Slippery Slope

Valuable lessons were learned in designing and constructing composite liner systems, leachate recirculation, surface water management and interim slope stability.

By V.L. Wilson, W.D. Evans and T.D. Stark

Correcting a landfill slope failure can be an arduous experience, but one disposal facility has discovered it also can provide a better path for those who follow. Located on 86.5 acres, this landfill receives approximately 100,000 tons of municipal solid waste yearly. The site began accepting waste in 1977, and a permit to expand the landfill was approved in May 1991.

The lateral expansion involved constructing a new disposal area adjacent to the existing landfill. Cell 2 of the lateral expansion was constructed first and began accepting waste in 1994. Cell 1 was built three years later. Both areas included a composite liner system and a leachate collection and removal system.

In October 1996, the landfill owner/operator began recirculating leachate into the waste through vertical wells and a pipe network embedded in Cell 2. A slope failure occurred in August 1997 as the soil drainage layer was being placed in Cell 1, causing damage to the geomembrane and other geosynthetics in the lateral expansion area.

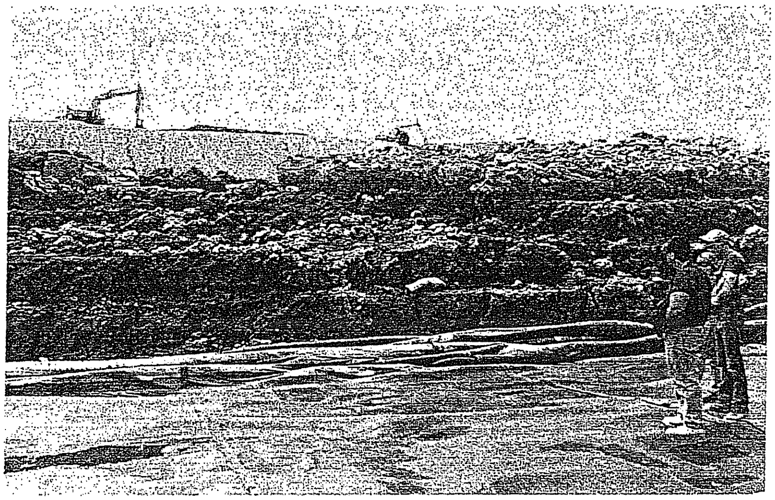
The lateral expansion was designed so that the two cells would slope toward each other with the middle of the combined cells being the lowest point. Leachate collection sumps were located in both cells with a low-permeability soil berm separating them.

The composite liner system consisted of (from the bottom up):

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

The cell floor and its composite liner system was sloped at a minimum of 2 percent toward the sump to promote leachate flow. The composite bottom liner system — on the 1 vertical-to-2.5 horizontal, i.e. 40 percent — side slopes was similar, except the geonet was heat-bonded to two geotextiles. The composite liner system was located under the low-permeability cell berm separating the two cells.

A smooth 60-mil-thick HDPE geomembrane, underlaid by the CCL, was placed under the cell separation berm. This berm consisted of compacted clayey soils. The slopes of the cell separation berm were 1 vertical-to-2 horizontal and rose 6 feet above the geomembrane. The berm's crest width was a minimum of 15 feet.


Workers examine terraces in the soil fill, the excavated soil placed at the top of slope and the damaged geomembrane at the slope's toe.

To limit leachate migration through the cell separation berm during the lateral expansion's construction, a geomembrane flap was installed. This smooth 60-mil-thick HDPE geomembrane flap was extrusion-welded to the smooth HDPE geomembrane of the permanent liner system, which lay underneath the cell separation berm. The geomembrane flap extended 4 feet up the 1 vertical-to-2 horizontal side slope of the cell separation berm that faced the active placement area (Cell 2).

The geomembrane was anchored at 4 feet up the inside slope of the separation berm. Therefore, it did not cover the upper 2 feet of the separation berm facing Cell 2 and the cell separation berm side slope facing the lateral expansion (Cell 1).

The southern edge of the cell separation berm was located approximately 30 feet north of the extent of waste in Cell 2. The smooth geomembrane for the permanent liner system extended underneath the cell separation berm to within 1 foot to 2 feet of the berm's northern edge. To join or tie the geomembranes from Cell 2 and Cell 1 together, the northern 1 foot to 2 feet of the cell separation berm had to be excavated to expose the existing Cell 2 geomembranes prior to welding to the new Cell 1 geomembrane.

At the Cell's Intersection

To control the continual leachate outbreaks that occurred along the waste slopes' toe, soil fill was placed on the 1 vertical-to-3 horizontal waste slope. Initially, a 2-foot thick soil lift was placed over the slope toe but was unsuccessful in controlling the outbreaks. Several subsequent 2-foot thick soil lifts were also placed in unsuccessful attempts to control the outbreaks. Finally, an approximately 10-foot thick soil lift was placed over the slope and toe. The soil fill then extended into Cell 1 — the distance shown by the line at approximately a 1 vertical-to-2 horizontal slope.

It was assumed the outbreak's abundance and magnitude resulted from leachate recirculation, surface water infiltration and the lowest portion of the cell being along the toe of the interim waste slope. Additionally, the permanent sump was located at the northeastern end of the cell separation berm. It was concluded that leachate was building up behind the low-permeability cell separation berm causing the outbreaks.

To "tie-in" the composite liner systems in both cells, it became necessary to remove a substantial portion of the soil fill that extended into Cell 1 and remove some of the cell separation berm. Cell 2's geomembrane, located under the cell separation berm, had to be exposed prior to welding the two cells' geomembranes. As a result, the soil fill was excavated so that the northern portion of the cell separation berm could be excavated to expose Cell 2's geomembrane. The slope above the cell separation berm was excavated in 3- to 5-foot-high terraces. Removing the soil fill from Cell 1 decreased the buttressing affect provided to the soil fill at the slope toe.

Some of the excavated soil was placed along the crest of the terraced slope. This soil loaded the slope with additional driving force and effectively dammed or trapped some surface water runoff at the terraced slope's top.

Failure and Remediation

In less than 24 hours between Aug. 17 and 18, 1997, a block of the soil fill and portions of the temporary cell separation berm from Cell 2 translated laterally 15 feet to 20 feet into Cell 1. The slope failure was approximately 300 feet long, 20 feet high and involved about 30,000 cubic yards of primarily soil fill.

To investigate the potential for damage to the composite liner system a significant portion of the soil fill was excavated. Wrinkled and torn geomembrane was discovered in the portions of the liner system outside of the active cell area indicating that the failure plane occurred within the cover soil in the active cells. The sliding occurred at the interface between the compacted clay liner and the smooth geomembrane in the active and developing cell. However, operators also suspected that some of the damage was due to the saturated soil fill slumping or bulging into Cell 1.

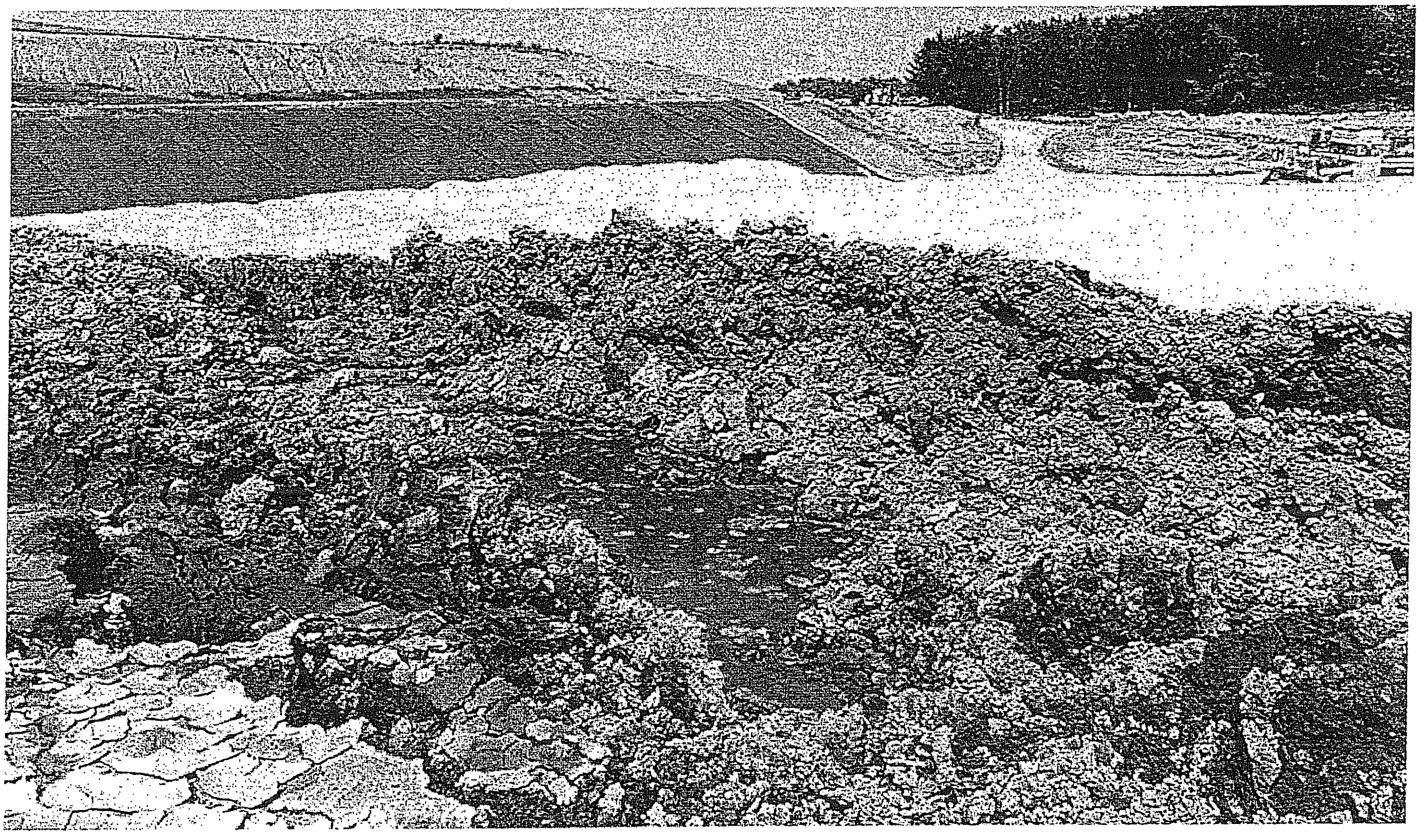
To repair the facility, operators had to remove the soil fill, waste and damaged geomembrane, then replace the composite liner system's damaged portions.

Recirculating Leachate

The leachate recirculation system included 4 vertical wells that connected multiple hubs of horizontal trenches. The wells were located about every 100 feet horizontally from the cell separation berm throughout Cell 2.

Each vertical recharge well had two hubs that were connected to eight horizontal trenches, which were filled with high-permeability material such as sand and/or tire chips. The trenches from the four vertical wells covered most of the cell floor to distribute the leachate. The lowest or deepest hubs were approximately 30 feet above the composite liner.

According to landfill personnel, leachate generation increased dramatically during and after it rained. This



With leachate appearing at ground surface, excavated soil fill was placed at the top of the slope.

increase was thought to be the result of surface water infiltrating the waste mass. Surface water run-on in the recirculation area was increased by disposal activities, the haul road and the adjacent landfill slopes. And this probably contributed to increased infiltration around the recharge wells. Leachate had not been recirculated at the site for approximately nine months prior to the slide. Therefore, surface water infiltration was the primary contributor to the slide.

In the future, the landfill's operators recommend facilities that recirculate their leachate actively promote surface run-off so that large quantities of water do not infiltrate the waste and contribute to slope instability. If less-permeable cover materials than the waste are used, a diligent effort should be made to slope these materials away from interim slopes so waste is not directed to the interim slopes causing leachate outbreaks.

Additionally, settlement around the recharge wells allowed surface water to pool near the wells, and for some surface water to enter the wells and infiltrate the waste. If the leachate recirculation is successful and waste settlement occurs, it probably will be greatest near the wells that may promote collection of surface water near the well.

Field observations also suggested that the increase in leachate was influenced by surface water infiltrating in and around the vertical wells and flowing to their bottom. Likely, liquids left the bottom of the vertical wells, flowed to the bottom of the waste, i.e. to the top of the geomembrane, and toward the sump area at the intersection of the two cells.

The geomembrane and the 2 percent 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 the presence of leachate in a manhole located on the west side of Cell 2, furthest away from the sump. This leachate buildup behind the cell separation berm probably contributed to the leachate outbreaks on the soil fill slopes in Cell 2.

According to the landfill, the slope failure occurred shortly after a large rainfall, when leachate was allowed to build up behind the cell separation berm. Additionally, saturated conditions may have existed at the bottom of the landfill due to the effectiveness of Horizontal Trench A (lower level) as compared to Horizontal Trench B (upper level) in diffusing fluids from the recirculation system into the waste mass.

Sliding Analysis

The buildup of leachate behind the low-permeability cell separation berm adversely affected the slope toe's stability in at least two ways: It increased the waste and soil fill unit weights from a moist to a saturated value; and it increased the horizontal pressure on the back of the cell separation berm.

It is possible that the sliding and/or slumping of the soil fill resulted from the earth pressure from the saturated waste, the fluid pressure from the leachate buildup acting along the back of the cell separation berm, the additional driving force from placing some of the excavated soil at the top of the slope, and removing the toe buttress for the saturated soil fill. This allowed the soil fill and waste to move into Cell 1 and damage the geomembrane in the developing cell.

Initially, the leachate buildup in the waste did not influence the CCL/smooth geomembrane interface because the geomembrane contained the leachate. As a result, a sliding analysis of the slope toe for this condition should not model the leachate acting on the CCL/smooth geomembrane interface. However, the analysis should model the saturated unit weight of the waste and 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 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 safety factor against sliding.

The minimum safety factor can be determined using Coulomb's 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 be used to 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.

Lessons Learned

Based on this slope failure, several lessons can be learned, including:

•Excessive piezometric pressures may be generated by buildup of piezometric head within a landfill due to surface water infiltration, leachate recirculation or other reasons, which can lead to slope instability. A stability analysis should be conducted for this condition with the fluid pressures properly modeled.

The piezometric pressures only influence the materials and geosynthetic interfaces above the geomembrane if a geomembrane is installed below the waste. 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.

•Piezometric or seepage analyses should be conducted to assess the size and frequency of leachate outbreaks during normal and erratic leachate generation periods. If low-permeability cover material is used for daily cover, it should be sloped away from interim slopes so water or leachate is not directed to an interim slope, which could facilitate leachate outbreaks. Techniques for managing leachate outbreaks that do not adversely affect slope stability should be developed. Slopes at landfills should be inspected regularly for saturated areas, and these areas should be treated.

•Failing to successfully manage surface water can result in saturated conditions and piezometric pressures that can cause slope instability. This may be especially relevant in leachate recirculation well areas. Additional settlement may occur around recirculation wells due to increased waste degradation that may hinder surface run-off and increase infiltration. This potential increase in infiltration could adversely influence slope stability.

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

•State-of-practice testing and analyses, as well as a suitable safety factor should be used when geosynthetics are involved. **WA**

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This feature was based on a paper presented by the authors at the Waste Tech 2000 landfill conference.

Leachate Directory

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Central Plastics	*Circle 154 on reply card*
CES-Landtec	*Circle 155 on reply card*
Clean Environment Equipment*	*Circle 156 on reply card*
Delta Controls Corp.	*Circle 157 on reply card*
Desilt Services	*Circle 158 on reply card*
Environmental Systems Corp.	*Circle 159 on reply card*
EPG Companies	*Circle 160 on reply card*
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