the RUMPKE landslide

It was a big landfill event, and its cause and lessons to be learned are still being analyzed and discussed.

NEW INFORMATION

By W. Douglas Evans and Timothy D. Stark

On March 9, 1996, the largest slope failure in a municipal solid waste (MSW) landfill, based on volume of waste involved, occurred at the Rumpke Sanitary Landfill near Cincinnati. This case history provides many lessons to the solid waste industry, including the importance of operation, expansion, and stability of existing landfill slopes. The original reports of the waste slide appeared in *Waste Age* in April 1996 (p. 8) and July 1996 (p. 8).

In March, *Waste Age* published a technical paper (p. 67) prepared for Waste Tech '97, which was held in February. The article, by Richard J. Kenter and Kenneth R. Miller of Civil & Environmental Consultants, Inc. (Cincinnati), and Bruce O. Schmucker, a Rumpke executive, discussed the Rumpke landfill failure in detail and generalized about some potential causes. At the Waste Tech conference itself, there were several presentations, including one by Kenter and one by another consultant, David Hendron, associate, GeoSyntec Consultants (Chicago). Hendron had been brought in by Rumpke specifically to do a forensic investigation of the landslide. An April 1997 *Waste Age* article reporting on the conference (p. 103) attributes to Hendron the contention that "much of the blame [was due] to the harsh winter of 1995-96 and to the frost penetration at the toe of the landfill blocking the leachate collection system."

Hendron proposed that unseasonably cold temperatures caused the interim soil cover over the waste to freeze to a depth of about one foot, which in turn prevented leachate from seeping out through the toe of the

Evans is a civil engineer, Central Office, Division of Solid and Infectious Waste Management, Ohio Environmental Protection Agency (Columbus, Ohio), and Stark is associate professor of civil engineering at the University of Illinois (Urbana, Ill.).

"grandfathered" landfill. According to this theory, the buildup of the leachate in the waste reduced stability and caused the failure. New information, however, suggests another mechanism for the waste slide. This article presents this information and suggests some of the lessons that were learned from the experience that can benefit other waste containment facilities.

Site description

The MSW landfill occupies 135 acres approximately nine miles northeast of Cincinnati. This facility is currently permitted for 234 total acres of waste placement and has a total area of 436 acres. The landfill is the largest facility in Ohio based on annual waste receipts. The facility accepts an average of 5,000 tpd of solid waste for disposal by landfilling. The family-owned company currently collects and disposes of waste from approximately 750,000 residential customers in 63 counties and 150 municipalities across Ohio, Kentucky, and Indiana.

Disposal at this site began in 1945 and initially consisted of pushing waste over the edge of existing ravines. The native soils on the bottom and sides of the ravine were not excavated prior to waste placement, which was the typical mode of operation. The native soil consists of a brown colluvial material. Colluvium is a poorly sorted mixture of fine-grained soil and angular rock fragments. Colluvium is derived from physical and chemical weathering of bedrock and thus the engineering properties of the colluvium are related to the composition of the bedrock. Colluvial deposits are usually marginally stable because they are continually in a near failure state due to constant downslope movement caused by gravity and seepage. These deposits are usually less than 40 feet thick and are thinnest near the crest and thickest near the toe of each slope. In the Cincinnati area, the colluvium layer is usually less than 20 feet thick and is underlain by gently dipping interbedded shale and limestone of the late Ordovician Age. Cincinnati has one of the highest annual per-capita costs of damage due to landsliding in the U.S. Most of these landslides occurred in natural slopes underlain by colluvium.

Lateral expansion

In 1994 the owner/operator was granted a permit for a 120-acre lateral expansion. The lateral expansion involved creating a 140-foot-deep rock excavation at the toe of the existing landfill and installing a composite liner system in the expansion. The liner system was to consist of five feet of compacted clay, 60 mil high-density polyethylene geomembrane, and a leachate collection and removal system. The large and deep excavation was nearing completion at the time of failure after being open for approximately 18 months prior to the wasteslide. Compacted clay liner placement had only recently begun in a portion of the excavation at the time of failure. The lateral expansion was designed and being constructed by the owner/operator.

The site was overbuilt by approximately 1.2 million cu. yds. at the time of the wasteslide. Approximately 475,000 cu. yds. of this overbuild was involved in the wasteslide; 482,000 cu. yds. remained at the top of the landfill after the wasteslide; 101,000 cu. yds. were placed

Figure 1

Slope Cross-Section Prior to March 10, 1996, Failure

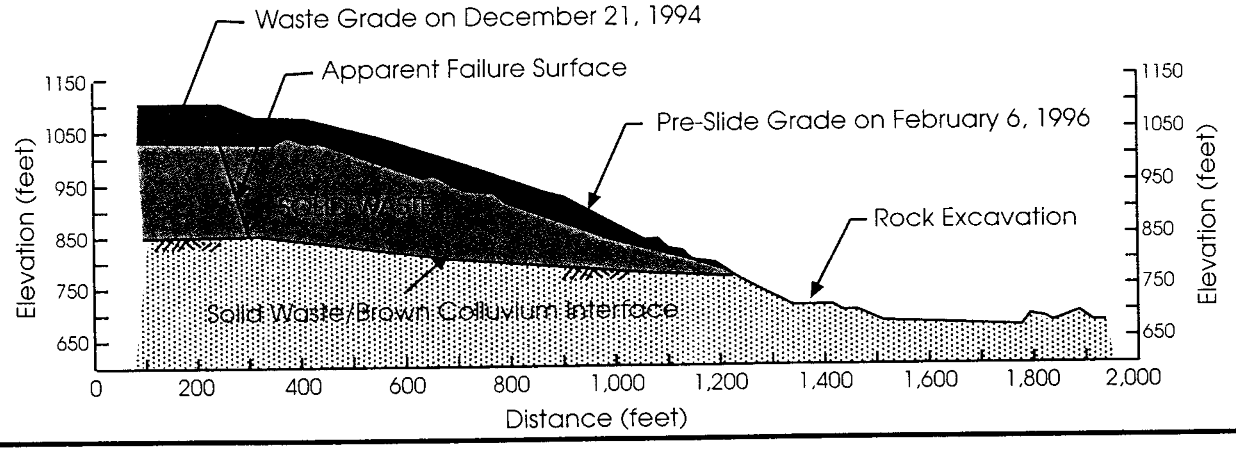


Figure 2

Failed slope and compactors at edge of scarp

on an adjacent slope; and the remainder of the overbuild was spread throughout the site. As a result, the slope that failed was overbuilt by approximately 957,000 cu. yds. Figure 1 presents a cross-section of the slope prior to failure. The two slope grades represent the waste grade on Dec. 21, 1994, (approximately 15 months prior to the slide) and Feb. 6, 1996, (approximately one month prior to the slide). A comparison of these two grades indicates that a large amount of waste was placed on the slope and at the top of the landfill between Dec. 21, 1994, and Feb. 6, 1996. Therefore, it may be concluded that the majority of the approximately 957,000 cu. yds. of overbuild occurred in the 12 to 18 months prior to the failure. In fact, immediately after the slide, three compactors were located at the edge of the scarp (Figure 2). One of these compactors was so close to the scarp that it had to be pulled, instead of driven, away from the edge.

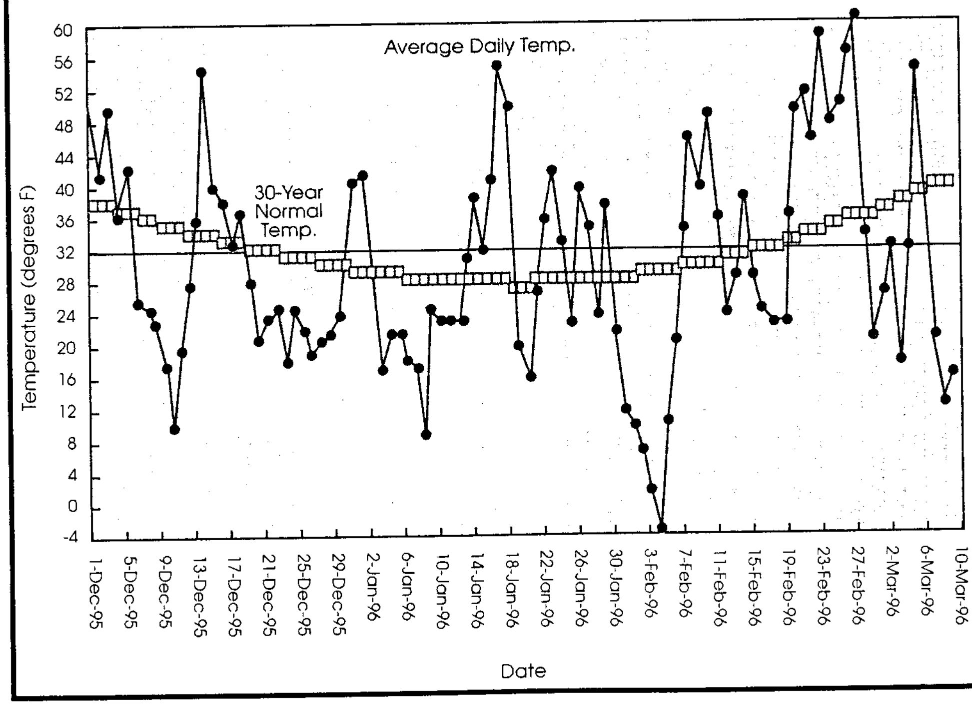
As part of the 1994 expansion permit, the maximum elevation of the landfill was permitted at +1065 feet From Figure 1 it can be seen that the maximum elevation of the landfill was approximately +1105 feet on Feb. 6, 1996. In addition to exceeding the maximum elevation, the slope of the "grandfathered" area adjacent to the excavation was oversteepened. The average slope was 2.6 horizontal:1 vertical, but some portions of the slope were steeper than 1.85H:1V. In addition, a 15- to 20-foot-high nearly vertical excavation was constructed at the toe of the slope for a composite liner anchor trench and an access road. The impact of this overbuild and over-steepened slope on the stability of the slope are discussed subsequently.

Freezing mechanism

Figure 3 summarizes the weather station data from the Greater Cincinnati airport. It can be seen that between Dec. 1, 1995, and March 9, 1996, each cold period was

Figure 3

Average & Normal Daily Temperatures at the Greater Cincinnati Airport



followed by a warm period. Therefore, there was no extended cold period in the three months prior to the wasteslide. In fact, during this three-month period the number of days at or above freezing (32 degrees F) and below freezing were 44 and 55, respectively. In addition, the average daily temperature appears to follow the 30-year normal temperature except from Feb. 19 to March 4, 1996. From Feb. 19 to 28, all of the average daily temperatures were above freezing and ranged from 34 to 60 degrees F. On Feb. 26 and 27, approximately 1.1 inches of rainfall occurred in the Cincinnati area. These warm temperatures and rainfall would have reduced and possibly eliminated any frost penetration. From Feb. 29 to March 4, the site experienced subfreezing temperatures between 18 and 32 degrees F. (Cracking was first observed at the top of the landfill on March 4.) Therefore, it appears doubtful that the frost penetration remaining, if any, on Feb. 28 and the frost penetration possibly created from Feb. 29 to March 4, could have blocked a substantial amount of fluid or leachate at the toe of the slope.

Figures 4 and 5 summarize the soil temperature data from the Miami, Ohio, recording station that is approximately 17 miles northwest of the Rumpke Sanitary Landfill. Figure 4 presents the soil temperature data at a depth of 4 inches. It can be seen that at no time during the three months prior to the March 9 wasteslide did the soil temperature at a depth of 4 inches drop below freezing (32 degrees F). In addition, the soil temperature data appears to follow the 14-year average for this site. Figure 4 presents the soil temperature data at a depth of 2 inches. It can be seen that between Dec. 9 and 12, 1995, and between Feb. 4 and 7, 1996, the average daily soil temperature dropped slightly below freezing. From Feb. 19 to March 9 the soil temperature at a depth of 2 inches was significantly above freezing. In addition, the soil temperature is significantly higher than the 14-year average soil temperature from Feb. 19, 1996, to March 8. The data in Figures 3 through 5 do not support the claim that frost penetration reached a depth of about 1 foot throughout the three months prior to the wasteslide.

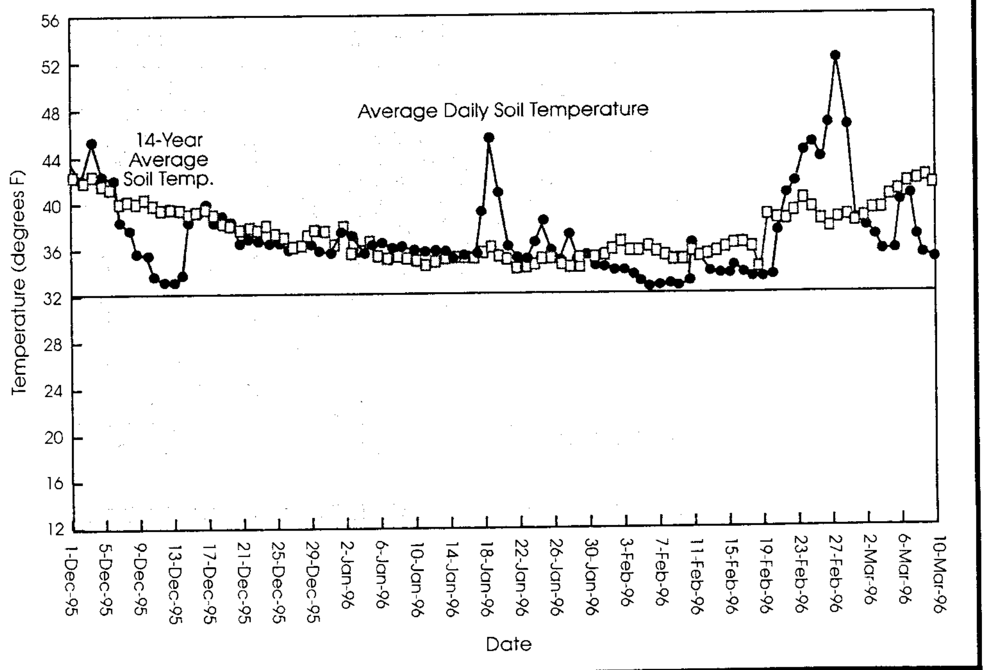
In fact, it would be expected that the frost depth in the landfill interim soil cover would be less than at the Miami, Ohio, site because of the heat generated by the underlying waste. The waste temperature measured during the post-failure subsurface investigation was 118 to 125 degrees F. (These temperatures are typical for an MSW landfill.) The elevated temperature of the waste was also evident when the slide mass moved into the adjacent excavation by the amount of steam that was released.

Finally, the pore-fluid chemistry of cohesive soils usually results in temperatures below 32 degrees F being required to freeze the soil. This decrease in freezing point usually ranges from 1 to 5 degrees F depending on soil plasticity. Based on this information, the temperature data in Figures 3–5 do not indicate that frost penetration would have reached a depth of 1 foot.

It should also be noted

Figure 4

Average & Normal Soil Temperatures for a depth of 4″ at Miami, Ohio



that many other landfills have experienced more severe freezing conditions than those in Cincinnati and have not failed. This suggests that other factors contributed to this wasteslide. These other factors will be discussed subsequently.

The landslide event

On the morning of Monday, March 4, 1996, operating personnel at the landfill noticed some cracking at the top of the northwest slope. Owner/operator personnel reviewed the entire slope including the toe below the cracking to determine if the cracks were an indication of slope instability. No other cracks or other indications of slope movement were identified on the slopes or at the toe. The location of this cracking was just near the northern edge of the vehicle turnaround on top of the landfill. This cracking essentially corresponds to the location of the scarp after the wasteslide and thus indicates the extent of the initial slide mass.

The cracking continued to appear each day until the wasteslide occurred on Saturday, March 9. Between work stoppage on Friday, March 8, and the early morning hours of March 9, the cracks widened substantially, and 1.5 to 2.5 feet of vertical displacement occurred just to the north of the vehicle turnaround. This cracking extended across the top of the landfill and down the east and west sideslopes.

Field observations and photographs of the failure show that the slope began to move as a large, single slide block toward the deep excavation around noon on Saturday, March 9. As the large block moved, a graben formed just behind the slide block, and a 100- to 150-foot-high nearly vertical scarp was created behind the graben (see Figure 2). A graben is defined as a down-dropped block or depression that forms as a slide block moves away and the material behind the graben remains stable, creating a vertical scarp.

The scarp location again corresponds to the location of the initial cracking observed at the top of the landfill. This reinforces the field observations that the slope failed as a single block. The formation of a large slide block, graben, and vertical scarp is indicative of a translatory landslide. Translatory landslides have been observed in many other cases and are caused by sliding along a weak underlying layer, which may be nearly horizontal or slightly dipping away from the slope.

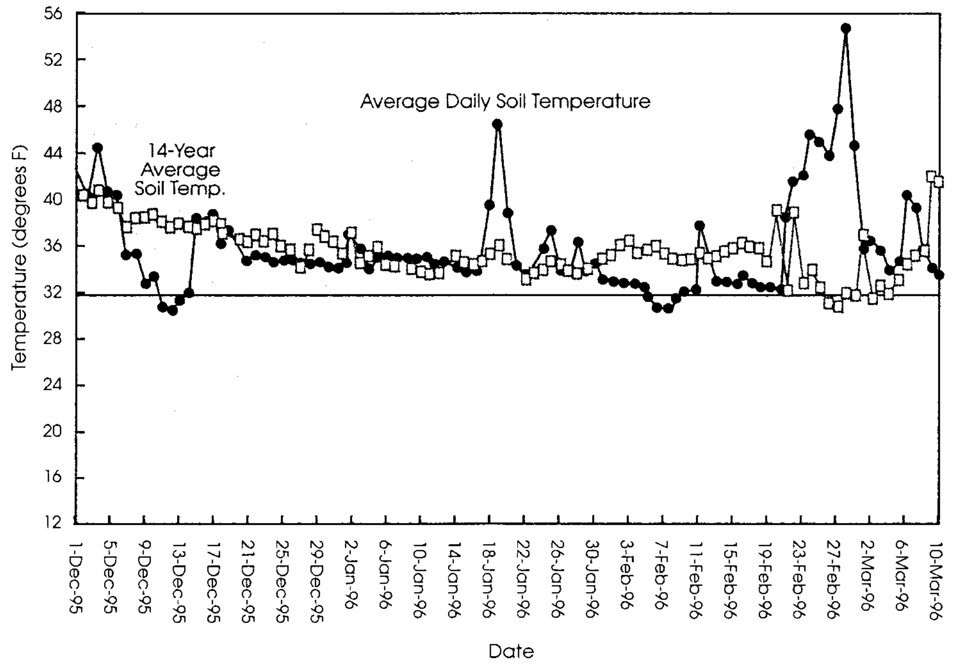
Approximately 20 acres of waste slid into the 11-acre excavation at the toe of the "grandfathered" slope, resulting in a total of 31 acres being impacted by the slide. The toe of the "grandfathered" slope moved approximately 800 to 900 feet to the northern edge of the deep excavation. The slide involved approximately 1.5 million cu. yds. of waste, making it the largest slope failure at an MSW facility in U.S. history.

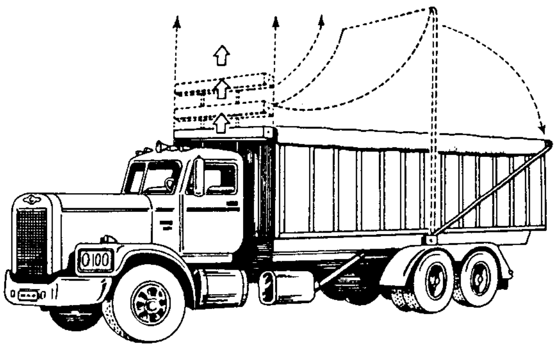
Slope reconstruction

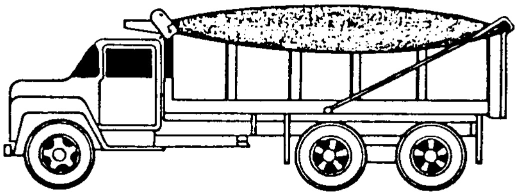
The slope was reconstructed by constructing two rock

Figure 5

Average & Normal Soil Temperatures for a depth of 2" at Miami, Ohio







Rumpke landslide contd.

berms at the toe of the slide mass and rebuilding the slope from the toe of the slide mass up toward the scarp. This involved placing new solid waste at the toe of the slope and excavating overbuilt waste from the top of the slope to achieve the final grade. The inclination of the reconstructed slope is approximately 5H:1V to the maximum permitted elevation. The majority of the slope reconstruction was completed by January 1997.

One disadvantage of this slope reconstruction plan was the time that a large amount of solid waste was exposed as the slope was reconstructed from the toe to the scarp. This lead to 18 fires at the site, three of which became uncontrolled. The fire on May 23, 1996, spread to approximately 5 acres in size near the middle of the slope. This fire was covered by leveling the slide blocks or "wastebergs" with large excavators and bulldozers. It took five days, working 24 hours per day, to cover this fire.

The fire on July 23, 1996, involved the vertical scarp. Access could not be gained to the scarp because of the deep graben at the base of the scarp. In addition, the scarp could not be safely reduced from the top because of the nearly vertical height of 100 to 150 feet. As a result, the local fire chief ordered new waste to be used to buttress the scarp to gain access for fire elimination purposes and allow emplaced waste to be pushed from the top of the scarp down to the bottom to smother the fire. This fire was extinguished after approximately eight days. The local fire chief also ordered placement of new waste in the remaining portions of the graben to facilitate scarp removal and thus reduce the remaining fire hazard.

Failure mechanism and cause

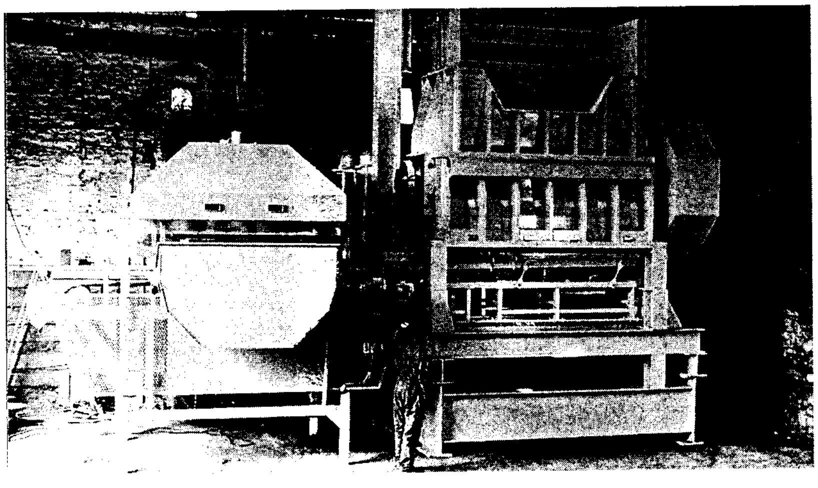
A limited subsurface investigation was initiated 54 days after the wasteslide by the owner/operator to determine the cause of sliding and determine appropriate shear strength parameters for design of the reconstructed slope. Based on field observations and the results of the subsurface investigation, the failure surface appeared to have passed through the solid waste at a near-vertical inclination to the underlying brown colluvium (see Figure 1). After reaching the colluvium, the failure surface passed through the brown colluvium, and thus along the original ground surface, and "daylighted" at the vertical face of the excavation at the toe of the "grandfathered" slope. This failure surface is in agreement with the observed translatory nature of the wasteslide. After the failure the authors investigated a number of causes of the wasteslide. However, based on observations of the translatory failure, the shear behavior of the brown colluvium and the overbuild were thought to be the main causes.

To investigate the shear behavior of the brown colluvium, a back-analysis of the wasteslide was conducted. The back-analysis revealed that the shear strength of the brown colluvium at the time of failure could be characterized using an effective stress angle of internal friction of 10 to 11 degrees and an effective stress cohesion of zero. Initially, it was thought that this low value of friction angle might correspond to a residual or minimum value. Laboratory ring shear tests and empirical correlations also confirmed a residual friction angle of 10 to 12 degrees. The liquid limit, plastic limit, and clay-size fraction of the brown colluvium tested by the first author are 69%, 28%, and 55%, respectively. However, this site had not experienced any previous sliding during landfill operation, which suggests that a peak shear strength should have been mobilized and not a residual value. However, sliding probably had occurred prior to landfilling during formation of the colluvium.

The mobilization of a residual shear strength at a site that had not undergone recent previous sliding was perplexing and could have a large impact on the stability of other "grandfathered" landfills founded on colluvium. As a result, an extensive study was conducted to determine the shear strength mobilized in other colluvial slope failures. A literature review produced references concluding that colluvial slopes mobilize a shear strength significantly less than the peak or maximum value.

In fact, the state-of-practice is to excavate all colluvium prior to new residential and commercial construction because of the large number of reported failures. Since colluvium underlying "grandfathered" landfills cannot be excavated because of the large cost, it is recommended that these slopes be designed using a drained residual shear strength. This conclusion will undoubtedly have a large impact on the expansion and operation of "grandfathered" landfills, such as the one in Cincinnati.

Colluvium is defined as a mixture of residual and transported soil slowly moving downslope under the influence of gravity and seepage. The downslope movement causes shear displacement in the material and thus

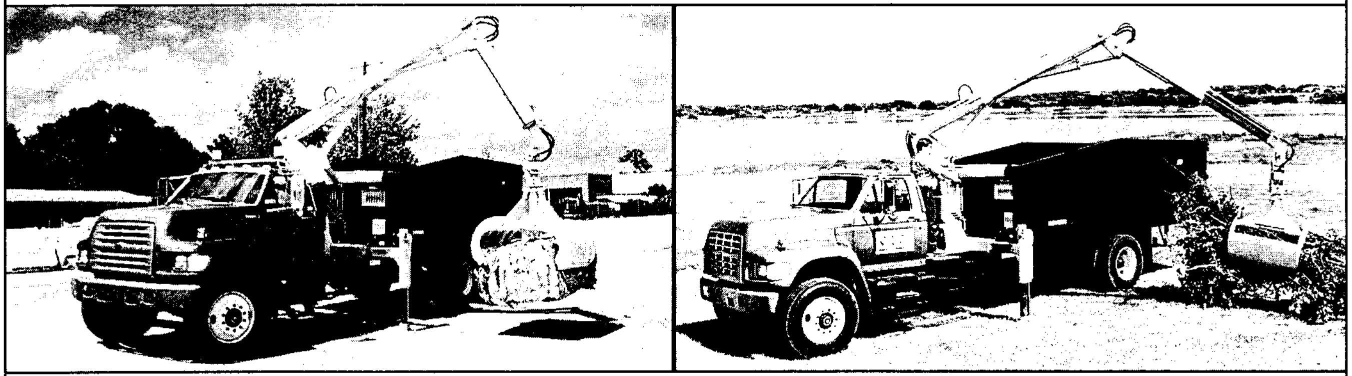


a shear strength that is less than the peak value. This downslope movement results in thin, highly polished, and striated failure surfaces in the colluvium. These failure surfaces usually combine to create a shear zone that results in a post-peak shear strength being mobilized. Trenching conducted by the U.S. Geological Survey (USGS) in the Cincinnati area clearly showed the presence of thin, highly polished, and striated failure surfaces in the colluvium.

As a result, USGS recommended designing slopes underlain by colluvium in the Cincinnati area using a post-peak shear strength. The thin nature of the failure surfaces and the soil smearing that occurs along the walls of the sampler during sampling make it difficult to detect the presheared nature of the colluvium even when continuous sampling is used in the subsurface investigation. As a result, it is recommended that a drained residual shear strength be used for cohesive colluvial materials underlying "grandfathered" landfills. Some additional causes for mobilization of a residual strength at the Cincinnati site are the toe excavation, strain incompatibility between the waste and colluvium, and waste placement activities. Toe excavations create a large stress concentration at the base of a slope that can lead to slope instability. Measures are usually required to prevent this slope instability such as quickly buttressing the slope or filling in the toe excavation so failure cannot occur.

As mentioned previously, the excavation at the toe of the slope was open for 18 months prior to the wasteslide. Clearly, the time that a toe excavation is left unbuttressed should be minimized to ensure slope stability. The detrimental impact of toe excavations on slope stability was illustrated clearly by the 1989 failure of a large MSW landfill in Maine. This failure occurred after a leachate trench was excavated at the landfill toe, reducing the lateral support of the slope. The landslide began with a rotational failure through the weak marine clay underlying the landfill.

Another cause for development of a post-peak shear strength is strain incompatibility. MSW mobilizes a peak



shear strength at a displacement 30 to 40 times larger than the displacement at which a soil mobilizes a peak shear strength. As a result, the soil will mobilize a post-peak shear strength before the peak strength of the waste has been mobilized. This strain incompatibility can facilitate development of slope instability because the colluvium may mobilize a residual strength before the peak strength of the waste is mobilized.

Finally, initial waste placement activities at this site involved pushing waste from the top to the bottom of the existing ravines. This probably caused some additional downslope movement of the colluvium, which probably increased the magnitude of shear displacement that occurred in the colluvium. As the colluvium moved downslope, the soil was undergoing shear displacement, leading to the development of a post-peak shear strength.

In summary, the depositional nature of colluvium, the excavation at the toe of the "grandfathered" area, strain incompatibility between the waste and colluvium, and initial waste placement activities resulted in a residual shear strength being mobilized in the brown colluvium, even though landsliding had not occurred during the landfill operation. Of course, landsliding probably occurred prior to landfilling in the development of the colluvial slope.

The other major contributor to the wasteslide was the 1.2-million cu. yds. of overbuild. Using the back-calculated, measured, and estimated residual friction angle of the brown colluvium, i.e., 10 to 11 degrees, the factor of safety for the slope was calculated as the maximum height of the landfill increased from elevation +1005 feet to elevation +1105 feet The analysis revealed that the factor of safety decreased from approximately 1.15 at elevation +1005 feet to unity at elevation +1105 feet.

Therefore, it was concluded that the overbuild was the triggering mechanism for the marginally stable slope. The main cause was the mobilization of a residual shear strength in the brown colluvium. Mobilization of a residual shear strength in the colluvium would result in a weak layer underlying the waste, which is in agreement with the translatory nature of the failure.

Lessons learned

The following main lessons can be discerned from this extraordinary slope failure in a major MSW landfill. Based on the approximately 150-foot-high scarp that remained nearly vertical for six to seven months at this site, the results of large-scale laboratory test results on MSW, and other slope failures involving MSW, it appears that municipal solid waste is a strong material. The mechanisms for deriving this high shear strength are not known but clearly the interconnection of the plastics and other materials plays a significant role in developing this high shear strength. As a result, one of the lessons from this case history is that testing and (static and seismic) stability evaluations should focus more on the materials that interface with MSW (e.g., geosynthetics or native materials), and not on the waste itself.

This case history clearly illustrates the importance of the shear behavior of native materials underlying the waste. These native materials should be sampled and tested to evaluate their shear strength and the resulting impact on interim and final slope stability. In addition, the shear strength of colluvial materials underlying existing waste slopes can have a large impact on stability.

Based on the analyses conducted for this case history, it is recommended that a drained residual shear strength be used to characterize the shear strength of colluvial soils underlying existing waste. Of course, the colluvium directly underneath the waste should be tested to estimate the drained residual strength because of the natural variability that may occur in colluvium across a site. This variability is caused by a number of mechanisms, including differences in the parent rock(s), chemical and physical weathering processes, colluvium thickness, inclination of the ravine, and thus the rate and magnitude of downslope movement, as well as the effect(s) of leachate on the engineering properties of the underlying soil. Colluvium samples from other areas or ravines around the site probably may not accurately represent the material directly under the waste, which will ultimately control the static and seismic slope stability.

The next main lesson involves the importance of toe excavations and the stability of interim slopes. As mentioned previously, the critical time for the stability of a slope is while the toe is excavated, which exposes or daylights a weak layer. Clearly the presence of a weak layer should be known and the time that the weak layer is exposed or daylighted must be minimized. Careful planning should be conducted to ensure that the slope is exposed for a minimum amount of time. The interim slope may warrant instrumentation to monitor slope movements while construction personnel are working below the slope. In addition, if there are delays in construction, waste may need to be diverted to another facility to ensure that the adjacent slope is not overbuilt. Engineers should investigate the stability of interim slopes, even though it may not be required by regulations, to ensure slope stability during construction.

Finally, if landfill slopes continue to fail, state agencies may be forced to regulate the maximum inclination of landfill slopes to ensure stability and the feasibility of closing a site without having to reduce the slope inclination. For example, Michigan requires that final cover slopes have an inclination less than or equal to 4H:1V to ensure slope stability and prevent erosion.

In the aftermath of this wasteslide, Ohio already has issued a slope advisory that presents recommendations for slope inclination and filling procedures to ensure slope stability. Ohio also is in the process of drafting a slope stability policy that will probably limit slope inclinations to 3H:1V. But these regulations on slope inclination still may not prevent failure because of the presence of weak layers, such as colluvium or geosynthetics, underlying the waste. For example, in colluvial slopes the slope inclination may be less critical than the inclination of the rock underlying the colluvium and/or the pore-water pressure in the colluvium.

In summary, if landfill slope failures continue, states may regulate the slope inclination and remove one of the most challenging and innovative aspects of waste containment design. ▮