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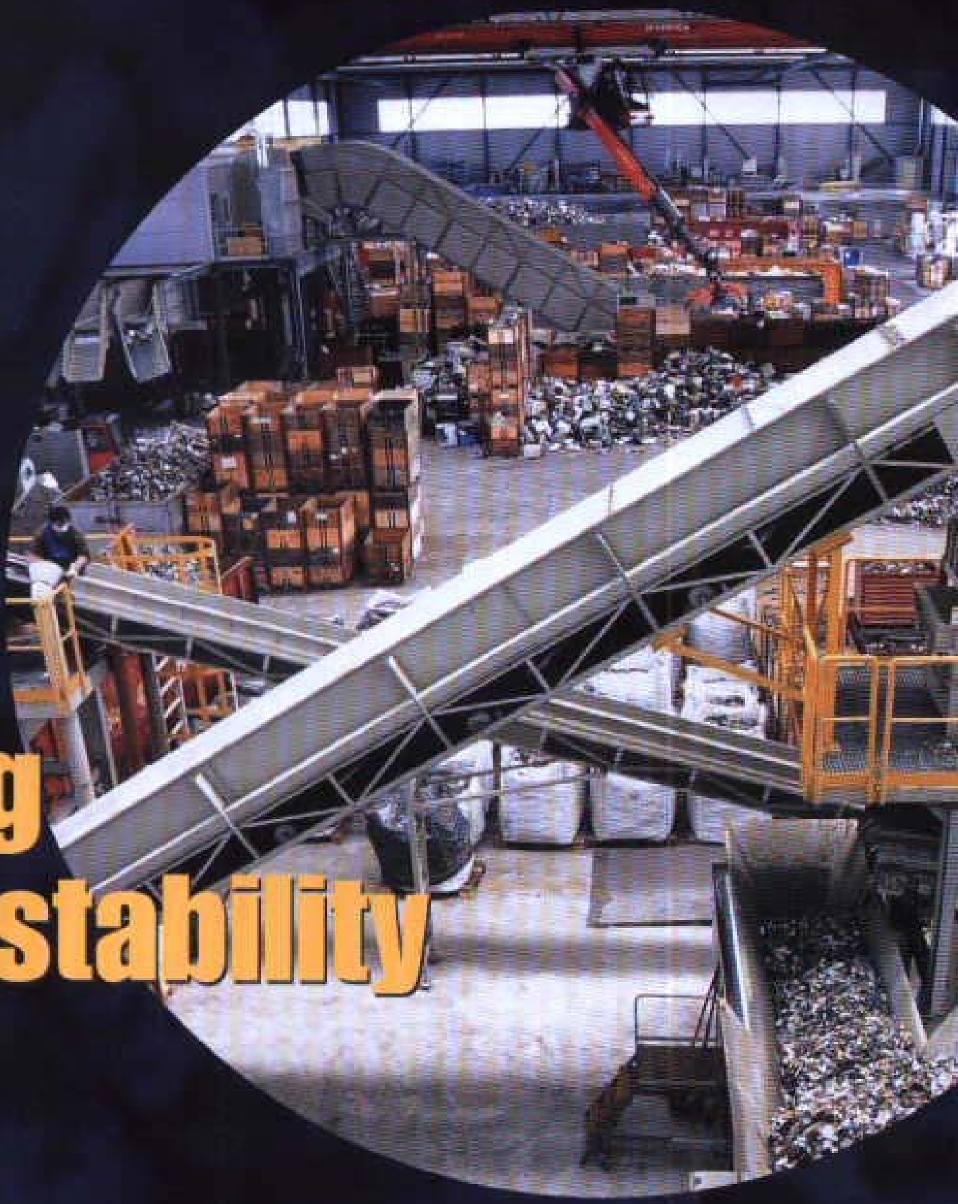

Ensuring landfill stability

Waste in a larger Europe

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INTERNATIONAL SOLID WASTE ASSOCIATION
Promoting sustainable waste management worldwide

by **Florian Kölsch and Gunnar Ziehmann**

Landfill stability

Risks and challenges

In 2000 a dumpsite in the Philippines failed and caused a major landslide, killing more than 200 people with hundreds more missing. An understanding of waste mechanics is crucial in identifying potentially unstable landfills and can prevent future disasters.

Stability of landfills is one of the major geotechnical tasks in landfill design and operation, and has been a problem for years. Heterogeneous waste composition, obstacles in determining waste strength parameters, and a lack of knowledge about the principles of waste mechanics resulted in considerable uncertainties in stability calculations. In the early 1990s, the German Government increased efforts to investigate waste mechanics. Meanwhile, the problem of landfill stability in Germany seems to have been resolved. Even extreme landfill slope geometries have been constructed during remediation and mining measures. The state of the art has been documented in the technical recommendations issued by the German Society of Geotechnics.

Nevertheless, several heavy landslide events have occurred due to landfill failure in other countries during recent years. The most tragic reported case was definitely the Payatas landslide in the Philippines in July 2000, while the most recent one happened in March 2003 in Athens, Greece. Both failures raised new questions about the influence of different climate conditions or variations in landfill operation and waste composition. In forensic analysis, the main approach to check whether the advanced German calculation models for landfill stability cover those cases and whether they reflect the stability correctly. Examination of landfill failures, forensic analysis and advanced stability calculations are used here to address the most up-to-date understanding in waste mechanics.

Landslides

Payatas, the Philippines, July 2000

The Payatas dumpsite is located in the north-east of Metro Manila within the boundaries of Quezon City on Luzon, the major island of the Philippines. About 1000 tonnes/day of municipal solid waste (MSW) are delivered to the site, some 15%–20% of the total amount of MSW generated in Metro Manila. In the City of Payatas B, about 80,000 people are settled around the dumpsite. Many of them work in waste businesses such as at junk stores or as waste pickers (scavengers). The scavengers, who have the worst job in this micro-economy, often live directly on the open waste surface. On

ABOVE A landfill failure in Payatas, the Philippines, killed more than 200 people. Waste and debris completely covered an area of around 30,000 m² in front of the toe of the slope BELOW The collapsed slope of the Payatas landslide four weeks after the event FACING PAGE Landfill failure in Athens, Greece. In this landslide, about 800,000 m³ of waste moved, leaving a 300- to 400-metre-wide gap in the slope behind

10 July around 5 a.m., a slope of the landfill failed and 1.2 million m³ of waste slid down. This 'garvalanche' buried the scavengers' cottages and part of the Payatas B settlement area under 10 metres of waste. An area of around 30,000 m² in front of the toe of the slope was completely covered by waste and debris. Rescue actions were hindered by landfill gas, which created several fires. More than 220 people were found dead in the covered area. Rescue efforts were suspended four weeks after the landslide. There was no more hope to find survivors, and an estimated 200–800 people are still missing. The area was levelled and secured only by simple measures (peripheral trench, block lines).

A specific and detailed forensic analysis of the Payatas landslide has never been conducted. Both the authorities and the operator – public agency MMDA (Metro Manila Development Agency) – have focused on analyses for the remaining landfills in Metro Manila, first at the San Mateo landfill. This procedure seems to be inappropriate, since new stability calculations without any enhanced input by forensic analyses would bring the same results as before. Four weeks after the failure, the geotechnical company Dr. Kölsch Geo- und Umwelttechnik went to make a visual evaluation of the case.

Basically, a landslide happens in the case where a slope is constructed steeper than the shear strength of the material. Since the strength of waste is not well known and is usually not investigated in the laboratory, the waste is placed according to common experiences. The geometry of the Payatas dumpsite seems to have met the slope requirement, showing slopes of about 1:3 with a height of

25–40 metres. However, some specific conditions that are particularly true in tropical developing countries were apparently not considered thoroughly:

- *low density of waste* – due to a high portion of light plastic materials and insufficient waste compaction
- *unrestricted water percolation* – water percolation usually decreases with the presence of paper. Observation has shown a lack of paper due to the outstandingly high recycling ratio
- *extremely high rates and non-uniform distribution of rainfall.*

The major reason for the landslide was the low waste density resulting from the composition of waste delivered to the Payatas dumpsite. The waste material was characterized by a high proportion of plastics and organics and a total absence of other materials (paper, glass, metals). MSW with this composition is resistant to conventional compaction methods, even using heavy equipment. The waste composition in Manila is typical for urban areas in developing countries and countries with emerging economies. Basically, this results from an extraordinary consumption of plastics as packaging material, a lack of recycling systems for organic waste and an outstandingly high recycling rate for reusable materials. The high recycling rate primarily reflects the country's poverty, which forces people to earn their living by segregating waste at dumpsites. The impact of low waste density on landfill stability was amplified by heavy rainfall, which is characteristic for the tropical location. The low waste density reduced the surface flow of rainwater and evaporation, resulting in a high rate of water infiltration. Landfill leachate decreased the shear strength of waste by mobilizing pore water pressure and flow pressure, finally triggering the failure. The settling of waste, due to the high content of organic materials, was also driving this effect.

Athens, Greece, March 2003

The municipal solid waste of the Greek capital Athens is disposed at several landfills in the metropolitan area. One of these is the landfill in Ano Liossia, located 10 km north of downtown Athens. This site is operated by the public agency ΕΣΑΚΝΑ (in English, ACMAR, the Association of the Communities and Municipalities of the Attiki Region). The dumping area amounts to approximately 0.5 km², and its height varies from about 60 to 80 metres. The site is surrounded by chains of hills, opening to the north to the Attiki plain.

In March 2003 the eastern slope of the landfill failed and cracked down, covering the 20-metre-deep notch between the slope and the recycling facilities with waste. Approximately 800,000 m³ of waste moved, leaving a 300- to 400-metre-wide gap in the slope behind.

A detailed forensic analysis is

not available yet. Water is very likely to be a cause as it is in all cases of landfill failure, but no significant water outlet from the failing slope has been reported by the operator. This point makes the case even more interesting, since landfills in arid and semi-arid areas have not been endangered unless the internal water balance is massively disturbed. Since the landfill has been constructed according to current European standards with liner and drainage systems, there was no reason to expect waterborne stability problems. It hasn't become finally clear why the slope failed. It may also be a consequence of a fire, which occurred two weeks before in the landfill stretch concerned. Landfill fires are extremely dangerous for stability; smouldering fires, which do not burn with open flames on the surface, are especially dangerous. A smouldering fire may feed its way to deeper waste layers, leaving plastics and paper burnt and sweeping their reinforcement effect away. Fighting smouldering fires with water may even double the problem, because the fire is pushed forwards while the water level inside the landfill may increase.

Waste mechanics

It is well known to many landfill operators that waste has an extremely high strength, even enabling the construction of vertical temporary slopes. However, it is essential to understand what the material's strength is based on in order to evaluate landfill stability realistically. If the geotechnical engineer is not able to conduct an appropriate stability analysis specifically reflecting the strength characteristics, then the factors limiting safety can never be identified and the operators may carry out bad operating measures. As a consequence, more failures will happen.

Background

Municipal solid waste shows strength characteristics that are considerably different from soils. MSW strength is determined by the fibres and foils contained in the waste. These components produce an effect similar to reinforcement. Just like reinforced soil, the shear resistance of MSW takes into account the friction between the granular particles and the tensile forces in the fibrous components.

The eastern slope of the Ihlenberg landfill, where the cessation of waste dumping had caused a depression in the landfill's geometry

The shear resistance due to reinforcement effects is called *fibrous cohesion*. The fibrous cohesion generated by tensile stress in the fibres depends on the normal stress (load). Therefore, shear strength increases with the depth of the deposit. The total shear strength resulting from friction and reinforcement is much higher than the shear strength of soil.

Because waste is normally placed in the landfill in roughly horizontal lifts, the fibrous components are directed horizontally, leading to an inherent anisotropy of the fibrous cohesion. Therefore, the angle between a slope failure surface and the main direction of the fibres has to be considered in the shear testing and stability calculations.

Consequences

Without diving deep into geotechnical details, major conclusions can be derived from a basic understanding of waste mechanics.

Due to the anisotropy of the reinforcement effect, the parts of the sliding figure that lay more horizontally contribute far less to the overall stability than the steeper parts. Therefore, the inner parts of a landfill slope are more important than the outer, lower parts (toe and adjacent areas). As a side effect, waste forms larger sliding figures than soil because the small contribution of the lower parts allows the length of those parts to increase, moving the steep part far into the centre of the landfill. Additionally, all effects influencing the lower parts of the sliding figure (water pressure, weak zones) have minor importance for overall stability.

The high shear strength of waste usually generates sliding figures crossing either the landfill base or leading through weak surfaces inside the landfill liner system (between mineral and synthetic liners), because those materials are weaker than the lower waste layers.

Other than friction, reinforcement effects have some typical limits. Though reinforcement strength increases with normal load due to improvement of the fibres' anchoring, the extent to this increase is limited by the strength of fibres. Therefore, it is not possible to increase landfill height even with a constant slope angle without analysing the properties of reinforcement. Further, reinforcement is sensitive to damage – once the reinforcement effect disappears, it never recovers.

Subsequently, the investigation of reinforcement is the major geotechnical objective of landfill stability analysis for operating or forensic purposes.

Stability analysis – Ihlenberg landfill case study

Ihlenberg landfill is located 15 km east of the City of Lübeck in the German state Mecklenburg-Vorpommern. The landfill is one of the largest waste disposal sites in Europe, currently covering a dumping area of 0.7 km². The designed landfill height is up to 70 metres, and its current height is about 45 metres. The site is a favourable location in terms of hydrogeological properties. Beneath the landfill liner systems lies a natural clay deposit with a thickness up to several 100 metres. Most parts of the landfill are constructed according the current technical regulations (combined liner system of mineral–synthetics, drainage system). Waste disposal started in 1979. Disposal capacity amounts to about 750,000 tonnes/year.

As required by German technical regulations, stability analysis has been conducted once a year.[1] In 2001, the stability calculations for the eastern slope resulted in a factor of safety of $\eta = 1.21$, which is significantly less than the value required by law ($\eta = 1.30$). The authority, the Mecklenburg-Vorpommern agency for Environment and Mining, ordered the closure of the landfill area concerned. As a result, 400,000 m³ of potential landfill volume was lost. The cessation of waste dumping had caused a depression in the landfill's geometry in the eastern slope.

Analysis

Although the existing slope angle of 1:3.3 is not extraordinarily high, the slope stability seemed to be endangered. Two major factors reduced the calculated stability: some gas extraction wells showed water tables at a level of 80 mNN with the landfill base at 60 mNN. This was unfavourably considered as an uninterrupted water level above the landfill liner, although it could just have been a 'floating layer' of water. Therefore, the water pressure at the most unfavourable point of the landfill base amounted to a 20-metre water column, equal to 200 kPa water pressure. Meanwhile, the strength of waste was calculated by literature values with an angle of friction $\varphi = 25°$ and a cohesion of 10 kPa. The classic polygon sliding method (according to German DIN 4084) was chosen as the calculation method.

In 2003, the landfill operator IAG ordered Dr. Kölsch Geo- und Umwelttechnik to run advanced stability studies. Other than the previous calculations, advanced analysis should reflect the most up-to-date understanding in waste mechanics. The concept and method of advanced stability analysis is regulated by technical recommendation E 2-29, issued by the German Society of Geotechnics.[2] To conduct an advanced stability analysis according to E 2-29, material values that describe the reinforcement properties are required. These values can either be estimated by analysing the waste composition[2] or determined by laboratory testing. IAG decided to go for testing. In July 2003, a five-tonne sample was drilled out of the landfill and carried to the testing facility at Technical University Braunschweig. A tension test under normal load was carried out. In this test a specific material value ξ, the internal angle of tensile stress, is determined. The sample from Ihlenberg showed an angle ξ = 14° and a cohesion of 21 kPa, which is typical for decomposed or 'old' waste, while 'fresh' MSW usually comes out with ξ = 35°. Under 30 metres of waste deposit (normal load 360 kN/m²), the reinforcement effect generates a total cohesion of 111 kPa, resulting from 90 kPa fibrous cohesion (360 x tan 14°) and 21 kPa cohesion.

Stability analyses have been carried out using the testing results from the laboratory. Parameters for hundreds of hypothetical slip bodies in three different landfill cross-sections have been calculated. Figure 1 shows one of the cross-sections in the eastern slope and the calculation results for the sliding part found to be the most unfavourable, slip body 11. This polygonal sliding body begins at the toe of the slope, follows the mineral liner 130 metres into the landfill before crossing up to the waste. The vertical lines indicate the slices, while the amount of activated fibrous cohesion – displaying the distribution of back-holding forces around the slip body – is indicated by the slanted lines below the vertical slices.

The calculation showed that the overall stability of the eastern slope amounts to η = 1.44 just by considering the reinforcement effect, instead of η = 1.21 according to the previous calculation based on soil mechanics theories. Therefore, in November 2003, the authorities reopened the closed landfill area.

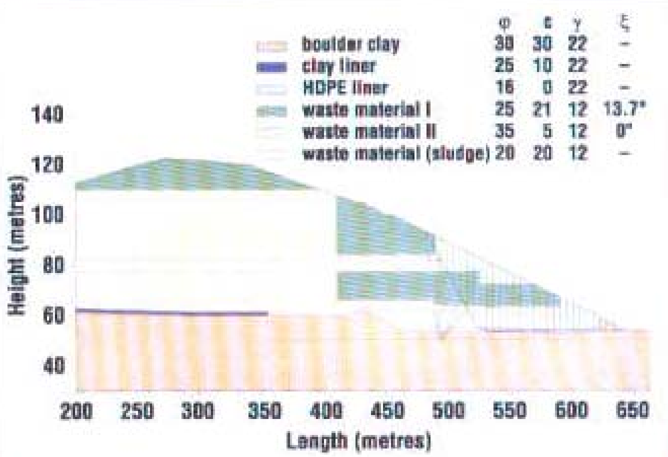
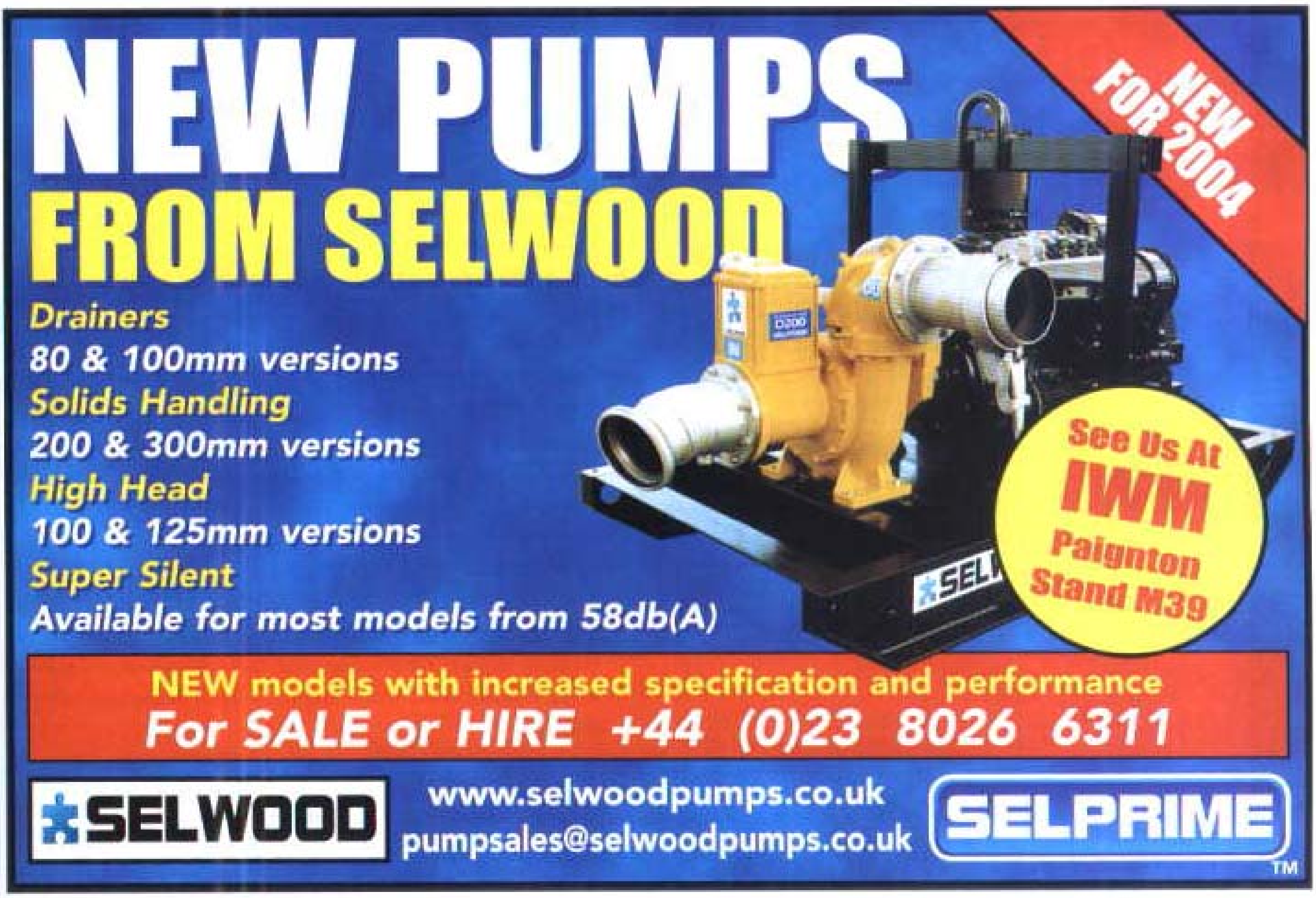


FIGURE 1. Stability analysis of the Ihlenberg landfill. Slip body 11, indicated by vertical lines, is found to be potentially the most unfavourable part; the slanted lines with the lighter shade indicate the distribution of activated fibrous cohesion. Material I consists of soil and some fibres; material II, degraded MSW. Slip body parameters: φ = angle of friction; c = cohesion (kPa); γ = weight (kN/m³); ξ = tensile angle. A safety factor η = 1.44 has been calculated for this slip body, fulfilling the legal requirements of η = 1.30



ABOVE LEFT AND CENTRE A sample being drilled at the Ihlenberg landfill for examination of waste composition and laboratory testing. ABOVE RIGHT The drilled sample undergoes a tension test under normal load, in which the internal angle of tensile stress, a material-specific value, is determined

Recommendations

Landfill operators should follow two basic rules: 'protect holding forces – reduce driving forces'. Several suggested operating measures are:

- good compaction to reach high density, small settlements, and less water percolation
- homogeneous permeability and proper drainage system to prevent water barriers and improper water balance
- controlling the portion of reinforcement particles by means of tracing changes in waste composition and condition
- if necessary, measures to improve certain waste strength properties.

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