

STABILITY OF LANDFILLS – THE BANDUNG DUMPSITE DESASTER

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SUMMARY: In February 2005 Leuwigajah dumpsite in Bandung (Indonesia) collapsed. 2,7 million cubic meter waste went down like an avalanche. 147 people died when the waste hit a settlement close by. The stability analysis proved that water pressure in the subsoil and a severe damage of reinforcement triggered the failure. The reinforcement was destroyed due to a smouldering landfill fire which burned over months combusting waste particles like plastic fibres and foils. The analysis proved clearly, that a realistic stability calculation is essential to recognize the stability problems correctly and to identify the appropriate response. In this case, drainage measures for the subsoil and a collection of surface run-off, as well as a consequent fire fighting could have saved the lives.

1. INTRODUCTION

Stability of landfills is one of the major geotechnical tasks in landfill design and operation. The knowledge about waste mechanics has significantly improved over the last decade. In Germany several large research projects have been conducted. In 1997, German Geotechnical Society released a technical recommendation reflecting the state of art in stability analysis. However, there are still open questions particularly about the influence of regional parameters such as tropical climate conditions, but also about variations in landfill operation and waste composition. Several heavy landslide events occurred in countries all over the world during the last years. A tragic case was reported from the Philippines, when hundreds died in the Payatas landslide in July 2000 (Kölsch, Ziehm, 2004). In March 2003 a landfill collapsed in Athens (Greece). The most recent landfill failure happened close to Bandung (Indonesia) in February 2005. Regarding the number of casualties and the volume of waste, it was the heaviest failure, which ever hit a dumpsite. The following article presents the results of the forensic analysis. It was one special task of the analytic work to check whether German advanced calculation models for landfill stability covers those cases and whether they reflect the stability correctly.

2. THE FAILURE

2.1 The site

Bandung is the capital of the West Java province in Indonesia. The population of Bandung Metropolitan area accounts to approximately 6 million. Several dumpsites are operated in Bandung Metropolitan area, with the Leuwigajah dumpsite as the largest one. 4500 t municipal solid waste per day are delivered to the site. The site is operated by three different authorities, the City and the District of Bandung, as well as the City of Cimahi.

The dumpsite is located within the boundaries of Cimahi. It was established in a narrow valley in the outskirts of Leuwigajah, a neighbourhood of Cimahi. From a hydrogeological point of view, the valley is a suitable site. The subsoil consists of rock covered by a thin layer of 1 m of silt or clay material, performing as a natural barrier. Before the waste disposal started, small water streams were running through the valley in wet season (October till April) carrying the surface run off. Precipitation is high in the region, between 1500 and 2000 mm per year while rain distribution is significantly non-uniform. Heavy rainfall and thunderstorms are common during wet season.

Waste disposal procedure is on a basic level. Dumping activities started from the top of the valley just dropping the waste over the edge. Compaction machines were in place, but appeared recently in a poor condition. It is not clear, whether they have been in use or not. West Java EPA noticed the dumping area to 6.5 ha, but the site was looking much bigger. The natural landscape of the valley showed a small slope of approximately 5-10 % in the bottom of the valley and a slightly higher slope in the upper end. Before the failure happened, the maximum height of the dumpsite arose to 60-70 m. According to the meaning of local experts, the front slope facing the open valley showed a slope angle between 30° and 45°.

2.2 The collapse

The landslide happened on February 21st, 2005 at 2.00 A.M. After 3 days of heavy rain, 2.7 million cubic meters of waste started sliding down the valley. The waste covered a 200-250 m wide stripe on a length of 900 m. It is not finally clear how quick the landslide occurred. It seems to be very likely, that it takes not more than a few minutes. Witnesses reported a roll of thunder somehow like an explosion. Regarding the speed, those observations indicate that the waste came down quite similar an avalanche.

The death toll was high. Down the valley one small settlement was destroyed by half (see figure 1, close to upper left corner), another village faced light damages. Rescue teams uncovered 147 dead bodies out of the waste. Rescue activities have been carried out only in the area close to the two settlements. It is not clear, whether there were people staying overnight on top of the dumpsite, which probably were killed in other areas.

Figure 1 shows a satellite image generated by the Department of Geodetic of the Bandung Institute of Technology (ITB). The winding line in the right side of the image, which splits the dark and the light area, indicates the edge of the remaining slope. The former borderline of the dumpsite can be imagined by a straight line starting on the lower end of the existing slope. The centre part of the image shows the valley now covered by waste. Following the waste far to the left, surrounding untouched rice fields can be seen. The image indicates that the area now covered by waste have 4-5 times the size of the area where the waste originally was placed.

Rescue works last for about 3 weeks. They were massively hindered by landfill fires. No survivors could be found.



Figure 1: Satellite images of Leuwigajah dumpsite (taken by Bandung Institute of Technology)

2.3 Observations

Forensic analyses have been conducted close after the case. A task force was formed by experts from ITB supported by German landfill stability expert Dr. Koelsch, who arrived in Bandung on March 18th. The local visit provided some clear hints about the mechanical waste properties, the geometry of failure and the parameters which might have influenced the stability.

The condition of the older waste which had been sliding down showed a fairly good mineralization. In the covered valley area, waste blocks could be found which were still in original shape. Blocks even showed unbroken left-overs from the surface green although they had moved several hundred meters in the avalanche. The waste contained a significant portion of fibres and foils, particles which are considered as reinforcement. Portion was estimated to some 20-25 %, what classifies the waste as municipal solid waste after degradation.

Due to the observed level of mineralization, a significant biological degradation had obviously occurred in the old waste. That indicates an unsaturated long-term landfill milieu. The waste down in the valley was not soaked of water, but hold a medium moisture content, estimated to 30-40% by manual prove. In the remaining part of the dumpsite upper waste layers appeared to be slightly saturated by water, indicating that those layers are able to hold back water from infiltrating into the waste quickly. It seems to be unlikely, that heavy rainfall during wet season regularly generated high water level in this landfill. Even the 3 day rainfall prior to the landslide might not have affected the internal conditions of the waste significantly. However, the close follow-up of rainfall and landfill failure is suspicious.

The observations on waste conditions lead to the result that the internal strength of the waste might have been high. Strength properties were likely to be quite similar to German municipal solid waste after degradation. Shear strength was unlikely to be significantly affected by water pressure from a high water level.

Shape and local geometry of the failure area showed clearly, that in many parts the waste had moved directly on the underlying silty subsoil. Wide areas of subsoil could be found open to the sky, now. This observation corresponds perfectly to the evaluation of waste strength. In case, that the internal shear strength of the waste is extraordinarily high, the surface between the soft subsoil and the waste automatically becomes a critical shear plane.

The subsoil to waste interface may additionally have been affected by water pressure. After the failure, large areas in the upper end of the valley were opened to the surface. Immediately, run-off water and groundwater springs formed small streams on the bottom of the valley merging into a small creek. The wet areas can be seen in figure 1, those are the dark areas close to the cliff line. Neither the geological nor the hydrological situation on site was completely clear. Based on experiences from other landfills, which are located in valleys, it is well known that ground water and infiltrating rain water build up water pressure in the soft subsoil. If water has any impact on the stability, it is basically due to this effect, which weakens effective stress in the subsoil.

The combination of waste strength and weakened subsoil creates a very special overall stability situation: The sliding of the entire waste body on the subsoil becomes the most unfavourable failure condition. However, the geometry of Leuwigajah dumpsite does not allow this displacement. The valley has a narrow section, which is located close to the former borderline in front of the toe of the previous slope (see figure 1). In the upper located waste disposal area the valley opens up a bit and is slightly wider. In terms of displacement, the waste had to pass the narrow section like through a funnel. Since this movement is mechanically impossible, shear planes were required to cross the waste, no matter what the strength is.

The quest, what weakened the waste strength to allow a shear failure, could be revealed. Figure 2 shows the crest of the remaining slope. It is curious to see, that the huts, where scavengers stayed during the day or lived overnight, cluster in some areas while others are free from any civil constructions. The experts suspected that smoke and smell from smouldering landfill fires may have expelled the scavengers from certain areas. Operator's staff confirmed that the landfill was burning regularly and for months. Though there was no access to the lower part of the waste cliff, some areas of the open vertical slope looked burned.



Figure 2: Slope crest with civil constructions clustering on the right and in the back

2.4 Stability calculations

The stability calculation has been conducted according to the technical recommendation of the German Geotechnical Society (DGGT, 1997). The calculation method considers the reinforcement effect, which is generated by tensile forces in fibres and foils. The mobilization of tensile forces depends on the normal stress on the fibres. Tensile stress and normal stress are related by a linear function, which is mathematically described by the internal angle of tensile stress ζ . The component of shear strength which is created by tensile forces is called fibrous cohesion. The fibrous cohesion is calculated from the internal angle of tensile stress ζ , the normal stress σ , a transmission factor and a function considering the anisotropy (direction between the fibres and the shear plane). The calculation term is implemented in conventional calculation formulas used in soil mechanics like the Bishop formula (Koelsch, 1996).

The results of the stability calculations for the Leuwigajah failure are displayed in figures 3 and 4. In Figure 3 a situation has been modelled without landfill fire. The overall stability amounts to $\eta = 1,13$. The impact of heavy rain has been considered by assuming a pore water pressure in the subsoil reducing the effective stress by approximately 150 kPa. The shape of the sliding figure corresponds with the situation found on site. Hundreds of alternative sliding figures have been calculated, particularly those forming shear planes through the waste. However, the most unfavourable one is that one shown in figure 3.

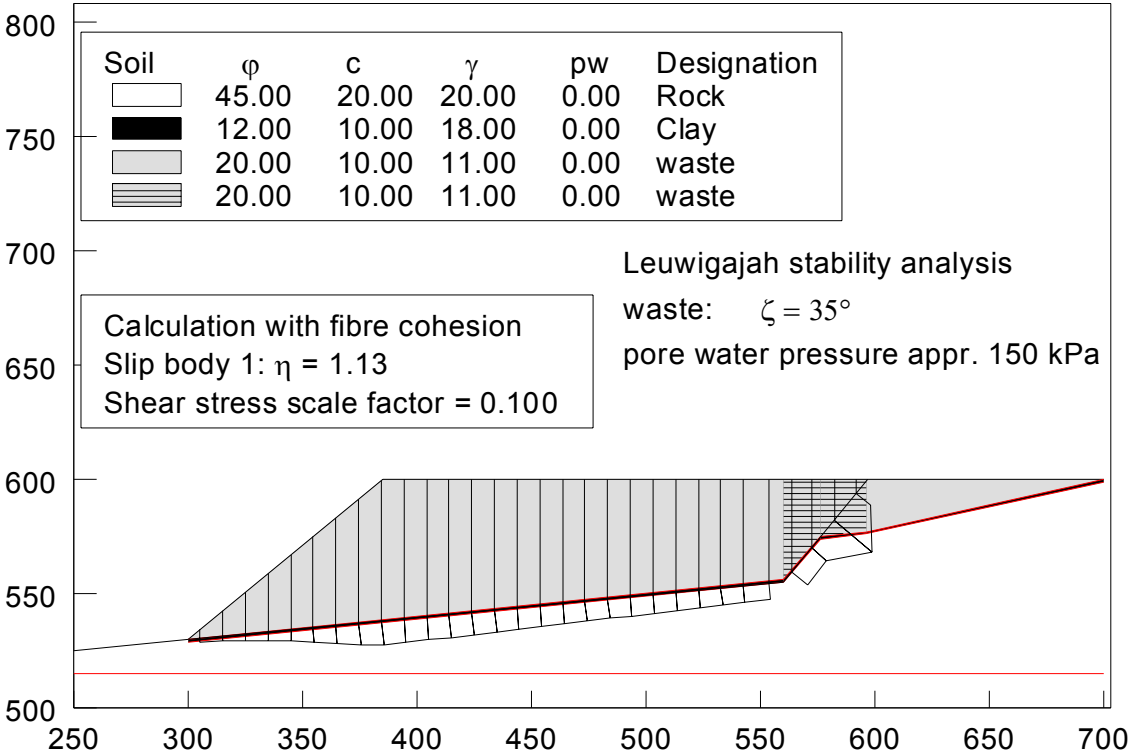


Figure 3: Stability analysis for Leuwigajah dumpsite – case: non burned waste

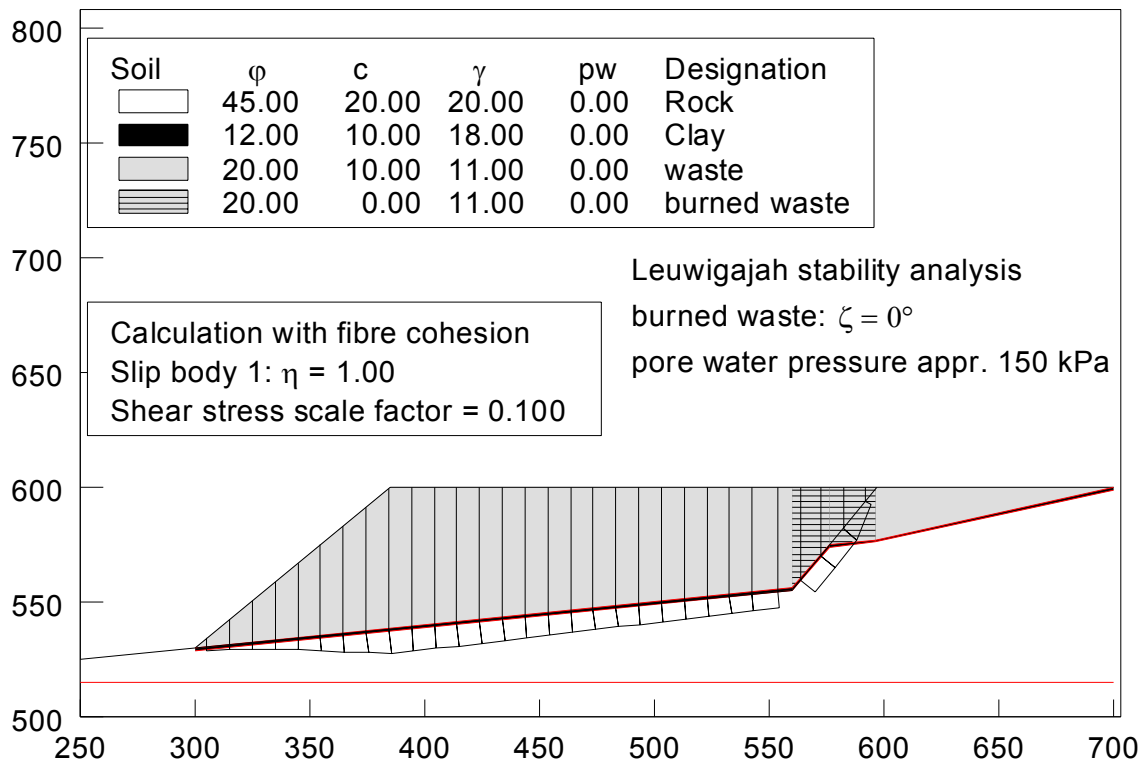


Figure 4: Stability analysis for Leuwigajah dumpsite – case: burned waste

Figure 4 shows the situation after the landfill fire had destroyed the reinforcement particles in the upper part of the landfill. It was assumed that all tension based components of shear resistance (tensile angle ζ and cohesion c) have been cut down to zero. Friction components were considered not to be concerned. Overall stability dropped down from 1,13 to 1,00, the dumpsite becomes instable. Again, the shape of sliding figures fit to the on site observations. No other figure with a smaller factor of safety has been found.

The shear resistance, which is drawn on the bottom of each slice, shows clearly the impact of the fire. The peak of shear resistance at slice 2 and 3 in the upper end of the sliding figure in figure 3 has disappeared in figure 4. Just the shear resistance due to friction is left. The smouldering fire had contributed significantly to the stability problems.

Regarding its impact, the water pressure inside the subsoil is more important. Provided a proper construction and a appropriate operation, the landfill would not have faced any stability problems at all. Figure 5 shows the situation, reflecting the case of proper drainage and no fire. Overall stability is $\eta = 1,63$. Therefore, stability problems could have been avoided by simple measures.

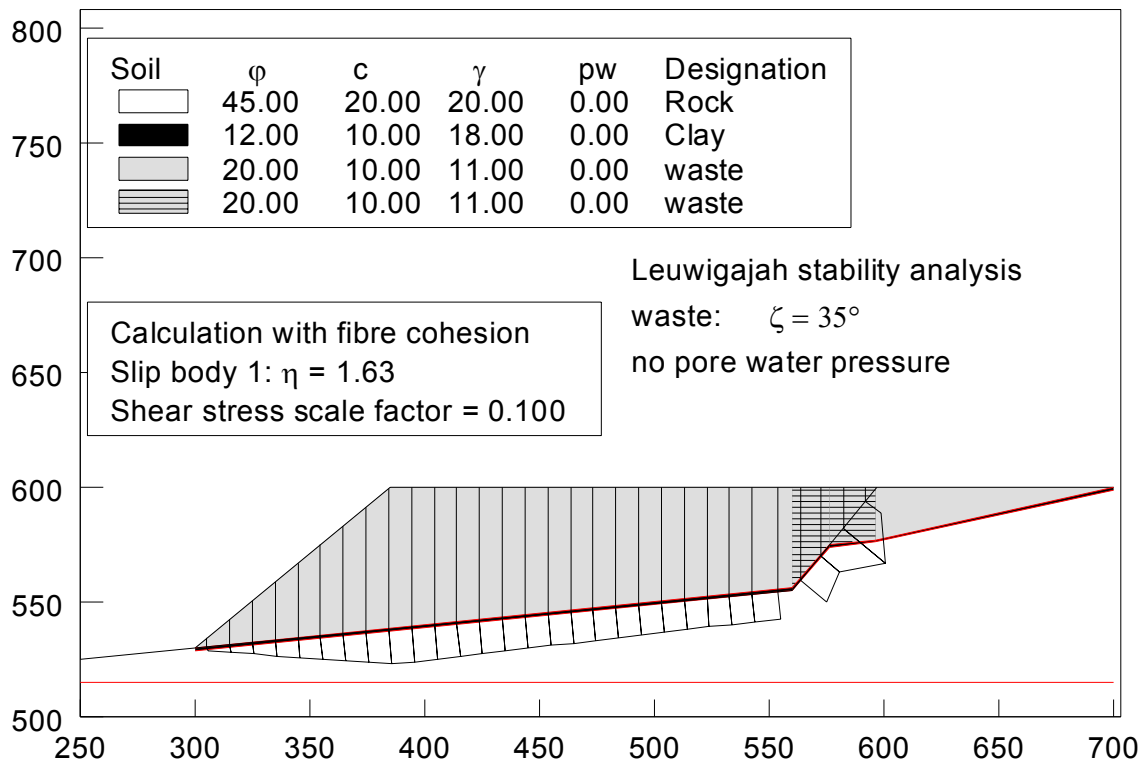


Figure 5: Stability analysis for Leuwigajah dumpsite – case: proper construction and operation

3. CONSEQUENCES

The stability analysis proved that the failure most likely have been triggered by water pressure in the soft subsoil in combination with a severe damage of reinforcement particles due to a smouldering landfill fire. This result addresses a specific stability problem in tropical countries. Since precipitation is high, but non-uniform, both events may happen. On one hand there are acute drainage problem coming along with pore water pressure in soft soils or high water tables inside landfills. On the other hand, an extreme risk of landfill fires exists during the dry period. It is an important task to adjust landfill operation in those countries.

Regarding landfill construction it is necessary to ensure proper drainage. As the Leuwigajah case has shown, the strength of the waste is not the major problem, since strength capacity is more than sufficient. It is more important to take care for the soft sections of the landfill construction. Especially the soft soils need protection, no matter whether it is a natural deposit or a technical barrier.

Regarding the operation, the message is perfectly clear: landfill fires can not be accepted. Smoking mountains are well known in poor countries, but the risk of disasters is enormous. Landfill fires require immediate fire fighting actions, smoke and smell should be recognized as a serious sign of alert not as an ugly, but common attitude of landfill operations.

The forensic analysis addresses a very specific, additional point. Conventional methods for landfill stability would never have obtained the results presented in this article. Waste strength is considerably underestimated in conventional analysis, because the reinforcement effect is not considered correctly. Regarding the overall stability, the underestimation of waste strength may not be a problem; it just makes believe a lower safety.

However, it becomes very critical in case stability analysis is conducted aiming to identify critical factors. In case of Leuwigajah, the operator initially considered the slope angle of 30-45° the major problem, now it turned out it was not. In fact, overall stability in this case does not depend very much on the slope angle. It makes almost no difference between 40° and 25°. However, conventional stability calculation is drawing the attention on slope angle as a major factor influencing the safety. Responding to those calculations, the landfill operator decided to reconstruct the slope of his other landfill in Jelekong down to a slope angle of 1:4. This measure has not much impact on stability, but the operator erroneously believes the problems under control now. That is not the case. The measure is just good to get rid of airspace. Major points are still kept out of consideration like the landfill fires, which considered an unlucky mistake, yet. The analysis of Leuwigajah landfill disaster definitely demonstrated, that it is essential to conduct stability analysis as realistically as possible to find the weaknesses and threads.

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