Comparison of Speedbumps and Geogrids as Reinforcement Elements for Stability in a Class A Landfill Cell Design.

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Abstract

This paper focuses on the slope stability analysis conducted during the design of a hazardous landfill waste cell located in Gauteng, South Africa to compare the use of speedbumps (as a reinforcement method) also referred to as 'stability berms' in place of geogrids. Stability analysis is conducted as part of landfill design to assess the long-term stability of the landfill. For the barrier system, Stark and Poeppel (1994) recommended that when assigning residual shear resistive properties to the side slopes and peak shear resistive properties to the basin, a factor of safety (FoS) of 1.5 for permanent slopes and 1.3 for interim slopes should be achieved. The initial stability analyses did not achieve these and therefore reinforcement measures were considered. The addition of stability berms has proven to increase the Factor of Safety and improves stability like geogrids do, with an additional advantage of being relatively less expensive than geogrids.

Keywords: *landfill, slope stability, speedbumps, geogrids, Factor of Safety*

1 Introduction

Slope stability analysis is important in the design of hazardous landfills to determine if the landfill can be filled to the designed or license height without failure or movement of the slope surface. The stability of a landfill is significantly influenced by a range of factors, such as the strength of the shear interface, the performance of the drainage system, the angle at which the waste is placed as well as the height of the waste. All these have critical implications on the overall stability conditions. Slope stability reinforcement measures such as the use of geogrids and stability berms should be considered if insufficient factors of safety are obtained. These are slope support measures, acting as reinforcement to carry the force of the failure surface in tension. The slope stability analysis was carried out using limit equilibrium where stability is determined by the equilibrium of shear stress and shear strength.

2 Background

An existing hazardous landfill is nearing its designed capacity and therefore an expansion of the landfill is required. The expansion consists of the design of a new cell to accommodate future incoming hazardous waste volumes. The new cell (Combination of Cell 12 and 13) was designed to butt against the existing facility as seen in Figure 1. This will be developed in phases. Figure 1 (right) shows the development phases of the waste cell, with Cell 13A being the first waste cell to be utilized and Cell 12 being the last cell. The cells are designed with a lifespan of between 3 to 5 years. The succeeding cell will be constructed when the current cell is nearing capacity. Once the succeeding cell is in commission, the previous cell will be capped and made free draining, and runoff will be considered clean.

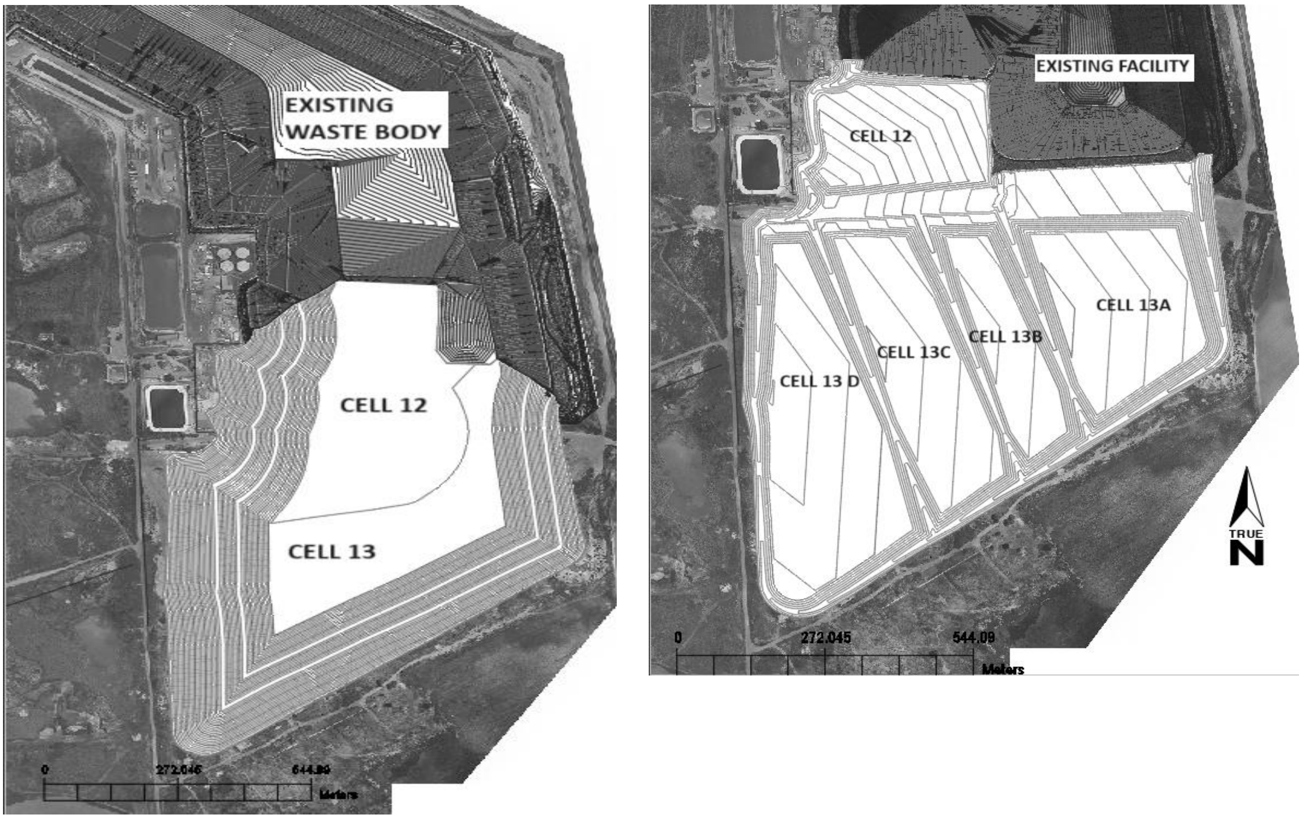

Figure 1: The designed expansion waste cell against the existing facility

The overall design of the cell is based on the requirements of a Class A facility contained in GNR 636 of August 2013, the "National Norms and Standards for Disposal of Waste to Landfill" with some reference to the Minimum Requirements for Waste Disposal by Landfill (Second Edition, 1998) as published by the Department of Water Affairs and Forestry (DWAF). The waste cell is designed to a maximum height of 51.3 m relative to the basin, hence its failure mechanism was explored using limit equilibrium to determine if the required factor of safety is obtained for the mitigation of the effects of environmental threats.

A factor of safety of 1.5 is recommended for the barrier system when conducting a stability analysis, Stark and Poeppel (1994). This was however not met for two of the phases during the analysis and therefore reinforcement measures were introduced. Two reinforcement methods were analyzed which included the use of geogrids as one option and the use of speedbumps as the other option to increase the factor of safety and therefore improving stability.

3 Slope Stability Analysis

Stability analyses were carried out using GeoStudio Slope/W based on a circular mode of failure and method of slices according to Morgenstern & Price (1965). The Morgenstern & Price limit equilibrium method satisfies equilibrium of both the force and moment conditions under either constant or variable ratios of horizontal to vertical inter-slice forces. The material properties of the waste body were assigned to that of the Minimum Requirements for Waste Disposal by Landfill (DWAF, 1998) which assumes a friction angle of 15°, cohesion of 25 kPa, and a unit weight of 10 kN/m^3. However, due to high ash and liquid content anticipated, the unit weight of the waste is increased to 15 kN/m^3. Furthermore, increasing the friction angle to 18° was implemented to represent the existing 1V:3H slopes that have been stable at the facility.

3.1 Initial Stability Analysis

When undertaking the slope stability analyses for a lined facility, it is imperative that the critical shear strength interface of the barrier system is included. It is also imperative that the critical shear strength interface is included as a normal-shear function from test data compiled from the previous designed cells. The large-displacement shear resistance mobilizes along the side slopes of liner systems (Stark and Poeppel, 1994). Therefore, a large-displacement composite envelope was modelled into the slope stability analysis to represent the shear resistive properties of the side slopes of the cell.

The leachate collection system was designed so that the phreatic level was kept within the drainage stone of the liner system (at a maximum height of 0.3 m above the primary liner), using the method detailed by Giroud et al. (2004). This phreatic surface was represented in the slope stability analyses by modelling a piezometric line above the barrier system located on the basin. Due to the void ratio of the drainage stones, negative pore-water pressures were neglected.

2D Profile geometries of the of the waste cell were taken using AutoCAD Civil 3D to represent the geometric model of the designed waste cell. Figure 2 shows the plan view (waste cell on the right and waste body on the left) of the critical cross-sections of the two waste cells that initially did not achieve the required factor of safety with Section C-C taken along Cell 13C and Section D-D taken across Cell 13D.

Figure 2: Plan view of the analyzed critical cross Section for Cell 13C and Cell 13D

The profile views of the respective cells, used in GeoStudio for the stability analysis are shown in Figure 3 (with Cell 13C profile at the top and Cell 13D profile at the bottom. The results of the initial slope stability showed non-conformance to the required factor of safety of 1.5 of the critical failure surfaces for Cell 13C and Cell 13D. Figures 4 and 5 show the GeoStudio analysis results depicting a critical failure surface with the respective factors of safety of the two cells. It is clear from Figure 5 and 6 that there is a huge mass of waste sliding along the weakest failure plane which is significantly influenced by the vertical height of the waste to the final landform.

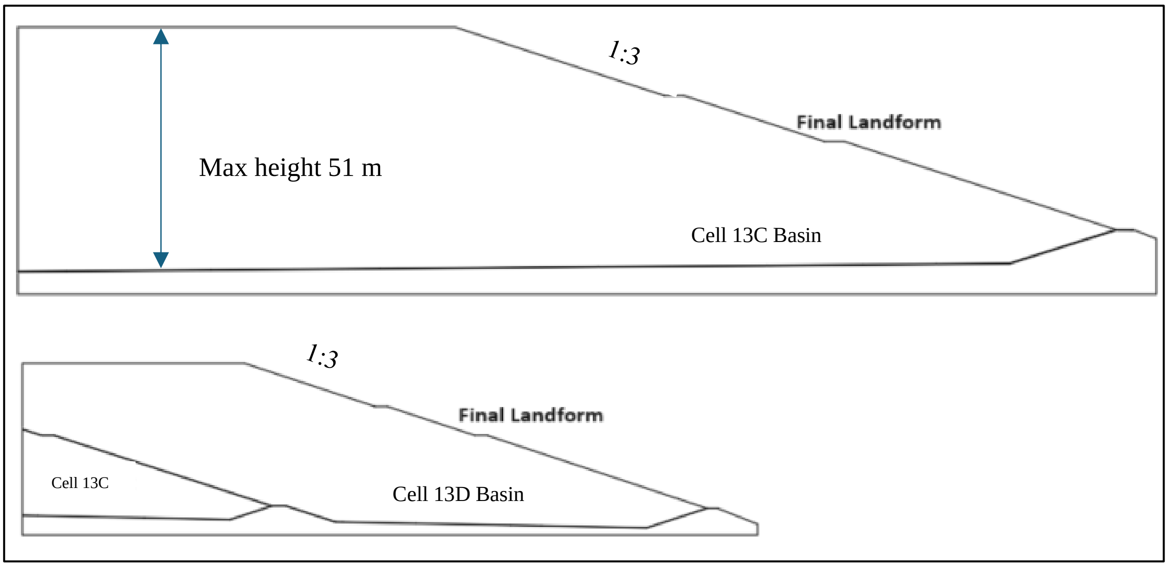

Figure 3: Critical profile view sections of Cell13C and Cell 13D

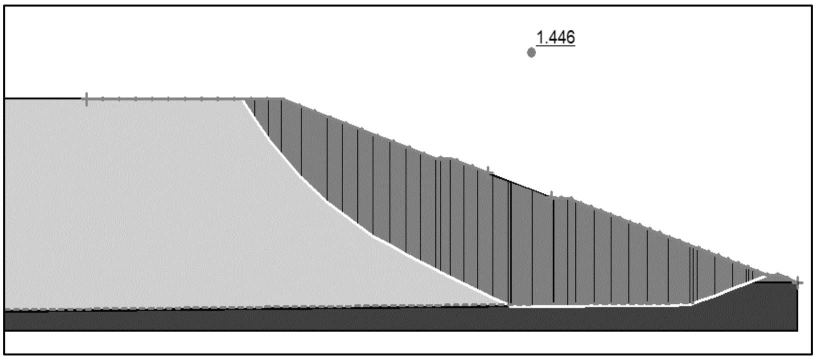

Figure 4: Cell 13C Initial slope stability results

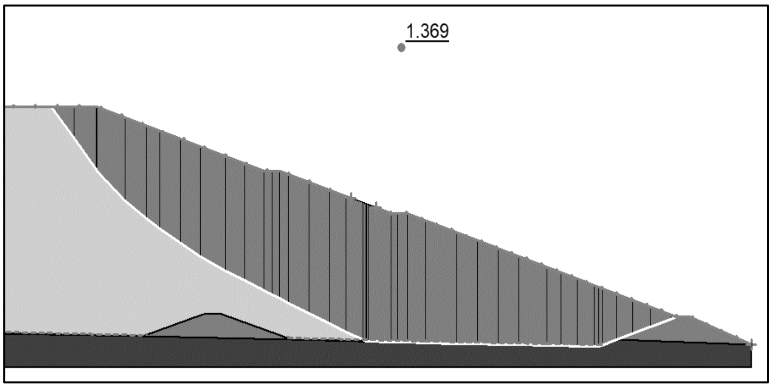

Figure 5: Cell 13D initial slope stability results

3.2 Geogrids Reinforcement

Geogrids are geosynthetic material that can be used to provide reinforcement by preventing the movement of soil and therefore providing stability to the soil structures. Landfill waste bodies tend to experience slip surfaces within the waste body due to the self-weight of the waste and thus reinforcement measures such as geogrids are used to prevents the development of failure slip surfaces that may cause damage to the surrounding environment and major repair costs. Geogrids are usually incorporated into the barrier systems of waste cells or placed within the waste body as load transfer mechanisms to carry the load of the sliding waste mass. Various studies as well as the stability analysis carried out in this design has proven geogrids to provide reinforcement and stability when installed in waste cells. However, geogrids can be relatively expensive depending on the grade required, as well as the footprint area for installation. The installation of geogrids within the waste body has also been proven to be challenging as opposed to installation within the liner system.

The slope stability analysis was run again with the inclusion of a geogrid on the waste body above the slip plane, so that the shear force of the weakest plane will be exerted on the geogrid before reaching the weakest interface. The results obtained show an increase in the factor of safety and therefore a great improvement in the stability of both cells. Figures 6 and 7 depict the stability results obtained with the installation of a geogrid.

To achieve the required factor of safety, geogrids with high tensile strength (400KN/m^2) were used and placed as depicted below. As much as the use of the geogrid helped solve the instability issues, it also proved to be relatively expensive given the large footprint area of the waste cells, and would be impractical to install, given the phased nature of the cell development.

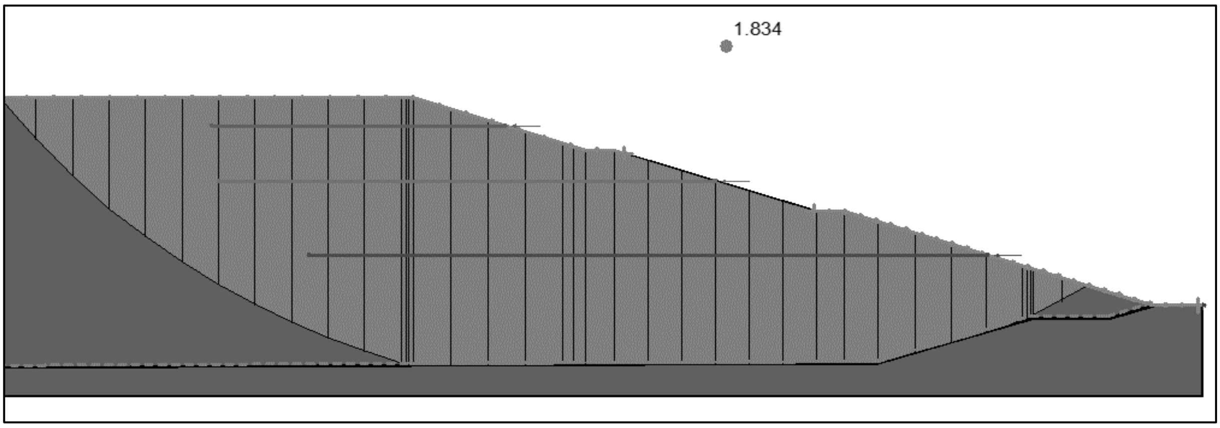

Figure 6: Cell 13C critical section Stability results with geogrid reinforcement

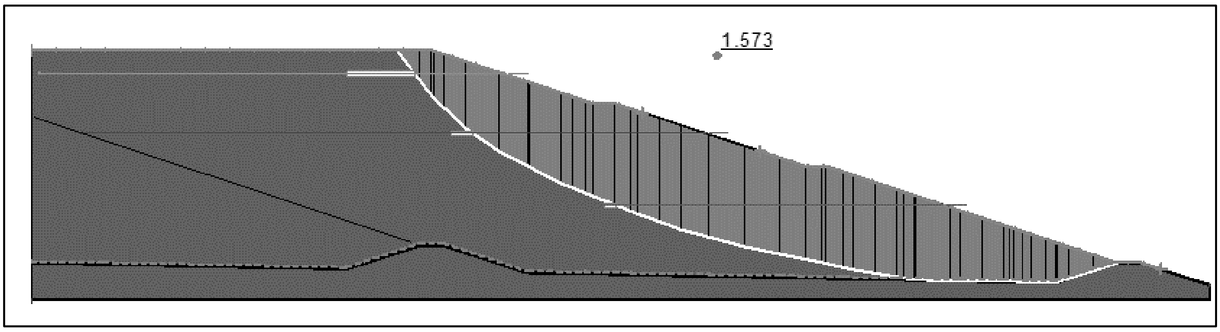

Figure 7: Cell 13D critical section Stability results with geogrid reinforcement

3.3 Speedbumps

Speedbumps also referred to as stability berms are often placed within the basin of a waste cell to reduce the weight of the sliding wedge (Arun Kumar Bhat, 2018). The speedbumps were modelled into the slope stability analyses to increase the factor of safety to the required 1.5. The stability berm in Cell 13C was modelled to have a berm crest width of 1.5m, with a maximum height of 2.9 m above the primary liner at 1:3 side slopes. The same berm crest width and side slopes were kept for berms in Cell 13 D but at a maximum height of 4.7 m above the primary liner. The height of the stability berms was based on the height of the starter walls. The berms will be built during the earthworks phase so that the barrier system of the cell will be installed over the berms, meaning, the stability berms will not be built on top of the barrier system and thus the barrier system will be modelled to pass over the stability berm. This configuration prevents potential slip surfaces from occurring underneath the stability berms and undermining the stabilizing effect intended by the berms.

Berms with different height/size and at different locations were analyzed to get the required factor of safety. Based on the different analysis carried out, it was proven that the location of the speedbumps within the basin as well as their height/size does influence the factor of safety. Figures 8 and 9 show the analysis carried out with the addition of stability berms within the basins of Cell 13C and Cell 13D, respectively. The factors of safety obtained have increased and are higher than the required 1.5 as opposed to the initial analysis. Based on the project fee estimate, the addition of stability berms compared to geogrids significantly reduced the cost by 30%. Even though stability berms have been proven to reduce airspace, their addition as compared to geogrids is highly significant in terms of costs.

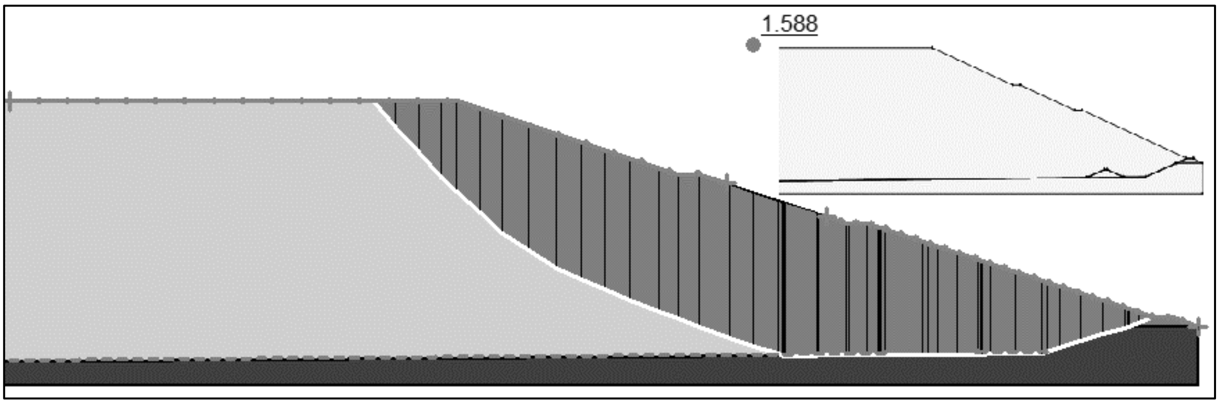

Figure 8: Cell 13C critical section Stability results with geogrid reinforcement

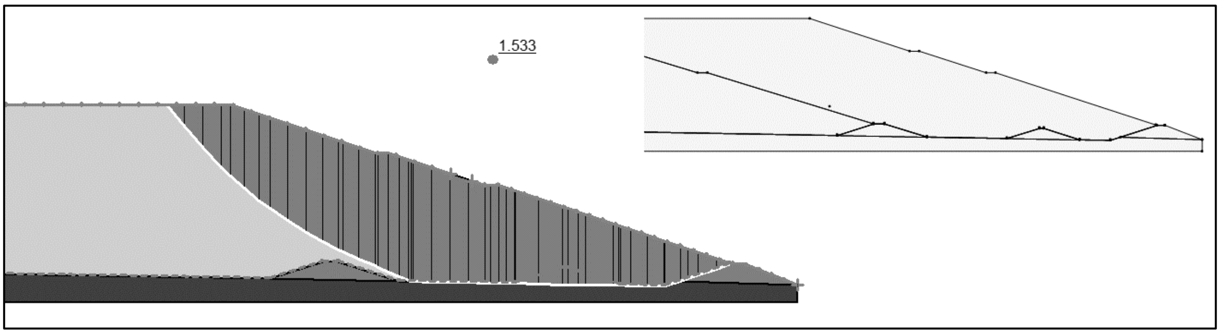

Figure 9: Cell 13D critical section Stability results with geogrid reinforcement

4 Results and Conclusion

A slope stability analysis was carried out as part of the design of a new waste to investigate potential failure of the waste cell to determine the long-term survivability of the landfill by calculating the shear strength, designing successful slopes and evaluating the need for reinforcements. The initial slope stability conducted showed instability in two of the cells making up the expansion cell. The results obtained showed a factor of safety less than the required 1.5. Options such as the reduction of the slope were considered but these were resulting in massive reduction in airspace and thus reinforcements measures were adopted.

Based on these results, a reinforcement solution using geogrids was proposed and a stability analysis was carried out to determine an increase or improvement in the factor of safety. The results obtained with the installation of geogrids proved to increase the factor of safety to be higher than the required. This, however, resulted in a significant increase in the cost of the project due to the large footprint area of the design and relatively high price of the proposed geogrid.

Another option which proved to be cost effective was carried out to determine if it will improve instability of the waste cells at a lesser cost than the proposed geogrids. The option included the use of speedbumps which were modelled into the basin to reduce the weight of the sliding wedge and therefore improve stability of the waste cell. Table 1 compares the results of the initial stability analysis to the results obtained with the addition of reinforcement measures. Stability berms were concluded as the deigned solution given the amount of money saved while achieving the desired stability results.

Table 1. Factors of Safety Obtained

Description	Initial Stability	Geogrids Analysis	Stability berms Analysis
Cell 13C	1.45	1.83	1.59
Cell 13D	1.37	1.57	1.53

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