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The use of high-strength geogrids in fill embankments

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Abstract. The uses of geosynthetics in civil engineering are relatively well-defined according to their functions. There is still, however, an inclination to use traditional methods over geosynthetics. The use of high-strength geogrids is not as widely used as lower-strength geogrids which are commonly applied in civil engineering applications. Zimbali Lakes Resort was a development that required earthworks conducted before the construction of the facilities. The initial construction required high-engineered fills that were designed to reach a height of up to 15m. The excessive load projected instability, and the high-water table necessitated the requirement for control measures. Reinforcement was required to increase the shear strength of the soil before it can support the self-weight of the fill. High-strength geogrids were used to restrict the vertical displacement of the fills by preventing base sliding, controlling differential settlement, and protecting the embankment against internal and global stability failures. Keywords: Geosynthetics, Geogrid, Reinforcement

1. Introduction

There are often design constraints affiliated with the construction of embankments taking place on the East Coast of South Africa, Durban and surrounding areas, due to the soil characteristics. The in-situ material that is found is often characterized by its weak shear strength and high compressibility. Extensive site considerations and careful design measures have to be carried out to ensure that premature slope stability failure is mitigated.

In South Africa, traditional methods of specialized geotechnical work are commonly used in the soil improvement of embankments. These methods include piling, soil replacement, stone columns and soil mixing. However, there are a handful of projects that have tried and tested the technology of using high-strength geogrids. The performance of an embankment is improved by using high-strength geosynthetic geogrids. The grids can absorb the highly imposed load and spread or dissipate these loads uniformly.

The construction of Zimbali Lakes Resort required a vast amount of earthworks to be carried out on soils that had low shear strength, high compressibility, and time-related settlement issues. Using high-strength geogrids for the basal improvement of the embankment required a detailed feasibility analysis and a systematic design approach with accurate computations.

BS 8006-1:2010 Code of practice for strengthened/reinforced soils and other fills prescribes reinforcement techniques using a limit state design approach. This guideline was used for the design of the embankment using high-strength geogrids for basal reinforcement. This paper

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is aimed at highlighting the major technical and economical advantages of using high-strength geogrids and geosynthetic technology in fill applications.

2. Zimbali Lakes Resort

The Zimbali lakes resort is a multi-generational living development situated on the North Coast of Durban (*Figure 1*). The carefully planned estate is to consist of many luxury facilities that require massive earthworks and present major challenges concerning geotechnical investigations and solutions. The resort is situated on land that was previously used for sugar cane farming; hence, the topography is made up of severely undulating landscapes. Early in 2020, Zimbali Lakes Resort commenced the construction of the estate.

2.1 Locality

The site is located 45 Kilometers North of Durban.

Figure 1: Locality Plan of Zimbali Lakes (Google Maps)

2.2 Geotechnical Classification

The in-situ material had low shear strength and high compressibility. The geotechnical investigations concluded that the in-situ soft rock material varies between clayey sand/ sandy clay and clay (Colluvium/ Hill-wash / Residuum / Berea red formation), grading into Vryheid formation, soft rock/siltstone/sandstone. The inferred material classification is G10+, with a very low inferred shear strength of $\phi = 21°$ with C=3kPa.

2.3 Traditional Solutions

Traditional methods see the use of piling, stone columns, cement columns and more recently geogrid-reinforced piles as a technique for embankment improvement. The fundamental principle is to create a platform that supports the loading on top of the support system due to the inherently poor characteristics of the in-situ material mainly comprising soft compressible soils.

2.3.1 Piles

One of the benefits of using this method is that the construction has no height restriction. Piling also has various advantages such as its ability to effectively accelerate construction while minimizing deformation. However, the use of piles is expensive and without the inclusion of a geosynthetic, the spacing between the piles is reduced increasing the number of piles required. BS 8006:2010 assumes that the embankment loading is transferred through the piles down to the foundation. Piles are installed to combat poor founding materials and because the piles are stiffer than the subsoil material causing differential settlement.

A preliminary consideration of using piles was considered. Specification considered 300mm diameter reinforced concrete Pile, 8m deep and spaced in a 3.5m matrix.

2.4 Traditional Solutions

A preliminary analysis of the embankment yielded negative results as the embankment has a global stability safety factor of 0.783 (Figure below). This was analysed on Maccaferr's internal software – MacStars.

This implied that the embankment required a solution that will deem the embankment safe from failure

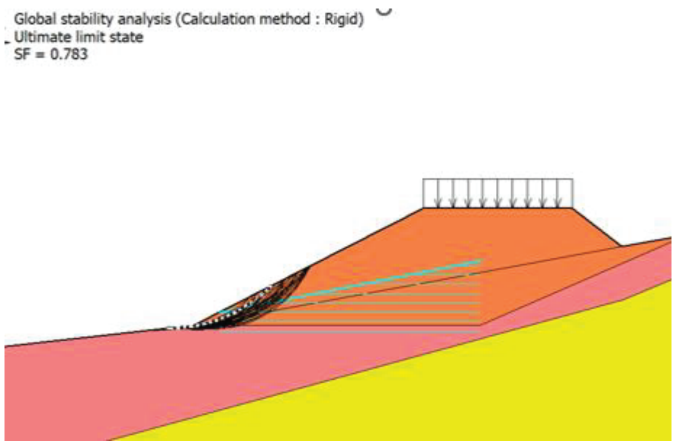

Figure 2: Global Stability analysis of embankment

2.5 Embankment stabilization solution

The high-engineered fills were initially designed to reach a height of up to 15m and therefore, required a high-strength geogrid, with an ultimate tensile strength (UTS) of 800kN/m to improve the shear strength and global stability of the embankment. The in-situ cut banks beneath the fills were to be reduced to a maximum slope of 1:2 to reduce the potential differential settlement effects propagating to the road surface. Further to this, to reduce the water table, a 1-metre-thick rockfill heel was created to pull down the water table and improve stability. A woven geotextile was used as a separation and filtration layer, while the high-strength geogrid was used to improve the tensile strength (Figure 2). The moisture within the fill was envisioned to cause time-related settlement problems. The adjudged outcome is that as the pore water dissipates, the embankment settles. The Rockfill toe with a

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layer of geogrid on the upper and lower bound assisted with the pore water pressure reduction, separation of material and accelerating the consolidation of the fill.
The high-strength properties of the geogrid provided the much-needed stability to the embankment by limiting differential settlement, base sliding and protected the embankment against internal and global failures.

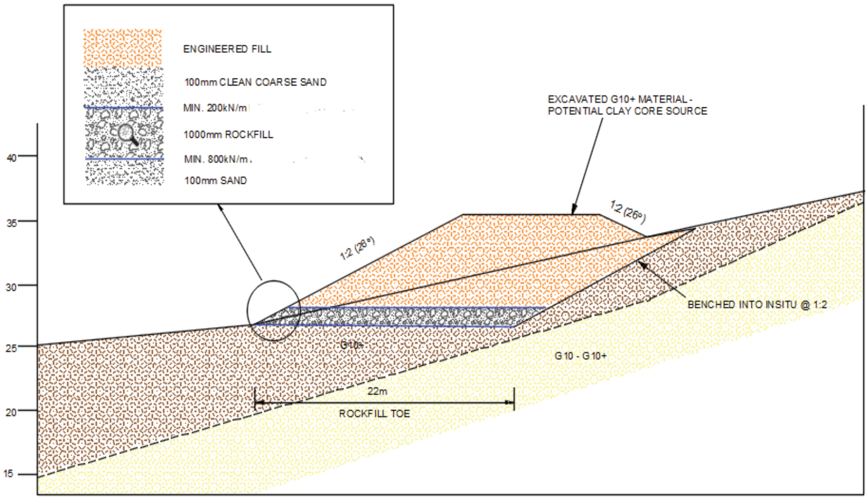

Figure 3: Cross section of Embankment at Zimbali Lakes

2.6 Cost Analysis

	Piles	unit	Geogrid Solution	unit
Area	14000.00	m²	14000.00	m²
No. of	1143.00	ea.	14000.00	m²
Rate	R3,500.00		R232.50	
Total	R4,000,500.00		R3,255,000.00	

The geogrid solution proved to be more cost-effective with a R745 500 saving ($41 400) approximately an 18% saving.
The Geogrid solution costing included both layers and the stone drainage layer.

3. Drainage

3.1 Design Approach

The design was carried out according to the guidelines prescribes in *BS 8006-1:2010 Code of practice for strengthened/reinforced soils and other fills.* The design is based on limit state design principles where ultimate and serviceability limit state considerations are to be accounted for. The approach is based on applying partial safety factors (Table 1) to increase destabilizing moments and decrease stabilizing moments to provide reliability on the Factors of safety achieved, without having to conduct a probabilistic calculation.

The design was analyzed on Rocscience – Slide software.

Partial Safety Factors		**Ultimate Limit State**	**Serviceability Limit State**
Load Factors	Soil Unit Mass, e.g. Embankment fill	ffs = 1.3	f*fs* = 1.0
	External dead loads, e.g. Line or Point Loads	f*f* = 1.2	f*f* = 1.0
	External Live Loads, e.g. Traffic loads	f*q* = 1.3	f*q* = 1.0
Soil Material Factors	To be applied to tan **f'***cv*	f*ms* = 1.0	f*ms* = 1.0
	To be applied to *C'*	f*ms* = 1.6	f*ms* = 1.0
	To be applied to *Cu*	f*ms* = 1.0	f*ms* = 1.0
Reinforcement Material Factor	To be applied to reinforcement base strength	The value of f*m* should be consistent with the type of reinforcement to be used and the design life over which the reinforcement is required - see 5.3.3 and Annex A	
Soil/reinforement interaction factors	Sliding across surface of reinforcement	f*s* = 1.3	f*s* = 1.0
	Pull-out resistance of reinforcement	f*p* = 1.3	f*p* = 1.0

Table 1: Partial Safety Factors prescribed by BS 8006-2010

During construction the performance of the geogrid is most critical as the low permeability of the soil does not allow for consolidation to occur in the normal time frame of construction. Therefore, the short-term shearing strength improvement provided by the geogrid must be, at all times, greater than or equal to the applied loads – until consolidation is reached.

3.2 Soil parameters considered in the design of the embankment.

A geotechnical investigation was performed to understand the current properties of the in-situ material. The unit weight, friction angle and cohesion, found in Table 2, were important parameters required for the design and calculations to be undertaken.

Material Type	**Unit Weight (kN/m³)**	**Cohesion (kPa)**	**Friction angle (Ø)**
G10 Fill	19.5	1	30
Rockfill	21	0	45
Clayey-colluvium/Residuum	17	3	21
Clayey sand - Hillwash/Residuum/Berea Red	20	1	28

Table 2: Soil Parameters considered at Zimbali Lakes Resort

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3.3 High-strength geogrid parameters

The high-strength geogrid used for the design is made from high molecular weight, high tenacity multifilament yarns. The yarns are woven and knitted under tension in the machine direction and completed with a polymeric coating as shown in Table 3.

Mechanical Properties	Unit	Geogrid	Test Method
Tensile Strength (MD)	kN/m	805	EN ISO 10319
Strain at max strength (MD)	%	10	EN ISO 10319
Tensile Strength (CMD)	kN/m	105	EN ISO 10319
Strain at max strength (CMD)	%	12	EN ISO 10319

Table 3: Mechanical Properties of Geogrid

3.4 Design Analysis

The Mohr-Coulomb failure criterion is considered in the analysis. Fundamentally, the Mohr-Coulomb failure criterion represents the linear envelope that is derived from the correlation between the shear strength of a material vs the applied normal stress.

$$\tau = c + (\partial - u) tan\,(\theta') \qquad (1)$$

Where: τ = maximum tangential stress
c = cohesion
∂ = total normal pressure
u = pore water pressure
θ' = friction angle

Three methods using slip circle analysis were considered during the analysis (Figure 4 and 5). Factors of safety (FOS) required are to be above a minimum of 1.3 which has been achieved as seen in Table 4.

- Simplified Bishop Method – Uses the method of slices
- Spencer Method
- General Limit Equilibrium (GLE)/Morgenstern-Price Method
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Method Name	FOS achieved 16m Rockfill Toe	FOS achieved 22m Rockfill Toe
Simplified Bishop	1.320	1.354
Spencer	1.319	1.353
GLE/Morgenstern-Price	1.318	1.352

Table 4: Factors of safety achieved

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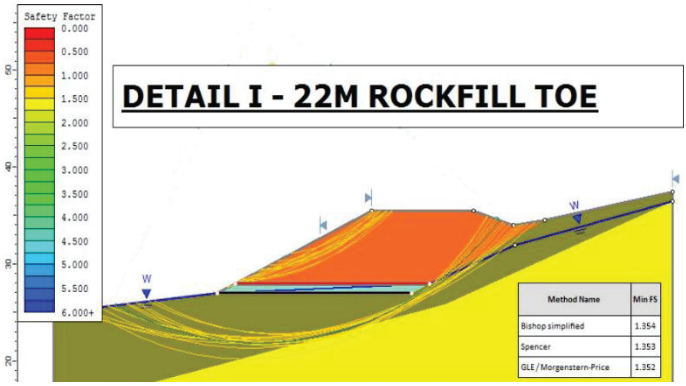

Figure 4: Cross section of Embankment with 22m rockfill toe

4. Construction Methodology

The construction procedure for installing geogrids is relatively rapid and simple. The following steps were followed as per the quality control procedures.

- Properly prepare the uniform subgrade by removing and clearing large rocks, vegetation and topsoil.
- Geogrids were tensioned by hand and anchored with pegs to remove any waves or wrinkles
- Geogrid rolled out and laid with the machine direction perpendicular to the embankment
- At the join of each roll, the geogrid was overlapped 500mm along the width and 1500mm along the length
- The rockfill toe was then installed with the geotextile filter on the upper bound of the toe
- Fill material was placed over from either end to maintain an axisymmetric condition (Figure 7).
- At every stage of construction, compaction was completed in one direction along the alignment until the final height was reached

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Figure 5: Tensioning of geogrid by hand

5. Advantages

Several technical, and economical advantages can be attained by using high-strength geogrids, which include;

- Achieving an optimum embankment height over a minimal area.
- Rapid construction operations, saving time and costs.
- Protection against base sliding.
- Even load transfer to control differential settlement.
- Increase in the bearing capacity of the embankment structure/foundation.
- Prevent global or internal failure.
- A more cost-effective in comparison to other methods of basal reinforcement.
- Low carbon footprint than traditional solutions.

6. Conclusion

The growing need for sustainable development, coupled with the favorability of 'green' engineering makes this solution desirable and effective. The carbon footprint of using geosynthetics is much lower than that of traditional methods, thus providing an environmentally friendly solution.

The technology of using high-strength geogrids is being cultivated in the South African construction industry as engineers develop a greater understanding and trust in the benefits that they provide. The number of projects using high-strength geogrids is increasing and the sustainability aspect, providing an extended design life, is encouraging.

The Zimbali Lakes Resort is situated in an environmentally sensitive area and possessed many technical and economic challenges. The use of high-strength geogrids for the stabilization of the embankment highlighted the advantages of using geosynthetics in such applications. The solution undoubtedly provided cost savings to the client, confidence to the consulting engineers, as well as a satisfied contractor.

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References

1. BSI, BS 8006, 2010 Code of practice for strengthened/reinforced soils and other fills.
2. Geo Engineer, 2020. Slope Stability: The Bishop Method of Slices. www.geoengineer.org
3. Kempton G and Naughton P, 2008. Design and construction of embankments over areas prone to subsidence
4. Mandlal J.N, 2014. Geosynthetics Engineering: In Theory and Practice. Dept. of Civil Engineering IIT Bombay
5. Officine Maccaferri, 2020. Basal Reinforcement applications. www.maccaferri.com.
6. Officine Maccaferri, 2020. MacGrid WG80 - Technical Data Sheet.
7. Wai-Choo Kok B et al, 2009. Application of high strength woven geotextile in embankment
8. stability control on soft soils. GIGSA GeoAfrica 2009 conference
9. Whittle A.J et al, 2002. Geosynthetics in Construction. Encyclopedia of materials: Science and Technology