Design and construction challenges for a 15.84 m high Terramesh wall, South Africa

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ABSTRACT: This paper focuses on the design and construction challenges for the 15.84 m high Terramesh retaining wall at Goodenough abstraction works designed in accordance with BS 8006:2010 (SANS 207: 2011) using Limit Equilibrium methods and Finite element analysis. The project site is off the uMkhomazi River, approximately 5 km inland of Umkomaas on the KwaZulu-Natal (KZN) south coast. The abstraction works on the river's southern bank, requiring a significant slope stabilisation with a height of 15.837 m to support hydro clones, a balancing tank, a high lift pump station, V5D rooms, etc. Significant slope stabilisation is then required for this project, thus the chosen retaining system was the Terramesh® being adopted for the given height. Both Limit equilibrium and Finite element methods were used to assess the global and internal stability of the Terramesh wall. The result from both analyses indicates that the performance of the 15.84 m high section of the wall is satisfactory. Quality control and constant liaising with the contractor assisted in overcoming major challenges on this project.

1 INTRODUCTION

1.1 *Overview of Water Challenges in KwaZulu-Natal*

Goodenough abstraction water project on the Lower uMkhomazi River is located at 30°10'15.79"S 30°42'31.90"E, south of Durban, South Africa (Fig. 1). The project's goal is to expand raw water availability due to the demand for water from the 50,000 households on the South Coast in both the eThekwini Municipality and the Ugu Municipality, which both have significant problems with KwaZulu-natal water supply. The Umkhomazi Bulk Water Supply project is anticipated to increase to about R20 billion which is expected to be completed in December 2027. The uMkhomazi River catchment's Mean Annual Precipitation (MAP) may exceed a maximum of 1500 mm, with summer rainfall accounting for the majority of the rainfall and isolated winter rainfall making up the balance (Beater et al. 2017). Due to the Department of Water and Sanitation's proactive involvement and resolve, this large-scale project that had previously been hampered by delays has recovered. The bulk water project commenced in 2022.

There are several activities listed that include the new access roads of about 13,90 km corresponding with upgrading of existing access roads of 5.95 km, pump station, pipelines, expansion of dams and weirs depending on any alterations to arise from the construction affected by the geology and slope challenges as per locality plan inThe project involves multiple activities, including the construction of approximately 13.90 km of new access roads, along with the upgrading of existing access roads measuring 5.95 km. Key components also include the establishment of a pump station, the installation of pipelines, and the expansion of dams and weirs. These developments may be subject to changes based on geological conditions and slope challenges identified in the locality plan depicted in Figure 1 below (Natasha Odendaal 2024).

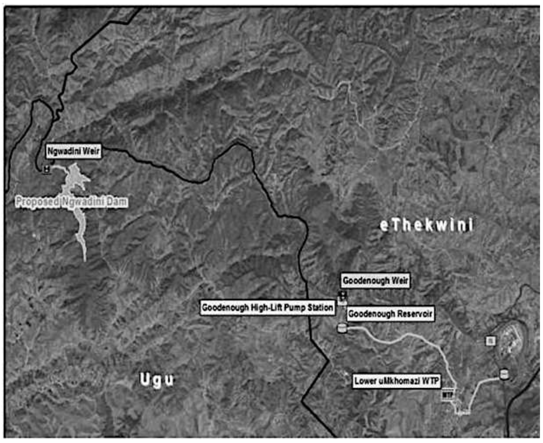

Figure 1. Location of the Umkhomazi River Goodenough Abstraction Works Site

2 PROJECT OVERVIEW

2.1 *Topography and study area*

The catchment on the uMkhomazi River at an altitude of 2500 mm originates within the Drakensberg. This is a steep elevation that slopes down toward the uMkhomazi River and valley basins. The project construction works will impact the visual aesthetics of the local environment. To facilitate the construction of the infrastructure (High lift pump station, balancing tank, access roads, etc), the earthworks platforms required retaining structures of heights varying from 5 m to 15.84 m. This paper focuses on a Terramesh wall supplied by Macaferri, which was constructed to hold up the fill surrounding the High Lift Pump station and the balancing tank as shown in Figure 2a. The progressive construction of the Terramesh wall is shown in Figure 2b to completion. The highest point is 15.84 m as shown in Figure 2c.

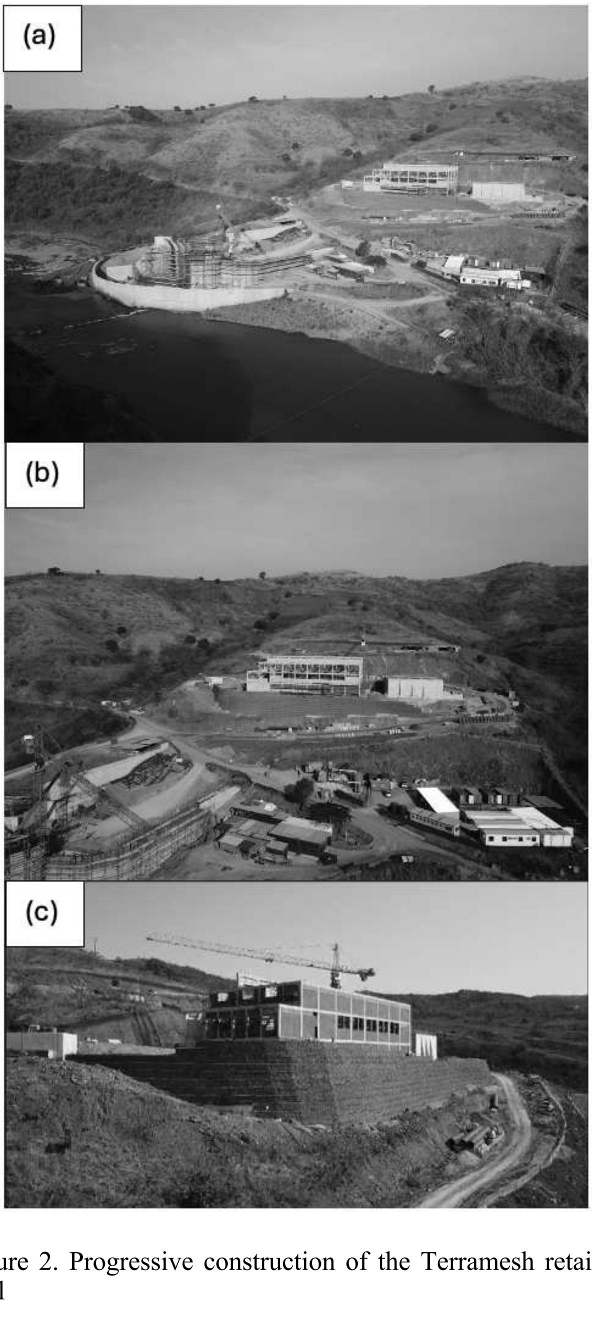

Figure 2. Progressive construction of the Terramesh retaining wall

2.2 *Geotechnical properties of the site*

According to the geological map (1:45 000) shown in Figure 3, the site is composed of sandstone and shale which dominates in the geological vicinity of the uMkhomazi River Catchment underlain by a combination of igneous, sedimentary, and metamorphic rocks that vary in age and distribution.

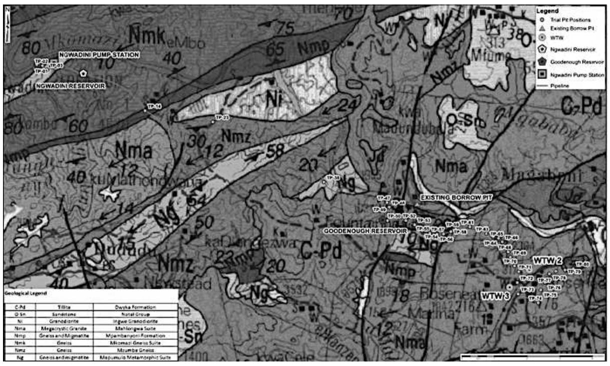

Figure 3. Scheme Geological Map

Four rotary core boreholes were bored at the High Lift pump station) HLPS. Based on observations made on site and from the borehole drilling carried out, the site is underlain by Dwyka Group tillite.

Residual tillite sampled along the pipeline route was classified as clayey sands (SC). These soils are generally regarded as having good workability as a construction material, and low compressibility when compacted. The upper soils consisted of colluvium which was subsequently stripped during the earthworks operations to form the platforms.

No groundwater seepage was encountered in any of the relevant trial pits. These soils have a low potential for expansiveness, fair workability as a construction material, compressibility when compacted and saturated, and are semi-pervious to impervious when compacted.

The major constituents of tillite are primarily primary minerals and the rock is generally highly susceptible to decomposition in the more humid areas. The AEG Core Logging Committee (AEG CLC 1978) classified the grades of weathering and corresponding trade names as used in Natal as follows: (A.B.A Brink, Engineering Geology of Southern Africa Volume 3).

The topography and geology of the area exhibited distinct stages of rock weathering, each reflecting a decrease in strength and structural integrity. In the W1 (Unweathered) stage, the material consisted of completely fresh, very hard rock, with a high Unconfined Compressive Strength (UCS) ranging from 122-298 MPa. As weathering progressed to the W2 (Slightly Weathered) stage, the rock remained hard but was stained brown along discontinuity planes, reducing the UCS to 80-130 MPa. By the time the area reached the W3 (Medium Weathered) stage, the material had become fully brown, with rock varying from soft to hard, exhibiting a UCS of 10-40 MPa. Further weathering led to the W4 (Highly Weathered) stage, where the rock turned yellow, pink, or white, becoming very soft and retaining the original structure, with a UCS of 5-22 MPa. Finally, in the W5 (Completely Weathered) stage, the rock had transformed into dark brown to black, gravelly residual soil with little to no inherited fabric, typically loose gravel, and a UCS of less than 1 MPa, indicating a dramatic loss in strength. These weathering stages highlighted the geological changes that occurred in the area, shaping its current topography.

The rock mass consisting of Dwyka Tillite (W3 medium weathered) was a challenging construction material as the base of the wall was irregular and undulatory posing major construction challenges.The rock mass parameters were derived using the Hoek-brown Criterion and are summarised in Table 1.

Table 1. Hoek-Brown Criterion to derive rock mass parameters input

Rock Type	Dwyka Tillite		
Description	Parameters	Value	RMR Rating
Point Load (kN)	P	6.00	
Sample diameter (mm)	D	53	
Point Load Index	Is	1.10	
UCS of intact rock material (MPa) (Beniawski 1973)	sci =	26.4	4
Drill core quality (%)	RQD =	60	10
Joint Spacing (mm)	JS =	100	7
Joint Condition (Condition 1 to 5)	JC =	3	12
Intact rock Constant	mi =	9	12

Table 2. Hoek-Brown Criterion to derive rock mass parameters input

Output		
Description	Parameter	Value
Beniawski's Rock Mass Ratio	RMR76 =	33
Geological Strength Index	GSI =	33
Rock mass Parameters		
Modulus of Elasticity (MPa)	E =	3758,374
Angle of internal friction (Degrees)	f =	32
Cohesion (MPa)	C =	0,411
Strength of intact rock mass (MPa)	scm =	1,48911

3 RETAINING WALL STRUCTURE SELECTION

The design incorporates a modular geogrid-reinforced wall system, with wall heights ranging from 6.69 m and a width of 5.4 m to 15.84 m in height and 9.05 m in width. In areas with no road level, gabion units of various sizes 4x1x1 m, 2x1x1 m, 1.5x1x1 m, 2x1x0.5 m, and 2x0.5x0.5 m are used to provide structural stability and support. The units are reinforced with geotextile materials to ensure both structural integrity and resistance to erosion. To address water management, a well-planned drainage system is incorporated, utilizing drainage elements with a diameter of 110 mm, which effectively mitigates hydrostatic pressure and prevents water accumulation behind the wall.

The backfill material consists of compacted G7 material, placed in 150 mm layers and compacted to 97% of the Modified AASHTO standard. This enhances the overall strength of the soil and reduces the risk of settlement over time. Several retaining system options, such as gravity walls, anchored systems, and reinforced earth systems, were considered. The selected system was determined to be the most suitable due to its ability to handle varying site conditions, including the need for erosion control, drainage, and the high variability in material strength across the site. The modular system's adaptability, combined with the use of geogrids and reinforced backfill, made it the most efficient solution for ensuring long-term stability and performance in this challenging environment.

The gabion wall was designed and shaped to meet both geometric and aesthetic requirements while ensuring ease of on-site construction by cutting and folding the geogrid-reinforced modular system. In areas with spatial limitations where a complete gabion unit could not be installed, the system was folded and overlapped, securely connected to adapt to the specific site conditions. The curved structures introduced unique considerations, requiring modifications to gabion placement and connection procedures. These structures were designed to bend to a radius of 18 to 21 meters without the need for alterations, allowing flexibility to conform to the site's contours.

To enhance slope stability, a 2:1 benching slope was incorporated, effectively controlling erosion and reducing overburden stress. A 100 mm thick, 15 MPa concrete foundation was provided to offer a stable base, particularly in areas where the underlying rock mass was undulating. The integration of reinforced soil techniques, coupled with an efficient drainage system, significantly mitigates risks related to hydrostatic pressure. Proper compaction of the backfill further enhances the overall stability of the structure. These design features work synergistically to prevent common issues such as sliding, differential settlement, and water-induced erosion. The combination of these elements ensures the long-term stability of the wall, which is essential for supporting the access road in the Lower Umkhomazi River area, as depicted in the design cross-section shown in Figure 5.

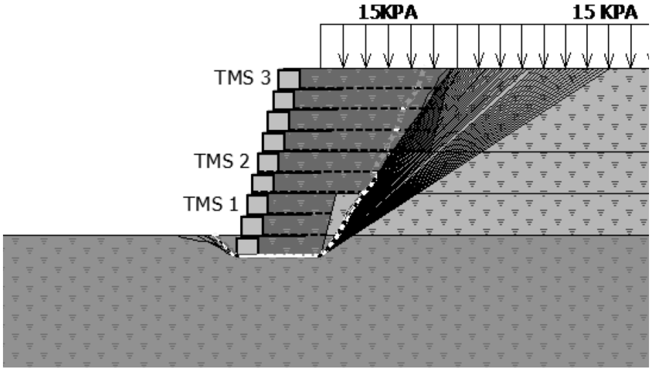

Figure 5. Typical representation of the wall

3.1 *MSEW Design Challenge*

The slope angle of up to 70° of Retaining walls was designed with a 10:1 set back at each 1 m height of the Terramesh gabion basket, creating an 84° back slope. Three intermediate horizontal berms were incorporated to give the wall a lighter visual aspect. Foundations are 1.5 m deep, while the vertical spacing of Paralink 300 was used as per design requirements.

The design process and parameters used to cause the least amount of disruption during the full operating life span of the Mechanically Stabilized Earth Wall (MSEW) structures had to be carefully considered due to the extreme rainfall conditions and high loads placed on the structures. This was accomplished through the various conditions that were present on site (Govender et al. 2023)

Terramesh is a proven flexible MSEW system that has drawn its popularity from its ease of installation and reduced costs. This system comprises a 3 m wide rectangular gabion-like facing with an integral 3 m ‘tail’ to which high-strength polymeric geogrids are fixed.

The facing consists of pre-assembled units that are manufactured with double twisted wire mesh (Type 80 – 8 x 10). Long-term durability is ensured by galvanizing the wire mesh with Galfan (Zn95Al5) and polymer coating, thus increasing its resistance to chemical abrasion. Previous compression tests have been conducted on the Terramesh units showing that a filled Terramesh basket is resistant to approximately 600 kPa of surcharge directly applied on top of the unit.

The high-strength polymeric geogrids provide structural stability to the reinforced mass by transferring the destabilizing forces from the active zone to the passive zone through the frictional bond between the geogrid and soil. (Govender et al. 2023). The amount of water on site and the variability of both loading and ground conditions placed a premium on these aspects.

3.2 *Design and Geometry*

The design for the Terramesh system was undertaken in accordance with SANS 207: 2011. MacStars W-Rel 4.0 is a software developed to check the stability of soil reinforced structures, i.e structures which provide slope stability using reinforcements capable of absorbing tensile stresses. The software uses the conventional limit equilibrium approach of Bishop and Janbu and takes into account different reinforcement types, complex geometries and the effects of the surrounding structures and their load influence on the design. The software allows the user to conduct global and internal stability analysis, wall and sliding checks and settlement calculations.

The latest versions incorporate limit state design using BS 8006-1:2010 which is similar to SANS 207:2011. Based on the shear strength parameters derived from the geotechnical assessment, the soil properties for the wall backfill, foundation soils and insitu soil are used in the software. The geometry is selected, and the coordinates are input to define the Terramesh wall system.

Internal stability for case A yields a Factor of Safety (FOS) of 2.14 as shown in Figure 6. In addition, a Finite element assessment was undertaken to assess any movements. Stabilised backfill was modelled for the 15.84 m section.

Table 3. Summarised geology concerning design

WTP 1	WTP 2
The upper layer of colluvium overlying residual tillite	Underlain by a the layer of colluvium overly residual tillite with cobbles and boulders overlying tillite rock
Allowable bearing pressure of 100 kPa	Allowable bearing pressure of 200 kPa.
Underlain by a layer of colluvium overlying residual tillite with cobbles and boulders overlying tillite rock	Residual tillite (silty clay) at a depth of 1.5m.

Table 4. Summary of geotechnical design parameters and shear strength parameters in the design of the MSEW

Material	γ (kN/m3)	c’ - (kPa)	Ø -(deg)
Backfill	20	0	35 °
Reinforced soil	18	0	32 °
Foundation soil	18	0	35 °
Gabion rock	17,5	27	40 °

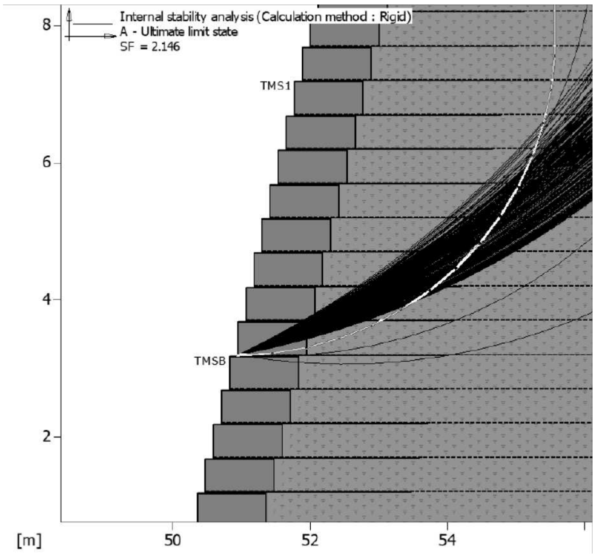

Figure 6. Internal stability analysis for Case A Limit State

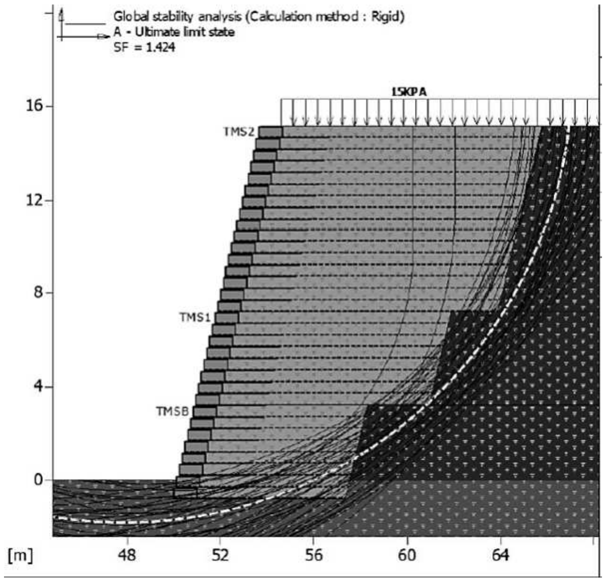

Figure 7. Internal stability analysis for Case B Limit State

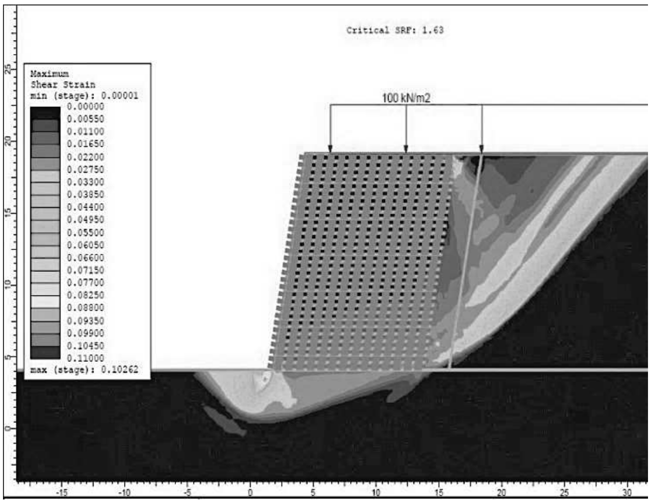

Figure 8. Slope Stability for the MSE wall

Figures 7 and 8 show the output for a finite element analysis for the MSE wall with a corresponding maximum Shear Strain min (stage) of 0.1026. The displacement is a maximum of 21 mm at the top.

4 CONCLUSION

The Terramesh wall was selected as the optimum retaining solution based on prevailing geological conditions and earthworks designs for the high lift pump station and balancing tank. The paper presents the construction challenges due to undulating Dwyka Tillite rock mass. The design was undertaken using BS 8006:2010 for stability checks of a trapezoidal wall configuration. Both Limit equilibrium and Finite element methods were used to assess global and internal stability of the Terramesh wall. The result from both analyses indicates that the performance of the 15.84 m high section of the wall is satisfactory. Quality control and constant liaising with the contractor assisted in overcoming major challenges on this project.

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