

Design and construction of a composite nailed and mechanically stabilized embankment structure across a talus slope

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ABSTRACT: A new section of road on a greenfields alignment, over grasslands and indigenous and exotic forest is under construction from the Ncembu Plateau to the Langeni Sawmill, Eastern Cape Province, South Africa. Retaining wall number 1 starts as the road leaves the escarpment and runs beneath a dolerite cliff face. The wall is founded on steeply sloping boulder and clay talus. A mechanically stabilized earth (MSE) solution was chosen for construction of the retaining wall. The contractor's hard rock source was located at the top of the escarpment and the haul road providing access to this rock source fell within the road prism of retaining wall 1. A solution became necessary to construct this wall, while keeping the haul road open to traffic. This paper outlines the solution which comprises a composite structure, combining the use of self drilling, self grouting hollow soil nails, and an MSE structure using synthetic reinforcing strips. Although this type of solution is not new, the particular circumstances on this project are unique and called for a particular solution.

1 INTRODUCTION

The construction of a road, between the town of Ugie and the Langeni Sawmill in the Eastern Cape Province of South Africa, is presently nearing completion. This is a 110 million dollar government project to link extensive timber plantations in the Ugie-Maclear district to a large sawmill at Langeni. The final 17 kilometres of the road crosses the Ncembu Plateau, before descending the 500 metre high Langeni escarpment to Langeni Sawmill. The escarpment is dominated by sheer cliffs of dolerite, extending for many kilometers in each direction. The key to the route down the escarpment is a break in the cliff line which takes the form of a steeply sloping "nose". This is illustrated in Figure 1.

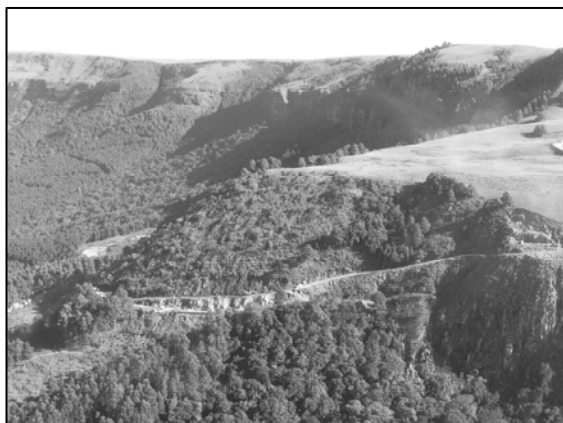


Figure 1. Road and temporary haul road crossing talus slope

By cutting deeply into the dolerite cliffs of the escarpment edge, it was possible to locate a route down and around this "nose". The road gradient is 11 percent and a 680 metre long MSE has been used to carry the road across the slope. The route down the escarpment presented many challenges, leading to innovative design and construction. This paper describes specifically a 150 metre length, in two sections, of the MSE where soil nails were used to form a composite structure, satisfying both the space constraints and stability requirements.

2 GEOLOGY

The dolerite cliffs are the remnants of a massive sill intrusive into Beaufort Group mudrocks, siltstones and sandstones. The reason for what appears to be a talus slope located in the break between the line of the dolerite cliffs is not clear. The core drilling investigations carried out found that a layer of transported unweathered dolerite boulders in a doleritic soil matrix overlies undisturbed, open jointed dolerite bedrock. The size of the boulders varies from small to several metres across.

3 INVESTIGATIONS CARRIED OUT

24 core boreholes were drilled along the 680 metre length of the embankment. It proved difficult to identify the base of the transported layer with any certainty. Generally the thickness of this layer varied between about 5 metres and 12 metres in depth. The open jointed and blocky dolerite extended to depths of between about 10 metres and 20 metres below ground level. A typical geological section is shown in Figure 2. Generally the water table levels were found to lie deep within the slope, often near where the undisturbed dolerite level was estimated to be.

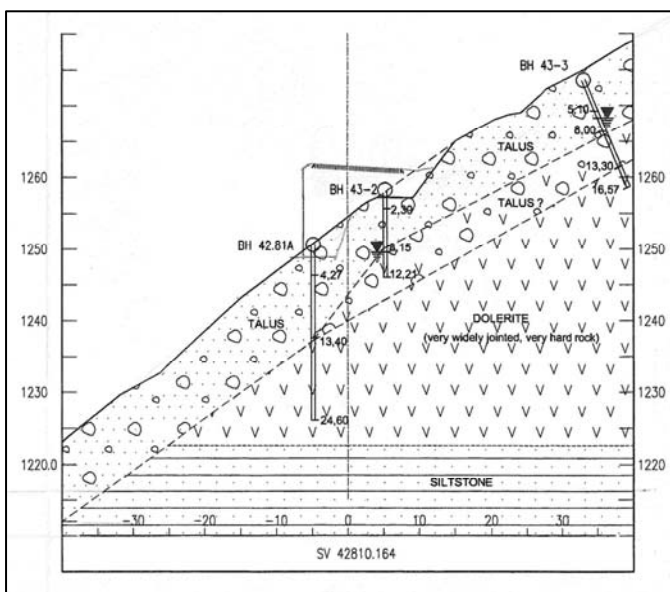


Figure 2. Geological Section

Six undisturbed block samples of the doleritic matrix soil were taken from depths of about 3 metres below ground. 9 shear box and 3 triaxial tests were carried out on these samples. No successful tube samples were obtained from the boreholes. The matrix soil is a clayey silt, with a high natural moisture content. The average effective stress parameters obtained from the triaxial tests were cohesion = 12 kPa and internal friction = 35 degrees. Drained shear box tests gave average values of cohesion = 29 kPa and internal friction = 31 degrees.

An air photograph study was carried out using both recent and 30 year old photographs. Although pine trees masked much of the area on the recent photographs, the older photographs showed the talus to have a consistent slope with none of the typical signs which may indicate previous or incipient instability. This was verified by careful field reconnaissance, which yielded no sign of any instability of the slope.

4 SHEAR STRENGTH AND STABILITY OF THE TALUS SLOPE

The maximum slope of the talus surface is 40 degrees. A stability analysis of the natural slope using the results of the shear box and triaxial testing on the talus matrix gave factors of safety ranging between 0.84 and 1.07. This implies that the slope should be showing signs of incipient instability, which was clearly not the case. The soil / boulder mix therefore has a higher shear strength than the soil matrix alone. In order to develop a solution and analyse its effect on the stability of the slope, an estimate had to be made of the strength of the boulder and soil mix. Due to the large variation in size and spatial distribution of the boulders, in-situ testing was not considered to be a realistic option.

Based on the borehole core logs, the initial assessment of the proportion of boulders in the talus was 60 percent. Subsequent monitoring during soil nail installation proved that this figure was about 45 percent. Boulder size varied from small to several metres across. Figure 3 shows a photograph of a cutting through the talus and illustrates the boulder distribution.



Figure 3. Cutting in talus slope

Since no signs of significant soil creep or hummocky ground due to past slumping were evident, the assumption of a natural slope factor of safety of 1.2 was considered reasonable. A back analysis gave effective stress parameters of cohesion = 25 kPa and internal friction = 38 degrees. The increase in factor of safety using these parameters over that obtained using the shear strength of the matrix only was about 25 percent. An internet search produced very limited information on the shear strength of boulder-soil mixes, but did suggest that an increase in factor of safety of 20 percent to 25 percent for boulder-soil mixes with a boulder content of 50 percent was realistic. Some modelling of failure through the boulder-soil mix within the talus was carried out using Geo-

slope's program SLOP/W with various boulder distributions. An exhaustive analysis of this type would be time consuming. The limited analyses which were carried out confirmed that the tortuosity induced in the failure surface by the boulders resulted in a substantial increase in the factor of safety.

Initial analyses and cost comparisons during the preliminary design stage indicated that the use of a flexible mechanically stabilized embankment to cross the talus slope was likely to be more cost effective than stabilizing a deep cut slope in this material.

5 FORMULATION OF SOLUTION

5.1 Original MSE design

Wall 1 was originally designed as a standard MSE structure with cross section as shown in Figure 4.

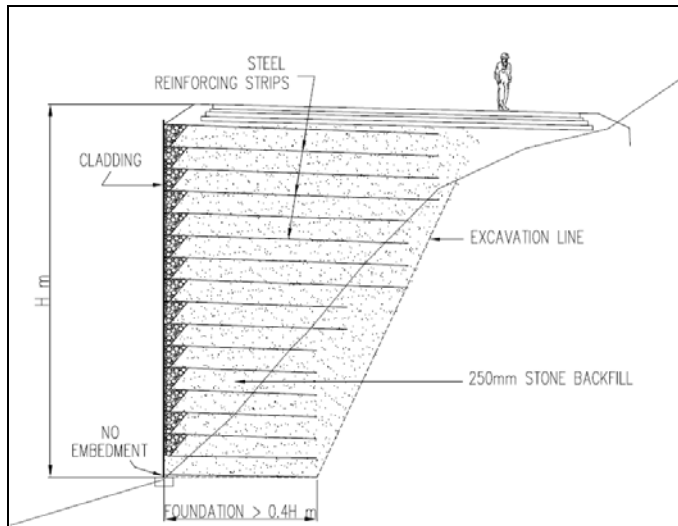


Figure 4. Cross section of original design

The structure is a flexible one and is able to accommodate settlements and differential settlement. The width of the structure, equal to the length of the reinforcing strips is dependent on overall stability and economical considerations. In this case due to space limitations the narrowest trapezoidal shaped structure possible, satisfying overall sliding and overturning criteria as well as internal stability requirements, was designed. In order to further limit the bulk excavation required for preparation of the foundation the structure was designed without embedment. The boulder and clay matrix talus foundation was deemed sufficiently strong and the risk of erosion sufficiently small to eliminate the need for such embedment.

Constituent materials: Cladding: The road grade is steep. In order to facilitate construction and survey of the wall and also to ensure a smooth continuous

top level of the cladding the structure is designed on grade. The cladding is a 'weldmesh' with 100mmx100mm apertures and 8, 10 and 12mm diameter bars. Each cladding unit is 3 metres long and 720mm high. Tie strips envelop the lower and upper waler bars in order to connect the cladding by way of a single bolt in double shear to the reinforcing strips. The cladding is backed with rock and the rock in turn with geo-fabric to provide a durable and aesthetically pleasing appearance with free draining properties while preventing loss of fines through the cladding.

Reinforcing strips: The reinforcing strips are made of medium tensile steel with 50 x 4 mm cross-sectional area. The length of the reinforcing strips varies from 6 metres to 10 metres. The strips are of medium tensile steel and are hot dip galvanised. They are ribbed to improve frictional properties with the backfill.

Backfill: Rockfill, with maximum size 250mm was specified for wall 1. This material eliminates the need for drainage and is easily placed in all weather conditions. The MSE backfill is defined as the volume contained by the face area of the cladding and the length of the reinforcing strips. Figure 5 shows the section of wall, unaffected by the haul road, constructed according to the original design.



Figure 5. Original design construction

5.2 Redesign of section of wall 1 to accommodate haul road

At an early stage in the construction process it was necessary to construct a temporary haul road across the talus slope to haul crushed aggregate from the crusher, located on top of the escarpment, down to the site of a 280 metre long reinforced concrete viaduct located on the lower slopes. Environmental controls were such that the haul road had to be constructed within the earthworks prism. This limited

the width of excavation which could be carried out below the embankment to about 3 metres.

Over two sections of the wall a solution was required to enable the MSE structure to be constructed around and over the temporary haul road. In addition the construction of the 12 metre high embankment across the talus slope would result in a reduction in the assumed overall factor of safety of the natural slope of 1.20. Some form of slope stabilization was therefore required which would raise the factor of safety above this value.

6 DESIGN OF COMPOSITE MSE AND SOIL NAIL STRUCTURE

The use of a composite structure satisfied all the design criteria: 15 metre long soil nails intercepted deep seated failure surfaces and increased the overall factor of safety of the embankment and the hillside to in excess of 1.40; the soil nails provided stability for the steep cut face below the haul road; and the use of a polyester strap as earth reinforcement, connected to the soil nail heads with a yoke, allowed the construction of an MSE structure in a confined space.

For the stability analysis the water table depth was assumed to be slightly less than that measured during the investigations. Very high water loss was experienced during the core drilling investigations and the excavation for the temporary haul road exposed several voids in the talus. It was therefore considered that the slope was too permeable for a general rise in the water table so near the surface. This assumption was borne out by the very high grout takes during grouting of the soil nails.

6.1 Design philosophy

Although sufficient space was available to place the upper reinforcing strips, insufficient space was available to place the lowermost reinforcing strips. In order to ensure internal stability of the abbreviated MSE mass the lowermost strips could be connected to nails driven into the talus. In order to ensure and enhance overall stability these nails could be extended into the talus to ensure that slip surfaces did not develop behind and beneath the structure. The bearing capacity of the foundation should be such that it would be able to support the now narrow based and tied back MSE structure.

6.2 Internal stability

An MSE structure should behave as a coherent gravity mass dependent on the strength and frictional interaction of the reinforcing strips and the backfill. At each level of reinforcing strips the horizontal

stresses in the strips are determined by calculation of the vertical stresses on the strips and applying to it a coefficient of earth pressure. The strips should be strong enough to resist the horizontal stresses and should be long enough to ensure that they are able to mobilise these stresses in friction and do not pull out of the backfill. In this case the nails are designed to be strong enough, both in strength and pull out, to resist the loads imposed on them by the reinforcing strips and by overall stability requirements.

6.3 The connection of the reinforcing strips to the nails

A system of connecting synthetic reinforcing straps had been previously developed and was considered practical for use on this project. All steel strips in the standard cross section which were too long to be placed were replaced with synthetic straps consisting of discrete channels of closely packed, high tenacity, polyester fibres encased in a polyethylene sheath. The strap is supplied in a 100 metre long coil and is laced between tie points and hooks on the cladding and the yokes placed over the head of the nails. A nut was used to hold the yoke onto the nail head and to tension the link reinforcing straps between the yoke and the cladding. The density and position of the nails was determined by the density and position of the reinforcement straps which were to be attached to them. Since each nail head is attached to two tie points on the cladding, the vertical and horizontal spacing of the nails was 720mm and 1450mm respectively. The nails were also positioned on grade to match the position of the reinforcing strips.



Figure 6. Placing of synthetic link reinforcement

6.4 FLAC analysis confirmed that extensible and inextensible strips cannot be mixed in section

Inextensible steel reinforcing strips could not be used above the extensible polyester straps. A "FLAC" numerical analysis showed that the extens-

ible strips accept load until such time as the first layer of inextensible strips is placed. Thereafter the inextensible strips collect all future stresses. The design was finalized with synthetic strips placed from bottom to top of the structure; connected to the nails at the lower part of the structure and simply placed in the backfill where space permitted it above the level of the nails.

6.5 Foundation of composite structure

On account of the fact that there was no embedment and that the MSE structure was narrow at its base and differential settlement between the nailed slope and the MSE backfill would impose large loads on the foundation a reinforced concrete base with minimum thickness 250mm was specified. The lowermost reinforcing strap was omitted and the lowermost row of nails was cast into the foundation. The bottom of the cladding was also cast into the foundation.

The main constraints and components of the solution are illustrated in Figure 7 and construction is shown in Figures 8 and 9.

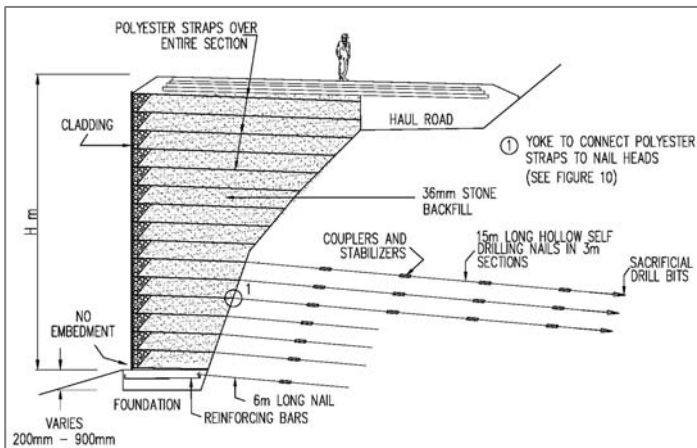


Figure 7. Typical section as redesigned to accommodate haul road and enhance the overall stability

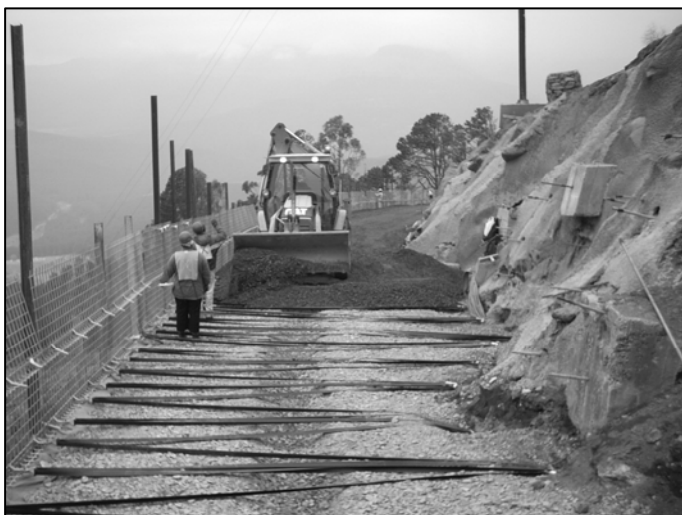


Figure 8. Construction of combined MSE / nail solution



Figure 9. Installation of the soil nails

7 BACKFILL

The coarse rockfill used for the bulk of wall 1, although suitable for steel reinforcing strips, would probably have damaged the synthetic strap reinforcement. A material that would not damage the straps was required; ie fill the irregularities of the boulder slope around the nails without the need for compaction and also provide adequate drainage of the cut slope face. An evenly graded 36mm stone backfill met all these requirements and was specified for the entire sections where synthetic reinforcing straps were used.

8 THE NAILS

The nails: Pre-drilling and later installation of nails into grouted holes was deemed to be too onerous. Hollow self-drilling, self-grouting nails were required for installation into the massive boulder and clay talus. These nails are supplied in 3 metre lengths. A sacrificial drill bit with diameter 72mm is attached to the first 3 metre length. Additional 3 metre lengths are joined together during the drilling operation by means of couplers. A centraliser is placed at each coupler. The larger diameter drill bit and centralisers position the nail in the centre of the hole. During the drilling operation grout is pumped down the central hollow core of the nail, flows through the drill bit and back up the drill hole created by the larger diameter drill bit. Figure 9 illustrates the installation of the soil nails.

9 DURABILITY

The structures are designed for a service life of 70 years. The hollow nails are not stressed and are covered with a thickness of at least 20 mm of grout. The nail is also approximately twice as strong as required

and consequently has considerable sacrificial thickness. The ground waters are not particularly aggressive. The nailed talus slope structure is an indeterminate one and should failure of a nail occur the loads would be redistributed to the other nails. For these reasons it was only felt necessary to galvanise the last 3 metre nail piece which protrudes into the backfill without grout covering and onto which the hot dip galvanised yoke and nut are attached. The MSE part of the composite structure is designed for durability according to standard MSE design codes (see references).

10 CONSTRUCTION

The solution adopted was only developed once the construction had been underway for several months. All parties on site reacted positively to the proposed solution and this attitude facilitated its successful construction. In particular the installation of the nails to precisely surveyed positions on an unstable massive boulder and clay talus slope in a high and persistent rainfall area was a considerable challenge readily accepted by the contractor. In order to install the nails a drill rig was required and a 3 metre wide temporary shelf had to be created in front of the toe of the cut face. The average rate of installation of the nails varied from about 40 metres to 100 metres per day. A total length of 9000 metres of nail was required. Many days were lost to rain. There was also a substantial learning curve period during which a number of difficulties in the installation process had to be overcome. The nail installation period took approximately 10 months using on average 2 drill rigs. The placement of backfill, cladding and link reinforcement proceeded smoothly, the pacing item being the placement of the backfill. Figure 10 illustrates the connection between synthetic reinforcing strip and the nail head.



Figure 10. Connection of synthetic reinforcing strip to nail head.

11 COSTS

Over the cladding area affected the cost of the re-designed solution, excluding bulk earthworks, was approximately 10 times the cost per square metre of the originally specified solution. No other solution was considered practical or economical.

12 CONCLUSIONS

The solution to the problem proved to adequately meet the technical, economical and environmental requirements. The environmental requirements were to minimize the visual impact of the road on the side of the mountain as well as the area of indigenous forest which had to be cleared. The solution allowed the width of the earthworks prism to be substantially reduced and so achieved these requirements. The appearance of the structure is unchanged from the specified solution. The combination of in-situ reinforcement and MSE structures opens up many possibilities. This solution may be used to found and widen roads on steep slopes without disruption to traffic and at the same time enhance the overall stability of slopes on which the road is founded.

13 REFERENCES

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