An innovative connection between a nailed slope and an MSE structure : application at Sishen mine, RSA

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ABSTRACT: The expansion project at Sishen Mine Northern Cape, RSA includes the construction of a primary crushing facility. The primary crusher building is founded at a depth of 35metres below the natural ground level. MSE wing-walls are required to provide access for 400^T trucks to the tipping areas. The wing-walls are tiered and split into 14m and 21m high structures, which in effect are equivalent to higher structures because the dry density of the hematite backfill is $33kN/m^3$. Insufficient space was available for placing the reinforcing strips on one of the lower walls viz. Wall B. Additional excavation to accommodate the strips was not feasible and a solution was required to connect the narrow MSE structure to the existing cut slope. This has been undertaken by the installation of nails into the cut slope; attaching a high friction strip to the nail heads and then lapping shortened reinforcing strips attached to the cladding with the friction strip. The frictional interaction between the MSE reinforcing strips and the extended nails ensures the internal stability of the MSE mass. Monitoring of the load at the nail head has been attempted by means of strain gauges. This paper describes the MSE wing-walls and in particular the design and stability of Wall B.

1 INTRODUCTION

The Sishen Mine is one of the largest open pit mines in the world. It is undertaking an expansion project to increase its production from 29 to 42 million tons per year. This entailed the construction of a primary crusher building. The building is 35 metres high. Mechanically stabilized earth (MSE) tip walls and wing-walls to crushing plants have become standard practice in Africa (Smith 19) and were required for the wing-walls for this particularly massive structure.

2 SISHEN MINE PROJECT

The new primary crusher is situated at the edge of the existing pit and in an area where the existing pit had been backfilled. Excavation through the natural inside edge of the pit as well as the backfilled material was undertaken in order to found the structure at the minus 35m level. Figure 1.

Figure 1. Excavation completed

2.1 *General*

The backfill material is Hematite and has a bulk density of $33kN/m^3$. This has the effect of increasing the stresses in the MSE of the order of 65% or increasing the effective total height of the 35m high tiered structures to 35m x 1.65=58m. The reinforcing strips needed to be stiff to reduce deflection and bulging. Hot-rolled ribbed strips with 50x4 and 45x5mm cross-section were used. The 45x5mm strips are padded to prevent any loss of strength at the connection and these were used for all strips with length longer than 11m. The maximum length of strip was 23m. The cladding needed to be strong yet flexible enough to accommodate differential settlements as well as the large number of reinforcing strips required. A weldmesh cladding with 8mm, 10mm and 12mm diameter bars and a height of only 320mm was used. Once excavation had been completed and construction of the crusher building was underway Wall B was moved several metres nearer to the excavated cut face. In order to improve the stability of the cut face soil nails were installed in particular locations.

2.2 *Wall B*

The existing slope was, in one location, as close as 2 meters from the projected position of the wall facing, with an inclination of about 40° about the horizontal. Further excavation of this excavated slope was avoided on account of overall stability concerns. The position of Wall B was relocated several metres nearer the excavation line and it became necessary to find a cost effective solution for a 14 m high vertical structure, with an available space at the bottom of about 2 m, i.e. 15% of the height (Figure 2). The standard practice for MSE retaining walls lies generally between 60% and 70%, with a minimum set in the major design codes to 40% at the base. The recent Shored Mecahnically Stabilized Earth (SMSE) Wall Systems Design Guidelines, edited in February 2006 by the US Central Federal Lands Highway Division, states that the width at the base should be at least 0.3H and concentrates on vertical and near-vertical backslopes.

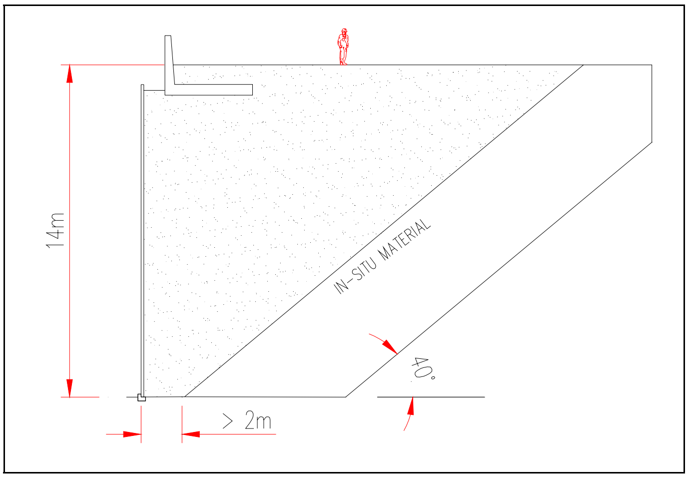

Figure 2. Wall B – Typical cross section

2.3 *Fill material: hematite backfill*

The backfill material commonly available at the site is an iron ore called hematite. Hematite (Fe_2O_3) has a particular high density, compared to common quarry materials. The grain density is 5.24 g/cm^3, and the design fill density is 3.4 t/m^3 (33 kN/m^3). This material is insoluble. Its internal friction angle was taken as 40°.

A test was done to compare the corrosion behaviour of a galvanised steel sample placed into saturated hematite, with a similar sample placed in tap water. The rates measured showed similar behaviour. The resistivity of the hematite ore saturated with de-mineralised water at 20°C is 11,600 Ω.cm, and the pH level is slightly alkaline at 8.3. About 1% of fine elements is enough to give to the water a strong red colour, similar to blood, which gives its name (in Greek) to the ore.

Figure 3. Comparative corrosion testing between saturated hematite and de-mineralised water

3 PROPOSED SOLUTION FOR WALL B

In order to ensure a satisfactory level of safety, the structure had to be tied to the existing slope. This is commonly done by anchoring a concrete beam or plinth to the slope with the help of tie-backs. The solution presented made it possible to save a large quantity of concrete, by using the locally available granular material.

The use of hollow self drilling nails allowed rapid installation of anchoring points.

The height of the structure and density of the backfill led to the choice of the use of inextensible steel reinforcing strips to link the existing slope with the new facing. The use of a direct link would have required the use of adjustable devices, such as turnbuckles, in order to cope with the naturally distorted alignment of the existing slope. This was considered to be impractical, expensive and difficult to install. Moreover a rigid link between the slope and the new face may have led to a high concentration of loads, since it would not provide sufficient flexibility.

3.1 *Friction connection*

The conception of this solution is based on the observation that the use of friction between the reinforcements and the backfill is at the basis of the performance and reliability of MSE structures.

There have been previous attempts, in the design of retaining walls to disconnect the main reinforcements from the cladding elements. Berg et al. (1986) presented an MSE retaining wall in Lithuania where the main reinforcements, made of HDPE geogrids, were not positively connected to the facing, but overlapped geogrids embedded in the cladding panels, with a minimum thickness of fill between them. Construction was reported to be difficult, which may be a consequence of the flexibility and extensibility of the geogrids. Freitag et al. (2004, 2005) presented a similar concept, but with the use of discrete reinforcements; strips and geostraps.

3.2 *Sishen concept*

A similar layout was proposed for the Sishen structure. Instead of trying to make a positive connection between soil nails and the new facing, leading to issues described above, it was decided to make use of the friction connection between reinforcing strips extending from the facing and specially designed highly frictional ladder reinforcements connected to the nails. The elements were designed so that an overlap of 2 metres would be enough to ensure stability. A patent on this concept was filed in January 2006 by Terre Armée Internationale.

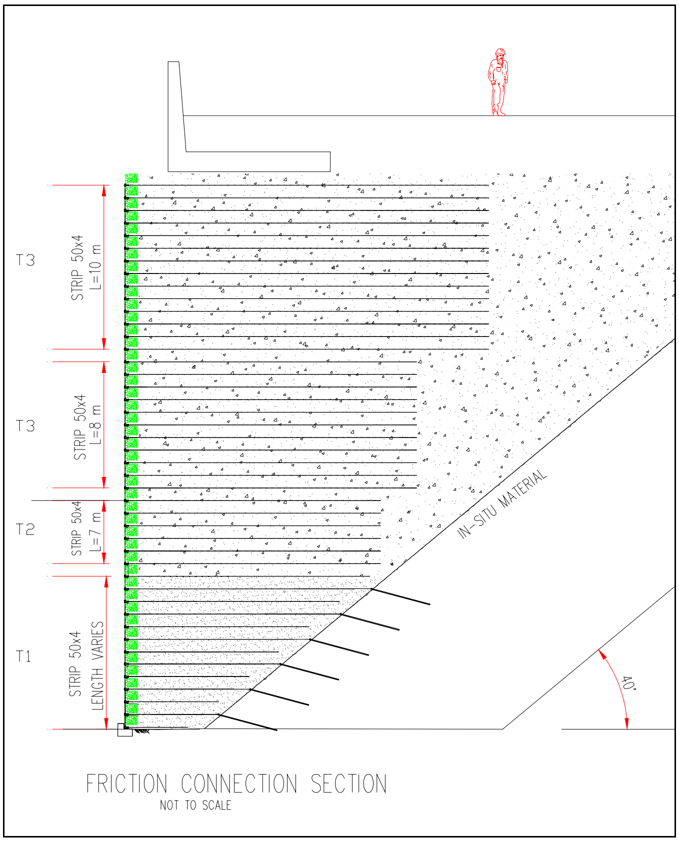

Figure 4. Sishen cross section

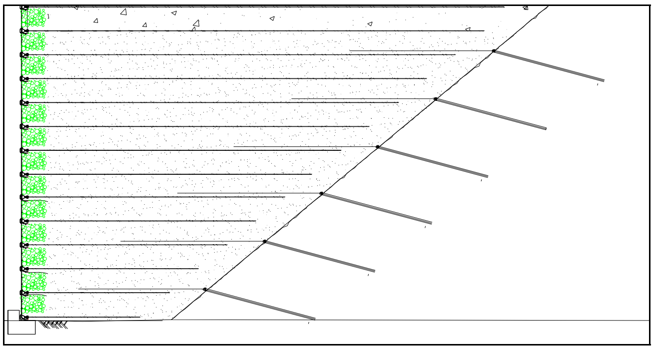

Figure 5. Friction connection

3.3 *Technology*

The facing was made of galvanized wire-mesh, backed with stone. Due to its flexibility and engineered compressibility, this combination delivers a high quality in terms of constructability and appearance. The height of the structure in combination with a very dense backfill material led to the use of low height panels, increasing the number of reinforcement layers, in order to minimize the facing deflections due to bending or bulging.

The cross section is basically divided into two sections. The lower section on the RHS of the crusher building was too narrow for standard MSE technology, so the friction connection was used to link the reinforced soil mass to the slope. The upper section was constructed using standard MSE technology.

The facing was connected to standard high-adherence steel strips, which extend up to the slope in the lower section, and have common lengths in the upper sections.

Since the nails are independent of the reinforcing strips the positioning of the nails in the excavated slope does not have to comply with the position of the reinforcing strips. The nails were approximately twice as strong as the reinforcing strips and consequently their density was approximately half that of the strips. A friction strip was required to bond two reinforcing strips to one nail and led to a specific design of the friction ladder. Depending on the level, one or two such ladders were connected to one nail head. Figure 6 shows a typical top view with one ladder per nail.

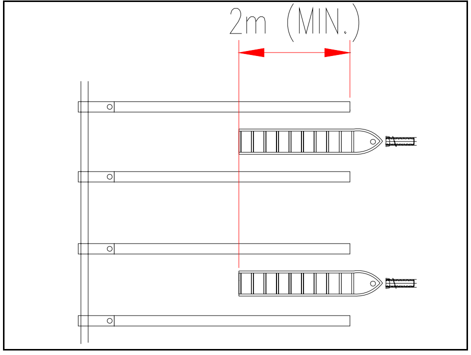

Figure 6. Typical top view of a layer comprising steel strips connected to the facing and ladders connected to the nail heads

3.4 *Construction*

The schedule for construction of wall B was tight. Firstly, all the nails were installed in early June 2006 (Figure 7), followed by the construction. Free draining crushed stone backfill was specified for the 2m wide zone extending from the excavated face. This material facilitated compaction of the backfill around the protruding nail heads.

Figure 7. Nail installation

In places, the spacing between cladding and cut slope was less than 2m. To ensure sufficient strength at these locations, concrete was used instead of backfill. A mass concrete foundation was constructed below the entire length of the nailed section of Wall B to ensure adequate bearing capacity of the foundation. After one or two lifts, when the spacing reached 2m, the hematite backfill was used. In early August 2006 construction of wall B reached the stage shown in the photograph (Figure 7).

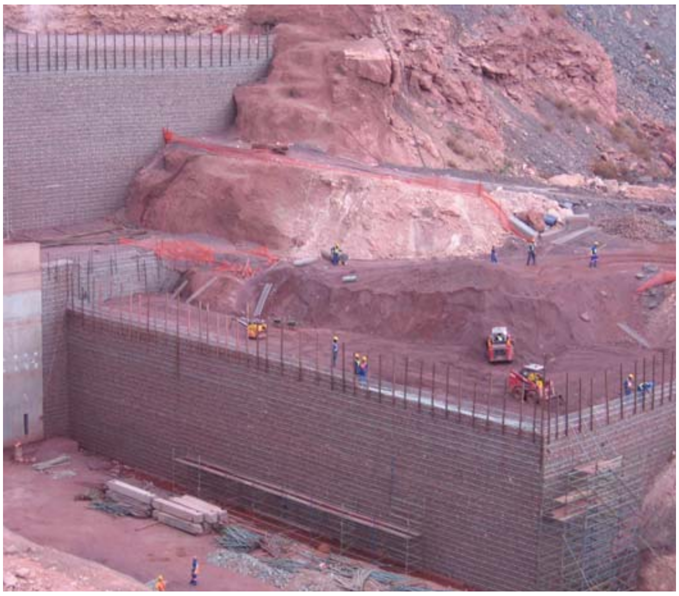

Figure 7. Wall B close to completion

4 DESIGN / JUSTIFICATION

4.1 *Internal stability*

The internal stability was checked using the standard "coherent gravity" method. It was applied to the long term strength of the high-adherence strips throughout the section and the adherence capacity of the strips in the upper section. This was considered to be conservative in this case, as the nailed backslope bears a portion of the vertical stress due to the fill weight and it does not apply an active earth pressure at the base. In parts where the cut slope was not rock the active earth pressure is resisted by the friction and the soil nails.

As explained in §4.4, the internal stability was confirmed by numerical modeling.

4.2 *Block horizontal stability*

A conservative analysis of the horizontal stability was undertaken, considering that the foundation soil did not offer any sliding resistance. Consequently all the horizontal force due to the earth pressure in the upper section and to the sliding on the slope in the lower section was distributed among the soil nails and ladders. The total resisting force R_h is determined so that the horizontal stability is ensured (Figure 8).

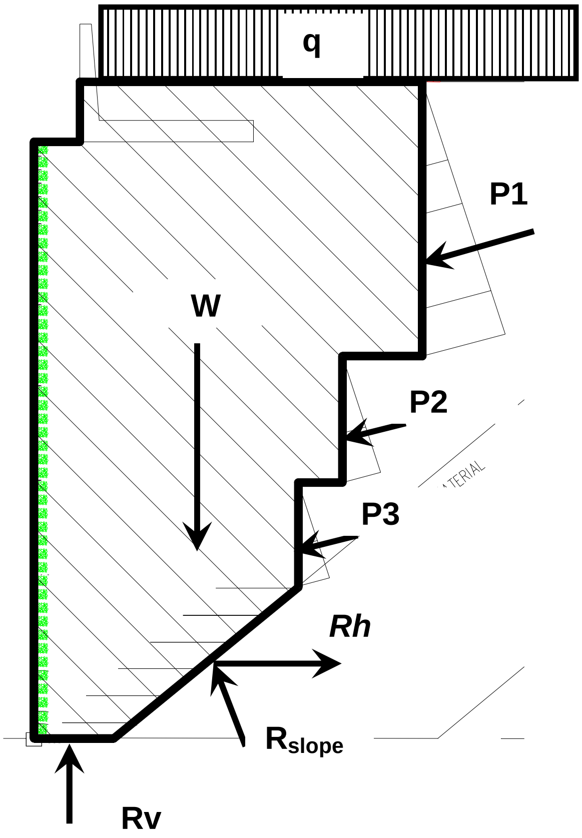

Figure 8. Block horizontal stability

4.3 *Wedge and circular stability analysis*

The Bishop method with slip circles and the Perturbation method with broken lines were used to check that the proposed solution satisfied these general stability criteria.

4.4 *Finite difference analysis*

All previous analysis only dealt with static force and stress equilibrium, with no consideration of the deformations of the structure during the construction. However the novelty of this layout made it necessary to make a step by step analysis of the stress/strain build-up in order to validate and refine the design.

This was done with the help of the geotechnical finite difference program, Flac 5.0, which incorporates a specific structural element to model discrete reinforcements as steel strips or ladders. The modeling was made with the “large displacements” option which allows better simulation of arching and membrane effects (so-called second order effects). Figure 10 shows the overall model.

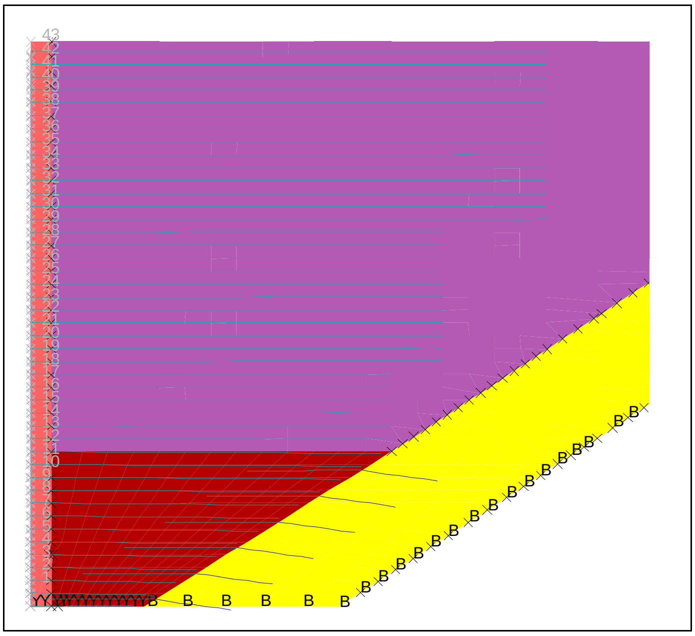

Fig. 10: Flac model

This modeling confirmed that overall stability is ensured, but the upper two of the six layers of ladders connected to nail heads are more stressed than the four lower ones, which required an increase in the density of ladders for these two layers. This is due to the fact that the existing slope is stiff, and settlement of the reinforced fill during construction, tends to overstress the upper connector levels. One could comment that once again the classical slope analysis programs do not allow us to represent any type of overstressing due to deformation or differential settlement. Figure 11 shows the estimated relative tensile forces in the reinforcements of the lower section. The higher tensile force in the lower ladder is artificial due to the assumption of zero friction capacity at the bottom of the fill.

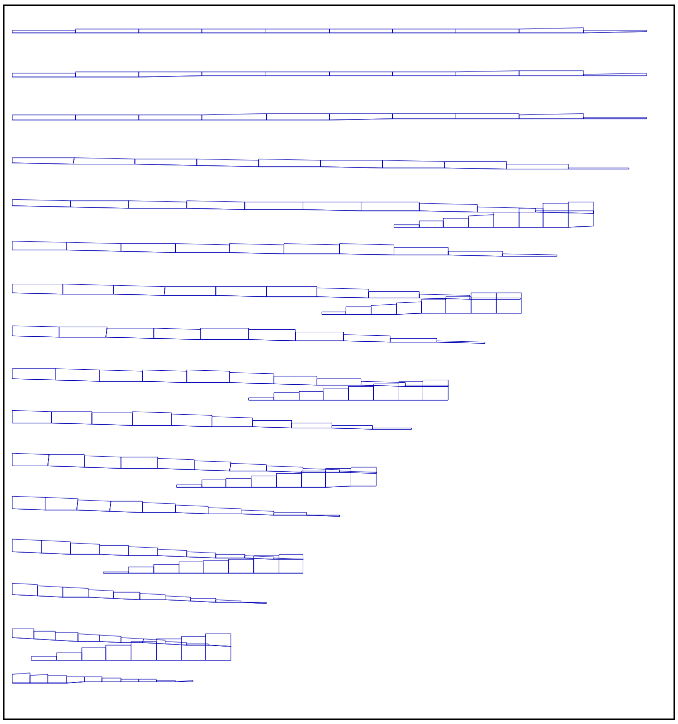

Figure 11. Relative tensile forces in the reinforcements of the lower section

5 INSTRUMENTATION

The connection between the nail and friction ladder is by means of an eye bolt and a shackle. A Wheatstone strain–gauge bridge was used to instrument six shackles. These were calibrated at the University of Pretoria and installed in pairs at three levels viz. 0.32m, 1.28m and 2.20m above the foundation. The lowermost and middle sets showed almost zero tensile stress. One of the top shackles showed a tensile load of 85.8kN while the other top shackle did not respond, probably due to failure of the electronics in a harsh environment. These results agree with the numerical analysis and confirm that the upper ladders are more stressed than the lower ones.

6 CONCLUSION

The construction of MSE wing-walls at Sishen has been successfully tested in practice. It has been shown that tensile forces can be transferred in friction from one reinforcing strip to another. In addition it has verified that narrow MSE structures with base width less than 15% of the height can be constructed if they are bonded to reinforcements installed into in-situ material in excavated back slopes.

This type of solution has application in the construction of MSE structures in cut situations and also for the widening of fills without the need for bulk excavation.

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