SUMMARY
The Franschhoek Pass (R45) is one of South Africa’s iconic mountain passes, serving as a gateway to the Overberg. The year 2013 saw numerous cases of slope instability along the route due to unseasonably high rainfall. In response, SMEC South Africa (Pty) Ltd was tasked by the Western Cape Department of Transport and Public Works with repairing damaged drainage infrastructure and road surfacing, implementing erosion-mitigation measures and stabilising a progressive, deep-seated slope failure on the lower western flank of the pass. The solution involved the use of an unconventional slope stabilisation method synchronous with the surrounding environment (Figure 1).

INTRODUCTION
The history of the Franschhoek Pass, which is a vital link between the small towns of Franschhoek and Villiersdorp, stretches back to the early 18th century when a route over the Middagkransberg was sought by Lord Charles Somerset,
the governor of the Cape Colony from 1814 to 1826. Completed in 1825, the Franschhoek Pass is one of South Africa’s oldest roads, along which South Africa’s oldest operational bridge traverses Jan Joubert’s Gat. Legend has it that a route over the Middagkransberg was cut into the mountain side following a popular elephant migration path, dubbing the route Oliphants Pad for almost 150 years.

Whether accurate or not, it was these cuttings that were a major cause for concern almost 190 years on, following unseasonably high rainfall in the region during the latter half of 2013. Surficial instability in the form of ravelling and rock falls was prevalent, resulting in a breakdown of the road drainage infrastructure, severe scouring, and, in a gully on the lower western flank, a deep-seated slope failure.

Remediation measures to reinstate the safety of the route and mitigate the risk of future instability-related problems were required. These comprised:

■ The stabilisation of a scoured embankment (Figure 2) by means of an anchored gabion wall
■ Steel meshing of several cuttings to mitigate future ravelling
■ Reinstating and improving sections of the route’s road drainage, including dissipater structures, culverts and debris barriers
■ Shear reinforcement, by means of soil nails and high tensile strength steel wire mesh, of the progressive deep-seated slope failure along the lower western flank (the primary focus of this article).

AN UNCONVENTIONAL APPROACH

In the design for the remediation of the deep-seated failure on the western flank, the need to avoid the use of unsightly concrete anchoring blocks and retaining walls required an unconventional and multi-faceted approach, as outlined below (and illustrated in Figure 3).

■ Optimisation of the slope geometry to reduce the slope’s gradient, while not compromising the slope’s stability through disturbance to the toe of the slope – this resulted in a shallow lower slope and a steeper upper slope.
■ Tecco® high-tensile strength steel wire mesh, four times stronger than normal steel wire mesh, was used together with large steel anchor plates on the lower portion of the slope where anchor loads were greatest.
A hydro-seeded erosion control mat was placed between the subsoil and high-strength steel mesh to minimise erosion and to aid in the timely revegetation of the slope.

On the upper, steeper portion of the slope, sprayed concrete was required. By using various dyes the mottled effect closely matched the surrounding soils, thus providing an aesthetic, pseudo-natural finish.

The surface and subsurface drainage was improved, thus reducing pore-water pressures acting on the failure plane. To this effect 12 m deep perforated-pipe-and-geotextile drains were inserted at regular intervals at several different levels into the slope at an inclined angle. The surface drainage was improved by providing a cut-off trench over the crest of the slope, and by providing benches to the slope with drainage channels on each step to collect and rapidly discharge the collected water.

In order to ensure that the mesh-and-soil-nail solution worked as intended – by distributing the high anchor loads anticipated into the mesh – detailed analyses of both the geotechnical and structural elements were required. This was particularly important, as this system is conventionally used for shallow superficial failures and thus would result in over-stressing of the mesh if poorly designed. In addition, as the load deflection properties of the mesh are specific to the site conditions, nail spacing, mesh-soil interaction and the associated yield stresses, detailed geotechnical and structural analysis were required to ensure that the design would function as intended.

The geo-structural components were modelled utilising Limit Equilibrium (LE) and Finite Element Method (FEM) software to ensure the integrity of the chosen system, and that each component integrated with the overall geotechnical solution. The nails were spaced and sized according to these results. Results of one of the Ultimate Limit State (ULS) analyses are illustrated in Figure 4.

Thereafter, structural FEM modelling of the mesh was undertaken to evaluate the yield characteristics, considering the specific soil interface at specific applied loads, whilst varying the spike plate sizes and nail spacing.

This in-depth numerical modelling facilitated the application of an established surficial rock support system to that of a global soil instability problem. However, this was not without its challenges, most notably the numerical modelling of matric suction and partially saturated soil conditions – a common phenomenon in decomposed quartzite, granite and talus slopes – some details of which are presented in the following section.

**SOME NUMERICAL MODELLING CHALLENGES**

Groundwater is one of the main factors responsible for slope failures. However, quantifying its influence accurately can be challenging. During extended periods of rainfall, the groundwater table rises, leading to an increase in pore-water pressure and an associated loss in the shear strength of soils. The converse is true for completely dry soil fabrics. However, this behaviour relates to just two extreme limiting conditions of a soil.

The traditional soil mechanics approach was inadequate in describing the behaviour of the slope failure, due to its partially saturated nature and the central role that matric suction plays in such scenarios.

The effect of matric suction is depicted graphically in Figure 5 in the extended Mohr-Coulomb plot whereby...
\((u_a - u_w) \cdot \tan(\phi_b)\) results in an increased apparent cohesion and associated increase in shear strength. \(u_a\), \(u_w\), and \(\phi_b\) denote the respective atmospheric and pore-water pressures, and \(\phi_b\) the unsaturated shear strength angle. This influence is often ignored during design due to the nature of \(u_w\) to fluctuate, through infiltration of groundwater, over the service life of the slope.

Based on the results of back analyses and sensitivity evaluations, the drainage measures implemented on the remedial slope were designed specifically to minimise infiltration of groundwater. Following this, various FEM seepage models, incorporating soil nails and mesh, were constructed to assess the effect of the drainage measures on the water table. Thereafter matric suction functions, incorporating the Soil-Water Characteristic Curve (SWCC), were used in the FEM analysis to assess the increase in stability due to negative pore-water pressures. The slope geometry was optimised further to reduce the effect of overburden pressures exerted on the high-tensile strength steel mesh and to ensure an extended drainage profile (Figure 5).

After assessing the effect that matric suction has on reducing the lateral pressures, the high-strength steel mesh was modelled in structural FEM software to assess the moments that would develop in the mesh, as shown in Figure 6. This was an iterative process which involved revisiting the geotechnical FEM models and changing the nail spacing to reduce pressures, and the associated moments, to acceptable levels. In other parts of the world the mesh has been doubled up where moments cannot be controlled sufficiently.

**DRAINAGE INFRASTRUCTURE AND ANCILLARY WORKS**

A number of stormwater inlet and outlet structures were damaged during the flood events. These were redesigned as follows, firstly to protect them from theft and vandalism, and secondly to make the standard provincial design purpose-suited to the particular challenges faced on the project:

- The inlet allowed by a standard polymer grid was too small and clogged easily. Once clogged, the water would overshoot the inlet, causing significant scouring of the road shoulder and side drains. This was overcome by redesigning the inlet with a narrow slot, and offsetting this within a channelled collector dish.
- Furthermore, rock falls and ravelling in the vicinity of the stormwater inlets were deemed to pose an elevated risk to the functioning of the inlets, as debris can overwhelm the inlet. Keeping the inlets open and operational was considered key to the functioning of the stormwater drainage system and minimising damage after heavy rainfall events. Subsequently, at identified inlets, the slopes above the inlets were stabilised and or protected from erosion, either through the provision of gabion-type structures, or more commonly by providing localised steel mesh.
- Dissipating structures were constructed in regions of concentrated flow to prevent scouring of inlet and outlet...
structures and the subsequent undermining of the road pavement.

Where sprayed concrete was necessary, this was coloured and shaped to blend in with the natural slope. Retaining walls, with the primary purpose of preventing rock debris from infringing the road, were also required. These were cladded with packed sandstone rock on the roadside to match the surrounding mountainside and the existing historic dry stone walling along the route. However, there existed a risk that the cladding could delaminate, especially after an impact. The cladding was therefore monolithically cast into the retaining wall.

Figures 7(a) to (c) illustrate a few of the drainage measures and other works implemented along the pass.

CONSTRUCTION CHALLENGES

Due to the urgent nature of the project, the contract was let out on the basis of a preliminary design for which certain variables would need to be confirmed once the contractor had established himself on the site. This emergency project thus required on-site design inputs during construction, with regular oversight or advice from specialist design engineers to assist in the on-site problem-solving. This was all overseen by the project manager/engineer who collaborated and kept in regular contact with the client to ensure that his interests were also met.

Notwithstanding this, a number of construction challenges were faced:

- With access to the face of the slope being difficult, the design solution was tailored for the use of light drilling equipment which could be operated by hand, using rope access and harnesses on the slope. This equipment had been developed by the contractor, Penny-farthing (Pty) Ltd, on previous projects, and could therefore be tailored for use on this particular slope geometry and soil nail dimensions.

- As part of the hydro-seeding operations, small pockets were excavated into the face of the slope where seeds and topsoil could be placed, as the excavated slope was not an appropriate growing medium. The slope was subsequently hydro-seeded before a biodegradable erosion control mat...
was placed over the seeds, followed by the mesh.

In one instance a natural gully on the slope needed to be protected from erosion, requiring geotechnical stabilisation. The high-tensile strength steel mesh and erosion control mat was not suited to high concentrated flows, so this was integrated subsequently with a bolted down reno-mattress to achieve a strengthened mesh facing and the flexible erosion solution offered by the reno-mattress. Figure 8 illustrates the challenging working conditions, the novel drilling techniques and the plant that had been developed.

RISK MANAGEMENT

The project is highly visible and recognisable, and the design involved the use of a number of innovations in order to effectively mitigate, at a reasonable cost, a proportion of the risk associated with the frequent failures. Ultimately, as with most underground and geotechnically related projects, the solution cannot be both practical and risk free without becoming too robust and uneconomical.

A gradation system was created whereby slope stabilisation and other interventions were focused on higher-risk and/or high-frequency areas.

The design team formed an integral part of the construction monitoring, thereby ensuring that designed elements were suited to the conditions, as some of these, due to the nature of the project, only became evident once areas were cleared or opened up during construction.

The final solution was a direct product of the quality of the design process and the adaptability thereof to suit conditions on site, coupled with rigorous quality assurance monitoring. This attests to the value of maintaining close contact between the geotechnical design team, the site personnel and the contractor throughout construction.

CONCLUSION

Geotechnical problems are inherently high in uncertainty, requiring solutions that are effective, but adaptable. The stabilisation of a progressive slope failure and drainage improvement on the Franschhoek Pass illustrated this clearly, and showed that a multidisciplinary design team and design approach, integrated with the contracting party throughout construction, can reduce this uncertainty, resulting in the delivery of a holistic solution.

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PROJECT DATA

Client: Western Cape Department of Transport and Public Works
Engineer: SMEC South Africa (Pty) Ltd
Contractor: Penny-farthing (Pty) Ltd
Value of works: R30 million