ASH RESOURCES

MATERIALS FOR TODAY AND THE FUTURE

For many decades, embankments in the vicinity of Van Reenen's Pass on the N3 highway between Johannesburg and Durban, have been exhibiting continuous displacement. The problem arises from the presence of mobile colluvium, on which the embankments were built. Pretoria based engineering and management consultants, BKS (Pty) Ltd, were commissioned by the N3 Consultants Consortium (N3CC) to evaluate the probability of failure of an embankment, designated Slope 3.

The colluvial soils, on which the road support embankments had to be built, have long been known to be prone to persistent and intermittent creep. This phenomenon does not necessarily lead to catastrophic slope failure, but if the slopes are left unattended, large cracks could develop which could lead to a large scale collapse during high rainfall periods. Examples of this are clearly evident on the old N3 road in the embankment directly below Slope 3. It is for this reason that the N3CC had arranged careful monitoring of Slope 3 since February 1999. Although work had been done previously to evaluate the factor of safety in the embankment (Knight Hall Hendry, December 1993), BKS are believed to be the first to calculate the probability of failure of Slope 3.

BKS determined the probability of failure to be approximately 2,2% to 8,6% (with and without trees). "These values were considerably larger than the suggested value of 0,5% that is considered acceptable for permanent slopes where free public access is allowed," says BKS's Dr Johan Lourens, Divisional Director - Geotechnical Engineering. "Consequently, we recommended that the stability of Slope 3 should be improved. Our recommendation was accepted and BKS was contracted by N3CC to undertake the design of the stabilisation works." N3CC were appointed by the Dabulantaba Joint Venture (N3JV), who are the contractors for the N3 concessionaire, N3 Toll Concession Limited (N3TC).

The core structural elements of the BKS design are 51 reinforced concrete piles, 1000mm in diameter and varying in length between 8 and 20m. The piles are spaced 2m apart and socketed into the rock for a length of at least 2m. "Unlike the piles typically used in buildings, these piles carry a negligible axial load," comments structural engineer, Erhard Kruger, an Associate of BKS Structures North. "In this design, after the pile has been installed, a portion of fill is excavated and the pile restrained horizontally by a ground anchor attached near the top. The anchor is imbedded into the upside fill and anchored into rock. The fill exerts an enormous horizontal load on the pile, which is acting as a propped cantilever. The bending moments and shear forces in the piles are very high, with the working load bending moments approaching 1600kNm and the shear forces 1150kN." The spaces between the piles are filled in with shotcrete arches. Mesh is put against the soil and then a 100mm layer of shotcrete applied to it. In this way, looking back up the embankment, the exposed stabilising structure is a series of pillars and shotcrete arches.

The piles are obviously the crucial elements restraining the fill from slippage. While the integrity of the piles is the key factor in a design lifespan of fifty years, the high bending moments they are subjected to will inevitably lead to flexural cracking in the concrete on the tension faces of the piles. The design surface crack widths could be of the order of 0,5mm, not merely surface crazing and could result in the reinforcement being in contact with the ground water. With this concern, BKS paid considerable attention to evaluating the soil conditions and to the design of the piles.

The services of corrosion experts, Corrolec, were used to establish the corrosivity of the ground conditions. Some areas of the soil were found to be fairly acidic with a pH as low as 4,8 and also with a low resistivity. Corrolec classified the soil as borderline 'corrosive'. This confirmed that

special precautionary measures were required to ensure the durability of the concrete and the reinforcement.

The key to producing strong durable concrete is to use a low water/cement ratio of 0,5 and to blend the cement with a pozzolan. "We have been and are involved in designing a wide range of water retaining structures," says Kruger. "We did the designs for the Grand Central Water Tower, the 9 megalitre reservoir at Kopanong in the Winterveldt, Venterdorp Sewage Works and numerous reservoirs. In all of them we used Dura-Pozz®, the quality fly ash from Ash Resources as the pozzolan. We have always been very pleased with the performance of Dura-Pozz® mixes and the real benefits that they impart to the concrete. The density and impermeability is improved while for mass pours, the heat of hydration is lowered. The off-shutter finish is excellent and even if fine cracks develop through a structure with some leakage, there is the benefit of autogenous healing. In the presence of Dura-Pozz®, fine cracks tend to seal themselves over time."

For the pile design BKS wanted to take extra precautions by achieving an even denser and more durable concrete. They decided to incorporate the ultra-fine fly ash, Super-Pozz® in the mix as well as Dura-Pozz®. The size of Dura-Pozz® is typically 90% passing a 45 micron sieve, whereas for Super-Pozz®, 90% passes an 11 micron sieve. Super-Pozz® is a product from Micron Materials, an associate company of Ash Resources. Although it is quite possibly the first time in South Africa that the two products have been used together in a concrete mix, both are well established in the Middle East. In the highly corrosive and aggressive environment of the Arabian Gulf, Dura-Pozz® , used in conjunction with Super-Pozz®, have become established as standard specified cement extenders in high durability concrete mixes, particularly for marine structures.

The R8,6 million contract for constructing the piling stabilisation barrier was awarded to Ground Engineering (GEL) and they started work on site in September 2003. They approached Lafarge South Africa's Product Assistance Department (PAD) to help with the design of the required mix. The original intention had been to use Lafarge's Buildcrete 32,5N, a blended CEM II/B-V 32,5N cement, which incorporated Dura-Pozz® and to add 5% Super-Pozz®. However, this combination would have pushed extender content higher than the specified maximum of 30%. At the time, Lafarge had just launched a successor to Buildcrete 32,5N in the form of Buildcrete 42,5N, a CEM II/A-V 42,5N formulation containing 17% Dura-Pozz®. PAD proposed that this should be used to blend with 6% Super-Pozz®. The proposal was approved by BKS.

In view of the low water/cement ratio being used in the mix, a Chryso admixture was also added to improve workability.

Super-Pozz® is a highly reactive alumino-silicate pozzolan with a unique particle size distribution. With a mean particle diameter typically ranging between 3,9 and 5,0 micron, Super-Pozz®'s bi-modal distribution and ultra-fine particle size effectively fills the void spaces between the cementitious components, creating an ideal fine filler effect. With durability being a key factor in the design of the piles, the dense paste matrix produced with Super-Pozz® addition was ideal.

Designing an impermeable, high durability concrete was still not sufficient for BKS. Corrolec had advised that galvanic corrosion was a possibility, resulting from the exposure of reinforcement to ground water at flexural cracks. Although cathodic protection of the reinforcement would have been the cheapest option, it requires regular maintenance and the equipment is vulnerable to vandalism. Hot dip galvanised reinforcement was also ruled out because of the acidic nature of the soil. BKS finally decided to use 3CR12 reinforcing in the piles in conjunction with a 75mm concrete cover. This added another dimension to the construction cost control. With the fairly high unit price of 3CR12 compared with normal steel, it was important to optimise the cutting lengths to minimise wastage.

"This has been a particularly interesting project for BKS," comments Rudi Kühn, Project Director of BKS, "starting with the challenge of establishing the probability of failure of an embankment

that has been on the move for more than ten years. On the structural engineering side, we then had to design piles to withstand abnormal and extremely high loads. This involved non-standard reinforcing and a highly specified concrete which saw the first use of Super-Pozz® in South Africa for such an application. The work went well - the depth of the rock, the consistency of the soil and the water conditions gave us no nasty surprises and we finished on schedule in December, 2003."