Bramhoek Dam – South Africa's 1st Grout Enriched Roller Compacted Concrete Dam

E. LILLIE, Bramhoek Consultants JV, Johannesburg, SA.
M.J.E. NEUMANN, Bramhoek Consultants JV, Johannesburg, SA.
L. VAN ZYL, Concor Roads and Earthworks, Johannesburg, SA.

SYNOPSIS. The Bramhoek Dam forms the lower reservoir to the Ingula Pumped Storage Scheme. Although only 337m long and 37m high, the dam incorporates interesting features and has proved a challenge to construct. The presence of extensive huge dolerite boulders tightly bedded in clay required a combination of 70t excavators and blasting to reach suitable founding. For speed and economy of construction, the upstream and downstream faces are composed of grout enriched roller compacted concrete (GE-RCC). An extendable mobile conveyor belt with a reach of 41 metres was used where access was restricted. To accommodate flood inflows, even while the scheme is in generation mode, a high capacity outlet in the form of two 2.8m diameter pipes was installed.

BRAMHOEK DAM DESIGN ASPECTS

Background

This paper presents the design aspects, supervision and construction of Bramhoek Dam, which will form the lower storage reservoir for the 1332MW Ingula Pumped Storage Scheme (IPSS). The hydropower scheme will make use of an active water storage capacity of 19Mm³ at a capacity of 21 GWh, to generate approximately 60 million kWh of peak-time power on a weekly cycle. The site was handed over to the Bramhoek Dam Joint Venture (BDJV) on the 2 April 2008 and the commencement of impoundment is scheduled for 10 April 2010. The planned completion date is 23 October 2010, at an estimated contract price of R389M including escalation. Early impoundment of the dam is essential in order to ensure initiation of the first generation unit in 2012.

Location and Geology

Bramhoek Dam is located on the Bramhoekspruit in the upper catchment of the Klip River, at the toe of the Drakensberg escarpment in KwaZulu-Natal

Managing Dams: Challenges in a Time of Change. Thomas Telford, London, 2010

province, some 22km north-west of the town of Ladysmith. The dam site and reservoir area is underlain by sedimentary rocks of the Volksrust Formation, Ecca Group, Karoo Supergroup, which have been intruded by post-Karoo dolerite sills and dykes. The Volksrust Formation sediments comprise primarily dark grey to black silty mudrock and subordinate light khaki brown shale. Figure 1 below presents a geological long section along the dam setting out line.

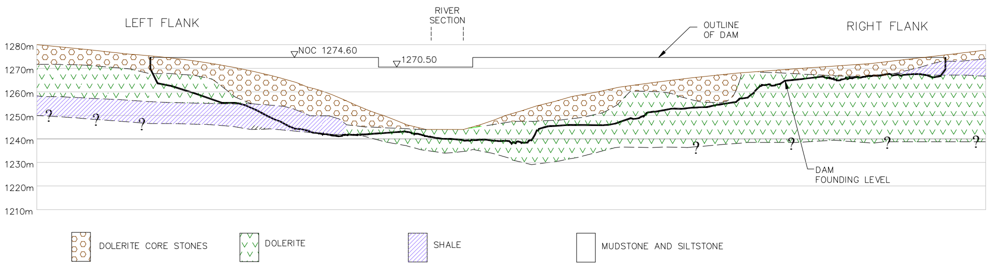

Figure 1. Geological long section along the front face of the dam

DAM CHARACTERISTICS

Project Statistics

Bramhoek Dam was registered with the Dam Safety Office on 9 February 2005 and, in accordance with the RSA Water Act, has been classified as a Category III dam with a high hazard potential. The principal components of Bramhoek Dam are detailed below, with project statistics shown in Table 1.

Principal Components

- A single curvature RCC gravity dam wall, 337m long with a maximum structural height of 37.2m and a height above river bed level of 31.1m. The upstream and downstream facing consists of 400mm wide grout enriched roller compacted concrete (GE-RCC) – see Figure 2 below.
- An uncontrolled 40m crest length ogee, stepped spillway, with a short flip (roller) bucket apron. The crest level will be 500mm above the full supply level, to effectively eliminate the risk of loss of water due to wind and wave action, as well as through over-generation for a maximum period of approximately 1 hour – see Figure 4 below.
- Intake works, Outlet House and release control works on the right side of the Spillway, built into a conventional concrete block in the dam wall – see Figure 3 below. The intake works encompasses twin 2.8m diameter high capacity outlet pipes (75m^3/s) which run parallel in the mass concrete body of the dam, emerging in a sump at the toe where flow will be released through 2.8m diameter butterfly valves. Discharges will be controlled using 1.8m diameter hooded sleeve valves

immediately downstream of the butterfly valves. The high capacity system's primary purpose is in facilitating flood management.

Table 1. Project Statistics

General & Hydrological		**Dam Statistics (continued)**	
Location	$28^{o}17'$S $29^{o}34'$E	Minimum operating level (MOL)	RL 1258m
Catchment area	60.11km²	River Bed Level	RL 1243.5m
Mean Annual Precipitation	1053mm	Lowest Foundation	RL 1237.4m
Mean Annual Runoff	14.6Mm³	Reservoir surface area at FSL	240 Ha.
k value for RMF	5.0	Gross Storage at FSL	26.26Mm³
		Live Storage at FSL	19.32Mm³
Material volumes		Storage above RL 1258m	21.92Mm³
Excavation	120 000m³	Dead Storage below RL 1258m	4.34Mm³
Backfill	50 000m³	Allowance for Evaporation	0.765Mm³
RCC	67 000m³	Allowance for Siltation	1.35Mm³
Mass concrete	10 500m³	Gross Storage at RL 1270.5m	27.48Mm³
Reinforced concrete	4 600m³	Dam Height (above river bed)	31.1m
GE-RCC	20 800m³	Dam Height (above foundation)	37.2m
		Dam Crest Length	337m
Dam Statistics		Spillway Crest Length	40m
Full supply level (FSL)	RL 1270.0m	Spillway capacity	715m³/s
Spillway Crest Level	RL 1270.5m	Maximum scheme generation flow for Spillway crest length	348m³/s
Non Overspill Crest Level	RL 1274.6m		

Regular compensation flow and general river releases will be discharged via a 1m diameter low capacity outlet pipe (3.5m³/s). The downstream measuring weir will provide a tailpond and stilling basin for flood releases through the high capacity outlets and when overtopping of the spillway occurs.

The water license requires that the system should be maintained at the optimum storage volume, releasing additional inflow into the system after an allowance for evaporation, until the system volume reaches optimum operating level. If spilling is to occur during generation conditions, generation may continue provided the outlets are closed and spillage does not exceed 120% of the maximum release rate.

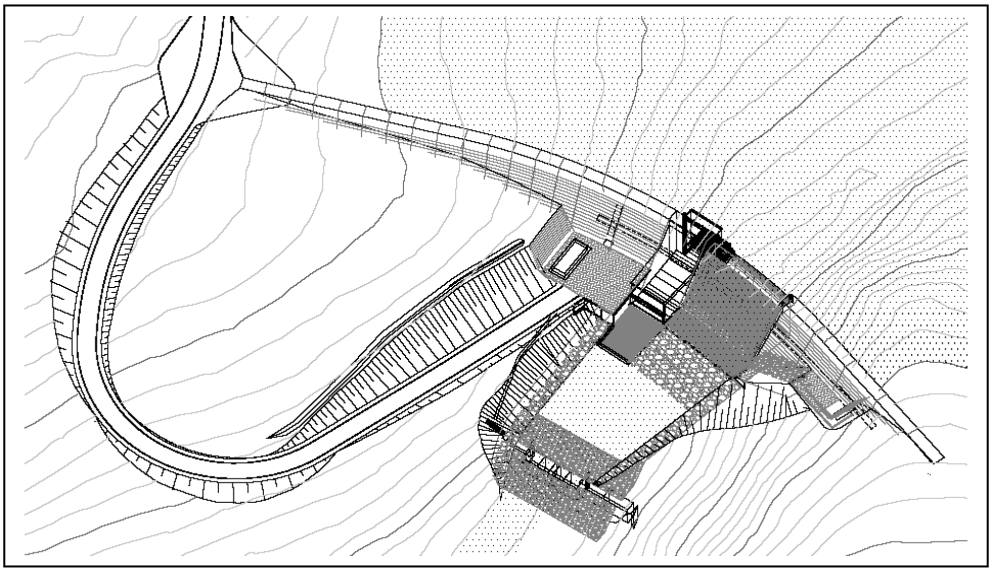

Figure 2. Isometric view of the Bramhoek Dam, Downstream Weir and Access Road

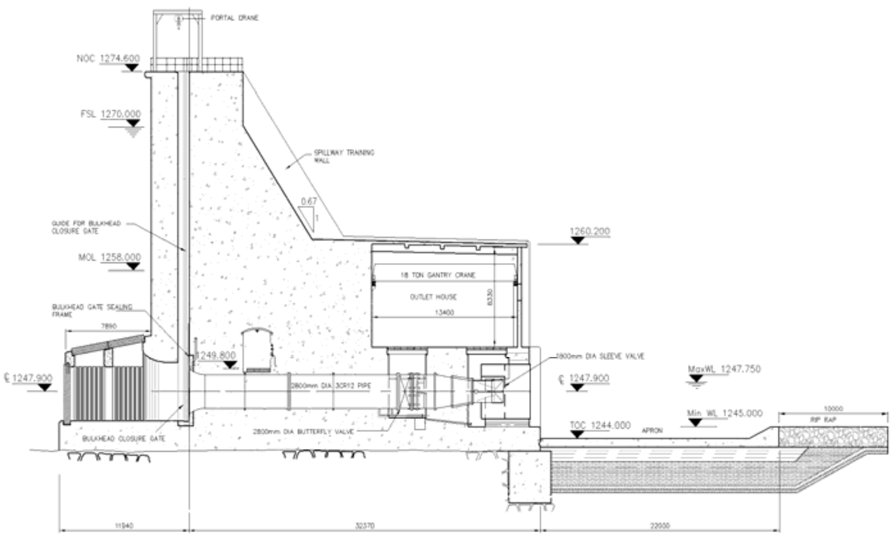

Figure 3. Cross section through Outlet Block

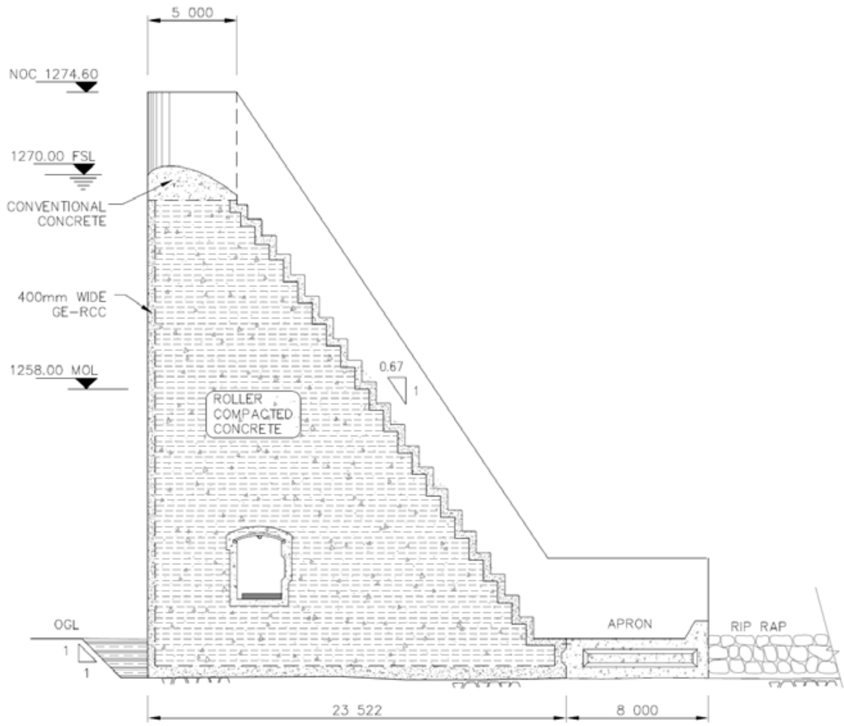

Figure 4. Cross section through Spillway

CONSTRUCTION OF THE DAM

RCC Mix Designs and Test Sections

The RCC aggregates and other processed stone materials are mined on site in a quarry nearby the dam site, from the same dolerite sill that the dam is founded on. The quarried rock is processed at a crushing plant operated by B & E into three broad grading bands for the coarse aggregate, namely 4.75mm to 19mm; 19mm to 37.5mm and 37.5mm to 53mm. The RCC fine aggregate is manufactured to a specific grading to yield a well and evenly graded crusher sand. The design parameters for the RCC, progress of the site trials and fine tuning of the mixes are shown in Table 2 below. Due to delays in the site establishment, the RCC trial mix testing was performed initially off site at an approved laboratory, and thereafter moved to site once the batching plant and site laboratory were operational.

Following the development of the "original" mix in a Johannesburg based laboratory, site trials were conducted whereby the RCC was placed in the aggregate storage bays and wherever slabs were required for site establishment. From the onset problems were experienced with the workability, as can be expected when concrete is manufactured from aggregates wholly produced by mechanical milling. The coarse shape and high crusher dust content of the fine aggregate required excessive water to provide a measure of workability. The harsh mix yielded Vebe times exceeding 45 seconds.

A further four modified mixes were tested on site before arriving at mix T4. The table below shows the gradual progression of the RCC mix design optimization in that (i) the cementitious content was raised, (ii) the fly ash content was raised, which effected increased lubrication of the mortar fraction, (iii) the coarse aggregate content was significantly increased, with emphasis on the coarser bands, (iv) the crusher sand content was significantly reduced, which enabled (v) a significant reduction in the water content. Mix T4 was used for the first trial section cast on site in late February 2009, of dimensions 60m long x 10m wide in plan and cast in four layers each of 300mm compacted thickness.

Table 2. RCC Mix Design Progression

Constituent	**Description**	**Specified limits**	**Orig. mix**	**Mix T4**	**Mix T5**
Cementitious	Cement CEM I 42.5	≥57 kg/m^3	70	55	70
	Fly Ash	≥ 45 %	70	95	95
Aggregates	37.5mm/53mm	Water	400	487	500
	19mm/37.5mm	absorption	450	675	640
	4.75mm/19mm	≤1%	400	423	423
	RCC crusher sand	abs ≤1%	1180	926	905
Liquids	Water		135	105	110
	Admixtures		None	None	None
Ratios	Water/Cement	0.5-1.0	0.96	0.70	0.67
	Aggregate/Cement		17.4	16.7	15.0
	Sand/ Aggregate	0.33-0.45	0.49	0.37	0.37
	Paste / Mortar	≥ 0.35	0.35	0.37	0.38
	Vebe (seconds)	10-25	35-40	80-90	15-20
Strength (MPa)	7 days maturity	4.5	4-6	3-5	5-7
	28 days	12.5	11-13	9-12	12-14
	90 days	17.5	15-18	14-16	17-20

Note: Mix T4 used in Test Section 1; Mix T5 used in Test Section 2.

Although mix T4 yielded a workable RCC, achieving the specified Vebe times still proved difficult and this was demonstrated at the test section where the mix still appeared somewhat harsh, prone to segregation when levelled with a dozer and exhibited rapid drying out. When cores were extracted in March 2009, it became immediately apparent that the construction methods used for placing and compacting the RCC and grout enriched RCC (GE-RCC) needed to be changed. The vertically extracted cores broke apart at nearly every horizontal layer interface and the horizontal cores broke apart at the GE-RCC / RCC interface. The 90 day strengths, of core sections that could be salvaged, did not exceed the design strength of 15MPa by a sufficient margin, and hence a further refinement was implemented to arrive at mix T5. This mix was used for the second test section.

The effect of fine tuning of mix T4 was quite marked in that mix T5 yielded a RCC that did not segregate, retained its moisture and hence remained workable for longer, compacted to a smooth finish with the vibratory roller, and retained a slight "sponginess" after compaction. The placing and compaction of the RCC was closely monitored to ensure that the time from batching to final compaction did not exceed 40 minutes. Measured quantities of grout were poured inside wooden open frames sized specifically for the grout quantity required over the 400mm wide by 300mm deep facing concrete. The grout was left to settle for 5 minutes before the facing concrete was compacted with immersion poker vibrators. To verify the GE-RCC / RCC compaction, the formwork was stripped from one corner the following day and a 1m x 1m section ripped off with an excavator. The interface was not discernable, proving the suitability of the revised construction methods. Cores were extracted after 56 days maturity, but these still tended to part at the horizontal layer interfaces. It was surmised that extraction of cores from RCC with a low cementitious content and high fly ash percentage, requires extended curing times and cannot be performed with the type of core drill found in most laboratories.

Based on the successful placing and compaction of mix T5 at the second test section, this mix was selected for construction of the RCC dam wall. Cores of 150mm diameter will be extracted once the RCC has reached 90 days maturity, with a specialized rig of a mass and rigidity that will limit disturbance of the core during drilling and extraction. If necessary, split casings will be used.

<u>Excavations</u>

While the RCC mix designs and trials were being performed, excavation of the dam footprint commenced from the lowest point in the centre and progressed up the flanks. The geotechnical investigations indicated the dolerite sill being located a few meters below ground level. Once excavation commenced it was, however, determined that the upper section of the dolerite sill had weathered into large dolerite blocks several metres in cross section, surrounded by completely weathered material and clay. A comprehensive drilling programme was initiated, consisting of 35 holes drilled up to 11m in depth, to determine the hard founding level. An average of 8m of blocks, corestones and material was removed with the 70t and 50t excavators – refer Figure 5 below.

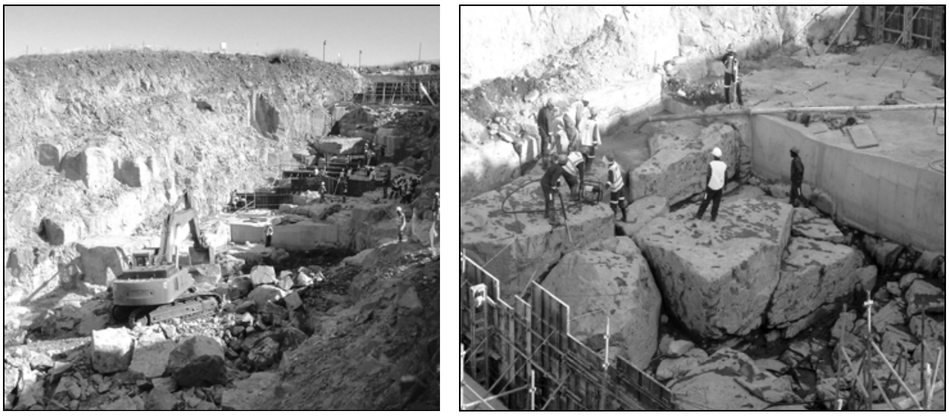

Figure 5. 70t excavator used to pull out loose dolerite blocks and corestones

Placing of RCC and GE-RCC Facing Concrete

A Tsekoura Icon batching plant was established above the right flank, within a kilometre of the dam. The plant is sized for mixing 2m³ at a time and is rated for 135m³/hour. To date, the batching tempo has averaged between 80 – 100m³/hour. The RCC is transported to site using three 30t Volvo articulated dump trucks (ADTs), each truck being loaded with 10m³ RCC per trip. The temporary site access road to the dam footprint, and the branch-offs at different chainage and elevations, have been surfaced with RCC to keep the tyres clean and thereby minimize contamination of the surface of previously placed RCC within the dam footprint. Prior to commencement of placing RCC the roadway is cleaned by a Bobcat with a mechanical broom attachment.

The RCC surface to be covered is thoroughly cleaned with a high pressure air/water hose, all excess water blown away and thereafter placing of RCC commences at the point most distant from the access point. If the previously placed RCC layer is more than a day old, then mortar is placed with squeegees to a depth of ≈ 10mm and thereafter the ADTs dump their load of RCC on top of this mortar bedding layer. The RCC cones are levelled by a Komatsu D51, a 7t dozer, riding on top of the loose RCC, to an uncompacted thickness of approximately 360mm. Thereafter the ADTs reverse up to the leading edge of the uncompacted RCC and dump their loads onto the same. Once a sufficiently large area has been levelled, then the RCC is compacted by a 16t vibratory roller to within 1m of the upstream and downstream formwork – refer Figure 6 below. In general 6 to 8 passes are required to compact the RCC to a 300mm thick layer and to the required wet density of 97% of 2650kg/m³.

Figure 6. Placing of bedding mortar, dumping of RCC, levelling and compaction thereof.

Grout with a water/cement ratio of 0.9 is then poured over the uncompacted RCC within a 400mm wide strip from the facing formwork and allowed to seep in for roughly 5 minutes. The 400mm wide strip of GE-RCC is then vibrated with immersion poker vibrators, taking care to push the vibrator into the previously cast underlying GE-RCC layer – refer Figure 7 below.

Figure 7. Compaction of 400mm wide GE-RCC strip against formwork and the rockface.

From the trial sections it was determined that 10 litres of grout applied to the 400mm width and a 1m running length was sufficient to ensure a dense, GE-RCC facing concrete. The GE-RCC / RCC interface is thereafter compacted with a 2t vibratory roller and small walk-behind rollers, up to the RCC already compacted by the 16t vibratory roller. The same procedure is used where RCC is cast against the rockface of the excavated dam footprint.

The compacted RCC surface is kept continuously moist with hand-held hosepipes and sprinkler systems, to ensure uninterrupted hydration of the cement. This required constant monitoring, especially during the dry winter months and more so between the windy period of July – September.

Placing of RCC is performed on a 24/6 basis, with successive layers being placed on hot joints where initial set has not taken place or warm joints where initial set has taken place but the fresh RCC is still able to penetrate into the previously compacted layer (generally within 250°C hours (temperature x time)). Whenever placing of RCC had stopped for any appreciable time such that no penetration was possible, as typically occurred after a weekend or extended plant breakdown, then the surface of the RCC was treated as a cold joint. This entailed green cutting the surface with the mechanical broom on the Bobcat and thereafter keeping the surface wet – refer Figure 8 below.

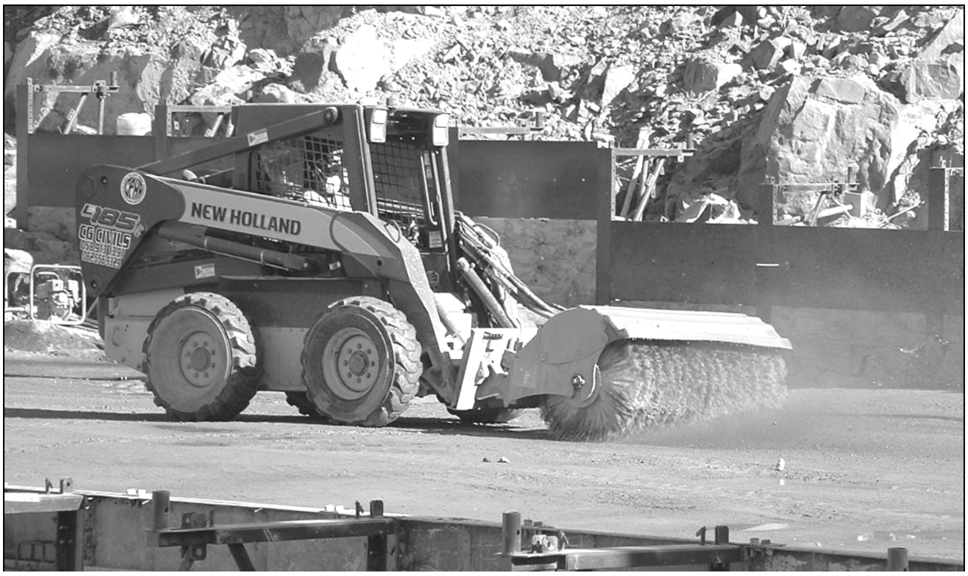

Figure 8. Green cutting of the RCC surface using the Bobcat mechanical broom

Due to the steep topography and extensive dolerite outcrops around the dam footprint, access to certain areas of the excavated dam footprint was restricted. The placing of RCC commenced initially either side of the Outlet Block, situated in the deepest section of the dam. Ramps composed of RCC were constructed in tandem with the 1.2m lifts of RCC placed in the dam wall. Once the gallery level was reached, some 10m above the lowest foundation level, a Putzmeister Telebelt TB130 was used for conveying the RCC to the elevated dam level, specifically the 5m wide strip between the gallery wall and the upstream face of the dam. In this restricted area the

RCC was levelled with the Bobcat skid steer loader and compaction of the RCC effected with the 2t and smaller vibratory rollers. To facilitate the discharge of RCC from the wide ADT bin into the narrow hopper of the Telebelt, a purpose made chute was manufactured at the site workshop which fitted onto the hopper.

Due to the speed of concrete placement enabled by the Telebelt, the latter proved most useful for mass concrete pours on the Outlet Block, downstream weir, retaining walls either side of the Spillway, apron slabs and wherever pours were required at elevated and restricted access - see Figure 9 below.

Figure 9. Putzmeister Telebelt used for placing RCC at elevated and restricted access areas

Routine Testing

Due to the low cementitious content and dry nature of RCC when placed, the batching thereof has to be rigidly controlled to ensure that the fresh RCC delivered to site is workable. Corrections for moisture content of the fine aggregate are performed every four hours and the consistency of the RCC (Vebe time) is recorded for every 180m³ of RCC batched. The ambient and fresh RCC temperatures are recorded for every delivery. The maximum placing temperature of the RCC may not exceed 23°C, in order to prevent excessive thermal gradients developing within the mass of the compacted RCC. This is achieved by storing the fine and coarse aggregates under cover and spraying the latter with chilled water at 4°C.

The density of the in-situ RCC is determined via the use of a Troxler nuclear density gauge. Three sets of 9 No. 150mm sized cubes are cast for each day of RCC placement, for crushing at 3, 180 and 365 days maturity. A core drilling programme will be implemented in due course, for extracting 150mm diameter cores to determine the in-situ compressive strength and for determining the shear strength, tensile strength, density, permeability and Poisson's ratio, both in the parent material and across the lift joints.

Instrumentation

The following instruments will be installed to monitor the performance and behaviour of the RCC dam wall and the dam foundation during the construction and operation of the dam:

- Eight Long-base-strain-gauge-temperature meters at strategic locations across induced joints in the body of the RCC.
- Three dimensional tilt meters on ten joints on the dam NOC.
- Two v-notch weirs for measuring seepage in the gallery drains.
- Eleven piezometers to measure foundation pressures.
- Two air, two water and four concrete temperature gauges in and on the dam wall.
- An array of six strain gauges will be installed to measure temperature related strain across the dam structure in an upstream to downstream direction.
- Survey and settlement pins will be installed at strategic positions on the dam crest.

THE WAY FORWARD

The use of RCC for dam construction is well established in South Africa. The use of GE-RCC, instead of conventional concrete for the upstream and downstream facing, is, however, a new concept. Initially it was regarded with some misgivings by many on site, but the simplicity and speed of this operation quickly overcame initial reservations. Although the Bramhoek Dam is relatively small in comparison to the many big dams constructed in Southern Africa, the successful use of GE-RCC will no doubt lead to this facing material being widely selected for future dam construction.