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Proceedings of the

International Symposium on

“Appropriate technology to ensure proper Development, Operation and Maintenance of Dams in Developing Countries”



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International Symposium on

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Foreword

From the Chairperson of the Local Organising Committee of ICOLD 2016 and Chairperson of the South African National Committee on Large Dams (SANCOLD)

We are extremely happy that this ICOLD Symposium was staged in South Africa as part of the 84th ICOLD Annual Meeting held in Johannesburg in May 2016.

Sunny South Africa is known:

- for its friendly "rainbow" nation as demonstrated during the highly successful 2010 Soccer World Cup event;
- for its beautiful scenery with the Big Five animals in our National and Private Game Parks, the Drakensberg Mountains with its Lesotho Highlands dams and Cape Town with its world heritage site Table Mountain;
- to have 5 030 registered dams of which more than 1 114 are large dams;
- for contributing significantly since 1965 to ICOLD and Africa regarding development of the art and science of dam engineering.

Our SANCOLD Local Organising Committee worked very hard to ensure that this event was well organised, had a high technical content and could provide a forum to experience Africa.

This Symposium reflects much of local, regional and international experience with dams with an emphasis on the developing Africa. The keen interest we received from authors reflects that the subject matter is apt and we hope that these Proceedings together with the delivered Symposium Presentations will form a valuable resource for the future of dams throughout the world.

Danie Badenhorst
Chairperson of the Local Organising Committee of ICOLD 2016
Chairperson of SANCOLD

Preface

Not only do many countries in Africa and other developing countries still require major water resources and dam engineering development for both water and energy supply but these countries also experience problems with proper long term operation and maintenance of their existing infrastructure. These problems in many cases lead to unsafe and unsustainable conditions that negatively impacts on the surrounding communities as well as the environment.

To try and mitigate this and share the some of the collective wisdom and knowledge available in the larger ICOLD family it was decided have organise an International Symposium titled “Appropriate technology to ensure proper Development, Operation and Maintenance of Dams in Developing Countries” to address some of these issues, in conjunction with the 84st Annual Meeting of the International Commission on Large Dams (ICOLD). The ICOLD Meeting host, the South African National Committee on Large Dams (SANCOLD), organized the Symposium.

These Proceedings contain papers on 9 different themes. Before the Symposium call for papers, 8 different themes were identified as appropriate. A number of relevant abstracts that satisfied the main theme but that did not necessarily satisfied any of the 8 chosen themes were received and subsequently categorised under a theme called “Other”. The 9 themes for the Symposium therefore are:

1) Social and environmental impacts and mitigation measures;
2) Advances in the rehabilitation of dams and appurtenant works to extend their service life including the following:
   a) Improving spillway capacity and flood hydrology determination;
   b) Structural improvements to mitigate the effects of Alkali aggregate reaction, internal erosion potential, foundation failure;
3) Innovative river basin management including the optimisation of the operation of dams;
4) Reservoir sedimentation and management;
5) The state of the art of the tailings dams for their complete lifespan;
6) Strategies for proper surveillance of dams;
7) Sustainable hydropower development in developing countries; and
8) Other

We have received a total number of 333 papers for the Symposium. After the review process 245 papers from 42 different countries were chosen for publication in the proceedings. Of these 245 papers, 96 papers from 34 different countries were chosen for oral presentation in 4 parallel sessions and another 68 papers from 26 different countries were chosen for poster presentation.

All papers submitted for the Symposium were subjected to a full process of peer review and the proceedings contain only those papers that were accepted following this process. The review of the papers was undertaken by the members of the review panel acting independently on one or more assigned papers. This invaluable assistance, which has greatly enhanced the quality of the Proceedings, is gratefully acknowledged.

Finally, the editor wishes to thank the authors for their efforts at producing and delivering quality papers of appropriate quality and relevance. We trust that the Proceedings will be a valued reference for those working in the various fields covered and that it will form a suitable basis for discussion and future development and research.

Louis C. Hattingh
Editor

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Theme 5. The state of the art of the tailings dams for their complete lifespan

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Theme 8. Other

Theme 6. Strategies for proper surveillance of dams

International Symposium on "Appropriate technology to ensure proper Development, Operation and Maintenance of Dams in Developing Countries", Johannesburg, South Africa, 18 May 2016

SURVEILLANCE OF BEDFORD AND BRAMHOEK DAMS

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ABSTRACT

Bramhoek and Bedford Dams are the two reservoirs for the Ingula Pumped Storage Scheme. Bedford Dam is the upper storage dam which is a 41m concrete faced rockfill dam. Bramhoek Dam is the lower storage dam which is a 32m high roller compacted concrete dam. Both Bedford and Bramhoek Dams have been provided with a wide range of instrumentation to measure their performance. Bedford Dam is currently below the minimum operating level. Bramhoek dam starting impounding water in November 2010 before the end of the construction period. Bramhoek dam filled very quickly during January 2011 and was at the full supply level by the end of April 2011.

The instruments in Bramhoek Dam have provided useful information of its performance. Some of the main findings were; not all the induced joints in the RCC dam opened, the RCC left bank rotated after first filling more than the right bank, the piezometers all showed a rapid increase in uplift pressure during first filling which stabilised quickly, the strain gauges indicated a maximum negative 200 micro strain in the core of the dam, the temperature rise in the RCC after placement was about 10 degrees Celsius and post construction the temperature in the core of the dam ranges by 2 degrees between summer and winter. The measured leakage from the dam was about 4.5l/s immediately after construction but is now less than 1l/s.

1. INTRODUCTION

This paper presents the dam safety surveillance approach for Bedford and Bramhoek dams. At the time of writing this paper, Bramhoek Dam has been full since April 2011, Bedford Dam water level remains below the minimum operating level. Bramhoek Dam forms the lower storage reservoir and Bedford Dam forms the upper storage reservoir for the 1332MW Ingula Pumped Storage Scheme (IPSS). The hydropower scheme will make use of an active water storage capacity of 19 million m^3. Although neither Bedford nor Bramhoek Dams are very large dams, they are very important structures as the IPSS depends on their reliability. There are also complex environmental release requirements that must be adhered to in terms of the Water Use Licence issued by the Department of Water Affairs and Sanitation. These releases must also be effectively measured for auditing purposes.

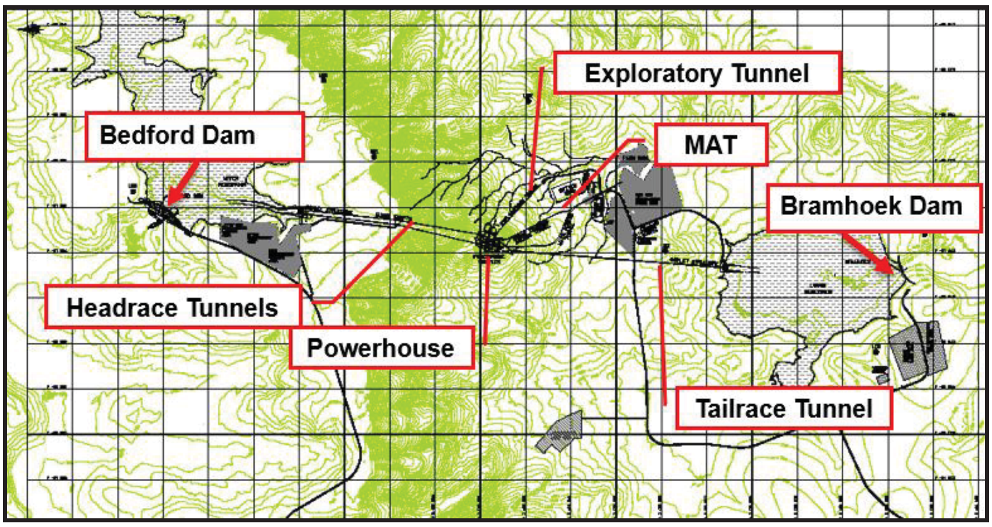

Figure 1. Ingula Pumped Storage Scheme Layout

2. BEDFORD DAM INSTRUMENTATION

Bedford Dam was classified by the Dam Safety Office as a Category III dam with a high hazard potential. Bedford dam is a 41m high Concrete Faced Rockfill Dam (CFRD) with a storage capacity of 22.6 million m^3. The crest length is 774m and the fill volume is just over 1 million m^3.

Instruments are included to monitor the performance and behaviour of the CFRD embankment, the concrete face, the plinth, the perimetric joint and the outlet conduit during the construction and operation of the dam. Magnetic Flow meters were installed on the outlets pipework to measure flow releases to the downstream wetland.

The instrumentation included the following:

- Joint meters for opening, settlement and shear monitoring at 5 locations on the perimetric joint.
- Joint meters to monitor openings in the face slab where opening is anticipated.
- Tilt meters are located on the CFRD face.
- Survey and settlement pins are installed at strategic positions on the dam embankment.
- Internal embankment settlement cells are installed on a specific cross section.
- Piezometers are installed in the foundation and in the dam embankment to monitor pressure.
- A seepage gauging weir is strategically located to allow the monitoring of seepage from the CFRD dam.
- Strain gauges and pressure cells monitor imposed loading and deformation of the outlet conduit.
- A water level meter is installed on the inlet/outlet tower.

3. BRAMHOEK DAM INSTRUMENTATION

Bramhoek Dam was also classified by the Dam Safety Office as a Category III dam with a high hazard potential. Bramhoek dam is a 32m high Roller Compacted Concrete Dam (RCC) with a storage capacity of 24.9 million m^3. The crest length is 337m and the concrete volume is just over 80 000m^3.

Instruments are included to monitor the performance and behaviour of the RCC dam. Measurements are taken of the micro strains in the concrete, movement of the dam, relative movement between blocks, induced joint openings and the pore water pressure in the foundation. A crump weir has been constructed downstream to measure flow releases.

The instrumentation included the following:

- Eight Long-base-strain-gauge-temperature meters at strategic locations across induced joints in the body of the RCC.
- Three dimensional joint meters on eight joints on the dam crest.
- Tilt meters on eight joints on the dam crest.
- Fifteen piezometers in four rows to measure foundation pressures.
- An array of five strain gauges was installed to measure temperature related strain across the dam structure in an upstream to downstream direction.
- Three air, three water and five concrete temperature gauges in and on the dam wall.
- Four V-notch weirs for measuring seepage in the gallery and at the toe of the dam.
- A crump weir downstream to measure releases from the dam.
- Survey and settlement pins was installed at strategic positions on the dam crest.
- A water level meter was installed at the inlet/outlet works.

Most instruments are of the vibrating wire type, capable of remote reading and fully waterproof.

Trigger limits were set for each instrument with instructions on actions required should these limits be reached.

4. BRAMHOEK DAM INSTRUMENTATION RESULTS

4.1. Long-Base-Strain-Gauge-Temperature-Meters

Long-base-strain-gauge-temperature-meters (LBSG) are very effective and reliable for the measurement of induced joint openings and temperature in RCC dams. A row of these instruments are installed across three joints in the dam wall at gallery level.

The joints that are instrumented with LBSGs are at 180m on the right bank, the central joint on the spillway section at chainage 220m and the joint above the lowest point on the foundation at chainage 260m as shown on figure 2.

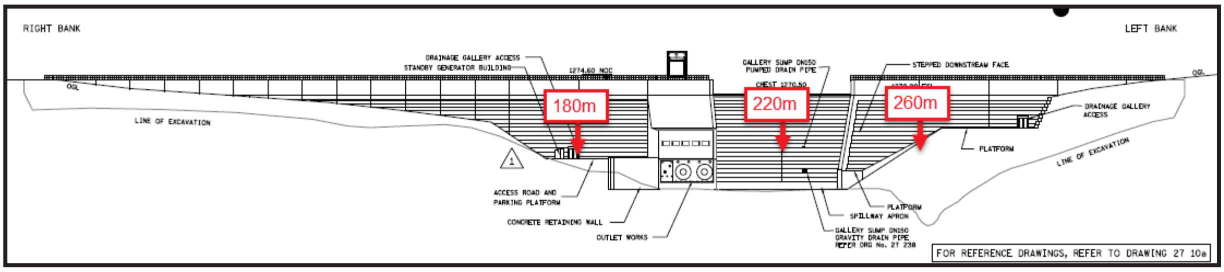

Figure 2. Position of LBSG

The LBSGs at chainage 260m indicated a maximum joint opening of 1.5mm. The joint on the downstream side at chainage 260m opens and closes with the seasonal change in temperature over a range of approximately 0.4mm. The gauge on the upstream side remains open at 0.6mm and only changes marginally with the seasons in line with the small fluctuation in temperature of the upstream face. The temperature does not vary much as the upstream face of the dam is sealed with a clay plug on the left bank.

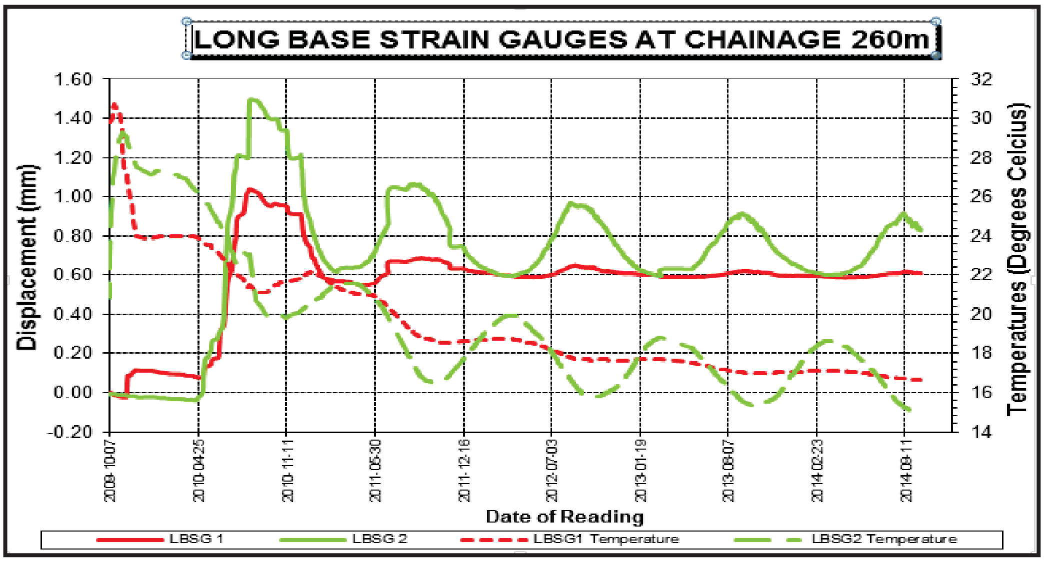

Figure 3. Braamhoek Dam LBSG at chainage 260m

The LBSGs at chainage 220m indicates that this induced joint in the centre of the dam has not opened.

The LBSGs at chainage 160m indicated a maximum opening of 1.6mm. This joint also opens and closes with the seasons over a range of approximately 0.4 mm. For a seasonal change in temperature of about 3 degrees, it is expected that the joint will open and close by 0.5mm. This is very much in line with what has been measured.

The specified maximum placement temperature of RCC was 23°C, there was then a measured increase from placement temperature of approximately 10°C due to the heat of hydration. The temperature then reduced gradually to fluctuate about approximately 16.5°C which is the long term mean temperature of the region. The range of the seasonal fluctuations in temperature is much higher on the downstream edge of the dam associated with the larger seasonal variation in temperature.

4.1 Three Dimensional Crack & Tilt Meters

Three dimensional crack and tilt meters are installed across eight induced joints on either side of the spillway. The instruments are installed in a small recess at the downstream side of the non-overspill crest. The instruments are electronic and take readings at set intervals. The reading are transferred to a data logger in the outlet house.

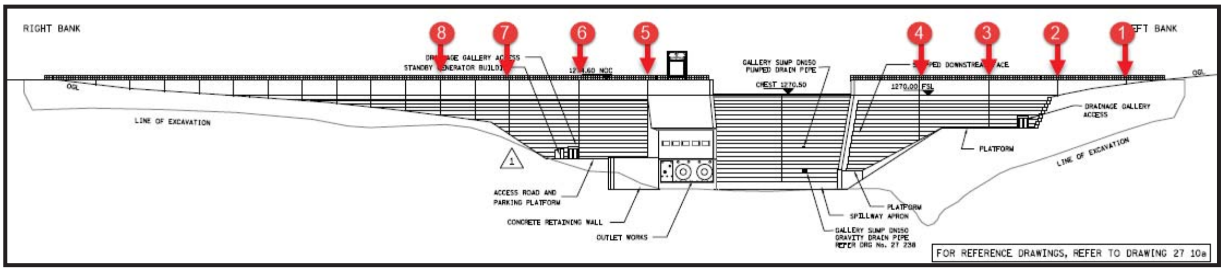

Figure 4. Position of 3D crack meters and tilt meters

Right bank has shown little to no rotational movement.

Left bank has shown two distinct rotations in time. On the 2011/01/03 when Bramhoek dam experienced rapid rise in water level due to heavy rainfall (158mm in 24 hrs), tilt meters 1, 3 and 4 showed rotational movement. Tilt meter 2 showed no relative movement, where gauge 3 showed the most significant movement. Then on the 2011/01/26 when Bramhoek dam was approaching the FSL, tilt meters 1, 2 and 4 indicated a rapid rotational movement with gauge 2 showing the biggest movement.

Tilt meter 3 and 4 showed the most significant overall rotation. These gauges are located at the highest point of the dam and the left bank is on residual mudstone. It is important to note that all the tilt meters have shown no significant additional movement since the last movement occurred just after the first filling of the dam at the end of January 2011.

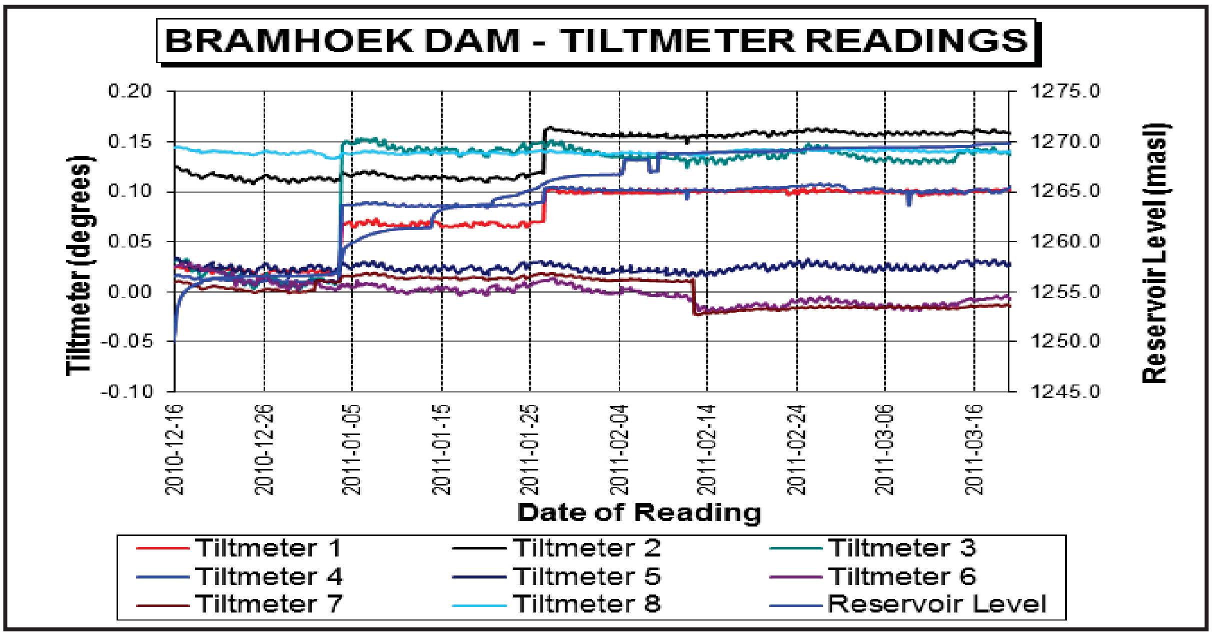

Figure 5. Bramhoek Dam Tilt Meter readings

The 3D crack meters indicated, the movement in the X direction was in the range of 0.6mm to 1.3mm with the blocks in the middle opening more than the blocks towards the abutments.

The results indicated that all the measured joints opened and that there is a definite seasonal movement in the joints, opening and closing is approximately 0.5mm between winter and summer.

4.2 Piezometers

A row of piezometers are installed in 76mm diameter drilled 3m deep into the foundation on four lines, in an upstream-downstream direction beneath the dam wall. The location of the lines are beneath the high point on the left bank, on the induced joint in the middle of the spillway, under the outlet block and immediately to the right bank side of the end of the drainage gallery on the right flank. The cables for the piezometers are routed via a conduit in the upstream face GE-RCC to the gallery and subsequently to the data logger in the outlet house.

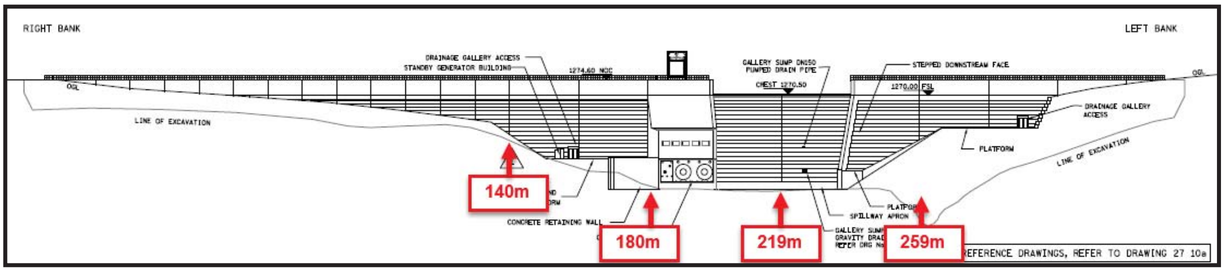

Figure 6. Bramhoek Dam Position of Piezometer rows

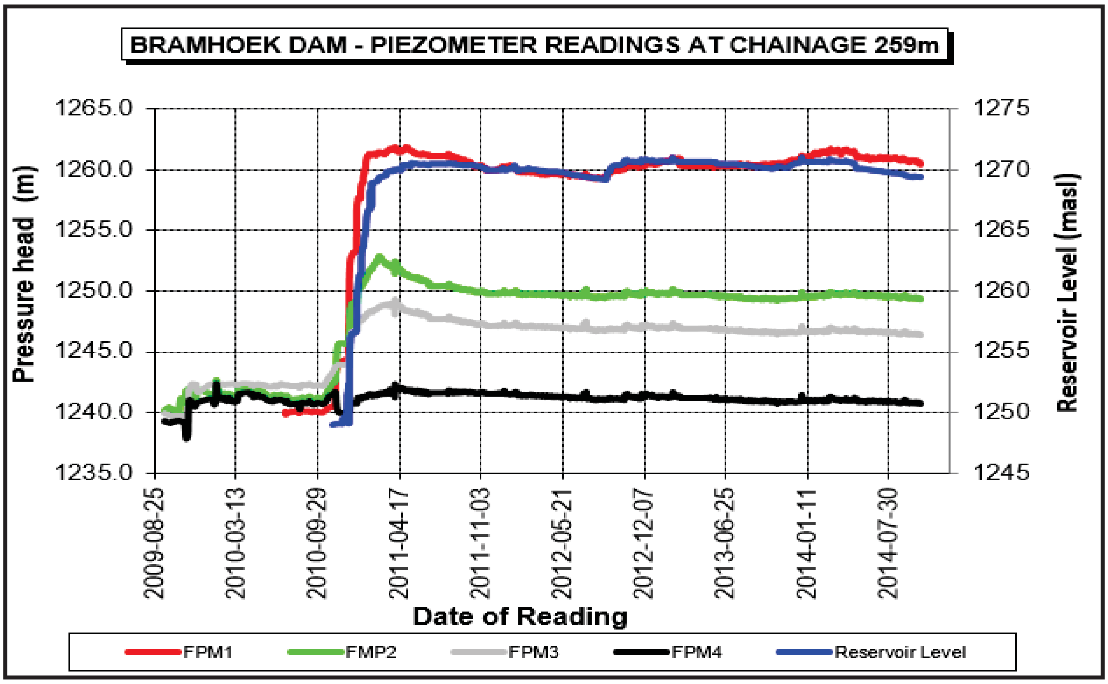

Figure 7. Bramhoek Dam Piezometer readings on the left bank

Piezometer 1 is close to the upstream face of the dam and piezometer 4 is the near to the downstream toe of the dam. Impoundment started on the 4th November 2010. Bramhoek dam filled rapidly in the beginning of January 2011. Bramhoek Dam was at the full supply level by April 2011. All the piezometers reacted rapidly to the increase in upstream water level as shown on Figure 7. The rapid increase in water pressure was of concern to the designer and the piezometers were carefully monitored after first filling to confirm the stability of the dam should the water pressure under the foundation continued to rise rapidly. However the water pressure did stabilise and even reduced slightly to the levels assumed in the design for most piezometers. A few of the furthest downstream piezometer did go marginally above the expected design water pressure levels. The stability was then rechecked for these measured water pressures.

4.3 Strain Gauges

An array of strain gauges are installed at chainage 237m on the gallery level to measure the development of strain in an upstream-downstream direction close to the highest section of the dam wall.

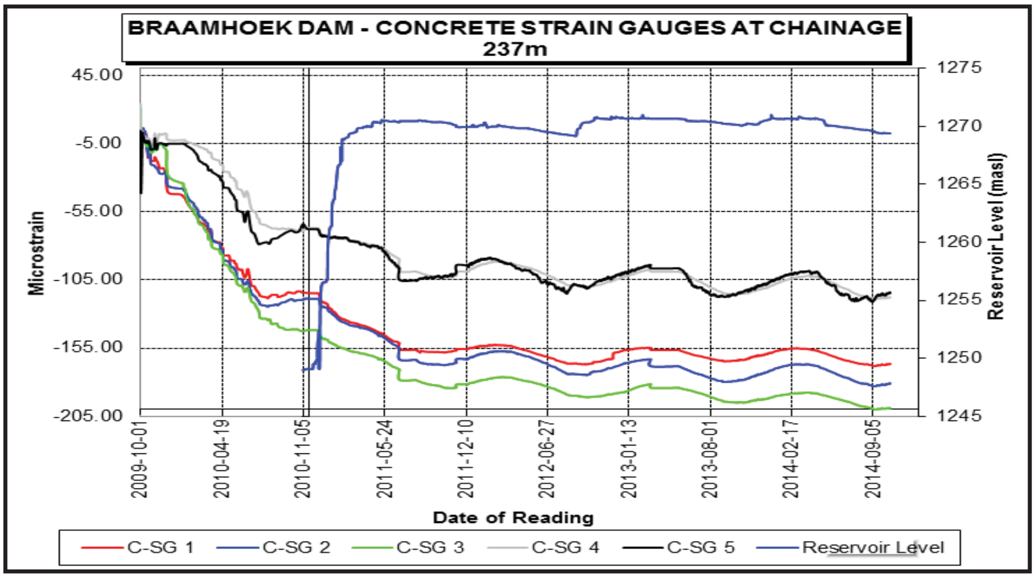

Figure 8. Bramhoek Dam Strain Gauge readings

Strain Gauge 1 is near the upstream face, Strain gauge 3 is in the middle of the dam section and strain gauge 5 is near the toe of the dam. The largest negative strain is in the centre of the dam section with a micro strain of approximately minus 200, the lowest strain is at the toe of the dam and is about minus100 micro strain. The estimated stresses based on the elastic modulus of the RCC is about 3.5MPa in the centre of the dam and 2MPa at the toe of the dam. All strain gauges indicated compression stress only. The design strength of the RCC was 15MPa, the actual measured strength was above 25Mpa.

4.4 Temperature Gauges (Thermistors)

Gauges to measure air and water temperatures are installed in recessed boxes in the down- and upstream faces of the dam respectively. Thermistors are also be installed in the RCC at strategic locations. All cabling is routed back to the data logger in the outlet house.

Table 1. RCC seasonal temperatures

Description	Upstream	Upstream to middle	Middle	Middle to downstream	Downstream
Summer	19.0°C	18.7°C	18.6°C	22.3°C	24.1°C
Winter	14.4°C	15.3°C	16.4°C	18.3°C	13.7°C
Range	4.6°C	3.4°C	2.2°C	4°C	10.4°C
Average	16.1°C	16.4°C	17.1°C	17.2°C	16.7°C

As expected the temperature range about the mean is dependent on the location of the temperature gauge in the RCC. The maximum RCC measured temperature was 24.1°C and the minimum was 13.7°C with the largest seasonal variation of about 10°C recorded near the downstream face. The temperature in the middle of the dam ranges by only 2.2°C from summer to winter. The temperature range for the upstream face is approximately 4.6°C.

The water temperatures in Bramhoek Dam ranges from approximately 22°C in summer to 12°C in winter. The air temperature ranges from above 30°C in summer to 0°C in winter.

4.5 V-notch Weirs

V-notch weirs are provided in the drainage gallery to measure seepage entering the pump sump separately from left and right bank. V-notch weirs are also be located approximately 10m beyond the inclined (stepped) sections of gallery on either flank on the downstream toe of the dam. The arrangement allows the dam foundation and wall drainage to be divided into 4 zones.

SW1 is measuring leakage under the foundation on the left bank downstream of the dam toe. A leakage of approximately 1.5l/s occurred after construction, this amount has steadily decreased and has tended to zero in 2015.

SW2 is measuring leakage through the dam on the left bank in the gallery. After the dam had filled a leakage of approximately 0.5l/s has occurred. This leakage has also steadily decreased to approximately 0.27l/s in 2015.

SW3 measures leakage from the right bank and the outlet block in the gallery. SW3 has showed the most leakage from all V-notch weirs and was due to a damaged waterstop on the joint between the dam and the mass concrete outlet block at chainage 180. The leakage after construction was approximately 4.5l/s in 2011. This decreased to an amount of 1l/s in 2012. The leakage continued to further decrease to an annual average of 0.5l/s. This value now has a strong seasonal pattern between summer and winter as the joint at 180m opens and closes with temperature change. In 2015 the leakage ranges between 0.71l/s to 0.33l/s. Winter having the highest leakage.

SW4 measures the current leakage under the foundation on the right bank on the downstream toe. Leakages after construction amounted to approximately 3.49l/s, this amount has decreased over time and current leakage is approximately zero.

The current total measured leakage from Bramhoek Dam is approximately 0.8l/s. This amount varies between 1l/s in winter and 0.6l/s in summer; this is well below the limit of 10l/s stated in the operation and maintenance manual.

4.6 Downstream Crump Weir

In view of the environmental sensitivity of the scheme and the associated importance of observing the ecological water releases required by the Water Use Licence discharge metering facilities are provided by a flow measuring Crump weir downstream of the dam. On the basis of a water level readout displayed in the outlet house, the discharge is set using a calibrated table. Once the flow has stabilized, the release is checked and adjusted if necessary on the basis of measured flow data.

The downstream crump weir is designed for a gauging capacity of 175m^3/s. The crump has three notched levels to improve the accuracy at lower flows. The releases are made according to those specified by the water use licence. A record is kept of the releases for environmental audits.

4.7 Reservoir Water Level Recorder

A Rittmeyer wall level recorder is located on the crest of the dam. This instrument measures the water level in the dam very accurately for operational purposes. The dam level measurement equipment provides an indication of the dam level to an accuracy of at least 10mm. This is provided by measuring the water level in the embedded 400mm water recorder pipe at the dam Intake Tower. The water level is transmitted via the SCADA system to the control room from where decisions are made on the operation of the water release system.

Bramhoek Dam started impounding in November 2010 and was fill by April 2011. The hydrology study estimated that it would take at least to average rainfall/run off years to fill Bramhoek Dam and should a drought occur it may have taken more than four years to fill, as a result of this study, Bramhoek Dam was on the critical path of the whole project. Bramhoek Dam has remained full since April 2011. Bramhoek will not be drawn down until the scheme is commission and the water pumped up to Bedford Dam.

5. CONCLUSIONS

The central joint in the dam has not opened. Most other joints opened by approximately 1.5mm. The joints opening fluctuates with the seasons by approximately 0.5mm.

The left bank rotated more than the right bank during first filling, due to the poorer founding conditions on the left bank.

The Piezometers reacted very quickly to the rise in upstream water level. Most piezometers indicate water pressure at the assumed design levels.

The maximum strain measured in the RCC dam was minus 200 micro strain.

The temperature of the dam now fluctuates about 16.5°C, the range is about 5°C near the upstream face, 2°C near the middle of the dam and 10°C near the downstream face.

The current total measured leakage from Bramhoek Dam is approximately 0.8l/s. This amount varies between 1l/s in winter and 0.6l/s in summer.

The use of instrumentation in RCC dams is well established in South Africa. The type and level of sophistication is dependent on the classification of the dam. It is important to maintain and continue to measure data in existing dams.

6. ACKNOWLEDGEMENTS

The author would like to acknowledge ESKOM, the owner of Bedford and Bramhoek Dams, for giving permission to publish this paper.

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