The Drakensberg Pumped Storage Scheme
Description of scheme and principal data

W Z PYZIKOWSKI*

Introduction
The Drakensberg scheme operates between two artificial reservoirs located some 4 km apart and with an average difference in elevation of approximately 446 m. The scheme has a dual purpose namely:
1. To operate as a pumped storage facility capable of generating normally 1 000 MW during the peak demand hours and up to 1 080 MW under high head conditions, and utilizing relatively cheap surplus power available during the off-peak periods for pumping.
2. To effect the inter-catchment transfer of water between the Tugela River basin and the Vaal River basin.

The most unusual feature of the project by world standards is the very large volume of the upper and lower reservoirs which can support operation of the scheme, in generating mode, with a weekly load factor of up to 30 per cent. This means that during the scheme’s weekly operating cycle the full output of 1 000 MW can be generated for up to 10 hours each day during the five working days, Monday to Friday.

Very few pumped storage schemes in the world, including Europe, Japan and the United States, generate longer than two to three hours daily without pumping and many of them have been designed to generate for less than one hour at a time. In the case of Drakensberg, the unusual operating pattern was dictated by the shape of the daily load demand curve of the ESCOM national grid with its several hour long demand peak.

Upper reservoir (Driekloof)
The upper reservoir is created by the Driekloof rockfill dam constructed across one of the arms of the large storage reservoir formed by the Sterkfontein Dam. This arrangement is unique by comparison with other schemes in the world in that the full supply level of the Sterkfontein reservoir at 1 702 m above sea level is higher by 2 m than the full supply level of the Driekloof reservoir. Consequently, for approximately 12 per cent of the time, the crest of the Driekloof Dam spillway will be submerged and the upper 2 m of the Sterkfontein reservoir will be used as the upper reservoir of the pumped storage scheme.

When the water level in the Sterkfontein reservoir is too low for supplying the pumped storage scheme, the Driekloof Dam creates an independent upper reservoir adequate for operation of the scheme on a weekly cycle. The inter-basin transfer of water is effected by allowing water to flow over the baffled chute spillway located centrally on the Driekloof rockfill embankment. The principal data of the dam and reservoir are listed below in Table 1.

Lower reservoir (Kilburn)
The lower reservoir of the scheme is situated on the farm Kilburn on the Mjnnareni river, one of the minor tributaries of the Tugela River. As a result of optimization studies, the full supply level was established at elevation 1 256 m and the minimum level for generating with all four machines at 1 235 m. The resultant live volume of the reservoir is adequate for operation of the scheme on a weekly cycle with a load factor of 30 per cent in the generating mode.

Waterways
The waterways shown on Fig 1 consist of an underground system of tunnels, shafts and penstocks extending over a horizontal distance of approximately 4 500 m measured along the straight line from headrace screens to tailrace screens.

The headrace system
Water is conveyed from the upper reservoir to the four pump turbines located in the underground machine hall, via two conduits, each bifurcating near the underground caverns and thus supplying two machines. Proceeding from the upper reservoir to the pump turbines the major components of the conduits are: the headrace intake structure,

---

* Senior Engineer, Hydro Design Group. ESCOM.

---

Table 1: Details of upper and lower dams

<table>
<thead>
<tr>
<th>Name</th>
<th>Upper Dam</th>
<th>Lower Dam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of dam</td>
<td>Driekloof</td>
<td>Kilburn</td>
</tr>
<tr>
<td>Height of dam crest above lowest foundation</td>
<td>465 m</td>
<td>510 m</td>
</tr>
<tr>
<td>Length of crest</td>
<td>500,0 m</td>
<td>825,0 m</td>
</tr>
<tr>
<td>Crest level</td>
<td>1 702,44 m</td>
<td>1 259,0 m</td>
</tr>
<tr>
<td>Type of spillway</td>
<td>Baffled apron on embankment</td>
<td>Side channel with chute</td>
</tr>
<tr>
<td>Spillway crest level</td>
<td>1 700,0 m</td>
<td>1 256,0 m</td>
</tr>
<tr>
<td>Capacity of spillway:</td>
<td>From Driekloof to Sterkfontein: 250,0 m³/s</td>
<td>320,0 m³/s</td>
</tr>
</tbody>
</table>

| Volume of dam wall | 843 000 m³ | 2 900 000 m³ |
| Full supply level  | 1 700,0 m | 1 256,0 m |
| Gross capacity of reservoir under FSL | 35,64 x 10⁶ m³ | 36,21 x 10⁶ m³ |
| Minimum draw down level with four machines generating | 1 680,0 m | 1 235,0 m |
| Dead storage volume under minimum draw down level | 8,15 x 10⁶ m³ | 6,80 x 10⁶ m³ |
| Live volume       | 27,49 x 10⁶ m³ | 29,41 x 10⁶ m³ |

W Z Pyzиковский was born in 1932 in Lublin, Poland. He obtained his Master’s Degree in Mechanical Engineering at the Technical University of Wroclaw, Poland in 1956, specializing in hydraulic machines and hydro electric power stations. From 1956 to 1965 he worked for the Power Plant Design Office, ‘Energojproekt’, Consulting Engineers, Warsaw, eventually heading a design group working on the layout and equipment of hydro-electric power stations. He spent the next five years in Nigeria as a senior design engineer responsible for C W systems of various power stations of the Electricity Corporation of Nigeria.

In 1970 Mr Pyzиковский emigrated to South Africa where he worked for the then Department of Water Affairs as a mechanical engineer for the first year, after which he joined Escom where he has been a senior engineer in the Hydro Design Group since 1973.

He has been involved in the inception of the Drakensberg Pumped Storage Scheme and later acted as a design leader of the scheme. He has also carried out feasibility studies for several pumped storage schemes in the Republic and is currently involved in designing the Palmiet Pumped Storage Scheme.
two headrace tunnels, two pressure shafts with upward extending surge shafts, two pressure tunnels and the penstocks.

The headrace intake structure (see Fig 2) consists of two identical 46 m high gate towers with a common deck and access bridge designed for a load of 30 t. At the bottom of each tower there is a 7.30 m high by 5.88 m wide opening for a set of sliding type maintenance stoplogs and a 6.95 m high by 5.34 m wide opening for a wheeled emergency gate. Each of the two intakes is provided with an independent bellmouth and screens.

The headrace tunnels have been dimensioned for a water velocity of 5.5 m/s under maximum flow conditions. For structural reasons the cross section of the tunnels is horseshoe-shaped with a sectional area equivalent to that of a circle 6 m in diameter. The total developed lengths of the headrace tunnels measured along the centrelines from the screens to the intersections with the pressure shafts is 1 539.60 m and 1 534.65 m for tunnels 1/2 and 3/4 respectively. The decision to employ two smaller tunnels instead of one large one was made to reduce the risks of tunnelling in the poor geological conditions prevailing in the upper strata.

The pressure shafts have circular cross sections 5.5 m in diameter restricting the maximum water velocity to 6.8 m/s. The depth of each shaft measured between the intersection of its centrelines with the centrelines of the headrace tunnel and the pressure tunnel is 275 m. Link shafts with the same alignment and of the same diameter as the pressure shafts extend above the level of the intersections with the headrace tunnels located at elevation 1 558.3 m to the bottom level of the surge shafts.

The two surge shafts are identical and over their entire height have an internal diameter of 14 m. From the bottom level at 1 643 m they extend
vertically to the crest level at 1 731,8 m for a total height of 88,8 m. They operate as simple surge tanks and have not been provided with any special devices like throttles or expansion chambers. Their volumes allow the most critical sequences of operations to be performed with all four machines in operation, leaving a safety margin of at least 2 m in the case of both up and down surges.

The pressure tunnels slope with a gradient of 1 in 10 towards the pump turbines and connect the pressure shafts to the steel penstocks. They have circular cross sections of the same diameter as the pressure shafts, to which they are connected via vertical bends with radii equal to four diameters. The extent of the concrete-lined pressure tunnels was determined by the decreasing rock overburden and the prevailing internal pressures. The total developed length of the pressure shaft and tunnel measured along the centreline from the end of headrace tunnel to the beginning of the steel lined taper of the penstock is 1 092,63 m in the case of conduit 1/2 and 1 117,98 m in the case of conduit 3/4.

The penstocks commence with tapers each 6 m long, which reduce the diameter from 5,5 m to 4,8 m. Within the length of the tapers the maximum flow velocity increases from 6,6 m/s to 8,6 m/s, the latter figure having been adopted on consideration of such aspects as the governing stability of machines and the maximum pressure rise under transient conditions due to water hammer. The developed length of each 4,8 m diameter penstock measured along its centreline from the end of the tapers to the bifurcations is 411,34 m in case of conduit 1/2 and 383,02 m in case of conduit 3/4.

At the bifurcation both 4,8 m diameter conduits split into two 3,4 m diameter branches, each connecting to one machine. The developed length of each branch measured from the bifurcation to the beginning of the 9,5 m long taper is 43,57 m. The diameters are further reduced from 3,40 m to 2,25 m across these tapers and the corresponding maximum flow velocities increase from 8,6 m/s to 19,6 m/s, the latter being the highest velocity in the waterways. The length of the 2,25 m diameter penstock measured from the end of the taper to the centreline of the pump turbines is 53,57 m, including the spherical valve.

The tailrace system
Proceeding from the pump turbines to the lower reservoir the waterways consist of the following main components: four draft tube tunnels, two surge chambers, two branches of tailrace tunnel, the tailrace tunnel and the tailrace outfall structure.

The draft tube tunnels have an internal diameter of 4,5 m and a developed length of 112,3 m each measured from the end of the theoretical draft tube to the gate sealing face located in the surge chamber. The geometry of each pair of tunnels is identical, with 1 and 2 designed as mirror images of each other and likewise 3 and 4. The tunnels are concrete lined and their inverts rise from level 1 160,55 m at the end of the theoretical draft tube to level 1 208 m at the base of the surge chambers. The entry of each tunnel to the surge chamber is formed by an opening 3,5 m wide by 4,5 m high which is provided with a wheeled gate that serves basically as an isolating gate but can also close in unbalanced conditions.

The surge chambers are situated at the points where each pair of draft tube tunnels converge. Both surge chambers are identical and have diameters of 16 m over their entire height of 81,8 m, measured between the bottom level of 1 208 m and the floor level of the gate hoists at 1 289,8 m. The gate hoist compartment is square in plan measuring 16 × 16 m with a height of 5 m. In order to restrict the down surge during the most adverse operating conditions the surge chambers are inter-connected just above their bases by the surge tunnel which has a live volume of approximately 5 000 m³.

The combined volume of the surge chambers and the surge tunnel is adequate to perform the most critical sequences of operations with all four machines in operation leaving a safety margin of at least 2 m in the case of both up and down surges.

The branches of the tailrace tunnel connect both surge chambers to the tailrace tunnel. Each of the branches has a developed length of 129,8 m between the wall of the surge chamber and the bifurcation. They have a horseshoe-shaped cross section and their sectional area is equivalent to that of a 6 m diameter circle.

The tailrace tunnel has a horseshoe-shaped cross section, equivalent in size to an 8,5 m diameter circle. The overall developed length from the bifurcation to the screen is 1 424,6 m. The maximum flow velocities in both branches and in the tailrace tunnel are the same and do not exceed 5,5 m/s.

The tailrace outfall structure has been designed as a free standing

---

**Fig 3: Axonometric view of the underground cavern complex**

THE CIVIL ENGINEER in South Africa — August 1982
bellmouth extending from the tailrace tunnel portal with a backfill surround. The bellmouth is provided with screens and no provision has been made for stoplogs or gates.

Underground caverns

The underground complex of caverns shown in Fig 3 consists of three main caverns, namely the machine hall, the valve hall and the transformer hall. The caverns house the pump/turbines with their generator/motor and all auxiliary mechanical and electrical plant. The two surge chambers, previously described, and a number of interconnecting tunnels, shafts, access tunnels and exploratory and construction adits also form part of the cavern complex.

The machine hall houses four 250 MW reversible Francis sets and most of their auxiliary equipment. The roof of the hall is located approximately 146 m below the surface and the cavern is 168.3 m long, 15.5 m wide and 28.5 m high, measured from the lower machine hall floor level of 1 177.5 m to the soffit. There are four local pits with a bottom elevation of 1 156.5 m housing the pump/turbine draft tubes. The hall has been designed with two operational floors, namely the generator/motor floor at 1 184.0 m where the motor motors, unit boards and excitation panels are located, and the pump/turbine floor at 1 177.5 m where auxillaries such as the cooling water pumps, compressors, coolers, governor oil pressure units, etc are installed.

The generator/motor busbars are located in four horizontal tunnels connected to the transformer hall. The main access tunnel enters the machine hall between sets 2 and 3 at the generator/motor floor level.

The valve hall is parallel to the machine hall and is located 42.5 m away (distance between the centres) towards the upper reservoir. The main floor level is the same as that of the machine hall, ie 1 184 m and the cavern is 152.1 m long, 7.5 m wide and 12.8 m high, measured from the main floor level to the soffit.

There are four local pits with a bottom elevation of 1 163.5 m housing the pump/turbine spherical-type shut-off valves and associated oil pressure units. Each pit is drained by gravity via a drainage shaft and drainage gallery to the 6 x 6 m main drainage tunnel with its lowest floor level at 1 153.47 m. The drainage tunnel runs parallel to the machine hall and originally served as an access adit for the civil contractor during excavation of the horizontal portions of draft tubes and draft tube tunnels.

The idea of locating shut-off valves in a separate cavern was conceived with a view to minimizing the machine hall span which was considered critical to the excavation of a large cavern in the prevailing geological conditions.

The transformer hall runs parallel to the machine hall and is located 45 m away (distance between the centres) towards the lower reservoir. The main floor level is the same as that of the machine hall, ie elevation 1 184 m, and the cavern is 176.6 m long, 120 m wide and 11.3 m high.

The main access tunnel dimensions were dictated by the sizes of the generator/motor transformers, and the stator quadrants when transported on a low loader. The tunnel is approximately 1 000 m long as measured from the portal to the centreline of the machine hall and is 7.5 m wide and 7.0 m high. The steepest slope of the floor does not exceed 1 in 10.

The auxiliary access tunnel links the top of the surge chambers with the surface and in addition provides aeration during surging. The dimensions of the tunnel, 4 m wide and 5 m high, enable transportation of the draft tube gate components and also guarantee that the velocity of air during the most severe surging does not exceed 20 m/s. The slope of the tunnel is approximately 1 in 8 and its developed length is about 230 m, as measured from the portal face to the centreline of the surge chamber link tunnel.

The lift shaft has a diameter of 5.75 m and a total depth of 193.7 m measured from the surface building main floor level at 1 349.2 m to the 1 155.49 m level in the drainage gallery just forward of the dewatering pump chamber. At elevation 1 295 m there is a discharge sluiceway which links the lift shaft with surge chamber 3/4 via the auxiliary access tunnel.

The additional components of the underground complex listed below and shown in Fig 3 are not described in detail:

- A seepage and dewatering pump chamber.
- A control block cavern.
- A system of ventilation shafts and headings.
- A system of penstock drainage tunnels.
- An exploratory adit leading to the penstock test chamber, machine hall test enlargement and plate bearing test adit.
- A number of construction adits.

Principal data of scheme

The principal data of the scheme for all four machines operating are tabulated below in Table 2.

<table>
<thead>
<tr>
<th>Table 2: Principal data of scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum static head</td>
</tr>
<tr>
<td>Minimum static head</td>
</tr>
<tr>
<td>Maximum flow rate in generating mode</td>
</tr>
<tr>
<td>Maximum flow rate in pumping mode</td>
</tr>
<tr>
<td>Maximum continuous output at terminals</td>
</tr>
<tr>
<td>Maximum temporary output (1/2 hour) at terminals</td>
</tr>
<tr>
<td>Maximum power input at terminals</td>
</tr>
<tr>
<td>Head loss in generating mode</td>
</tr>
<tr>
<td>Head loss in pumping mode</td>
</tr>
<tr>
<td>Efficiency of the cycle, ie ratio of energy returned to the grid to the energy utilized for pumping</td>
</tr>
<tr>
<td>Maximum duration of generating at full load</td>
</tr>
<tr>
<td>Minimum submergence of spiral casing centreline</td>
</tr>
</tbody>
</table>

*Q = total rate of flow of all four machines

Acknowledgement

Production of a special issue of the Journal such as this requires a tremendous amount of planning, co-ordination and effort. The Division of Hydraulic and Water Engineering has been responsible for obtaining and screening the editorial matter for this issue, liaising with the Institutions of Electrical and Mechanical Engineers, and for assisting with selling advertising, layout and production.

The time and effort put into this project by Dr Paul Roberts and Mr James Perkins, both of the Department of Environment Affairs, and Mr Nick Terblanche of ESCOM, is gratefully acknowledged. Our thanks is also extended to the referees who assisted with the task of editing and preparing papers for publication.

The following firms kindly subvented the printing of coloured photographs in this Journal: