PALMIET – A FORERUNNER IN ENVIRONMENTAL ENGINEERING

Cooperation for progress

For several years the Department of Water and Sanitation (DWS) conducted investigations in the Western Cape to survey possible dam sites to augment existing water supplies to the Cape Town metropolitan area. The Palmiet River basin in the Hottentots Holland Mountains not only conformed to these requirements but also provided a potential site for a pumped storage scheme. It was clear that a venture such as this required the expertise of Eskom. Close working relationships forged over the years between the DWS and Eskom have established close links of technical, administrative and financial cooperation. Consequently, the development of the Palmiet Pumped Storage Scheme as a joint venture between the DWS and Eskom was a logical step.

Eskom provides the technical management and coordination expertise for its participation in the scheme. The design and construction of the power station and waterways were undertaken by Eskom, whereas that of the two reservoirs, Rockview and Kogelberg, together with the connecting canal and pipeline between the Rockview and Steenbras Dams were the responsibility of the Department of Water and Sanitation.

The contribution of the DWS amounted to about 25% of the projects financial outlay.

In a highly successful blend of the need for environmental management with the demands of technological progress, the Palmiet Pumped Storage Scheme has fashioned an integrated approach to engineering in South Africa. The old antagonism between environment and technology has been dispelled by a comprehensive cooperation between protagonists of both ethics.

Pumped Storage Schemes

Pumped Storage Schemes constitute a variation of the run-of-river concept normally associated with hydro-electric power stations. The power station of a pumped storage scheme is situated on the waterway which links an upper and lower reservoir. It supplies electrical energy during periods of peak demand or emergency when water is allowed to run from the upper to the lower reservoir through reversible generator-motor/pump-turbine sets. When excess generating capacity is made available by low energy demand, this same water is pumped from the lower to the upper reservoir by the reversible sets. Using the surplus generating capacity in off-peak periods also assists in flattening the system's load demand curve. Such generating stations can be brought on stream in less than three minutes, whereas coal-fired stations require a minimum of eight hours to start generating power from cold start-up. The pump turbines used in Eskom's two pumped storage schemes at Drakensberg and Palmiet provide average generating and pumping efficiencies of over 90% and total cycle efficiencies of 73,7% and 77,9% respectively.

The Palmiet Pumped Storage Scheme

The scheme is situated in one of the spurs of the Hottentots Holland Mountains where the potential of the fluvial system is virtually untapped. The catchment area of the Palmiet River could in fact supply sufficient water for four more dams in addition to Kogelberg. Palmiet acts not only as a hydro-electric pumped storage scheme, but also as a water transfer scheme.

The scheme comprises two new dams, the lower Kogelberg Dam on the Palmiet River south of Grabouw and the upper Rockview Dam on the watershed between the Palmiet and Steenbras rivers. A conduit between the two reservoirs conveys water to the reversible pump turbines in the 400MW station on the bank of the Kogelberg reservoir. During the off-peak period, water is pumped from Kogelberg to Rockview reservoir. From here water specifically allocated to the DWS for water supply flows by gravity into the Steenbras reservoir via a separate conduit. This supplements Cape Town's annual water supply by an average of 25 million m^3.

The power generated at the Palmiet Pumped Storage Scheme is fed into the national transmission network at the Bacchus substation near Worcester. An additional 400kV line was commissioned during 2007 and feeds directly into the Stikland substation near Cape Town. A special feature of the high-voltage yard at Palmiet is the tubular low-level high-voltage busbar system which has been used to minimise its visual impact.

The power station and waterways

The power station is situated about 2 km upstream of the Kogelberg dam wall and has a nominal generating capacity of 400 MW. The two 200 MW pump-turbine generator-motor sets and auxiliary equipment are located approximately 60m below ground level at the base of two 23 m diameter concrete-lined vertical machine shafts. The auxiliary equipment includes the pump-turbine governor and spherical valve with their respective oil pressure units, the CW pumps, water depression air tank and the unit transformer and unit board. At a depth of 80m, a set of dewatering and drainage pumps is located in a 5 m diameter service shaft between the machine shafts. The surface machine hall houses a huge crane with a lifting capacity of 360 ton, span of 30 m and hoisting height of 65 m. The control room is situated 5,5 m below the machine hall floor. Adjoining surface buildings house the switchgear, air-conditioning plant, starter, blow-down compressors and offices.

In the generating mode, up to 185 m3/s of water is admitted at the intake from the upper reservoir (Rockview Dam) through a surface cut-and-cover headrace tunnel, 750 m long and 6,2 m in diameter. It flows through a 55º inclined shaft, 130 m deep and 6,2 m in diameter, to a pressure tunnel, 487 m long and 6,2 m in diameter, which ends at a portal. From there water flows into a cut-and-cover penstock, 561 m long and 5,4 m in diameter, which bifurcates into two inclined penstock shafts, approximately 131 m and 139 m long respectively and 3,9 m in diameter, tapering to 2,6 m in diameter. The penstocks convey the water into the power station complex.

From the power station, two inclined concrete-lined tailrace tunnels, 84 m and 57 m long respectively, link the machines to the tailworks in the Kogelberg reservoir.

The surge tank is situated at the end of the surface cut-and-cover headrace tunnel. A 34 m long conduit, 6,2 m diameter, branches from the headrace tunnel to lead to the bottom of the surge tank. The cylindrical free-standing concrete structure of the surge tank is 61 m high and 21 m in diameter. To minimise visual pollution the surge tank was not constructed on the highest point of the terrain, but set back from the cliff so that it is less prominent to viewers from the Palmiet River area. The surge tank prevents excessive pressure fluctuations in the penstock during transient conditions.

From the Rockview Dam wall, an access bridge leads to the headrace works which were constructed in the form of a 68 m high headworks tower. This tower houses the 15 m wide, 14 m high screened intake, the mechanically operated maintenance stop logs and the hydraulically operated emergency gate.

Within the headrace tower is a vertical duct with a spillway on top which makes it possible to close the emergency gate during any phase of surging in the waterways. This is a unique safety feature designed by Eskom engineers. The duct houses the emergency gate, provides for the discharge of the surplus volume of water during emergency closure and allows aeration of the headrace tunnel after closure of the gate. The outlet works on the bank of the lower reservoir consist of twin 45 m high tailworks towers constructed next to the power station. Each tower houses an 8,7 m wide and 9,5 m high screened opening, a mechanically operated wheeled maintenance gate and a submersible pump which supplies the fire-fighting storage tank.

The power station operates on a weekly cycle. Power is generated at peak periods from Monday to Friday. The water used for generation is only partially pumped back from the lower Kogelberg to the upper Rockview reservoir every day. Consequently during the week, the level of the water in the Rockview reservoir is gradually lowered. Over weekends, when system demand is low, water is pumped back from the Kogelberg into the Rockview reservoir at an average rate of approximately 126 m^3/s over a period of about 33 hours to restore the reservoir to full capacity.

The Reservoirs

The Upper Reservoir – Rockview Dam

The upper reservoir has virtually no natural catchment area as it is situated on the watershed between the Palmiet and Steenbras rivers. Its basin is formed by a rockfill and an earthfill wall known respectively as the main and northern embankment. The waterways lead from the main embankment to the power station. From the northern embankment, a canal and a pipeline connect the Rockview reservoir to the upper reservoir of the Steenbras scheme. Water transfer to augment water supplies takes place along this route.

The main embankment

This is a 3 100 000 m^3 rockfill dam, constructed of material provided from the basin of the reservoir itself. It consists of a 556 000 m^3 clay core seal with rockfill sides for stability and an additional 206 000 m^3 of filter materials which provide a buffer zone between the clay and the rockfill. A layer of high-quality rockfill protects the embankment against the wave action of the water. It has a crest length of 1 250 m.

The northern embankment

The northern embankment is a 150 000 m^3 sandfill wall containing a 102 000 m^3 clay core with an additional 33 000 m^3 of filter materials. A rockfill blanket protects the sand from erosion by wind and wave. Since there was insufficient sandfill available to construct the whole dam, it was completed by approximately 146 000 m^3 of rockfill. The northern embankment's crest length is 700 m.

Waterways to the upper reservoir of the Steenbras Scheme

The waterways to the upper reservoir of the Steenbras Pumped Storage Scheme begin as a low-gradient concrete-lined trapezoidal canal, 1,80 km long, which leads into a small forebay. From here a 2,0 km long steel penstock with a discharge capacity of 4,72 m^3/s channels water into the Steenbras reservoir. From this upper reservoir, water will be supplied to the Cape Town municipality via the existing Steenbras Pumped Storage Scheme owned and operated by the Cape Town City Council.

Borrow pits

Sand and rockfill for the construction of the embankments were obtained from the reservoir basin. Clay for the core of the dams was brought in from a borrow pit adjoining the upper reservoir of the Steenbras scheme. This borrow pit has been covered with topsoil, reshaped to blend with the terrain and planted with pine trees.

The lower dam – Kogelberg Dam
The Kogelberg Dam is designed with a mass gravity concrete arch wall. It has a separate earth saddle embankment on the left flank about 850 m long at a maximum height of 19 m.

The Concrete wall
The concrete wall has a gravity section arch configuration and an ogee overflow with a concrete apron beneath to protect the riverbed from erosion. River outlets are provided to allow compensating water to flow into the river downstream of the dam. All material for the construction was obtained from the Rockview reservoir basin.

The earth embankment
The earth embankment is a saddle wall which dams the low-lying area adjacent to the concrete wall. The clay core, built of material from a nearby borrow pit, has a volume of 35 000 m^3. The flanks consist of 146 000 m^3 of semi-pervious material drawn from the dam basin and a further 15 000 m^3 of filter materials. A 24 000 m^3 layer of rip-rap protects the embankment from wave action.

Preliminary site investigation
Eskom and the Department of Water and Sanitation commenced exploratory site investigations three years before any contracts were awarded. This included the sinking of a shaft, 65 m deep by 6 m in diameter, near the proposed machine shafts, and the excavation of a 250 m long adit parallel to the main tunnel. These works permitted the investigation and analysis of significant features of the folded geology such as jointing and cross-bedding from which areas of possible rock instability could be established. Ground water conditions and the presence of phyllite-filled joints were determined and monitored. Detailed information on the geological structures, including rock formations and underground waterways and shafts was incorporated in a geological/geotechnical report issued as part of the tender documents for the civil contracts. As a result, a very accurate assessment of contractual risk could be made by the tenderers.

Electrical features
The generator motors are directly coupled to the pump turbines and are designed to operate in three modes:

- The generating mode – potential energy is converted into electrical energy.
- The pumping mode – off-peak low-cost electrical energy is converted into potential energy by pumping water from the lower to the upper reservoir.
- The synchronous condenser mode – reactive power is either sent out or absorbed by the machine to control the voltage on the transmission system.

The generator motors produce power at 16,5 kV which is then stepped up to 400 kV by generator step-up (GSU) transformers installed in the high-voltage yard adjacent to the station.

The rotating plant is designed in such a way that it may be started and synchronised even when connected to a blacked-out network. Normally, lack of power would prevent the operation of the auxiliary plant necessary for the safe running of the unit. An accumulator system installed for the Palmiet units injects previously stored high-pressure oil into the thrust bearings to ensure the safe starting of the machine. Run-up is achieved by opening the guide vanes by means of previously stored hydraulic pressure which allows water into the turbine. Once rotating, the generator builds up voltage by “field flashing” from the station battery and, when excited to full voltage, is capable of supplying all its own auxiliaries from its generated output.

The units are fitted with a magnetic thrust bearing which decreases the load by means of a magnetic field thus reducing bearing friction losses. The bearings themselves are self-lubricating (except during actual start-up). This eliminates the need for oil pumps and associated piping. These measures reduce the cost of unit auxiliaries and increase plant efficiency.

When the pump turbine operates as a pump the generator motor assumes a motoring condition. When starting the pumps, the high inertia of the rotor makes it impossible to switch the generator motor directly on to the transmission system without causing excessive voltage dips. A static frequency convertor (SFC) is used to achieve a “soft” start of the motor. Converting the 50 Hz mains frequency to much lower frequencies (0 up to 50 Hz) it increases the generator motor speed gradually to avoid the voltage dips caused by sudden excessive current demand. Furthermore, before starting rotation of the machine as a pump, air is blown into the pump turbine to reduce the run-up current to a minimum.

In the unlikely event that the SFC is not available, it is possible to start one unit in pump direction using the back to back mode with the other unit operating as a generator. The two machines then run up together.

Low-level tubular busbars are used in the high-voltage yard instead of high-voltage connecting cables, thus minimising the visual environmental impact.

The generator motors are phase-reversed and connected to the generator transformer through 5 x 16,5 kV isolators and a 16,5 kV load switch. The load switch utilises SF6 technology, thus making more effective use of space.

The scheme is used for supplying peak power as well as for system frequency control, system voltage control and emergency standby. The machines have been designed to cope with high-fatigue stresses resulting from the frequent mode changes (up to 600) anticipated in their monthly operations.

Fusion of nature and progress

Palmiet is situated in an ecologically sensitive area of the Western Cape. From the outset, a firm of environmental consultants was appointed to assess the impact of the scheme on every aspect of natural and human environment, establishing a comprehensive programme of control, protection and restoration which, in a unique move, was written into the civil engineering contract. A resident environmental control officer (RECO) was appointed to monitor the implementation of the Environmental Impact Control Plan, liaising with and advising construction teams.

In South Africa today, umbrella legislation on environmental protection provides measures to compel developers to minimise the negative impact of their undertakings on both natural and man-made environments. No such legislation existed at the time of construction. Co-operation between industrialists, engineers and environmentalist arose from a mutual desire to achieve the best possible balance between technological progress and environmental management.

Certain aspects of environmental management, introduced during the construction of Eskom's first pumped storage scheme at Drakensberg, had a profound influence on Eskom's approach to the Palmiet project. The Palmiet Pumped Storage Scheme is one of the major engineering undertakings in South Africa that has seen a total integration of both environmental and technical principles with the willing cooperation of all disciplines. From the inception of the scheme, constructors and engineers recognised the importance of environmental protection and restoration. They welcomed and encouraged a new approach to construction by accepting and enforcing environmental impact control requirements in the civil engineering contract. All civil design deviations were first submitted to the officially appointed environmental consultant and the RECO who assessed their impact on the environment and formulated control measures that were mandatory. The RECO enjoyed arbitration to the highest levels of authority. Workers at all levels were individually involved by means of education audio visuals in English, Afrikaans and Xhosa and their participation encouraged by the award of an Environmental Floating Trophy for excellence in environmental impact control.

In addition to these considerations, the visual impact of the scheme was evaluated and action taken to minimise pollution. Access roads were routed to avoid scenic outcrops of rock or sensitive plant growth areas and to follow natural contours thus blending in with the landscape. The Palmiet Power Station, as well as the waterway linking the Rockview and the Kogelberg Dam, was placed underground and indigenous plants were re-established on the disturbed site. Quarrying of construction materials from the Rockview basin was restricted to a specific height below the full supply level.

Water pollution from cementing, drilling, grouting and general activity on the site was eliminated by allowing sedimentation in special settling tanks before the water was returned to the river.

The main approach of the Environmental Impact Control programme was preventive rather the curative. From a purely economic aspect the benefits of this preventive approach have been tangible and savings of as much as 1, 5% of the project cost are anticipated. From social and natural environmental aspects, the repercussions have not yet been assessed to their full extent.

Restoration undertaken concurrently with construction rather than on completion of the projects is considerably cheaper. This approach has also heightened individual perception of the need for environmental management and has encouraged greater understanding in the engineering profession of the importance of a carefully planned and monitored interaction with the environment. The fusion of both engineering and environmental principles and objectives created a unity of action and purpose which produced an improved quality of life for all concerned, both during and after construction.

Unique aspects of the Environmental Control Programme

The scheme is largely situated within the Kogelberg Nature Reserve which has been established as a conservation area for mountain and riverine fynbos. Propagation of certain fynbos species depends on the eating habits of the indigenous porter ants which take the seed underground, eat the gland and leave the kernel, thus enabling the seed to geminate. Extensive measures were adopted to prevent the introduction of the exotic Argentinian ant which could possible exterminate the local ants as well as contribute to the destruction of the fynbos by leaving the seeds exposed to fire and the elements.

Consequently, specific eating sites were delineated and the removal of all rubbish and waste strictly controlled. Construction materials were carefully inspected to eliminate the possible introduction of non-indigenous plants and insects. Topsoil, which generally contains the valuable fynbos seed, was removed and conserved to be replaced in specific areas once construction was completed. Fynbos was re-established along the side of roads. Disturbance of fauna and flora is prohibited.

Kogelberg Biosphere Reserve

The Kogelberg Biosphere Reserve (KBR) was the first of its kind in South Africa and was designated as such by UNESCO's Man and the Biosphere Programme (MAB) in December 1998. Eskom was a signatory to the application for biosphere status, which aimed to integrate conservation of biodiversity and the sustainable utilisation of natural resources.

A Declaration of Commitment was signed in 1998 acknowledging Eskom's responsibility to pursue the objectives identified in the UNESCO Action Plan for Biosphere Reserves as identified in the Seville Strategy.

The Kogelberg Nature Reserve, heart of the Fynbos Plant Kingdom, is part of the Kogelberg Biosphere Reserve, which comprises the entire coastal area from Gordon's Bay to the Bot River vlei and inland to Grabouw and the Groenland Mountain – approximately 92 000 ha.

TECHNICAL DATA:

The Reservoir
Upper reservoir (Rockview Dam)

Type	
Main embankment	Rockfill
Northern embankment	Sandfill
Height above lowest foundation	
Main embankment	50 m
Northern embankment	35 m
Length of crest	
Main embankment	1 250 m
Northern embankment	700 m
Volume content of dam wall	
Main embankment	3,1 million m^3
Northern embankment	0,43 million m^3
Full supply level	531 masl
Lowest operational level for two machines generating	504 masl
Minimum level	501 masl
Gross storage capacity	20,8 million m^3
Active storage capacity	17,0 million m^3
Surface area at full supply	73,4 ha
Capacity	
Canal/pipeline into Steenbras Dam	12 m^3/s
Spillway	none

Lower reservoir (Kogelberg Dam)

Type	Mass gravity concrete arch wall with separate earth saddle embankment
Volume content of concrete dam wall	70 000 m^3
Volume content of earth embankment	220 000 m^3
Non-overflow crest	252 masl
Full supply level	246 masl
Lowest operational level for 2 machines generating	230 masl
Minimum level	228 masl
Gross storage capacity	19,3 million m^3
Active storage capacity	15,0 million m^3
Surface area at full supply level	155,4 ha
Capacity of spillway	1 060 m^3/s
Type of spillway	Ogee
Max dam height above river bed	57 m
Length of concrete wall crest	186 m

Headrace tunnel

Number	1
Internal diameter	6.2 m
Length	739.4 m
Type of construction	Steel lined

Surge tank

Number	1
Type	Cylindrical, free-standing structure
Internal diameter	21 m
Height	61 m
Orifice diameter	4.2 m
Construction	Post-stressed concrete

Inclined pressure shaft

Number	1
Length	122.7 m
Diameter	6.2 m
Type of construction	Steel lined
Angle of horizontal plane	55°

Pressure tunnel

Number	1
Diameter	6.2 m
Length (including taper to 5,4m diameter)	494 m
Type of construction	Steel lined
Inclination	1:10

Penstock

Number	1 (bifurcating)
Length of bifurcation	561.2 m
Diameter	5.4 m
Type of construction	Buried in trench
Inclination	1:10, 1:6 and 1:15

Branches of penstock

Number	2
Machine No 1	
Diameter	3.9 m tapering to 2.6 m
Length (including taper to 2,6m diameter)	134.8 m
Machine No 2	
Diameter	3.9 m tapering to 2.6 m
Length (including taper to 2,6m diameter)	125.0 m
Machines 1 & 2	
Diameter	2.6 m
Length to machine centre line	26.6 m

Power Station

Pump-turbines

Number of machines	2
Type of pump-turbine	Single-stage reversible Francis
Rated power output at shaft per machine	203.5 MW
Range of net head for generation using 2 machines	245.5 m to 285.6 m
Range of pumping head using 2 machines	264.7 m to 306.2 m
Maximum permissible pressure in the penstocks	5,39 MPa
Rated speed for both directions of rotation	300 r/min
Method of pump starting	Static frequency converter
Type of control	Local and remote

Generator motors

Continuous rating of each machine for generation	200 MW at terminals at 0,8 power factor
Rated voltage	16,5 kV
Rated MVA	250.00 MVA
Rated current	8 748 ampere

Power factor pumping/generating	0.8
Rated frequency	50 Hz
Rated output of starter (SFC)	22 MW
Speed	300 r/min
Transient runaway speed	497 r/min
Inertia GD^2	9.7 x 106 kg/m^2
Excitation	Static feed from machine terminals

Tailrace tunnels

Number	2
Internal diameter	5 m
Length – sets 1& 2	83.6 m and 57 m respectively
Type of construction	Concrete-lined

Operating data

Generation energy equivalent to 15 million m^3	Approximately 10 GWh
Time required to pump 15 million m^3 of water from lower to upper reservoir	Approximately 33 hours
Type of operational cycle	Weekly
Cycle efficiency	77.9%

Construction/Commissioning

Commencement of construction	November 1983
Commissioning	May 1988

Major consultants

Civil engineering

Civil consulting engineers	SVE (a consortium of companies consisting of Ninham Shand, Van Niekerk, Klein & Edwards, and Electrowatt)
Environmental consultants	Ecokonsult Incorporated

Major contractors

Exploratory excavation	Department of Water and Sanitation
Preliminary civil work	Savage & Lovemore (Pty) Ltd
Main civil work	Palmiet Civil Contractors
Rockview & Kogelberg dams	Department of Water and Sanitation

Mechanical engineering

Pump-turbines, governors and spherical valves

Penstock steel linings

Gates and screens

Machine hall crane

Low-pressure service pipe-work

Electrical engineering

Generator-motors

GSU Transformers

Load switches and reversing isolators

Control room equipment

JM Voith GmbH West Germany

Sorefame Africa (Pty) Ltd

John Thompson Africa (Pty) Ltd

Mannesmann Demag (Pty) Ltd

Steel Metals

Fuji Electric Co Japan

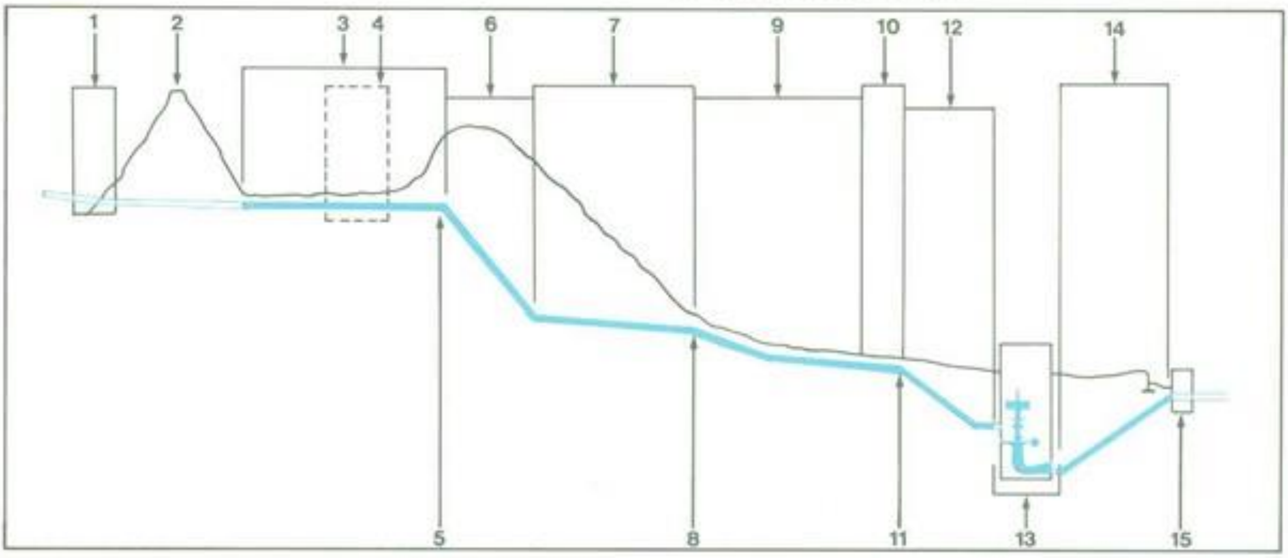
Siemens Koncar

Brown Boveri (SA) (Pty) Ltd

Andritz

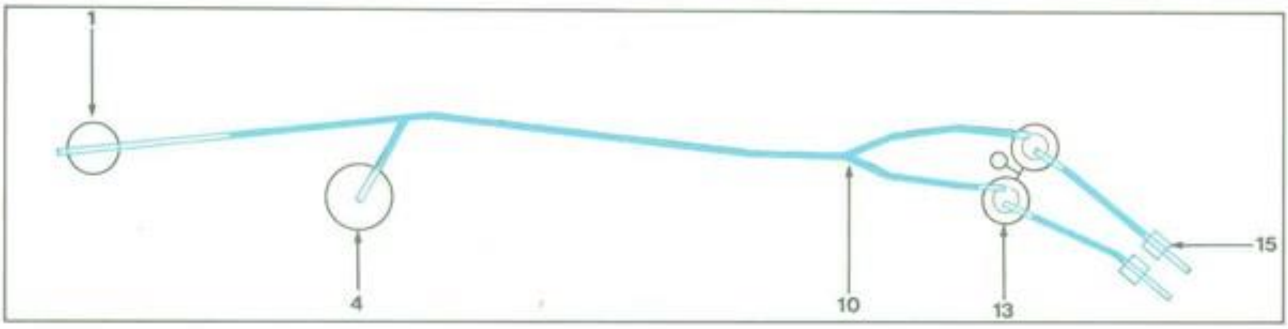
General layout of Palmiet Pumped Storage Scheme

Longitudinal section

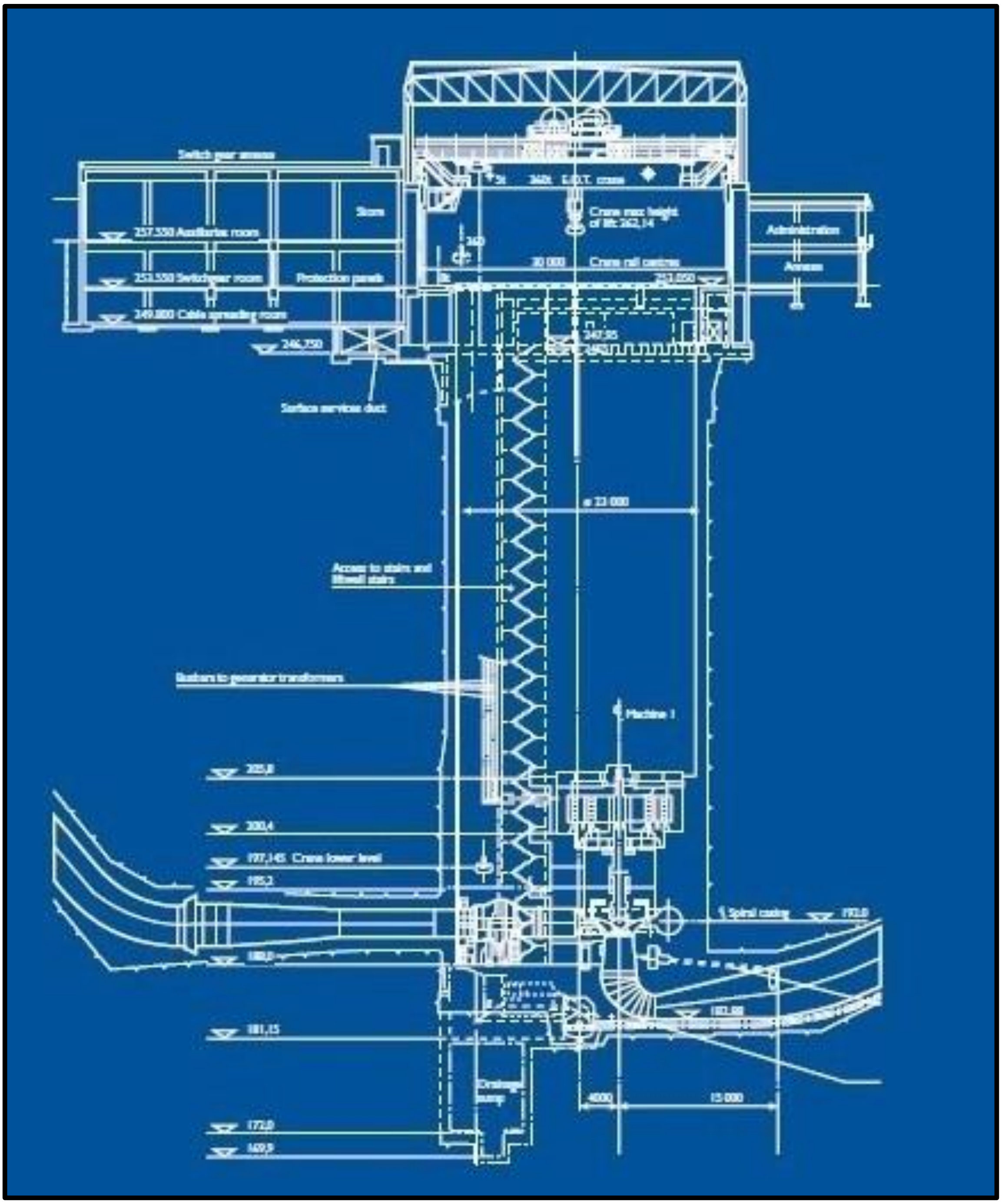


Plan

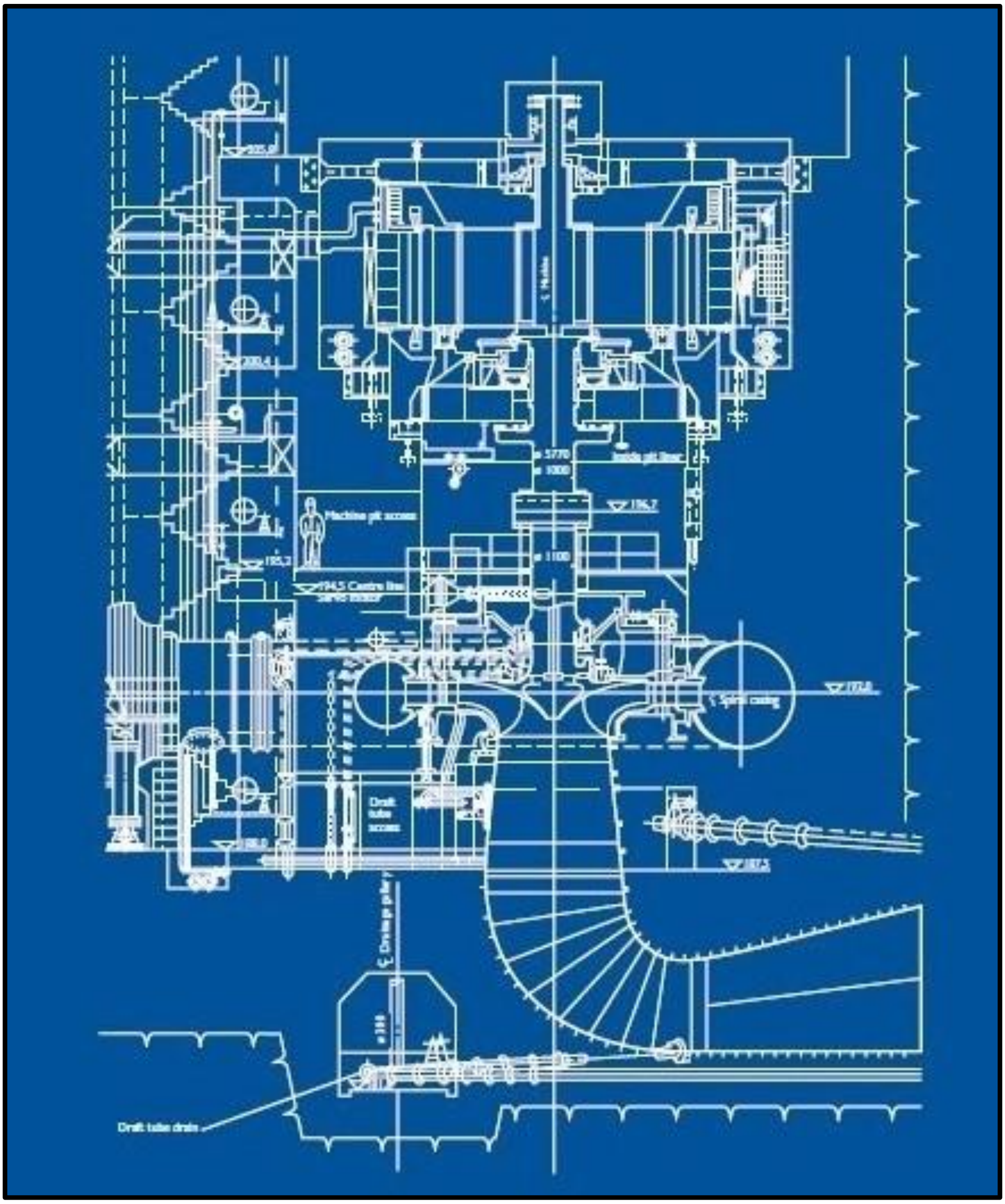
Plan



1. Headrace tower
2. Rockview dam wall
3. Headrace tunnel
4. Surge tank
5. Portal
6. Inclined shaft
7. Pressure tunnel
8. Portal
9. Penstock
10. Bifurcation
11. Portals
12. Penstock shafts
13. Machine shafts
14. Tailrace tunnels
15. Tailrace towers



Machine Shaft



Machine pit access
Draft tube access
Spiral casing
Draft tube drain

Machine

SUMMARY DESCRIPTION OF THE CIVIL WORKS

Section of works	**Brief description**	**Principal dimensions or quantities**	**Methods of construction**
Headworks - Tower	Control and access tower in upper Rockview reservoir with emergency stoplogs and maintenance gate to the inlet/outlet bellmouth at bottom, leading to headrace	- Excavation 6 000m^3 - 70m high prestressed tower - 11m x 14m elliptical section comprising wet and dry wells - 50m bellmouth tapering from 2 x 14m x 7m rectangular to 6,2m dia	Excavation: As for headrace (below) Tower: Climbing shutter Bellmouth: Conventional RC construction
- Access bridge	Vehicular access from Rockview Dam crest to permit gate loads	- 4 x 20m deck spans Piers up to 50m high	Deck: Precast beams and launch girder Piers: Conventional climb
Headrace	Trapezoidal section cut-and-cover trench to accept welded in situ steel liner later encased in concrete	- 500m long - Depth variable 8m to 22m - Excavation 35 000m^3 - Steel liner dia 6,2m - Gradient 1:225	Conventional surface drill and blast and rock support techniques Conventional RC encasement followed by void grouting
Surge tank	Circular tank in open excavation off-line but connected to the end of the headrace by a 60^o Y-piece	- Excavation 32m wide, depth 22m - Tank 21m ID, 78m high, prestressed	Excavation: As for headrace (above) Conventional climbing shutter to prestressed structure
Inclined shaft	Underground circular inclined shaft and bends connecting headrace/ surge tank to pressure tunnel steel liner as headrace	- 125m long inclined - Excavation dia 7,8m - Steel liner dia 6,2m - Gradient 1:0,7 (55^o)	Raise-bore to pressure tunnel, D&B widen, muck out through pressure tunnel Mass concrete type backfill with three-stage grouting of rock and voids
Pressure tunnel	Underground horseshoe section tunnel with steel liner as headrace	- 500m long - Excavation dia 7,8m - Steel liner dia 6,2m - Gradient 1:10	Conventional drill, blast and support: 1. Pantafort – drilling (two-boom jumbo) 2. Heading and bench (hardness of rock and short length precluded TBM excavation) Concrete and grouting as for inclined shaft

Penstock and bifurcation	Similar to headrace, with bifurcation at lower end	- 560m long - Depth variable 8m to 18m - Excavation 45 000m3 including bifurcation - Steel liner dia 5,4m - Gradient 1:15	As for headrace (above)
Penstock shafts	Twin circular inclined shafts and bends connecting bifurcation to base of machine shafts, via a horizontal section in each	- About 92m long inclined - Gradient 1:1 - 4,7m dia excavation for liner 3,9m dia - 37m long horizontal excavation tapering to 3,4m dia for liner tapering to 2,6m dia	As for inclined shaft, except raise-bores and mucking were done to the horizontal drives from machine shafts
Machine shafts and services shaft, drainage and services galleries	Twin vertical shafts to accept pump turbines, motor generators and ancillaries. Services shaft and galleries located between two main shafts. Base of main shafts to accept draft-tubes to tailrace	- Main shafts • Excavated dia 26m • Concrete lined dia 23m incorporating lift-shafts • Depth 70m • Concrete embedment and support framework to pump turbines and motor generators with access floors and galleries at shaft base, 30m high and 23m dia - Ancillaries • Services shaft 6m dia • Galleries about 6m dia horseshoe sections 34m long	Excavation 1. Spiral D&B excavation by segments 2. Drilling by crawler rigs 3. Mucking by crane to surface loader and trucks 4. Rock support by bolts, anchors and mesh-reinforced shotcrete to designed parameters Concrete machine-embedment with RC operation temperature controlled Concrete wall lining by climbing shutter
Tailrace shafts	Two asymmetrical inclined shafts and bends connecting draft-tubes to lower Kogelberg Dam and tailworks control structure, lined with reinforced concrete	- 93m and 68m long - Gradient 1:1,9 and 1:0,9 - 6,0m dia excavated 5,0m dia lined	As for inclined shaft, but no raise bore possible to 1:1,9 gradient where full-face D&B was used. Concreting to collapsible steel shutter specials to bends

Tail works - Tower - Access bridge - River diversion	Twin control and access towers in lower Kogelberg reservoir surmounted by common control house for maintenance gates to twin intake/outlet bellmouths at bottom, leading to tailrace shafts Vehicular access from power station platform to permit gate loads Widened river channel and reinforced concrete training wall anchored to rock with mass concrete coffer-dam across tailrace excavation	- Excavation 36 000m3 - 7m square tower sections - 33m high towers - 28m x 7m x 12m high control house - 1 x 11,5m span - 1 x 20,0m span - Single pier 9m high - Channel 80m long, 10m wide - 120m long, 6m high coffer-dam	Excavation: As for headrace (above) but rock support as for machine shafts Bellmouth: Conventional RC construction Deck: Precast beams Pier: Climbing shutter Conventional excavation, rock support and RC construction
Power Station - Main building - Annexes	Reinforced concrete rectangular layout two-tier structure surrounding the machine shafts with crane beam to carry 360t traveling crane. Superstructure in structural steel and cladding Two RC annexes on either side of the main building: - a two-tier administration annexe - a three-tier switchgear annexe	- 11m x 30m x 16m high RC structure - 10m high steelwork over whole building - 12m x 73m x 9m high - 30m x 92m x 16m high -	All conventional RC structural/building work and finishes with usual services. Trenches and box-outs as are common in power station works
- Ancillaries		All conventional civil engineering and building work, details too various to mention (switchyard, roads, stormwater and sewerage, security fences, retaining walls and minor buildings).	

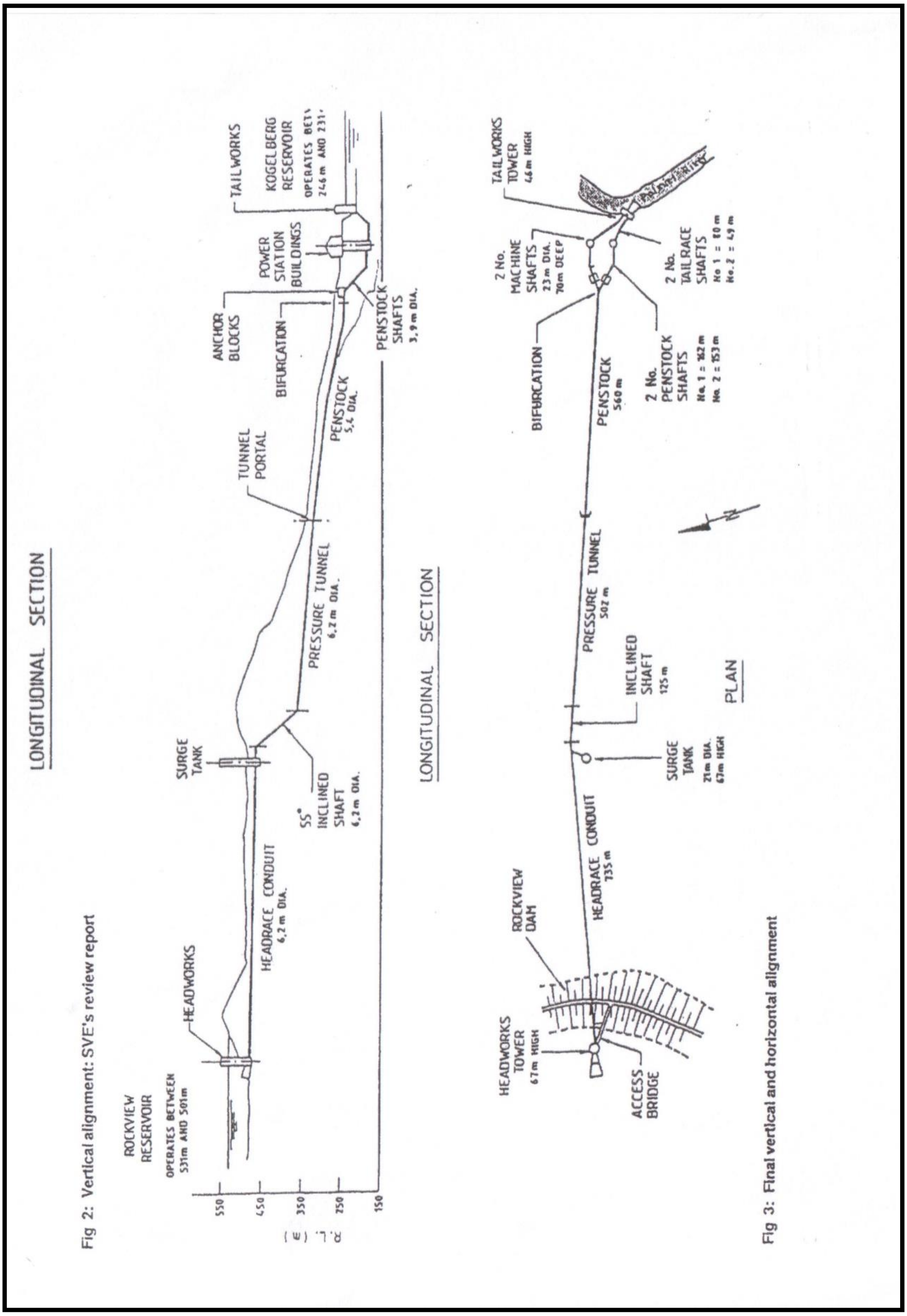


Fig 2: Vertical alignment: SVE's review report

Fig 3: Final vertical and horizontal alignment

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