

# Construction and Commissioning of the 'Muela Hydropower Project

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**Abstract** — The Lesotho Highlands Water Project involves impounding the surplus water from the rivers in the Highlands for transfer through the Maluti mountains and across the border to South Africa, where it will supplement the overtaxed water resources of the Vaal River basin. The first phase of the project just before the completion of Phase 1A includes the construction of Katse Dam, 82 km of tunnels through the mountains, a 72-MW hydropower station and regulation dam at 'Muela, and all associated infrastructure. This paper discusses the contracts for the electromechanical equipment for the 'Muela Hydropower Project portion of the LHWP. © 1999 Published by Elsevier Science Ltd. All rights reserved.

## Introduction

A major binational project, the Lesotho Highlands Water Project involves impounding the surplus water from the rivers in the Highlands for transfer through the Maluti mountains and across the border to South Africa, where it will supplement the overtaxed water resources of the Vaal River basin. The first phase of the project just before the completion of Phase 1A includes the construction of Katse Dam, 82 km of tunnels through the mountains, a 72-MW hydropower station and regulation dam at 'Muela, and all associated infrastructure.

The 'Muela Hydropower Project is situated approximately midway between the Katse Dam and the Outfall in South Africa (see Fig. 1). The concrete-lined Transfer Tunnel from the Katse Intake structure to the 'Muela Hydropower Station is 45 km long, with an inner diameter of 4.35 m, following by a 100-m-long steel lining of a diameter of 3.35 m with connection via a throttle to the Upstream Surge Shaft, which is 165 m high. Via a steel lined reduction piece  $\phi 3.35 \text{ m} / \phi 2.5 \text{ m}$ , a horizontal penstock continues into the Penstock Guard Valve Chamber, where a bi-plane butterfly valve 2.5 m in diameter is provided. Further, via a steel-lined vertical Penstock Shaft approximately 155 m high and a horizontal Low Level Penstock, both 2.5 m in diameter, water is routed via two bifurcations and three manifolds, each 1.15 m in diameter, into the Powerhouse Cavern to the Turbine Inlet Valves (TIVs).

The Powerhouse Cavern (Figs. 2 and 3) is 60 m long, 30 m high and 15 m wide and houses three turbine generator units. Adjacent to the Powerhouse Cavern is a Trans-

former Cavern accommodating three Unit Transformers. Access to the Cavern is via a access tunnel 6.5 m, 6.5 m wide and approximately 780 m long.

Passing the hydraulic Francis turbines after power generation, water is discharged from the draft tubes and concrete-lined connection tunnels into the 40-m-high Downstream Surge Chamber and, via a 1.4-km-long Tailrace Tunnel of 4.1 m diameter, enters the 'Muela Reservoir.

Because water transfer to South Africa to deliver maximum 32.5 m<sup>3</sup>/sec was required before the 'Muela Hydropower Station could be completed and commissioned for commercial operation, a Station By-Pass had been designed and constructed. Through a steel lined bifurcation of  $\phi 3.35 \text{ m} / \phi 2.0 \text{ m}$ , situated about 800 m upstream of the above mentioned Upstream Surge Shaft, the water is diverted by a steel-lined, 515-m-long tunnel of 2.0 m diameter to the Station By-Pass Building, which includes a Guard Valve (GV) of a bi-plane butterfly type of 2.0 m diameter and a Energy Dissipation Valve (EDV) of a Howell-Bunger fixed cone type of 1.5 m diameter. Well aerated water from the EDV, impinged onto the walls of the dissipation structure, is then discharged through a 350-m-long concrete-lined chute down to the stilling basin; and, via an upgraded river channel, approximately 1 km long, the water finally reaches the 'Muela Reservoir.

The electro-mechanical works concerning the 'Muela Hydropower Project, in addition to other civil works, are included in the following Contracts:

- Contract LHDA 129A: Underground Power Facilities;
- Contract LHDA 129B: 'Muela Dam and Appurtenant Works;
- Contract LHDA 134: Turbines, Generators and Ancillary Plant, consisting of
  - Mechanical Works divided into 11 Sections,
  - Electrical Works, divided into 18 Sections,
  - SCADA System, and
  - HVAC System.

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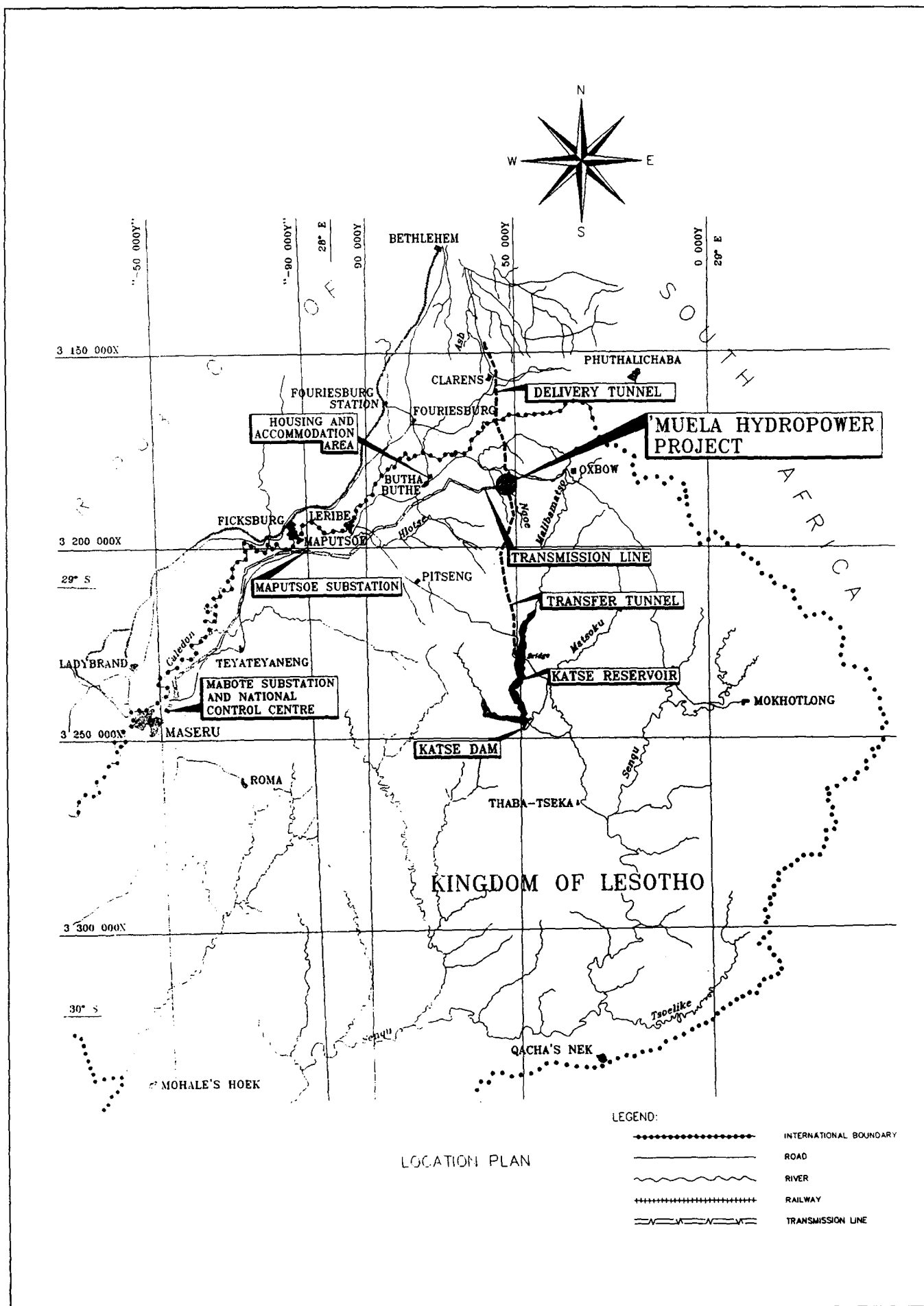
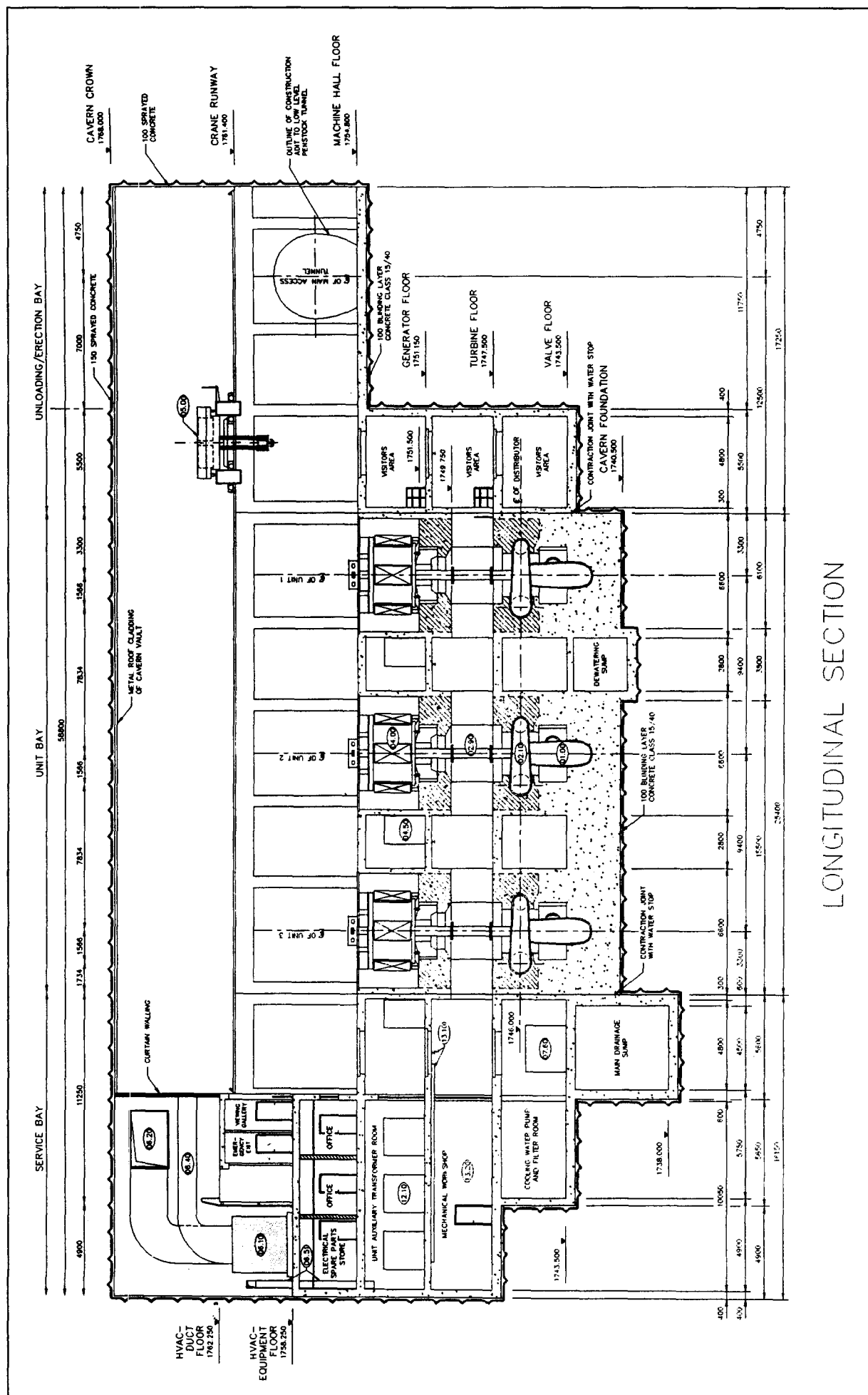


Figure 1. Location of the 'Muela Hydropower Project.



**Figure 2. Longitudinal section of the Powerhouse Cavern.**

- Contract LHDA 135: Transformers and 132 kV Switchgear;
- Contract LHDA 136: 132 kV Transmission Line and Substation Bays

The further description for the 'Muela Hydropower Project concerns only the electromechanical equipment.

## 2. Contract LHDA 129A: Underground Power Facilities

### 2.1. Contractual Data

#### Contractors

Main Contractor: MHPC (Joint Venture)

Subcontractors for electro-mechanical works:

- Penstock steel lining,
- Tailrace Gate and Station

By-pass steel lining

- Cable Shaft Lift
- Power station Crane
- Station By-pass Valves

GEC Alstom -  
Neyrpic (France);  
Otis (S. Africa);  
Condra (S. Africa);  
Kvaerner Boving (U.K.)

#### Contract Dates

Commencement Date

22 March 1995

Completion Date

22 September 1998

### 2.2 Scope of Work and Main Data

#### 2.2.1. Steel lining

The scope of the work covers the steel lining between the connecting joint with the Transfer Tunnel and the connection joints to the Turbine Inlet Valves in the Powerhouse and consists of the following main items:

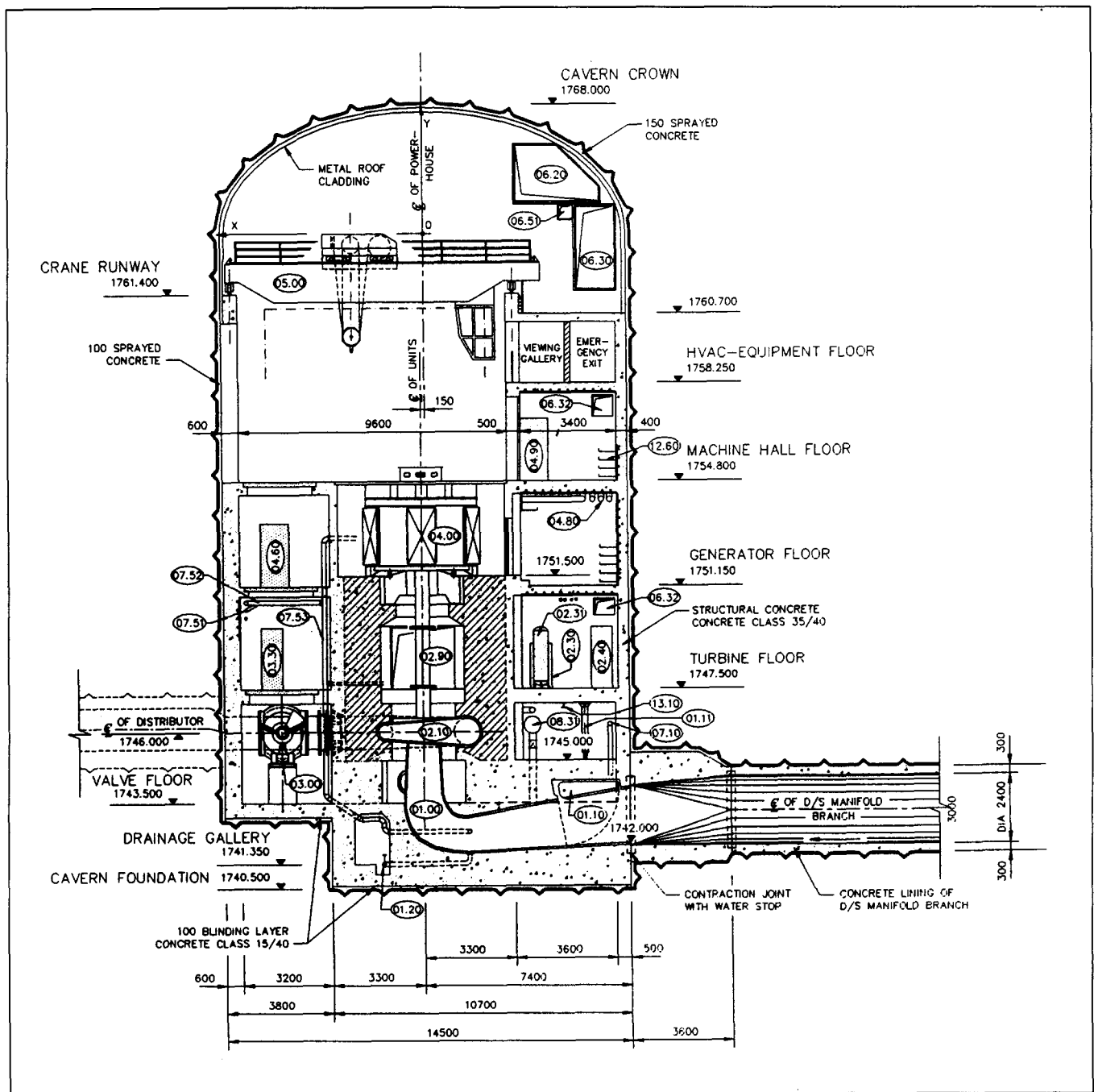


Figure 3. Cross-section through unit axes.

- Headrace tunnel steel lining:
 

Inner diameter	3.35 m
Length	100 m
- Steel lining to surge shaft riser:
 

Inner diameter	2.5 m
Throttle diameter	1.85 m
- Penstock steel lining:
 

Inner diameter	2.5 m
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- Penstock and manifolds with two bifurcations:
 

first one, of inner diameters	2.5 m/2.05 m/1.45 m
second one, of inner diameters	2.5 m/1.45 m/1.45 m
- Inspection cart.

**Work implementation** . The steel lining was manufactured by Deutsche Babcock (Nigel, South Africa), in the form of spools, 5.9 m–8.9 m long. The installation of the steel lining at the site started in November 1996. Some parts of the manifold and riser were pressure tested in the workshop in December 1996.

The installation of the steel lining upstream of the Penstock Guard Valve was completed in April 1998, followed by the re-impounding of the Transfer Tunnel on 3 April 1998. The inspection cart was installed and operated for testing and training purposes in April 1998.

### 2.2.2 Cable shaft lift

The following main data pertains to the cable shaft lift and associated equipment installed in the shaft between the underground Powerhouse and the access tunnel to the valve chamber:

- |                    |                     |
|--------------------|---------------------|
| • Lifting capacity | 630 kg or 8 persons |
| • Rated speed      | 2.5 m/s             |
| • Lift travel      | 168.5 m             |

**Work implementation.** The cable shaft lift was inspected during manufacturing in the OTIS workshop in Johannesburg in November 1996 and April 1997. The installation was completed and the lift was commissioned in January 1999.

### 2.2.3 Powerstation crane

The Powerstation crane installed in the underground Powerhouse Cavern serves for assembly, installation and maintenance of the turbine-generator units, turbine inlet valves and associated equipment. The following data pertain to the Powerstation crane:

- Lifting capacity:
 

– Main hoist	60 ton
– Auxiliary hoist	5 ton
- Rail track length 48 m

**Work implementation** . The Powerstation crane was inspected during manufacturing in the CONDRA workshop in Johannesburg in November 1996 and April 1997. The crane erection was completed and the crane was commissioned in December 1997.

### 2.2.4 Tailrace gate

The tailrace gate, a vertical slide gate type, is operated by means of a mechanical gate hoist under balanced pressure. It closes the tailrace tunnel of the 'Muela Power

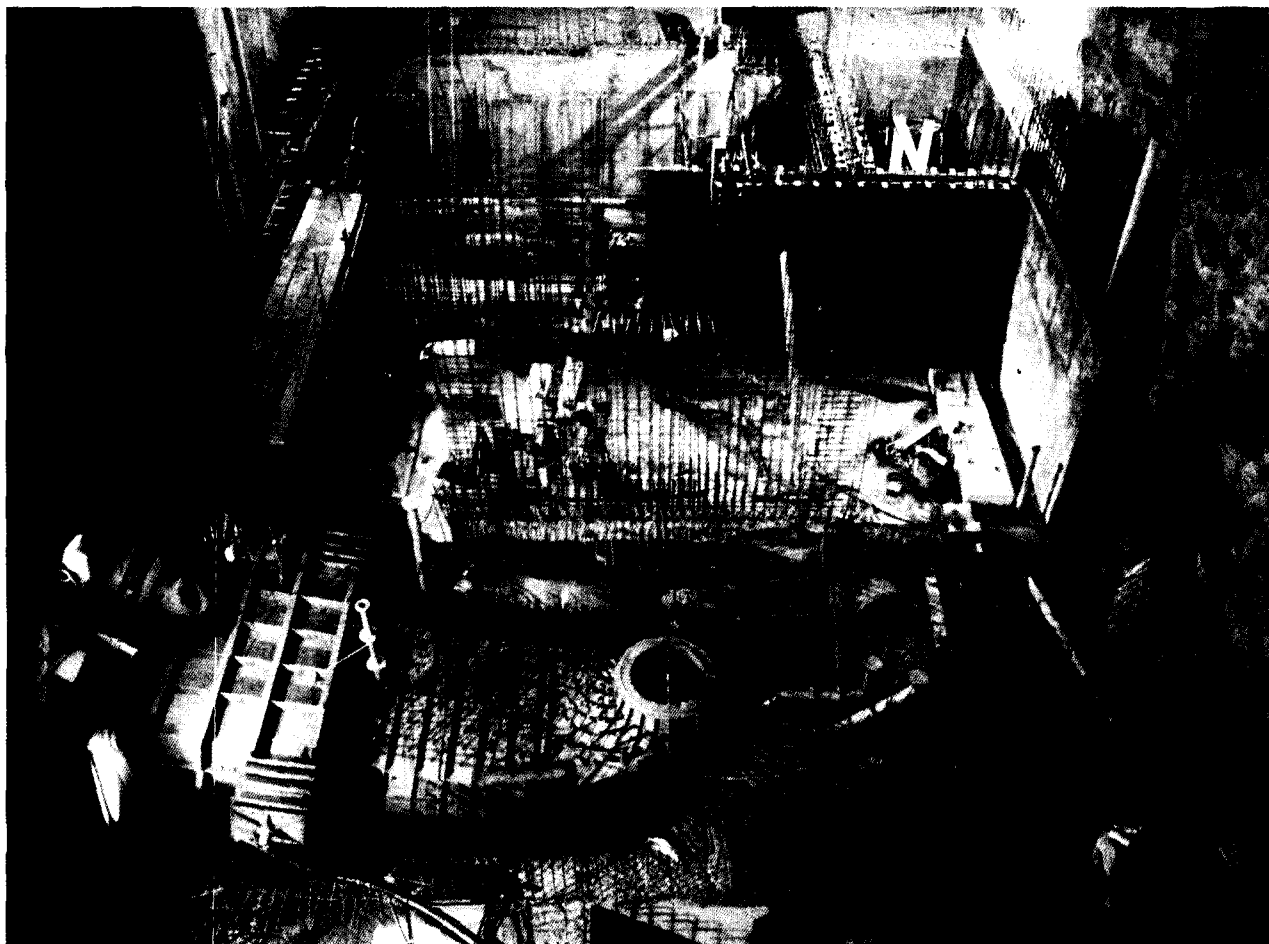


Figure 4. Assembly of draft tube #1 in the powerhouse cavern.

station from the Muela Reservoir for an occasional dewatering, inspection and maintenance of the tailrace tunnel. The following main data pertains to the Tailrace Gate:

- Clear gate width x height:  
4.1 m x 4.1 m
- Lifting / lowering speed:  
3 m/min.

**Work implementation** . The Tailrace Gate was inspected during manufacturing in FEL International (GEC Alstom) Manchester workshop in August 1996. The erection and dry/wet commissioning were completed in June 1998.

## 2.2.5. Station By-pass steel lining

The following main data pertain to the steel lining between the connecting joint with the Transfer Tunnel and the connection joint with the By-Pass Guard Valve:

- T-piece in Transfer Tunnel and reduction of diameters:  
3.3 5m/2.0 m
- By-Pass steel lining diameter: 2.0 m
- Length: 515 m

**Work implementation** . The by-pass steel lining was manufactured by Deutsche Babcock (Nigel, South Africa) in the form of 11.8-m-long spools. The erection of the steel lining at the site started in July 1996 and was completed in August 1997.

## 2.2.6. Station By-Pass valves

In the Station By-Pass Building, two by-pass valves are situated at the end of the by-pass steel lining, i.e. the Guard Valve (GV) and, via an intermediate pipe, the

Energy Dissipating Valve (EDV). The Guard Valve at the first has a isolating function, i.e. to open before and to close at the end of the water discharge through the station by-pass; this occurs under balanced pressure upstream and downstream of the GV. The second important function of the Guard Valve is to close at emergency, when the discharge through the station by-pass reaches or exceeds the maximum flow of 35 m<sup>3</sup>/s either due to malfunction of the EDV or due to pipe rupture downstream of the GV.

The function of the EDV is explained by its name, i.e. to dissipate energy of discharging water by means of well aeration of the conical water jet before impinging onto the walls of the dissipation structure and then entering the chute down to the stilling basin. Normally the EDV operates at the GV in open position. The main data pertaining to the by-pass valves is shown in Table 1.

**Work implementation and problems experienced.** Erection of the by-pass valves began in June 1997 and, after being completed in September 1997, was followed by dry and wet tests. During the wet tests on 26 September 1997 and, later, at an unplanned emergency trip of the by-pass guard valve, problems were experienced with extruding of the rubber music note service seal. In all cases, a new seal of the same size was fitted and the station by-pass was put into operation. Despite these problems, the station by-pass was in commercial operation from 08 January 1998 until 23 February 1998.

The Transfer Tunnel was dewatered via the station by-pass on 24–25 February 1998, in order to complete the works necessary for impounding the upstream waterways.

The Energy Dissipating Valve was then dismantled and a new sleeve of a revised and more sturdy design was fitted in the Premier Valves Workshop in Johannesburg. The modified EDV was again installed, inspected and successfully tested by LMC/LHDA on 14 March 1998.

Table 1. Main data pertain to the by-pass valves.

<b>By-pass valve centerline elevation</b>	1890.5 masl
<b>By-Pass Guard Valve (GV)</b>	Butterfly biplane type
Inner diameter	2.0 m
Design pressure	20 bar
Maximum operating discharge	32.5 m <sup>3</sup> /sec
Maximum discharge, when Flow Data Processing Unit initiates an emergency closure of the GV	35.0 m <sup>3</sup> /sec
Maintenance seal on the upstream side of the disk	
Service seal on the downstream side of the disk elastometric music note	80 IRHD
Operating of GV by Oil Pumping Unit and	2 oil-hydraulic servomotors
Opening time	3 min. 15 sec.
Closing time	
– with no surge tank available	30 min.
– with surge tank available	11 min.
<b>Energy Dissipating Valve (EDV)</b>	Howell-Bunger fixed cone type
Inner diameter	1.5 m
Design pressure	20 bar
Maximum operating discharge	32.5 m <sup>3</sup> /sec
Maximum discharge, when Flow Data Processing Unit initiates closure of the EDV	34.0 m <sup>3</sup> /sec
Operating of EDV by an electric actuator and screw stem type mechanism	
Opening and closing time	3 min. 45 sec per 10%
Opening at max. discharge of 32.5 m <sup>3</sup> /sec. and Full Supply Level of Katse Reservoir of 2053 masl	41%

The Guard Valve was fitted with a new rubber service seal on bottom tolerance limit after the clamp ring segments were grid-blasted in order to increase friction holding seal in place, and the re-watering of the Transfer Tunnel started on 02 April 1998.

On 27 April 1998, following the integration of the upstream surge shaft into the hydraulic waterways system, a full flow emergency closure test of the GV was undertaken under the following conditions: Katse Reservoir level, 2053.00 masl; static head U/S of the valve, 16.3 bar, flow 35 m<sup>3</sup>/sec.; reduced closing time of the GV to 11 min. 5 sec.

The valve failed to close again, remaining open about 12 mm measured on servomotor piston. The following morning on 28 April 1998, it was possible to close the valve completely, and during inspection it was observed the seal had extruded between 10 o'clock and 2 o'clock positions. The damaged seal was again replaced and the station by-pass re-started the water discharge on 29 April 1998.

To overcome this situation and problems with the Guard Valve, a new seal design inserting fiber fabric reinforcement into the rubber seal and a new modified clamp ring were proposed by the Sub-Contractor KBO. The new seal arrangement was tested at the KBO premises in December 1998. The installation of the new seal and clamp ring, and the emergency closure of the Guard Valve, as a final proof of its faultless and reliable operation, is scheduled for April 1999.

### 3.0 Contract LHDA 129B: 'Muela Dam and Appurtenant Works

#### 3.1 Contractual Data

##### Contractors:

Main Contractor: MHPC (Joint Venture)  
Subcontractors for Bottom Outlet and Compensation Water Outlet: Stewart Scott, Premier Valves, Ainsworth Engineering (all South Africa), Blackhall Engineering (U.K.), Abb Kent-Taylor (Italy)

##### Contract Dates:

Commencement Date 01 March 1994  
Completion Date 30 January 1998

#### 3.1. Scope of Work and Main Data

##### 3.2.1. Bottom Outlet and Compensation Water Outlet

The bottom outlet equipment discharges a total of 8 m<sup>3</sup>/s through the 'Muela dam for emergency drawdown, silt discharge, and downstream compensation flow when required. The total discharge of 8 m<sup>3</sup>/s is obtained by 7.56 m<sup>3</sup>/s through the bottom outlet line and 0.44 m<sup>3</sup>/s through the compensation water outlet.

The bottom outlet line consists of an isolating gate valve (DN 900 mm, PN 10 bar) and a sleeve valve (DN 700 mm, PN 10 bar) for flow control. The compensation water line is provided with an isolating gate valve (DN 300 mm, PN 10 bar), a Larner Johnson valve (DN 300 mm, PN 10 bar) for flow control and a digital flowmeter device.

All valves are manually actuated, and, with exception of the Larner Johnson valve, they are manufactured from stainless steel.

**Work implementation.** The gate valve (DN 900 mm) and the sleeve valve (DN 700 mm) were pressure tested in the workshop in March 1996 and February 1997.

The installation of the equipment started in April 1997, and the site dry and wet tests were performed from September 1997 through November 1997 in parallel with the impounding of 'Muela reservoir.

### 4.0 'Muela Hydropower Station Contract LHDA 134: Turbines Generators and Ancillary Plant

#### 4.1. Contractual Data

##### Contractor Consortium: ABBGKBC

##### Consortium Partner for

- Electrical Works and SCADA System ABB Generation (Sweden)
- Mechanical Works and HVAC System Kvaerner Bovine (U.K.)

##### Contract Dates:

Contract Commencement Date 1 April 1994  
Commissioning April 1997 to November 1998  
Contract Completion Date (original date) 17 October 1997  
Contract Completion Date (after 1st EOT) 22 September 1998  
Contract Completion Date (after 2nd EOT) 21 December 1998

It may be noted that a time extension (1st EOT, 341 days) with respect to the original contract date had to be given to synchronize the time schedule for the equipment under LHDA 134 with those of the civil works under contracts LHDA 129A and 129B, which had suffered a considerable delay in award of the contracts.

A further time extension had to be granted (2nd EOT, 90 days) to compensate for a workforce strike in 1996, and other delays meanwhile incurred through the civil works.

#### 4.2 Main Data for Generating Units and Essential Equipment

**Turbines.** The main data pertaining to each of the three Francis turbine-generator units installed in the Powerhouse Cavern is given in Table 2.

Each turbine assembly consists of the following major assemblies: draft tube liner, suction cone, spiral case and stay ring, bottom cover, top cover, runner and shafts, guide bearing, guide vane apparatus, and overspeed device.

The draft tube liner assembly is a steel welded fabrication, manufactured in two pieces, that was installed and welded on site. The suction cone assembly, supplied as an removable upper and lower cone section, is provided with a manhole for inspection inside of the draft tube.

The draft tube liner and the suction cone incorporate tappings for thermodynamic field efficiency test measurement, pressure pulsation measurement during commissioning and testing of the turbine, suction cone pressure monitoring, and water level check.

The spiral case (Fig. 5), partially embedded in concrete, was completely manufactured and tested in the workshop and incorporates tappings for flow measurement (Winter-Kennedy) and pressure measurement during commissioning and testing of the turbine.

The runner assembly (single piece stainless steel casting Cr Ni 17 4) is via turbine shaft and intermediate shaft coupled to the generator rotor shaft. The direction of rotation is counterclockwise, viewed from the generator, with the rotating mass supported by the generator thrust bearing.

The turbine is provided with self-lubricated guide bearing with six bearing pads. The measurement and protection instrumentation of the turbine include indicators, alarms and trip protection devices for the guide bearing, shaft seal and the overspeed device.

**Generators.** The following main data pertains to the generators:

Rated capacity	32 MVA
Maximum capacity	35.2 MVA

Rated voltage	11 ± 10 %
Rated power factor	0.85
Rated frequency	50 Hz
Flywheel effect	84 tm <sup>2</sup>
Weights:	
– Complete stator	50 ton
– Complete rotor	3 7.5 ton

**Turbine inlet valves (TIVs).** Three turbine inlet valves (TIVs) control water inlet to the respective turbines. The TIVs allow the turbines to be dewatered and the penstock flow to be shut off in case of emergency. The following main data pertains to each TIV:

Inner diameter	1.15 m
Design pressure	36 bar
Normal flow	12 m <sup>3</sup> /sec
Emergency free flow	45 m <sup>3</sup> /sec
Operating times:	
– Service seal OFF and opening of TIV	approx. 40 sec.
– Closing of TIV and service seal ON	approx. 45 sec.
Weight complete	18 ton

Each TIV is rigidly connected to the respective inlet penstock section and, via a sliding and dismantling joint assembly, to the spiral case inlet. This arrangement allows the TIV to slide axially on its foundations to accommodate slight elongation of penstock length caused by pressure differences when the valve opens or closes, and does not transmit any axial loads from the TIV to the spiral case.

Normally the TIV operates in balanced condition (i.e. at zero flow with the turbine guide vanes closed), but in a case of emergency it is capable of closing against full turbine flow. Each TIV is opened and closed by a servomotor operated by oil pressure supplied from a separate oil pumping unit.

The TIV is provided with a service seal activated by the penstock water pressure and a maintenance seal activated manually by hydraulic oil pressure by means of a portable hand pump.

**Draft Tube Flap Gates.** As integral parts of the turbine draft tube linings, three draft tube flap gates shut off the tailrace water from the turbines and allow turbine

dewatering for inspection and maintenance. Each draft tube flap gate operates under balanced pressure by means of oil operated servomotors. The draft tube flap gates are hydraulically and electrically interlocked with the Turbine Inlet Valves (TIVs), which inhibits closing of the draft tube flap gate when the TIV is open, and to open the TIV when the draft tube flap gate is closed. The draft tube flap gate in the open position is a condition for the starting sequence of the Unit. Each draft tube flap gate has the following main characteristics:

Clear width	2.680 m
Clear height	1.477 m
Operating times:	
– Opening	approx. 50 sec.
– Closing	approx. 50 sec.
Weight	14 ton

**Governing System.** The 'Muela Powerstation is designed for manual, automatic and remote control. The control system allows the following modes of operation:

- manual and automatic control of each unit from the Unit Control Board (UCB) in the Powerstation at the Machine hall Floor;
- automatic control of each unit from the control room in the Operation Building and remote control; and
- supervision from the National Control Center (NCC) in the future.

The governing systems for the three Francis turbines consists of the following principal components: governor electronic digital control unit, governor oil pumping set with auto isolating valve (AIV); air/oil pressure accumulator, oil piping system with valves, guide vane servomotors, guide vane position transducer and guide vane position multi-limit switch.

The turbine governing system controls the guide vanes of the Francis turbine and provides the following main functions: speed control at no load operation, automatic start and stop frequency regulation sequences including automatic synchronization, power output control, under isolated network conditions with possibility of switching over to an alternate feed back loop in the case of change-over

*Table 2. Main data for each of the three Francis turbine-generator units installed in the Powerhouse Cavern.*

Net Heads, depending on Upstream Water Levels (Katse Reservoir), Downstream Water Levels (Muela Reservoir) and operation of units:	
Rated net head	236 m
Maximum net head (one unit at full load)	287 m
Minimum net head (three units at maximum guide vane opening)	196 m
Outputs, guaranteed by the Contractor:	
Rated turbine output at rated net head of 236 m	25.20 MW
Maximum turbine output, one unit at full load at max. net head of 287 m	33.45 MW
Turbine output, three units at max. opening and min. net head of 196 m	18.3 0 MW
Runner nominal diameter	1.072 m
Number of runner blades	17
Number of guide vanes	20
Synchronous speed	750 rpm
Guaranteed maximum runaway speed	1450rpm
Design and maximum guaranteed pressure for spiral case and TIV	36 bar
Guaranteed maximum speed rise for load rejection of all three units from full load	55%
Guaranteed Weighted Efficiency at five different net heads and loads from 50 % to full load	92.84%





Figure 5. Installation of Spiral Case #4.

from output control to frequency control, spinning reserve operation, load sharing between the units in "joint control" mode, emergency shutdown in two different sequences, i. e. emergency shutdown on electrical and bearing failures, interface with turbine inlet valve control, and draft tube flap gate control.

The following guide vane stroking times have been adjusted and traced:

Manual opening / closing	21 sec. / 21 sec
Auto opening closing	8.1 sec.
Normal trip closing	11 sec
Emergency closing	11 sec

**Penstock Guard Valve.** The Penstock Guard Valve (PGV) serves to guard the flow of the generating water to all three turbines. Normally, the PGV maintains open. In case of emergency, the valve closure can be controlled at the maximum turbine flow conditions from an emergency push button in the powerhouse or against full burst flow rates by an overvelocity detector. The PGV has the following main characteristics:

Inner diameter	2.5 m
Design pressure	20 bar
Normal maximum turbine flow	36 m <sup>3</sup> /s
Emergency free flow	60 m <sup>3</sup> /s
Opening time	3 min. 18 sec.
Closing time	1 min. 54 sec.
Weight	42 ton (approx.)

The PGV is a butterfly valve with a double seal lattice disc. The upstream maintenance seal is normally open and is manually closed at closed position of the PGV for maintenance purposes.

The PGV is rigidly connected to the upstream penstock flange and, via a dismantling joint assembly, connected to the downstream companion pipe. This arrangement allows that the PGV can slide axially on its foundations to accommodate slight alterations of the penstock length caused by pressure differences as the valve opens or closes and to avoid any axial loads to be transmitted to the downstream section of the penstock.

The companion pipe is fitted with two anti-vacuum valves to prevent formation of vacuum downstream of the PGV and with an air relief valve. Two by-pass assemblies, controlled by hydraulic operated needle valves, are provided for the impounding of the penstock and to balance the pressure upstream and downstream before opening of the PGV.

The PGV is opened by two double-acting servomotors by oil pressure supplied from the oil hydraulic pumping unit with a hydraulic pressure accumulator providing also a permanent make-up of oil leakage to keep the disc fully open. The PGV closes under the effect of the counterweights and a hydrodynamic torque on the valve disc, while the servomotors act as oil dash-pots.

**Ancillary Equipment.** The ancillary equipment, which serves for safe and suitable operation of the Muela Hydropower Station consists of the following sections: compressed high and low pressure air systems; water

distribution system, including cooling water system, dewatering and drainage system, water measuring system and instrumentation; oil purification system; and maintenance and workshop equipment. The main data and function of the ancillary equipment are appropriately designed and granted under this Contract, but because of their great extent are not described in detail in this paper.

The Powerstation Crane 60/5 ton, installed in the underground Powerhouse Cavern, is described under the Contract LHDA 129A: Underground Power Facilities (Section 2, above).

**Power Generation Scheme.** Power generation is lined up unitwise, i.e. every one of the three 32 MVA, 11 kV generators in the power cavern is directly linked with its own 32-MVA step-up transformer, located in a nearby underground chamber and feeding into a 132 kV SF6 gas insulated switchgear (GIS), which is accommodated above ground level in a separate switchgear building that also includes other general services, particularly the 33 kV and 11 kV station switchgear.

Power transmission is being effected by 11 kV and 132 kV XLPE cables. The latter cables are laid through an approx. 160 m vertical cable shaft and an approx. 270 m horizontal cable gallery.

The GIS is built up as a double busbar system with three generator/transformer feeders, two feeders, one bus coupler, and one outgoing for a regional 20 MVA transmission line transformer, catering to the needs of the power station and also capable of supplying power to the rural Butha Buthe/Khukune network (LEC), which is at present fed only from a 66 kV ESKOM substation in South Africa.

**Auxiliary Power Reticulation.** For delivery power to the various power station general and unit auxiliaries, the following options exist:

- Power is derived directly from either unit #1 or unit #3 via step-down transformers.
- Power is delivered from the 132 kV GIS via the regional 20 MVA transformer and the 3 MVA area transformer, connected in series, and terminated in a 33 kV and 11 kV switchgear, respectively. Power supply into the power cavern will be effected by means of a 11 kV overhead line in the outdoor part and a power cable through the main access tunnel.
- Power can also be received from a nearby 33 kV substation (LEC) via a 33 kV overhead line which is subsequently stepped-down into 11 kV level via the area transformer, as mentioned above.
- In the event that all primary power sources fail, a 600 kVA diesel generator is provided for emergency power supply.
- All major LV distribution boards are equipped with double infeeds and bus couplers which will automatically disconnect non-essential loads upon power failure, and, thus, after a short break, maintaining power supply only to essential power consumers upon automatic start-up of the emergency power source.
- The power station also features two entirely separated 110 V DC systems employing two battery chargers and two batteries each. The same arrangement applies to the a 48 V DC power supply systems which are required for the power station SCADA and computer system.
- For non-interrupted power supply requirements of AC consumers, two 230 V inverters have been installed.

**SCADA Systems.** The 'Muela Hydropower Project includes two separate SCADA systems—one located at the 'Muela Control Centre (MCC), and the other at the National Control Centre (NCC) in Mabote, some 120 km away.

The MCC SCADA provides remote supervision and control of all items associated with the 'Muela Hydropower Plant, HV switchyard and water transfer/delivery systems.

The 'Muela Control Centre SCADA system comprises computer workstations, printers, distributed process computers, remote terminal units (RTU), and power line carrier (PLC) systems. The workstations and process computers are connected by means of a dual Local Area Network (LAN) and provide process supervision and control of the various functional groups for power generation, switching and transmission.

The workstations are based on Hewlett Packard 9000/700 series RISC-based desktop computers with UP UNIX operating systems to provide high performance and high-resolution graphics. The workstations are located in the Operations Building central control room to provide the human-machine interface for supervision and control of the process. From the operator keyboard and VDU monitors, the operators are able to control and supervise the hydropower plant, as well as monitor the water transfer and delivery schemes. The status of the process is presented on color graphic monitors in the form of process displays, trend displays, alarm and event lists. In addition, an Information Management System Station (IMS) provides management with process information such as storage and handling of historical data and generation of reports, and an Engineer's Station provides the SCADA Engineer with the software tools to maintain the system.

Remote Terminal Units (RTU) are provided for retrieving data locally from remote sites, such as level and flow signals from Katse Dam, NgaoJane Flow Metering Station and Muela Dam and transferring this data to the central control room by radio or power line carrier systems, for supervision of the water schemes.

Power Line Carrier (PLC) equipment is located in 132 kV and 66 kV substations and provides data transmission, voice communication and teleprotection between remote outstations RTUs and the 'Muela control centre. The communication is accomplished by using the line transmission network as communication links.

Radio equipment is located at the 'Muela Dam and NgaoJane flow metering station to provide data and voice transmission between the remote outstation RTUs and the 'Muela control centre.

Similarly, the NCC SCADA will provide supervision and control of the national grid high voltage power transmission network and distribution systems through the associated substations. The substations are linked to the NCC SCADA by means of RTUs and the PLC systems. In addition, the NCC SCADA will be linked to the MCC SCADA to exchange data and for automatic control of the power generated at Muela in order to maintain a minimum level of power imported from ESKOM (SAR).

#### 4.3. Work Implementation

Installation of the embedded parts of the turbines started with the draft tube and draft tube flap gate of the turbine #1 on 16 December 1996, ending with the concrete embedment, curing of the concrete and removal of the test ring from the spiral case of turbine #3 on 19 December 1997.

Erection of the turbine #1 started in September 1997, followed by the mechanical installation of the draft tube flap gate #1 in November 1997 and of the TIV #1 in January 1998. In parallel, mechanical and electrical installation of all ancillary systems was also carried out.

Prior to the start of the wet tests and commissioning of the Unit #1, all ancillary equipment (e.g. the Drainage and Dewatering System, Compressed Air System, Cooling Water System) was dry- and wet-commissioned within the period 26 May 1998 to 30 July 1998. The Draft Tube Flap Gates of all three Units also were dry-tested from 19 May

Table 3. Scope of Work and Main Data for Contract LHDA 136.

**One (1) 132-kV double circuit transmission line between Muela Hydropower (LHDA) and Maputsoe S/S (LEC).**

Rated line voltage	132 kV
Number of circuits	2
Conductor configuration	Double vertical arrangement
Transmission capacity	105 MVA per circuit
Type of support	galvanized lattice steel frame tower
Length of the line	60.8 km
Number of towers	181

**Extension of Maputsoe Substation comprising:**

2 line bays for Muela Hydropower  
1 line bay for Mabote S/S  
Single busbar extension  
Substation gantry extension.

**Extension of Mabote Substation comprising:**

1 line bay for Mabote S/S  
1 bus coupler bay  
Single busbar extension to the existing busbar forming a double busbar system  
Substation gantry extension.

**The scope of work also comprises design, manufacture, transport, installation at site of the above-mentioned equipment, including civil works.**

to 11 July 1998, and the Tail Race Tunnel was impounded on 22–23 July 1998. All three Turbine Inlet Valves (TIVs) were dry-tested / commissioned in the period 09 July to 20 July 1998 to be ready for filling of the penstock. The Penstock Guard Valve was wet-tested and commissioned from 23 July to 1 August 1998.

The wet-test and commissioning of the Unit #1 started on 03 August 1998 with the initial filling of the turbine #1 and was completed on 21 August 1998. The Post Commissioning Operation Period was successfully completed after 400 operating hours, and the Unit #1 was taken over by the LHDA on 9 September 1998.

The wet test and commissioning of the Unit #2 started on 10 October 1998 with the initial filling of the turbine #2 and was completed on 22 October 1998. The Post Commissioning Operation Period was successfully completed after 400 operating hours and the Unit #2 was taken over by the LHDA on 08 November 1998.

The wet-test and commissioning of the Unit #3 started on 9 November 1998 with the initial filling of the turbine #1 and was completed on 25 November 1998. The Post Commissioning Operation Period was successfully completed after 400 operating hours and the Unit #3 was taken over by the LHDA on 15 December 1998.

The remaining Sections (e.g. the Oil Handling System, Mechanical Workshop and HVAC System) will be completed, commissioned and taken over by the end of March 1999, and the SCADA System is foreseen to be completed and commissioned in June/ July 1999.

No major problems were experienced during the commissioning of the electro-mechanical equipment. Small deficiencies were remedied immediately, and even small design improvements were made by the Contractor's commissioning engineers in consultation with LMC. To date, the turbines #1, #2 and #3 have fulfilled all performance data and values as predicted by the model tests of the turbine.

A performance test was done during December 1998 at generator #1, which proved full compliance with the guaranteed data.

The load rejection test for three Units (82 MW) was performed on 3 February 1999 and revealed good results with the calculated figures. The maximum permissible

pressure surge in the Transfer Tunnel corresponding to Katse level 2050.8 m.a.s.l. was not exceeded.

The system islanding operation test (ESKOM feeders disconnected), performed on 7 February 1999, confirmed stable unit operation under variable power generation modes.

## 5.0 Contract LHDA 135: Transformers and 132 kV Switchgear

### 5.1 Contractual Data

Contractors: ABB Calor Emag Schaltanlagen FRG  
ABB Powertech SAR

#### Contract Dates:

Contract Commencement Date	8 Dec. 1993
Commissioning	Nov. 96 to Dec. 97
Contract Completion Date (original date)	25 June 1997
Contract Completion Date (after EOT)	3 Sept. 1998

It may be noted that extension of time (455 days) with respect to the original contract date had to be given to synchronize the time schedule for the equipment under LHDA 135 with those of the civil works under contracts LHDA 129A and 129B, which had suffered a considerable delay in award of the contracts.

### 5.2. Scope of Work and Main Data

- Power Transformers with accessories, mainly comprising:
  - Three (3) unit step-up transformers, 32 MVA rated output (continuous overload 32.5 MVA), 138/11 W, forced oil/water cooled, vector group YNd1 (star/delta) with off-load tapchanger. Installation underground;
  - One (1) regional transformer, 20 MVA rated output, 132/34 W, natural cooled, vector group YNd1 (star/delta), with off-load tap changer. Installation outdoors;

- One (1) area transformer, 3 MVA rated output, 33/12 W, natural cooled, vector group YNyn0 (star/star) with on-load tap-changer. Installation outdoors;
- One (1) lot of siliciumoxyde surge arresters for the above transformers;
- One (1) fire deluge system for 3 unit step-up transformers;
- One (1) 132 kV SF6 gas insulated, double busbar switchgear installation (GIS) with associated equipment, indoor installed plant, mainly comprising:
  - Two (2) transmission line feeders to Maputsoe S/S;
  - Three (3) cable feeders for unit step-up transformers;
  - One (1) transformer for regional transformer;
  - One (1) busbar coupler.
- Outdoor installed equipment, mainly comprising:
  - Six (6) capacitive voltage transformers (CVT) for measuring and coupling to power line carrier systems, connected to the 2\*3 phases of the outgoing transmission lines;
  - Six (6) siliciumoxyde surge arresters (SA), connected to the 2\*3 phases of the outgoing transmission lines;
  - Two (2) line traps for blocking of power line carrier signals installed in the center phase of every transmission line system;
  - One (1) terminal gantry of the galvanized, steel lattice tower type.
- The scope of work also comprises design manufacture, transport, installation, commissioning of the mentioned equipment, excluding civil works.

### 5.3. Work Implementation

Installation of the GIS began in October 1996 and was completed in February 1997. The GIS is installed indoor in a substation building next to the Plant Operation Building. The outdoor portion (gantry, CVT, and SA) forms the physical interface with the transmission line under contract LHDA 136.

During assembly of the GIS, a series of mechanical tests (gas tightness, functional operation of switchgear, etc.) was performed. There was no further activity throughout one year following the erection progress of the power station electromechanical equipment under contract LHDA 134.

In December 1997 all electrical functional tests and interface signal checks were performed, and permanent energizing took ultimately place on 6 August 1998.

Delivery and site assembly of the various transformers followed a different schedule which was governed by the availability of the relevant transformer foundations:

- Three unit step-up transformers located in the power cavern as the link between the hydrogenerators and the GIS were delivered to site and assembled in sequence during August/September 1997; site tests were performed subsequently. Energizing took place in line with the unit commissioning program.
- One regional transformer installed outdoor next to the GIS and also fed from the same is to fulfill a dual purpose, i.e. to provide auxiliary power for the hydropower station and to export power into the regional area of Khukune and Buttha Buthe as part of the rural LEC 33 kV network.

- The transformer was delivered to site and assembled during November 96 and subsequently site tested. Permanent energizing took place only late in conjunction with the GIS.
- One area transformer installed outdoor next to the regional transformer is linked with the regional transformer on the 33 kV side and is meant to supply 11 kV power solely for the hydropower station. Installation and permanent energizing of this transformer followed the same schedule as the regional transformer.

## 6.0 Contract LHDA 136: 132 kV Transmission Lines and Substation Bays

### 6.1. Contractual Data

#### Contractors:

Main contractor — Norelec (France)

Subcontractor for civil works — Thescons (Lesotho)

Subcontractor for tower erection — Helibib CC Sar

#### Contract Dates:

Contract Commencement Date 25 July 1995

Start Commissioning 19 February 1998

Contract Completion Date 13 June 1998

### 6.2 Scope of Work and Main Data

The scope of the work and main technical data for this contract are given in Table 3.

### 6.3 Work Implementation

A most essential part of the works under this contract was construction of the 132 kV transmission line.

The final land survey of the transmission line route was completed at the beginning of July 1996, followed by a soil investigation on 34 locations typical of the landscape during February 1997.

In the course of 1997, all tower foundations were constructed, and the first tower erection test was done in December of same year. Due to the partly inaccessible terrain and a time delay already encountered, the Contractor decided to erect the towers with the help of a helicopter.

At the end of tower erection, the working procedure was highly optimized by preassembly of tower segments, refined logistics, and experience of workforce: 3 towers could be erected per 45 minutes, yielding 15 towers per day. In the total run, an average of 9 towers could be erected per day.

Since tower erection with helicopter is a highly skilled and risky task for all participants, it is worth mentioning that no major injuries or accidents occurred during this process.

Stringing of conductors had to be carried out “under tension”, i.e. conductors could not touch the ground or other obstacles. This procedure is a special technology and had never been carried out in Lesotho before. Therefore, local employees had to undergo a period of training before the expected progress and performance could be achieved. Stringing was completed in July 1998, with an average progress of 2.8 km per week.

Parallel with erection of the transmission line, installation of the electrical equipment in both of the substations was undertaken without problems.

Upon contract completion all equipment was handed over to LEC, the Lesotho network operator.