INNOVATIVE OPERATING SYSTEM: DESIGNED AND IMPLEMENTED AT ORANGE-RIET CANAL: BALANCING DAM S1 DESIGNED AND EQUIPPED WITH AUTOMATIC WATER CONTROL VALVES

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ABSTRACT

A new balancing dam is currently under construction along the existing Orange Riet canal to provide an assured water supply to the irrigation schemes' increasing irrigation requirements at Jacobsdal. The outflow from the balancing dam is controlled by three large automatic valves to maintain the required flow rate in the canal with varying upstream water levels in the dam. The valves do not require an external source of power to activate them and are thus suitable for this remote location. This paper discusses the design and construction of the dam and the functioning of the automatic valves.

1. BACKGROUND AND HISTORY OF THE ORANGE RIET WUA.

The Department of Water Affairs and Forestry (now The Department of Water Affairs or DWA) appointed BKS (Pty) Ltd (now AECOM SA (Pty) Ltd) for the planning, design and construction supervision of Balancing Dam S1 along the Orange-Riet Canal, located approximately 74 km from the ***Scheiding Pump Station*** and about 40 km from Jacobsdal.

The Oranje-Riet Water Users Association (ORWUA) is responsible for the operation and maintenance of the canal scheme. All the operations are controlled from the office in Jacobsdal, while the DWA remains the owner of the infrastructure.

The Construction of the balancing dam is currently being undertaken by the DWA: Construction East, one of the DWA's construction divisions, which is based in Standerton. A Memorandum of Understanding (MOU) containing the contract between the Contractor, DWA: Construction East and the client, DWA: Chief Directorate: SAM forms the basis of the design and construction management services.

The design, manufacture and installation of the hydro-mechanical and electrical components are undertaken by a nominated Sub-contractor, the WK/SWE Consortium. Amanzi Flow Projects rendered the professional design services for the Contractor as Sub-contractor, designing all the hydraulic steelworks and designing and manufacturing the cranes. The electrical and telemetry design was also done by a Sub-contractor.

The Orange-Riet Canal is part of the Van der Kloof Canal Scheme, which supplies water to the Oranje-Riet Rivier Government Water Scheme, and is managed by the *ORWUA*. The purpose of the proposed Balancing Dam S1 is to improve the operation of the canal and to meet the additional demand of new agricultural developments at the Oppermansgronde and irrigation extensions along the Lower Riet River and the Scholtzburg areas. The run-time for the water from the Scheiding Pump Station to the S1 Balancing Dam is 36 hours. The location of this proposed balancing dam is shown in **Figure 1.**

The Orange-Riet Canal Scheme comprises a pump station (Scheiding Pump Station) directly downstream of Van der Kloof Dam at the end of the Van der Kloof Right Bank Canal, which pumps water to the level of the canal. The first stretch of the canal, with a design capacity of 16 m^3/s, terminates at the proposed Balancing Dam: S1 approximately 74 km from the pump station. From this point, the canal has a design capacity of 13,4 m^3/s and extends for 42 km to the existing Balancing Dam S2 at the Riet River Settlement of Jacobsdal.

Regarding the operation of the dam, the following parameters are relevant:

- The function of the dam is to balance water. Therefore, canal water must be conveyed through the dam and the dam must be operated at levels that are as low as possible during normal conditions to allow for possible surplus water. This may be as a result of a number of reasons, such as stopping use from the canal because of rain or a power failure on the irrigation scheme.
- During abnormal conditions, the dam must fill and excess water must be spilled over the canal reject (spillway of dam) to the pan.
- The proposed capacity level of the pan required for storing water was based on:

✓ 36 hours storage volume to be provided in the pan plus the 1:20 year storm run-off at the same time. This is associated with 15 m^3/s flow in the Orange-Riet canal taking 36 hours to drain from the starting point at Van der Kloof Dam. ;

✓ Spilled water from the canal into the pan should be evaporated within one year.

✓ The road adjacent to the pan from Jacobsdal to Luckoff should not be inundated during the spilling event.

✓ The level meeting the above requirements is RL 1162.0 m.

The various layout options which were evaluated include a balancing dam in line with the canal and an off-canal balancing dam on the right side (uphill side). It was proposed, and accepted by the DWA, that the balancing dam should be provided on the right side of the existing canal, based mainly on the lower estimated construction cost for the off-canal balancing dam.

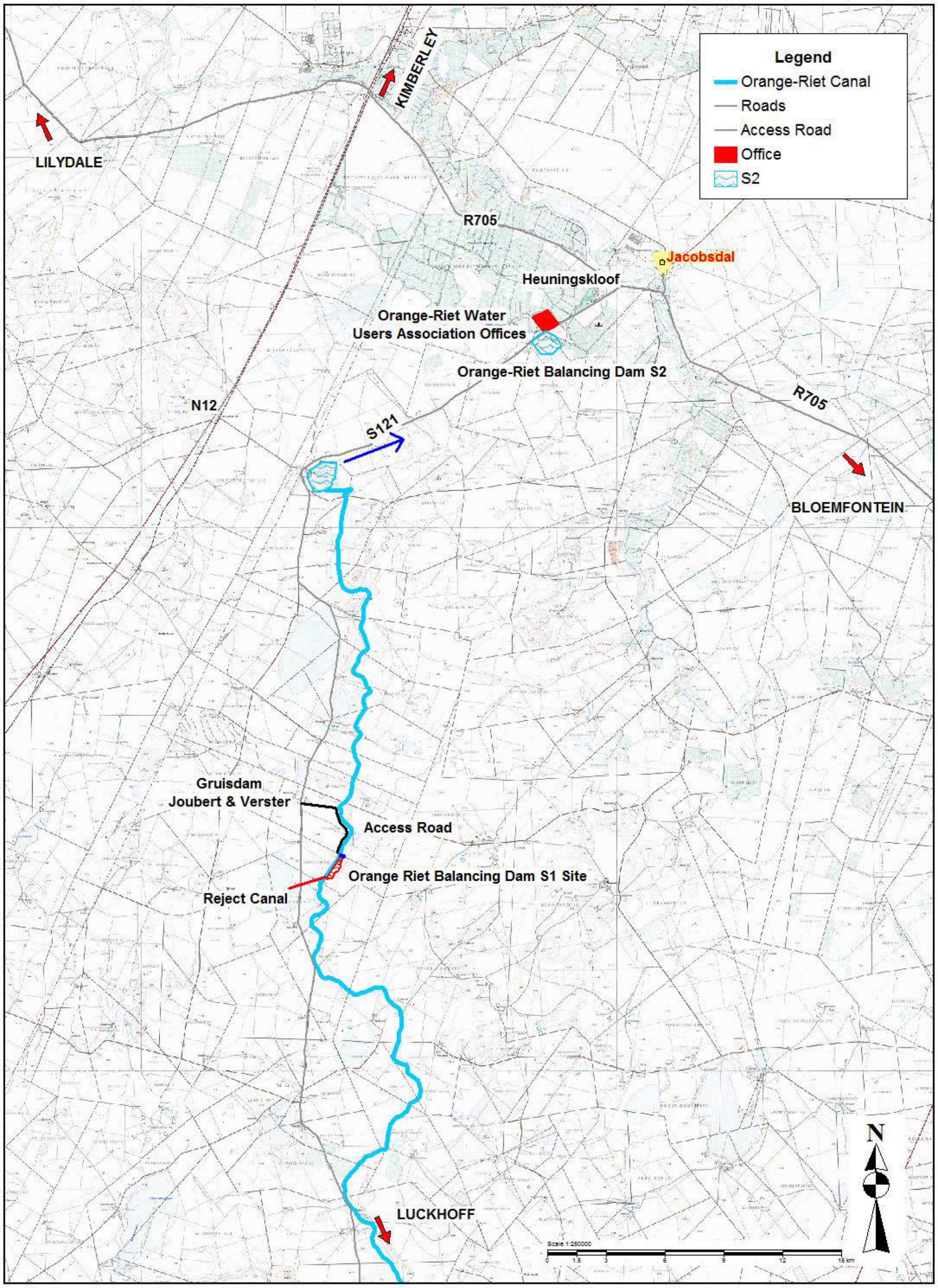


Figure 1: Locality Map

2. BASIC INFORMATION

2.1 TOPOGRAPHICAL SURVEYS

Topographical surveys of the site of the proposed balancing dam with canal invert and top of lining levels were carried out by the DWA's Central Region Survey Section in Bloemfontein. The topographical maps produced, together with the sections taken on the Canal, were used in the planning and design of the balancing dam and the associated works.

2.2 GEOTECHNICAL INVESTIGATIONS

Geotechnical investigations were done by DWA in 2005 and by BKS (now AECOM) in **2008**. Foundation and embankment materials were investigated and the design of the embankment was based on these investigations.

2.3 ENVIRONMENTAL CONSIDERATIONS

A scoping report was prepared by BKS (2008) **[9]**, and the DWA liaised with the Department of Environmental Affairs and Tourism (DEAT) regarding the environmental procedures to be followed. It was agreed that the Full Environmental Impact Assessment study had to be carried out and Aurecon undertook this for the DWA. The Environmental Authorisation for the project was obtained on 24 August 2010. The Environmental Management Plan (EMP), in accordance with this authorisation, was included in the Memorandum of Understanding (MOU).

2.4 CANAL DETAILS

The dimensional details of the canal upstream of the intake works and downstream of the outlet works are summarised in **Table 2.1** below.

Table 2.1: Dimensional Details of Canals

Feature	Upstream of Proposed Dam	Downstream of Proposed Dam
Chainage (m)	73 435	74 435
Top of lining RL (m)	1 177,03	1 172,80
Canal invert RL (m)	1 174,7	1 169,86
Lining depth (m)	2,33	2,94
Top width of lining (m)	11,257	9,260
Bottom width (m)	4,267	2,000
Side slopes (V:H)	1:1,5	1:1,5
Gradient	1:5 000	1:3 333
Design flow: Q (m^3/s)	16,0	13,4
Flow depth (m) (n * = 0,016)	2,065	2,150

* *n = Manning friction coefficient for old concrete lined canal*

2.5 BALANCING DAM DETAILS

The following alternative net storage capacities of the balancing dam were evaluated in the *DWA Report C 330/05/0002 [2]*:

Alternative 1: Minimum net storage capacity of 345 600 m^3. This is based on a difference of 2 m^3/s in flow rate of the upstream and downstream canal in the event of a power failure of approximately two days when farmers cannot pump from the upper canal. (The minimum net storage capacity increases to 518 400 m^3 for a 3 m^3/s difference in flow rates).

Alternative 2: Maximum net storage capacity of 600 000 m³. This is based on a maximum application rate of 56 mm/week for 800 ha irrigation development at Oppermansgronde, amounting to 515 200 m³, including 15 % losses.

This will allow for the irrigation of 800 ha during the peak demand. The DWA subsequently decided by that the maximum net storage capacity should be taken as 600 000 m³.

Full supply level (FSL)	:	RL 1 176,660 m
Non-overspill crest level (NOC)	:	RL 1 178,200 m
Lowest draw-down level (LDL)	:	RL 1 172,500 m
Crest of reject on upstream canal	:	RL 1 176,660 m

3. GENERAL DESCRIPTION OF BALANCING DAM

3.1 GENERAL

The general layout of the balancing dam with the service roads and locations of the inlet-, outlet-, bypass control works and the reject control structure is shown in Figures 3.1.

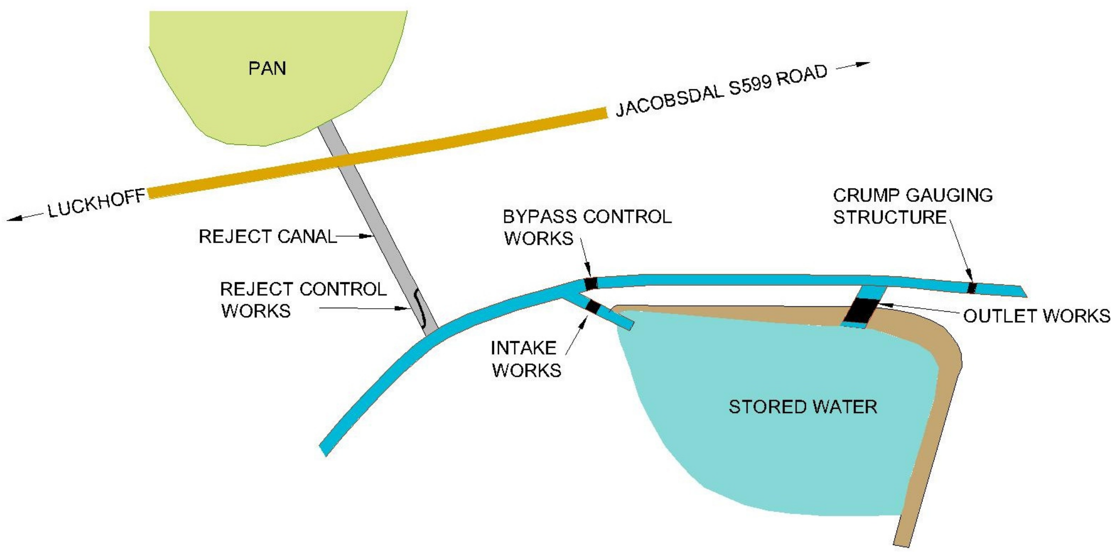


Figure 3.1: General Layout of the S1 Balancing.

3.2 EMBANKMENT

The embankment along the right side of the canal comprises earthfill with an impervious clay core, a chimney filter with strip drains a toe drain, upstream rip-rap protection and a gravel capping on the downstream face. The details are shown on the drawings in **Figure 3.2.**

The core was constructed from a clayey windblown sand and the outer zones from completely weathered shales. The toe-drain decants downstream of the main canal and a flow gauging structure was constructed to measure and monitor the leakage from the balancing dam.

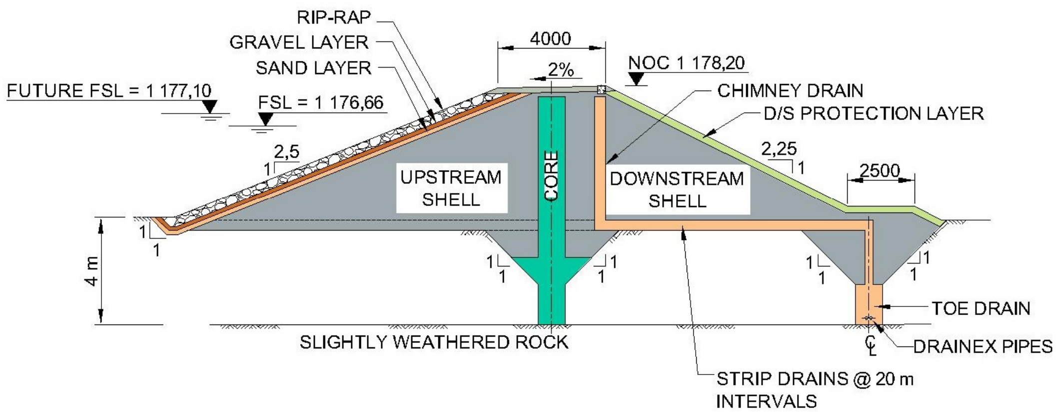


Figure 3.2: Embankment detail.

The DWA directed that the embankment crest be constructed higher than required for the existing inflow to allow for possible future enlargement of the upstream canal with a higher inflow of 20 m^3/s. This also required that the invert level of the bridge of the intake works be constructed 50 mm higher than the future full supply level (FSL) to allow the inflow of the 20 m^3/s.

3.3 OUTLET WORKS

The outlet works comprises a concrete structure (see **figure 3.3)** with diaphragm valves (DV) to control the releases up to a maximum equal to the design flow of the downstream canal. These valves are described in Section 3.5. The control structure is 11,4 m high, 57,4 m long and 20 m wide.

Emergency gates were required upstream of the DVs as the compartments leading to the valves would have to be closed off for maintenance or emergency purposes under full flow conditions. The diaphragm chambers downstream of the DVs will be isolated for maintenance purposes under balanced conditions and only service gates are required. A full set of eight emergency gates is supplied to isolate one DV valve at a time. A set of six service gates is supplied to isolate the downstream diaphragm chamber, again only one DV can be isolated at a time. These gates will be stored together with the two grappling beams in storage pockets and secured with dogging pins.

A set of 21 stainless steel fine screens are provided upstream to prevent floating debris from interfering with the operation of the diaphragm valves. Eighteen permanent fine screen panels are installed and an extra set of three panels will be rotated during the cleaning operations. The extra set of screens will be placed downstream of the set, which is to be cleaned, thus preventing any debris from entering the DV chambers. This process is to be repeated until all the screens are cleaned. The main challenge expected is water grass and windblown tumble weed, which require regular cleaning to allow water to flow at all times.

A three-ton, electric-driven overhead gantry is provided for operation of the upstream emergency gates and stainless steel fine screens. The guide frames for the bulkheads (emergency and service gates) and screens are built-in stainless steel frames.

A three-ton monorail crane is provided at the downstream side providing crainage for the downstream service gates. A cantilever at the end of the monorail crane is provided with an access ramp so that the stoplogs can be loaded for maintenance purposes.

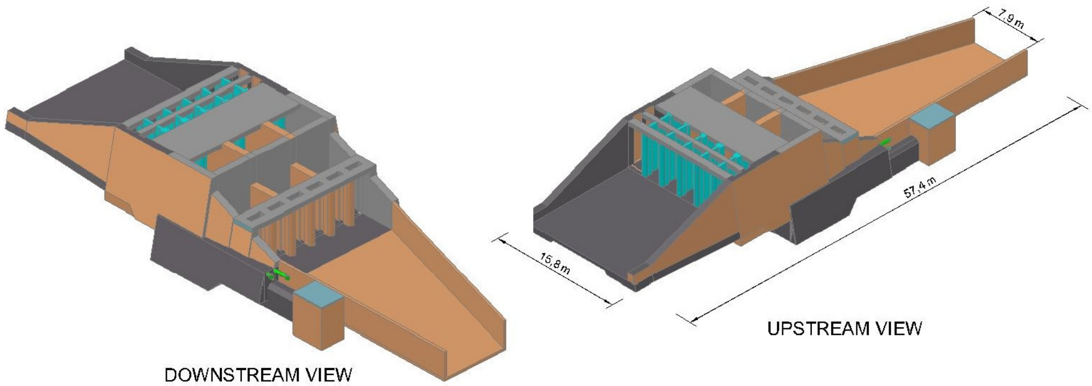


Figure 3.3: Outlet Works

A remote control for the diaphragm valves using the existing telemetry system is provided (this is explained in **Section 3.4**). The existing system used by the ORWUA was designed by Pro-design and, in the interest of a stable platform, the telemetry will again be designed and supplied by Pro-design.

A service road on the non-overspill crest of the embankment will service the top of the outlet works to allow for maintenance and cleaning of the fine screens and emergency gates.

The outlet works was designed with a gallery connecting the DVs and the float chamber. The DVs will be adjusted remotely using an electrical actuator operated through the telemetry.

3.4 AUTOMATIC WATER CONTROL VALVES: SELECTION OF OUTLET VALVES

3.4.1 INTRODUCTION

When the original Orange Riet irrigation scheme was designed and constructed in 1988, the Jacobsdal Water Board required outlet valves that would automatically control the outflow from the dam into the downstream canal.

Because of the remote location of the dam and to eliminate maintenance and operational challenges associated with electro-mechanical valves, two Fluid Dynamic System (FDS) automatic DVs, each 1500mm diameter, were installed.

These two DVs have operated successfully since then with minimal maintenance.

Consequently, the ORWUA specified that the new dam S1 must use the same type of automatic DV.

3.4.2 DESCRIPTION OF THE AUTOMATIC DIAPHRAGM VALVE (DV)

The DV was developed by the late Mr Laurie Turner in the 1970s and the first DVs were installed on his irrigation scheme on the Little Fish River, Eastern Cape.

The DVs automatically controlled a number of level control canals which was probably the first supply controlled irrigation system in South Africa. Since then, numerous DVs have been used to control flow, mainly in irrigation schemes.

The DV comprises an inlet pipe, generally a downward facing bend, or downstand bellmouth, but it can also be an upward facing bend, which discharges onto a deflector plate supported by a rubber diaphragm.

A control pipe connected to the upstream water body feeds a small flow through a sediment pot to remove sediment and debris, before connecting to the diaphragm. An exhaust pipe connects the diaphragm to a float valve downstream of the DV.

The float valve is set at a required water level and the DV maintains the downstream water at that constant level, regardless of the fluctuation in water level upstream of the DV in the dam or weir.

The diaphragm inflates slightly when the discharge is greater than required to reduce the outflow, and deflates if the outflow is lower than required. Therefore, it automatically controls the outflow at a constant required level. By calibrating the water level over a measuring weir (usually a crump weir for larger flows), the downstream flow rate is controlled automatically.

3.4.3 THE DVs ON DAM S1

The DVs are designed to pass the maximum flow of 11 m^3/sec through two DVs. However, three equal-sized DVs 1.35 m NB are provided in the event that one DV is closed for inspection.

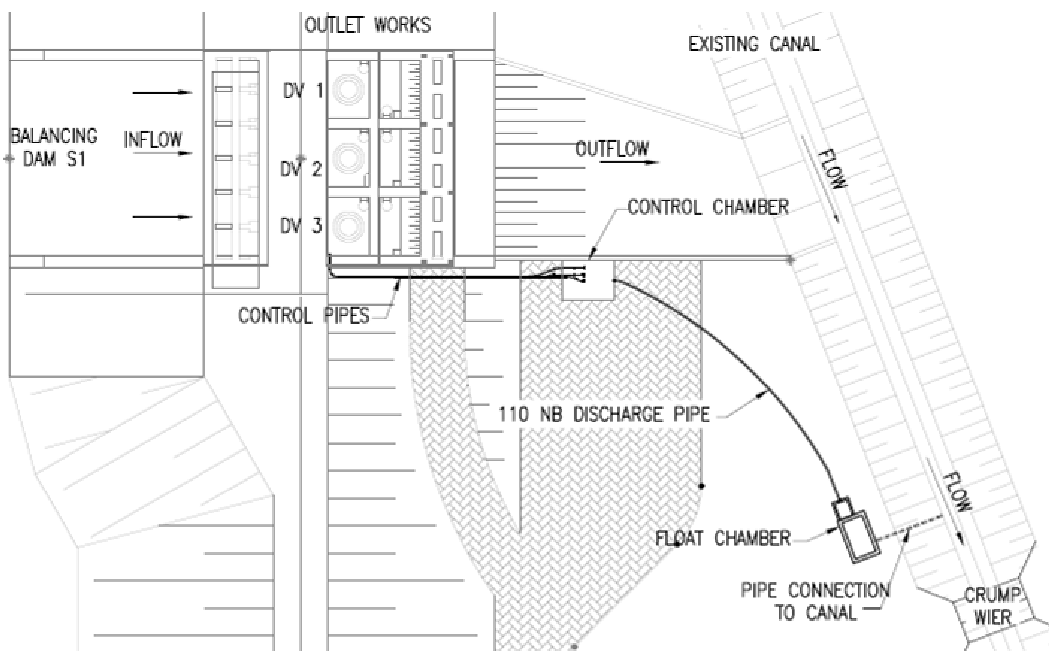


Fig. 3.4.1 Layout of DVs

The maximum operating head is 4.2 m and the minimum operating head 2.7 m. The DVs are probably the only automatic control valves that can operate with minimum operating heads as low as 0.4 m.

The discharge capacity is given by the formula $Q = kv^2/2g$ where k is the discharge coefficient, which varies between 1.8 and 2.2, depending on the upstream piping configuration and downstream condition.

The DVs are situated in three separate chambers, each of which can be isolated under full discharge from the dam with stoplogs on both the up and downstream sides of the DV chamber.

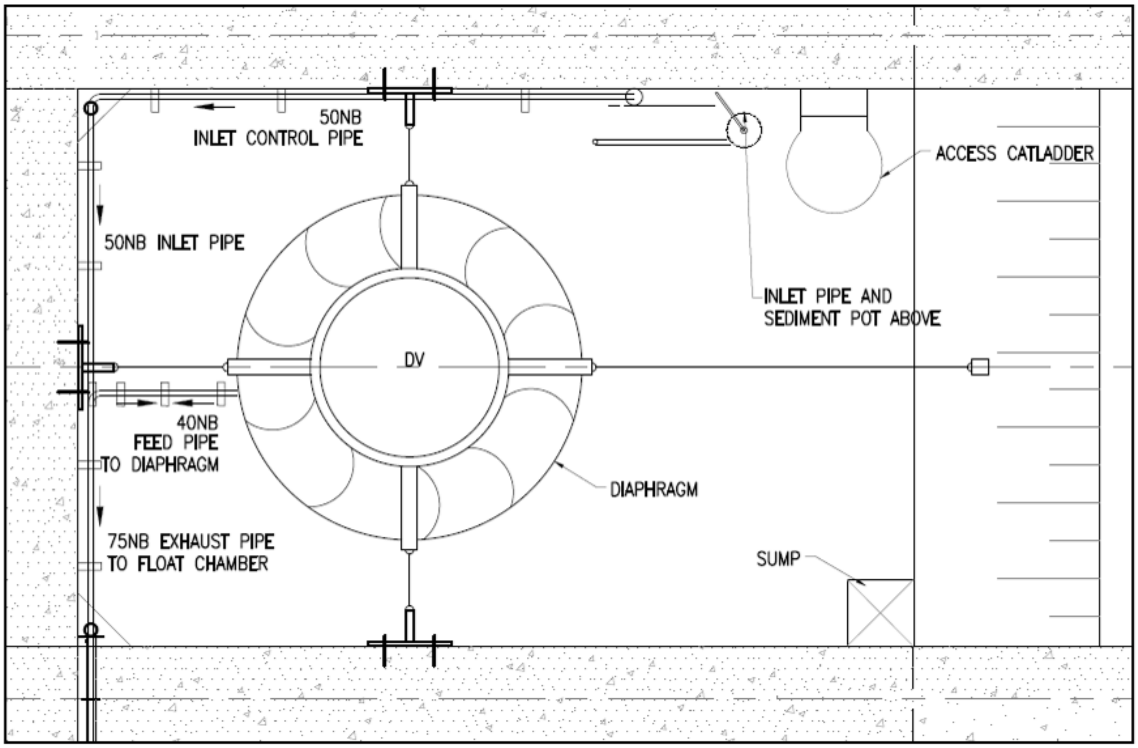


Fig. 3.4.2: Plan of DV Chamber

The flow entry to the DV is a bellmouth cast into the concrete roof slab. The water discharges onto a deflector pot supported by a large diaphragm.

The inlet to the control piping (50NB) is taken from the upstream water level and led through a sediment pot to remove sediment and debris.

The control piping is connected to the diaphragm and continues as the exhaust pipe (75NB) to the control chamber. The three sets of control pipes from each DV come together into one large 110NB discharge pipe leading to the float chamber, some 30 m away.

The control chamber consists of a series of valves to regulate the discharge of the DVs, as well as a ball valve for each DV to close of the DV completely.

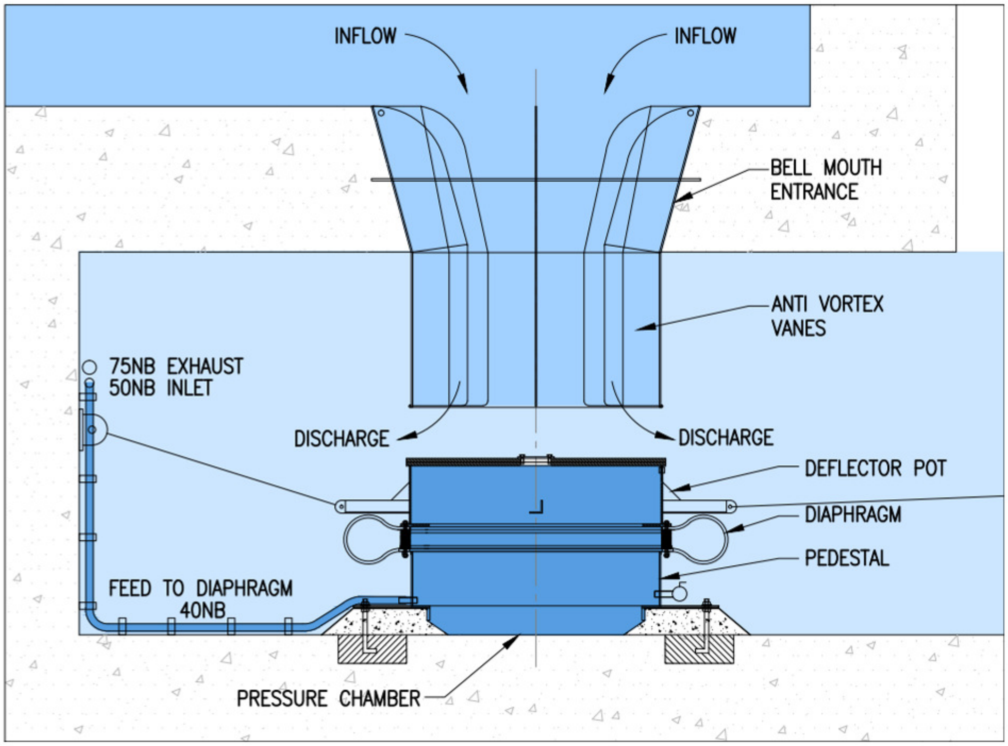
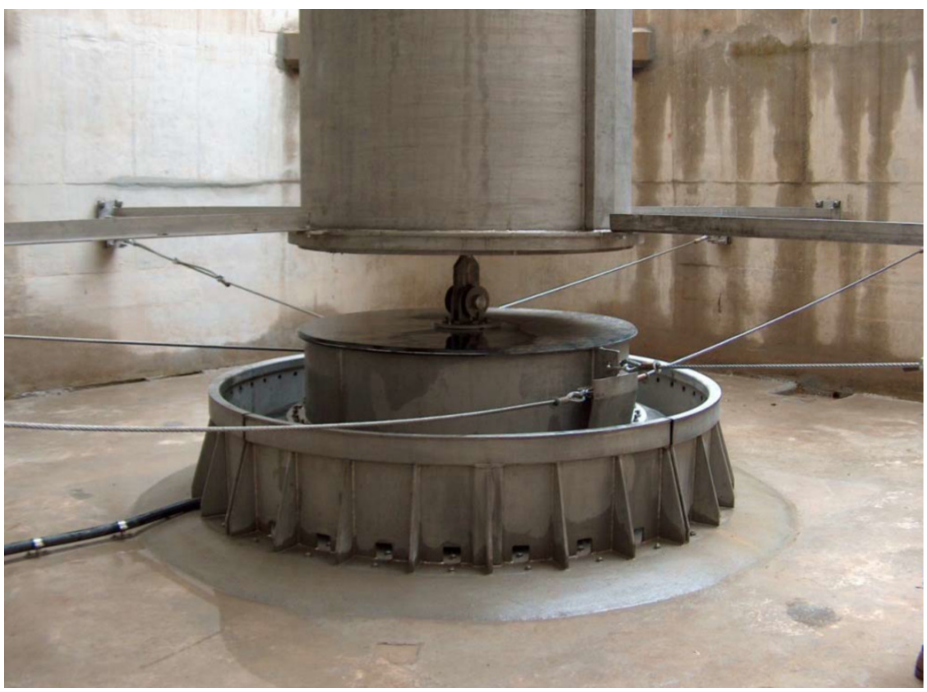


Fig. 3.4.3: Section through DV



Photograph 1: Diaphragm Valve

All three DVs are controlled by a single float valve. The float valve chamber is connected to the canal through a 150 mm diameter pipe so that the water level in the canal is the same as the water level in the float chamber.

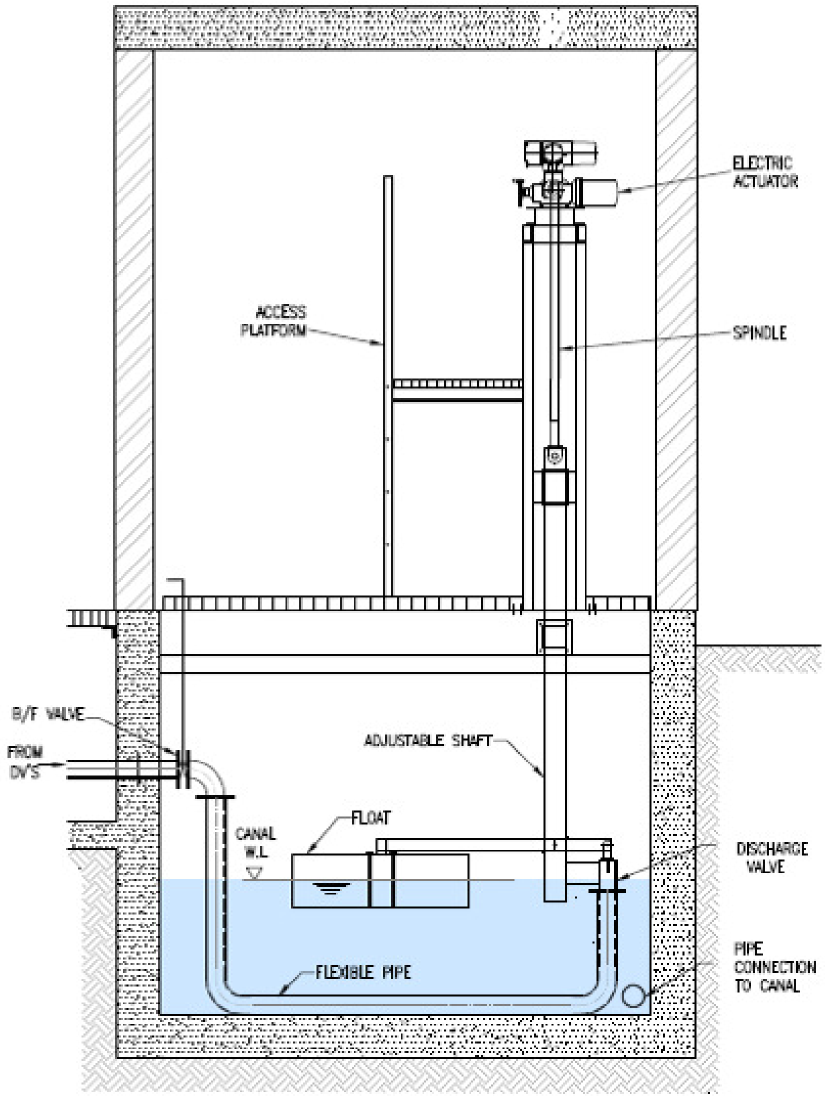


Fig. 3.4.4: Float Control Valve

The float valve consists of a large float acting on a pivot arm to close off a discharge pipe with a simple flat lid. The float valve can control the water level to an accuracy of 10-15 mm.

The flow in the canal is measured over a crump weir and the position of the float is calibrated against the water levels over the crump weir for different flows.

The float mechanism is connected to an electrical actuator which is controlled and set by telemetry from the control room in Jacobsdal.

The material used for the DVs and float mechanism is 3CR12 with applied corrosion protection, in accordance with DWA specifications.

The control piping comprises HDPE pipes with compression fittings, clamped to the walls and floor. The control piping valves are all stainless steel.

The DVs are scheduled to be commissioned in August 2013.

3.5 INTAKE WORKS

The inlet works is situated immediately upstream of the steep change in gradient in the existing canal. It comprises of an off-take from the existing canal into the balancing dam with three electrically actuated gates to isolate the dam should it be required for inspection and maintenance purposes.

The gates at the Inlet Works and the Bypass Control Works will be manually operated. The gates would only be operated during the monthly routine testing and when the dam is to be inspected. The electrical actuators have been rated to be able to open and close one cycle without overheating.

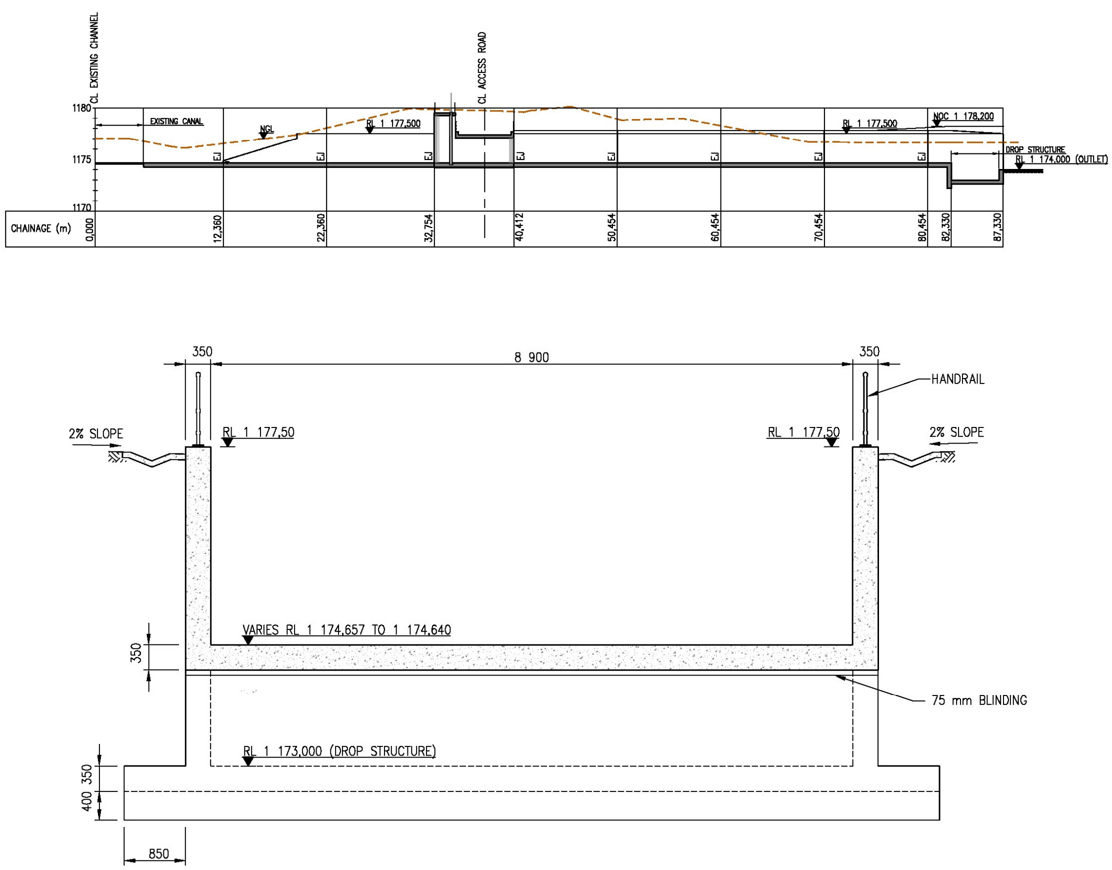


Figure 3.5: Intake Works with a typical section through inlet canal

3.6 BYPASS CONTROL WORKS

The canal will be used as a bypass for the balancing dam during inspection and maintenance activities on the dam.

Two electrically actuated gates are provided in the existing canal immediately downstream of the off-take to the inlet works. These gates will be closed during normal operation and will only be raised if the upstream incoming flow needs to bypass the dam. The gates will be operated manually.

Road bridges are provided across the existing canal (as part of the bypass control works) and over the inlet (as part of the inlet works) to the dam. The bridge has been raised to allow for future raising of the water level in the balancing dam (see **Figure 3.2**).

3.7 REJECT CONTROL STRUCTURE AND REJECT CANAL

The reject is situated on the existing incoming canal upstream of the off-take to the dam and serves the purpose of a spillway for the dam, as shown on the drawings in **Figure 3.7**

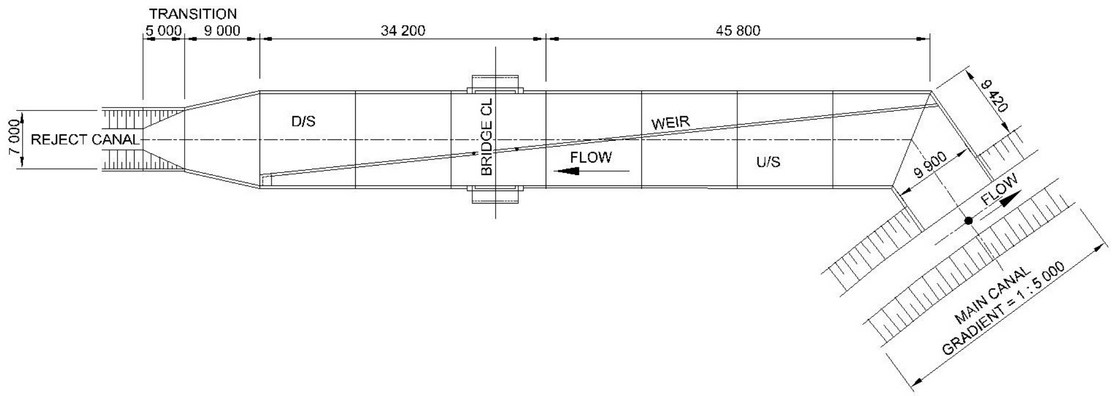


Figure 3.7: Reject Control Works

The flow from the upstream canal will be through the dam under normal operation conditions. The inlet gates and outlet DVs should not be closed without opening the gates in the bypass or existing canal. With reference to the *Preliminary Design Report* , the DWA directed that the reject and reject canal be designed for the present operational flow of 15 m^3/s with no outflow through the dam outlet, allowing for human or mechanical error. In such cases, the gates in the bypass control works (in the original) canal may thus be closed. The DWA indicated that the upstream canal will be enlarged for a design flow of approximately 20 m^3/s as opposed to the existing 16 m^3/s. In addition, the natural inflow (or runoff) to the dam is also handled by the reject.

The reject canal conveys the discharge from the reject to the pan, which is situated about 1 km to the south west. The reject canal is concrete lined to avoid erosion on the relatively steep slope to the pan.

3.8 SERVICE ROADS AND BRIDGES

The existing service road next to the canal on the western side of the new dam is to be retained. A bridge on the service road over the reject overspill structure and a bridge over the reject canal for the Road S599 were designed and constructed.

A bridge is also provided over the reject canal to allow access by the landowner and Eskom for maintenance of the power lines.

As indicated in **Section 3.6**, road bridges are provided across the existing canal as part of the bypass control works and over the inlet canal as part of the inlet works. Maintenance of the embankment and control of the outlet works will be done using the crest road on the embankment, a bridge is also provided along the crest of the dam over the outlet works.

4. FULL SUPPLY LEVEL AND STORAGE VOLUME

4.1 FUTURE INFLOW OF 20 M^3/S

As mentioned in **Section 3.3**, the upstream incoming canal will probably be enlarged for a design inflow of 20 m^3/s. This can be achieved with a concrete coping beam on the top edges of the existing canal lining. The upstream canal will then have a design flow depth of 2.315 m at the reject and the overflow crest will have to be raised by 0.4 m to RL 1 177,06 m, which will become the future FSL (RL 1 177,10 m). The net storage volume for this future FSL at RL 1 177.10 m becomes 798 800 m^3 .

5. CONSTRUCTION ISSUES

5.1 THE CIVIL CONTRACTOR

The Civil Contractor is the DWA: Construction East. The following challenges were experienced during the construction of the S1 scheme:

- The team's limited experience at the start of the work caused delays and some of the work had to be re-done. The Engineer facilitated in the recommendation and approval of the Contractors normal procedures and quality aspects. The team quickly developed their skills and with the increase in skill the work rate increased significantly.
- The Contractor is bound to the Departmental Procurement system, which, if not managed very carefully, can cause delays. Not all issues with the procurement system can be pre-identified, but in many cases this can be managed. The construction management and construction supervision strategy had to be developed and changed to accommodate the procurement challenges.

These challenges have been met by the following:

- The Contractor is prepared to correct errors more readily than some commercial Contractors, without disputing the merits of the instruction.
- The general spirit of the team is very good. Special preparations for temporary works were taken during the two dry-periods where mortar-lined coffer dams in the canal were constructed to withstand the erosion of the flowing canal. They have withstood flooding by rain and flows in the canal for over a year.
- In the end the quality of the work obtained is outstandingly good.

6. CONCLUSION

This paper covered the layout purpose and some design issues for the Orange Riet Balancing Dam: S1. Innovative aspects include:

- A simple low maintenance automatic control valve system.
- Achieving excellent quality results through effective management of the Contractor with a team of inexperienced workers and a demanding procurement system.

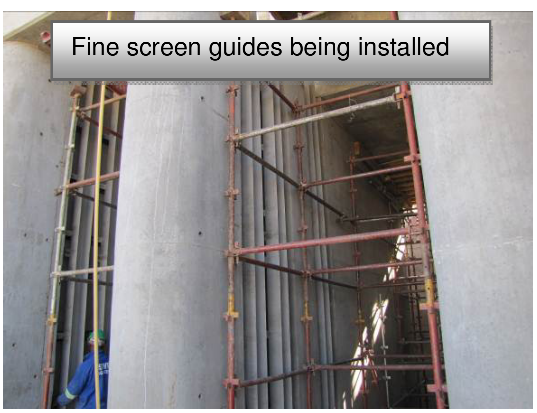
7. PHOTOGRAPHS

Installed diaphragm valve

Screening the rip rap from mine rock

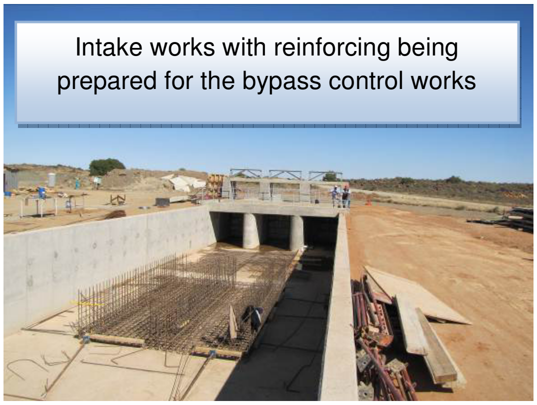
Placing of rip rap

Outlet works under construction



Fine screen guides being installed

Reject control long weir



Intake works with reinforcing being prepared for the bypass control works

Temporary concrete wall constructed in the canal to allow construction of the approach channel to the intake works