# An Incident at Ogston Reservoir

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SYNOPSIS. In the autumn of 2001 an incident occurred at Ogston Reservoir which led to the catastrophic failure of the pipework in the draw-off shaft. An uncontrolled release of water commenced which was only prevented by the quick actions of two operatives in the shaft. This paper describes the investigations carried out to establish the cause of failure, the remedial works which were carried out and the lessons learnt.

## INTRODUCTION

Ogston Reservoir is owned and operated by Severn Trent Water. Completed in late 1959, the reservoir is situated about 6 km north west of Alfreton, Derbyshire. The treatment works, situated immediately downstream of the reservoir, supplies water to areas in North East Derbyshire, Chesterfield and Sheffield.

The dam, which is an earthfill embankment with central puddle clay core, has a height of 19.8 metres and is 213 metres long. It impounds a maximum storage of 6,180,000 cubic metres of water.

The forebay tunnel, overflow shaft, valve tower, and combined overflow and draw-off tunnel are situated in the centre of the embankment and constructed of mass concrete. The complex arrangement of these structures is shown in Figures 1 and 2, with the draw-off tower forming a single structure with the overflow shaft. The overflow tunnel and draw-off tunnel are also formed as one structure.

There are three levels of draw-off comprising 24″ (600mm) diameter cast iron pipework and in-line guard and duty gate valves, feeding into a common 30″ (760mm) diameter draw-off stack. Water passes vertically downwards in the stack to join into a similar diameter cast iron draw-off main which passes along the discharge tunnel under the embankment to Ogston Water Treatment Works.

The scour facility prior to the incident comprised 30″(760mm) diameter cast iron pipework with a 30″(760mm) guard gate valve known as G4, and a 700mm duty butterfly valve known as S1.

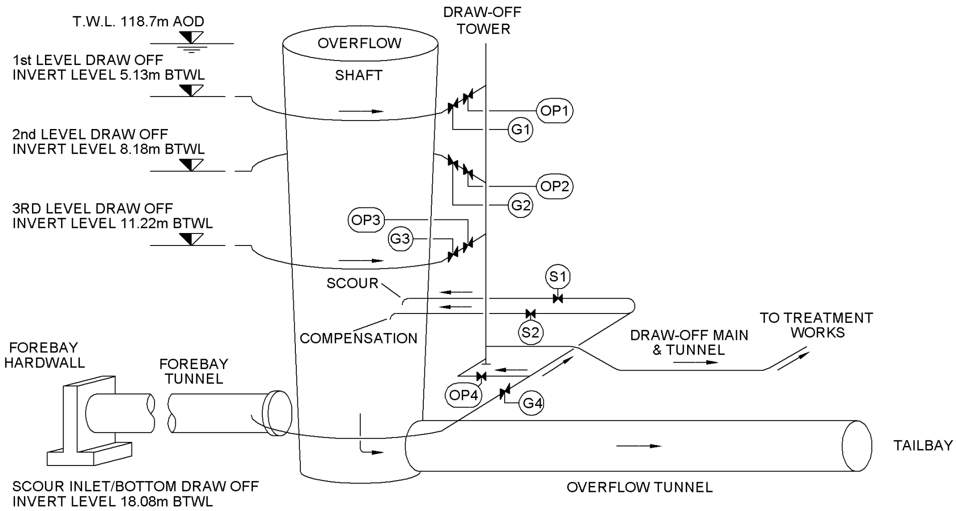


Figure 1: Schematic diagram of draw off and overflow arrangement

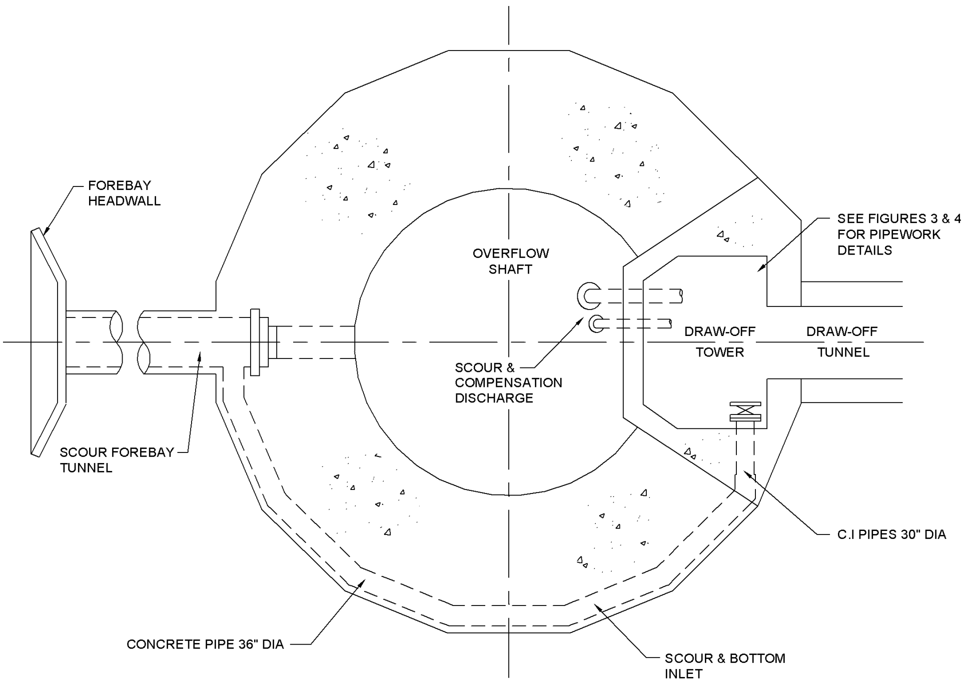


Figure 2: Plan showing scour arrangement

Discharge of scour water is via a pipe outlet through the wall of the draw-off tower into the base of the overflow shaft. A 9″ (225mm) branch connection from the scour pipework incorporated a Larner Johnson streamline valve, known as S2, for the release of compensation water. The butterfly valve (S1) was a recent replacement for the original 30″-24″-30″ (760-600-760mm) diameter Larner Johnson streamline valve which had been found to be in a poor condition, difficult to operate and requiring rehabilitation or replacement. The original and modified layouts of the scour valves in the draw-off tower are shown in figures 3 & 4.

INCIDENT

As part of the refurbishment process to return the Larner Johnson to a serviceable condition alternative valve options were considered due to the extent of the refurbishment work that would be required on the original valve. A value engineering exercise was carried out and a 700 mm diameter butterfly valve was chosen to replace the Larner Johnson. A Panel Engineer was not involved in the value engineering exercise, however subsequently one was consulted on the proposal to install a butterfly valve. The Panel Engineer, having carried out some calculations, commented that the velocities appeared to be high and recommended that confirmation be sought from the manufacturer as to the valve's fitness for purpose with respect to the maximum expected velocity and its location within the pipework arrangement. This confirmation was provided and the valve was obtained and installed.

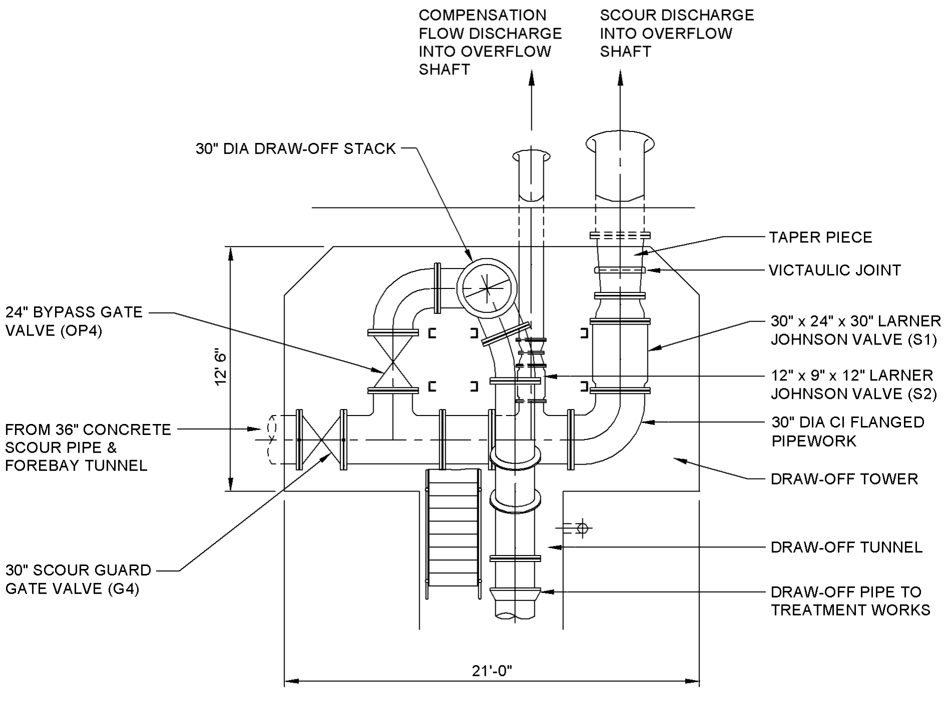


Figure 3: Original scour valve layout in draw-off tower

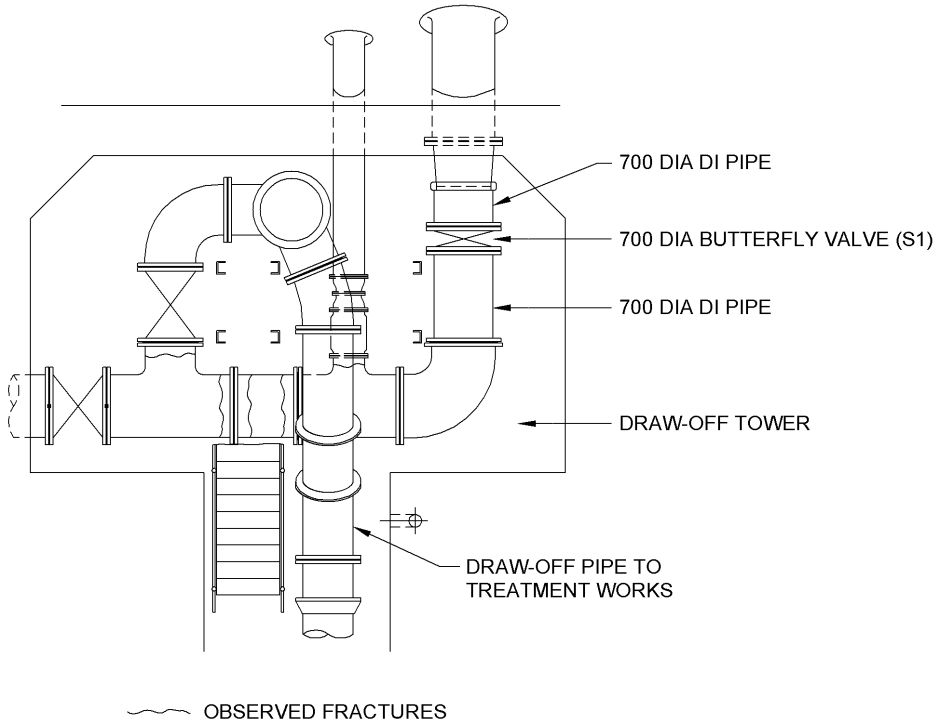


Figure 4: Modified scour valve layout in draw-off tower prior to incident

Following the installation of butterfly valve S1 some difficulties were experienced. Initially the valve was found to be very stiff to operate and a number of modifications were made including increasing the diameter of the operating hand wheel and increasing the capacity of the gearbox. During the commissioning tests on the butterfly valve, the pipework immediately upstream, including the compensation water branch, suffered catastrophic failure resulting in the sudden uncontrolled release of water from the scour pipe into the base of the draw-off tower where there were two men trying to operate the valve. This discharge quickly started to fill the draw-off tunnel until it blew the doors open at the downstream end allowing water to discharge back to the downstream tail-bay area.

Guard valve G4 was subsequently shut to isolate the discharge by the men going back through the discharging waters.

ADVICE
Dr Hughes, who was the appointed Inspecting Engineer at that time, having recently carried out a routine inspection of the reservoir in accordance with the Reservoirs Act 1975, was informed of the incident. Details and recommendations arising out of his subsequent site visit were included in his report.

Technical advice was provided to the owner throughout the project by Dr Hughes, and by the Review Panel, the owner's retained experts, headed by Mr R E Coxon.

Kellogg, Brown and Root (KBR) were appointed to design and supervise the construction and installation of all temporary, enabling and permanent works involved in the restoration of the scour and compensation facilities, taking due account of all personnel health and safety and reservoir safety considerations.

During the initial site inspections it became apparent that the draw-off tower and draw-off tunnel were not safe places to work, since catastrophic failure of the pipework had occurred in a number of places and had left the scour guard valve G4 unsupported and unrestrained in the base of the draw-off tower. Fortunately the flanges on the scour pipework either side of valve G4 appeared to have survived the surge pressures generated by the failure of butterfly valve S1. However, because of the uncertainty regarding the condition of the valve G4 and the adjacent flanged puddle pipe it was considered unsafe to operate the guard valve. Therefore there were now no means of effecting scour draw-off from the reservoir should the need arise and so 'emergency' remedial works were recommended by Dr Hughes 'in the interests of safety'.

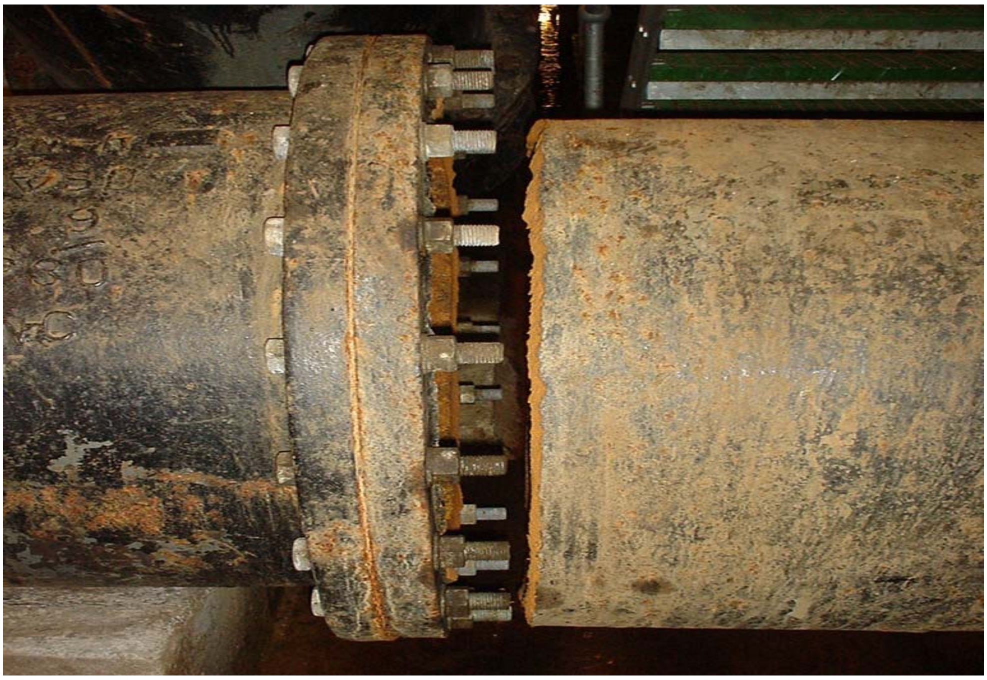

Plate 1: Fractured 30" scour pipe


Plate 2:  Fractured compensation pipework


Plate 3:  Damaged draw-off tunnel doors

The following permanent works were deemed to be necessary:-

- Reinstatement of the scour and compensation pipework and valves.
- Reinstatement of associated accesses and floor stagings where necessary.
- Reinstatement of tunnel access doors.

It was immediately apparent that:-

- The full extent of damage was unknown.
- That the working areas were very restricted.
- The reservoir would have to remain partially full during the works in order to protect the fisheries and the shoreline nesting bird population, as agreed with English Nature (the shoreline was a designated SSSI).
- The compensation flow of 6 Ml/d would have to be maintained.
- No record drawings existed – although construction drawings were available.

It was also recommended that:-

- An additional 600mm diameter washout facility be provided in the raw water supply pipeline to provide scour facilities and greater control of the reservoir water levels in the short term.
- A temporary bulkhead should be installed on the scour forebay tunnel headwall to enable safe access into the draw-off tower to facilitate the investigation and repair works. In order to assess the feasibility of the bulkhead installation an underwater survey of the scour forebay headwall would be required.

## PROPOSED APPROACH

The approach proposed was to work closely with the owner to ensure the safety of the reservoir whilst undertaking the necessary investigations and surveys required to formulate a strategy for the method of repair.

Therefore, in order to achieve a successful outcome to the project, an 'Operational Plan' was written with the owner to:

- Provide the owner with sufficient information to operate the reservoir so as to meet water supply requirements and the needs of the scour valve repair project. In the case of the latter it was arranged to reduce water levels over an agreed timescale to meet the start date for the repair contract.

- Identify the steps necessary to ensure the safety of the reservoir, company project personnel and the public.
- Identify key contacts and responsible persons.
- Ensure that all statutory and legal requirements were met.
- Provide a framework for liaison with all interested parties.
- Ensure that all environmental issues were fully recognised and managed.

The Operational Plan was considered to be a 'live' document subject to continual review and update as the project proceeded. New operating control curves were drawn up and a number of draw-down and refill scenarios as well as 'unusual events' modelled to assist the operators and contractors engaged to undertake the surveys, investigations and permanent works.

It was not considered likely that the embankment would fail in the event of the scour pipework failing upstream of guard valve G4, however the uncontrolled release of water which would take place through the draw-off tunnel and the eventual draining of the reservoir had to be considered.

PROJECT PROGRAMME AND ENABLING WORKS

The Operational Plan included a very detailed programme and methodology covering all activities necessary to control the reservoir level over the winter period and achieve a managed draw-down to the lowest draw-off level in the spring of 2002 to facilitate the installation of the replacement scour pipework and valves in the draw-off tower.

An additional 600mm gate valve washout facility was provided, via a 600mm branch off the 24″ raw water supply main to the treatment works. This was installed and commissioned before the onset of winter.

An underwater survey was undertaken by divers. The objectives of the survey were to:-

- Determine the silt levels and accessibility of the scour forebay headwall.
- Undertake a survey of the forebay tunnel headwall.
- Assess the feasibility of installing a temporary watertight bulkhead. The bulkhead would be used to enable dewatering of the forebay tunnel and scour pipework around the overflow shaft, and allow examination of the embedded puddle pipe (immediately upstream of valve G4) in the draw-off tower wall. Information obtained would be used in the design of the subsequent valve replacement works.

## PERMANENT WORKS

It was immediately evident from the inspection following the failure of the butterfly valve S1 that the surge pressures generated by the incident caused fracture and complete failure of the scour pipework. What was not known was whether the surge pressure had caused overstressing of the valve bodies and other fittings which did not show any visible signs of failure. It was possible that the surge pressures had caused damage to:-

- 30″ scour guard valve G4 and the associated puddle flanged pipe set into the wall of the draw-off tower.
- 36″ concrete scour pipe that ran around the base of the overflow shaft.
- 24″ bypass valve OP4, 90 degree bend and connection with the draw-off stack.
- 9″ Larner Johnson streamline valve S2.

In addition, the movement of the scour pipework may have caused damage to the 30″ and 9″ compression couplings downstream of the Larner Johnson streamline valves on the scour and the compensation pipework respectively.

The temporary and permanent works were designed, therefore, to replace the majority of the above pipework and valves by the construction of a temporary bulkhead on the scour forebay tunnel headwall, so as to provide a safe environment inside the draw-off tower for construction operatives and supervisory staff.

The temporary and permanent works involved:

- Contractor designed watertight bulkhead on scour forebay tunnel headwall with a facility to dewater the tunnel by pumping.
- Removal and replacement of all damaged and suspect pipework and valves.
- Construction of new thrust blocks.
- Carrying out in situ non-destructive testing of all built – in pipework, all couplings and any pipework likely to be left in position.
- Modifications to platforms, ladders and stairs as required.
- Replacement of damaged doors at entrance to access tunnel.

Following an assessment of the options for replacing the scour valves, KBR recommended that the butterfly valve should be replaced by a Larner Johnson valve. Fortunately it was possible to track down the original Larner Johnson valve which had been removed and have it refurbished for subsequent installation by the appointed contractor.

Because of the dangers associated with entering the draw-off tower and also the lack of detailed drawings there were a number of uncertainties and concerns at the time of tendering regarding the feasibility of using a bulkhead to facilitate the de-watering of the scour forebay tunnel and pipework. These uncertainties included:-

- achieving an adequate seal between the bulkhead and scour forebay tunnel headwall;
- the structural capacity of the headwall to support the bulkhead;
- the quantity of leakage into the forebay tunnel and scour pipework around the overflow shaft;
- the structural capacity of the scour forebay tunnel to withstand the proposed de-watering;
- the feasibility of manoeuvring the Larner Johnson valve along the draw-off tunnel;
- whether the Victaulic joints could be refurbished or replacements found.

## CONSTRUCTION PHASE

Prior to awarding the contract detailed interviews with tenderers were held to ensure that their proposed methodology, risk assessments and strategies for dealing with the project uncertainties detailed earlier in this paper had been properly considered and evaluated. Following this process Norwest Holst Construction Ltd was appointed as Principal Contractor.

The contractor successfully completed the safe refurbishment of the scour facility in October 2002 by following the basic order of procedure detailed in the Operational Plan. The principal activities were:-

- Installation of a temporary bulkhead on the scour forebay headwall to allow dewatering of the forebay tunnel and the safe removal of the damaged scour pipework and butterfly valve.
- Carrying out a detailed survey of valve shaft pipework.
- Removal of scour guard valve G4 and testing of the embedded puddle pipework.
- Installation of anchor frame on puddle pipe flange and new 30″ scour guard valve. It is worth noting that outline pipework and valve designs were carried out by KBR at an early stage to facilitate the early procurement of the valves. The Contractor was given the detailed design of the pipework and valve arrangements following an accurate survey of the existing pipework in the tower. This survey could only be undertaken once the bulkhead had been fitted.
- Installation of new scour and compensation pipework and refurbished Larner Johnson valves. The Contractor elected not to

dismantle the Larner Johnson scour valve once it had been factory refurbished. Following delivery to the site a specially designed trolley enabled the valve to be moved along the tunnel and then positioned in the base of the shaft.

- Commissioning of valves and pipework.
- Removal of temporary bulkhead.

Plate 4: Draw-off main within the draw-off tunnel

Plate 5: Transporting the Larner Johnson Valve

## INVESTIGATION OF VALVE FAILURE

Even though it was clear from the initial visit that the butterfly valve had been installed in a far from ideal position almost immediately downstream of a bend and discharging into almost free air with zero downstream pressure it was essential to find the reasons for the catastrophic failure witnessed at Ogston. Therefore an investigation was devised to determine the physical condition of the damaged pipework including:

- remaining wall thickness
- degree of corrosion
- evidence of welding
- flange rating
- strength

and to investigate the cause of the failure of the butterfly valve by:

- establishing that the valve had been constructed to the manufacturer's specification
- identifying the point and mode of failure
- performing strength tests on the failed components
- determining whether the valve had any locking device

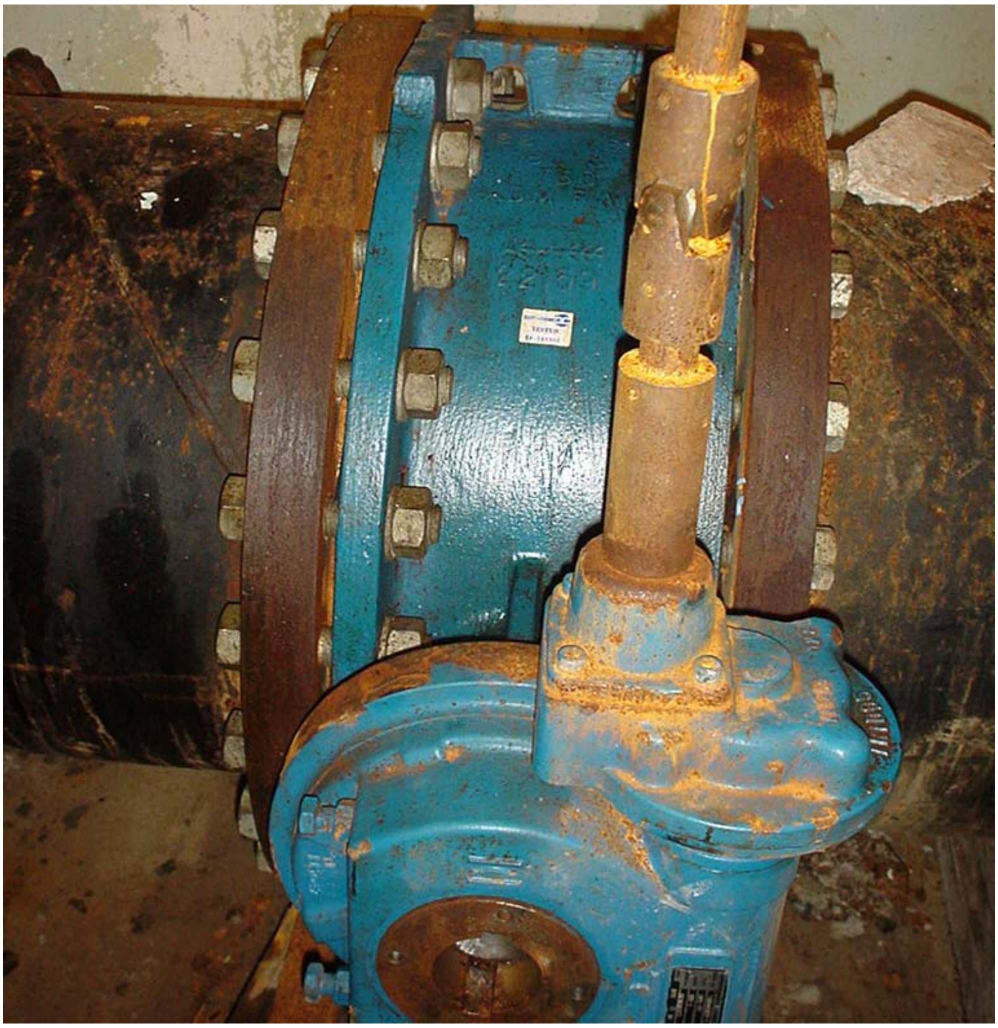

Plate 6: Failed butterfly valve in position and failed gearbox component

Following removal from the draw-off tower the butterfly valve and several pieces of pipework were taken to an independent testing laboratory for detailed examination and testing. A visual inspection of the valve identified no external damage, however, an internal investigation of the valve and gearbox made some interesting findings. The principal findings of the investigation were:

- The gearbox fitted to the valve was undersized for the application. The connection between the valve and the gearbox failed as a result of the excessive torque required to operate the butterfly valve beyond 50% open. This was due to the calculated presence of full cavitation and uneven flow profile, caused by the close proximity of the bend and the positioning of the valve.

- The capability of the gearbox was considerably reduced by one of four screws used for coupling the gearbox to the valve drive sleeve being missing.
- When the connection between the valve and gearbox failed there was nothing to prevent the valve slamming shut.
- There was little external corrosion of the pipes; however internal corrosion within the structure of the metal had reduced its tensile strength to some degree.
- The estimated surge pressures generated by the instantaneous closure of the butterfly valve would have resulted in the failure of new pipe to the same specification as that installed.

In summary, the failure of the pipework was due to the torque required to operate the butterfly valve being underestimated by its manufacturer and the gearbox being too small for purpose. This problem was exacerbated as one of the screws was not fitted into the gearbox drive sleeve and the remaining screws were not able to take the applied load. They subsequently failed allowing the valve disc to be rotated by the water flow, slamming closed and bringing the water flow to a sudden halt. The resulting change in momentum caused a pressure surge estimated to be in excess of 55 bars. This surge caused several sections of the pipework to fracture releasing a considerable quantity of water.

## CONCLUSIONS

This paper describes an incident which put operatives at risk and resulted in the sudden uncontrolled release of water following the catastrophic failure of scour pipework. The failure of the pipework was caused by the fitting of an inappropriate valve and gearbox for the required duty and system configuration. The lessons to be learnt include:-

1. The specification for the design of a valve should take account of, inter alia, its purpose, location, fixings, hydraulic loading, adequacy and configuration of existing pipework and valves, thrust/tension resistance, intended operating procedures, frequency of use, accessibility and ease of operation, maintenance and facility for subsequent removal.
2. The valve manufacturer should design the valve, together with gearbox, actuator, etc, to meet the specification and should certify compliance by providing supporting calculations and details of works tests.
3. Due regard should be taken of such phenomena as cavitation and spiralling flow.

4. Engineers should understand how various valves work and consider their possible modes of failure. In the case of butterfly valves it needs to be recognised that a failure of the connection between the gate and the gearbox will result in the gate slamming shut instantaneously.
5. Expert advice both in terms of mechanical plant and reservoir safety should be sought when considering the replacement or refurbishment of valves in existing scour and draw-off arrangements.

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