Water ingress through levelling culverts during design flood event

Date:	24 July 2023
Project name:	Grangemouth Flood Protection Scheme
Project no:	B2386100
Attention:	Barry Heeps
Company:	Forth Ports
Prepared by:	James McGilligan
Reviewed by:	Charles Schelpe
Document no:	B2386100-JEC-S4-C03-XXX-TN-C-0003
Copies to:	Alan McGowan, Richard Meeson

CH2M HILL United Kingdom
95 Bothwell Street
Glasgow, Scotland G2 7HX
United Kingdom
T +44 (0)141 243 8000
F +44 (0)141 226 3109
www.jacobs.com

Introduction

The Port of Grangemouth is served by an entrance lock channel with three lock gates, each with a pair of levelling culverts: one on each side of the channel. In day-to-day operations, these levelling culverts serve to equalise the water level between locks such that a closed gate may be opened. The culverts are operated by a penstock gate which when open allows water through the culverts to equalise water levels, and when closed seats onto a sealing surface to allow for a differential head to develop across a closed gate. As the entrance channel and the gates are designed to operate with a dock water level exceeding or equal to the level of the water in the outer or inner lock, the penstock seals in one direction only. In the event of a tidal surge that exceeds the level of the water in the impounded basin or its lock channel, the penstock may be off-seated by the head of water from the estuary side, allowing a degree of leakage through the levelling culvert system. This note seeks to estimate the effect of such leakage on the dock water level during the design flood event.

Penstock arrangement

The penstock comprises a stiffened steel bulkhead restrained within fabricated steel guides which support a pair of wheels mounted on each side of the penstock. The penstock is located within a shaft in the reinforced concrete abutment structure and is actuated by a hydraulic cylinder mounted towards the top of the shaft (Figure 1).

In order to allow for the smooth operation of the penstock, clearances have been allowed for by its designer. As fabricated and with the guide wheels in contact with the on-seating surface of the guide channels, 1/4" clearance has been provided in the direction of flow through the culvert (Figure 2). When seated, a P-seal provides a seal against water bypassing the seating arrangement, pre-compressed by 1/8" by the 'upstream' water pressure. When new, if this system were to be off-seated by 'downstream' (i.e. from the estuary) water pressure, the assembly would be pushed 1/4" towards the opposite side of the guide channel. Relaxation of the P-seal may partially block the resulting 1/4" gap, but wear on the penstock assembly (wheel bearing surface, bushes and guide fabrications) may offset this effect. In the cross-channel direction, the gap is restricted to 1/4" by angle sections mounted on the penstock such that along these edges, the apparent gap to water bypassing the off-seated penstock will be no greater than 1/4" irrespective of the degree of wear on the components. At the bottom edge of the penstock, the fabrication is seated tight against a stainless steel cill (Figure 3).

Taking the foregoing into consideration, it was considered reasonable and conservative to assume that when off-seated, a 1/4" gap would result on all edges of the penstock including the bottom edge.

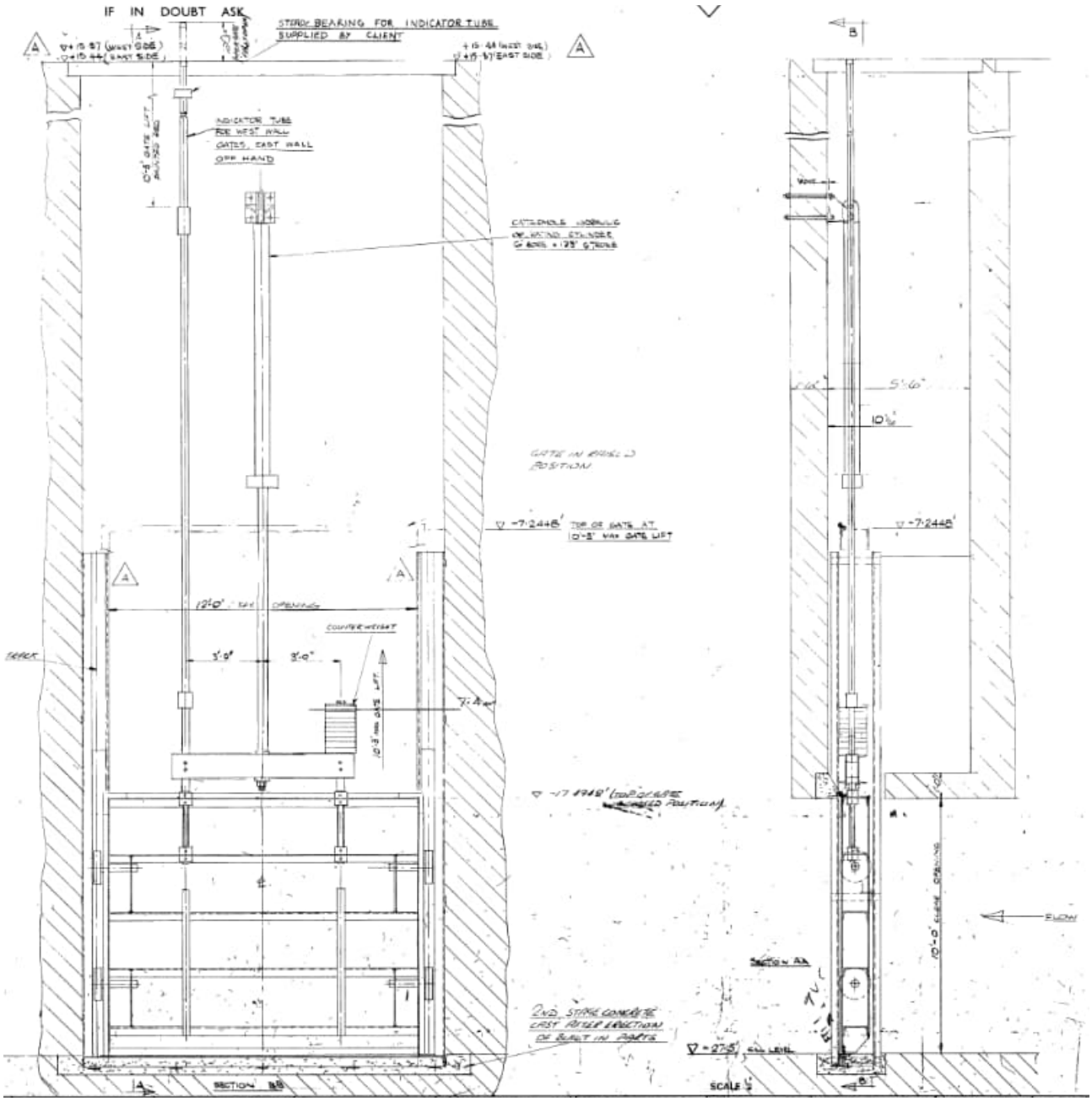

Figure 1: Penstock arrangement

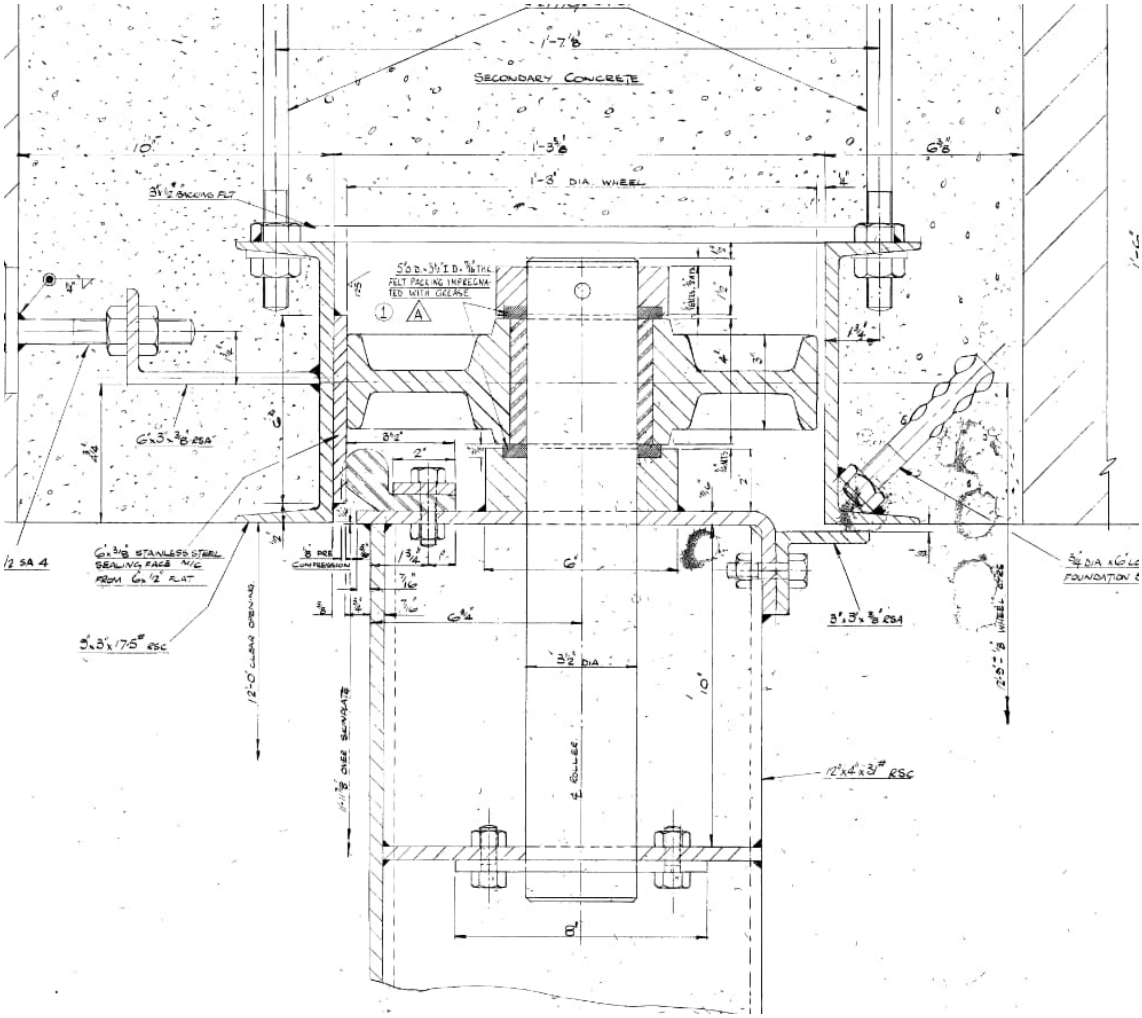

Figure 2: Penstock seating arrangement

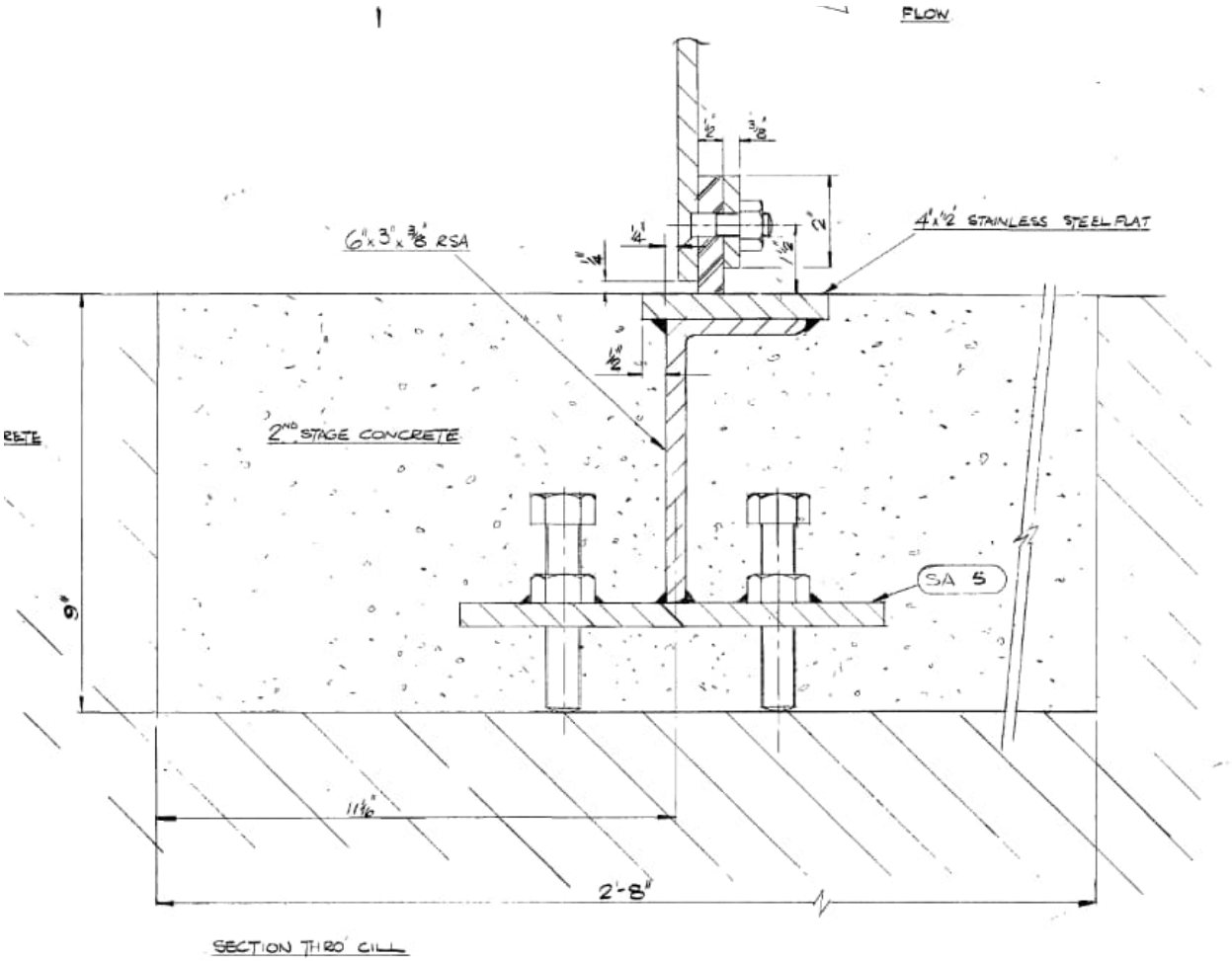

Figure 3: Penstock cill arrangement

Ingress calculation

To carry out the calculation on water flow through the gap opened up by off-seating the penstocks, the following parameters were used:

- Design flood level: 5.80mOD (this is exceedance of the scheme protection level of 5.20mOD)
- Design impounded water level: 2.89mOD*
- Tidal event duration: 6.17 hours (note for simplicity it was assumed that the tidal event maintains the design flood level for the entire period, instead of following the tidal curve as it would in reality. This constitutes a major conservatism)
- Area of impounded basin: 540,056m^2

**Minimum operational impounded water level from 'Forth Ports Authority, Port of Grangemouth, Mitre Gates, Sluices, Machinery & Anchorages for New Entrance Lock – Maintenance Manual and Operating Instructions Volume 1' (Rendel, Palmer and Tritton) which notes a minimal operational dock water level of 0.75ft below the maximum operational level.*

Three methods were used to quantify volumetric flow through the gap: Bernoulli's equation, Colebrook White and Hades modelling software. Bernoulli's equation returned the most conservative estimate of 0.45m^3/s per culvert when the tidal surge is at its highest stage (i.e. using the levels above). Based on this flow rate and the assumption that the flow rate is maintained for the entire duration of the tidal surge, the calculated impact on impounded dock water level is a 37mm rise.

Summary

The simplifications made in the estimate of water ingress via the levelling culverts are several: assuming a gap opens on all sides of the penstock; the selection of the most conservative flow calculation; assuming a constant high water level rather than one that follows the tidal curve. As such, the calculated dock water level should not be treated as a best estimate for the impact on the water level within the docks under the design flood event, but instead should be regarded as a demonstration that leakage through the levelling culverts would have an insignificant overall effect on impounded dock water level.

As the estimated effect that floodwater bypassing the levelling culvert penstocks has on the impounded dock water level is insignificant and given that modification of the culvert infrastructure to better prevent bypassing by floodwater may carry potential operational risks, it is considered that such works are best avoided by leaving the levelling culvert infrastructure as constructed.