Foss Barrier and Pumping Station

FACTUAL REPORT ON FLOODING ON 26TH DECEMBER 2015

Prepared for

Environment Agency

5th May 2016

Park House
Headingley Office Park
Victoria Road
Leeds LS6 1PF

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Contents

Acronyms and Abbreviations

AOD	Above Ordnance Datum
m	metres

SECTION 1

Executive summary

On the morning of 26th December 2015 the Foss Barrier was in the lowered position and all pumps at the Barrier were operating to pump water from the River Foss into the River Ouse. This had been the situation for the previous five days, a planned operational response to high water levels in the River Ouse.

Within the pumping station, power, control cables and drainage pipes are routed beneath the building through a service tunnel. The service tunnel extends beyond the building, providing a route for services to the barrier structure from the building. Both the pumping station building and barrier structure are constructed on piled foundations whereas the area between them, upon which part of the service tunnel is founded, is not constructed on piles. The foundations of the service tunnel therefore vary along its length. This has resulted in the section without piles settling over time more than the piled section. At the junction where the service tunnel meets the barrier structure this difference in settlement has opened up the construction joint, providing a route for water to leak into the service tunnel.

The service tunnel is fitted with a drain to cope with the small amounts of water that might be expected to leak into a chamber of this design. The drain carries the water from the service tunnel to a drainage pump station located between the building and barrier structure from where the water is then pumped off the site. On 26th December, the drainage pump was in operation, but the amount of water leaking in was more than the pump could handle, resulting in a buildup of water in the service tunnel. If left unchecked the water would rise in the service tunnel and enter the building through access points in the floor. To address this water is pumped out of the service tunnel by supplementing the drainage pump with a mobile pump. This procedure necessitates the removal of a sealed cover and lowering of a submersible pump into an access chamber.

At 07:45 hours on the 26th December 2015 flow in the River Foss increased and although all eight of the pumps were operating, the water level in the River Foss started to rise. The peak flow in the River Foss on 26th December 2015 was extreme and equates to an event with an 0.5% (1 in 200) probability of occurring each year. By noon, the River Foss had reached the same level as the open external access cover from which water was being pumped using the mobile pump. The level of the River Foss continued to rise which increased the pressure of water in the open access chamber thereby increasing the flow into the drainage system. As a result, the buildup of water in the service tunnel combined with water flowing through the drainage filled the service tunnel until it emerged from the floor access points inside the pumping station building.

This understanding of the mechanism by which water entered the Foss Barrier Pumping Station on 26th December 2015 has informed the identification of remedial steps to minimise the risk of water entering the pumping station in the future. Access openings between the building and the service tunnel should be sealed so that when water enters the service tunnel it cannot rise and flood the building. The drainage could be configured in a way which eliminates the need to pass through the perimeter of the building below flood level ie by having a small pumping system to pump it up and over the flood risk level. After adopting these remedial steps there will always be a residual risk of water entering the building because it is located below extreme river levels. This residual risk can be eliminated by relocating the water sensitive equipment above the flood risk level.

SECTION 2

Purpose of this report

2.1 Client brief

The Environment Agency instructed CH2M to undertake the following investigation:

1. Determine the mechanism by which water entered the Foss Barrier Pumping Station on 26 December 2015 and;

2. Identify the remedial steps needed to be taken to minimise the risk of water entering the Pumping Station in the future.

2.2 This report

This report provides a summary of facts relating to the 26th December 2015 when water entered the building at the Foss Barrier during a Boxing Day flood event, hereinafter referred to as 'the event'. Using knowledge of the event and the facility this report outlines remedial steps to minimise the risk of water entering the pumping station building in the future.

Background

The Foss Barrier is located at the confluence of the River Foss and the Ouse just south of the historic city centre of York. The Foss Barrier comprises a barrier gate and pumping station, hereinafter referred to as 'the facility'. This section explains how the facility operates and other matters of relevance to the event.

3.1 Facility arrangement and operation

This section includes general information about the operation of the facility under normal circumstances. For the purpose of this report 'normal' is when the flow rate of the River Foss is less than the pump capacity of the facility.

3.1.1 Facility arrangement

3.1.1.1 General arrangement

With reference to Figure 1 and 2, when the barrier is lowered to prevent water from the River Ouse entering the River Foss, up to eight pumps draw water through the intake. The water passes through the lowest part of the facility at a level of 3.2mAOD, beneath the service tunnel that is at 6.2mAOD and the ground floor at 8mAOD. The water is lifted through pump chambers, over individual weirs into the discharge culvert through which it flows before discharging downstream of the barrier. The weir crests are at a level of 10.5mAOD. Backup generators and a control room are located on the first floor level. A selection of construction photographs are appended to this report.

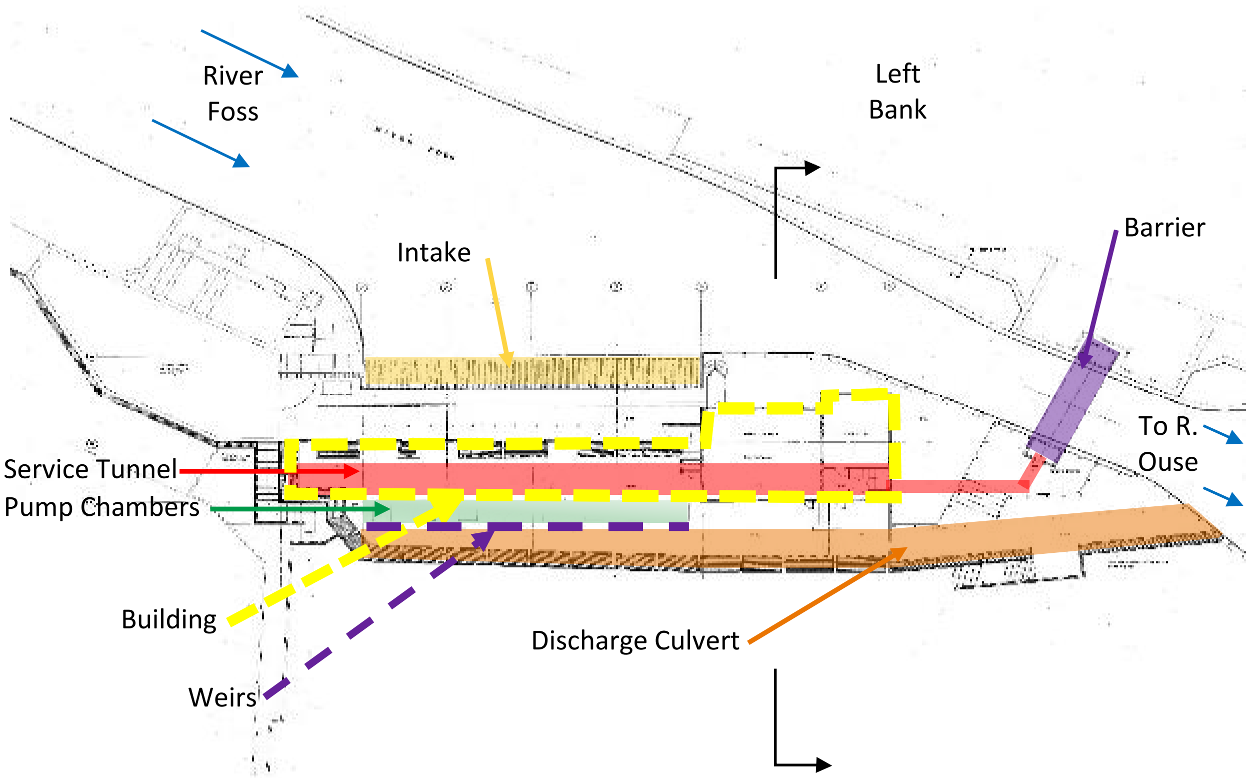


Figure 1. General layout

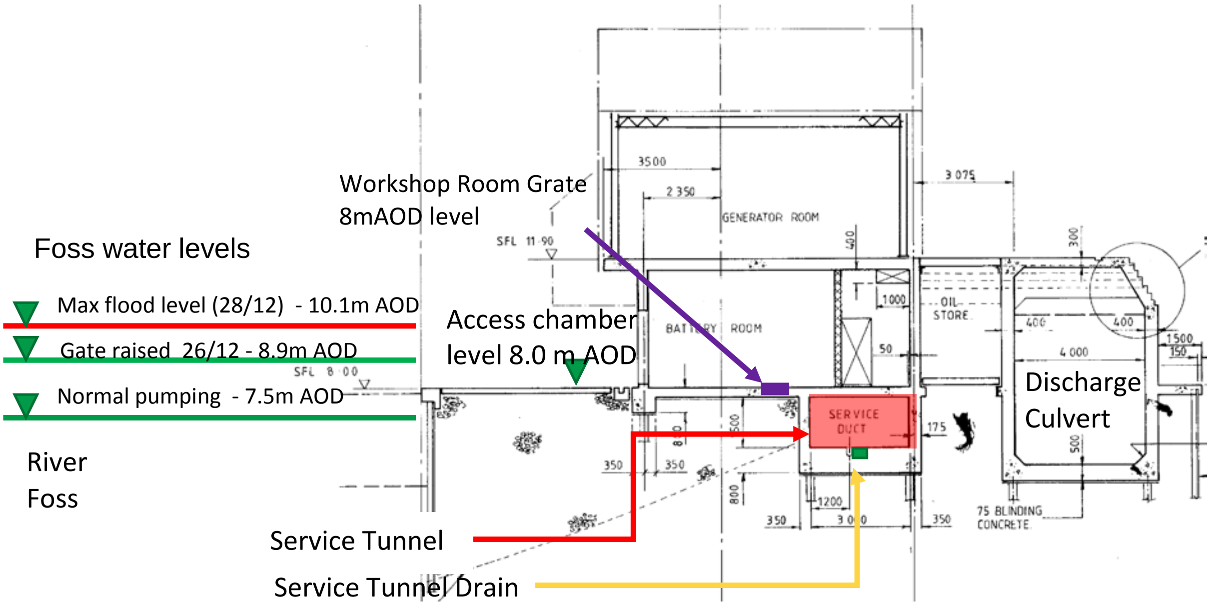


Figure 2. Section through the building

3.1.1.2 General construction

The reinforced concrete facility was constructed within a steel pile cofferdam and founded on concrete piles. Most of the cofferdam is integrated into the structure with the exception of the pump intake. Concrete piles support the building, the discharge culvert and the barrier structure. Between the building and the barrier structure, the service tunnel is founded on made ground.

The building is designed to be watertight. Joints in the concrete incorporate a surface waterstop cast in situ and doors and windows are watertight.

3.1.1.3 Service tunnel

The service tunnel is designed to carry cables, drainage pipes and other services from within the building to the barrier structure and to drainage chambers on the outside of the building. There is also a small recess in the floor of the tunnel to capture any leakage and carry the leakage to the drainage system. The service tunnel is accessed via a number of openings from the building of the facility and also via a high level opening and shaft adjacent to the barrier structure. The service tunnel was inspected on 25th February 2016. A defect was observed at the joint between the tunnel and the barrier structure where the tunnel appears to have settled relative to the barrier structure. The construction joint filler and mastic were displaced inwards and water was flowing into the tunnel through the joint.

In summary, the construction joints are designed to be watertight and the service tunnel foundations across construction joints differ from piles on one side to spread foundations on the other. This difference in foundation has resulted in differential settlement and a damaged watertight construction joint. Leakage of groundwater through the construction joints may originate from the Rivers Foss and Ouse, there is also a possibility that water leaks from the discharge culvert into the ground. The groundwater may originate from either or a combination of these sources.

3.1.1.4 Discharge culvert

The accessible length of the discharge culvert was inspected on 25th February 2016. It was noted that beneath the water level, sealant was missing from a joint in the concrete.

On the same day, 25th February, pilot holes were drilled through the base of the discharge culvert and water emerged from the hole furthest downstream. The level of the invert at this location is between 5.5mAOD and 6mAOD.

3.1.1.5 Drainage

Drainage from the ground floor and first floor level of the facility is routed via a sealed cast iron pipe network. Pipes pass through the service tunnel and the wall of the building before connecting to the external drainage. The external drainage consists of chambers, an interceptor (for oil and diesel spills) and a drainage pump station from which the waste water is pumped. Figure 3 shows the southern end of the building where elements of the drainage pass through the perimeter of the building. The green circle is the location of the floor grate through which water was observed flowing into the building during the event. The red lines on Figure 3 show locations where drainage infrastructure pass through the perimeter of the building and the blue shapes are the external drainage chambers. On both Figures 1 and 3 the service tunnel is shaded in transparent red.

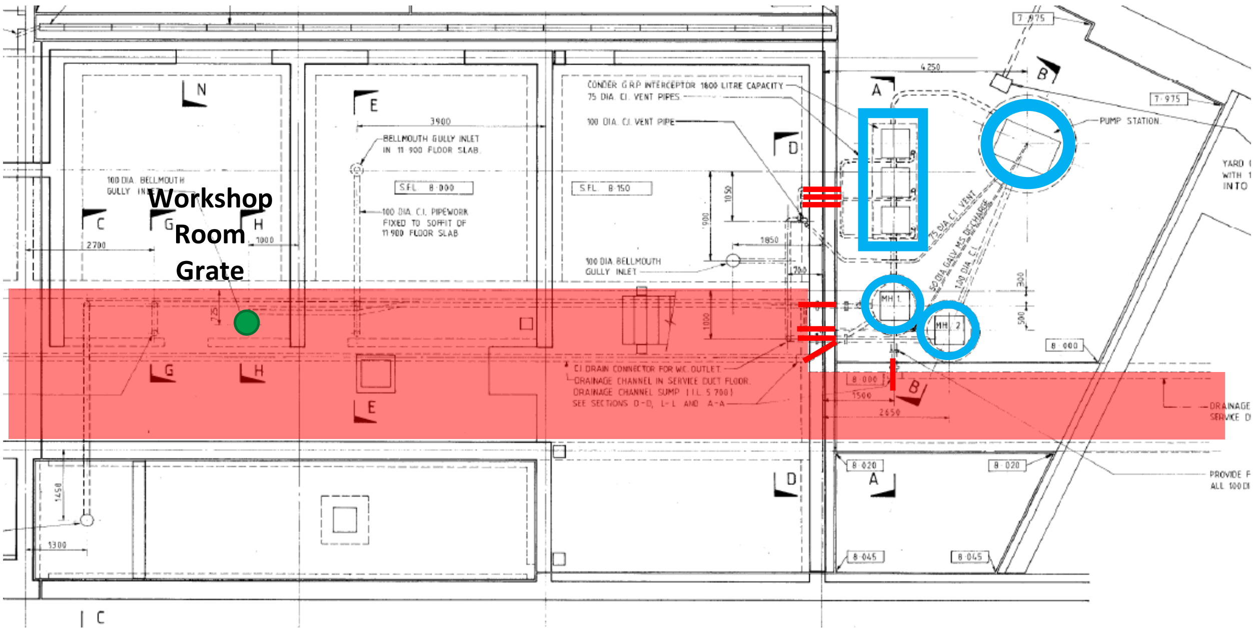


Figure 3. Drainage Plan

3.1.2 Facility operation

The barrier is a turnover lift gate weighing 16.5 tonnes. It is held horizontally above the river when not in use. This allows navigation to pass beneath and access for maintenance.

When the River Ouse reaches 7.4mAOD, the duty officer for the barrier is alerted. When the forecast level for the River Ouse is 7.60mAOD or more the duty officer makes arrangements for the Foss Barrier to be manned and operated.

As soon as the River Ouse reaches 7.60mAOD, the barrier is lowered. Visible and audible alarms are activated to warn navigation craft. The pumps are run for a few minutes to clear any rubbish and silt from the riverbed at the barrier so that the barrier is a watertight fit. The electrically driven barrier is then lowered, which takes approximately four minutes.

Once the barrier is in place, the flow from the River Foss is transferred around the barrier and into the Ouse by up to eight pumps. These pumps automatically maintain the water level of the River Foss at around 7.5mAOD and are capable of pumping approximately 30 cumecs of water. When the flood subsides and the level of the River Ouse drops to 7.5mAOD, the levels on either side of the barrier are equalised. A second audible/visual warning is given before the gate is opened and the pumps shut down.

3.1.2.1 Leakage management

Water is known to enter the facility's service tunnel. A degree of leakage into the service tunnel is accommodated in the design of the facility with the provision of channel drains in the base of the service tunnel. With reference to Figure 4, the channel drains convey water to an access chamber (yellow) outside of the building and onward to interceptor chambers (green) before discharging to the waste water pump station (purple). Water is pumped from the waste water pump station away from the facility. The access chamber (yellow) and interceptor chambers (green) have sealed covers so that water cannot enter them from above. Waste water discharges into the pump station through a flapped outfall.

On occasions, the rate of leakage exceeds the capacity of the pump station. In this situation water backs up the drainage system and the water level in the service tunnel rises. If left unchecked the water would rise and enter the building at ground floor level through access openings in the floor. Site operatives draw this water level down by pumping the excess water from the interceptor. This procedure necessitates removal of a sealed cover and lowering of a submersible pump into the interceptor. The electric pump used for this operation has a maximum capacity of 240 litres per minute reducing to 130 litres per minute at 7m head. The actual head during this operation is approximately 3.3 metres, but may be less depending on the water level in the interceptor.

The reported operation of pumping water from the interceptor chambers provides anecdotal evidence that leakage rates previously experienced were below 240 litres per minute. On these occasions the River Ouse water level was elevated and the River Foss water level was below 8mAOD.

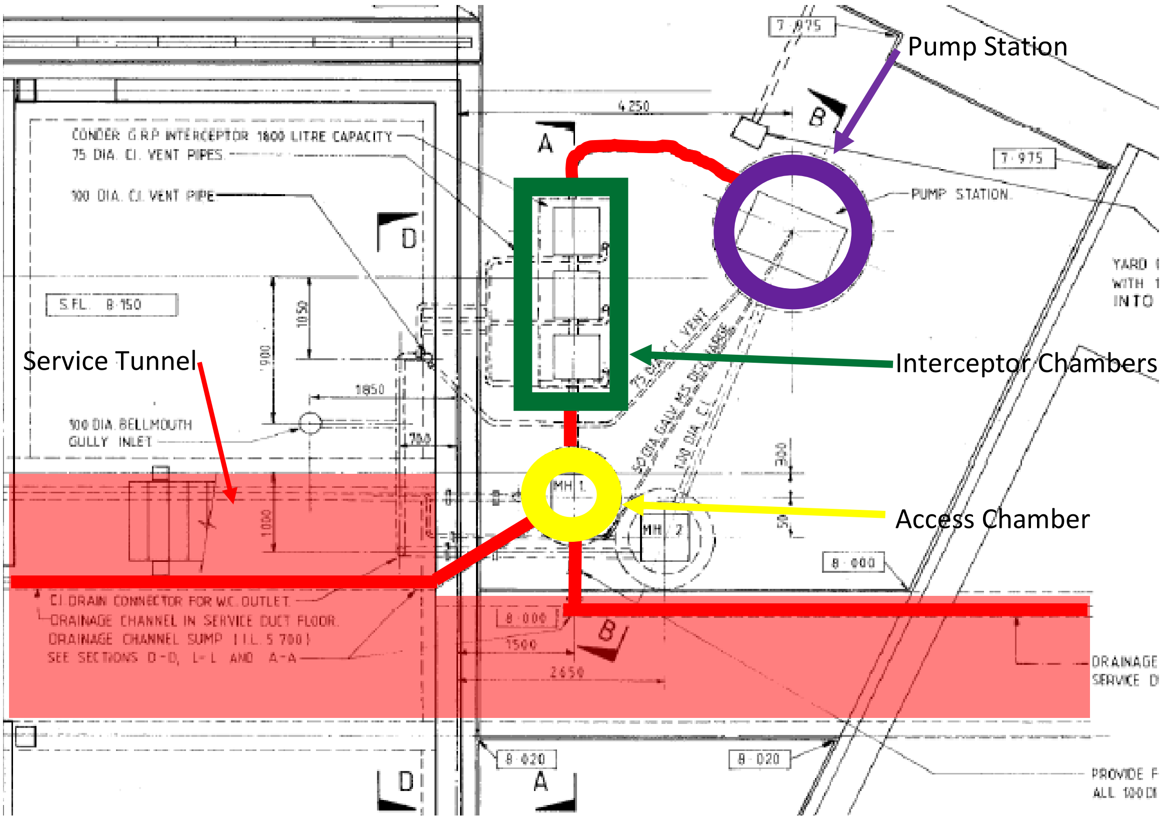


Figure 4. Service Tunnel Drainage Plan

3.1.2.2 Ground floor drainage

This section relates to the grates located in the southern end of the building. The workshop room grate is located at a level of approximately 8.0mAOD and the other at 8.15mAOD. With reference to Figure 5, these floor grates are connected to the foul drain and convey waste water outside of the building to an access chamber (turquoise) before discharging to the waste water pump station (purple) through a flapped outfall.

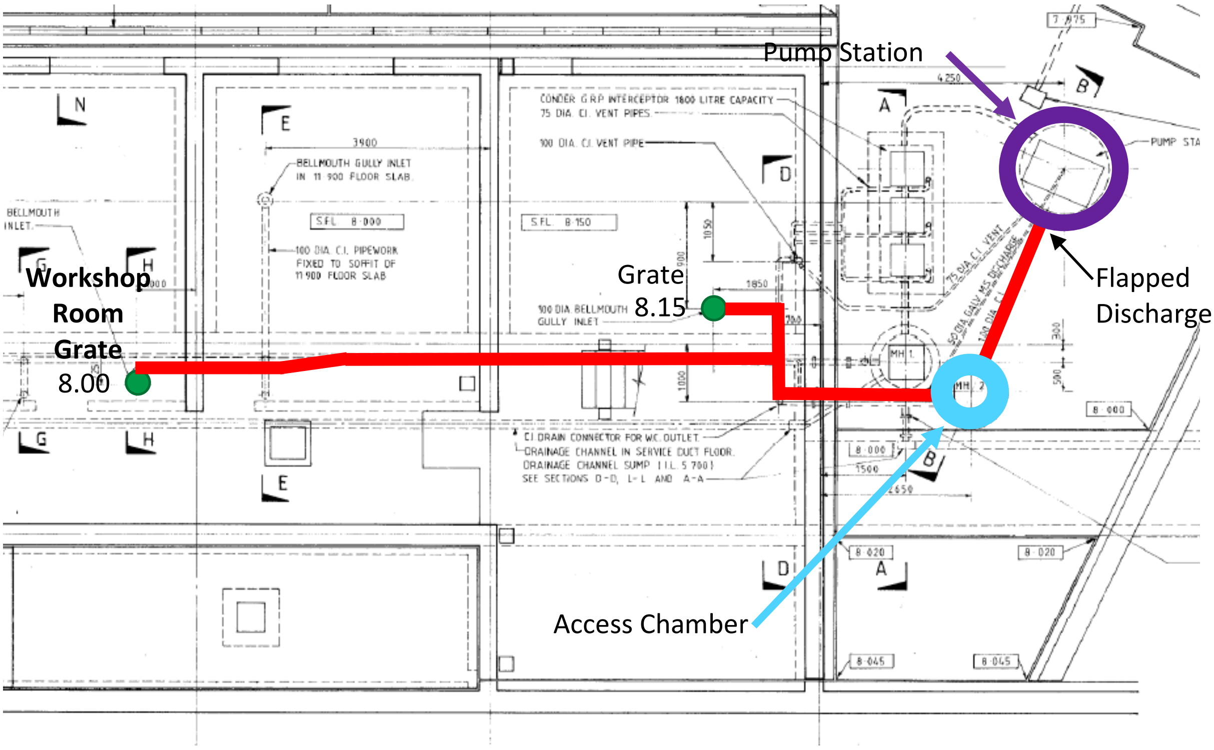


Figure 5. Ground Floor Drainage

3.2 Information relating to the event

Reports of water entering the facility during the event and this investigation have identified the drainage network and the service tunnel as the pathways for flood water.

3.2.1 Event timeline

Appendix B includes information and an account of incident management activities at the time of the event.

3.2.2 Event operations

3.2.2.1 Hydraulics

On the 26th December 2015 during the event all eight pumps at the facility were operating until immediately before the barrier was raised at approximately 19:00 when they were turned off. Figure 6 shows the water levels at the River Foss Basin and the River Ouse (either side of the Foss Barrier). Water levels were being maintained at a level of around 6mAOD until 07:45. After this time the level in the River Foss Basin rose at a rate of approximately 70mm per hour to a level of 7.84mAOD at 11:00. From 11:00 to the time just before the gate was raised at approximately 19:00 the rate of water level increase in the River Foss Basin was approximately 140mm per hour. The peak flow in the River Foss on 26th December 2015 was extreme and equates to an annual exceedance probability of 0.5% (1 in 200 year).

Figure 6 shows the water level upstream and downstream of the barrier during the event, along with an approximation of water levels in the River Foss Basin if the barrier had not been raised. With all eight pumps in operation the water level in the River Foss Basin was rising. Extrapolating the observed water level data it can be seen that if the barrier had not been raised the level in the River Foss Basin would have continued to rise until it spilled over the barrier into the River Ouse. The attenuated water level in the River Foss Basin would have been higher if the barrier had remained in the lowered position. Furthermore, the peak water level would have occurred some eighteen hours earlier. Both the possible higher water level and the timing of the peak water level are identified on Figure 6 by the purple arrows.

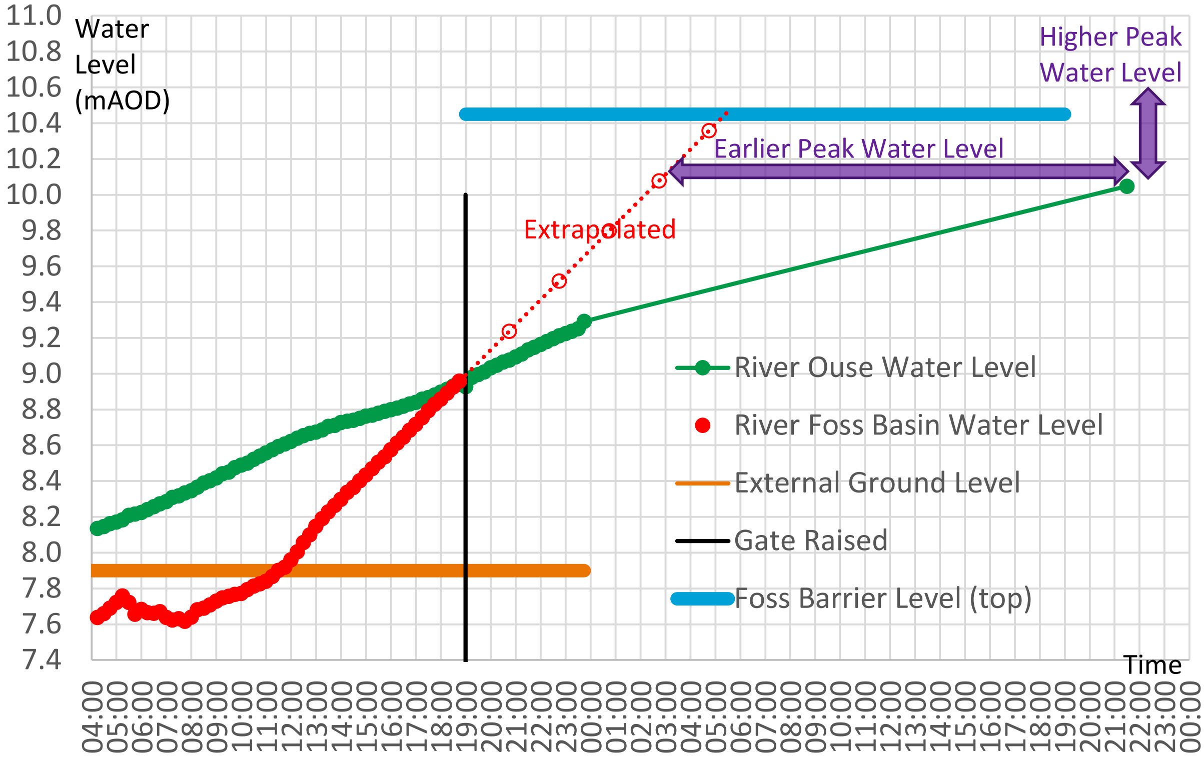


Figure 6. Operational Response in the Event (26/12/2015 – 27/12/2015)

3.2.2.2 Leakage management

During the event, water levels were rising in the service tunnel due to leakage through the construction joint and the procedure described in Section 3.1.2.1 to remove this water was implemented. As water levels in the River Foss Basin rose, river water covered the location of the open interceptor cover and flowed through the service tunnel drainage infrastructure and into the service tunnel. The rate of flow through the drainage infrastructure would have slowly increased as water pressure built as a result of depth of water at the interceptor chambers.

Using a mathematical model of the service tunnel drainage and open interceptor cover it is possible to simulate water entering the building via the service tunnel drainage infrastructure. This model provides confidence in our understanding of this mechanism but is not able to precisely model the timing of event.

3.2.2.3 Ground floor drainage

Waste water was observed arising from the workshop room floor grate located at a level of 8mAOD at approximately 13:30. The most probable cause of this is the water that entered the interceptor flowed into the waste water pump station. Referring to Figure 5, the flapped discharge between the access chamber (blue) and the pump station (purple) has failed to completely close.

3.2.3 Event scenarios

There are alternative scenarios which could be attributed to the event such as leakage of the watertight doors or windows, or leakage from the pump chambers. However, there is no evidence that the cause of water entering the building at the Foss Barrier is a result of anything other than the leakage into the service tunnel and flood water entering the service tunnel drainage.

3.2.4 Understanding of the event

3.2.4.1 Primary flood source

Differential settlement has caused watertight construction joints in the service tunnel to leak. During previous flood events an operational response to manage the effect of leakage has been successful. However if the levels in the Foss rise above 8.0m AOD then this operational response exposes the drainage system at the facility to flood water and presents an additional pathway for water to enter the building. See sections 3.1.2.1 and 3.1.2.2 for details of the drainage. The proportions of water that entered the building from service tunnel leakage and the drainage system is difficult to determine with a degree of accuracy. Two pieces of information provide an insight to understanding this:

- A small pump has previously been sufficient to manage the effect of leakage through the service tunnel
- A model demonstrates that flow through the service tunnel drainage system alone results in flooding to the building similar to that observed.

Both these pieces of information have limitations, they indicate however that most of the water which entered the building entered via the service tunnel drainage system.

3.2.4.2 Secondary flood source

Ground floor drainage which connects the floor grates has been described separately in preceding sections 3.1.2.2 and 3.2.2.3. The possible cause of this flood pathway, a failed seal, is a minor contributing factor because the water passing through this seal originates from either of the primary sources.

SECTION 4

Conclusions

This section brings together an understanding of the facility and observations from the event. It also answers the two main questions raised in the brief which were; to determine the mechanism by which water entered the facility and, identify remedial steps needed to minimise water entering the facility in the future.

4.1 Mechanism of Flooding

Reports of water entering the facility during the event have identified the drainage network (service tunnel and ground floor) and the service tunnel as the pathways for flood water. As explained above in section 3.2.4.2, the risk of flooding from the ground floor drainage is secondary to that from leakage and the service tunnel drainage.

4.1.1 Service tunnel

The most likely origin of flood water into the service tunnel is from the construction joint adjacent to the barrier structure. Water was flowing through this joint during the recent inspection and the investigation at the discharge culvert identified the hydraulic pressure of ground water to be higher than the receding river level. The extent of structural damage arising from the differential settlement between the piled structures and un-piled service tunnel is uncertain and remedial measures would be difficult to implement with certainty.

4.1.2 Service tunnel drainage

Water entered the service tunnel drainage via an open access cover on the interceptor chambers. The chamber cover was opened in an attempt to increase pumping of the drainage system to control the flows coming through the service tunnel as described in Section 3.1.2.1

4.1.3 Ground floor drainage

Water entering the building via the ground floor drainage is believed to originate from a leaking seal on a flapped discharge, see Figure 3. However, the water exerting pressure on the valve originated from the service tunnel leakage and service tunnel drainage, as explained in section 3.2.4.2.

4.2 Remedial steps

Flooding of the facility arose from leakage of the service tunnel and the service tunnel drainage. It is impossible to determine the proportion of flow attributed to each source, either the service tunnel leakage or service tunnel drainage. We know that either sources of flooding have the potential to result in flooding in the building and therefore remedial steps must address eliminating both sources. While the ground floor drainage infrastructure presents a secondary flow path, the event has identified a lack of resilience in the asset's performance. There is a risk that without undertaking the remedial steps a repeat of the event would compromise the facility. Remedial steps should focus on operations and maintenance as well as structural measures.

4.2.1 Service tunnel

Access openings between the building and the service tunnel should be sealed so that when water enters the service tunnel it cannot rise and flood the building. Permanent, immoveable physical seals will eliminate operational risks associated with the existing moveable covers.

The facility's power supply enters the building at the northern end of the service tunnel. It will be necessary to retain access to this area.

Rerouting services to a higher level is anticipated with this option. The service tunnel is a confined space and so removing it from the facility will deliver a safer working environment.

The sealed openings will be designed to withstand hydraulic pressures exerted on them from beneath during a flood events to stop the ingress of water.

4.2.2 Drainage

Waste water from the facility is small in quantity and arises from spills, cleaning and domestic facilities. The drainage could be configured in a way which eliminated the need to pass through the perimeter of the building below flood level ie by having a small pumping system to pump it up and over the defence height. If this measure is adopted, all existing drainage routes which pass through the wall of the building would be sealed.

As with the service tunnel, sealed openings will need to be designed to withstand the hydraulic pressures on them during a flood event.

4.2.3 Residual Risks

The ground floor level is at 8mAOD and while the measures outlined above would eliminate some risks of water entering the building, other risks remain. The watertight envelope of the building is reliant on door and window seals. If it is not possible to eliminate or reduce these residual risks to an acceptable level, the alternative is to move the water sensitive equipment above the flood risk level. Locating water sensitive equipment above the flood risk level will reduce the consequence of water entering the building and increase the overall resilience of the facility.

Appendix A
Photographs

Construction Photograph 1.
Downstream view, service tunnel within main building.

Construction Photograph 2.
Downstream view, service tunnel within main building.

Construction Photograph 3.
Upstream view, service tunnel within main building.

Construction Photograph 4.
Upstream view, service tunnel within main building, piling for building.

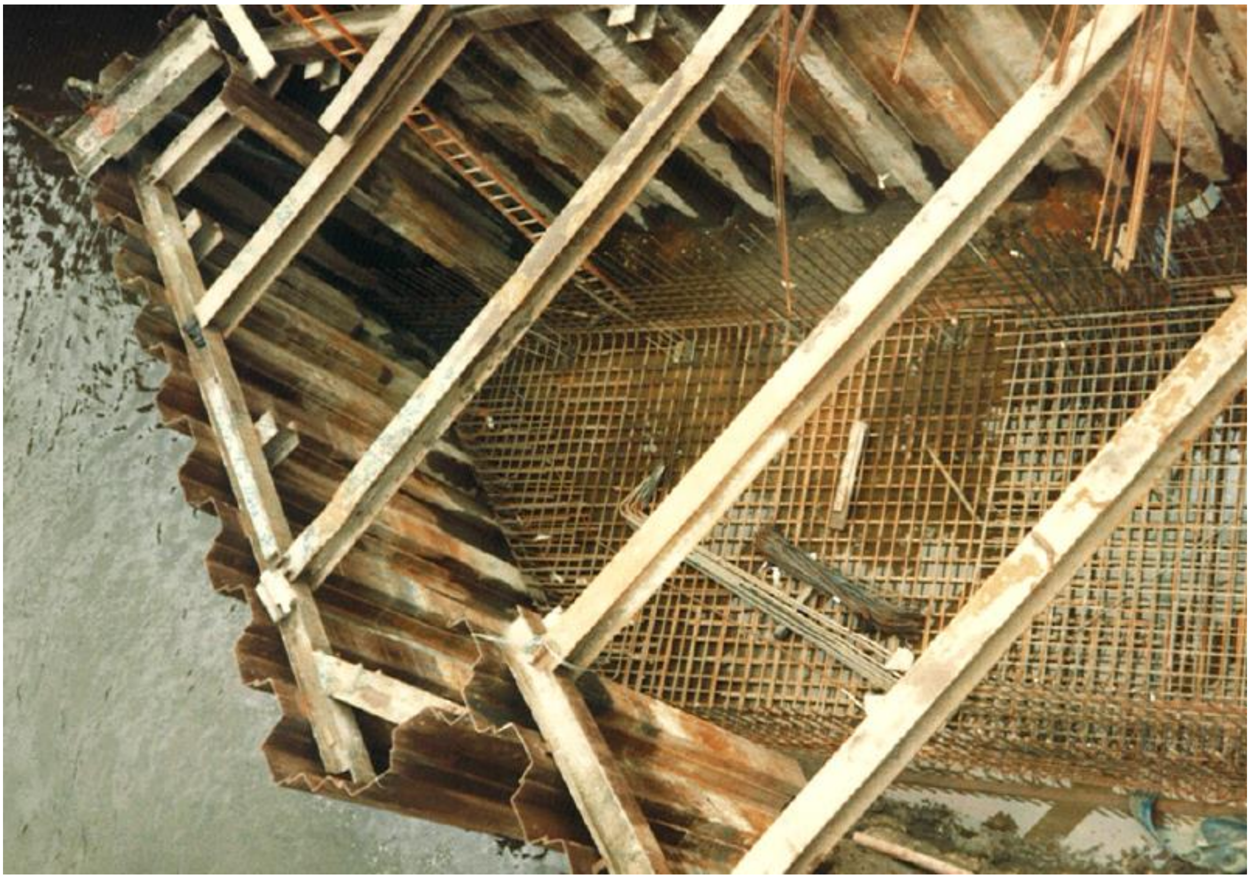
Construction Photograph 5.
Upstream view, service tunnel within main building.

Construction Photograph 6.
Downstream view, service tunnel formation between main building and barrier structure.

Construction Photograph 7.
Downstream view, service tunnel between main building and barrier structure.

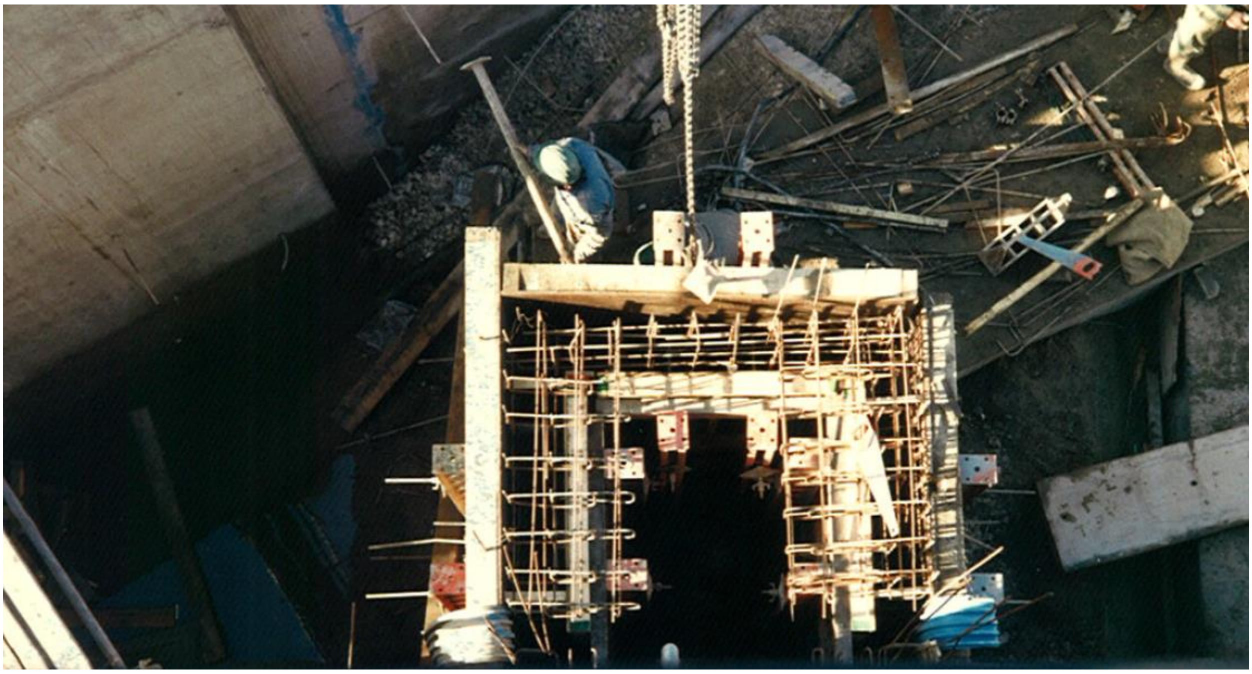
Construction Photograph 8.
Upstream view, discharge culver blinding (left) and service tunnel right).

Construction Photograph 9.
Downstream view, discharge culvert formation (right) and service tunnel (left).



Construction Photograph 10.
Discharge culvert.

Construction Photograph 11.
Downstream view, discharge culvert.



Construction Photograph 12.
Service tunnel shaft and tunnel beneath.

Construction Photograph 13.
Interception chambers (left) and vents (x3) and building drainage.

Construction Photograph 14.
Interception chambers (right) and wet well.

Appendix B
Sequence of events

Ref No.	Date	Time	Key event	Ouse level m AOD	Foss level m AOD
1	20/12	00:00	Levels in the Ouse and Foss within channel flowing normally	7.0	7.0
2	20/12	12:00	Heavy rainfall causes Ouse and Foss to start to rise	7.5	7.5
3	21/12	00:30	Foss barrier closed and pumps activated	7.5	7.5
4	21/12 to 23/12		Foss levels stabilise. Pumps operating normally. Ouse levels slowly rise	8.0	7.5
5	23/12	12:00	Temporary pump installed in external chamber to support sewage pumps	8.5	7.5
6	23/12 to 25/12		Foss levels stable. Pumps operating. Ouse levels stable	8.5	7.5
6a	25/12	06:00	Water leaking into Foss barrier building but managed by small mobile pump	8.5	7.5
7	25/12	12:00	Foss at Huntington road starts to rise again following local heavy rain. Foss levels downstream being managed by pumping station.	8.0	7.5
8	25/12	18:00	Ouse at lowest level and starts rising again.	7.8	7.5
9	26/12	07:07	Flood Alert issued for river Foss	8.3	7.5
10	26/12	10:41	Flood warning issued for River Foss at Huntington	8.5	7.5
11	26/12	11:00	Flow in Foss has been increasing over last 17 hrs. Levels in the Foss basin by the barrier begin to suddenly rise even with all 8 pumps running. Ouse is steadily rising.	8.5	7.5
12	26/12	13:00	Drainage system begins to let in water. Levels inside building have been under control but now begin to slowly rise. Temporary pumps can't cope with inflow.	8.6	8.0
13	26/12	16:51	5 Flood warnings issued for the Foss basin		
14	26/12	18:00	Levels in Foss have risen quickly. Pumps operating but not managing the levels. Ouse still rising.	8.8	8.7
15	26/12	18:00	Water levels inside pump-house are rising as water comes into building through drainage system and service duct. Situation is becoming unsafe and will trip the electrics	8.8	8.7
16	26/12	18:30	Decision made to open gate, shut down pumps and issue more warnings	8.8	8.8
17	26/12	18:45	Pumps turned off. Foss barrier opened before power is lost	8.9	8.9
18	26/12	19:05	6 Severe Flood Warning issued for Foss basin	8.9	8.9
19	26/12	23:00	Electrical switch room and power system flooded	10.0	10.0
20	28/12	00:45	Ouse and Foss peak	10.1	10.1
21	28/12	09:00 to 24:00	New pump starters are lowered onto roof and connected to pumps. New generator connected to gate. Ouse and Foss around 10.2 m AOD but slowly falling	10.0	10.0
22	29/12	00:50	Gate lowered and 4 pumps working and levels in the Foss start to fall.	9.7	9.7
23	30/12	19:00	All 8 pumps fully operational. Levels in Foss fall to around 7.5m AOD	8.6	7.5

Source: Environment Agency