

## **Bradford Area Reservoirs' Group - Flood Routing Remedial Works at Leeming, Doe Park and Hewenden Reservoirs**

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**SYNOPSIS.** Following detailed flood study investigations and extensive physical model testing, it was demonstrated that the overflow works at three existing Yorkshire Water reservoirs situated to the west of Bradford were inadequate to handle the PMF design flood. A programme of design and construction of remedial works was therefore carried out to overcome the deficiencies.

In each case, remedial works were required to increase the capacity of the spillway and to provide adequate embankment freeboard for both still water flood rise and wave surcharge in order to prevent overtopping. However, whilst the three projects had certain similarities, there were also differences in the nature of the works and the approach that was adopted. This paper describes the remedial works carried out at each of the sites as delivered by the MMB joint venture team. For each project the emphasis was on the development of innovative solutions in order to reduce costs and minimize construction time, whilst providing a viable technical solution which was in keeping with the local environment.

At Leeming reservoir the solution involved deepening and widening of the tumble bay and the enlargement of the spillway using conventional reinforced concrete and masonry cladding construction. At Doe Park there were extensive works to raise the dam crest and a pre-cast wave wall solution was adopted to facilitate the construction and to maintain access for local residents during the works. At Hewenden the spillway walls were heightened in in-situ concrete using molded formwork and concrete staining to give the appearance of stone. In the lower section of the spillway there was a certain amount of out of channel flow that was tolerable and appropriate protection works were included at the embankment toe.

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### INTRODUCTION

The Bradford area group of reservoirs are located approximately 5 miles to the west of Bradford and consist of six dams of a traditional pennine type embankment construction. All of the dams were constructed in the latter half of the 19<sup>th</sup> century to supply Bradford's ever increasing demand for water.

The reservoirs are Leeshaw and Leeming which are located to the South of Haworth and which discharge ultimately into the River Worth, and Thornton Moor, Stubden, Doe Park and Hewenden which are in cascade and are located in and around the village of Denholme, and discharge into the River Aire at Bingley.

Following statutory inspections that were carried out in 2004 by the late J.Beaver, it was recommended that a flood study should be carried out to determine if the reservoirs had sufficient freeboard and spillway capacity to pass the design flood event (PMF). The flood study confirmed that there were significant deficiencies and that capital works were required to rectify the problems.

The works at Thornton Moor and Stubden proved to be minor and were carried out straight away. Works at Leeshaw were more significant and were completed as part of Yorkshire Water's AMP3 capital programme in 2004. The works at Leeming, Doe Park and Hewenden were scheduled for the current AMP4 programme and are the subject of this paper. The key parameters for the three reservoirs that determine the design criteria for the improvement works are summarised below.

Reservoir	TWL (mAOD)	Wave Surge (m)	Permissible Flood rise (m)	Min Crest Level (mAOD)	Min Wave Wall level (mAOD)	Peak outflow (m <sup>3</sup> /s)
Leeming IRE	254.97	0.60	1.32	256.29	257.53	89
Doe Park IRE	244.91	0.65	1.76	246.67	247.54	120
Hewenden IRE	205.74	0.65	1.65	207.39	207.39	79

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### LEEMING RESERVOIR

#### Physical Hydraulic Model

A physical hydraulic model was constructed to assess the performance of the existing spillway arrangement. The model consisted of the weir and its approach channel, the tumble bay arrangement including part of the by-wash channel and the spillway chute. The testing confirmed that the restricted exit to the tumble-bay caused the weir to drown under PMF conditions, with the result that the flood rise exceeded the permissible value. To prevent the weir from drowning it was concluded that a widening by 1m and deepening by 2m of the downstream end of the tumble bay was required. The model also showed that over a large part of the chute the flow depths were greater than the height of the side walls. The problem was exacerbated by small up-stands at the downstream end of each cascade step which were shown to cause a localised increase in flow depth. It was decided therefore that the up-stands should be in-filled so as to induce skimming flow and reduce depths.

#### Preferred Solution

The remedial works project comprised the following components:-

- Deepening and widening of the tumble bay
- Enlargement of the spillway chute
- New access bridge across the spillway
- Reinforcement of the embankment wave wall

Optioneering concentrated on the construction of these works in order to determine the most practical and cost effective solutions. Several alternatives were considered for the wave wall including pressure grouting to reinforce the lower part of the wall (up to still water flood level), demolition and re-building of a like for like wall, or construction of a completely new wave wall with a central concrete section that would be linked to the clay core. For the lower end of the spillway the possibility of limited out of channel flow with appropriate protection works such as gabion mattresses or concrete slabs was also examined.

However, following the Boltby incident it was decided that in this case all of the flow should be contained and hence a new, larger, reinforced concrete channel was required. Given the nature of the existing spillway and its proximity to the embankment mitre, it was determined that the most practical solution was to construct a new enlarged reinforced concrete channel as a lining to the existing masonry chute.

## ENSURING RESERVOIR SAFETY

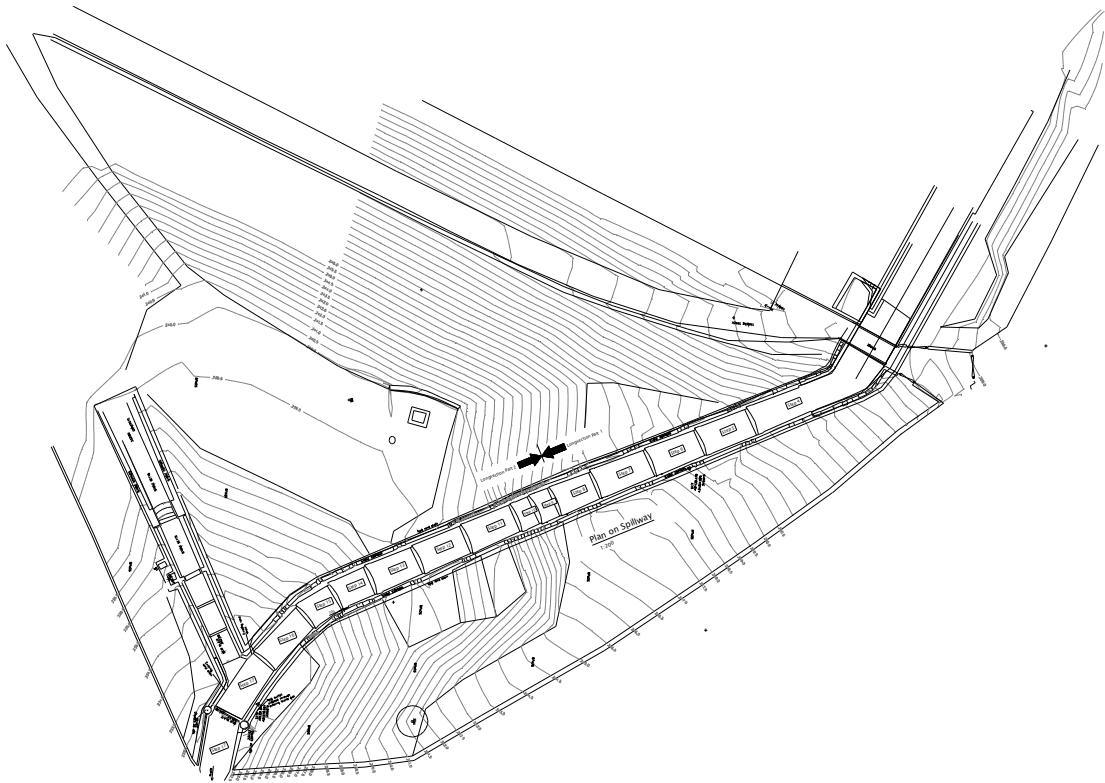


Figure 1: Leeming Reservoir Embankment and Spillway Arrangement

### Construction and flood risk protection

Reservoir safety works of this type require a detailed contingency and temporary drawdown plan for the construction phase. The design criteria demanded that the 1:100yr flood should be accommodated without causing inundation of the partially completed works or overtopping of the embankment. The storage buffer that was needed resulted in a temporary drawdown of 4.5m at Leeming, together with a 1m drawdown of Thornton Moor Reservoir which is located upstream. In addition a weir on the incoming catch-water system was temporarily removed at Thornton Moor to prevent overflow into Leeming catchwater, this meant that as much as possible of the incoming flow could be diverted away from the reservoir.

The spillway was constructed in three distinct phases. First the base of the spillway was constructed, then the existing spillway structure was lined using a single face shuttering system and finally the top section was cast using a two faced shutter system. Overall, the depth of the new spillway cascade averages 6m. The structure is predominantly buried with only the top 1.1m visible from the embankment. All of the external faces have been clad using local stone from re-claimed sources.

## AIREY AND CARRUTHERS

The modifications to the tumble bay were the most complex parts of the project in that the new works had to be incorporated within the existing structure. The excavation to deepen the tumble bay was about 8m deep, and Larssen LX16 piles 10m long were pre-driven and braces were installed prior to demolition and excavation of the existing arrangement. The bracing arrangement was complex as there was only one side of an excavation to push-off, so that raking props had to be used to provide the required thrust.

As part of the contingency plan all excavated surfaces were to be blinded with concrete at the end of every shift to provide some erosion protection should the reservoir have filled and overflowed. The tumble bay was constructed using reinforced concrete with a masonry clad face on exposed vertical surfaces. To increase the length of any potential leakage path a key was cast around the outside of the structure where it passed through the clay core. Upon completion of the new reinforced concrete works the majority of the sheet piles were removed. However, those which had been driven into the clay core were left in place and were cut down to crest level. The interface between the new structure and the piles was also a potential leakage path, and to overcome this problem a puddle clay plug was constructed between the key and the face of the sheet piles.

The access bridge across the spillway provides the only access for residents to the west of the dam, and access had to be maintained for all vehicles at all times throughout the duration of the scheme. It was necessary to provide a temporary access bridge and diversion route in order that works on the tumble bay could proceed.

Raising of the clay core proved to be particularly interesting. The sourcing of good puddle clay in Yorkshire proved to be difficult: there are many sources of clay but testing showed that several of these contained traces of arsenic and for obvious reasons could not be used. Upon finding a suitable source of good clay it was necessary to re-work the clay to the specified parameters. This operation of re-working the clay was carried out at the source site as there was insufficient room on-site for this re-working process. A concrete lined and covered bin was provided on site to enable the deliveries of clay to be kept free of contamination and at the required level of workability. The raising of the clay core was carried out using 2 excavators and 2 dumpers each of them handling either new or old clay to prevent contamination of the new clay. Compaction of the clay was carried out using a vibrating plate attachment on the clean excavator, compacting the clay in 150mm layers.

At the outset of the works it was intended that the wave wall should be strengthened by pressure grouting. This approach was found to be

## ENSURING RESERVOIR SAFETY

impractical as the central cavity of the wall had, over time, filled with debris. It was not possible to grout the wall with the debris present so the decision was taken to re-build the wall utilizing the existing walling stone with a reinforced concrete core.



Figure 2: Tumble bay under construction

## DOE PARK RESERVOIR

### Investigations

The flood study and subsequent testing of the spillway indicated that there was a significant shortfall in both embankment freeboard and spillway discharge capacity. Remedial works were essential to overcome these deficiencies and again it was determined that the outflow discharge (PMF) should be fully contained along the length of the spillway channel. In addition the existing wave wall along the crest of the embankment was in a poor state of repair and needed to be replaced.

### Preferred Solution

The main components of the remedial works project were:

- Increased wall heights for the spillway channel
- New wall to upstream side of crest to retain wave and flood rise
- New boundary wall to downstream side of crest
- New road bridge across the spillway
- Raising of the valve shaft to accommodate the predicted flood rise.

## AIREY AND CARRUTHERS

Various value engineering options were examined to facilitate construction and to minimise costs. For the crest walls the following alternatives were considered:

- (a) Re-construct with wet-walling to current standards
- (b) In-situ concrete wall with stone cladding
- (c) In-situ concrete with form liner and stain finish
- (d) Pre-cast concrete with form liner and stain finish

In the case of the new 17m span spillway bridge the focus was on the arrangement and construction method that would cause minimum disruption. These included:-

- (a) Re-construct bridge pier with knife edge and strengthen bridge
- (b) Construct a new double span bridge with knife edge pier
- (c) Construct a new single span bridge in pre-cast concrete
- (d) Construct a new single span bridge in steel.

For the spillway channel the alternatives considered involved the choice between masonry cladding or a form liner finish to the concrete. The possibility of battered walls was also compared with vertical walls, where the increased channel capacity and hence reduced height had to be measured against the more complicated formwork that would be required.

For the valve shaft modifications the alternative of raising the outer walls to a level that was above the flood rise level was compared with the option of capping and sealing the top of the shaft which in any case was no longer to be used as an overflow.

In the preferred solution the wave and crest retaining walls were re-built using pre-cast concrete wall units that were linked to the clay core using an in-situ cut-off trench. Essentially this widened the crest by 450mm as the reinforced concrete wall units were thinner than the existing wall units. The bridge across the spillway was built of pre-cast bridge beams with an in-situ deck. This solution dispensed with the risk of blockage beneath the bridge. The spillway was re-constructed in reinforced concrete with a formliner and stain finish to the visible external surfaces. The shaft was raised in concrete with an ashlar formliner and staining to the external surface. The concrete stain that was selected was 'ebony' which best matched the concrete and masonry of the surrounding environment.

## ENSURING RESERVOIR SAFETY

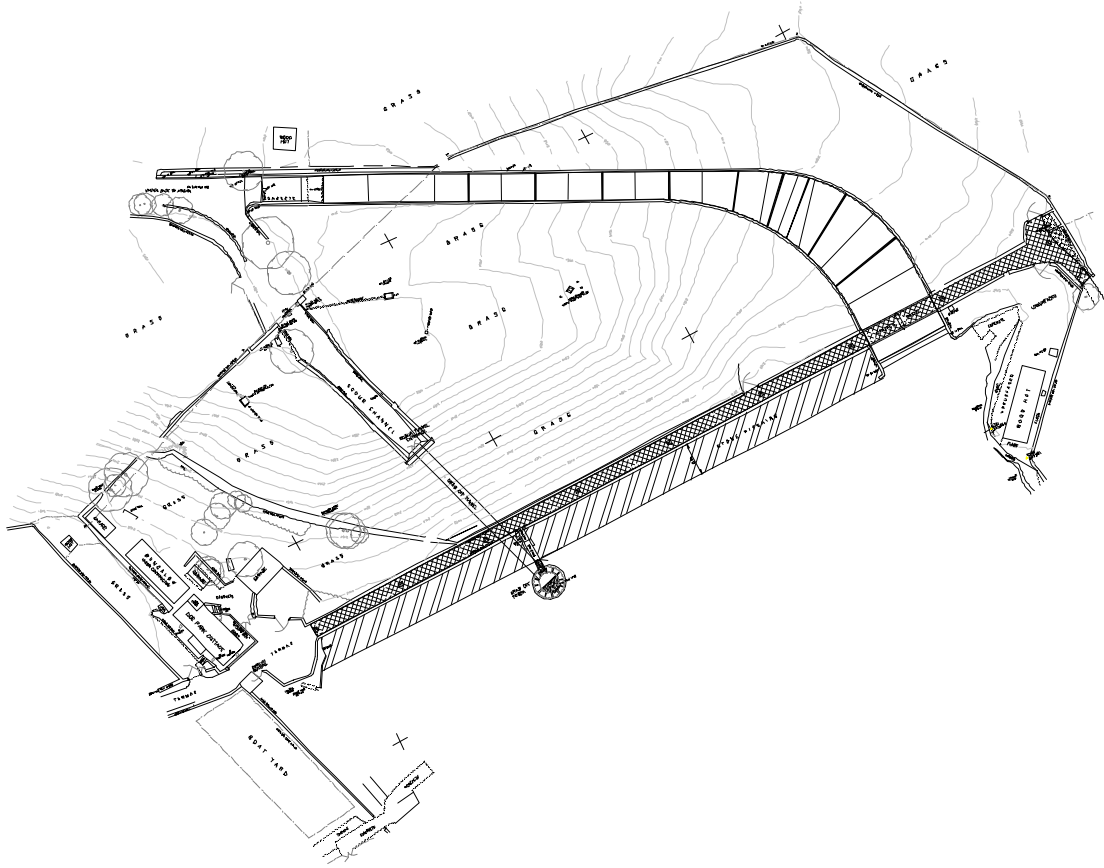


Figure 3: Doe Park Reservoir - General Arrangement

### Construction and flood risk protection

The remedial works at Doe Park were to be constructed concurrently with similar works at Hewenden reservoir, which is located directly downstream. Thus the contingency plan was formulated to give adequate protection to both of the projects. It required a temporary drawdown of Doe Park reservoir by 4.5m, together with draw downs of 1m and 2m at the upstream reservoirs of Thornton Moor and Stubden respectively.

The first phase of spillway construction was to form temporary mass concrete protection bunds on either side of the existing channel. This was done prior to the demolition of the existing walls. The provision of the temporary channel proved its worth in December 2006 when after a period of prolonged and heavy rainfall all of the reservoirs in the cascade filled and overflowed. The contingency plan that was in operation at the time meant



## AIREY AND CARRUTHERS

that the incident was well managed. All parties involved knew what to do and who should be contacted. Whilst spilling from the reservoir was unavoidable, the temporary works proved to be very effective in that the discharge was restricted to the middle portion of the partially completed channel. There was some disruption to construction activities but no damage was sustained to either temporary or permanent works.



Figure 4: Doe Park Reservoir - Overview post construction

## HEWENDEN RESERVOIR

### Investigations

The model testing of the Hewenden spillway showed that the horseshoe shaped weir operated under free discharge conditions, but even so the predicted flood rise under PMF conditions was above the embankment crest. Hence works were required to raise the core of the embankment and to provide a substantial wave wall that could withstand both the still water flood rise and the wave surcharge. It was also shown that overtopping of the spillway walls would occur over a large part of the channel and to address this deficiency, modifications were needed to enhance the channel capacity and contain the flow.

### Preferred Solution

The main components of the remedial works project were

- A reinforced concrete wave wall along the embankment crest with a concrete nib beneath its base slab that extended into the clay core.

## ENSURING RESERVOIR SAFETY

- A new concrete slab invert and concrete side wall to part of the overflow channel; this replaced the original masonry that was in poor condition.
- Wall heightening to both sides of the spillway channel over most of its length.
- Protection works in the downstream area between the end of the spillway and the outlet channel from the draw-off tunnel. This area would be inundated under extreme flood conditions but the movement of flow was shown to be away from the embankment toe.
- Modifications to the top of the valve shaft to contain the maximum surcharge level.

In a similar way to the other schemes a number of alternatives were considered during the planning and design of the works in order to improve constructability, minimize the visual impact of the new works and reduce the overall construction period, thereby reducing costs. In the case of the wave wall, conventional masonry construction with a concrete core was compared with a reinforced concrete wall with either masonry cladding or form liner finish. It was the concrete wall with a stained form liner finish that proved to be the most economic, whilst providing a final appearance that was acceptable to all parties. Similar comparisons were made for the raising of the spillway walls where it was very important that the appearance of the new walls should be in keeping with the existing masonry.

### Construction and flood risk protection

Works at Hewenden reservoir were timed to coincide with works at Doe Park reservoir in order to reduce the impact on water stocks. A combined flood contingency plan based upon protection for floods up to the 1 in 100 year event was therefore developed. This required a 4m temporary drawdown at Hewenden along with the 4.5m of flood storage that was available at the upper reservoir. The two sites were managed as a single operation and there was close liaison with YW Operations staff to ensure that the plan was implemented successfully.

Works to the spillway were split into three phases; re-construct the 60m long upper portion of the channel in reinforced concrete, raising of the remainder of the channel walls and construction of the scour protection slab to the downstream area beyond the embankment toe. For the building of the wave wall, the use of pre-fabricated reinforcement cages greatly reduced the construction time, with the average rate of construction of 10m/day being achieved. Upon completion of the concreting works the structure was left to cure for a period of thirty days before the final stain was added. In tests on site it had become apparent that the stain reacted differently to fresh and aged concrete and that this inevitably affected the final appearance.



Figure 5: Hewenden Reservoir – Completed Wave Wall

### Conclusions

The three projects were similar in nature as each involved the provision of a new wave wall to an existing embankment dam and significant modifications to the overflow works in order to contain the PMF discharge. However the special characteristics of each site meant that different approaches were required for both the design and construction of the remedial measures. In addition new techniques were tested that facilitated the construction and reduced costs, whilst providing a solution that was technically viable and comparable with conventional construction methods. In particular the following conclusions can be taken from the execution of these projects:-

- At Leeming the continuous access requirements through the site and over the spillway channel were a significant challenge. A ‘first time’ permanent bridge solution in preference to a temporary diversion bridge and the permanent bridge on a different alignment would have resulted in less disruption.
- The use of concrete with form liner and staining has been shown to be a real alternative to masonry cladding. Construction times are greatly reduced and the cost is significantly less. In order to achieve a uniform staining and final appearance of the concrete there needs to be a consistent concrete mix combined with tight control of curing and stain application.

## ENSURING RESERVOIR SAFETY

- At Doe Park the use of pre-cast units for the new wall gave a significant reduction in the construction period with the main length of wall (approx. 150m) being completed in just 3 weeks. This had a positive impact in minimizing the disruption to access along the crest.
- Pre-fabricated reinforcement as used at Hewenden was found to be cost neutral on installation, but as the construction process is speeded up there were considerable savings in site preliminary costs.
- The final appearance of the completed works at all three locations is very pleasing. The new works are in sympathy with those parts of the existing works that have been retained, and in general they blend well with the surrounding environment.
- The contract strategy that Yorkshire Water employs for the delivery of its projects can work to great advantage. In each case the turnaround from the issue of project contract to the beneficial completion of the works was approximately 18 months meaning that compliance dates were met in all cases. Issues arising were dealt with quickly and without any contractual wrangling.
- There was close cooperation between the designers, the construction team and the operations staff. This was demonstrated in the successful development and implementation of flood contingency and drawdown plans which ensured the safety of the reservoirs during the construction of the improvement works.

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