Bewl Water spillway remedial works

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SYNOPSIS. Bewl Water is a major impounding reservoir in South East England, UK. In the mid-1990's an external inspection confirmed that the crest of the spillway shaft was suffering from severe cracking. A paper, by one of the authors, presented at the British Dam Society Conference in Bangor in 1998 described the investigation that was carried out to determine the cause of the cracking. This paper describes the remedial works contract that was undertaken to replace the pre-cast concrete crest blocks that were suffering from Alkali Silica Reaction, and describes the extensive temporary works over the top of the spillway shaft, the methods used to remove the existing pre-cast units and the design of the new units. The new crest units have been designed to allow the crest to be raised by 350 mm without the need for further major temporary works over the top of the shaft.

BACKGROUND

General

Bewl Bridge Reservoir is a large, raw water reservoir situated approximately 10 km south east of Royal Tunbridge Wells in Kent. The reservoir is primarily filled by the Yalding Pumping Station with additional water from the original pumping station on the River Teise and the relatively small natural catchment of 1.9 km^2.

A 30.5 m high earthfill embankment with a central rolled clay core retains the reservoir. A bellmouth spillway shaft located within the reservoir was designed to discharge floods up to a Catastrophic Flood of 115.5 m^3/s. Water is abstracted from the reservoir via pipework within a 36 m high reinforced concrete draw-off tower adjacent to the spillway tower. Impounding of the reservoir started in 1976 and was full by mid 1978.

Spillway Shaft

The overflow structure, as shown in Figure 1, consists of a vertical shaft from the reservoir bed up to the full supply level of the reservoir. The lower

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section of the shaft is 3.5 m in diameter internally and has 500 mm thick reinforced concrete walls. Over its upper 7.75 m, the shaft flares out to give a weir crest diameter of 10.8 m. The crest is formed by a series of 32 pre-cast concrete blocks that form the lip of the weir which is divided into quadrants by anti-vortex piers that prevent a vortex forming in the shaft when it becomes submerged. A 1500 mm deep reinforced concrete beam boat fender surrounds the weir reducing the size of waves impinging the weir and preventing boats from getting too close to the overflow crest. The boat fender is located 2 m away from the weir crest and is supported by four radial beams spanning out from the rear of the anti-vortex piers.

At the base of the tower the shaft turns through a 90^{o} bend into the discharge tunnel which passes under the dam before discharging into the river downstream. The tunnel is a horseshoe in section and is approximately 3.3 m in diameter.

THE PROBLEM

The Supervising Engineer carried out a detailed inspection by boat of the cracking and spalling of the pre-cast concrete blocks around the spillway crest in 1995. In February 1996, McDowells Consulting Engineers carried out a preliminary investigation of the cracking, and recommended further investigation of the boat fender and upper section of the shaft, including removal of core samples from the crest blocks and *in situ* concrete. The cause and extent of the cracking were unknown and it was unclear whether the condition was deteriorating. The Inspecting Engineer considered that ASR was a possible cause and recommended repair or replacement.

THE INVESTIGATION

A detailed investigation was carried out using roped access techniques during the summer of 1997. This investigation included carbonation testing, concrete sampling, a covermeter survey and ultrasonic pulse velocity testing. In addition, a visual crack survey and a photographic record of the inside and outside of the tower were carried out. The concrete samples taken from the *in situ* and pre-cast concrete around the crest of the shaft were tested in a laboratory. Reference 1 gives details of this investigation.

CAUSE OF CRACKING

The investigation concluded that the cause of the cracking was due to Alkali Silica Reaction (ASR) in the pre-cast weir units around the top of the shaft. The units had been secured by dowels during construction, and as the units swelled, due to the ASR, the radial geometry of the units caused them to be forced outwards. This in turn caused the *in situ* concrete to which they were secured also to move outwards and, as a result, tension cracks appeared on the flared section of the shaft and on the anti-vortex piers.

REMEDIAL WORKS DESIGN

Three remedial works options were considered:

1. "Do Nothing"
2. Replace all the crest units thereby removing the problem and preventing further expansion.
3. Selective replacement of units and provision of expansion joints which would allow further expansion of the blocks without causing further distress to the *in situ* concrete.

Monitoring of the crack widths was carried out throughout the winter of 1997 and 1998, by measuring tell-tales with a vernier gauge, to try and determine if the expansion of the concrete was still taking place. A more sophisticated system of monitoring had been considered that would have allowed smaller amounts of expansion to be measured but the estimate of the costs of installing and maintaining the system was not significantly less than the cost of the remedial works.

No signs of movement were detected, although this was possibly due to either the movements being smaller than the accuracy of the vernier gauge or the temporary suspension of the expansion. ASR requires moist conditions to occur and during the monitoring period the reservoir level was below the level of the pre-cast units.

Bewl Water is one of Southern Water's most important assets and since under the worst case scenario deterioration of the spillway could lead to loss of storage in the reservoir, the "Do Nothing" option was discounted early on.

The main portion of the cost of the remedial works was the temporary works required by safety considerations to operate over the water on the outside of the shaft and over the 36 m drop on the inside of the shaft. The difference in costs between the selective and complete replacement of the units was not significant and therefore a decision was made to replace all of the units.

Although replacement of the pre-cast units would prevent further expansion of the top of the shaft, the *in situ* concrete directly under the units had already been cracked, and it was considered that ingress of the reservoir water into the cracks could lead to corrosion of the reinforcement. It was therefore decided to apply a waterproof membrane onto the outside of the shaft using a Flexcrete cementitious coating.

During the inspection several areas of exposed reinforcement were identified on the upper sections of the anti vortex piers. It was decided to

carry out a detailed cover meter survey and determine the steel condition by removing the concrete from areas with very low cover. The concrete would then be reinstated using a cementitious compound and the whole anti vortex pier would be then grit blasted and coated with an anti carbonation coating, to reduce the risk of further deterioration of the reinforcement due to lack of cover.

FULL SUPPLY LEVEL RAISING

As a separate project but at the same time as the remedial works design was being carried out, MWH was asked by Southern Water to consider the potential for raising the top water level of Bewl Water by reviewing the amount of wave run-up. During this study a potential for raising the top water level by 350 mm was identified, without raising the embankment crest level or carrying out work on the draw-off tower. This would increase the reservoir storage by 7%, a valuable addition to Southern Water's assets.

It was proposed to carry out the raising by increasing the height of the pre-cast crest units on the spillway shaft. However, full investigation of the effect of the raising and approval of the scheme by the Environment Agency were not possible within the time scale of the remedial works contract, so the shape of the new crest units were designed so that they could be easily raised in the future.

As discussed previously, the major portion of the cost of any works on the spillway is temporary works due to safety considerations. To reduce the risk of working over the centre of the shaft the units were designed so that the future units could be lowered into place and secured from a floating barge without the need for accessing the inside of the shaft.

The blocks to be installed under the remedial works contract were designed with a 200 mm step on the upstream side and a socket in the upstand. The pre-cast section that could be added later to raise the top water level has a corresponding step and socket so that the two blocks can be bolted together and then grouted in place. Sealing of the downstream joints could be carried out by roped access techniques without the need for erecting scaffolding on the shaft.

REMEDIAL WORKS CONSTRUCTION

General

The contract was awarded to Brent Construction following a competitive tender procedure and work began at the beginning of the summer in 1999. Bewl Water is not only a major water supply resource shared by Southern Water and Mid Kent Water but it is also a major amenity used by thousands

of visitors each year. The reservoir and its surrounding footpaths are used for fishing, sailing, walking and riding. It was therefore essential that extra care was taken to ensure that no interruption or disturbance was caused to the other users of the reservoir. An excellent working relationship was developed between the Southern Water staff, especially the local rangers, and the contractor. At the end of the contract Brent Construction were presented with a Customer Care Merit award by Southern Water. The contract was complete on programme and under budget.

Temporary Works

Access to the shaft for materials and plant was by barge equipped with Hi-ab crane. Daily access for personnel was by smaller boats.

During the investigation stage of the project, a scaffold walkway had been erected around top of the boat fender. This platform was maintained throughout the remedial works contract, and, in addition, a scaffold platform was erected over the void of the shaft with another hanging walkway suspended around the outside of the weir crest to allow access to both sides of the working area. The central platform effectively blocked the only spillway facility at Bewl Water so the works were programmed for the end of the summer when the water levels are normally low and falling and sufficient storage existed in the reservoir to contain low return period floods without interfering with the works.

Removal of Existing Weir Units

During the design stage consideration was given to the method of removal of the existing pre-cast units. Due to the restrained expansion of the pre-cast units it was considered that a sudden release of any in built stresses could cause problems. Therefore slots were required to be cut through the units prior to their removal. This was carried out by diamond drilling a hole through the base of one of the units nearest an anti-vortex pier in each quadrant. A diamond rope saw was then threaded through the hole and a slot cut upwards through the block (see Figure 2). No sudden release of stresses was noticed.

Further holes were then drilled in the base of each block at the intersection with the *in situ* concrete. A hydraulic jack was then inserted into the hole and pressure applied. The joints on all three sides fractured cleanly and the units were all able to be lifted off in one piece by the crane on the barge.

This operation left a good clean and smooth surface that required little preparation before the new units could be installed. With the units removed it was possible to see that some of the cracking in the *in situ* concrete had penetrated more than half way through the thickness of the shaft walls

validating the decision to apply an external waterproof coating to prevent further deterioration.

Installation of New Weir Units

The new pre-cast units were installed using the crane on the barge. The units were placed on thin metal shims and all units were located and levelled prior to any grouting of the vertical or horizontal joints (see Figure 3). Two vertical movement joints were installed in each quadrant, consisting of a 25 mm thick compressible joint filler surrounded by a joint sealant. All other joints were filled with a non-shrink cementitious grout and then pointed with an SBR mortar.

To prevent sliding of the pre-cast units on the smooth surface of the *in situ* concrete, vertical dowels were inserted through holes in the units into the underlying concrete and then grouted in place.

PRESENT SITUATION

The new units have now been in place for four years (see Figure 4) and recent observations made from the balcony of the adjacent draw-off tower indicate that the surface of the replacement units are without deterioration. During this period the reservoir has spilled and this confirmed the quality of the workmanship as spilling was uniform around the perimeter.

The protective coating on the anti-vortex piers is free of defects, maintaining adhesion and without noticeable cracking.

The low water levels in 2003, exposed the coating to the external surface of the spillway shaft, and again, this remains free from defects. No signs of seepage have been noted on the inside of the shaft at high water levels and it appears that the application of the coating has been successful.

ACKNOWLEDGEMENTS

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REFERENCES

1. Davison I (1998). Bewl Water Spillway Investigation, 10th Conf. British Dam Society. Bangor, pp140-150. Thomas Telford, London.

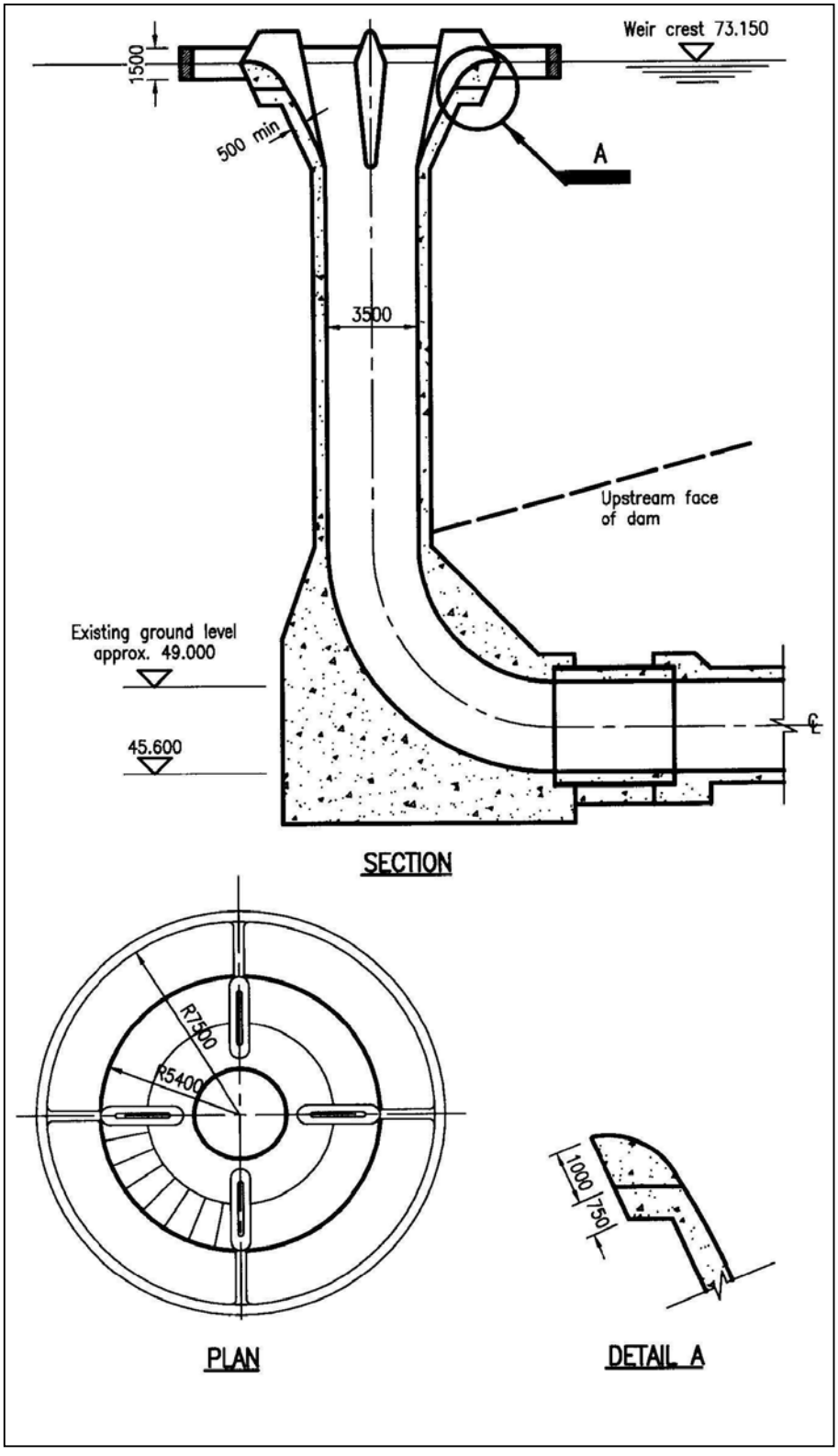

Figure 1 - Detail of the Overflow Structure

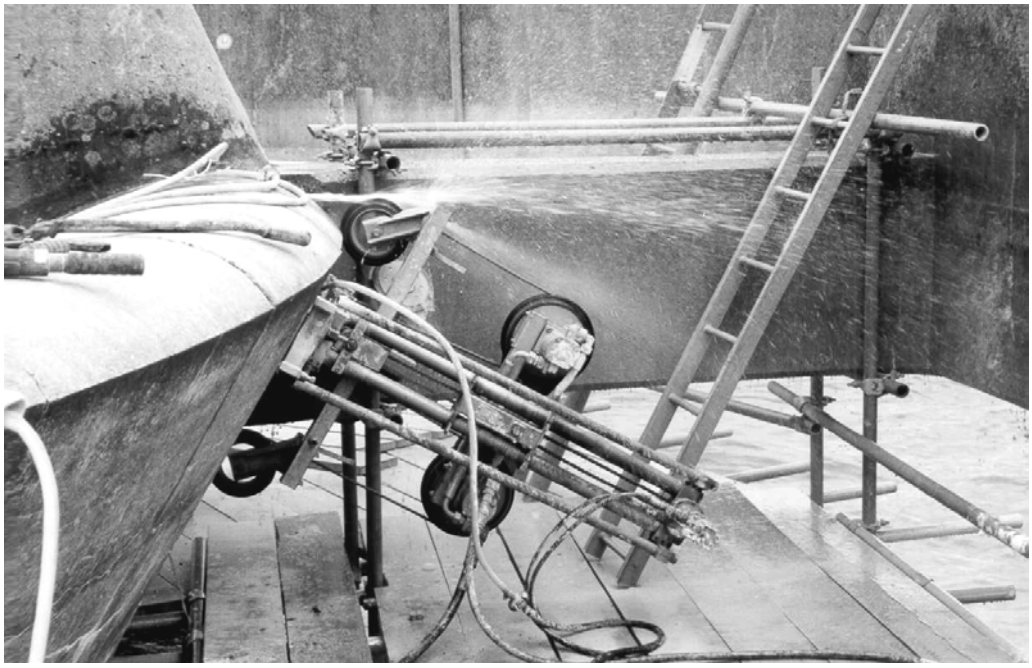

Figure 2 - Saw cutting between the existing blocks

Figure 3 - New blocks in place

Figure 4 - Completed spillway crest