Island Barn Reservoir – Embankment Leakage remedial works

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SYNOPSIS Island Barn Reservoir is a non-impounding reservoir retained by an earthfill embankment that has a history of leakage. Thames Water has undertaken a Portfolio Risk Assessment identifying seepage at the reservoir as a priority remedial work activity. A Willowstick® geophysical leakage detection survey was undertaken at the reservoir and three areas of leakage were identified through the embankment and foundation. Atkins was commissioned, as part of the Eight2O alliance, to design the remedial works required to seal the leakages. As result an impermeable barrier made of steel sheet piles was assessed to be the optimal solution to form a contiguous cut-off wall to reduce the leakage.

This paper describes how the leak was identified and remedial works proposed and undertaken. In particular, the conclusion of the feasibility study played a crucial role for the development of the remedial works planning along with the site space restrictions and associated waste disposal requirements. This paper examines all the stages of the project's development: from site survey, to the remedial works design and construction. This project demonstrates how remedial works can be carried out without affecting the integrity and stability of embankments whilst achieving sound results.

INTRODUCTION

Island Barn Reservoir is a non-impounding reservoir located near Walton-on-Thames, London. It is retained by an earthfill embankment (with a puddle clay core) approximately 10.8 m high and 2,700 m long. The reservoir has a capacity of 4,191,000 m^3 and a surface area of 489,700 m^2. The reservoir was constructed in 1911 and forms part of Thames Water's strategic raw water storage assets as an emergency resource, which also has recreational use by the Island Barn Sailing Club.

In 2014 a risk assessment was carried out to identify potential risks affecting the long-term dam integrity. A consequent survey established three critical leakage areas along the earth dam which required immediate repair.

PORTFOLIO RISK ASSESSMENT

A Portfolio Risk Assessment (PRA) was carried out for the portfolio of Thames Water storage reservoirs (2014). This included Island Barn Reservoir. The methodology used was based on the Guide to Risk Assessment for Reservoir Safety Management (RARS). For each reservoir, initial Tier 1 and 2 assessments were carried to estimate and analyse the probability of dam failure and the consequences of failure and evaluate the need for risk reduction works or further investigations for each reservoir. A dam break assessment was carried out as part of the PRA to identify the consequences of failure of the dam in relation to Likely Loss of Life (LLoL).

Tier 3 Risk Assessment

A Tier 3 risk assessment was carried out by Atkins (2016) at the request of Thames Water following on from the PRA. This assessment provided a more detailed assessment of the internal erosion probabilities of failure for those reservoirs defined to within or near to the ALARP (as low as reasonably practicable) zone.

The Tier 3 aim was to assess the probability of failure of the Island Barn Reservoir embankments through internal erosion. The results of the assessment indicated the main contributor to the probability of failure was internal erosion through the embankment primarily related to the relatively thin core and permeable embankment shoulders. The results of the PRA and Tier 3 assessment were combined and plotted on an F-N chart to assess the societal risk acceptability. A F-N chart plots the probability of failure (F) versus the LLoL (N). The assessed risk plotted in the ALARP zone of the F-N chart. As a result, further investigations were carried out in an attempt to identify possible ways to reduce the risk.

Willowstick Investigation

A suite of Willowstick® geophysical leakage detection surveys were programmed by Thames Water targeting specific reservoirs plotting within the ALARP zone. Priority was given taking the PRA results into account as well as where leakage on the external embankment has been historically identified. This resulted in Island Barn being selected for a Willowstick survey in order to identify if leakage was occurring through the core or foundation of the embankment, or both. It was noted at the initial PRA workshop that the embankment showed an isolated area of long term seepage which had been previously investigated but the specific origin was not identified.

The Willowstick survey technique identifies electric current flow paths or areas where seepage is occurring. At Island Barn, the survey showed three seepage areas, as shown in Figure 1, where a white indicates the approximate centre of the seepage path. The identified leakage was occurring through the embankment and its foundation consisting of the London Clay formation and Alluvium strata. In Area A the seepage is through the London Clay whereas in areas B and C it is through the puddle clay core (see Figure 2).

- Area A: Chainage 1,905 – 1,975, seepage path 16.2 m below the crest
- Area B: Chainage 2,450 – 2,550, seepage path 14.5 m below the crest
- Area C: Chainage 620 – 665, seepage path 14.5 m below the crest

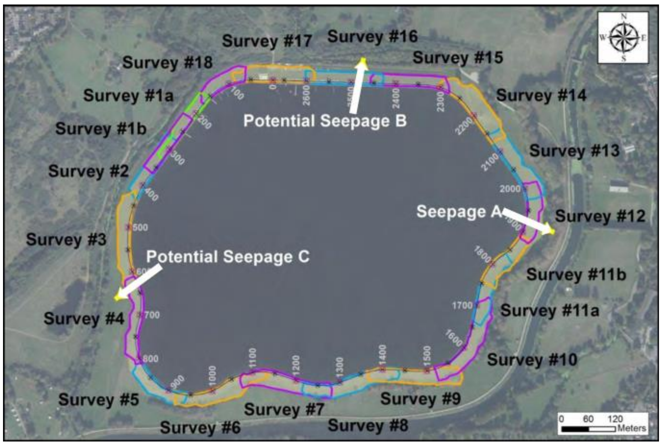

Figure 1. Willowstick Investigation – Plan View

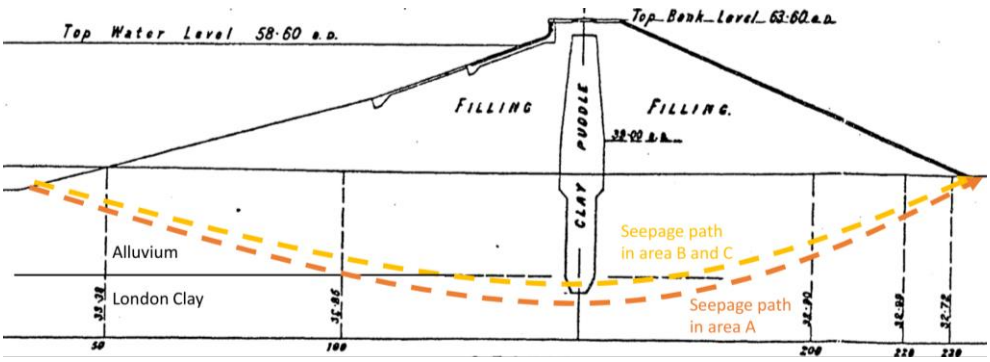

Figure 2. Willowstick Investigation – Typical Dam Section

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FEASIBILITY STUDY OF REMEDIAL WORKS

The leakage identified at three different locations at Island Barn Reservoir had the potential to increase and lead to internal erosion of the embankment and/or increase the downstream slope pore pressure which could trigger a slope failure. As a result, various remedial options were identified to stop leakage through the dam and reinstate the continuous impermeable barrier that had been provided by the puddle clay core. In the feasibility study two “tried and tested” techniques were considered as potential means to seal the identified leaks within the embankment at the critical problem depths.

The two options (A, B) comprised a cement-bentonite diaphragm cut-off wall and a steel sheet piling wall. Both cut-off solutions were intended to be installed at the centreline of the embankment crest through the clay core, acting as a continuous physical barrier to prevent internal erosion in the embankment fill and foundation materials. This would then reduce the risk of embankment and foundation failure.

The advantages and disadvantages of the two methods are outlined in Table 1 and 2.

Remedial Option A- Cement-bentonite diaphragm cut-off wall

Table 1. Advantages VS Disadvantages for the Option A

Ref	Type	Description
1	Advantages	Provides a formal positive seepage cut-off over the full depth of the core; It is an established method with a successful track record. It has been used successfully for remediation on Thames Water’s King George V reservoir.
2	Disadvantages	Extensive enabling works required to support large and heavy equipment; A significant volume of arisings and spoil from enabling works; Risk of water pollution due to slurry entering the reservoir.

A cement-bentonite slurry wall can be installed within the centre of the embankment in locations where leakage is detected. The cut-off wall acts as a continuous barrier over the entire depth of the embankment, sealing the leakage areas, reinstating the original flow path and increasing it to prevent additional seepage that may develop in the future. In addition, an increased length of the flow path reduces the quantity of seepage that occurs, lowers the water level in the downstream shoulder and improves the overall stability of the downstream slope.

Remedial Option B- Steel sheet pile cut-off wall

Relatively watertight sheet piles could be driven from the embankment crest and embedded into the London Clay, providing a complete cut-off along the installation areas. This has a similar effect to a slurry wall, extending the flow path and reducing the quantity of seepage through the embankment.

For a homogeneous clayey material, pile installation is quick and it requires limited excavation of the embankment crest to accommodate a suitable working platform for the plant and a shallow trench to allow the walking press-in piling machine. This also reduces the potential for water pollution and any material disposal.

The advantages and disadvantages of this method are outlined in Table 2.

Table 2. Advantages VS Disadvantages for the Option B

Ref	Type	Description
1	Advantages	Proven method of installing a low permeability continuous barrier; Moderate size of plant required on embankment; Minimum excavation required at the embankment crest; Weight of the plant is less than that required for the diaphragm wall.
2	Disadvantages	Complete sealing of sheet pile clutches can be difficult; Large cranes are required to pitch the piles. Special transport needed for 18.3m long piles; Difficult to ensure verticality over the full length of the piles; Pile refusal or misalignment due to obstruction, mudstone lenses or stiff London Clay may occur.

Selected Remedial Solution - Option B

The sheet pile cut-off solution was selected as it scored the highest considering the selection criteria adopted for the assessment including: effectiveness, buildability, dam safety, cost, maintenance and environmental impacts of site disposal.

In particular, the sheet pile wall solution was preferred to the diaphragm wall as it had the advantage of minimising the enabling works, the amount of soil disposal and consequently the CO_2 emitted by the transportation of material to and from site. The overall environmental impact was reduced by using the silent vibrationless piling Giken method.

SITE CONSTRAINTS

The potential instability of the embankment slope was identified as the main hazard during the remedial works when the piling crane was designated to operate from the crest. As a design control measure, a slope stability analysis was undertaken to verify the embankment stability during the operation. The factor of safety (FoS) against embankment failure was found to be marginal (FoS ≈ 1.0) and therefore an alternative construction method was recommended. The alternative installation procedure consisted of a pontoon floating on the reservoir to act as stockpile area for the equipment and lifting platform to feed the piles to the Giken walking press. The crest of the dam was therefore relieved from the excessive pressures provided by the piling crane, thus the risk of dam failure during the pile installation was significantly reduced. In addition, the silent vibrationless piling Giken method was used to reduce the uncertainty over the liquefaction potential of the embankment shoulders.

Working from the pontoon avoided extensive enabling works over the embankment crest such as the removal of the top metre of clay and replacement with stone to build a wide and thick platform to support the 80-tonne crane. Instead, minor tracking and working platforms were required over the crest along with a jetty to launch the pontoon (see Figure 6) that was required to operate the crane to pitch the piles and feed the Giken press (see Figure 9).

Site Investigation

A targeted ground investigation (GI) was undertaken to ascertain the ground conditions and provide additional information to assist in the design of the remedial and enabling works.

GI interpretation characterised the encountered soil properties and determined the level of the interface between the base of the puddle clay core and the London Clay.

REMEDIAL AND ENABLING WORKS DESIGN

The project includes the design and construction of three sheet pile walls with associated enabling earthworks and civil works such as access tracks and ramp, jetty and protection measures to the existing utilities.

Steel Sheet Pile Cut-off Wall

The sheet piles were intended to be embedded through the puddle clay core acting as cut-off wall without any specific structural function and the pile clutches sealed using Wadit sealant. The pile selection was based on the envisaged installation performance “during static driving” through the stiff London Clay (founding layer) and steel corrosion reduction for a design life of 100 years.

To ensure that the sheet piles intercepted the leakage paths a minimum penetration into the London Clay of 1.7m was specified and 18.3m long piles were chosen. The designated PU32 pile section, made of plain uncoated Grade S355GP steel, was selected based on the length of the piles and driving conditions, assessed to be: “easy” in the puddle clay core and “hard” in the underlain London clay in accordance with “Piling Handbook 9th edition” (ArcelorMittal, 2016).

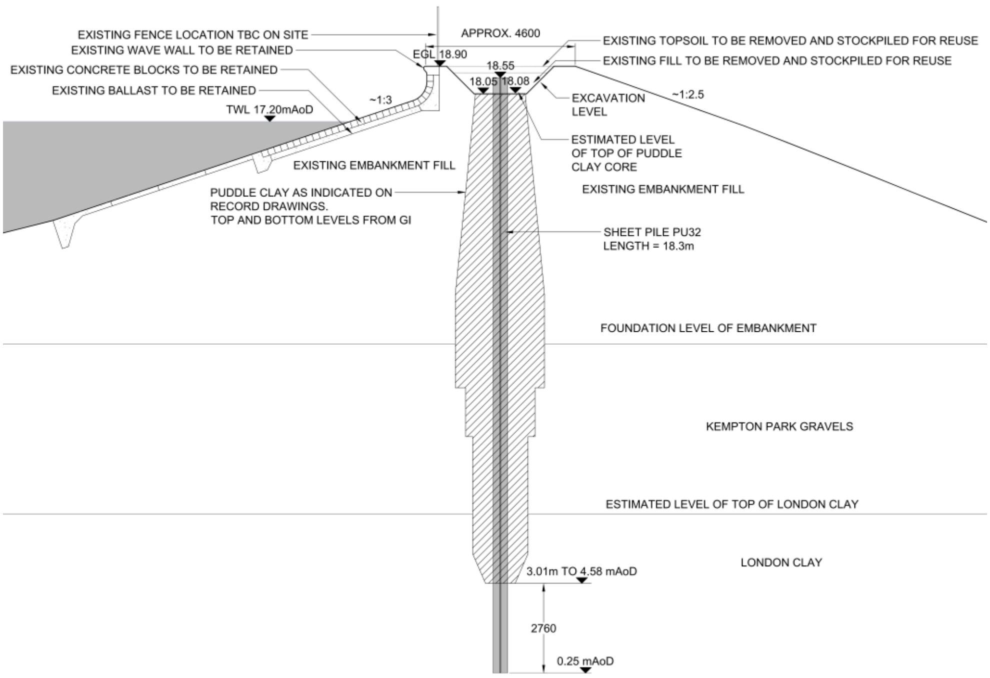

Figure 3. Dam section A – Sheet pile wall design

When stiff London clay was encountered at the toe of the pile, water jetting was recommended via “jetting” pipes to assist installation. A procedure for commencing the "jetting" was established to guide the installation supervision. Nevertheless, water jetting had to be avoided in the puddle clay core and for the bottom 0.5 m of the pile toe in order not to damage the soft clay core and to guarantee a water tight barrier at the toe of the pile into London clay.

Embankment Stability During Construction Works

The stability of the embankment was assessed for the minor construction works carried out at the crest to install the sheet piles. The Giken piling method required the provision of a reaction stand placed on the embankment to allow the driving of the first three reaction piles. The embankment stability was assessed in both short-term and long-term conditions. A section of embankment crest had to be lowered to provide an area wide enough to receive the stand. The stability of the embankment crest at these locations was assessed with Geo-Slope/W 2015 using the Morgenstern Price analysis method. Since the dam is an existing structure dating from 1911, the stability analysis used un-factored soil parameters to estimate the associated global FoS against failure. The results were compared to the guideline FoS presented in "An engineering guide to the safety of embankment dams in the UK" (BR363, 1999) where the minimum acceptable FoS is 1.3 and to CIRIA Report "Infrastructure embankments condition appraisal and remedial treatment" (C592, 2003) where the minimum acceptable FoS is 1.3 for a deep failure in an embankment.

To carry out the sheet pile installation, two types of platforms were required at the crest of the embankment, namely tracking platforms (to allow tracking along the crest) and working platforms (at the reaction stand areas). The platforms were designed in accordance with BRE guidance: "Working platforms for tracked plant" (BR470, 2004).

The results of the dam stability assessment using un-factored characteristic parameters indicated that the dam is stable during the temporary works with a minimum FoS greater than 1.3. The working platform for the reaction stands consisted of 0.3m thick stone reinforced with a Tensar TriAX 160 geogrid. Figure 4 shows the dam stability analysis for the lowered section subjected to working surcharge. The tracking platform to allow safe transit over the crest consisted of 0.2m thick stone reinforced with a Tensar TriAX 160 geogrid. Figure 5 shows the dam stability analysis for the original section subjected to tracking surcharge.

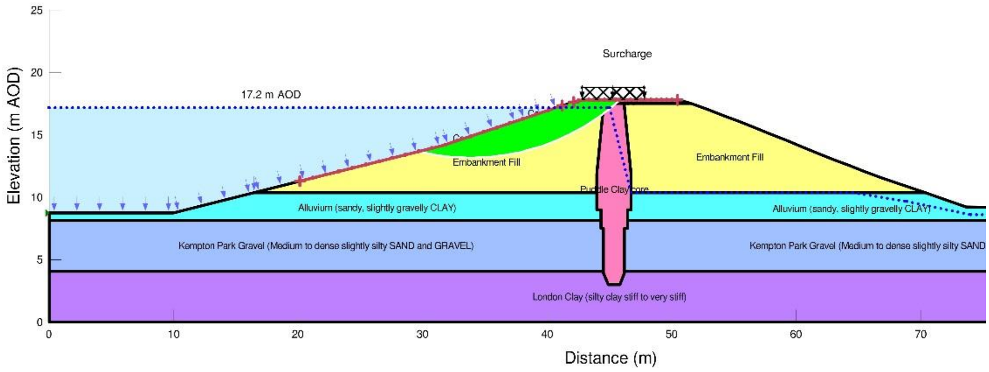

Figure 4. Dam Stability Analysis – Lowered section with working surcharge

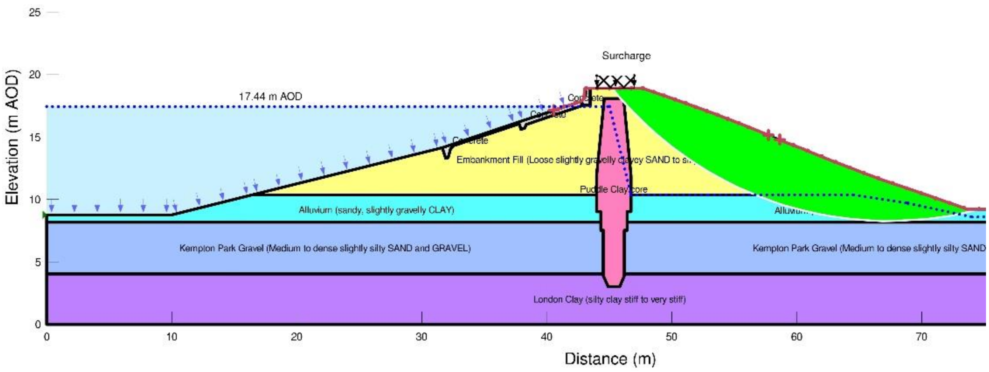

Figure 5. Dam Stability Analysis – Original section with tracking surcharge

After the works the dam crest was reinstated to the initial condition.

Enabling Works: Access road, Ramp and Jetty

The access roads were refurbished to support the machinery loads and to ensure stability of the embankment during construction, reuse of the stockpile material and reinstatement. A steel temporary bridge and protection slabs were installed to cross over the underground services and allow the access of heavy plant. The west access road along the toe of the embankment providing access to the ramp was enlarged using a sheet pile wall.

The existing ramp and embankment plateau, constructed at the south-west side of the reservoir in 1990, was assessed in a similar way to the main embankment. The reinforcement to provide suitable bearing capacity to support up to 235kPa (a 50-tonne crawler crane) consisted of Tensar Re570 uniaxial geogrids plus Type 1 stone fill. Also, the plateau over the clay core was reinforced.

The jetty was constructed to launch the pontoon onto the reservoir, to load the plant on to the pontoon, and to facilitate the installation of sheet piles from the water. The jetty consisted of a 4-sided rectangular cofferdam made of sheet piles, protruding from the crest wave wall into the reservoir and filled with graded granular material (See Figure 6). Its stability was assessed with the finite element software PLAXIS 2D. The maximum loading pressure considered for the analysis was related to the 50-tonne crawler crane which gave the highest bearing pressure.

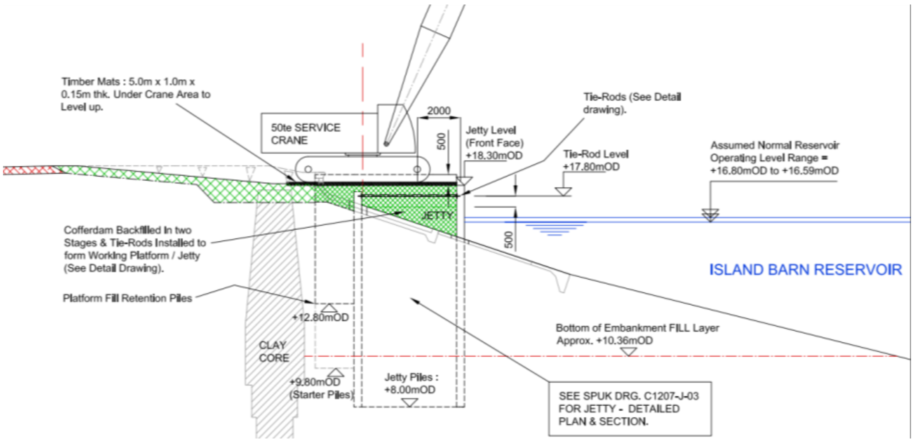

Figure 6. Jetty and Plateau (Extracted from Sheet Piling UK drawing)

CONSTRUCTION

The approach to the construction site includes the access ramp, plateau, jetty and pontoon launch as shown in Figure 7.

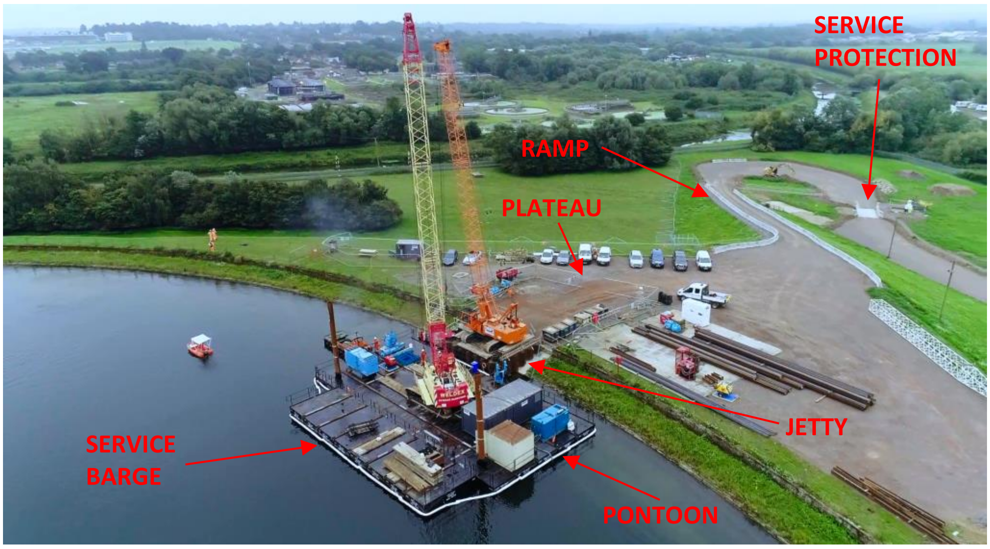

Figure 7. Access, Jetty, Plateau and Pontoon

Installation

The installation of the three sheet pile walls using the Giken press-in method and enabling works was carried out by Sheet Piling UK. The sheet pile installation consisted of the following construction phases (Figures 8 and 9):

- Tracking platform to provide a tracking road along the dam crest;
- Working platform (reaction platform) to allow the installation of the first reaction piles;
- A trench along the proposed sheet pile walls to allow the Giken press-in method of pile installation;
- Installation of the cut-off sheet pile walls.

Figure 8. Sheet pile installation at the embankment crest

Figure 9. Pontoon feeding the sheet piles to the Giken Press-in machine

Reinstatement

Following the pile installation, the dam crest was reinstated to the initial condition. The earthworks involved reinstatement of the clay core to the original condition where it had been excavated to accommodate the reaction stand.

Both puddle clay stockpiled from excavation of the existing core and imported puddle clay were used. Puddle clay was re-worked into a uniform consistency and specified moisture content (28% to 45%) at the stockpile site, before transportation to the embankment for placement.

Pinch, tenacity and elongation tests were carried out on the puddle clay core prior to its excavation to establish the in-situ conditions of the core. The results of these tests were used to recondition the excavated clay core prior to replacing it and to establish the required parameters for the imported puddle clay.

The clay was compacted by hand operated equipment (Figure 10).

The working platforms at the three areas and at the jetty were removed, and the parapet wall was reinstated (Figure 11).

Figure 10. Compaction of puddle clay core

Figure 11. Parapet wall reinstatement

CONCLUSION

At Island Barn reservoir remedial works were carried out to stop an occurring leakage identified through the reservoir, which may have developed and led to a potential earth dam failure. A sheet pile wall was assessed as the preferred cut-off wall solution to repair the leaking of foundation core. Three sheet pile walls were installed from the crest through the core and embedded into the impermeable founding layer. A total of 386 piles were installed providing 230 linear metre of contiguous, impermeable protection.

To reduce loading on the embankment crest the piling was undertaken from a crane placed on a pontoon floating on the reservoir, and the Giken method was adopted to install the piles. Enabling works to allow access for the plant were minimised to consist only of works for access onto the dam crest for pile installation and at the south west corner of the reservoir where a launching jetty was constructed.

The adopted technology and installation methodology was extremely effective from a design, safety and suitability perspective. This meant that site operations and construction were streamlined and the project accomplished ahead of schedule.

ACKNOWLEDGEMENTS

The project was overseen by the Dr Andy Hughes who was appointed by Thames Water as the Qualified Civil Engineer for the works at Island Barn. The support and direction of Dr Hughes in support of Thames Water during both the PRA and project implementation has been invaluable.

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