THE USE OF HYDROPHILIC WATERSTOPS IN DAMS CONSTRUCTION

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ABSTRACT

Nearly every concrete structure in Dams are constructed with joints sealed to prevent water infiltration and to ensure the integrity and serviceability. Hydrophilic waterstops have often been used to achieve the water tightness for convenience, cost savings and in locations where installing an alternative form of waterstop has been considered not practical. The hydrophilic waterstop is often preferred to traditional PVC waterstops given its simplified construction methodology whilst still providing seals of up to 50 m of head. The principle of the performance of the waterstop is that it is capable of expanding upon absorption of water to seal the joint, making it ideal for gap variation. However, recent experience has indicated that this ability to expand can generate large forces, which can lead to failure of concrete including cracking, spalling, and exposure of reinforcement and ultimately failure of joints. This paper reviews examples of the practice of hydrophilic waterstops in Dams, identifies the methodology of installation used, the conditions leading to the failure of the concrete, how these compare to the waterstop manufacturers installation recommendations, and discusses the design approach to using hydrophilic waterstops and its shortcomings in dam engineering.

1. INTRODUCTION

Waterstops are installed in concrete structures subject to water with the purpose of reducing the likelihood of water leaking into joints. Waterstops are also implemented to minimise the impact of hydrostatic and hydrodynamic forces when the concrete structure is subject movement caused by mechanical, thermal, hydraulic, chemical and structural stresses.

The installation of waterstops on dam and appurtenant structures can often pose constructability concerns with limited space to effectively install 'standard' waterstops (such as PVC). This problem can be further compounded when repairs are being conducted to an existing structure. As a result, hydrophilic waterstops are often preferred in these scenarios.

Specifically, waterstops are generally installed at construction and contraction joints, which are where one concrete pour meets another, thus creating a discontinuity in a structure. Other locations that often create discontinuities include pipe penetrations and repaired surfaces. These, are locations that will be subject to the transmission of water and pressures without effective protection. The leakage will not only affect the serviceability of the structure but may also lead to deterioration such as corrosion of reinforcement. In structures such as dams where water is inevitable, the need for effective waterproofing is paramount.

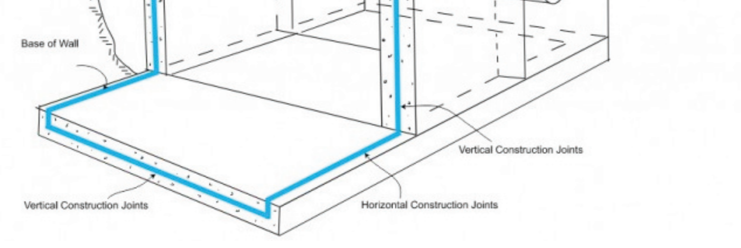

Figure 1 : Typical waterstop applications

In many cases, the more common waterstops used, are polyvinyl chloride (PVC) waterstop, or metallic (typically copper). These types of waterstop rely on good quality constructability to achieve their desired function. However, poor concrete compaction around the waterstop can be problematic and could lead to voids around the waterstop, leading to a continuous flow path allowing the transmission of water and pressures. Poor placement of the waterstop can lead to a redundant seal that provides minimal protection from water leaking into a joint. The location of a waterstop in a joint is a critical part of the design and construction process. If the waterstop is placed lower than the reinforcement, it creates the risk of exposing the reinforcement to water and corrosion. However, installing the waterstop above the reinforcement can lead to insufficient cover and possible exposure of the waterstop.

Alternative waterstop technology has been used in the past, continues to be developed, in part, to address these shortcomings, and includes crystalline waterstops, asphalt waterstops, rubber waterstops and hydrophilic waterstops. This paper focuses on the use of hydrophilic waterstops, in particular the need for careful detailing and quality control in the construction process.

2. HYDROPHILIC WATERSTOPS

A Hydrophilic waterstops is designed to swell after installation with subsequent swelling occurring when in contact with water. The waterstop will swell and block the intrusion of water. The waterstops are based on hydrophilic technology, which refers to materials that expand in a controlled fashion. The waterstop can swell by up to eight times in volume when in the presence of water and thus creating a pressure seal. When there is no moisture the waterstop will reduce back to original size.

This type of waterstop is considered more economical than PVC or copper waterstops and is often preferred due to its ease in constructability. Generally no welding, split-forming or splicing is required and is easy to handle making it attractive for situations where there is restricted space or there is a need to avoid reinforcement of other insertions. The waterstop is adhered one surface rather than being suspended in concrete such as PVC waterstops therefore requiring no additional adhesives. This makes the hydrophilic a more constructible option given the space and time constraints associated with typical dam construction, repairs and minor works. Applications for hydrophilic waterstops are not limited to cast-in-place concrete construction joints. Due to their flexibility and conformability, hydrophilic waterstops can be easily installed around pipe penetrations, I-beams, concrete pilings, and irregular-shaped surfaces. Waterstops are traditionally not recommended on joints with large movements and therefore not appropriate for expansion joints. Hydrophilic waterstops are also used to seal new concrete placed against existing concrete. The installation efficiency of this type of waterstop makes them a favourite amongst contractors.

However there a number of examples hydrophilic waterstops being used in Dams construction and performing poorly, resulting in spalling and cracking of the concrete. In many cases, the resulting level of damage has led to an increased potential for failure of the structure (and consequential impacts on dam safety) and has resulted in need for repair of the damaged waterstop and concrete.

For hydrophilic waterstops, manufacturers typically require a minimum 50 to 100 mm of concrete coverage depth, depending on the profile size and material type. These waterstops must be installed in strict accordance with the manufacturer's minimum concrete coverage guidelines to minimise the potential of concrete spalling due to insufficient concrete coverage. They need to be installed without overlapping adjoining strip ends; the strip ends must be tightly abutted to form a continuous system. Although this required cover of 50-100 mm is a key consideration it is often disregarded, as the available space can be minimal. Furthermore, there have been situations where the manufacturer's recommendations have been followed with damage still occurring.

The following sections present a number of case studies where hydrophilic waterstops have been used as the primary waterstop on a dam, with subsequent failure of the concrete and therefore the water leakage has occurred. In each case, the background of the dam is provided and the failure mechanism is discussed along with descriptions of alternative detailing which may have reduced the likelihood of failure occurring.

3. DAM A

3.1 The dam

Dam A is an 80 m high earthfill embankment with a mass concrete spillway located on the left abutment. The spillway has a crest width of 200 m and a chute of 65 m with a maximum height of 40 m in the non-overflow section and 33 m in the ogee section. The overflow section of the structure consists of three (3) bays each approximately 20 m wide.

The spillway was first constructed in the 1950s. The spillway chute composed of a slab formed by the set of eighteen (18) square slabs. These panels were constructed with the dimensions subsequent erosion and potential undercutting of the spillway structure was identified. Specifically the failure mechanism was assessed as having a significant probability of occurring.

For the 1 in 1 000 000 Annual Exceedance Probability (AEP) flood, the peak flow was estimated to be 7,500 m^3/s, which would produce a dynamic uplift of up to 30% of the velocity head according to the results of the spillway model. Since the original chute slab was expected to fail under such conditions, strengthening works were undertaken including the use of ground anchors and the modification of the existing chute slabs to include construction joints, which would provide continuity of the slabs in the upstream / downstream and cross channel directions. The design intent was to provide a continuous slab limiting the likelihood of allowing pressures to be injected through the original poor quality chute slab joints.

The upgraded slab was made continuous by excavating a 500 mm wide, 300 mm deep slot along the existing joints of the slabs, with 250 mm on each side of the joint. Reinforcing bars were drilled and grouted into the resulting faces of the trench along the joints. Prior to backfilling the slot with concrete, the sides of the joint were protected with a hydrophilic waterstop.

Critically, the waterstop was designed with 75 mm depth cover which was as per the manufactures specifications. This depth allowed the waterstop to provide sufficient protection to the joint and was located above the reinforcement, meaning no additional measures to protect the reinforcement from corrosion (such as stainless steel) were required. As part of the works, the slab was irrigated with cold water to reduce the temperature of the existing concrete to minimise the future possible contraction of the slabs, which may have led to the opening up of cracks at the interface of new and old concrete.

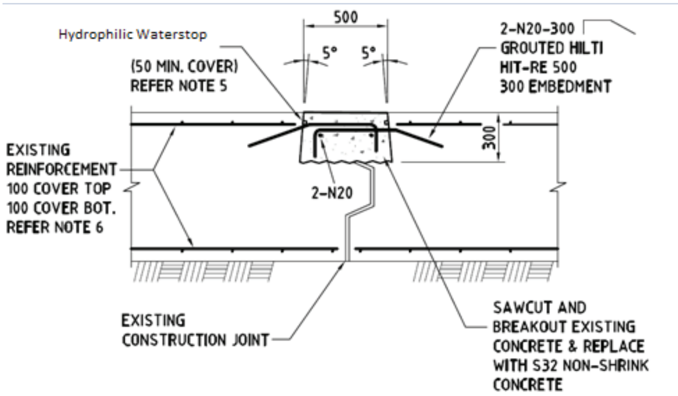

Figure 2 : Detail of joint repair at Dam A

3.2 The issue

In the years following the upgrade works to the slab, it was noticed during inspections that spalling and cracking of the new concrete in the slab was occurring. Over a number of subsequent reviews it was determined that the spalling and cracking was the likely the result of the hydrophilic waterstop activating swelling pressure. The spillway had not operated since the installation of the new joint details, meaning any swelling of the waterstops was the result of rainfall infiltration only.

Despite being installed in line with the specifications, the waterstop resulted in delamination and spalling failure of the concrete indicating that the manufacturer's recommendations may not have been adequate. Furthermore, if the concrete strength was limited to 15 MPa then it may be considered too weak for the purpose, however it is understood that the concrete had sufficient strength.


Figure 3 & Figure 4 : Damage of joints at Dam A

Given the relatively small cover, it is anticipated that waterstop swelling during rainfall events caused large tensile forces to form. These forces were transmitted to the concrete above, which had no reinforcement above the waterstop and therefore unable to resist the tensile forces. It is likely that this would have contributed to the spalling and delamination of the new concrete. During detailed reviews of the slab it was further suggested that the waterstop expansion alone might not have the caused the issue, however the cavity formed by the waterstop combined with the standard horizontal expansion forces formed from temperature would further exacerbate the issue.

An alternative solution to the joint repair is currently being undertaken and has not been shown in this paper. The design includes the installation of a PVC dumbbell waterstop above the existing construction joint. This design is considered more robust and defendable but difficult and time consuming to construct compared to the original modifications.

4. DAM B

4.1 The dam

Dam B is a 66 m high earth and rockfill structure with a spillway located on the right abutment. A curved ungated ogee crest with a length of 124 m controls the spillway.

The spillway was originally constructed in 1978 and was designed to pass the probable maximum flood (PMF). The PMF was later revised after the initial construction and indicated a significant increase in the magnitude of the PMF and therefore requiring an increase in spillway capacity. Furthermore, extensive erosion of the unlined chute had occurred since its construction and it was considered prudent to extend the lined section of the spillway to prevent this erosion extending in future spill events.

The upgrade design to the spillway included the raising of the existing upstream and downstream chute walls. This included breaking out the top one (1) metre of existing concrete and retaining the vertical reinforcement. A further 30 mm deep saw cut was made into the existing concrete to form a neat joint. This joint was protected with the installation of a hydrophilic waterstop so that a water seal could be provided. Other exiting walls (based on condition) were completely removed with the floor slab being broken back 1 m from the existing wall. A 30 mm deep cut was also made in this location and protected with a hydrophilic waterstop.

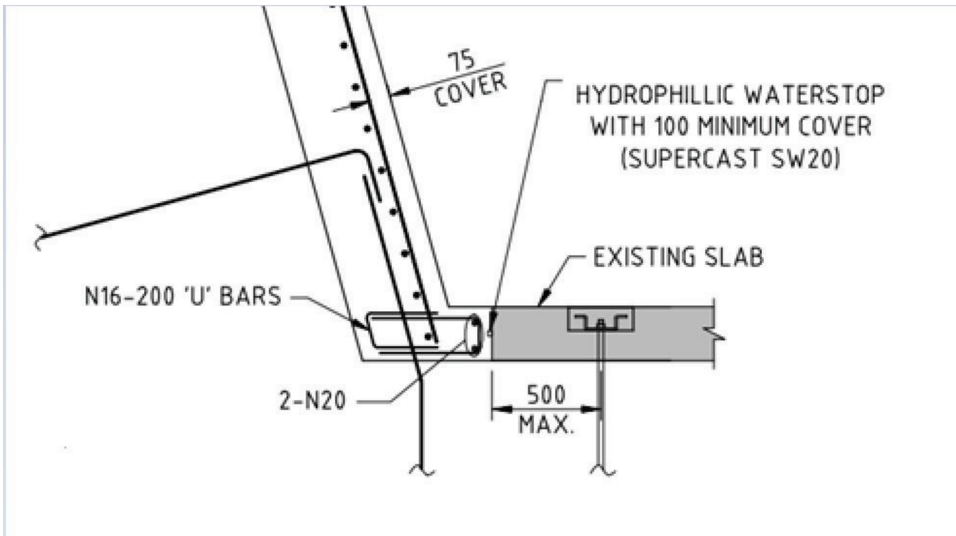

Figure 5 : Detail of wall repair at Dam B

4.2 The issue

During the comprehensive inspection of the spillway walls after the remedial works, it was observed that the repairs made previously at the joint had debonded from the existing concrete. The remedial design had allowed for 100 mm cover which meets manufacturer recommendations but when the repairs were later investigated it was seen that the cover was far less than the design with some as shallow as 40 mm. This indicates that without diligent supervision and quality assurance, the waterstops can be installed incorrectly.

Given the confined space available and the geometry of the slab and wall connection, it is possible that even with supervision, the waterstop may have still lead to spalling and delamination and seen in Figure 6 and Figure 7. The photos also show that the damage is seen in locations where the waterstop was at depth of less than 100 mm. In locations where the depth of waterstop was at 100 mm of more, there was no damage.

It is noted that the spillway experienced the flood of record shortly after the spillway remedial works were completed. However, there is no record of the joints failing during this event. It is concluded that the key reason for the damage to the concrete was insufficient cover above the waterstop.

The owner of the dam has undertaken repair works to the damage joints. This repair again included the use of a hydrophilic water stop but placed in the joint with a cover of 150 mm. Additional reinforcement and dowels have also been added.

Figure 6 and Figure 7 : Damage of points of wall interface

Figure 8 and Figure 9 : Exposure of waterstop at joint at Dam B

5. DAM C

5.1 The dam

Dam C is a 19 m high zoned earthill embankment with a spillway located on the left abutment. The spillway was originally constructed in 1969 and included a broad crested spillway with stop-boards and fuse plugs. When the dam was later raised, this original structure was removed and replaced with a labyrinth spillway with a total crest length of 41 m and a height of 2.9 m.

The upgraded works included the construction of spillway chute sidewalls. The walls were constructed monolithically with joints. The upgrade did not include any works to the approach channel or concrete lined chute. The existing chute walls were reinforced concrete retaining walls and included a concrete toe of the retaining wall on the inside of the chute to form the chute floor. The chute was made of eleven (11) rows of concrete slabs with longitudinal and transverse construction joints. During ongoing inspections, it was observed that the condition of the spillway chute had deteriorated with corrosion on reinforcement, blocked weep holes and cracked slabs.

Remedial measures were designed and constructed to the chute and connection to the walls. The remaining toe base was saw cut one metre from the inside face of the wall to achieve a neat and flat vertical face to be dowelled. The slabs were removed and replaced with a continuously reinforced concrete slab without joints. New steel reinforcement was installed and a hydrophilic waterstop placed above and below the reinforcement at the joint between the retaining wall and new slab (Figure 10). The design cover for the waterstop is believed to have been 50 mm. A further joint sealant was installed at the surface of the slabs. The choice of waterstop was driven by availability and constructability. Given the limited space and difficult geometry, it was believed that PVC waterstops would be difficult to install and place concrete around possible resulting in an ineffective waterstop.

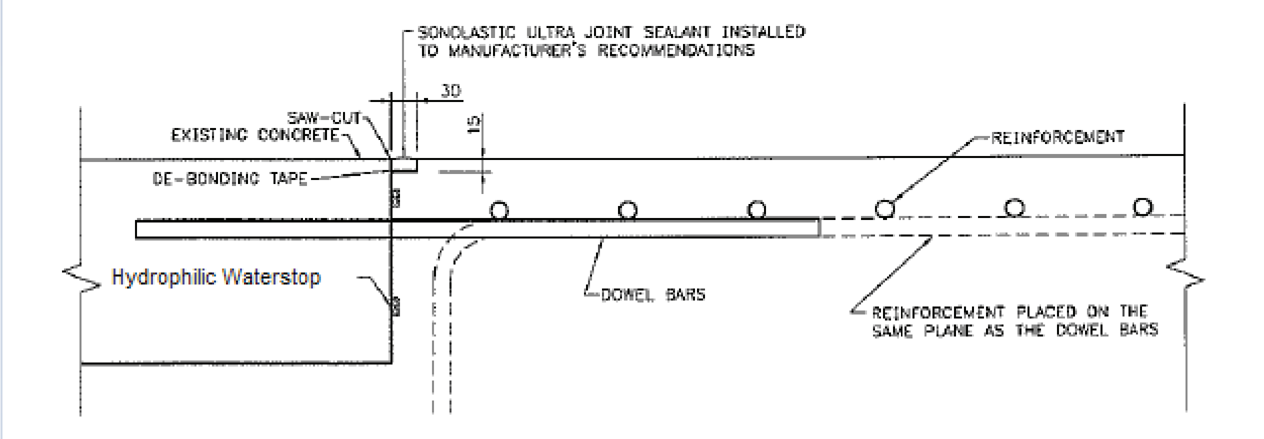

Figure 10 : Detail of joint repair at wall interface at Dam C

5.2 The issue

Following an inspection one (1) year after the upgrade works were completed, cracking, spalling and delamination was noted along the joint between the wall and slab. It is suggested that the hydrophilic waterstop was designed and possibly installed with inadequate cover and therefore damaged the concrete when it expanded. This example is similar to the Dam B with the insufficient cover resulting in excessive tensile forces being placed on the concrete above the reinforcement and failure of the concrete.

Figure 11 & Figure 12 : Damage of concrete slabs at wall interface

Following the inspection of the damaged concrete, it was agreed by the owner that given the consequences with such a structure, repairs would be necessary. The remedial measures included removing the damaged concrete around the joint as well as removing and hydrophilic waterstop where possible. Once cleaned, the repaired area was filled with a repair mortar.

As part of the remedial measures the spillway underwent a further upgrade including the installation of post anchors and pre-cast concrete walls. The walls were cast against the existing walls with a return slab connecting to the existing slab.

6. DAM D

6.1 The dam

Dam D is a 43 m high structure comprising of two (2) embankments with a central clay core and rockfill shoulder. Central between the embankments is a free overflow concrete spillway. The dam was initially constructed in the 1960s. The spillway was built with concrete training walls either side that supported the embankments and had heights of over 13 m. These training walls were subject to high deformation and were eventually assessed as having low stability and high stresses. Furthermore the assessment showed that the walls were also highly degraded.

The entire dam including spillway underwent a Dam Safety Upgrade which included the installation of post-tensioned anchors and pre-cast concrete training walls on the spillway. The new training walls were cast against the existing walls with a return slab connecting to the existing spillway slab. Two (2) types of waterstops were proposed as part of the design as seen in Figure 13 and Figure 14. Specifically, a PVC rear-guard waterstops (W1) was shown to be placed vertically between the new and old walls at each construction joint and hydrophilic waterstops (W2) were to be installed at the toe of the footing and top rear of the wall along the entire length of the walls. The walls were to be constructed in two (2) sections with the first pour to be half way up the wall.

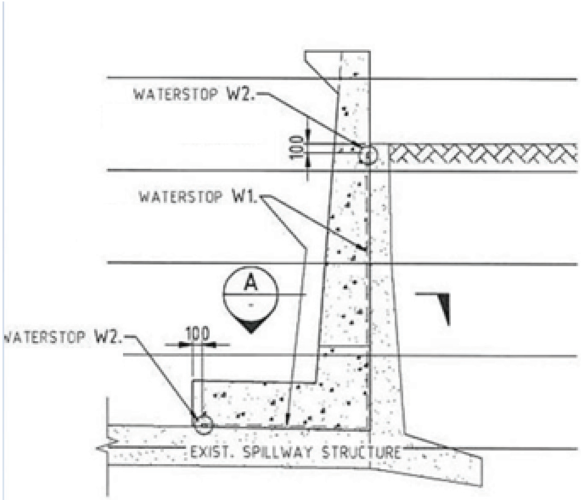

Figure 13 : Hydrophilic waterstop location

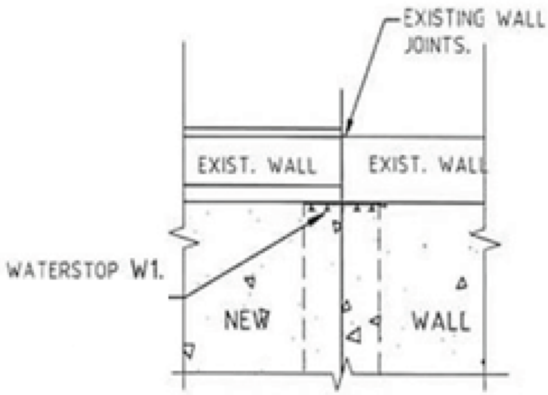

Figure 14 : PVC waterstop location – Section A

6.2 The issue

During the construction, the decision was made to remove the rear guard and install a hydrophilic water stop at the construction joint as well. This decision was based on the available room to install a PVC waterstop around the reinforcement cage. Furthermore, the waterstop was installed using a gunable product with no additional adhesive applied on the walls as recommended by the supplier. The decision not to follow the specifications eventually led to poor adhesion of the waterstop to the concrete and poorly placed waterstops, especially after the vibration of concrete was completed.

Following the completion of this stage of construction, spalling and cracking of the new concrete was visible, both due to the residual moisture in the concrete activating the hydrophilic waterstop. The combination of no correct adhesion, poor placement as well potential excessive tensile stresses from the waterstop is believed to have led to the eventual concrete damage. Following the construction of the first pour of wall it was decided that any water pressure getting into the walls would not compromise the integrity of the walls and that no waterstop was required at the top of rear wall. The damage in the concrete and any visible waterstop was removed and new patch concrete used.

Figure 15 : Newly constructed wall

Figure 16 : Removal of damaged concrete

7. DAM E

7.1 Boat Ramp and Outlet Pit

Dam E is a HDPE lined off stream water storage. The design of the storage included a boat ramp and overflow pit. The outflow pit was designed and constructed as a concrete channel and the ramp was designed as a series of concrete slabs.

Both the ramp and channel were designed with hydrophilic waterstops to protect the joints from water leakage. All waterstops were documented as being designed in accordance with manufacturer's recommendations.

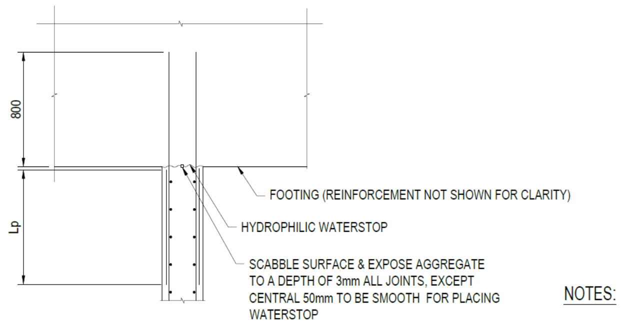

Figure 17 : Vertical construction joints

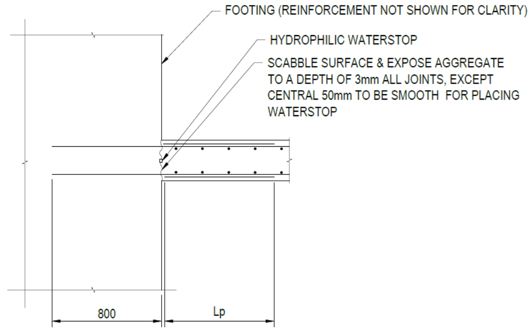

Figure 18 : Horizontal construction joints

7.2 The issue

The concrete connection to the HDPE liner anchor ring beam and boat ramp was observed to have cracked and spalled during routine inspections. This damage was attributed to insufficient cover allowing for the hydrophilic waterstop to expand and place excessive tensile forces on the concrete. The manufacturer specification for the waterstop required 50 mm cover (minimum) and constructions records indicate that this achieved throughout the process. It is understood that the continually submerged concrete was in progressively worse condition, which may be due to the waterstop expanding more, given the greater supply of water, or possibly, due to an initial mechanical damage, which would be exacerbated by the waterstop. This deficiency was also visible on the overflow chute but the damage was less. Ultimately the damaged observed on both structures was in the location of the hydrophilic waterstop and associated with the primary reason for the damage.

Both structures although not critical to the operation of the storage were seen as having consequences should they fail completely and both were repaired within two (2) years of first being noted. The repair measures included maintaining the hydrophilic waterstop and constructing a 150 mm nib wall, which included the drilling of starter bars. Prior to pouring the concrete, cracked and damaged concrete was removed. Since the repairs, no major damage has been noted.

Figure 19 : Damage of concrete at boat ramp

Figure 20 : Damage of concrete at outlet

8. SUMMARY

Each of these case studies involved the design and construction of hydrophilic waterstops, which have eventually resulted in failure of the concrete placed within the vicinity of the water stops, requiring extensive remedial measures. In each scenario, the decision to install the hydrophilic waterstop was driven by the difficulty and / or practicality of installing a PVC waterstop. Furthermore, in many cases the decision was also influenced by cost given that the construction either was considered relatively small or was part of a repair.

That a number of hydrophilic waterstops were installed in accordance with the manufactures recommendation and failure still occurred is of great concern.

Hydrophilic waterstops are often preferred instead of PVC waterstops given their simplified construction and lower costs. Instead, it is proposed that the choice of waterstop should be driven by the consequences if the waterstop were to fail. The damage posed by hydrophilic waterstops can be reduced by improved quality assurance with installation at depth, although it is noted, that even at the depths recommended by the manufactures failures have still been recorded.

Hydrophilic waterstops are considered an appropriate joint sealant in structure where the consequences associated with failure are considered low.

9. RECOMMENDATIONS

1. Where practical, avoid the installation of hydrophilic water stops, particularly in critical structures with high consequences of failure (Spillways, etc.). For critical structures, modify the detail of joints to allow for the inclusion of an alternative more robust waterstop (e.g. a PVC type), noting that it may result in higher construction costs.
2. If hydrophilic waterstops are to be used, consider the detailing, including increasing the cover as much as practical and containing the water stop within reinforcement.
3. Like any part of a dam, quality assurance is pivotal in the overall success and in terms of waterstops, it is no different. This paper has highlighted that hydrophilic waterstops can cause failure in concrete with and without good quality control. It is recommended that the choice to install a hydrophilic waterstop should be governed by the consequence of failure and that if alternative waterstops are chosen the quality control is maintained.

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REFERENCES

Australian Standards, AS 3600-2018

Hawker, Jeff. PVC versus Hydrophilic Waterstops [online]. New Zealand Engineering, Vol. 50, No. 9, Oct 1995: 30

US Army Corps of Engineers 1986, Repair of Waterstop Failures: Case Histories

Reports and papers specific to dams have not been referenced in this paper