Challenges and Solutions During the Re-Lining of a Concrete Covered Water Reservoir

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ABSTRACT

As part of an underground concrete water reservoir re-lining project for the City of Everett, Washington (completed in the fall of 2007) Layfield Environmental Systems fabricated and installed a 45-mil geomembrane containment system for a water treatment facility under some very demanding site conditions. This project included the installation of approximately 15,800 m^2 (170,000 ft^2) of flexible geomembrane in a confined working area around existing piping, concrete columns, and support beams while dealing with difficult water infiltration and structural concrete problems. The project also required tight safety standards, internal lighting, dewatering systems, water surge protection, and repair of damaged concrete. The project had a 55-day completion schedule and was subject to daily financial penalties if not completed on time. This paper discusses the various technical challenges and the innovative solutions that helped to finish the project on schedule.

INTRODUCTION

In the fall of 2007 the City of Everett, Washington tendered the re-lining of its Number 3 Reservoir. This was a Type 1 main underground reservoir which contained drinking water for the City of Everett and the surrounding community. This was a highly unique and challenging geomembrane installation project. The scope of work included replacing the existing geomembrane located on the reservoir sloped walls with a new Hypalon® Chlorosulphonated Polyethylene (CSPE) geomembrane and extending the geomembrane to provide a completely lined wetted surface area. This was required as the concrete slope and floor was in poor condition with substantial leakage being detected by the under drain monitoring system. One of the initial requirements for the consulting engineering firm was to determine the geomembrane selection to replace the original geomembrane on the slopes. To address the many site complexities of this difficult lining project, various design criteria needed to be reviewed by the consulting engineer. This included assessing the various geomembrane material alternatives. The project faced some very tight time constraints as the reservoir needed to be completed prior to high demand season as well as the fact that the City of Everett could not completely bypass the Number 3 Reservoir in terms of emergency back up. The City was also required to have several of their staff on site at extra expense for 24/7 monitoring and for adjusting flows to try and maintain water distribution while not flooding the

reservoir during construction. At all times during construction the Number 3 Reservoir would need to be available to handle up to 7.7 cubic meters per minute (3 million gallons per day) of back up overflow water surge being directed to the drain sump. In addition to tight time constraints, the project included a number of difficult and unusual challenges in terms of the geomembrane installation. The numerous complexities and constraints involved required a number of highly innovative installation techniques and tight project management.

The City of Everett Number 3 Reservoir was originally an open concrete pond that was covered later in its life with a concrete roof. The original reservoir liner was a 150 mm (6”) thick unreinforced concrete slab with copper waterstops. A number of years ago, leakage was stopped by installing a geomembrane on the slope sections of the reservoir. This geomembrane was mechanically attached at the top and bottom of the slope but did not cover the floor of the reservoir. Over a period of years the erosive force from the water coming in the inlet pipe had worn the surface of the geomembrane until a tear developed. As a result of the tear, the geomembrane on the slope failed and water got underneath the liner and started seeping through the concrete slope panels. Aside from this obvious tear, the remainder of the CSPE geomembrane appeared to be in good condition after approximately 18 years of service. The main purpose of this project was to remove and replace the old slope lining and reline the entire reservoir. To prevent a repeat failure of the geomembrane in the future, a key design feature in this project was to place a substantial splash plate under the main inlet pipe to reduce the erosive forces.

GEOMEMBRANE SELECTION

Various project criteria were reviewed regarding the selection of the geomembrane. The first requirement of the geomembrane was the need to be NSF 61 listed for use in potable water containments. The geomembrane also needed to have adequate long-term resistance to chlorine used as a disinfectant. This included resistance to chlorine levels as high as 50 ppm used for disinfecting the geomembrane prior to commissioning of the system (ANSI/AWWA C652 Method #3). The consulting engineering firm was especially concerned with choosing a geomembrane that would not crack when exposed to chlorinated water in long-term service. The geomembrane needed to have the flexibility to be mechanically anchored to inlets, outlet and overflow pipes, a multitude of concrete column footings, 4 unique slope columns and a 100 m (330’ lineal foot) seismic beam. Water was going to be present almost constantly during construction so the geomembrane needed to be prefabricated to speed installation and easily welded using various welding and gluing techniques. Finally, the geomembrane needed to be highly flexible, strong in tensile and sufficiently durable to withstand the construction and maintenance. The engineer produced a matrix of desired properties and matched them with various geomembranes available (Cooke, et al.) and concluded that a 45 mil Hypalon® (CSPE) white/black was the right material for this project.

Figure 1. Above Ground view of the City of Everett Number 3 Reservoir

CONSTRUCTION CHALLENGES AND SOLUTIONS

This project created some truly unique and difficult challenges in terms of installing the geomembrane system. In addition to the various known complexities there were some unexpected obstacles which added further challenges to the project. The project specifications primarily outlined the requirements for the geomembrane, geotextile, anchoring materials, project schedule, and quality assurance requirements. The remaining project details including: installation methods, design details, and sequencing, were structured more as a design build project with the responsibility placed on the liner contractor. The bidding and construction of this project required some significant innovation. Layfield Environmental Systems Corp. was the successful bidder, and on November 7, 2007 received the notice to proceed with the challenge of relining the City of Everett's Number 3 Reservoir.

3.1 Restricted Access

3.1.1 Challenge

All underground concrete reservoirs have limited access. In this reservoir there were only two 1.2 x 3.6 m (4' x 12') roof hatches on the south side of the reservoir located near the perimeter. One hatch was directly over a concrete stairway and the other was adjacent to it at the top of the slope. Although the staircase was adequate for personnel access, for materials and equipment it was severely limited. It was determined that the limited access would make it very difficult and time consuming to remove the existing geomembrane, geotextiles, and anchor system and replace them with new materials. These hatch locations required that the project materials and equipment be either carried or slid down the narrow stairs into the reservoir. The two existing hatches in the same relative location would also limit air circulation for the workers.

3.1.2 Solution

To address this issue Layfield commission the design and construction of a new equipment hatch that was placed on the opposite side of the reservoir and located over the toe of slope. By locating a hatch over the toe of the slope the materials could be lowered directly to the base of the reservoir. This allowed the heavy materials to be moved in and out of the reservoir with a crane. The new hatch was located so that City water operators had a direct view of the main inlet pipe. This would let them inspect this important pipe in the future without having to place a boat in the reservoir. Another important reason for installing the new hatch entry was to address the requirement for exchange of air under confined access rules. The new entry hatch provided us a point to mount an air circulation fan opposite from the original hatches which allowed for improved cross ventilation.

Figure 2. Main hatch showing restricted entrance

Figure 3. Staircase inside reservoir

3.2 Unpredictable Surge Water Flows

3.2.1 Challenge

This reservoir acts as a surge reservoir between the water treatment plant and other reservoirs in the system. Whenever a valve closes downstream there is the possibility of a water surge into this reservoir. This surge water could not be shut off during construction as there was no other adequate outlet. This was a major concern as this reservoir could receive, without warning, up to 7.7 cubic meters per minute (3 million gallons per day). This was a major safety and construction concern.

3.2.2 Solution

To address this concern, Layfield fabricated and supplied a 2 m (6.6') layflat bypass tube from reinforced Polypropylene. This tube was attached to the 1.2 m (48") surge in-flow pipe and extended into the primary drain in the bottom of the reservoir. This allowed incoming surge water to be directed to the drain inlet during construction. As a further back up, Layfield had on site two portable coffer dams (Aqua Dams®) that could be filled with water to dam off a section of the reservoir if the surge water tube unexpectedly didn't work. A plan was in place to inflate the two water-filled coffer dams in the event of an emergency using water from an available hydrant. This back-up plan would then allow time to retrieve equipment and to try and shut off the surge water. During the construction of this project we experienced about two to three surges per day, from a small trickle, to significant water flows. The bypass tube worked as designed and was removed after the final liner tie-in at the completion of the project.

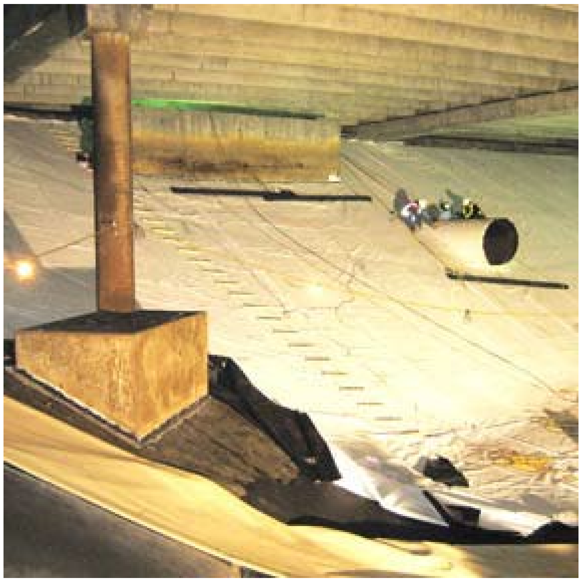

Figure 5. Surge tube (beige tube in foreground) directing surge water to the primary drain. Note the 1.2m (48") pipe boot and sloped column support in the background

Figure 4. Surge tube leading into a small bypass outlet that connects to the main drain (circular opening on the left)

3.3 Safety

3.3.1 Challenge

The confined space of an underground reservoir can be very challenging. Aside from the typical confined space challenges, the reservoir was cold, dark, with limited access, and could receive surge water at any time.

3.3.2 Solution

This site required a custom designed safety program. This document included site specific requirements to deal with surge water, emergency egress, power failure procedures, and air safety. High output fans were required at the new equipment hatch to create sufficient air turn over to protect workers in the reservoir. This was backed up with air quality monitoring devices within the confined area. An evacuation procedure was developed in the event of a power failure. All personnel on site were trained on this procedure.

Figure 6. Workers in reservoir showing PPE, hand cart for moving heavy objects, and rope ladders for slope safety.

3.4 Water Infiltration

3.4.1 Challenge

The installation of the liner was further impacted by unexpected water infiltration problems. With the high level of winter rains in the Northwest region, rain water would build up around the site perimeter at a rate faster than the existing storm water removal system could handle. As a result, water constantly found its way through unsealed areas around the perimeter and through leaks in the roofing system construction joints. During numerous rain events, a steady stream of water created additional dewatering requirements and several problems for the welding crews who were required to work around standing water. The south and north side of the reservoir were also affected by high ground water levels. These high water levels created uplift pressures and seepage through floor cracks leading to more liner welding problems.

3.4.2 Solution

Depending on the level of water infiltration and the stage of construction activity various counter measures were required including dewatering by pumping, wet dry vacuums, small mortar dams, squeegees and using elevated welding boards to keep the welding area dry and clean. Filling the concrete construction joints with mortar was a contract requirement and helped to reduce water infiltration as more of the joints were completed.

3.5 Lighting and Power

3.5.1 Challenge

The underground reservoir had no internal lighting system and very little natural light was generated through the hatch openings. Normally liner installations would use portable generators for power; however, the wet environment of this reservoir increased the risk of electrical danger.

3.5.2 Solution

Layfield needed to provide several modular high output flood lights throughout the underground reservoir. As the crews were always working in close proximity to water, ground-fault circuit interrupters (GFCI) were used on all equipment in the reservoir. Four 50 AMP 220 V temporary power cords from temporary power poles with a number of changeable power plug-in boxes provided several 110V circuits.

3.6 Geomembrane Anchorage

3.6.1 Challenge

The original geomembrane had been anchored around the perimeter at both the top and the bottom of the slope. The contract required that the existing anchorage system at the toe of the slope be removed. This required the removal of over 2,500 anchor studs. The studs had to be removed flush to the existing concrete to allow the new geomembrane system to be installed.

3.6.2 Solution

Removing the toe of slope anchor bars was accomplished by first removing the existing nuts from the studs by using battery powered impact wrenches. Some of the nuts were seized on the anchor studs; these were removed by cutting the anchor studs with angle grinders and cutting wheels. After the nuts and washers were removed, the anchor bars were removed from the reservoir. The anchor studs were then cut to floor level and ground flush with the concrete floor. The existing stainless steel anchor bars and bolts in the top anchor system were reused.

Figure 7. Special corner clamp to maintain pressure at the point of the concrete footing.

3.7 Penetrations and Attachments

3.7.1 Challenge

Underground reservoirs usually have a great deal of liner attachments due to the roof supports. This reservoir had a few additional challenges. Seven inlet pipes required waterproof pipe boots including sizes up to 1.2 m (48”). There were the expected 32 column footings that required water tight connections, but there were also four column footings located on the slopes requiring a much more complicated attachment. Finally there was a 100 m (300’) long seismic beam in the center of the reservoir that required over 230 m (750’) of water tight attachment. A particular challenge was to attach the liner to the vertical face of the column supports. This is a challenging connection as it is difficult to maintain batten bar pressure around the point of the corner.

Figure 8. Attaching the geomembrane to the large seismic beam in the center of the reservoir.

3.7.2 Solution

Layfield followed the guidelines of ASTM D6497 for pipe boots and attachments. For attachments on this project, 6 mm x 50 mm (¼” x 2”) 316 stainless steel batten bars and 9.5 mm (3/8”) 316 stainless steel anchor bolts on 150 mm (6”) centers were used. The four slope columns used the same batten system modified to accommodate the slope. The pipe boots followed the standard industry attachment guidelines but were challenged by tight space constraints, concrete remedial work, and dewatering requirements. To address the problem of sealing around concrete corners, Layfield designed and fabricated special compression corner clamps (Figure 7). The complicated penetrations and attachments in this project required a lot of time and detail.

Figure 10. Sealing the liner under multiple small inlet pipes.

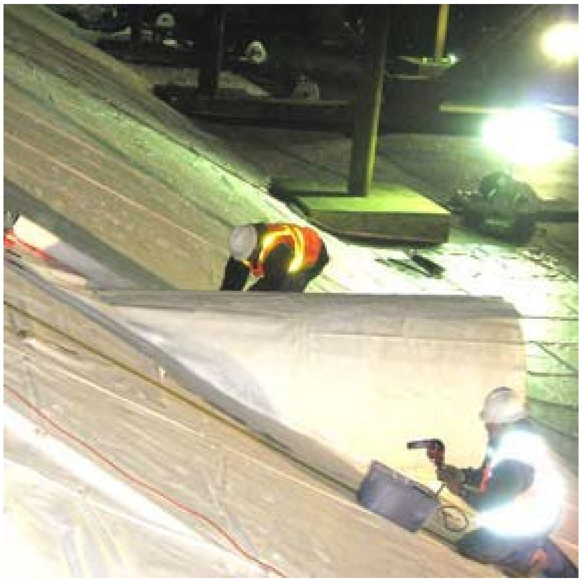

Figure 9. A boot on a large 1.2m (48") inlet pipe.

3.8 Unexpected Concrete Work

3.8.1 Challenge

The failure of the first geomembrane led to significant damage in two of the reservoir's concrete slope panels. The original project scope was limited to filling construction joints prior to re-lining. Once the liner system was removed it was observed that two concrete slope panels had shifted and had significant voids underneath. The damaged panels represented 200 m2 of unreinforced concrete 150 mm thick (2200 ft2, 6" thick). Removal of this 30 m3 (1000 ft3) of concrete was a significant problem as site and entry access for heavy equipment was extremely difficult. To compound this problem, a large amount of new liner material was already in place adjacent to the problem areas.

3.8.2 Solution

After discussions with the City of Everett and various concrete subcontractors a small remotely controlled hydraulic concrete breaker was sourced that could be lowered into the reservoir through the new equipment hatch. This electric unit did not generate fumes in the reservoir and had tracks so that it was stable on the slopes. The broken concrete and saturated subsurface materials were manually moved to a skip underneath the new equipment hatch and lifted out with a crane. New waterstops were added and then the concrete replaced with a concrete pump. The entire space was filled with concrete as it was not possible to compact any new fill materials with available equipment. Although one panel was located about 12 m (40 ft) horizontally from the new equipment hatch the subcontractor was able to pump the concrete without too much difficulty. The unexpected concrete problems resulted in a major project change order; however, the sequence of the installation was changed to give the subcontractor time to remove and repair the old concrete without affecting the schedule. Even with this change the project was completed within the original 55-day schedule.

Figure 13. Remote controlled concrete breaker working on reservoir slope.

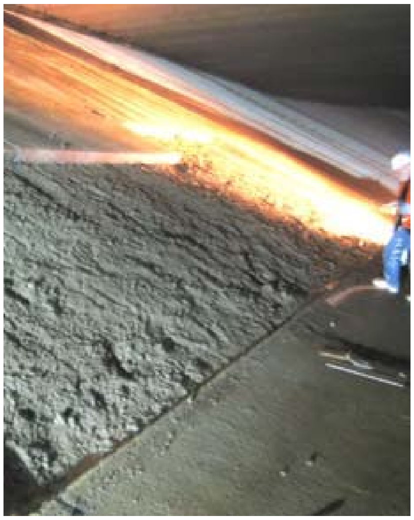

Figure 12. Once the concrete was removed an engineer determined how much of the saturated subgrade to remove.

Figure 11. Stainless steel splash plate during installation.

3.9 Stainless Steel Splash Plate

3.9.1 Challenge

The original liner had failed because the geomembrane had eroded on the slope underneath the inlet pipe. The contract specified that a 2.4 m wide x 6 m long, 6 mm thick (8'x20', ¼") stainless steel splash plate be installed to protect the liner system under the main 48" inlet pipe. The challenge was to place this 2000 pound piece of stainless steel 6 m (20') up the side slope without the use of heavy equipment. Not only was the weight a problem but the concrete on the slope was uneven making it very difficult to make a watertight seal.

3.9.2 Solution

A number of alternative splash pad designs were investigated. Finally a proposal was put forward to build the stainless steel splash plate in sections. Each section would be 1.5 m x 2.4 m (5' by 8'). A strip of stainless steel 6.35 mm (1/4") thick by 10.16 cm (4") wide was welded across the top of each section to form a joint. These joints were shingled in the direction of water flow. The side slope was lined with geomembrane underneath this splash plate and then the plate was placed on top of a protective wear pad on the liner. Neoprene gaskets were placed around the perimeter of the splash plate sections and each section of the plate was secured with a pattern of 12 mm (1/2") stainless steel bolts. Since the splash plate did not need to contain water (the geomembrane is continuous underneath it) it is not sealed between sections.

3.10 Unexpected Drain Pipe Cleaning

3.10.1 Challenge

Once the old geomembrane was removed, the entire reservoir was washed using fire hoses. There was an accumulation of silt in the bottom of the reservoir and this was washed down the primary drain. After this washdown the City inspected the drain line with camera and found that a quantity of steel nuts and washers had been washed into the pipe bells. It was determined that the hardware was likely lost in the sediment during the removal of the old geomembrane and had been swept into the drain during the washing of the reservoir. Normally small items in the drain do not cause problems; however, at this site the drain was also connected to the outlet pumps. The loose hardware could cause damage to the pumps if they found their way downstream during high flows.

3.10.2 Solution

Numerous ideas how to clean out this 700 mm (28”) drain pipe were proposed. After much debate it was decided that the best option would be to have a person go into the pipe. Because of the extreme nature of this confined space entry we hired a professional diving team. A site specific safety program for this confined space entry was prepared which included plans for the worst case scenario (the possibility of a surge of 3 million gallons of water coming into the reservoir). Part of the drain inlet was a 600 mm (24”) stand pipe which was installed prior to the diver going into the pipe. If a surge of water were to occur, this standpipe would prevent water from flowing into the pipe for up to an hour. Even though there would be no water in the pipe at the time, the dive team set up the diver with surface supplied air, a helmet mounted camera, and two way voice communications. The diver went approximately 36 m (120’) down the pipe, collecting the nuts and bolts as he went. When the diver came to a tee in the pipe he was able to turn around which made his exit easier than originally planned. The diver was in the pipe for approximately 40 minutes.

3.11 Disinfection

3.11.1 Challenge

The final part of the contract was to provide disinfection of the new geomembrane prior to commissioning of the system as per ANSI/AWWA C652 Method #3.

3.11.2 Solution

The disinfection method requires that a 50 ppm sodium hypochlorite solution be applied to the reservoir during initial fill. After working with the City on flow calculations and water quantities it was decided to bring in several 55 gallon drums of 12% sodium hypochlorite. The drums were placed at the new equipment hatch and a chemical feed pump was used to pump the sodium hypochlorite solution into a plastic hose that was placed directly in front of the inlet pipe to allow the mixing of the sodium hypochlorite with the inlet water as it cascaded down the splash pad.

Figure 14. The primary drain after liner installation and disinfection. The bell standpipe is for normal drainage and is designed to exclude silt. The dished section on the right is a small bypass for draining of the reservoir completely.

3.12 Project Time Frame

3.12.1 Challenge

Reservoir 3 needed to be retrofitted and commissioned before peak seasonal flows. Because of this operational requirement, the contract specified that the reservoir be fully accessible 55 days after the project start date in October 2007. There was a penalty clause in the contract that charged the contractor $5,000 for each additional day taken beyond the 55 day schedule.

3.12.2 Solution

Recognizing the importance of meeting the timeline for the City of Everett and the project risk, Layfield ensured this project received a high priority in terms of planning and project management. Even with frequent water intrusions interruptions and the additional time required to remove and replace concrete, the project was completed ahead of schedule. In fact, Layfield was able to apply for bonus money of $5,000 per day for early completion of the work.

Figure 15. Panorama of north side of completed reservoir.

GEOMEMBRANE FABRICATION & TESTING

It was a project requirement that the newly installed geomembrane system as part of the overall completed reservoir relining pass an allowable specified leak rate. To help achieve this Layfield prefabricated a large portion of the geomembrane system in its El Cajon, California facility. A special 75 mm (3") wide wedge was used for all factory and field welding of the geomembrane. This wider than normal 75 mm (3") wedge welding technique provided increased tensile strengths in the seam and a fully welded top and bottom seam with no lose edges. The wedge welding further reduced the need for chemical solvent welding which can lead to a less safe work environment. Both hot air welding and a specific CSPE adhesive were used in the field to fabricate pipe boots, sumps, corners and other custom fittings. All field or factory cut edges which had an exposed fabric scrim were flood coated with the adhesive to fully encapsulate the scrim. At the start of each day, mid day and the end of work day, peel and shear testing was performed on all factory and field welds. To confirm overall welded seam integrity, all factory and field seams were further probed and then air lance tested following the guidelines of ASTM D4437-08. Random destructive test samples were sent out for third party testing.

CONCLUSION

As stated in Section 5, at the completion of the installation, the reservoir was required to pass a water test to ensure it met an acceptable specified leakage rate. There was also an under drain system which was tested to ensure the system was not leaking. No leakage was found within the reservoir as determined by a static test and no additional water was found in the under drain system. There was also no chlorine residual detected in the groundwater or under drain system. This project included a large number of difficult challenges that added complexities and time constraints to an already difficult geomembrane installation. It was further impacted by a number of unforeseen external factors related to water infiltration and poor weather conditions. The City of Everett Number 3 Reservoir lining project was completed two days ahead of schedule and met all performance and water test requirements. It is our view that this difficult project was a success due to a number of factors including the quality of the project design provided by the engineer; excellent communications and cooperation between the contractor, owner and engineer; and the project management experience of our installation staff. Without the teamwork of the City of Everett, the design engineers and its sub-consultants in conjunction with the Layfield team, this highly difficult project would not have been completed on time or on budget and certainly would not have included the many system upgrades provided. All parties involved concluded this highly challenging project was well managed and successful.

Figure 16. View of the south side of the completed reservoir.

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