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Achieving Leak Tightness in New Savannah River Site Saltstone Disposal Units – 17454

Charles Keilers, Savannah River Remediation, LLC

ABSTRACT

Saltstone Disposal Unit (SDU) 6 is a new disposal unit at the Department of Energy's Savannah River Site Saltstone Disposal Facility. The Saltstone Facility is part of the site's overarching waste management and disposal system. It receives the low-level waste stream and will immobilize in grout more than 90 percent of the liquid volume generated during treatment of the site's liquid high level waste. SDU-6 is the first in a series of large disposal units to be constructed on site. Its internal diameter and height are 114 m (375 ft) and 13.1 m (43 ft), respectively. It uses a cylindrical wire-wrapped concrete water tank design (AWWA D110, Type I), and at 121 ML (32 Mgal), it is one of the largest structures of its kind in the country. Because of its size, SDU-6's base slab was placed in ten sections. Earlier placed sections restrained newer adjacent sections, resulting in shrinkage cracking. Visible cracks were repaired with epoxy. However, the SDU basemat leaked at less than an estimated 4L/min rate during its first full-height hydrostatic test (2015). The project baseline was to install a coating system to chemically protect the concrete from the high-pH, high-sulfate Saltstone solutions. The coating was not installed during the first hydrostatic test, and subsequently, an adhered elastomeric liner system was chosen to provide higher assurance of bridging floor cracks and preventing leakage. A robust process was used to select and install a liner that will not only provide chemical protection but also achieve leak tightness, which was successfully demonstrated in a second hydrostatic test late in 2016.

INTRODUCTION

Saltstone Disposal Unit (SDU) 6 is a new disposal cell at the Savannah River Site's Saltstone Disposal Facility, which is permitted by the state as a Class 3 Industrial Solid Waste Landfill for disposal of non-hazardous waste. The Saltstone Facility is part of the site's overarching liquid waste management and disposal system [1]. It treats and disposes of the low-activity liquid waste stream, which will include more than 90 percent of the volume generated by treatment of the site's liquid high level waste inventory.

The Saltstone Facility receives and immobilizes low activity salt solution by mixing it with cement, fly ash, and blast furnace slag, creating a grout slurry. The slurry is pumped to the Saltstone Disposal Units (SDUs), shown in Figure 1, and solidifies into a monolithic, leach-resistant, non-hazardous waste form. There are several different SDU designs. The six most recent operational units (i.e., SDU-2, 3, 5) use a cylindrical wire-wrapped concrete water tank design, each with a capacity of 8.7 ML (2.3 Mgal) [2, 3]. Structural design life is 25 years, although the SDUs are required to meet much longer term performance objectives for low-level waste disposal [5, 6].

In December 2013, construction began on SDU-6, shown in Figures 2 and 3. SDU-6 is the first in a series of larger disposal units to be constructed on site. Its internal diameter and height are 114 m (375 ft) and 13.1 m (43 ft), respectively. It uses a pre-stressed concrete water tank design, similar to the earlier SDUs but an order of magnitude larger in volume. At 121 ML (32 Mgal), it is one of the largest cylindrical wire-wrapped tanks in the country.

SDU-6 has posed challenges:

- The SDU-6 base slab has extensive tight visible cracks with widths of 0.07 to 0.5 mm (3 to 20 mils). Visible surface cracks were repaired with a flowable, gravity-fed epoxy, as shown in Figure 5. Early on, several cracks were ground down, and the cracking disappeared within 6 to 10 mm depth. However, concrete core samples taken in January 2016 in areas susceptible to shrinkage found cracks extending through the slab thickness [7].
- Construction joints should be avoided or, at least, minimized for a water-tight structure. Because of its large size, SDU-6's base slab was placed in ten sections, as shown in Figure 4, with water-stops across the construction joints. The "checkerboard" installation sequence created conditions conducive to shrinkage cracking due to restrained edges at construction joints. The thicker wall footing may also have restrained concrete shrinkage, causing cracking near the wall.
- The Saltstone waste form has chemicals that could attack concrete and steel reinforcement, particularly sulfates (i.e., greater than 10,000 ppm). Therefore, SDU-6 is required to have a chemical and radiation resistant coating or liner. SDU-6 is also required to use a specific concrete mix, including Type V cement per ASTM C150/C150M and a low water-cementitious ratio (less than 0.4). Under certain conditions, such mixtures present curing challenges and are susceptible to autogenous cracking [8].
- SDU-6 is required to pass a hydrostatic test with a dye tracer and with zero apparent leakage. When tested in late 2015, without a liner or coating, water flow and dye were observed between the upper and lower basemats and the slabs. Estimated leak rate is less than 4 L/min (1 gpm) (Figure 6). There was no measurable change in water level over the three days of the test.

During 2016, an adhered elastomeric liner system was chosen for SDU-6 to provide higher assurance of bridging floor cracks and preventing leakage. The liner's purpose is to not only provide chemical protection but also achieve leak tightness, which was demonstrated in a second hydrostatic test performed late in 2016. This paper will discuss some of the actions taken in SDU-6 and planned for future SDUs to address the challenges and achieve leak tightness in SDU-6.

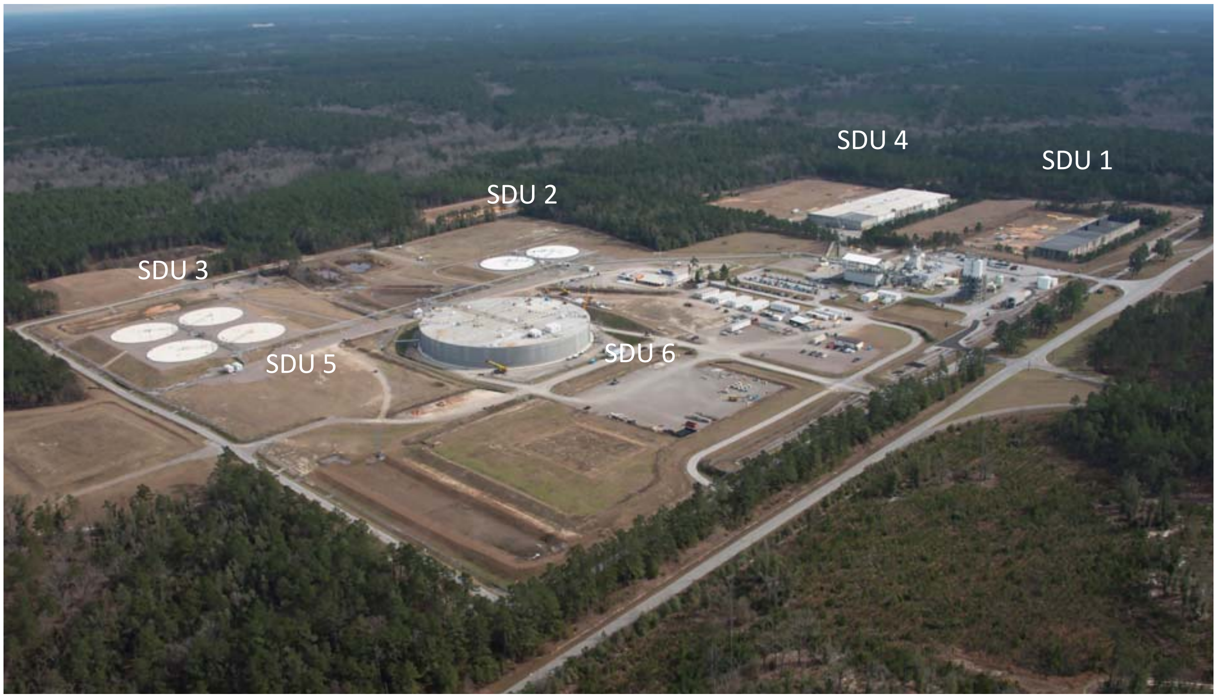


Fig. 1. Saltstone Production Facility, showing the Saltstone Disposal Units (SDUs).

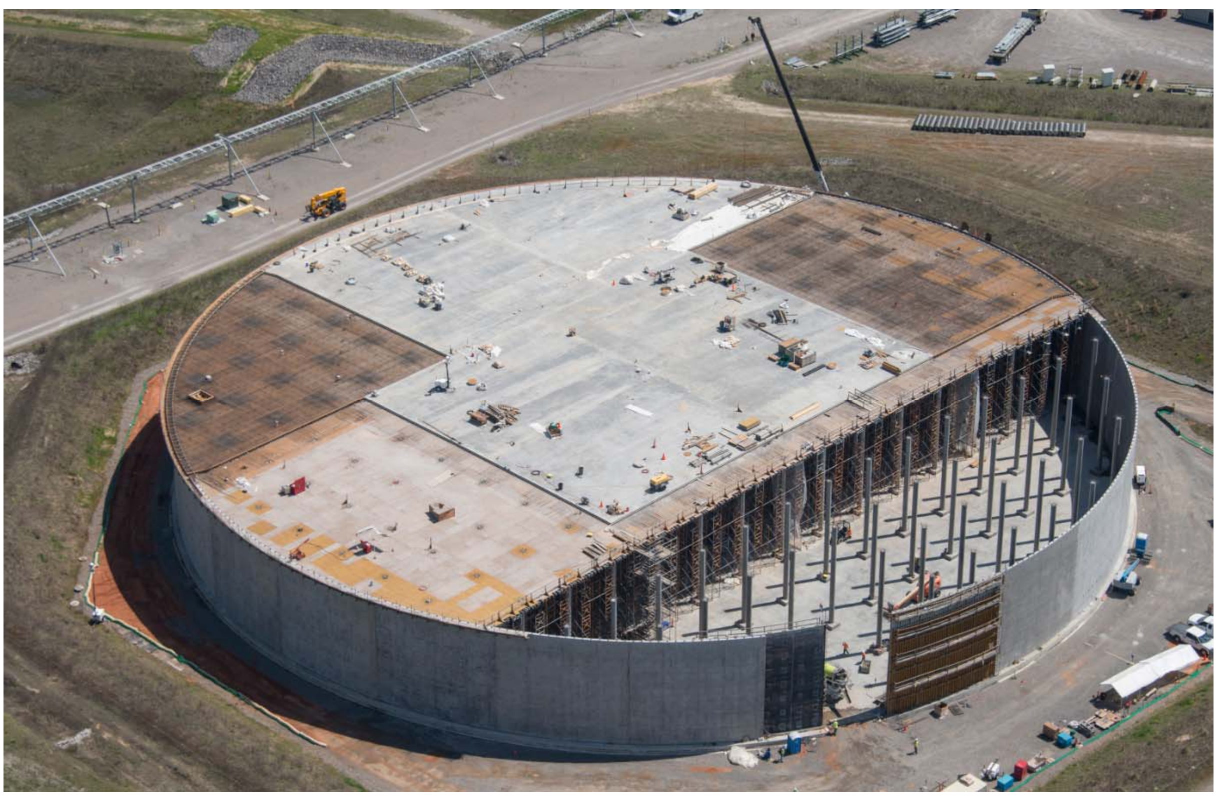
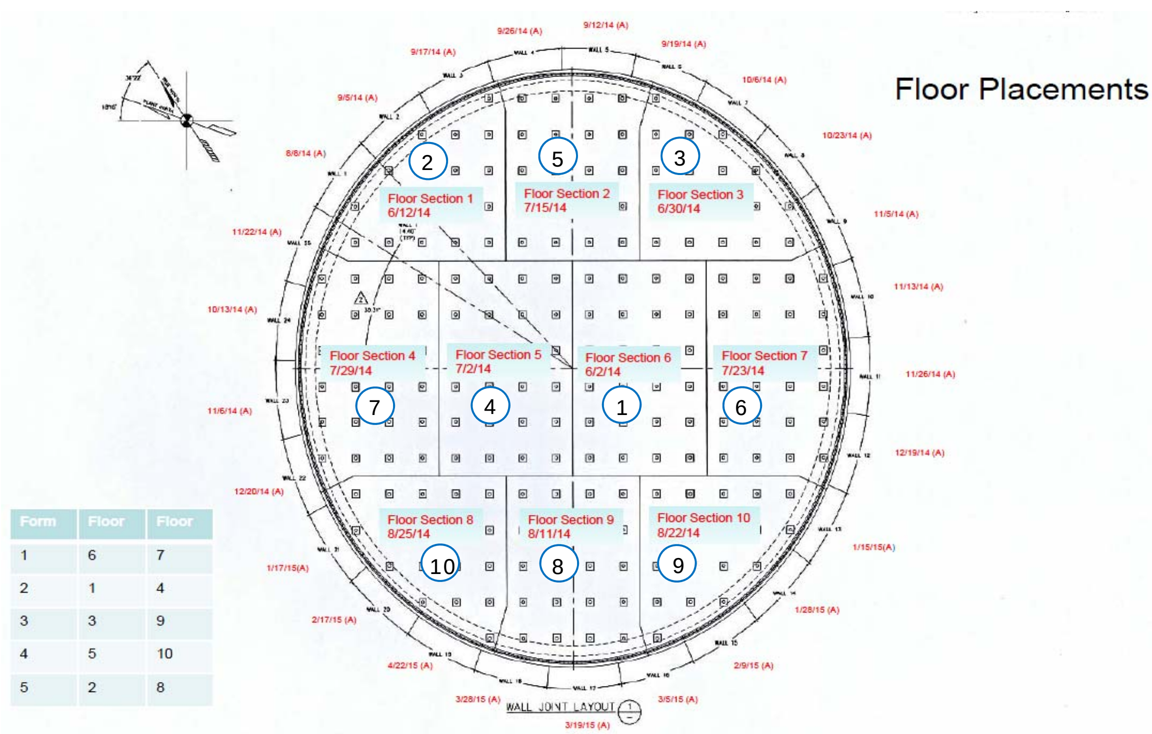


Fig. 2. SDU-6 during construction.

Fig. 3. SDU-6 near completion.



Form	Floor	Floor
1	6	7
2	1	4
3	3	9
4	5	10
5	2	8

Fig 4. SDU-6 floor sections, showing the “checkerboard” placement order that likely restrained shrinkage and enabled concrete shrinkage cracking.

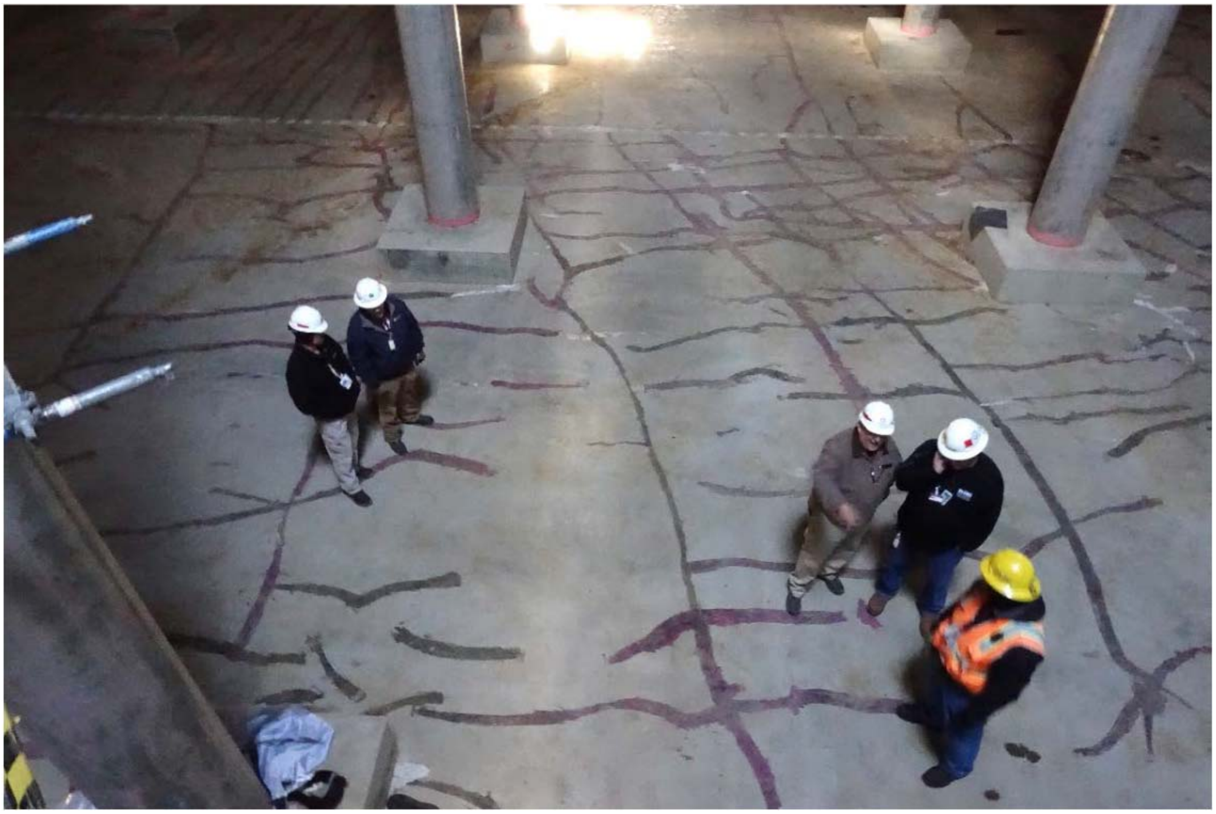


Fig. 5. Slab cracking, highlighted in purple from the dye used in the 2015 hydrostatic test adhering to epoxy that was gravity-fed into cracks (photograph from [7]).

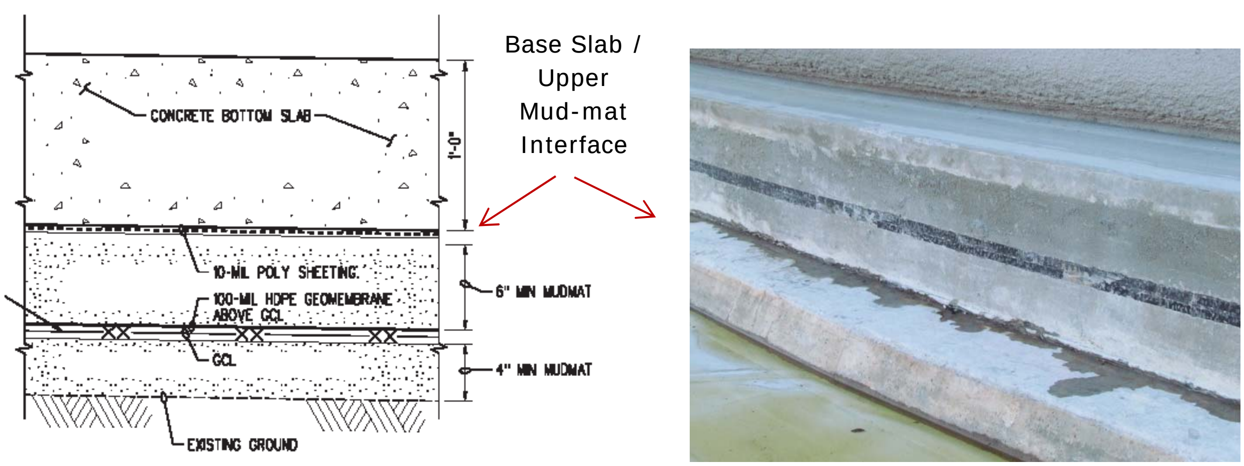


Fig. 6. Representative leakage between the SDU-6 base slab and upper mud mat during the 2015 hydrostatic test. There was no dampness on the walls and no measurable drop in level over 72 hours, but there was visible dye and flow at the basemat. Estimated leak rate was less than 4 liters per minute with tank at capacity.

DISCUSSION

The SDU-6 experiences identified improvements that can be made in design and construction of these large environmental engineering containment structures. The most likely cause of the base slab cracking is restrained drying shrinkage due to the checkerboard placement shown in Figure 4, possibly exacerbated by the concrete mix design. Even so, standard concrete design practices will lead to distributed tight cracks that still may not achieve the zero leakage criteria specified for SDU-6. The SDU-6 project baseline included an elastomer coating or liner to protect the concrete from the high-pH, high-sulfate Saltstone solutions. Because of a potential opportunity to eliminate the coating, it was not installed prior to the hydrostatic test. However, sufficient data relative to concrete chemical attack was not yet available to justify eliminating the coating. Following discovery of the leak during the hydrotest, an adhered elastomeric liner system was chosen, not only for chemical resistance, but also for higher assurance of bridging floor cracks and preventing leakage. In late 2016, the liner system was installed, and a second hydrostatic test demonstrated that SDU-6 meets the zero leakage criteria.

Some actions taken after the unsatisfactory first hydrostatic test included but were not limited to:

- Evaluated the possibility that flow could be bypassing the construction joint water stops by migrating through adjacent cracks.
- Pressure-injected construction joints and adjacent cracks with epoxy.
- Performed a leak test with 1.2 m water height; still observed weepage at the basemat.
- Took five concrete core samples for petrographic analysis [7]. Entered Non-Conformance Report (NCR) process, based on core samples having through-slab cracks.
- Obtained external technical advice on concrete materials and structural design to help determine the root causes for observed cracking and develop a path-forward.
- Evaluated the effect of postulated long-term degradation of the roof and floor slabs on the long-term environmental performance.
- Conducted a Systems Engineering Evaluation that identified and examined about two dozen options to address cracking in the base slab, and recommended installing an adhered elastomer liner.
- Conducted an alternatives study of various elastomer liner options that would meet requirements for chemical, thermal, mechanical, and radiation resistance.
- Conducted an 1,000 hour immersion soak test of liner materials on concrete specimens, using bonding adhesive and welded seams in accordance with manufacturer instructions.
- Conducted a mockup of the liner installation to demonstrate the surface preparation and liner installation and testing methods.
- Installed the liner, performed full spark-testing of the liner, repaired detected flaws, and conducted a second full-height hydrostatic test with dye.

The discussion below summarizes the SDU-6 structural design, hydrostatic testing, base slab cracking, and further design and liner considerations to achieve leak tightness.

SDU-6 Structural Design

SDU-6 was designed considering the more restrictive of the requirements from two standards: the American Water Works Association standard for wire-wound prestressed concrete water tanks (AWWA D110), and the American Concrete Institute standard for environmental engineering concrete structures (ACI 350) [2, 3]. Unlike the earlier SDUs, SDU-6 used cast wall sections instead of tilt up walls (i.e., AWWA D110 Type I instead of Type III).

SDU-6 has an internal diameter and height of 114 m (375 ft) and 13.1 m (43 ft), respectively. The roof is 0.305 m (12 inches) thick and is supported by 208 reinforced concrete columns. The core wall tapers from 0.254 m (10 inches) thickness at the top to 0.610 m (24 inches) at its base. The wall was constructed in sections, as shown in Figure 2, and then horizontally wrapped with more than 460 km of 9.5 mm pre-stressed steel cable and covered with shotcrete. Vertically, the wall was compressed by 400 post-tensioned threaded steel bars. The core wall has 40 durometer bearing pads at the top and bottom to allow relative motion radially.

Figure 6 shows the base slab and the upper and lower mud mats, which are separated by a polyethylene sheet and geomembrane, respectively.

As shown in Figure 4, the base slab was cast in 10 placements with water-stops between each section at the construction joints. The base slab is 0.305 m (12 inches) thick and has steel reinforcement bars running in each direction near the top and bottom surfaces for crack control (i.e., #5 @ 6 inches, top, and #6 @ 12 inches bottom, each way; minimum reinforcement ratio of 0.6 percent). At the outer wall, the foundation slab thickness increases to 0.610 m (24 inches), primarily to provide space for the wall reinforcement system. For external surfaces, concrete crack control followed ACI 350 for normal environmental exposure [3]. Internally, reinforcing at the top surface of the base slab is designed for severe environmental exposure (e.g., sulfate solutions exceeding 10,000 ppm).

The 2015 Hydrostatic Test

SDU 6 is required to pass a full-height hydrostatic test in accordance with the American Concrete Institute (ACI) 350.1, *Specification for Tightness Testing of Environmental Engineering Concrete Containment Structures* [4]. The acceptance criteria are: Part 1 – exterior surfaces shall not have moisture that can be picked up on a dry hand; Part 2 – there is no measureable decrease in level over three days, when adjusted for evaporation and precipitation. The qualitative test, Part 1, does allow for wet areas on top of the wall footing but no observed flow.

In addition to the ACI 350.1 test, SDU-6 is required to be hydrostatically tested with dye and to have no visually observed dye or evidence of dye fluorescence.

In late 2015, SDU-6 was hydrostatically tested without a coating or liner. Measured drop in level over 72 hours was less than the 1.6 mm (1/16 inch) detection threshold and less than the 3.2 mm acceptance criteria in Reference [4]. The walls were dry. However, water flow and dye were observed at the base slab and mud mats at numerous locations (Figure 6). SDU 6 was suspected to be leaking through either cracks in the base slab or via pathways around the construction joint water-stops. Visible floor cracks had been repaired with flowable epoxy before testing. After leak testing, additional cracks were identified in the base slab; however, these appear most likely due to pre-existing but undiscovered cracks that became visible after wetting with water with dye.

Since there was no measurable change in level, the leak rate was estimated as a maximum of 4 L/min (1 gpm). An adhered elastomer liner system was selected and installed to chemically protect the concrete and achieve leak tightness.

Base Slab Cracking

In January of 2016, five cores were taken from the SDU-6 floor slab. Four cores were taken at locations with visible shrinkage cracking, while one core was taken in an area free of visible cracks. The four core samples revealed cracks extending below the upper rebar layer, which was new information. The cracking went through the cementitious paste and, in some instances, through the aggregate without vertical displacement. This would be consistent with cracking due to shrinkage and not a thermal or structural over-load condition. A petrographic analysis concluded that the concrete appears to be high quality, it contains the desired constituents, and it was mixed in correct proportions per the project's specifications [7].

For SDU-6, the observed crack widths were 0.07 - 0.5 mm (3 - 20 mils). ACI 350 design practices are intended to ensure that any cracking that occurs within an environmental structure is appropriately distributed and has limited width. The SDU 6 crack sizes are within the regime deemed reasonable by ACI reports that formed the basis for ACI 350 and other ACI structural codes (e.g., [9], Table 4.1). For example, ACI 349.3R [10] defines the passive crack acceptance criteria in an existing structure as less than 1 mm (40 mils). Settlement survey data also indicates the expected structural response during construction and the subsequent liquid tightness test.

Reinforcement Considerations

The ACI 350 minimum reinforcing steel required for the SDU-6 base slab is 0.5% ([3], Table 7.12.2.1). The actual design provided 0.86% and 0.61% steel for the top and bottom layers, respectively. The SDU-6 design also meets ACI 350 requirements for shrinkage and temperature reinforcement, including exceeding the minimum specified bar diameter (13 mm; 0.5 inch) and not exceeding the maximum spacing requirement(0.3 m; 12 inches) ([3] Section 7.12.2.2). By design, this level of reinforcing steel should have appropriately controlled shrinkage cracking, consistent with the intent of the ACI codes. Given the 25-year service life, the reinforcement size and spacing, the calculated stresses, and the high pH environment, structural degradation should not occur.

Concrete Design and Placement Considerations

The SDU-6 concrete mix is intended to achieve a 56-day compressive strength of 41 MPa (6,000 psi) and a high sulfate resistance (i.e., Class 3 exposure, ACI 201.2R, [11]). By weight percent, the concrete mix design uses 40 % slag (Grade 100), 30% Type V cement, and 23% fly ash (Class F), and 7 % silica fume. The maximum water-cementitious ratio is 0.38. The aggregate weight ratio to total is 0.738.

For SDU-6, as the concrete cured, actual concrete strength increased with aging as expected. At 56 days, the average strength achieved was 54 MPa (8,000 psi). At about 90 days, the strength was 61 to 68 MPa (9,000 – 10,000 psi).

Higher strength concrete mixtures with low water-cementitious ratios and with silica fume or other pozzolans tend to develop dense microstructure within a few days that can limit or prevent diffusion of external curing water into the matrix, as discussed in [8]. The hydration reaction products occupy less volume than the reactants, causing chemical shrinkage. Autogenous shrinkage will occur if external water is unable to diffuse into the pores. Wet curing is needed so that a mix design with low water cementitious material ratio will not be affected by rapid surface drying. Such a mix design could exacerbate shrinkage cracking if insufficient water is available for curing and the boundaries are restrained.

For future SDUs, some improvements being considered include but are not limited to:

- Increase batch plant capacity, allowing placement of larger floor segments.
- Develop a concrete placement strategy and plan that addresses key attributes, including minimizing construction joints and restrained edges.
- Consider thermal protection to achieve gradual cooling during curing and minimize the potential for cracking.
- Better control moisture and curing practices to avoid rapid surface drying.
- Reevaluate the reinforcement detailing, considering anticipated construction loads, thermal and temperature loads, and construction sequence.
- Determine by test the actual shrinkage characteristics and the time-temperature and strength-gain characteristics of the mix design and reevaluate the mix design.

Liner Considerations

Standard ACI design practices will lead to distributed small, tight cracks, but these still may not achieve the zero leakage criteria for SDU-6. Therefore, an adhered elastomer liner was installed in SDU-6, not only for chemical protection of the concrete, but also to meet the zero leakage criteria.

ACI 350 [3] requires liners or coatings be used in environmental engineering structures when concrete is in contact with chemicals or corrosive gases that attack the cement mix or embedded reinforcement. The original SDU-6 design included a chemical resistant epoxy coating that had been used in earlier SDUs, although the coating had not been specified for achieving leak tightness. While the coating would be relatively flexible, the System Engineering Evaluation recommended an elastomer liner because of the extent of cracking in the SDU-6 base slab and the higher confidence in a liner achieving leak tightness.

The engineering alternatives analysis evaluated more than two dozen elastomeric liners for attributes, such as:

- Sulfate and chemical resistance
- 12.5 m hydrostatic head during testing
- High pH of the saltstone solution and low pH of the well water used for testing
- 100% humidity
- Wide temperature swings, between -11^{o}C and 70^{o}C
- 0.82 Mrad estimated radiation dose
- Mechanical elongation and expected radial wall deflections (~ 3 cm)
- Adherence to the concrete wall and base slab.

Some of the elastomeric liner options considered included the following, singularly or as mixtures: butyl rubber; chlorinated polyethylene; chlorosulfonated polyethylene; polyvinyl chloride and ethylene vinyl acetate. Thermoplastic liners, such as high density polyethylene are commonly used as geomembrane liners but were not considered for SDU-6 due to their lower elasticity, loose fit, and concerns over stress-induced cracking in high pH solutions at elevated temperatures.

After screening, a small number of candidate liners were immersion tested for 1,000 hours in a bounding simulated salt solution, including material pieces and welded segments, with and without adhesive. Measured quantities included tensile strength and elongation [12], seam integrity [13], and bond strength [14]. Liner installation and testing was demonstrated before installation.

CONCLUSIONS

Saltstone Disposal Unit (SDU) 6 is a new disposal unit that is part of the Department of Energy's Savannah River Site Saltstone Disposal Facility. It is the first in a series of larger disposal units to be constructed on site. It uses a cylindrical wire-wrapped concrete water tank design, and at 121 ML (32 Mgal), it is one of the largest structures of its kind in the country.

Because of its size and batch plant restrictions, SDU-6's base slab was placed in ten sections. Earlier placed sections restrained new sections as they were placed, likely resulting in shrinkage cracking. The thicker wall footing also restrained the base slab, causing conditions conducive to cracking. The elevated concrete strength and low water-cementitious ratio concrete mix also created conditions conducive to cracking. Insufficient wet curing may have exacerbated cracking since the low water-cementitious material ratio mix design can be affected by rapid surface drying.

Visible cracks were repaired with gravity-fed epoxy, and construction joints were pressure-injected. However, the SDU basemat leaked at less than an estimated 4L/min rate during the 2015 hydrostatic test. An elastomer liner was installed to chemically protect the concrete from the high-pH, high-sulfate saltstone solutions and has been demonstrated to also achieve leak tightness.

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