Savannah River Remediation
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April 26, 2016 SRR-SDU-2016-00006 Rev. 1

TO: FILE

FROM: T. Brooks, SDU6 Design Authority

SDU6 Tank Cracking SME Reports

A Subject Matter Expert (SME) conference was held on 2/10-2/11/16 to evaluate the SDU6 concrete cracking. The purpose of the document is to place the SME reports in a retrievable location. Please see attached.

Revision 1 includes an additional SME report from AECOM SME Allen Hulshizer.

BECHTEL CORPORATION
HOUSTON OFFICE OG&C
MATERIALS ENGINEERING TECHNOLOGY

March 29, 2016

Prepared By: **Patrick R. Nau**
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Subject: **Internal Coatings for SDU #6 Tank, SRS**

The SDU #6 concrete storage tank is intended to be 100% leak tight but leaked during hydrostatic testing. Leaks were attributed to extensive cracking of the floor. Savanah River Remediation (SRR) held a conference with the stakeholders and various subject matter experts to review the design and construction of the tank as part of an investigation into the cracking and leaking. SRS requested that a MET Protective Coatings Specialist visit the site to participate in the conference to review the possibility of mitigating cracking using a polymeric internal lining.

Achieving the required leak tightness with a polymeric internal lining material is conceptually feasible but poses significant challenges. It would require extensive and detailed engineering effort and possibly testing, mock-ups and/or field trials to:

- Identify and establish the viability of specific materials/products.
- Develop lining design details, application techniques, processes and procedures.

MET understands that it could conservatively take as long as 6 years to fill the SDU #6 tank. After filling with grout, SDU #6 will no longer contain drain water and will be maintained in a dry condition. Approximately 25 years after its filling operation, the final closure cap will be installed

No polymeric lining can be expected to retain its integrity and 100% leak tightness for 25 years without regular, and at some point, major maintenance if not complete replacement. Once filling the tank begins the lining will be inaccessible for maintenance so the first thing that must be established is the minimum maintenance free service life required of any candidate lining material where the lining maintains a complete seal of the concrete. Any lining materials service life will depend on the temperature and chemicals it is subjected to so service conditions must be defined and the linings ability to resist those conditions for the required length of time firmly established.

Generic approaches considered include:

- Coatings applied as a liquid directly to the concrete that adhere tightly after cure, such as temperature and chemical resistant epoxy novolac.
- Loose membrane liners of elastomeric sheet or polyurea spray applied over a reinforcing mesh.
- Polymeric membrane liners adhered directly to the concrete.

Liquid coating applied directly to the concrete is not considered practical. This type of product can provide excellent chemical and temperature resistance but is not especially effective over cracked concrete. Liquid applied coatings have little crack bridging ability so all but the narrowest of cracks must typically be addressed prior to coating application. This could be as simple as covering the crack with a woven mesh or cloth that becomes saturated with the coating, but could involve routing the crack out and installing backer rod and sealant prior to coating application.

Special details to address existing cracks can be effective over static cracks but any movement of the crack under the coating presents other problems. The most chemical and temperature resistant coatings are rigid and cracks in the concrete will readily propagate through these coatings if the crack moves (from expansion and contraction or settling). Some products offer a degree of flexibility (using at a decrease in chemical and or temperature resistance) and inclusion of a bond breaker on both sides of the crack, flexible caulk and reinforcement of the coating as part of the crack treatment detail can accommodate a slight amount of movement.

Given the number, length and extent of cracking existing in the floor of SDU #6 treating cracks prior to applying a liquid coating would require considerable time and effort. Even then, movement of the cracks or extension of the existing cracks when the floor is stressed by the full load of the hydrostatic test could compromise the coating and any cracks that may form after the coating is applied would propagate through it.

Loose polymeric membrane liners (pond liners or bag liners) are available in a number of different polymeric materials with varied chemical and temperature resistance so it is possible that such a product could be identified that is suitable for the SDU #6 service conditions. The benefit of this type of lining is that they tend to be much more flexible than liquid applied coatings and since they are not bound to the concrete they easily bridge cracks and easily accommodate crack movement, growth and the development of new cracks.

The major concern with this type of liner is effecting and maintaining a seal at terminations. Loose liners are typically fastened to the concrete mechanically with bolts and baton strips. Assuring a tight, lasting mechanical seal around the entire perimeter of the tank wall and on all of the 200+ columns would be a major undertaking.

An **adhered polymeric membrane liner** may be the most promising approach. Like the loose liners, a number of different polymeric materials with varied chemical and temperature resistance are available so it is possible that such a product could be identified that is suitable for the SDU #6 service conditions. Adhered membrane liners will readily bridge existing cracks and many are elastomeric. The elastomeric materials offer considerable flexibility and elongation allowing them to accommodate much more crack movement, growth and the development of new cracks compared to liquid applied coatings applied directly to the concrete. They would not be as resistant to concrete cracks as would a loose liner but they can be adhered to the concrete so a tight and lasting seal should be readily achievable.

BECHTEL CORPORATION
HOUSTON OFFICE OG&C
MATERIALS ENGINEERING TECHNOLOGY

March 15, 2016, Revised March 24, 2016

Subj: Report on Concrete for SDU #6 Tank, SRS

Summary

At the request of SRS personnel, MET participated in a conference and site visit to review the design and placement of concrete in the subject SDU #6 tank as part of an investigation into leakage experienced during hydrotesting.
A review of the background information, the tank design parameters, and observations during visual examination of the outside and inside of this tank are the basis of this report and the conclusions provided.

The leakage from the base of the tank perimeter is being caused by the "restrained drying shrinkage cracking" of the tank floor. In addition, the floor cracking also propagated during the initial hydrotest indicating an issue with movement of the floor due to a change in stresses which although calculated to be low was in addition to the restrained shrinkage stress. Cracking on the roof of the tank is partially due to drying shrinkage, but also due to early removal of the supporting shoring and formwork from the casting of the flat surface. Discussion during the conference indicated that shoring was removed based on compressive strength development of concrete samples.

An explanation of cracking in concrete, a detailed conclusion and recommendations for improvement of the placement of concrete for future tanks is provided.

Background

SDU (Saltstone Disposal Unit) #6 Tank is a storage unit for low level radioactive wastes at the Savannah River Site in Aiken, South Carolina. Its purpose is the long term storage of waste materials placed as a grout slurry. The approximate dimensions of the tank are 375 feet nominal inside diameter by 43 feet interior height. The tank has a 1.5% sloped floor and roof, post tensioned (cast-in-place core walls wrapped cable stressing, covered with shotcrete) walls, and 208, 24" diameter interior columns for roof support. The floor was cast in 10 sections between June and September of 2014. The time between each pour ranged from 2 to 18 days depending on location.

The tank floor perimeter is 2' ¾" thick for a 7' section which slopes to the overall floor thickness of 12". The roof is a constant 12" thick. The roof and wall have top and bottom layers of reinforcing steel and at each joint in the concrete a water stop has been placed at the center of the thickness. All areas in the tank utilized the same mix design as follows:

Amounts per cubic yard of concrete mix

Coarse aggregate 67 stone -	1880 #
Fine aggregate Nat. Sand -	990 #
ASTM C150, Type V cement -	213 #
ASTM C618 Class F fly ash	163 #
GBF Slag	284 #
Silica Fume	50 #
Water	32.3 gal.
Max. W/CM ratio	0.38 including moisture from aggregates and admixtures.
Actual W/CM ratio	0.35 to 0.36 based on trip tickets and added water.

Admixtures for water reduction, air entrainment, and super plastizer were included in mix.

The tank design intent was to provide a "Zero" leak rate after repairs with an approximate 41 feet height of water in the tank.

Leakage was determined to exceed the required "Zero" rate during the initial hydro using site well water having a pH of approximately 3.6. Leaking was attributed to extensive cracking in the floor. Attempts have been completed including gravity flow epoxy liquid into the cracks prior to the initial hydro test, epoxy injection of the construction joints after the hydro, and the promotion of autogenous healing (AH) with treated water. During the low level water treatment for AH, and after the epoxy repairs, minor (not quantified) amount of leakage was still noted on the tank perimeter indicating repair efforts have not been completely successful, and the requisite "Zero" leak rate has not been achieved.

NOTE: Leakage during the AH treatment was based on a water height of a few feet (< 7 feet), not the 41 feet height of the required hydrotesting.

Other, earlier tanks utilizing a coating along with the same concrete mix design and the same basic design have been successful but are only 150 feet diameter.

Concrete Cracking

Concrete inherently has shrinkage build into the mix design. Even with the best mix design parameters some minimal shrinkage is expected. According to the concrete specification for this project a tested limit of 0.048 percent (480 microstrain) is acceptable which, for the ~375 feet diameter of the tank at is a shrinkage of 1.5 inches (38mm) or a 0.3mm crack every 3 feet. Non Conformance Reports for the shrinkage testing of the concrete mix were accepted for shrinkage as high as 0.069 percent (690 microstrain).

Concrete shrinkage cannot be eliminated but can be minimized by following a few important rules.

1. Maximize the size of aggregate used in the mix, based on rebar spacing and thickness of pour.
2. Utilize a well graded aggregate, with absolutely no gaps in the sizing from coarse through the fine sand.
3. Minimize the fines from sand, follow ASTM C33 gradation for natural sand, no manufactured sand used.
4. Reduce the paste requirement and cement/cementitious materials requirements of the mix.
5. Minimize the water content to wet the aggregate surface and hydrate the cementitious materials.
6. Utilize a shrinkage reducing admixture combined with the above requirements.

The following is an explanation of the various form of concrete cracking.

Plastic Shrinkage Cracking –

As the name implies, these cracks occur on the surface of fresh concrete while it is still in its plastic state 1-6 hours after placement and typically during finishing. They are from a few inches to 3 feet apart, typically parallel and not connected together or to any perimeter joints. Plastic cracks are shallow and wide at the surface with a depth typically less than 1 inch and widths up to ¼ inch at the surface tapering to a point. Plastic shrinkage cracks are caused by the rapid drying of the concrete surface due to ambient conditions and the inability of the concrete mix to supply bleed water to the surface to replenish the evaporating moisture. As the water recedes from the surface a tensile force develops due to the menisci which forms between the fine particles of the cementitious material and fine aggregate. The use of evaporation retarders, foggers to raise the humidity level, shading to prevent direct sun exposure, and lowering the starting temperature of the concrete are methods to reduce the incidence of plastic shrinkage cracking. Observations during the inspection of the tank floor did not indicate the presence of plastic shrinkage issues.

Drying Shrinkage Cracking –

Natural drying of the concrete after initial set, due to surface loss of moisture is the cause of drying shrinkage. Concrete will always shrink and the amount is determined by the properties of the mix design. Drying shrinkage in itself does not cause cracking. Cracking only occurs when the concrete is sufficiently restrained, unrestrained concrete will just shrink.

Restrained Drying Shrinkage Cracking –

There are numerous forms of restraint for concrete pours including but not limited to the following:

1. Reinforcing steel
2. Placement directly on a surface which does not allow for free movement during the setting/drying of the concrete. (Plastic sheeting was used for the floor placement on top of the mud mat).
3. Placement of concrete bonded to existing concrete which restrains the movement/shrinkage of the new pour.
4. Placement of concrete with non-moving joints adjacent to previous pour. E.g. continuous rebar crossing joint.

In all these instances the restraint will not allow the shrinkage of the fresh concrete to occur without the development of tensile stresses within the new pour. If the tensile stresses are greater than the as developed strength of the new pour it will crack beginning at the location of the restraint and extending into the placement.

Pouring the floor of SDU #6 in large, thin sections led to some sections being restrained by one or more previously poured sections and partially by the surface of the mud mat onto which it was poured.

Plastic sheeting was installed between the mud mat and final floor pour which prevented direct bonding of the surfaces. Depending on the thickness of the plastic and the top surface of the mud mat, the weight of the floor placement would still provide an unknown amount of restraint and stress on the slow setting concrete.

Autogenous Cracking –

Internal drying (self-desiccation) of concrete occurs due to cement hydration and/or pozzolanic reactions. During self-desiccation moisture is drawn from the paste matrix into the pore gel by pozzolanic action creating internal tensile forces and pore surface tension. Autogenous cracking typically occurs in mixes with higher levels of fume silica (10% of cementitious materials), blended cements, and a water cement ratio of 0.40 or below. However, in blended cements with low cement content (<33%) or slowly setting cements it is highly unlikely to occur unless the water cement ratio is below 0.35.

Based on the truck trip delivery tickets for SDU #6 the actual water/cementitious materials ratio was 0.35 to 0.36 and the amount of fume silica in the cement blend was on the order of 7%. Although some internal micro cracking was noted in the petrographic report on the cores taken from the floor, there was no indication that the macro cracking which is the primary cause of the tank leakage was caused by autogenous issues, self-desiccation, or internal drying.

Thermal Cracking –

Differential thermal cracking is caused by a high temperature gradient between areas within a typically mass pour. It is a problem in mass pours where the core can generate high temperatures during the cement reactions, but the exterior surface is allowed to cool due to the ambient air temperature and surface heat loss. The 12-inch thickness of the floor would not have the mass per surface area to produce thermal cracking

Craze Cracking –

Craze cracking is very fine close pattern (spider web) or very shallow map cracks due to overworking the surface of the concrete during finishing. Hard troweling of a concrete surface with little bleed water produces a thin shell of fines which produce very close pattern crazing.

Craze cracking was noted in the petrographic examination of the top surfaces of the cores from the floor of SDU #6. These cracks, however, are unsightly but are not detrimental to the concrete's durability, and do not propagate below the thin surface.

Subsidence Cracking –

Subsidence Cracking occurs when concrete placed typically in a mass application, sees a volumetric shrinkage such that the mass subsides and any obstruction including the top rebar layer causes the setting concrete at the top surface to be mechanically cracked as the thickness of the pour is reduced. This type cracking is seen as a pattern over the reinforcing steel where the surface cracks correspond to the position of the rebar below the surface.

The SDU #6 floor has neither the mass nor the thickness that would result in subsidence cracking unless a very high water/cementitious material ratio mix had been placed.

Concrete Mix Design Issues

The historical basis for the existing concrete mix design is not available, but it would follow that the resistance to the chemicals in the grout slurry and specifically the sulfates which are potentially reactive with the concrete would have dictated the complicated blend of cementitious materials and reduced water/cementitious material ratio. In addition, the necessity for the volume stability or cracking resistance and low permeability of the tank floor to prevent leakage of the radioactive materials into the environment over the long storage period was taken into consideration.

Low permeability and low shrinkage to prevent cracking could have been produced using a concrete mix design with ASTM C150 Type V cement for sulfate resistance and ASTM C618 Class F fly ash, also to provide resistance to sulfate attack, higher strength, and a more rapid strength development. For this application the use of 25 to 40 percent fly ash would be acceptable, and removing the slag and fume silica from the mix would reduce potential issues with bleed water loss and rapid surface drying. Mixes of this type with the proper gradation of aggregate can have consistent shrinkage numbers of 300 to 350 microstrain or almost half of the tested shrinkage of 690 microstrain accepted by NCR for the present mix design.

As to the aggregate selection, information provided was for both ASTM C33, #56 and #67 coarse granite aggregates for which the majority of the largest sizes are less than 1 inch. A larger sizing up to 2 inch with an even gradation down through the fine natural sand will act to decrease the shrinkage. The addition of a shrinkage reducing admixture to the water reducer and superplastizer being used would also reduce shrinkage.

Testing should also be considered on expansive cements if the placement parameters dictate the necessity.

Concrete Curing Issues

Concrete mix designs with low water cement ratios, and very fine blended cementitious materials are highly susceptible to rapid moisture loss during placement and throughout the setting process. If bleed water cannot be brought from inside the concrete to the surface during finishing, insufficient moisture is available to prevent the myriad of cracking problems due to moisture loss. Prevention of cracking due to the surface moisture loss can be achieved by the following means:

1. Fogging during placement to maximize the humidity at the surface and prevent air drying.
2. Tenting of providing shading to prevent direct sun exposure and radiant energy surface drying.
3. Wind breaks at the perimeter of the pour to prevent wind exposure and drying.
4. Utilize an evaporation retarder to aide in reducing surface moisture losses.
5. Utilizing wet curing to maintain the surface moisture and replace any losses to the atmosphere during placement.
6. Do not use curing compounds as they are not 100% effective in preventing moisture loss and will allow a percentage of the surface water to evaporate through the "barrier".

In mixtures with high levels of supplemental cementitious materials, the high moisture loss and subsequent drying shrinkage cracking would exacerbated by the very slow strength development.

Conclusions and Recommendations

The primary cause of the leakage of the floor of SDU#6 tank is the restrained drying shrinkage cracking of the checkerboard pattern placement. The restraint driving stress in the thin concrete slab is from both the underlying mud mat layer and the interface between the numerous sections into which the floor was divided. Since "zero" leakage is the mandated requirement then the drying shrinkage should be kept to an absolute minimum and the placement should be designed to minimize any form of restraint. Observations from the site inspection of the tank floor did not indicate any additional affects from other forms of shrinkage which could or would have caused the cracking and subsequent leaking of the floor.

The tank roof cracking has a unique pattern which would indicate a structural issue probably due to early formwork removal. This concrete mix although developing acceptable compressive strength would require a much greater time to acquire sufficient tensile strength to prevent the top surface cracking located at the pillar tops and running between the pillar top locations. Less noticed drying shrinkage cracking did occur in the roof due to less restraint on the bottom surface from the formwork compared the floor on the mud mat. Any further discussion on the roof cracking should be provided by a structural subject matter expert.

An additional issue to be reviewed by the structural expert is if the 12-inch thickness of the floor is sufficient for the service. The loading from the columns and/or required hydrotest appeared to cause the initial cracks to propagate. This would indicate a structural instability and the possibility of movement or flexing of the floor due to the stress applied by filling the tank. It should be noted that the stress required to propagate existing cracks in concrete is a fraction of the compressive stress of the concrete, approximately 1 %.

It is recommended that the concrete mix design be modified for future tanks to reduce the shrinkage as mentioned above and that testing be performed to understand the shrinkage rate, creep rate, and strength development of the concrete mix based on field conditions. The placement of the concrete for the tank floor should be revised to remove the restraints from the mud mat surface and any joints between pours.

It is also recommended for future tanks that a wet mix batch plant with sufficient capacity (250 cubic yards per hour) to place large tank floor segments be provided. If possible the entire floor should be completed in a single placement using a thicker mat which would not be affected by movement or the additive stress of the hydrotesting. The concrete mix design could also be changed to self-consolidating concrete to speed placement and eliminate finishing issues.

Wet curing of the floor is necessary so that a low water cementitious material ratio low shrinkage mix design will not be affected by rapid surface drying. Since craze cracking was noted on the surface, then a simple broom finish after floating and minimal troweling would prevent this type surface defect.

Attempted repairs on the floor have improved the structural integrity, but have not corrected the leakage issues. It is recommended that a second hydrotest be completed, and the leaks found on the tank exterior perimeter be injected with a foaming, water reactive/setting polyurethane sealant. This material will fill, swell or foam and seal any leaks from the outside of the tank. There is a high probability that the hydrotest will cause additional crack propagation and leakage so preparation for the injection leak repair should be complete prior to the test.

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Summary Report

Evaluation of Concrete Tank at Saltstone Disposal Unit #6 at the Savannah River Site, Aiken, SC

Javeed Munshi, *FACI, FASCE, FSEI*

Javeed Munshi attended the SME Conference held at SRR on 2/10/16 and 2/11/16. The key objectives of the Conference were to 1) determine root cause(s), 2) determine an appropriate path forward to meet the current Structural, Leak Tightness and Performance Assessment (PA) requirements and 3) Identify improvements for future SDUs.

REPORT

Observations

It was reported that cracks appeared within a few days of each pour. Both shallow initial cracking as well as full depth cracking have been reported. The cracking appears to be as a result of early plastic and long-term drying shrinkage. Note that this initial plastic shrinkage plus long-term drying shrinkage of concrete has now been confirmed through the petrographic evaluation.

Probable Root-Cause

The formal root-cause has not been determined but it appears to be a combination of the following factors:

- Slower rate of strength gain and shrinkage characteristics of the mix with slag, fly ash and silica fume
- Restraint provided by thicker perimeter pours and outward slope of the base
- Lack of control joints to allow stress relief
- Relatively hot, dry and windy conditions during concrete placement/curing
- Insufficient protection and/or curing – this mix needed extended wet curing

Nature and Extent of Cracking

The observed cracking seemed excessive for the base mat compared to the roof both in extent and crack widths. For the base slab, the observed cracks were repaired with epoxy grout feed and injections at CJs. Note that with this much repair done, it is impossible now to find all the cracks/joint path ways for water leakage and seal them completely shut. For the roof, cracking was observed both around columns and in spans between columns. Some of the cracks appeared to be through cracks causing leakage.
In general, the cracking appeared to be a combination of shrinkage and flexural stresses. The nature and extent of cracking notwithstanding, the overall structural integrity does not seem to have been

compromised. However, it is prudent to review the structural calculations and details to confirm the structural adequacy of the tank.

Acceptance Criteria for Leak Testing

The tank was designed for ACI 350 Code which does not in any way guarantee a completely leak tight tank. Also, a leak-tight tank is unreasonable with unlined conventionally reinforced tank. With this applicable Code, commitment should have been to provide an "essentially leak-tight" tank to allow for some leakage per ACI 350.1. Once this ACI 350 leak tightness test is met, the concrete can be deemed to have achieved the initial condition assumed in PA. Note that all CJs have been epoxy injected along with most observable cracks sealed to minimize leakage.

However, based on the discussion at the meeting, it seems that client's expectation is to achieve a "leak-tight" tank which would require going above and beyond the requirements of the ACI 350 Code by providing either a post-tensioned base or by using appropriate liners or coatings to prevent leakage. For the existing tank in question, a liner may be preferred for the base slab while for the roof, a coating may be sufficient as it will be open for inspection and testing.

Recommendations for Repair

In my opinion, the base slab of the tank has been largely repaired to establish structural adequacy. But to achieve "leak-tight tank", either more repair or application of an appropriate coating or liner would be necessary to seal the leakage paths. The crack repair can be carried out through injection of polyurethane or similar material. However, this method may not guarantee a success path as it is nearly impossible to identify leaking cracks. To get a better location of leaking paths, a partial hydro test may be necessary to identify suspect areas from inside/outside, as appropriate.
Note that care should be taken not to fill the cable cavity or lock the movement joint at the base with the repair material. A better option would be to use a robust coating system or a liner to prevent leakage. The roof should be repaired with appropriate coating that is able to withstand seasonal temperature variations and weather exposures.

Recommendations for Future Construction

The design and detailing should be reviewed to ensure structural elements have sufficient strength and reinforcement to address not only the design basis loads but also the anticipated construction, sequencing of construction and thermal/temperature loads. In particular, special attention needs to paid to restraints to free thermal and shrinkage movements. In my opinion, ACI 350 criteria for shrinkage and temperature stresses may not be sufficient for such a large circular structure. An engineering evaluation is required to determine the reinforcement for shrinkage and thermal affects. The magnitude of tensile stresses expected in the base slab and roof with associated with concrete mix, restraints and no control joints should be determined. These shrinkage and temperature related membrane stresses need to be added to any tensile

membrane stresses developed as a result of service loads to ensure that there is sufficient reinforcement to keep cracks tight to prevent leakage under service condition.

The shrinkage characteristics of actual concrete mix need to determined and used in the above-mentioned shrinkage stresses evaluation.

The time-temperature and strength gain with time of concrete mix should be determined. This will help determine the need for any extended curing and protection of concrete and help decide appropriate time for form removal. If forms are to be removed early for the roof, early age effect should be included in calculation of deflection, creep and cracking.

Construction joint detail (Fig. 1) should be carefully reviewed as it may not be able to prevent leakage due to constructability issues. For the base slab, it may be better to use a water stop that can directly rest on the mud mat rather than at half-way depth. This will be easy to place and will ensure better leakage protection. For the roof slab, the water-stop should be preferably placed near/at the top face and can me designed and placed as an integral part of the coating system used, for example as in parking garages.

Construction sequence should be carefully engineered and planned to minimize restraints and time needed to complete the placement – see Fig. 2 for suggested placement for your consideration. The exterior thickened concrete (light blue) and the middle (dark blue) placement can be placed in a donut fashion. A gap (~5 ft) can be left between the exterior pours and interior pours to help the two pours shrink independently. When the initial shrinkage is over, the closure strip can be placed (as later as possible to allow the two pours to shrink) which will minimize the restraint forces in the base slab. To allow for multiple pours, the exterior and interior concrete placements can be subdivided in any even number of placements (see red line in Fig. 2) but the number of placements should be kept to a minimum and symmetrical to minimize uneven stress buildup.

Concrete should be wet cured for at least 7 days before applying the curing compound. Note that extended curing will be required for this mix because of presence of supplemental cementitious materials.

Concrete should be adequately protected from the environment by strictly following the specifications and industry standards for hot and cold weather concreting.

Fig. 1. Typical Construction Joint Detail Used

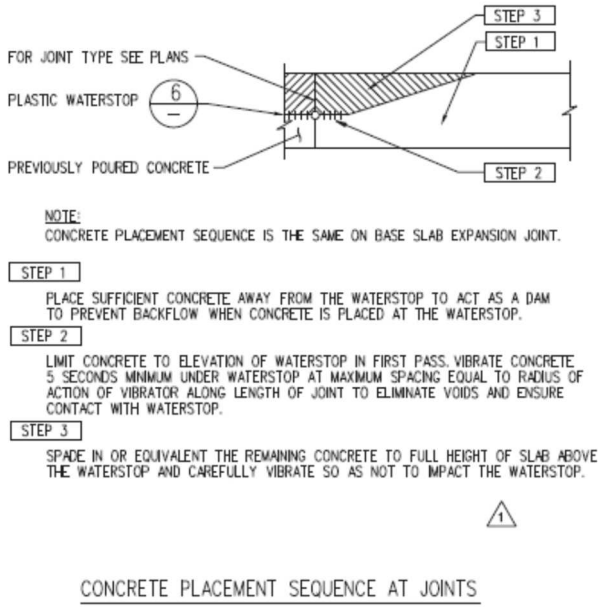
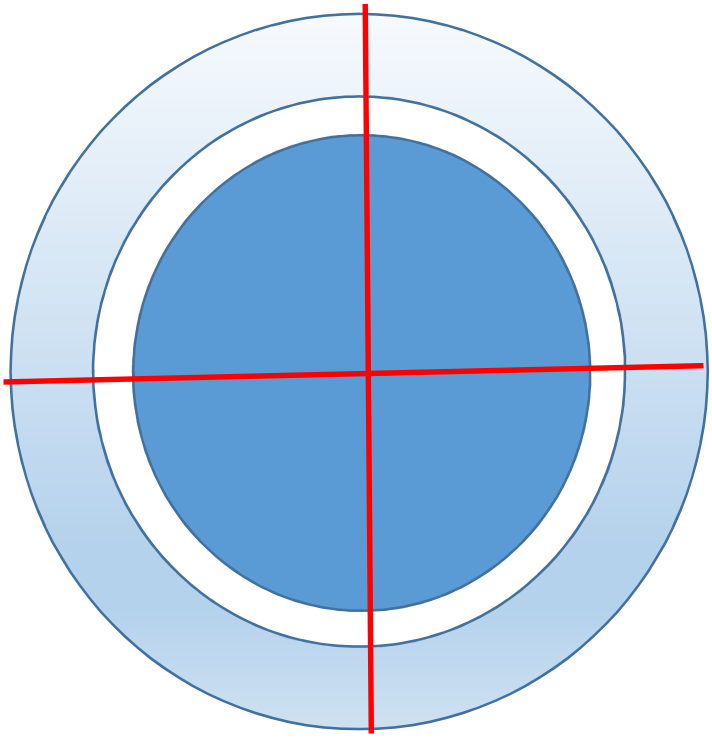


Fig. 2 Proposed Concrete Placement Sequence



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February 16, 2016

Savannah River Remediation
Saltstone Disposal Site SDU 6
Foundation and Roof Slab Cracking
Comments on Root Cause and Potential Future Remediation

Noel Chapman
SRR Project engineering Manager

Introduction: Mechanics of Crack Formation – The following is a basic reiterated, but basic description on the development of cracks in concrete as it germane to understanding the crack patterns and their formation in SDU6.S

Concrete cracks when it's principal tensile strain fails bond or it fails in shear. Shear cracking essentially occurs with differential loading and is marked by a deformation, movement along the plane of the crack. This is not the situation in SDU6 and will not be the subject of the remaining discussion.

Principal tensile strain cracks will basically occur in slab or wall type elements when there is either insufficient bond in the concrete matrix or to the reinforcing or a combination of both to resist or distribute the shrinkage strains. In the case of SDU6 it is generally agreed that the shrinkage is a result of Autogenous Shrinkage. When this occurs, the cracks will form along a line perpendicular to the resultant principal tensile strain. Slab restraint will also play a role in the direction of the resultant principal and other lessor tensile strains.

As originally put forth, there is a direct correlation to the slow setting of the use of Type V cement with a low C_3A content, slag cement and a high pozzolan contents and the development of the early cracking. The lack of bond development in either the matrix and or to the reinforcing is directly related to the sensitivity and slowness of the Project Type V Mix concrete mix setting time which can and will be effected by some external influences such as concrete placing and ambient temperatures. There is more than sufficient reinforcing to adequately distribute the concrete tensile strains if bond was present. The occurrence and orientation of the cracks is also exacerbated by various restraints to shrinkage movements. The placing ambient temperatures were recorded for each of the slab sections but no information was given for the actual temperature of the concrete being placed. i.e., was it cooled or heated for given situations?

Compensation for the autogenous shrinkage can be one with the use of shrinkage compensating cement as mentioned in your referenced paper "Mitigation Strategies for Autogenous Shrinkage Cracking" by Bentz and Jensen dated August 2004. In the case of the ARS SDU concrete, the introduction of another cement/concrete mix, cement, especially one the creates ettringite, has not faired well with respect to the need and the time to retest it to meet the SRS Remediation criteria.

The use of fibers in the existing mix, as was proposed in my letter of 2-12-16, could well be used without compromising the accepted SRS concrete Type V mix. Pretesting of the use of fibers and bentonite sealing is also covered in my 2-12-16 letter report.

The use of a single placement of the base slab was suggested as an alternate to eliminate the sectional placement restraints but I do not recommend that approach because of the complexities involved. I have participated in many placements much larger than this slab and I do not believe this would prove to be a simple or even satisfactory solution. There is more than sufficient rebar in the current design.

All are in agreement that the elimination of the checkerboard placing pattern would be a change in the right direction without the need to change and retest the SRS Type V mix properties.

However, the use of a non-chloride accelerator could prove to be a viable alternate to tailor a decrease in the setting time to achieve an earlier bond development without retesting the SRS Type V concrete mix.

Roof Cracking; Considering the beginning explanation on the mechanics of concrete cracking I believe that an examinations of the crack pattern of the roof cracking as portrayed in the Underside Roof Cracks will provide a different conclusion.

Given that the cracks will occur perpendicular to the resultant principal tensile strain(s), the roof cracks as depicted do not exhibit that pattern. As constructed, the roof slab essentially spans from the perimeter walls to the interior columns or column bands. As such, any flexural cracking must occur in a circumferential pattern to match the strains in the reinforcing. In the case of the bottom of the roof slab, the cracks would also have to occur in the middle of the span, not at the support locations. Further, the cracks shown near the perimeter wall are basically radial and not circumferential. Similar cracking studies can be made for the interior and roof panels to confirm the non-flexural shrinkage pattern.

The forms were apparently left in place for a number of days such that the early shrinkage cracking would not be evident.

In summary, the roof cracking is again shrinkage and not flexural, for the same reason that the shrinkage has been postulated to occur in the base slab and therefore solutions to mitigate the cracking should follow the means derived for the base slab.

Further, since the roof cracks are not flexural, there is no need to keep the forms on longer than 7 to 10 days if there is any advantage to removing and/or moving them. Even though the present Type V project mix is initially slow in developing set time and bond in the first day or so, it should be well towards 5,000 psi compressive strength after 7 days and be fully capable of performing it structural performance with dead load only.

Section 1 Restraint Romment: -My comment at the later part of the Wednesday site meeting regarding the circumferential cracks in the “free” outer part Section 1 was to illustrate the sensitivity as to when the concrete bond properties are being developed and the influence of restraints have on the crack development. The point being made was that even the change in stiffness of the slab itself, by nature of its thickness and natural restraint by the mud mat (HDPE protecting slab) was enough to cause the

shrinkage principal resultant strain to be radial and consequentially the larger cracks occurred circumferentially along the stiffer wall bearing section.
Note that I only have the crack maps for the underside of the roof and base Slab Sections 1 and 5, and have based my cracking evaluation based on them being indicative of the rest of the slab cracking patterns. Section 5 crack Map does further illustrate the cracks occurring via the resultant tensile restraint strains from the previous placed slabs.

Again, thanks for the forwarded paper on "Mitigating Shrinkage Cracks". It does fully support my evaluations and carries the same essentials I have been proposing since my involvement with the SDU6 cracking and construction issues.

Prepared by,

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