Grout Long Radius Flow Testing to Support Saltstone Disposal Unit 6 Design – 13352

D. B. Stefanko[*], C. A. Langton[*], M. G. Serrato[*], T. E. Brooks, II[**], and T. H. Huff[**]

[*] Savannah River National Laboratory, Savannah River Nuclear Solutions, LLC
[**] Savannah River Remediation, LLC,
Savannah River Site, Aiken, SC 29808

ABSTRACT

The Saltstone Facility, located within the Savannah River Site (SRS) near Aiken, South Carolina, consists of two facility segments: The Saltstone Production Facility (SPF) and the Saltstone Disposal Facility (SDF). The SPF receives decontaminated legacy low level sodium salt waste solution that is a byproduct of prior nuclear material processing. The salt solution is mixed with cementitious materials to form a grout slurry known as "Saltstone". The grout is pumped to the SDF where it is placed in a Saltstone Disposal Unit (SDU) to solidify.

SDU 6 is referred to as a "mega vault" and is currently in the design stage. The conceptual design for SDU 6 is a single cell, cylindrical geometry approximately 114.3 meters in diameter by 13.1 meter high and is larger than previous cylindrical SDU designs, 45.7 meters in diameter by 7.01 meters high (30 million gallons versus 2.9 million gallons of capacity). Saltstone slurry will be pumped into the new waste disposal unit through roof openings at a projected flow rate of about 34.1 cubic meters per hour. Nine roof openings are included in the design to discharge material into the SDU with an estimated grout pour radius of 22.9 to 24.4 meters and initial drop height of 13.1 meters.

The conceptual design for the new SDU does not include partitions to limit the pour radius of the grout slurry during placement other than introducing material from different pour points. This paper addresses two technical issues associated with the larger diameter of SDU 6; saltstone flow distance in a tank 114.3 meters in diameter and quality of the grout.

A long-radius flow test scaled to match the velocity of an advancing grout front was designed to address these technology gaps. The emphasis of the test was to quantify the flow distance and to collect samples to evaluate cured properties including compressive strength, porosity, density, and saturated hydraulic conductivity.

Two clean cap surrogate mixes (saltstone premix plus water) were designed to simulate slurry with the reference saltstone rheology and a saltstone with extra water from the process flushing operation. Long-radius flow tests were run using approximately 4.6 cubic meters of each of these mixes. In both tests the pump rate was 0.063 liters/second (1 gpm). A higher pump rate, 0.19 liters/second (3 gpm), was used in a third long-radius flow test.

The angle of repose of the grout wedges increased as a function of time in all three tests. The final angles of repose were measured at 3.0°, 2.4°, and 0.72°. The pump rate had the largest effect on the radial flow distance and slope of the grout surface. The slope on the pour placed at 0.19 liters/second (3 gpm) was most representative of the slope on the grout currently being pumped into SDU 2 which is estimated to be 0.7° to 0.9°. The final grout heights at 1/3 of a meter from the discharge point were 115, 105, and 38 cm.

Entrapped air (≥ 0.25 cm bubbles) was also observed in all of the mixes. The entrapped air appeared to be released from the flows within about 3.1 meters (10 feet) of the discharge point. The bleed water was clear but had a thin layer of floating particulates. The bleed water should be retrievable by a drain water collection system in SDU 6 assuming the system does not get clogged. Layering was observed and was attributed to intervals when the hopper was being cleaned. Heat from the hydration reactions was noticeable to the touch.

INTRODUCTION

Objective

The objective of this work was to provide data to close technology gaps and address technical issues identified in the Saltstone Disposal Unit 6, the proposed next generation saltstone disposal unit. More specifically data are needed to: 1) document the flow radius as a function of time and pump rate from a single discharge point and 2) determine whether pour radius impacts the quality of the grout.[1]

Background

A new disposal unit, SDU 6 is being designed by the Savannah River Remediation (SRR) Project Team to support the accelerated closure goals and salt waste disposition projections identified in the Liquid Waste System Plan [1]. The conceptual design for SDU 6 is a single cell, cylindrical concrete disposal unit approximately 114.3 m (375 ft.) in diameter by 13.1 m (43 ft.) high. This disposal unit has approximately ten times the capacity of the existing disposal cells [2].

The conceptual design for the new SDU does not include partitions to limit the pour radius of the saltstone slurry during placement. Nine roof openings are included in the design to discharge saltstone into the SDU with an estimated grout pour radius of 22.9 to 24.4 meters and initial drop height of 13.1 meters.

APPROACH

Large-scale flow tests were determined to be the best approach for correlating rheological properties measured on laboratory samples to realistic flow characteristics and behavior. Because of the expense and hazardous nature of simulated salt solution (pH ~ 14), clean cap formulations (premix and water plus admixtures as necessary) were identified as being appropriate for the large-scale testing. A review of saltstone and clean cap fresh property data and bench-scale testing were performed to identify clean cap mixes that represented a range of saltstone rheologies.

A wedge shape form with radius of 57.3 m (188 ft.) was scaled with respect to arc angle to represent a sector of the 114.3 meter (375 ft.) tank. Velocity of the advancing grout front as a function of discharge rate was used as the scaling parameter. Additional scaling parameters included a wedge angle and a leading edge thickness parameter. The scaling calculations also assumed that the material flowed from the center outwards in a uniform wedge [3]. The Sketches of these forms are provided in Figures 1 and 2.

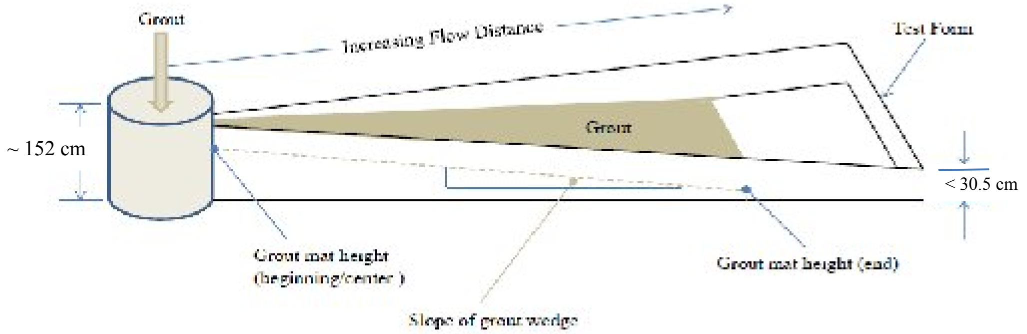

Figure 1. Schematic drawing illustrating the long-radius test configuration.

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[1] Quality refers to cured properties which control long term performance with respect to retention of contaminants of concern.

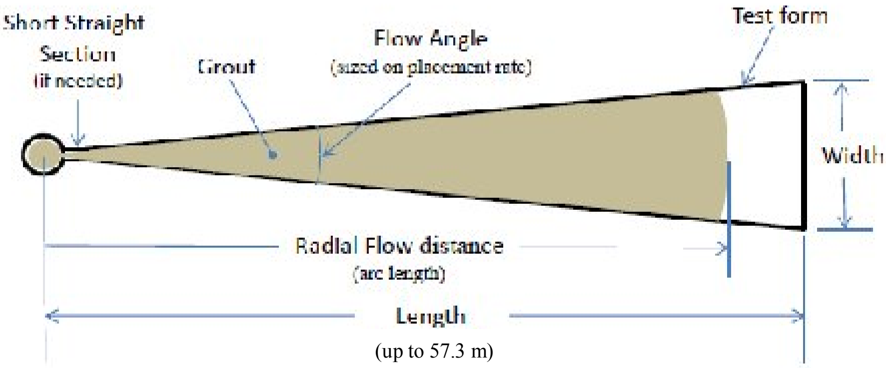

Figure 2. Plan view of the long radius test stand.

Gibson's Pressure Grouting Service, Inc., Smyrna GA was contracted to perform the long-radius flow test. The long-radius flow tests were recorded with a video camera and photographs. During the flow tests, the slurry rheological properties were evaluated for samples collected from the discharge hose. After the tests were completed, core and grab samples were collected at several locations along the form. The core samples were taken by driving 7.62 cm (3 inch) ID PVC pipes into the grout at selected locations. The grab samples were collected in a container at different locations. These samples were homogenized and used to cast 7.6 x15.2 cm (3x6 inch) cylinders which were placed in a moist cooler to cure. The core samples were removed from the test stand within 12 hour after the end of the test as part of the grout removal process. The samples are being cured for a minimum of 28 days, after which the quality of the cured material will be evaluated.[2] The evaluation will compare the quality of the cured materials as a function of distance from the grout discharge point for a given cure time.

The samples locations for tests T10, T11, and T12 are listed below. At the present time, only samples for test T12 will be evaluated for cured properties. Distances identified are from the discharge point.

Table I. PVC Pipe Core and Cylinder Sample Locations

Test	1.52 m (5 ft)	4.57 m (15 ft)	7.62m (25 ft)	10.7 m (35 ft)	13.7 m (45 ft)	16.8 m (55 ft)	19.8 m (65 ft)	21.3 m (70 ft)	22.9 m (75 ft)	27.4 m (90 ft)
T10			x	x	x	x	x			
T11			x	x	x	x	x	x	x	
T12	x	x	x	x	x	x	x	x	x	x

SALTSTONE AND CLEAN CAP RHEOLOGY

Saltstone Rheology: Characterization of the saltstone slurry prepared from the Tank 50 salt solution has been limited to gel time/settling rate, bleed volume and set time evaluations via a pour test and set time.[3] Rheological data has also been measured for saltstone prepared with actual Tank 50 salt solution [4]. Most of the rheological data reported for saltstone has been obtained from simulated non-radioactive samples

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[2] Compressive strength, saturated hydraulic conductivity, and porosity will be measured by a subcontractor, AMEC and SRNL.

[3] This work is performed in the SRNL shielded cells where time dependent slurry characterization is difficult.

prepared in the laboratory. These data have been applied to pumping evaluations (pump pressure, pipe diameter, flow regime, etc.) and to redesign of the slurry hopper [5].[4]

Ranges for saltstone slurry consistencies (plastic viscosities) and Bingham Plastic yield stresses were identified in the SDU 6 Task Requirements and Criteria Document Modification Traveler (MT-SS-2011-00010) [6] and are provided below:

- Grout viscosity (consistency): 55.93 to 202.20 mPa-s *(55.93 to 202.20 cP)*
- Grout yield stress: 2.03 to 10.82 Pa *(2.9E-04 to 15.7E-04 psi, 0.424 to 0.226 psf)*

Additional rheological data for saltstone prepared with simulated salt solutions in the laboratory are listed in Table II. The wide ranges in values are due to variability in salt solution compositions, salt loadings, water to premix ratios, and mixing methods used in these studies.

Table II. Summary of Simulated Saltstone Rheological Data from Laboratory Samples.

Reference	Consistency (cP)	Yield Stress (Pa)	Segregation
SRNL-STI- 2011-00665 [7]	56 - 202	2 – 11	Not reported
WSRC-TR-2005-00158 [8]	36 (blender) – 90 (stir)	8.5 (blender) – 8.1 (stir)	Very slight
SRNL-STI-2012-00558 [9]	41 – 138 w/pm = 0.5-0.7 (300 rpm paddle)	2 – 10 (300 rpm paddle)	Measurable at 1 day
WSRC-TR-2005-00447 [10]	43-103 w/pm = 0.5-0.65 (blender and 500 rpm paddle)	1.8 – 9.7 w/pm = 0.5-0.65 (blender and 500 rpm paddle)	0 – 4.9% Measured at 3 days

Saltstone Flow Profiles: Measurements of the flow profile (angle of repose) and flow rates during actual saltstone placements are very limited. The primary source of flow data is descriptive observations of flow patterns in SDU 2 and Cells in Vault 4. Recently, the time for saltstone slurry to reach the wall of SDU 2 and the height of the pour on the wall of SDU 2 were reported [11].

Clean Cap Rheology: Limited rheological data are available for clean cap formulations. Data were collected on samples prepared in the laboratory and on material mixed from commissioning a 2-inch Readco processor for SRNL scaled mixer studies [12] and mixer design evaluations based on results from a 5-inch Readco processor [13]. The resulting data are summarized below.

Table III. Summary of Clean Cap Slurry Rheological Data.

Reference	Consistency (cP)	Yield Stress (Pa)	Segregation
WSRC-TR-2005-00158 [8]	14 – 152 w/pm = 0.7 to 0.5 blender and stirred	3.5– 18 w/pm = 0.7 to 0.5 blender and stirred	Slight
SRNL-L3100-2012-00042 [12]	49 w/pm = 0.62 (Readco 2-inch mixer)	13.4 w/pm = 0.62 (Readco 2-inch mixer)	Not reported
SRNL-L3100-2011-00056 [13]	38 – 177 w/pm = 0.7 – 0.5 (Readco 5-inch mixer)	7 – 25 w/pm = 0.7 – 0.5 (Readco 5-inch mixer)	Not measured
SRNL-STI-2011-00465 [5]	Not considered	5 – 7 Surrogate saltstone, clean cap fluid	Not measured

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[4] Slurry data needed for pumping evaluations include flow curves (fluid response to shear) which provide flow behavior, consistency and yield stress; density; slurry stability (tendency to segregate which is a function of fluid properties and particle properties i.e., size, density, shape, etc.); and temperature.

CLEAN CAP SIMULANT MIXES AND LONG-RADIUS TEST CONFIGURATION

Selection of Mixes for the Long-Radius Flow Test: Three saltstone mixes were identified as representing slurries produced in the Saltstone Facility (reference saltstone with a water/premix (w/pm) ratio = 0.60). Another slurry represented a mixture of the reference material and 8 volume percent flush water (w/pm ratio = 0.74). The third slurry was similar to the first but had a slightly lower yield stress and a the initial w/pm ratio has been lowered to 0.59 in attempt to reduce bleed water.

The clean cap surrogate mix selected to represent reference saltstone was identified as CC1. The clean cap mix selected to represent saltstone plus 8 volume percent flush water was identified as CC2. Mix CC1A was a slight modification of CC1 and was selected to represent a clean cap mix with a lower yield stress. The target consistencies and yield stresses of these mixes are listed in Table IV.

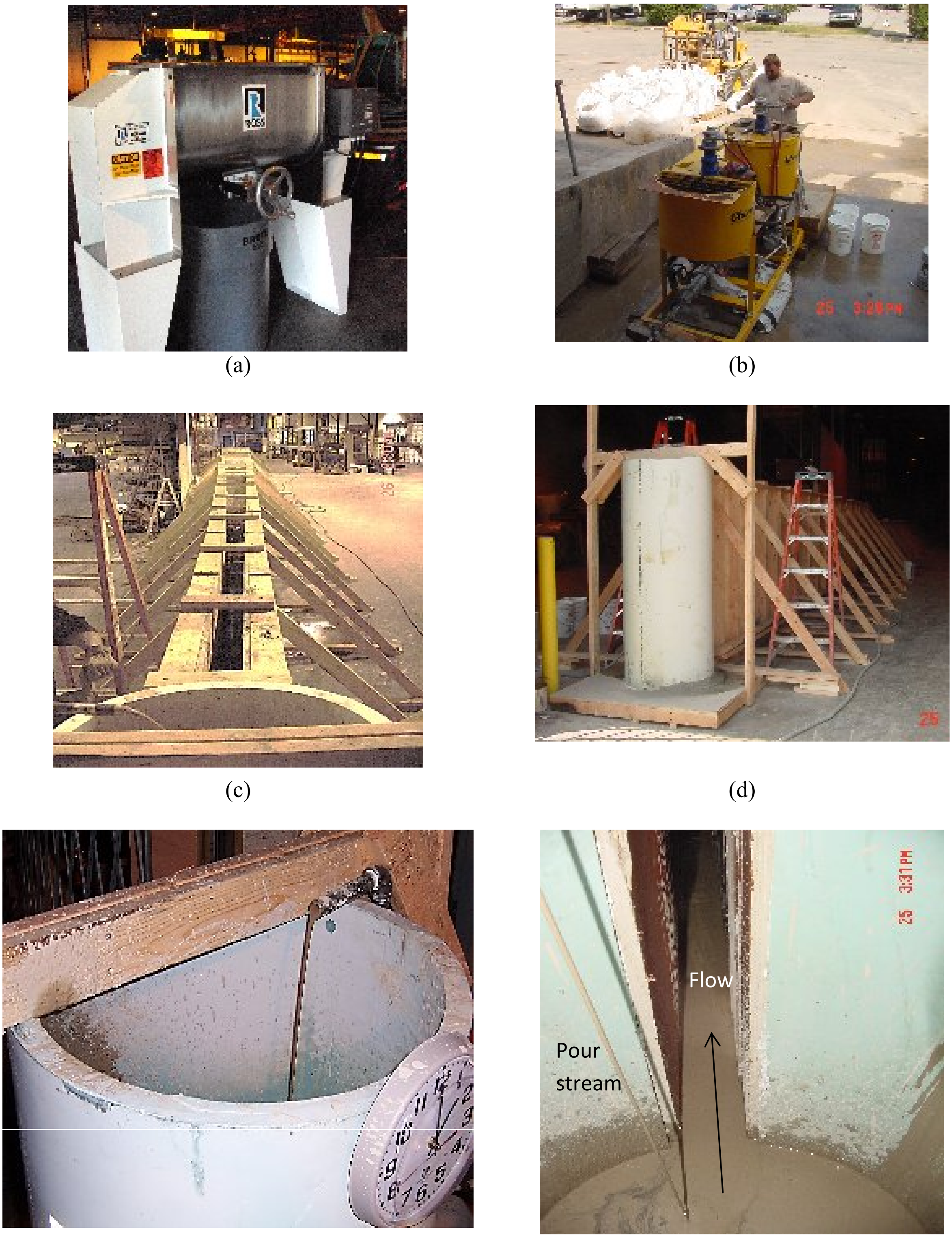
Comparisons of the reference saltstone and clean cap rheologies show that clean cap mixes reasonably simulate the reference saltstone consistencies, but in all cases the yield stresses for the clean cap mixes were about 2 to 3 times higher than those for comparable saltstone slurries.

Table IV. Target Saltstone and Initial Clean Cap Rheology Data for the Long-Radius Flow Test.

Mix ID and Description	w/pm	Consistency (cP)	Yield Stress (Pa)
Reference Saltstone prepared from 2011 Tank 50 WAC Simulant Laboratory paddle mixer, Temp 25° C	0.60	85	10
CC1 Laboratory paddle mixer, Temp 25.5° C	0.54	75	16.3
Saltstone prepared from 2011 Tank 50 WAC Simulant + 8 wt% flush water Laboratory paddle mixer, Temp 25.5° C	0.74	39	3.3
CC2 Laboratory paddle mixer, Temp 25.5° C	0.62	39	9
CC1A + admixture to reduce yield stress, consistency, and bleed compared to CC1 Laboratory paddle mixer, Temp 25.5° C	0.53	72	3.4

Long-Radius Test Configuration: The test configuration for the long-radius flow test is illustrated in Figure 3. Cement, slag and fly ash were procured from the same vendors that supply the Saltstone Facility with cementitious reagents. These reagents were weighed in the reference premix proportions (cement/slag/fly ash = 10/45/45 wt. %) and mixed in a Ross ribbon blender a few weeks prior to the long-radius flow tests. See Figure 3a. Fifty four bags of premix were blended for each 4.59 cubic meter (6 cubic yard) flow test, T10 and T11. Each bag contained material for preparing 0.085 cubic meters (3 cubic feet) of grout. The bags for Clean Cap mix CC1 contained 90.4 kg (199.4 lbs.) and those for CC2 contained 86.8 kg (191.3 lbs.) of premix. The water to cementitious ratios for these two mixes was 0.54 and 0.62, respectively. Forty bags containing 85.0 kg (187.4 lbs.) of premix were used for T12. The water to premix ratio for this mix was 0.53 and an admixture was used to bring the yield stress of the mix in line with saltstone data [4, 6, 7, and 8]. Water was weighed at the mixer.

The test stand was constructed of exterior grade plywood and screwed together so that it could be disassembled after each test for cleaning and then reassembled for the next test. It was set up on a level concrete floor in a covered warehouse. The form was leveled to within 2.54 cm (1 inch) over the length of the test stand, i.e., 53.3 meters (175 ft.). The seams were caulked and the surfaces of the plywood were sealed with curing compound to prevent water absorption. Form ties and bracing were used to provide structural stability.



(a) (b)

(c) (d)

(e) (f)

Figure 3. Long-radius flow test configuration. (a) Ross ribbon blender used to prepare premix. (b) ChemGrout® 6 cubic foot mixer and progressive cavity pump used to prepare and pump the

clean cap surrogate slurries. (c and d) Long-radius test stand. (e and f) Discharge into test stand and flow through 4 inch slot.

The grout was mixed in a double tub ChemGrout® paddle mixer with a capacity of 0.17 cubic meters (6 cubic feet). See Figure 3b. The batch size for tests T10 and T11 was 0.085 cubic meters (3 cubic feet). The batch size for test T12 was somewhat less than 0.085 cubic meters because premix material had been prepared for a higher w/pm formulation. Material was recirculated at the hopper through a 5.08 cm (2 inch) gate valve and rubber grout hose while at the same time a portion of the grout was being pumped through a 1.91 cm (¾ inch) line to the form. Grout flow was regulated with valves. The mixing time was about 10 minutes. The grout hold-time plus recirculation time was 20 to 25 minutes to achieve a discharge rate of 0.063 liters per second (1 gpm) in tests T10 and T11. For test T12, the grout discharge rate was 0.189 liters per second (3 gpm) and the hold-time plus recirculation time was about 7 minutes.

The grout slurry was pumped to the top of a thick walled PVC pipe stand (6 feet high by 2 feet in diameter) and discharged near the slot in the pipe at the head of the test wedge form. See Figures 3c to 3f. A six stage rotary progressive cavity pump was used. The system was pneumatically operated and discharge was controlled manually using a recirculation loop at the grout hopper and air adjustments to the pump. The grout flowed into the long-radius test stand through a 10.2 cm (4 inch) wide by 152 cm (5 feet) high slot in the PVC pipe. See Figure 3f. Grout was batched and continuously pumped into the form except for the times required to clean the hopper and to re-establish the 3.79 ± 0.38 liters per minute (T10 and T11) and 11.4 ± 1.14 liter per minute (T12) flow rates.

RESULTS AND OBSERVATION

Grout Slurry Rheology: Samples were collected from the discharge pipe at the test stand during each test to monitor and adjust the grout rheology. The target rheological properties and rheological properties from samples collected during long-radius tests T10-CC1, T11-CC2, and T12-CC1A are listed in Tables IV, V, and VI respectively. The grout temperature fluctuated throughout the test and was attributed to changes in ambient temperature and heat added due to the grout recirculation process. Minor admixture adjustments were required occasionally to maintain the grout rheology.

Table IV. T10-CC1 Grout Slurry Rheological Properties and Temperature.

T10-CC1			
Date and Time	**Consistency (cP)**	**Yield Stress (Pa)**	**Temperature (°C)**
Start 9/20/12, 14:15	Target 50 – 85	Target 8 – 10	22.0
14:47	74.2	12.5*	Not measured
15:12	61.7	10.4*	Not measured
15:50	53.2	5.8	29.4
17:42	56.7	8.7	30.5
20:04	50.6	8.3	27.9
21:53	52.7	7.9	29.2
23:28	58.5	10.0	29.2
9/21/12, 01:37	66.6	9.2	26.5
04:28	51.8	9.1	26.4
	58.4 Average	9.1 Average	28.4 Average

* These samples were collected from the mixing tub instead of the discharge point.

Table V. T11-CC2 Slurry Rheologies.

T11-CC2			
Date and Time	**Consistency (cP)**	**Yield Stress (Pa)**	**Temperature °C**
Start 9/25/12, 08:39	Target 20 – 40	Target 3 – 6	22.0
11:02	25.4	7.0	33.2
12:12	27.0	6.2	33.2
13:40	27.6	7.1	36.7
14:57	27.7	6.9	31.2
16:13	25.4	5.7	35.2
18:03	23.5	5.5	35.2
19:31	22.7	3.5	30.4
22:38	23.7	4.1	28.0
9/26/12, 00:37	28.9	5.2	26.2
03:08	29.2	5.3	25.9
	26.8 Average	6.0 Average	30.4 Average

Table VI. T12-CC1A Slurry Rheologies.

T12-CC1A			
Date and Time	**Consistency (cP)**	**Yield Stress (Pa)**	**Temperature °C**
Start 10/4/12, 12:25	Target 20 – 40	Target 3 – 6	22.0
13:11	69.0	8.0	25.0
13:27	57.6	6.3	27.8
13:49	48.8	3.9	27.4
14:15	62.1	5.6	NM
14:41	51.5	4.4	27.7
16:21	87.2	7.0	26.7
16:49	47.9	4.3	27.0
17:04	49.1	4.5	26.4
	64.0 Average	5.5 Average	27.3 Average

Flow Observations: Photographs and video recordings of the grout flow behavior were taken for the three tests, T10, T11 and T12. In all cases, entrapped air was observed being released from grouts at the head of the form. This was best illustrated during test T12 (3 gpm discharge rate). See Figure 4a. Bleed water and floating black fines were also observed in the discharge pipe at the front end of the test stand. See Figures 4a and 4b, tests T12 and T11, respectively.

In all of the tests, a sheet of bleed water covered the entire pour surface and advanced ahead of the leading edge of the grout. In all cases the bleed water was clear except for a thin layer of floating particles. See Figures 4c and 4d.

Both the grout and bleed water formed meandering channels as the angle of repose increased during the test. The steeper the slope of the top surface the narrower the meandering channels. The slope was inversely correlated to the discharge rate, i.e., the higher the discharge rate the flatter the slope. (Compare the surfaces developed during tests T11 and T12 in Figures 5a and 5b.)

The progression of the flow had at least three distinct features. The first was fresh grout flowing over stagnant grout as thin sheets which formed a rippled surface or in channels. This was observed through the Plexiglas observation windows in the form and was apparent at all of the windows. The second was sluffing or slumping of wedges of grout on sloped surfaces in the midsections of the flow. The third was fresh grout pushing material at the leading edge of the pour. Slower moving strips of material (few inches wide) were observed along the sides of the forms in all three tests and was interpreted as resulting from friction between the form walls and grout. See Figure 5c.

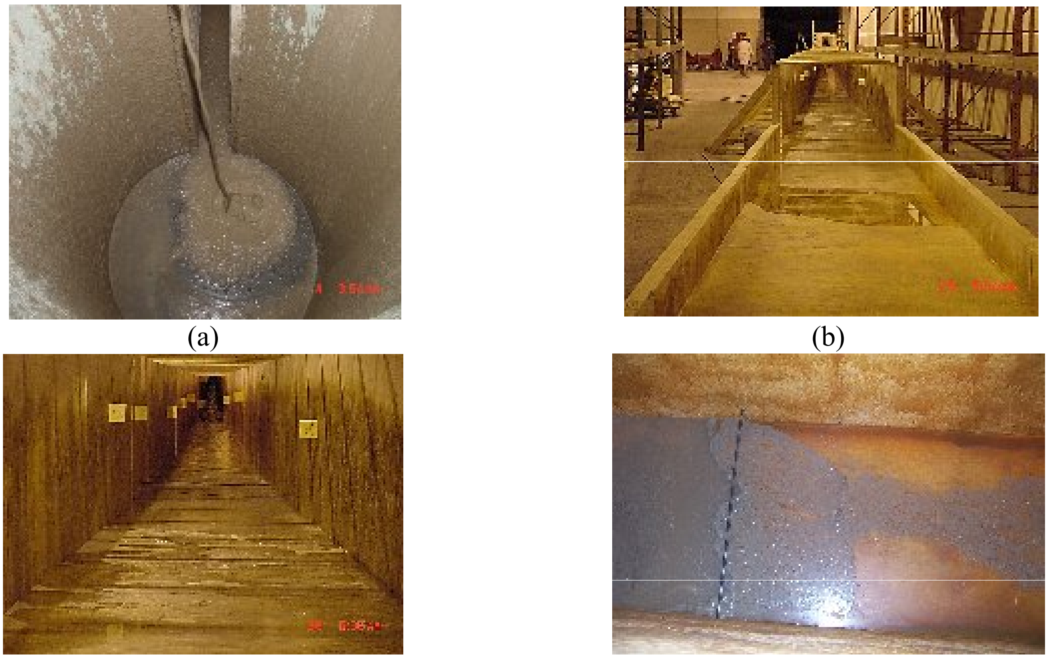

(a) (b)
(c) (d)

Figure 4. (a) Grout in the test stand illustrating entrained air and bleed water at head of test stand in T12. (b) T11 grout-bleed water interface. (c) T11 grout-bleed water interface. (d) Close up of final grout-bleed water interface for T10.

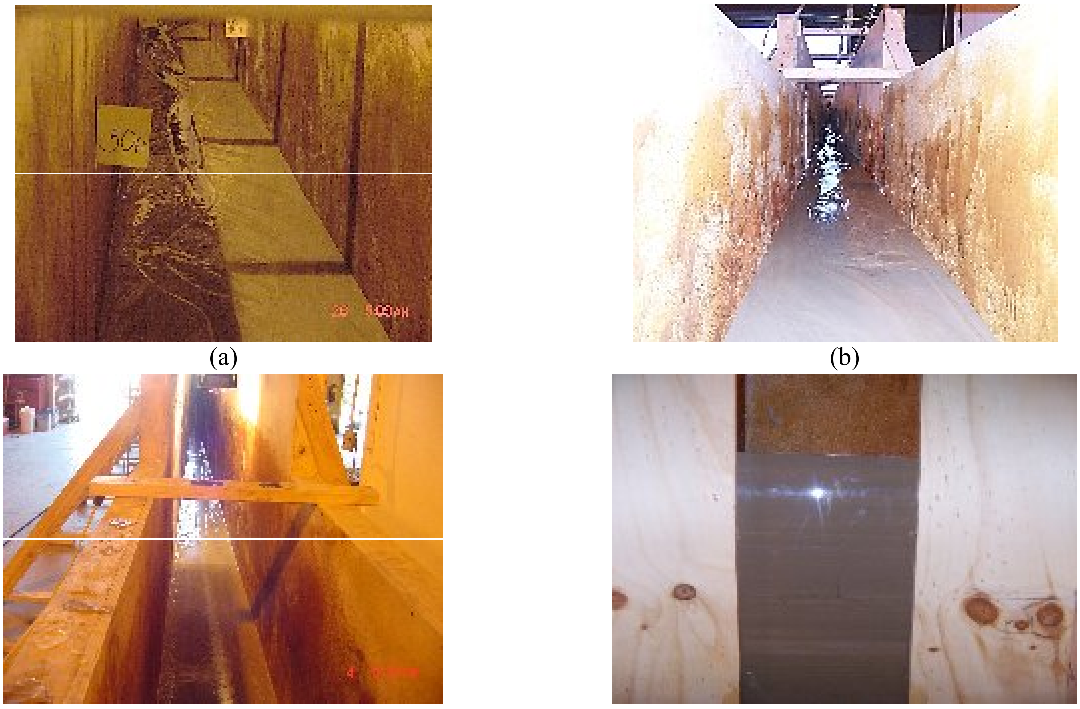

(a) (b)
(c) (d)

Figure 5. Grout flow in the test stand. (a) Narrow meandering channel and rippled surface characteristic of the test T11. (b) Medium meandering channel characteristic of the T10

surface. (c) Straighter flow channel characteristic of the T12 surface. (d) Striations in the flow as viewed through the Plexiglas® window about 61cm from the discharge point.

The thickness of the grout leading edge was 5 to 7 mm throughout the tests. The leading edges of the grout were sharp and well differentiated from bleed water which advanced ahead of the grout. See Figures 4d and 4b. Striations were observed in cross section views of the flow. See Figure 5d.

Grout Profiles: Grout heights in the form were measured several times during each run. The final grout heights about 30.5 to 61 centimeters (1 to 2 feet) from the discharge point were 115, 105, and 38 cm, in tests T10, T11, and T12, respectively. In T10-CC1, six cubic yards of the clean cap mix simulating reference saltstone (w/pm = 0.60) flowed about 22.3 m (73 ft.). In T11-CC2, six cubic yards of the clean cap mix simulating reference saltstone with 8 volume % flush water (w/pm = 0.74), flowed about 24.4m (80 ft.). In T12-CC1A, 4.4 cubic yards of the clean cap mix simulating saltstone grout with the most representative yield stress, i.e., 3 to 5 Pa flowed about 29 m (95 ft.).

Grout surface profiles as a function of run time are provided in Figure 6 for tests T10-CC1, T11-CC2, and T12-CC1A, respectively. The angles of repose of the grout in the test form were calculated for each time depth measurements were made. The final angles of repose of the grout in the test forms were 3.0º, 2.4º, and 0.72º, respectively. A summary of the data from the three SDU 6 long-radius test is provided in Table VII.

Table VII. Summary of SDU 6 Grout Flow Data.

	Total Grout Volume Placed (m^3)	Elapsed Run Time (hours)	Grout Height at Head of Test Stand (cm)	Grout Flow Distance (m)	Grout Height Furthest Flow Distance (mm)	Bleed Water Flow Distance (m)	Angle of Repose for Final Surface
T10-CC1	4.59	18.3	115	22.3	5 - 7	41.1	3.0º
T11-CC2	4.59	20.4	105	24.4	5 - 7	42.7	2.4º
T12-CC1A	3.36	4.67	38.1	29.0	5 - 7	36.6	0.72º

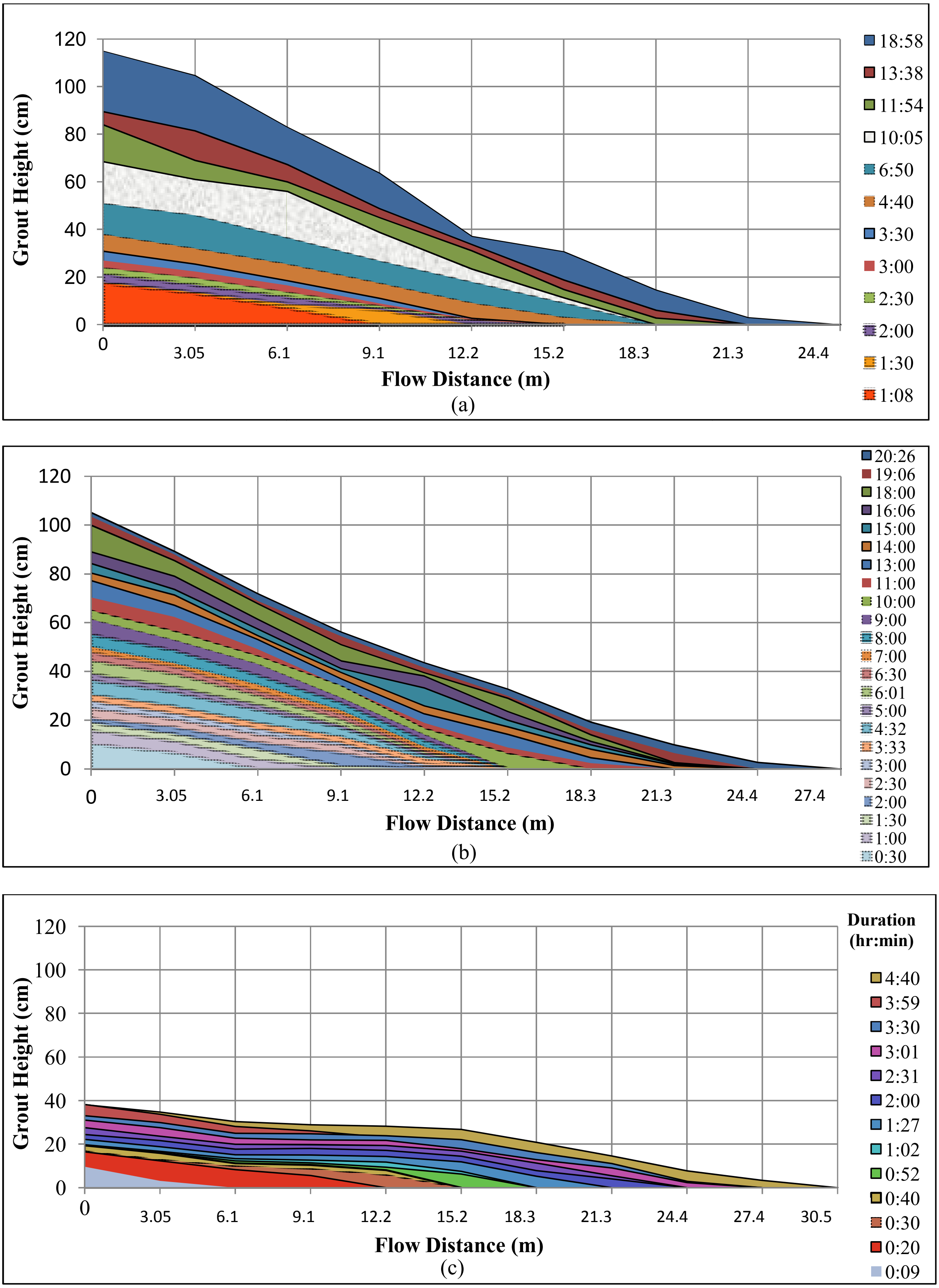


Figure 6. Surface profiles for long-radius pours: (a) T10-CC1, (b) T11-CC2 and (c) T12-CC1A

Upon completion of each test, grab samples and core samples were collected from material in the test stands. The grab samples were cast in 7.62 x 15.2 cm (3 x 6 inch) cylinders and placed in a cooler containing water to cure. For the core samples, PVC pipe with 7.62 cm inside diameter were driven into the grout and extracted after the form was dismantled. The excess PVC pipe was cut off and the samples were placed in a cooler to cure.

At the end of each test, the form was dismantled and cleaned. The final grout profile and core samples before and after removal from the test stand are illustrated in Figure 9. The quality of the cured grout collected as a function of distance from the discharge point will be evaluated after the samples have cured for 28 to 54 days. Compressive strength was measured per ASTM C 39, saturated hydraulic conductivity was measured per ASTM D 5084 Method F, and porosity was measured per ASTM C 642.

(a) **(b)**

Figure 9. Final grout profiles and core samples. (a) T11-CC2 final profile and core sample. (b) Core samples from T10-CC1 long radius flow test.

SUMMARY AND CONCLUSIONS

A scaled test stand was designed and constructed to evaluate saltstone flow as a function of distance from the discharge point. Six cubic yards (~ 4.59 m^3) of each two clean cap mixes were prepared and pumped into a long-radius test stand at 0.063 liters per second (1 gpm). These mixes were designed to be representative surrogates for a reference saltstone grout and a reference saltstone grout with 8 volume percent flush water.

In test T10, the clean cap surrogate used to represent reference saltstone flowed to about 21.3 m (73 ft.) in 18 hr. and 26 min. In test T11, the clean cap surrogate used to represent reference saltstone plus 8 volume percent flush water flowed to about 24.4 m (80 ft.) in 20 hr. and 26 min. In test T12, the clean cap mix modified to represent a reference saltstone with a slightly lower yield stress and pumped at 0.19 liters per second (3 gpm) rather than 0.063 liters per second (1 gpm) flowed to about 30 m (95 ft.) in 4 hr. and 40 min. About 27 % less material was placed in T12 compared to the tests T10 and T11. The higher discharge rate achieved a flatter angle of repose because the higher velocity increased the linear travel distance and consequently lessened the effect of settling near the discharge point.

The angle of repose of the grout wedges increased as a function of time in all three tests. The final angles of repose were 3.0º, 2.4º, and 0.72º for T10, T11, and T12, respectively. The values for both tests run at 0.063 liters per second (1 gpm) were higher than recent observations in SDU 2 reported by A. V. Staub who estimated an angle of repose for actual saltstone slurry of about 0.7º to 0.9º [11]. Test T12 run at 0.19 liters per second (3 gpm) was comparable to the observation in SDU 2.

Increasing the discharge rate from 1 to 3 gpm had the largest effect on the flatness of the grout surface. Well defined meandering channels were most obvious on the surface of T11, the grout wedge that developed the second highest angle of repose. Meandering channels were least apparent on the surface of the T12 grout, i.e., lowest angle of repose.

All of the clean cap mixes used as surrogates were physically unstable as indicated by formation of bleed water. Bleed water was observed in the test stand within 0.61 to 0.91 meter (2 to 3 feet) of the discharge point which was inside a 61 cm (24 inch) pipe, on the surface of the grout wedge throughout the test, and ahead of the advancing grout front.

Bleed water is an indication of settling and compaction which contributed to build up of material near the point of placement. Physical instability of any slurry resulting in settling/bleed hinders flow and particles transport by the carrier fluid.

Grout heights in the form were measured several times during each run. The final grout heights about 0.31 to 0.61 meter (1 to 2 feet) from the discharge point were 115, 105, and 38 cm, in tests T10, T11, and T12, respectively.

Entrapped air (≥ 0.25 cm bubbles) was also observed in all of the mixes. The entrapped air appeared to be released from the flows within about 10 feet of the discharge point. Solids were observed to settle out of the fluid phase within the first 3.05 m (10 feet) of the form. This was expressed as bleed water accumulation on top of the flow. Settling of solids from the fluid phase was considered more determinant of flow/spread distance and angle of repose than rheology or gelation, i.e., development of slurry structure due to hydration reactions.

The thickness of the grout leading edge was 5 to 7 mm throughout the tests and the leading edge of the grout was well differentiated from bleed water which advanced ahead of the grout. The bleed water was clear but had a thin layer of floating particulates. The bleed water should be retrievable by a drain water collection system during actual application assuming the system does not get clogged by the floating particles. The bleed water did not set into a low quality grout past the grout front edge. Layering was observed and was attributed to intervals when the hopper was being cleaned. Heat from the hydration reactions was noticeable to the touch. The quality of the grout as a function of distance from the discharge point will be evaluated by measuring properties of cured samples collected as a function of flow distance.

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