This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

WSRC-TR-2004-00626, Rev 0

Key Words:
Grout
Flow
Scale-up testing

Retention: Permanent

CASCADE LINE TESTING FOR HANFORD SINGLE-SHELL HLW TANK CLOSURE

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December 2, 2004

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Prepared for the U.S. Department of Energy Under Contract Number DE-AC09-96SR18500

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EXECUTIVE SUMMARY

Two proof-of-principle large-scale tests were performed to simulate the flow of grout into Hanford single-shell HLW Tanks and into cascade lines which interconnect the HLW tanks. The goal of the testing was to determine whether the HLW tank grout can enter the cascade line and solidify prior to flowing into an adjacent tank.

Two tests were performed as part of this task. The tests were conducted using the Phase 2 Structural Grout, SRG2, the structural grout mix that was used during scale-up testing last year.

The first test used a mix that had lower water content than the mix used in the Test 2. A flow (flow consistency) of ~13 inches was measured using ASTM D-6103. This grout, although it did travel a distance of 4.5 feet down the lower cascade line under the head pressure of an additional 6 inches of grout, stopped flowing when the lift was completed. No further movement of the grout down the cascade line occurred during the second lift, added approximately 4 hours later. The top cascade line in this testing had very little grout in the line since it did not have the immediate head pressure during the first lift nor was it forced into the line during the second placement of grout.

The second test used the same SRG2 Structural Grout but with a higher concentration of water than used in the first test. This higher water mix resulted in a grout with a flow greater than 14 inches as measured using ASTM D-6103. This grout was very fluid during placement and readily flowed down the two cascade lines used for Test 2. The cascade lines were 16 feet long (vs. ~ 27 feet in the Tank Farm) and both lines were entirely filled with grout. In this case, the grout flowed down the cascade lines even without the head pressure of additional grout.

The Hanford Grout Specifications provide specifications and guidance on mix designs for tank closure. For a given mix design and range of admixture concentrations, a flow of between 12 inches and 15 inches by ASTM D-6103 will produce a grout with acceptable compressive strength and no bleed water. However, the guidance directs the operator to increase water in the mix (but still be within the 12 to 15 inch ASTM D-6103 flow) if the grout flow in the tank is not sufficient to readily reach the edge of the tank.

This cascade line testing provided a proof-of-principle demonstration that self-sealing of the cascade lines is achievable during grout placement in HLW tanks for a grout mix design with an ASTM D-6103 flow of 13 inches. Although this mix meets the specifications (12 to 15 inch flow), it was not demonstrated that this mix has sufficient flowability to reach the cascade line. If for example, the operator increased the water content of the mix to increase flowability in the tank and in the process increased the ASTM D-6103 flow to 14 inches, then the grout would flow through the cascade lines.

Only two levels of water content in this grout mix (SRG2) were tested. Therefore, there may be a level of water content between these two tested levels that leads to a higher confidence in achieving good flow and self-leveling properties while also achieving self-sealing of the cascade line.

2. INTRODUCTION

Closure of Hanford's Single Shell High-Level Waste (HLW) Tanks will be accomplished in part by filling the tanks with grout. Caron steel pipes connect some of the HLW tanks in a cascade arrangement. The connecting pipes are referred to as Cascade Lines. The presence of cascade lines raises the possibility of grout entering the cascade line and flowing into a neighboring tank during placement of the grout. Since CH2M HILL will close one tank at a time, they must either isolate the tanks prior to grout placement or demonstrate that grout placement will lead to isolation through self-sealing of the lines with grout. This task addresses the latter option and tests, through a proof of principle demonstration, the feasibility of whether or not the cascade lines will self-seal during normal placement of the grout into the tanks.

The cascade lines are 3-inch, schedule 80 carbon steel pipes that extends 1 foot into the HLW tank. The nominal value for the length of a cascade line is 27 feet while the nominal value for the cascade line slope is 3.125% corresponding to an angle of 1.8 degrees with respect to horizontal. The location of the cascade line connection to the tank is in the region where Phase 2 Structural Grout will be placed.

Grout placed into a tank at the nominal maximum rate of 90 cyd/hr produces on average an increase in the height of the grout in the tank of 0.11 inch every minute. Once the grout reaches the bottom of the cascade line, it will take an additional 27 minutes of continuous placement at 90 cyd/hr to reach the top of the cascade line.

3. TEST OBJECTIVE AND TEST STRATEGY

Test Objective: Demonstrate that the cascade lines will self-seal during normal placement of grout in the High-Level Waste Tanks.

Test Strategy: Perform large-scale testing and be conservative with respect to rate of change of fill height with time, aging of the grout, angle of the cascade line, and roughness of the inner surface of the cascade line to ensure that the results, if successful, will demonstrate proof-of-principle self-sealing of the cascade line.

4. EXPERIMENTAL

The experimental set up is shown in Figure 1 and a video which was submitted separately as part of the deliverable for this task. Basically, the tank was simulated by a 16 ft (actual measurement was 15' 10") diameter swimming pool that was roughly 5 ft high. This pool was placed on a level, engineered concrete pad. Cascade lines were simulated using a transparent polycarbonate pipe that had a 3-inch internal diameter. These lines were connected to the pool at an angle of 2 degrees from horizontal such that the exit end of the cascade line was lower than the end that was connected to the pool. The locations of the four cascade lines were as follows:

Test Number	Cascade Line	Height to Center of Line	Angle	Length	Location
#	#	inches	degrees	feet	East or South
1	1	4	2	16	South
1	2	9	2	16	East
2	3	15	2	16	South
2	4	19	2	16	East

A variable speed Putzmeister TK-25 grout pump (0 -24 cyd/hr) was used to place the grout. The grout was pumped through a flexible slick line to the center of the pool and discharged downward into the pool (See video). The TK-25 can vary the placement rate between 0 and 24 cyd/hr. Calculations demonstrated that each stroke of the pump corresponded to 1 cyd/hr of grout. Therefore, strokes were counted to estimate the placement rates. The placement rates used in the two tests were:

Test Number	Cascade Line	Strokes	Rate
#	#	#/min	cyd/hr
1	1	23	23
1	2	23	23
2	3	23	23
2	4	12	12

The grout mix, SRG2, was used in both tests and the mix used in Test #2 had higher water content than the mix used in Test #1. The targeted and actual amounts of the components of this mix are provided in Tables 1 and 2.

Figure 1. Experimental Setup Showing the East Cascade Lines.

Table 1. Grout Mix Design for Test #1: Targeted vs. Actual Amounts of Components.

MIX NUMBER: SRG2 (STRUCTURAL)

SWIMMING POOL TEST #1 FOR CASCADE LINE TESTING

Fraction H2O in Sand: 0.045

DATE: November 9, 2004								
DESIGN MIX					**Batch Ticket**			
	AMOUNT/cyd		AMOUNT/x cyd		Target	Unit	Actual	
			8					
		Unit		Unit		Unit		Unit
PORTLAND CEMENT	75	lbs	600	lbs	600	lbs	595	lbs
SLAG	210	lbs	1,680	lbs	1,680	lbs	1,670	lbs
FLY ASH	375	lbs	3,000	lbs	3,000	lbs	2,970	lbs
SAND	2,150	lbs	17,200	lbs	18,010	lbs	17,800	lbs
WATER	483	lbs	3,864	lbs	3,054	lbs	2,876	lbs
	58	gal	463	gal	366	gal	345	gal
KELCOCRETE	413	grams	3,300	grams	3,300	grams	3,300	grams
ADVAFLOW	135	fl. oz	1,080	fl. oz	1,080	fl. oz	1,080	fl. oz

Table 2. Grout Mix Design for Test #2: Targeted vs. Actual Amounts of Components.

MIX NUMBER: SRG2 (STRUCTURAL)

SWIMMING POOL TEST #2 FOR CASCADE LINE TESTING

Fraction H2O in Sand: 0.045

DATE: November 9, 2004								
DESIGN MIX					**Batch Ticket**			
	AMOUNT/cyd		AMOUNT/x cyd		Target	Unit	Actual	
			9					
		Unit		Unit		Unit		Unit
PORTLAND CEMENT	75	lbs	675	lbs	675	lbs	680	lbs
SLAG	210	lbs	1,890	lbs	1,890	lbs	1,885	lbs
FLY ASH	375	lbs	3,375	lbs	3,375	lbs	3,355	lbs
SAND	2,150	lbs	19,350	lbs	20,262	lbs	20,380	lbs
WATER	483	lbs	4,347	lbs	3,435	lbs	3,493	lbs
	58	gal	521	gal	412	gal	419	gal
KELCOCRETE	413	grams	3,713	grams	3,713	grams	3,713	grams
ADVAFLOW	135	fl. oz	1,215	fl. oz	1,215	fl. oz	1,215	fl. oz

The amounts of water added at the (1) Lafarge Plant and (2) at the testing site to the mixes for Tests 1 and 2 are provided in Tables 3 and 4.

Table 3. Total Water Addition for Test 1.

Test 1 Cascade Line Field Testing - Water Addition				
Addtion #	Water	Total Water	Admixture	Flow
	gallons	gallons		inches
0	329	329		
1	1	330	added	11.5
2	10	340		12.5
3	5	345		13.0

Table 4. Total Water Addition for Test 2.

Test 2 Cascade Line Field Testing - Water Addition				
Addtion #	Water	Total Water	Admixture	Flow
	gallons	gallons		inches
0	373	373		
1	1	374	added	11.0
2	15	389		12.0
3	15	404		13.0
4	15	419		14.0

The approximate values of the parameters for the two tests are summarized in Table 5.

Table 5. Approximate Values of Relevant Parameters for the Two Tests

	TEST 1	**TEST 2**
Design Mix	**Structural, SRG2**	**Structural, SRG2**
Flow	**13 inches**	**14 inches**
Diameter of Swimming Pool	**16 feet**	**16 feet**
Volume of Placement	**8 cyd**	**9 cyd**
Height of Placement in Pool	**1 foot**	**1 foot**
Location of Placement	**Center**	**Center**
Rate of Placement	**23 cyd/hr**	**23 and 12 cyd/hr***
Length of Time for Placement	**20 minutes**	**25 minutes**
Change in Height with Time	**0.56 inches/minute**	**0.56 and 0.30* inches/minute**
Reference Tank Case - 90 cyd/hr	**0.11 inches/minute**	**0.11 inches/minute**
Ratio of Change in Height with Time to Reference Tank case	**5.1 (0.56/0.11)**	**5.1 and 2.7***
Ambient Temperature	**59 degrees F**	**69 degrees F**
Mix Temperature	**64 degrees F**	**68 degrees F**
Number of Cascade Lines	**2**	**2**

*The 23 cyd/hr placement rate at 0.56 inches/minute and a ratio of 5.1 was used for the lower cascade line and the 12 cyd/hr placement rate at 0.30 inches/minute and a ratio of 2.7 was used for the upper cascade line of Test 2.

5. RESULTS

The results from the two tests are described below. The video of the two tests and associated pours is provided separately.

Test #1. Test #1 used an SRG2 mix design with an ASTM D-6103 flow (flow consistency) of 13 inches. The amount of water required to achieve this flow was 55 gallons per cyd (43 gallons/cyd added and 12 gallons/cyd from the sand). This flow is within the range of the Hanford Grout Specifications. The grout readily flowed to edge of the pool, but was not entirely self-leveling at the placement conditions used in the test. The grout level was highest at the center and tapered off to the edge (see video). The grout placement rate for this test was constant at ~23 cyd/hr.

> **First Cascade line (lower line, south).** The grout entered this cascade line (centered at 4 inches) as the level of grout in the tank slowly increased to completely cover the opening of this cascade line. However, the grout only flowed about 1 foot into the line. As the grout level in the tank continued to rise during completion of the placement of the first batch, the grout flowed down the cascade line about 4 ½ ft of the 16 ft line. This slow movement of the grout down the cascade line was the result of head pressure of the added grout to the pool (total depth of the first pour was ~12 inches).
>
> **Second Cascade line (lower line, east).** The grout also flowed about 1 foot into the second cascade line (centered at 9 inches). It turned out that the placement of the first batch of grout at 8 cyd did not completely block the opening to this cascade line. A small opening was evident at the top (see video). It is interesting to note that during placement of the second batch of grout, grout could be seen entering this small opening but it did not continue to flow down the cascade line even with an eventual head from 12 inches of grout placed during Test #2.

Test #2. Test #2 used an SRG2 mix design with a slump-test flow (flow consistency) slightly greater than 14 inches. The amount of water required to achieve this flow was 59 gallons per cyd (47 gallons/cyd added and 12 gallons/cyd from the sand). (Four more gallons of water/cyd were used in Test 2 relative to Test 1.) This mix was more fluid than that used in Test #1 and was essentially self-leveling. Placement rate for this test was ~23 cyd/hr during the first phase of this placement and was reduced to ~12 cyd/hr when the grout level reached the bottom of the top cascade line. (At the lower placement rate of 12 cyd/hr, some shouldering of the top layer of grout was observed.)

> **Third Cascade line (upper line, south).** The grout readily entered this cascade line (centered at 15 inches) as the level of grout in the tank slowly increased to completely cover the opening of this cascade line. The grout completely filled the 16 ft of cascade line and began flowing out the end. This end was then corked off to prevent any further loss of grout from the pool.

Immediately prior to the start of the grout placement, a priming solution (several gallons) was added to the pump and this liquid entered the pool prior to the grout. The liquid migrated to the edge of the pool and eventually flowed out of the pool via the 3rd cascade line. Therefore, when the grout layer reached the bottom edge of the cascade line, all of the priming liquid exited the pool through this cascade line (captured on video).

Fourth Cascade line (upper line, east). Just prior to the grout entering the fourth cascade line, the placement rate was reduced to ~12 cyd/hr to determine the effect of a slower placement rate. The grout entered the fourth cascade line (centered at 19 inches) and readily made its way to the end of the cascade line. As was evidenced with the third cascade line, the grout completely filled the line and began to flow out of the end of the line. A bucket was used to capture the grout and a slump test was performed on this material. The slump was between 14 to 14.25 inches demonstrating that the grout was as fluid as it was when it exited the truck. At this point, a cork was used to plug the line and prevent further drainage of the grout from the pool.

6. DISCUSSION

These two tests provided two different outcomes for this task. In Test #1, self-sealing of the cascade lines was demonstrated. For Test #2, the lines did not self seal and the grout readily traveled the entire 16 feet (actual cascade lines are ~27 ft) and flowed out the end of the lines.

The only difference between these two tests was the amount of water added to the mix. The difference in water content was ~4 gallons per cubic yard of grout (55 gallons/cyd in Test #1 and 59 gallons/cyd in Test #2). The admixture was held constant at 135 fluid ounces of AdvaFlow and 413 grams of KelcoCrete per cubic yard. This difference in water content was reflected and readily apparent based on the results of the flow test. The grout used in Test 1 had a flow of 13 inches while the grout used in Test #2 had a flow of 14 inches. The difference of 4 gallons/cyd was even more evident in the flowability of the grout during the placement tests. The mix used in Test #2 was clearly more fluid and more self-leveling than the mix used in Test #1.

For comparison, the two SRG2 mixes used in the scale-up testing of grout placement in trenches used 60 and 61 gallons of water per cubic yard and both mixes had an ASTM D-6103 flow of 13.75 inches. Both of these mixes had the same amount of admixtures that were used in the cascade line testing.

During normal placement activities, a mix similar to that used in Test # 2 is preferred due to this high fluidity. However, at or near a cascade line, a mix similar to that used in Test #1 is preferred due to the fact that self-sealing of the cascade lines was observed. The tradeoff in using a stiffer mix as in Test #1 is a reduction in flowability and self-leveling property of the grout.

The two values of 13" and 14" for the ASTM D-6103 flow consistency of the mixes used in Test #1 and #2 can be compared to the range for flow specified for HRG 2 in the Grout Specifications (12" minimum and 15" maximum). These specifications were developed without the self-sealing property requirement.

The scaling factors and test parameters were selected to be conservative relative to actual field parameters. For example,

1. The actual rate of increase of the grout level in a 75 ft diameter HLW tank is maximally 0.11 inches per minute at 90 cyd/hr. This 90 cyd /hr placement rate for HLW tanks can be reduced at the locations of the cascade lines.
2. The tests performed in this task were based on rates of increase in the grout level of 0.6 (Test 1) and 0.3 (Test 2) inches/minute.
3. The inner surfaces of the carbon steel cascade lines are most likely much rougher than the very smooth inner walls of the transparent plastic "cascade lines" used in this test.
4. In an actual tank, the time for the grout to reach the tank edge is much longer than in Tests # 1 and 2. Therefore, any beneficial impact of (1) aging of the grout and (2) lower effective shear of the grout flow near the edge of the tank are not included.

7. CONCLUSIONS

The Hanford Grout Specifications provide specifications <u>and</u> guidance on mix designs for tank closure. For a given mix design and range of admixture concentrations, a flow of between 12 inches and 15 inches by ASTM D-6103 will produce a grout with acceptable compressive strength and no bleed water. However, the guidance directs the operator to increase water in the mix (but still be within the 12 to 15 inch ASTM D-6103 flow) if the grout flow in the tank is not sufficient to readily reach the edge of the tank.

This cascade line testing provided a proof-of-principle demonstration that self-sealing of the cascade lines is achievable during grout placement in HLW tanks for a grout mix design with an ASTM D-6103 flow of 13 inches. Although this mix meets the specifications (12 to 15 inch flow), it was not demonstrated that this mix has sufficient flowability to reach the cascade line. If for example, the operator increased the water content of the mix to increase flowability in the tank and in the process increased the ASTM D-6103 flow to 14 inches, then the grout would flow through the cascade lines.

Only two levels of water content in this grout mix (SRG2) were tested. Therefore, there may be a level of water content between these two tested levels that leads to a higher confidence in achieving good flow and self-leveling properties while also achieving self-sealing of the cascade line.

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