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Grout/CLSM Testing and Selection for the INTEC Tank Farm Closure

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5. Summary:

This Engineering Design File (EDF) describes the selection process and lab and field testing of grout and Controlled Low Strength Material (CLSM) for closure of INTEC Tank Farm.

CLSM/grout will be pumped into tank openings filling up the tank and the surrounding vault. The grout will be pumped over a hundred feet from outside the fence area and dropped into each tank. The grout fills tank void and eliminates subsidence. An initial application of grout must be thick enough to push residual liquids and “heel” to one end of the tank for removal. The next layers and most of the tank will be filled with a CLSM selected to provide structural stability in the tank and surrounding vault.

The most important implementability criterion is prior field testing or actual use in filling large radiologically contaminated structures. The requirements of pumping over large distances and not separating upon dropping were successfully tested in this full scale mockup. Requirements of pushing existing liquids to jet pumps, filling small pipes have been tested in previous full scale tests. Various cement/fly ash based mixes have been field tested on simulated waste, actual or mockups of legacy waste tanks and subsurface structures and vaults. The grout selection criteria and evaluation developed here are derived from laboratory and field tested grouts designed for other INL tanks, structures and TRU buried waste and lab and tank mockup testing. Grout and CLSM mixes were formulated based on described lab tests and pumping and placement full scale mock-up test. Grouts and CLSM were pumped over 120 feet and then dropped the height of the tank (approximately 20 feet). From this test implementation of tank fill CLSM and heel displacement grout were demonstrated.

The effectiveness criteria for the first heel displacement layer are to push residuals to the existing jet pump for removal. The fill properties of self leveling, low shrinkage and low heat of hydration were demonstrated in the mock-up test. Application of the final layer to fill the dome area at the top of the tank was also successfully demonstrated in the pumping mock up test.

Formulations, properties, and estimated costs for over 20 tank fill and 3 pipe fill that have been used or tested were compared. Low cost tank fill CLSM mixes with a strength >100 psi were tested in this pumping mockup. Those suitable for long distance pumping and tank fill benefited from air entrainment. They required >3% cement, > 6% fly ash and <80% sand with an estimated to cost <\$90/yd^3. A grout suitable for filling the dome has additional cement to allow the grout to be forced above the level of the input tube is estimated to cost 125\$/yd^3. The heel displacement mix was demonstrated in a successful previous specific mockup field test and tested for slump and the ability to be pumped a longer distance in this mockup. The fly ash mixture for pipe fill estimated at 130\$/yd^3 has been previously field tested and can go through pipes as small as ½ inch diameter.

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CONTENTS

1. INTRODUCTION 9

2. SCOPE OF WORK 10

3. .TANK FARM WASTE VOLUME 13

4. GROUT PROPERTIES 15

5. TANK CLOSURE GROUT SELECTION 17

5.1 Implementability 17

5.2 Effectiveness 18

5.3 Evaluation 21

5.4 Cost 22

6. TANK CLOSURE GROUT TESTING 23

6.1 Grout and CLSM Laboratory Testing 23

6.1.1 Equipment 23
6.1.2 Experimental Design 23
6.1.3 Results 24
6.2 Controlled Low Strength Material and Grout Placement Field Test 34

6.2.1 Equipment 34
6.2.2 Trench Design 35
6.2.3 Measurements 36
6.2.4 Description of Mockup Grout/CLSM Test 37
6.2.5 Coring 54
6.3 Test Evaluation 62

7. RECOMMENDATIONS AND CONCLUSIONS 66

8. REFERENCES 67

FIGURES

Figure 1. Grouted Tank Regions in a 300,000 gallon upright tank..... 11

Figure 2. Previous Test: Full Scale Tank Heel Displacement Grouting. 12

Figure 3. Volume and Status of 300,000 Tank Farm Tanks. 14

Figure 4 CLSM and Grout Unconfined Compressive Strength. 26

Figure 5 Comparison of CLSM 7 day Compressive Strength. 27

Figure 7 CLSM/Grout Unconfined Compressive Strength vs Water to Cement Ratio. 29

Figure 8 CLSM Viscosity from Viscometer, Slump and Flow test 30

Figure 9 Compressive Strength and Sand Content of CLSM and Grout Mixes 31

Figure 10 Compressive Strength and Graded C-33 Sand Content..... 32

Figure 11 Compressive Strength of Ungraded Sand Mixes..... 33

Figure 12 Pump Truck Boom Fully Extended Applying Grout Mix 35

Figure 13 Three Mockup Trenches, # 3, 2, 1 from left to right , 4” treme in trench 2 and 6” treme in 3... 36

Figure 14 Second Load CLSM with AEA Flowing from a 4” Treme Tube..... 39

Figure 15 Load Three CLSM Flowing from 8 inch Teme Tube..... 40

Figure 16 CLSM Flow from 8” Treme Tube..... 41

Figure 17 Free Drop of Load Four CLSM Containing both AEA and Plasticizer..... 42

Figure 18 Load 5 CLSM Containing both AEA and Plasticizer..... 44

Figure 19 Trench Three. 1st and 2nd application of dome fill cement through bottom hole of 6” Treme.... 45

Figure 20 Trench Three; third in sequence of Load 6 dome fill cement (Loads 6-8) after 6 yd3..... 46

Figure 21 Trench Three, Load 7; dome fill cement applied immediately following Load 6-..... 47

Figure 22 Trench Three; second in sequence applying Load 7 dome fill grout through 6” Treme 48

Figure 23 Trench 3; third in sequence of Load 7 dome fill grout showing layering over Load 6 and 3..... 49

Figure 24 Applying Load 8 dome fill grout in Trench 3; Application is through Pump Tube below the level of the grout..... 50

Figure 25 Trench Three after sequential application of dome fill grout (Loads 6-8) footprints after 4 hours51

Figure 26 Sequence in pouring :Load 11 Heel Displacement Grout 53

Figure 27 Fours Cores: A,B,D from Trench 3, C from Trench 2 55

Figure 28 Test Layout and Treme Tubes Schematic. 56

Figure 29 Segregation based UCS from Free and Treme Tube Drops 63

Figure 30 Segregation based on UCS from Free Drops of AEA and Plasticizer CLSM 2-1 64

Figure 31 Segregation in Grout based on UCS from Free Drops of CLSM 3-2 64

Figure 32 Distribution of UCS from Heel Displacement of CLSM 4 65

TABLES

Table 1. 300,000 gallon Tank Farm Waste Volume as of 10-31-05 13

Table 2. Grout Ingredients Considered for Tank Grouting. 15

Table 4. Composition of Selected Field or Lab Tested Fill and Dome fill Cementitious Grouts 16

Table 5. Criteria for Tank Farm Facility Closure Grouts 19

Table 6. Relative importance of specific *implementibility* and **effectiveness** parameters. 20

Table 7. Summary of Cementitous CLSM and Grout Samples 24

Table 8. Cementitous CLSM and Grout Lab Results 25

Table 9 Service List for CLSM/Grout Pumpability and Placement Field Test 34

Table 10. Summary of Mockup Test CLSM/grout Placement Data 57

Table 11. Summary of CLSM/Grout Mockup Pumping Operational Data 58

Table 12. Composition of CLSM and Grout Mockup Test Mixes 59

Table 13. Properties of CLSM and Grout Mockup Test Mixes 60

Table 14. Cores of Emplaced CLSM and Grout Mockup layers 61

Table 15. Summary of Pumping Cementitous Grout/CLSM Field Test 63

ACRONYMS

AEA	Air Entrainment Agent
ANS	American Nuclear Society
ASTM	American Society for Testing and Materials (ASTM International)
CERCLA	Comprehensive Environmental Closure of Landfill Act
CFR	Code of Federal Regulations
CLSM	controlled low strength material
EDF	Engineering Design File
FA	fly ash
GBFS	ground blast furnace slag
HLW	High Level Waste
HRWR	high range water-reducer (plasticizer)
HWMA	Hazardous Waste Management Act
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
MFT	Marsh Funnel Time
NA	not applicable
NRC	Nuclear Regulatory Commission
OU	operable unit
PC	Portland cement
RCRA	Resource Conservation and Recovery Act
SBW	Sodium Bearing Waste
SRP	Savannah River Plant
TFR	Technical Functional Requirements
TRU	Transuranic
TFF	Tank Farm Facility
WCF	Waste Calcine Facility
WIPP	Waste Isolation Pilot Plant

NOMENCLATURE

psi	pounds per square inch
cc	cubic centimeters
yd^3	cubic yards
kg	kilograms

Grout Testing and Selection for the INTEC Tank Farm Closure

1. INTRODUCTION

This Engineering Design File (EDF) describes selection of grout and controlled low strength material (CLSM) to close a number of tanks at the Idaho Laboratory's (INL's). The scope of the testing included a full scale mockup test of pumping and placing candidate mixes. Grouting has been used as a remedial action for other selected areas at INL including buried waste at the Sub surface Disposal Area (Shaw 2004), closure of the Waste Calcining Facility and tanks at Test Area North (Farnsworth 2005). The initial grout layer is used to push waste (liquids and solid heel) to a removal point. The final layer of fill may be made slightly thicker to be forced up into the dome of the tank.

CLSM is used to fill the tank totally encapsulating any residual waste. An estimated 25,000 yd^3 of CLSM/grout is needed, 60% placed within the tanks and 40% for the surrounding vaults. Tank and vault fill comprises over 97% percent of the material volume needed in the tank farm closure and is classified as CLSM. CLSM nominally includes mixtures with compressive strength <1000 psi. Higher strength grouts (>1000 psi) are used for heel displacement and pipe fill (3%).

The Idaho Nuclear Technology and Engineering Center (INTEC) Tank Farm Facility (TFF) tank system has been used historically for storage of high level waste (HLW) from spent nuclear fuel (SNF) reprocessing and other radioactive wastes derived from INTEC mission operations. Currently the remaining waste for processing called Sodium Bearing Waste (SBW) resides in three of the tanks.

The EDF describes the mockup test for pumping and placing material to fill the large tanks. The TFF tank closure consists of filling by pumping CLSM into eleven 300,000-gallon below ground stainless steel tanks contained within concrete vaults of various construction; four inactive 30,000-gallon below grade stainless steel tanks; and valve boxes, encasements, and various process and instrumentation piping associated with the tanks. CLSM and grout will be used for both phase I and II closure in response to DOE-ID Notice of Noncompliance Consent Order (Refer to TFR).

Tanks will be closed in phases. The first phase of TFF closure consists of heel displacement grout placement in tanks WM-182 and WM-183 and is a proof-of- process demonstration of the waste removal, decontamination, and sampling techniques. Waste liquids removed or generated during tank closure activities for a given phase will be transferred to other tanks continuing to operate in the TFF. Additionally, the first-phase demonstration of TFF closure will allow determination of the heel displacement grout to achieve reduction in non-HWMA/RCRA contaminant concentrations for evaluation of residual CERCLA risk and performance assessment.

The primary purpose of the CLSM after the residual liquid and heel is displaced is to fill the tank void. The non-HWMA/RCRA contaminants and CERCLA contaminants of concern (COCs) in washing residues will essentially be removed by the initial placement. Thus minute amounts of residuals containing Tc-99, I-129 do not require a reducing grout to minimize leaching as has been used in other tank closures (Langton, 2003). Other portions of the inventory are not mobile (i.e., TRU containing sludge or heel). Both liquids and heel remaining in tanks after cleaning currently do not need further contaminant immobilization. .

The Project Design shall proceed with the current design basis to grout the tanks and shall develop a sequence and techniques for grouting all affected tanks and piping. In accordance with the Closure

Approach (INEEL/EXT-99-01066, June 2000), Tanks WM-182 , WM-183, WM-180 and WM-185 will be closed first. Lessons learned form the initial closure efforts will be incorporated into subsequent closure activities.

Closure actions include grouting of tanks, surrounding vaults, and piping. The different goals: remove tank heel residuals, fill tank, and fill piping:. Tank closure involves pumping Portland-cement-based CLSM in 3 foot to 4 foot "lifts" to self level and solidify in the tank and surrounding vault. Grout applied initially for heel displacement will move contaminants to the removal pump inlet.

The grout selection criteria and recommendation developed below are a summary derived from previous laboratory and field measurements on: above and below ground stabilization materials (Shaw and Weidner 1996), tanks (Shaw 1997), in situ encapsulation of buried legacy fuel reprocessing and nuclear power development wastes (Shaw 2004) and in situ encapsulation of buried Be block containing Low Level wastes (Shaw 2003) and other miscellaneous closure projects.

The spacing of the tanks, volumes required and the distance from the pump truck require a tested physically stable grout, low heat of hydration, long set time, and low viscosity. Cementitious grouts from ORNL, SRP and INL tank closure activities that meet these requirements are compared in the list below. Unlike the ORNL and SRP situation with wastes needing encapsulation the tanks targeted for closure have been emptied of waste liquids and flushed clean. The residual liquid and small amounts of solids insoluble in acid are to be removed in the first layer of the grouting process.

Previous testing on buried waste and other tank closures (Poloski 2003, Shaw 2004, Jensen 1998) provide grouting implementation, grout selection criteria. The largest fill application was the INTEC Waste Calcining Facility (WCF). The mockup test used a higher sand, lower cementitous ingredient mixture fill grout estimated t to cost 40% less. This was a RCRA closure with applicability to the tanks and vaults. A current application for closure of the INTEC 603 Basin also will use a simple "fill" grout mix. The differences in this tank application will be considered in this grout selection EDF.

2. SCOPE OF WORK

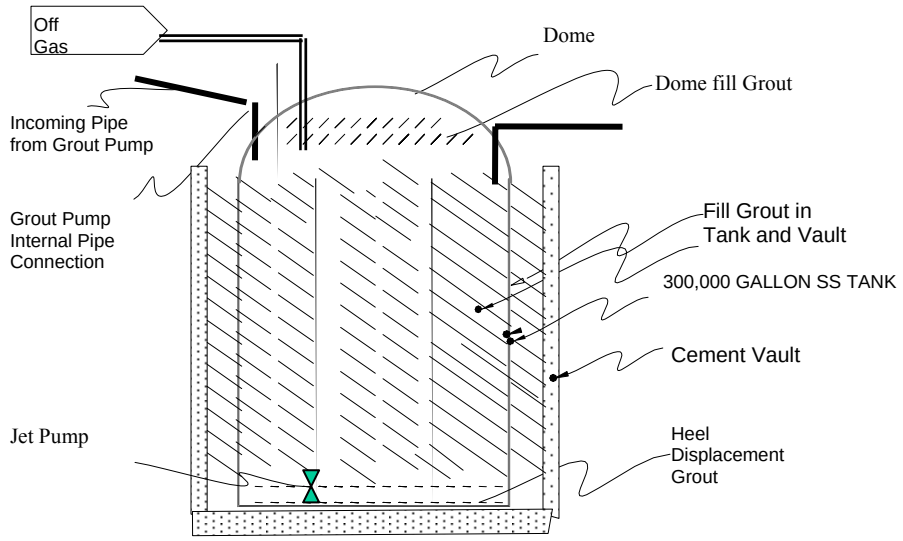
The scope of tank closure is filling eleven tanks with CLSM. The scope of this study is the testing and selection of liquid CLSM and grouts for the various phases in closing the tank farm facility (TFF). Grout and CLSM is pumped in lifts to each buried tank and the tanks surrounding vault to harden over time. The Tank and surrounding vault become one solid unit. Closure involves three phases and two to three different grouts: an initial viscous heel displacement grout, a low cement fill grout for the vaults and tanks, and a no aggregate cement and fly ash mix for filling of pipes. The final layer of fill in the tank dome may be performed with the same grout mix as heel displacement.

Each tank contains a thin layer of very lightly contaminated wash water and insoluble heel. This residual can be pushed to the pump by the first layer of grout. The main requirement for this initial "push" grout is sufficient viscosity for moving the heel to the sump as demonstrated in the "star pour" heel displacement field test (Nield 1998). The implementation requirements are the most demanding since heel displacement involves many directed placements to push contaminants to one end of the tank for removal.

After the first grout layer removes residual contaminants the Tank is filled with subsequent layers to eliminate tank voids and thus potential subsidence. Each layer involves pumping about 7,000 ft^3 of grout 150 feet, dropping it approximately 22 feet into a 300,000 gallon tank evenly without separation that would effect subsequent placements. Most of the layers will be fill CLSM. The first will be higher

strength grout as shown in Figure 1. The formulation for fill CLSM must have sufficient set time to avoid premature set and pump clogging.

Figure 1. Grouted Tank Regions in a 300,000 gallon upright tank.



A photograph of the heel displacement field testing in a full scale tank footprint are shown below in Figure 2 (Nield 1998). The grout piping was held by a forklift. The liquid simulated waste has been forced to the corner by successive placements of grout. The CLSM fill has a much lower cement content and will be applied using a high volume high “reach” pump truck as was tested in the mockup. The heel displacement grout was also retested in this field test with this pump truck and applied for used in filling the dome of the tank.

Figure 2. Previous Test: Full Scale Tank Heel Displacement Grouting.

3. .TANK FARM WASTE VOLUME

Tank Farm tank waste consists of liquids and semi solid heel itself substantially water (Poloski 1998). Tank waste for all targeted tanks is low since they have been repeatedly cleaned. Sampling has been performed in the cleaned tanks and of sediment from some tanks before cleaning. Sediment data was used to develop heel bounding conditions for the TFF and the initial grout heel displacement placement. (Nield 1998).

The tank waste is mostly water with a thin solid heel layer. The heel is the insoluble residue from spent fuel dissolution precipitated from tank liquids. The heel matrix composition physical properties for all tanks are assumed to be similar to those measured.

The water is the diluted remains of wash liquid that cannot be removed from the tanks. The highly radioactive liquids have been removed. The tank liquids essentially contain only contaminants leached from the heel remaining after the tanks are washed with demineralized water.

Table 1 lists the current total volume of residual waste after several washings with an estimate of the semi solid heel volume and the depth based on current monthly tank measurement. This small amount of water and solid heel waste will be displaced with the first grout layer. The waste remaining after the 1st phase heel displacement grout has pushed it to the pump inlet that will mix with the grout itself is unknown. Estimates indicate that so little will remain to be incorporated by the grout, that the remaining fill operation can be performed as in a non-radiological system.

Table 1. 300,000 gallon Tank Farm Waste Volume as of 10-31-05

Tank WM-	Liquid Tank Volume [a,c]	Solid Heel Volume	Heel Depth [d]	Vol% Solid Heel
	Gallons	Gallons	inches	%
180	7,600	100 [b]	6	1
181	7,300	50 [a]	6	1
182	6,200	230 [a]	5	4
183	6,200	130 [a]	5	2
184	2,800	100 [a]	3	3
185	5,900	140 [a]	5	2
186	6,600	100 [b]	5	1
Total Volume Targeted Tanks	42,600	850	35	2

a. Volume estimated from depth and solid particle density 2.0g/ml
b. Volume of heel based on estimates from other similar tanks.
c. Waste will be largely removed in the initial heel displacement
d. Depth based on tank instrumentation

. .

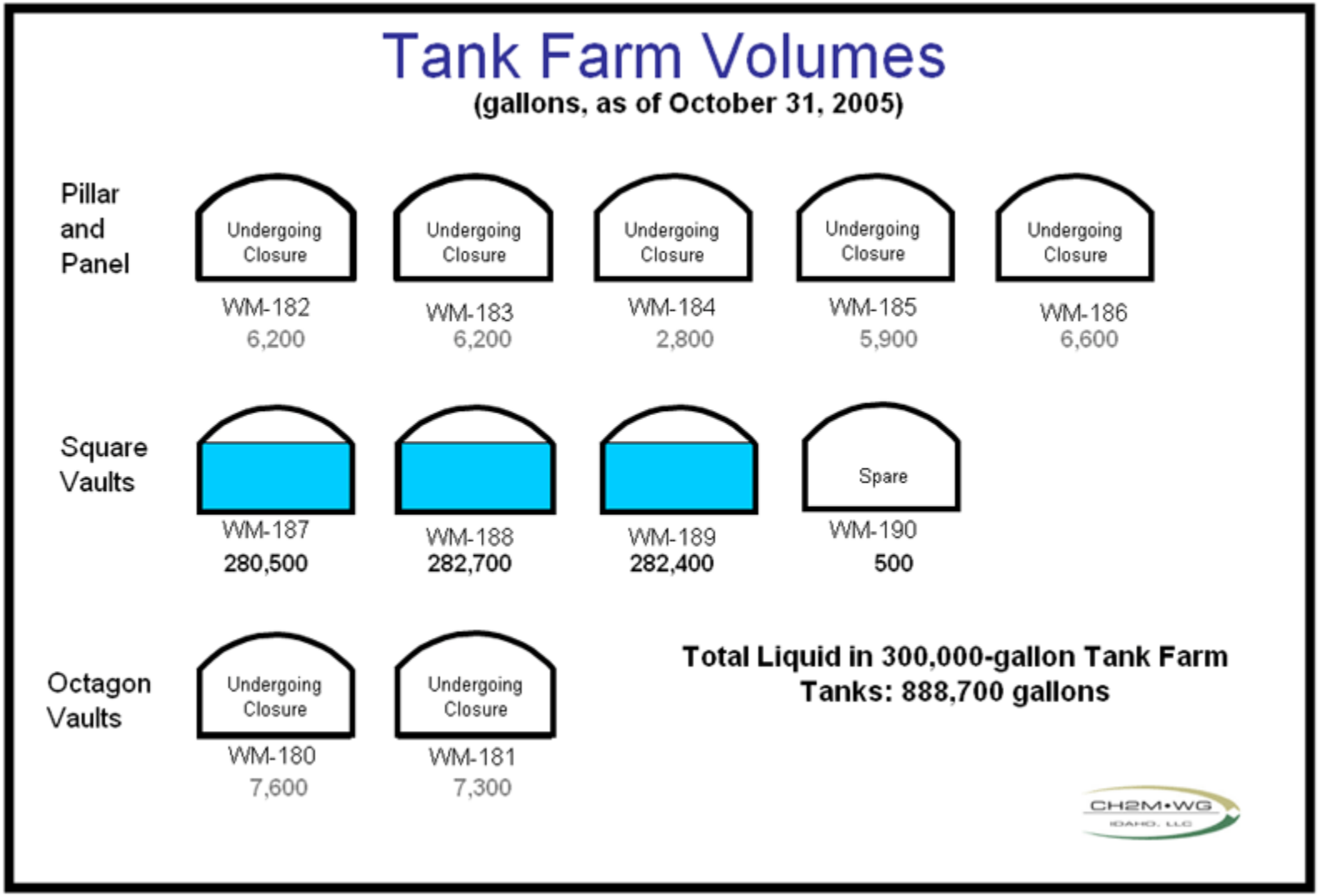


Figure 3. Volume and status of 300,000-gal Tank Farm Tanks.

4. GROUT PROPERTIES

A variety of grouts and Control Low Strength Material (CLSM) have been evaluated for WCF closure (Jensen 1998) and 603 Basin (Siahpush 2004). These evaluations are applicable to Tank Farm closure. Table 2 shows some of the implementibility features of cementitous grouts. Reducing grouts were lab tested using the NRC leach test for solidification of nuclear power plant waste (Shaw, 2004). Reducing grouts are not considered here due to the efficiency of the tank washing and heel displacement to remove contaminants.

An initial grout down-selection was conducted based on past successful mockup testing (Jensen 1998) on simulated tank waste solids at the INTEC. Ingredients for all closure grouts consist mostly of sand with small amounts of cement, fly ash (FA), and plasticizer are shown in Table 4. These are high sand (>60 wt%, >ton/yd3), low-water (<14 wt%, <57 gal/yd3), high-plasticizer formulations listed in Table 2. Implementation criteria are discussed in Section 5.1.

Past bench and field scale grout testing have demonstrated non aggregate containing formulations (the native soil would serve as aggregate). Common Portland cement Type I/II, sulfate-resistant Portland Type H or Type V grouts modified met the viscosity, particle size, and set times required for effective pumping and grouting under pressure. Some of the past reducing grouts were leach tested and though not field tested had suitable field emplacement properties such as viscosity, hydration temperature, and set time. Minimally they would need some set retardant as well as suspension agents for field use. A discussion of the impact of reducing additives particularly ground blast furnace slag (GBFS) and water content on leach resistance is given in previous studies (Shaw 2004).

Table 2. Grout Ingredients Considered for Tank Grouting.

Name	Abbrev	Purpose	Cost [a]	Density
			$/ton	(g/ml)
Water		Activate Cement	None	1.0
Sand		Aggregate Bulk fill	20	2.5
Portland cement	PC	Primary cementitous material, activates ash and slag, imparts alkalinity	195	3.15
Fly Ash	FA	Bulk fill, slight cementitous properties	95	2.3
Silica Fume [c]	SF	Pozzolanic, reducing characteristic	80	2.4
Ground Blast furnace Slag [c]	GBFS-	Pozzolanic, reducing characteristic, cementitous properties c	85	2.7
Additives- ,Plasticizer, Retardant, Air Entrainment AntiWashout	Ad	Minimize water, Improve flow properties	**20-50[b]**	1.1
Transport		Deliver to Site	35	

a. Costs estimated from factory quotes and current cost of 95$/yd^3 for standard construction concrete

b. Cost per gallon, usage depends on formulation

c. Used only in reducing grout formulation

Table 4. Composition of Selected Field or Lab Tested Fill Cementitious Grouts .

Base Material	Site Test	PC	GBFS [a]	Fly Ash[b]	Sand	Water	Additives [c,]	cement/ sand [e]	water/ cement [d]	Density [f]	Cost [g]
Intrusion Barrier Grouts		Weight %						ratio	ratio	g/cc	$/yd^3
Hanford Zero Bleed HRG9	SRS	8	6	5	64	17	0.4	0.29	0.83	2.0	94
SRS Intruder Barrier	SRS	16	0	0	67	16	0.8	0.24	0.99	2.0	139
Fill CLSM											
Conceptual INL Tank Farm Closure Fill Grout	INL	9	0	18	61	12	0.3	0.44	0.45	2.1	95
CLSM #1 Test Low Cement	INL	2	0	6	82	9	0.2	0.1	1.17	2.2	64
CLSM #2A Test Tank/Vault	INL	3	0	8	76	13	0.1	0.15	1.14	2.1	51
CLSM #2 Test Tank Farm/Vault Specification	INL	4	0	13	70	13	0.2	0.24	0.72	2.1	71
CLSM #3 Test GEM Mix Air Entrained	INL	4	0	7	80	9	0.1	0.1	0.83	1.7	47
Test Alternate, Tank Heel Displacement Spec	INL	7	0	13	66	14	0.4	0.3	0.67	2.1	82
SRS Zero Bleed Flowable	SRS	4	0	14	66	16	0.4	0.28	0.81	2.0	117
Hanford SRS Design Zero Bleed HRG2	SRS	2	6	11	66	14	0.7	0.29	0.73	2.0	119
Pipe Fill Grout No Aggregate											
Batch Plant Specification	INL	22	0	52	0	25	0.33		0.34	1.8	136
WCF RCRA Closure	INL	21	0	50	0	28	0.25		0.40	1.8	126

a GBFS–ground blast furnace slag, ASTM C989 grade or better.

b. Fly ash–ASTM C618, Class C or Class F.

c. All additives Plasticizer or high-range water reducer, Set Retardent, wt% of total material, ASTM C494 Type A, C, D, or F

d. Water to Cementitous material ratio (cement, GBFS, FA)

e. Sand to Cementitous material ratio (cement, GBFS, FA)

f Density as calculated with no entrained air

g. Cost is estimated for mixture in bulk includes transportation

h. CLSM Controlled low strength material

i. Underlined are Specification Mixes Tested at INL

5. TANK CLOSURE GROUT SELECTION

Field testing is the primary screen to select the "heel displacement" grout and fill CLSM formula. The pumpability field mock-up test of CLSM/grouts applicable to INTEC Tank Farm heel displacement, and fill is described in Section 6. Other field and laboratory tested grouts tested grouts deemed suitable for INTEC Tanks Closure are listed in the table above for comparison purposes.

The grout criteria for void fill and strength derive from for cementitous waste form performance criteria specified by the Nuclear Regulatory Commission (NRC-1991) the laboratory and field experience dealing with waste stabilization material testing for TRU buried waste (Loomis et al. 1995–2003), low level buried waste (Shaw 2004), cementing low level waste (Franz et al. 1994); and tank waste (Shaw 1996). Tank fill with cementitous material has been studied by Oak Ridge National Lab (Gilliam et al. 1990; Bostick et al. 1988). Grout formulations to move waste within a tank, fill voids and form an intrusion barrier have been developed and implemented by Savannah River Site (Langton 1987; Caldwell 1997; Greenfield et al. 1998; Kim and Boulgegue 2002) both for their tanks and those at Hanford.

5.1 Implementability

Tank fill does not present significant implementibility problems. The most difficult implementation step, the heel displacement has been field tested and parts were retested in the mockup test. The test stabilization materials will be applied using grout pump equipment similar to what has been used in past field testing pumping to fill a large structure (Poloski 2004). The selected grouts were field tested to demonstrate pumping over a long distance and dropping to adequately fill large tanks with minimal cracking, bleed water, and heat build up.

The selected fill grout formulations final field test confirmed critical implementibility parameters measured such as viscosity and initial gelation (set time). Table 5 presents both implementibility and effectiveness criteria of the TFF closure project. The INTEC Tank farm closure grouts identified here have been tested (field and/or lab).

The fill CLSM should have:

Field or Laboratory Test Data. The grouts must have been demonstrated operationally feasible in large fill operations through mockup tests or actually used in INTEC closures (Poloski. 2003). From these appropriate physical properties such as set time, viscosity, and set temperature are determined in laboratory tests.

Low Temperature of Set. Due to the volume of grout in filling the tank the fill grout must no exceed a set temperature of 70°C. The fill formulations considered have low cementitous material contents (<11%) such that temperature rise should be not much more than 35°F(19°C) (ACI, 2002) which is the temperature rise of 7% cement mixes. Temperatures rise needs to be minimized to reduce the chance of cracking and shrinking as the cement sets, especially in bulk emplacement.

Low Viscosity: The large volume of CLSM will be placed inside the tank in several lifts from two points and outside in the vault from one or two points depending on the vault construction. Grout needs to be self leveling so mounding does not prevent subsequent lifts from filling evenly. This reduces the chance of the outside vault being filled higher then the inside grout layer and possibly caving the tank. Low viscosity also aids in the long distance pumping, and permeation of grout into all parts of the tank. Fill grouts should have at least a 10 inch slump or 8 inch puddle diameter.

Long Set Time: The long distance the grout/CLSM must travel and the time needed to self level in each lift requires a set time over 2 hours for the transport and pumping. If the grout has to be trucked from town a set time of 4 hours is preferred. This reduces the chance of premature set requiring extensive pump cleaning or mounding that prevents full tank fill. Also long set times usually lower overall set temperature.

Hydraulic properties, A pumpable liquid -like material with suspendable solids. Particle sizes in the suspension for C-33 sand are less than 9 mm with the additives present to prevent settling during pumping. The particle size of the pipe fill is less then 1 mm based on the fineness of fly ash and cement.

The measurements for these parameters are:

- Fluid and pumpable, viscosities, >10.5 inch slump or >9 inch diameter in flow test
- Particles up to 9 mm should remain suspended over the entire pumping distance and under pressures up to 4000 psi
- Set times of at least 2 hours and hydration temperature <70 °C.

5.2 Effectiveness

The primary performance goals for TFF closure grouts is structural to fill tank without it being crushed or cracked through expansion or pressure from subsequent CLSM layers

General criteria that have been considered during previous grouting studies that apply to closure grouting are provided in Table 5. Table 6 evaluates tested grouts against the criteria for the tank farm. This section discusses effectiveness criteria for heel displacement, and fill grouts.

The first layer of grout starts the tank fill but is primarily used for heel displacement. The performance goals for the heel displacement grout are related to implementibility ie the careful placement of a grout of sufficient viscosity and density needed for pushing the heel for removal. Based on chemical reactivity, it is assumed that cementitious grouts will encapsulate the minute amounts of waste heel remaining. The subsequent layers of fill CLSM are essentially a contamination free system.

Due to the removal of radiological residues the heel displacement grout is not enhanced for leach resistance or long-term durability. Tank grouts from other labs required both structural and leach resistance material properties. These properties and natural analog experience are discussed in Shaw 2004.

The fill CLSM should have stability as a liquid and strength when solidified.

Stability.
The injected grout mixture will be pumped over 120 feet (37 meters) and dropped over 22 feet (7 meters) from the top of the tank so the aggregate and sand should not separate during the pumping or the fall into the tank as it self levels. CLSM were selected for this performance from the mock-up test. The heel displacement grout contain sufficient cementitous material to not separate upon implementation. They also do not have to fall 22 feet.

Strength.

The strength of the fill grout should support itself and be greater then the surrounding soil. The CLSM for tank fill needs sufficient strength, to resist deformation and subsequent subsidence. The strength of the grout is typically measured via compressive strength. CLSM should have minimum 28-day compressive strength of at least 100 psi. Other properties such as, density, and porosity contribute to physical stability and help to eliminate voids in the tank. Due to future capping of the entire Tank Farm, hydraulic conductivity in the fill is not a critical grout parameter.

Table 5. Criteria for Tank Farm Facility Closure Grouts.

	Criteria	Basis/Requirement
All	Application compatibility for long distance pumping. Grout has been field tested at INL or other facility.	Result reports from past; lab field testing. test in tank mockups
All	Particulate suspension in liquid. no free liquids remain after grout sets	no phase separation, < 0.5% free l liquid ANS 55.1
All	Set time.	>120 minutes set time.
All	Cost within project budget.	Fill, <70$/yd3, 97% of the total grout used. Heel Displacement -3% <130$/yd3
HD	Grout has been tested in a heel displacement.	Result reports from field testing.
HD	Density maximizes movement of less dense in heel	≥130 lb/ ft3, 17 lbs/gal, 2.0 g/cc, ASTM D4380
HD	Sufficient Viscosity to push heel toward jet pump	>10 Inch Slump, ASTM-143
Fill	Shrinkage.	<1% change in standard density, ASTM D4380
Fill	Heat generation: minimal heat given off during application.	Calorimetry, final temperatures not to exceed 80°C.
Fill	Viscosity. –self leveling	>10 inch slump, ASTM 6023 Flow Test >8 in ”puddle”
Fill	Resist subsidence from overlying grout.	Sufficient compressive strength to hold up fill, >100 psi and greater then surrounding soil ASTM C39
Pipe Fill	Particle size small enough to fill ½ inch pipe	<1 mm particle size, pass Sieve #20, ASTM E11-70

ASTM = American Society for Testing and Materials,
ANS = American Nuclear Society,
API = American Petroleum Institute
CFR = Code of Federal Regulation,
HD- Heel Displacement

Table 6. Relative importance of specific *implementibility* and **effectiveness** parameters.

Parameter	Importance	Performance Values	Selection of Value
Viscosity	***High(HD)***	Puddle Diameter >7 inches	Minimum
	Med (F, DF)	> 9 inches	Expected
		> 10 inches	Desirable
Set-time	*High*	>2 hr	Minimum
		>4 hr	Expected
		>6 hr	Desirable
Temperature of Set	*High (F)*	<160F, <70 C	Minimum
	Low (HD, DF)	<140F, <60 C	Expected
		<120F, <50C	Desirable
Density	**Low (DF)**	>105 lb/ft3 1.7 g/cc	Minimum
	Med (F)	>120 lb/ft3, 1.9 g/cc	Expected
	High (HD)	>130 lb/ft3, 2.1 g/cc	Desirable
Compressive Strength	**Low (F, HD)**	>100 psi	Minimum
	High (DF)	>1000 psi	Expected
		>1500 psi	Desirable
Shrinkage	**Med (F)**	<1%	Minimum
	Low (HD,DF)	<0.5%	Expected
		<0.1%	Desirable

a. *Implementability in Italics* b. **Effectiveness in Bold**

HD- Heel displacement, DF-dome fill, F-Fill

5.3 Evaluation

The Nuclear Regulatory Commission requires a minimum of 60 psi to support 20 ft of overlying soil in the shallow land burial of cemented waste (NRC 1991). For most studies on grouting TRU buried waste insitu this was raised to 500 psi to provide a ten fold safety margin (Shaw and Weidner 1996). The fill grout is specified as 100 psi Controlled Low Strength material (CLSM).

Heel displacement. Pipe Fill and many dome fill grout mixes surpassed 1000 psi in UCS due to lower water and higher cement content then the fill CLSM. All fill CLSM surpass 100 psi in strength though some take the entire 28 days to achieve sufficient strength even with ungraded high silt windblown sand. Table 8 lists UCS values for test samples of the heel displacement, and fill grouts using both graded C-33 sand and finer ungraded (roughly C-141 with excess fines) wind blown sand. Compressive strength of CLSM and grouts decrease with, increased, water, aggregate and fines.

Table 6 is a listing of the relative importance for the various parameters and recommended specific values for those parameters. The values are ranked as the minimum expected and desirable. The relative importance is given as high, medium, and low for each grouting application initial heel displacement, fill, and final dome fill.

The table below lists rankings based on experience gained from past grouting operations at the INEEL particularly WCF Cell Fill and the completed mockup test. The relative importance is largely based on field used, testing and engineering judgment. It is necessary to balance requirements. For instance, minimize cement in the fill CLSM to minimize cost and heat generation but increase cracking and the ability to suspend aggregate during pumping. Maximize density and viscosity in the heel displacement grout and dome fill grout to increase the ability in pushing the tank heel but increase difficulty in pumping.

In the Table, the “lowest acceptable” designation is the minimum expected value for that parameter in which the application is possible. Desirable is the best value seen in field or lab testing experience. Grouts and CLSM have different priorities for grout properties depending on whether they are fill or heel displacement. Initial heel displacement or final grout layer should be viscous enough to move liquids or fill the dome of the tank. The unconfined compressive strength. of the fill CLSM should be at least 100 psi to support further layers of CLSM.

The relative importance for the various parameters were chosen based on prioritizing important aspects of grout stabilization. These aspects in order of importance for closure grouting are:

1. Implementability- pumpability, cost, set temperature, resistance to separation, set time, viscosity.

2. Effectiveness- compressive strength, density.

Both CLSM and grouts were chosen from previous testing of a variety of Portland, Sand, Fly Ash grout mixtures. The CLSM for fill has 68-80 wt% Sand, 2-5 wt% Portland, 6-14 wt% Fly Ash. The grout for the heel displacement, has 69-73- wt% Sand, 6-7 wt% Portland, 12-14 wt% Fly Ash. The tested grout for the dome fill (modified heel displacement) has 77-79 wt% Sand, 7-8 wt% Portland, 4-6 wt% Fly Ash. All formulas require a plasticizer or air entrainment agent. These compositions have been field tested using the above performance criteria for TFF closure.

5.4 Cost

Implementation criteria include pumping over large distances; pushing existing contamination to jet pump, filling small pipes, and cost. Table 6 lists estimated costs for the three types of grout formulations being considered: reducing, dome fill and fill. Grout costs have been estimated based on prices from vendors and bulk suppliers. The cost estimates for grouts could increase somewhat with modifications to better suit the implementibility needs especially flow and cohesiveness requirements and sand that requires grading or extensive transport. Low cement formulations and sand that is unwashed or ungraded would decrease cost though savings are not realized if greater amounts of plasticizer to suspend the sand and minimize water are needed. Unwashed or ungraded sand may also cause consistency problems that may add to the cost.

The costs for field tested formulations are estimated to be: fill mix-\$70/yd^3, the heel displacement mix- \$110/yd^3, dome fill mix- \$90/yd^3 and the fly ash mixture for pipe fill- 190\$/yd$^{3.}$ Cost estimates for some 30 tested cementitious grouts with additives range from \$60–\$200/yd^3 (\$0.30-\$1.00/gal, \$40–\$110/ton). INL and SRS fill grouts, simple cement sand mixes, tested in tank mockups suitable for long distance pumping and tank fill averaged \$90/yd^3. Intrusion Barrier mixtures for Hanford and Savannah River tanks with additional cement averaged 100\$/yd^3 are suitable for both general fill and final dome fill exceed 1200 psi compressive strength.

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6. TANK CLOSURE GROUT TESTING

Both laboratory material testing and a Full Scale Mock up field test were performed on fill CLSM and heel displacement grout mixtures. Pipe fill and "heel displacement" grout have already been field tested. Laboratory testing used standard cement and testing apparatus on various mixes. Some mixes were involved in a simulated "drop" test. Field test equipment consisted of commercial concrete mixing and pumping trucks. This full scale mockup field test of grout applicable to INTEC Tank Farm fill augmented the laboratory tests for INTEC Tanks Closure CLSM and grouts. The laboratory testing is described with results listed in Table 7, 8. The mockup test described after this is summarized in Tables 9-13.

6.1 Grout and CLSM Laboratory Testing

Both INTEC Tank farm closure heel displacement grouts and fill CLSM mixes were evaluated in the laboratory for viscosity and compressive strength. These measurements were used to select grouts for subsequent mockup tests. Properties of candidate heel displacement grout and fill CLSM were measured and a simple drop test was performed on fill mixes to scope the potential to separate upon dropping in the tank.

6.1.1 Equipment

Laboratory testing was performed with standard cementitous material equipment including compressive strength test device, slump and flow test funnel and cylinder and molds for sample preparation. Materials have already been discussed and included both graded and ungraded sands, Portland Cement, Super-plasticizer and Class F Fly Ash.

<u>Mixer</u>

3 liter Hobart Mixer Laboratory , 1.5 ft^3 drum mixer

<u>Plastic Molds</u>

2"X2"X2" Cubes, 2"X4" cylinders, 1"X2" cylinders

<u>Viscosity measuring equipment</u>

3"X6" tube for Flow Test, 6"x12" funnel for Slump Test, Brinkman DVII+ Digital Viscometer

6.1.2 Experimental Design

The CLSM mixes for tank fill and heel displacement were prepared with aggregates, both graded C-33 Sand (9.5-0.3 mm) and ungraded, high fines, windblown, sand (roughly C-144- <0.6 mm) to simulate using an onsite source without grading facilities. The viscosity when mixed was measured with viscometer, flow test and/or slump test. The viscosity for ungraded sand mixtures was continually measured for up to an hour after mixing by flow test and laboratory viscometer. Graded sand mix viscosities were measured by slump test and flow test.

Cubes (2" x 2"x 2") and cylinders (2" x 4", 1" x 2") were prepared and Unconfined Compressive Strength (UCS) measured typically at 1 week intervals over a one month period for all CLSM/grout mixes. Four CLSM/ grout mixes with graded sand and two with ungraded sand were mixed, viscosity

tested, then had UCS measured. UCS was measured with 10,000 lbs digital readout load cell for small, lower strength CLSM samples and 25,000 lb hydraulic press for larger higher strength grout samples.

Three of the mixes made with ungraded sand were sampled after dropping 5-10 feet to see if any separation of the mix occurs upon falling. UCS was measured on discrete samples to determine if separation might occur when dropping high aggregate/low cement mixes into large tanks. As can be seen in the figures no appreciable separation occurred.

6.1.3 Results

In general, mixes had greater strength then expected but some low water mixes particularly those with ungraded fine sand need viscosity improvement for pumping and self leveling. The viscosity for ungraded sand mixtures at a given water content was higher then graded sand due to the fines content. No appreciable separation occurred upon dropping. CLSM mixtures all achieved 100 psi though in most cases this took several weeks to be developed. Grout mixtures achieved 1000 psi strengths. Table 8 Lists the test results.

Table 7. Summary of Cementitous CLSM and grout samples.

	Drop Height	Sand	Cem ent	Fly Ash	Water	Additives	UCS Samples	
Ungraded Sand (<0.6 mm)	ft	Wt%					#	Size
Heel Displacement High Water	5	67	6	12	15	0.24	14	1x2, 2x2x2
Heel Displacement 1	10	67	7	13	13	0.32	19	1x2, 1.5x3, 2x2x2
Fill CLSM Original Spec	10	70	4	13	13	0.20	30	1x2, 2x2x2
Dome Fill Grout	NA	57	11	20	12	0.33	16	1x2, 2x2x2
Fill CLSM #1 Low Cement High Water	None	75	2	6	17	0.42	27	1x2, 2x2x2
Graded Sand (9.5-0.3 mm)								
Fill CLSM #1 Low Cement	NA	83	2	6	9	0.23	6	2x4
Fill CLSM Original Spec	NA	70	4	13	13	0.21	18	2x4
Fill CLSM #2 Revised	NA	76	3	8	13	0.07	6	2x4
GEM cement #3 25% Air	NA	80	4	7	9	0.09	6	2x4
Heel Displacement	NA	66	7	13	14	0.25	15	2x4

NA- Not Applicable- Dome Fill and Heel displacement grouts will be placed rather then dropped

Table 8. Cementitous CLSM and Grout Lab Results

	Material			UCS					Viscosity Puddle test
	Ratio			psi					inches
	Water/ Cement, Fly Ash	Cement, Fly Ash / Sand	Cement/ Fly Ash	3 day	7 day	14 day	21 day	28 day	
Ungraded Sand (<0.6 mm)									
Heel Displacement High Water	0.8	0.27	0.54	20	24 [a]	99 [b]			*6* [c]
Heel Displacement 1	0.77	0.24	0.33		254	474		765	*4* [c]
Fill CLSM Original Spec	0.69	0.30	0.49		530	735	1176		5.5
Heel Displacement 2 (Dome Fill)	0.37	0.54	0.53		2480 [d]	3050	3400		*3.5*
Fill CLSM #1 Low Cement High Water [h]	2.16	0.10	0.33		411	480	500		3.1
Graded Sand (9.5-0.3 mm)									
Fill CLSM #1 Low Cement	1.17	0.10	0.33		80	111	128	154	7.25
Fill CLSM Original Spec	0.78	0.24	0.33	366	812	1241	1639	2077	10.5
Fill CLSM #2 Revised	1.14	0.15	0.33		216	235	286		8.75
GEM cement #3 25% Air	0.83	0.13	0.50				161 [e]	435 [f]	10.25
Heel Displacement 3	0.67	0.33	0.49	350 [g]	1337	1782	2817	3000	

a. 10 day,

b. 17 day,

c. Italics- puddle diameter estimated from instrument viscosity measurements

d. 11 day

e. 28 day,

f. 56 day

g. 1 day

h. GBFS used instead of Fly Ash

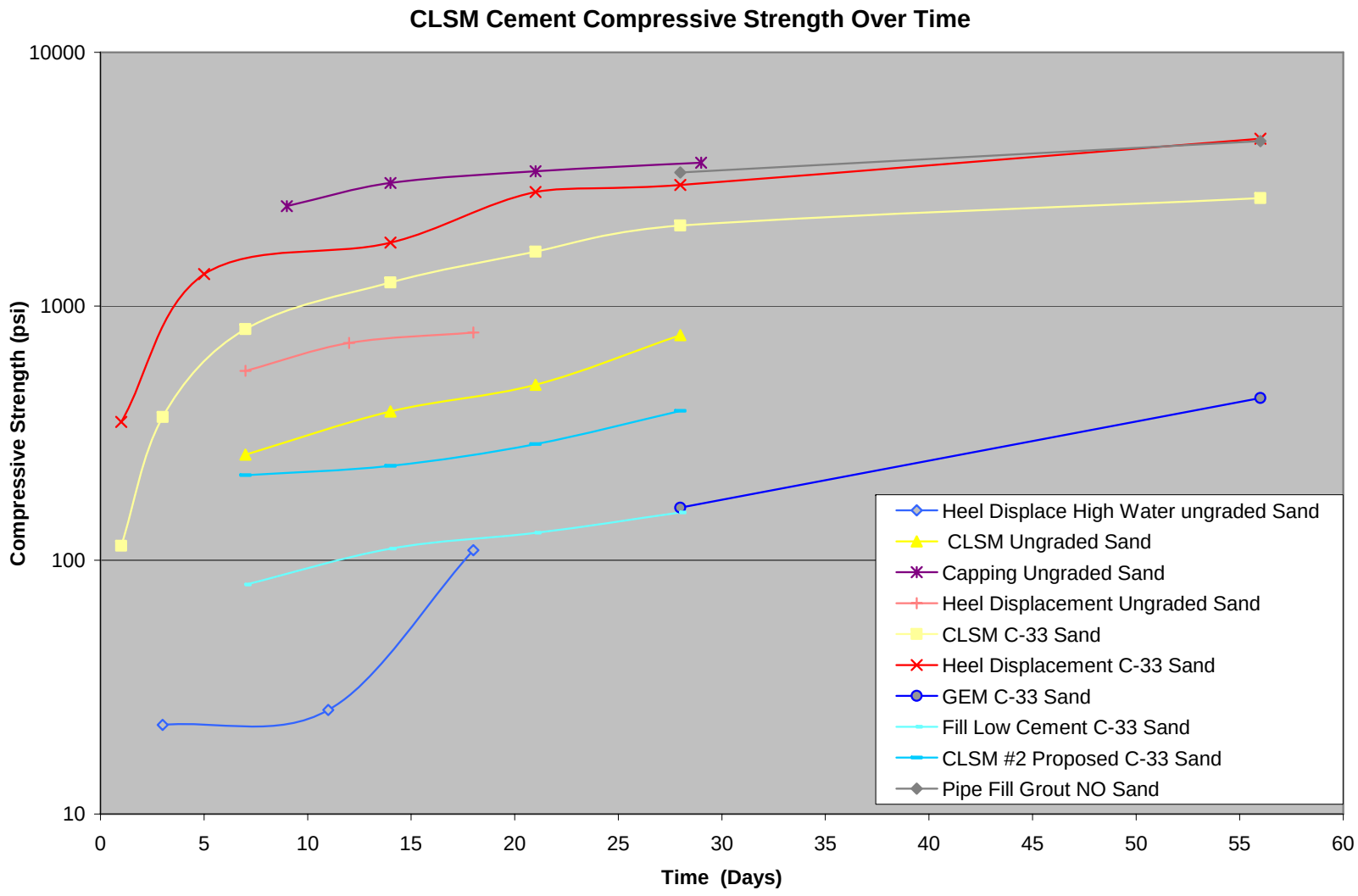

Figure 4 CLSM and Grout Unconfined Compressive Strength.

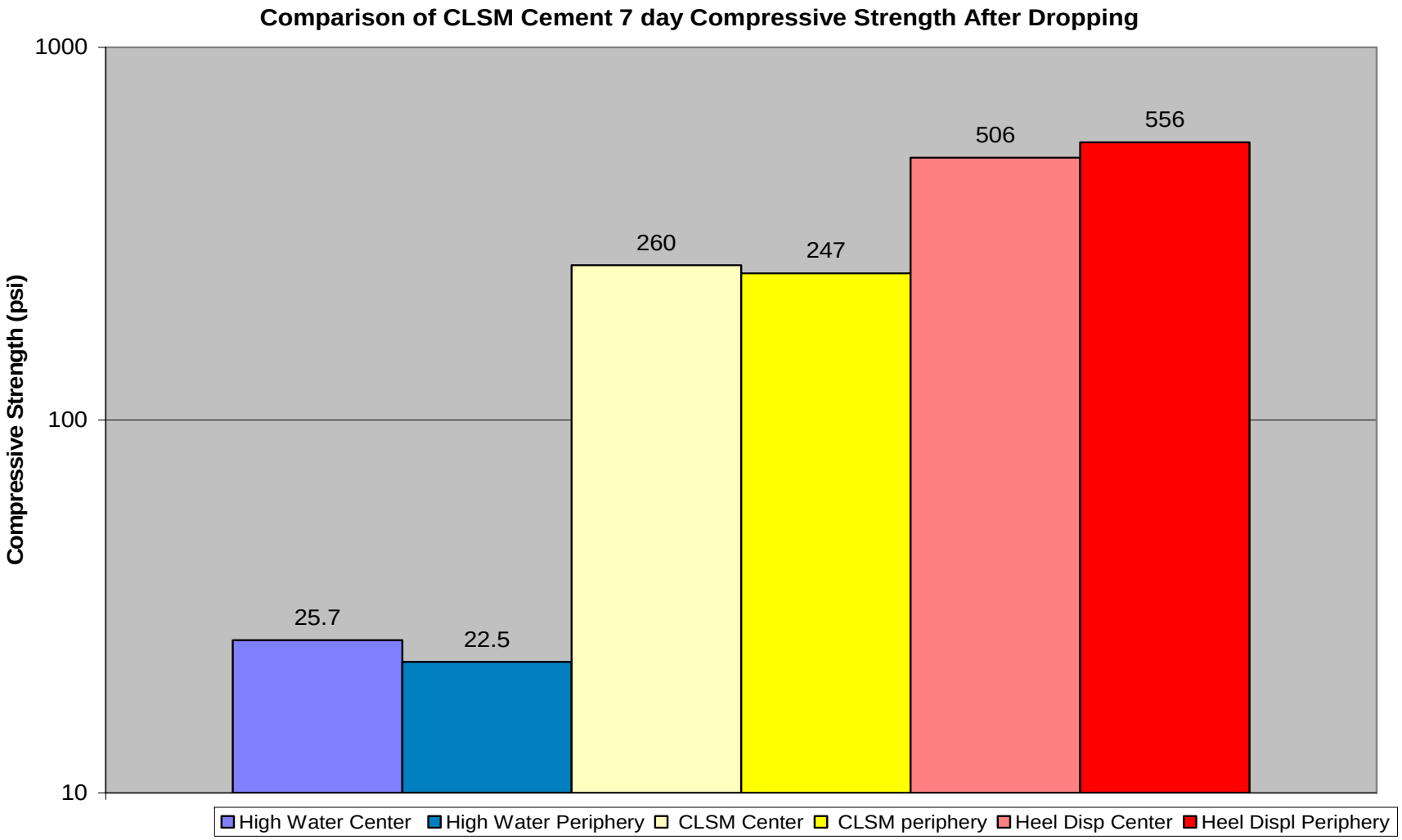

Figure 5. Comparison of CLSM 7 day Compressive Strength.

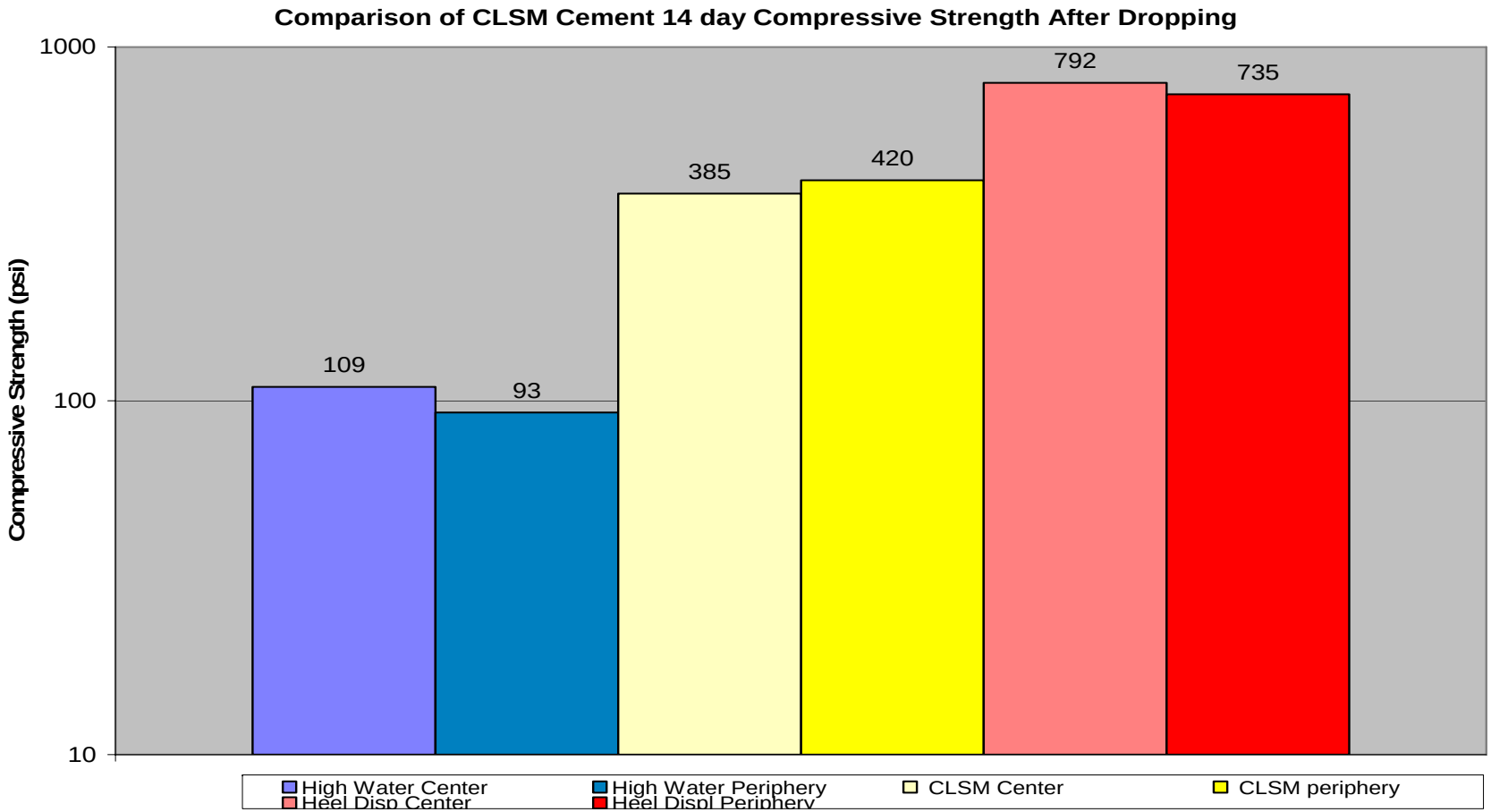

Figure 6. CLSM 14 day Unconfined Compressive Strengths.

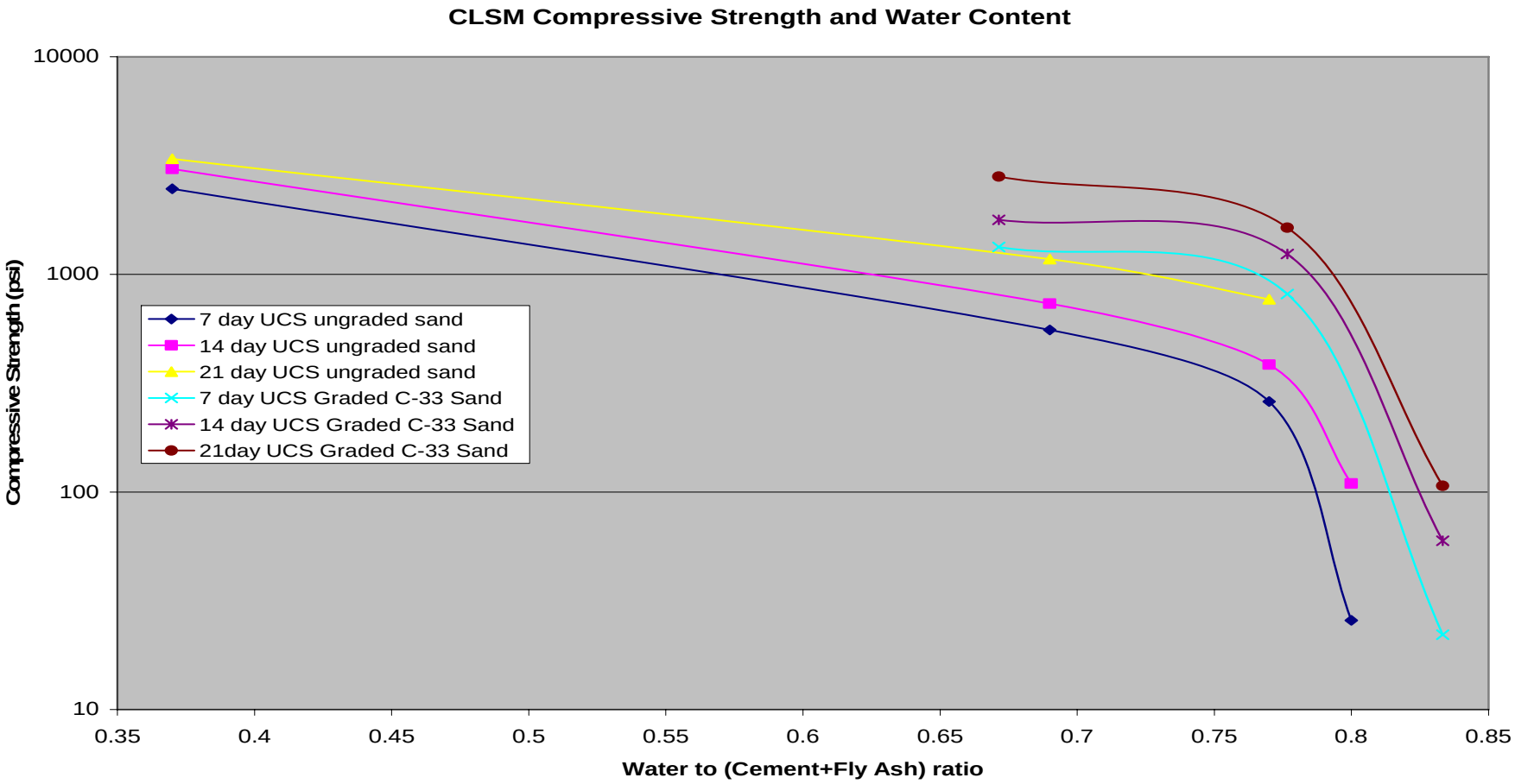

Figure 7 CLSM/Grout Unconfined Compressive Strength vs Water to Cement Ratio.

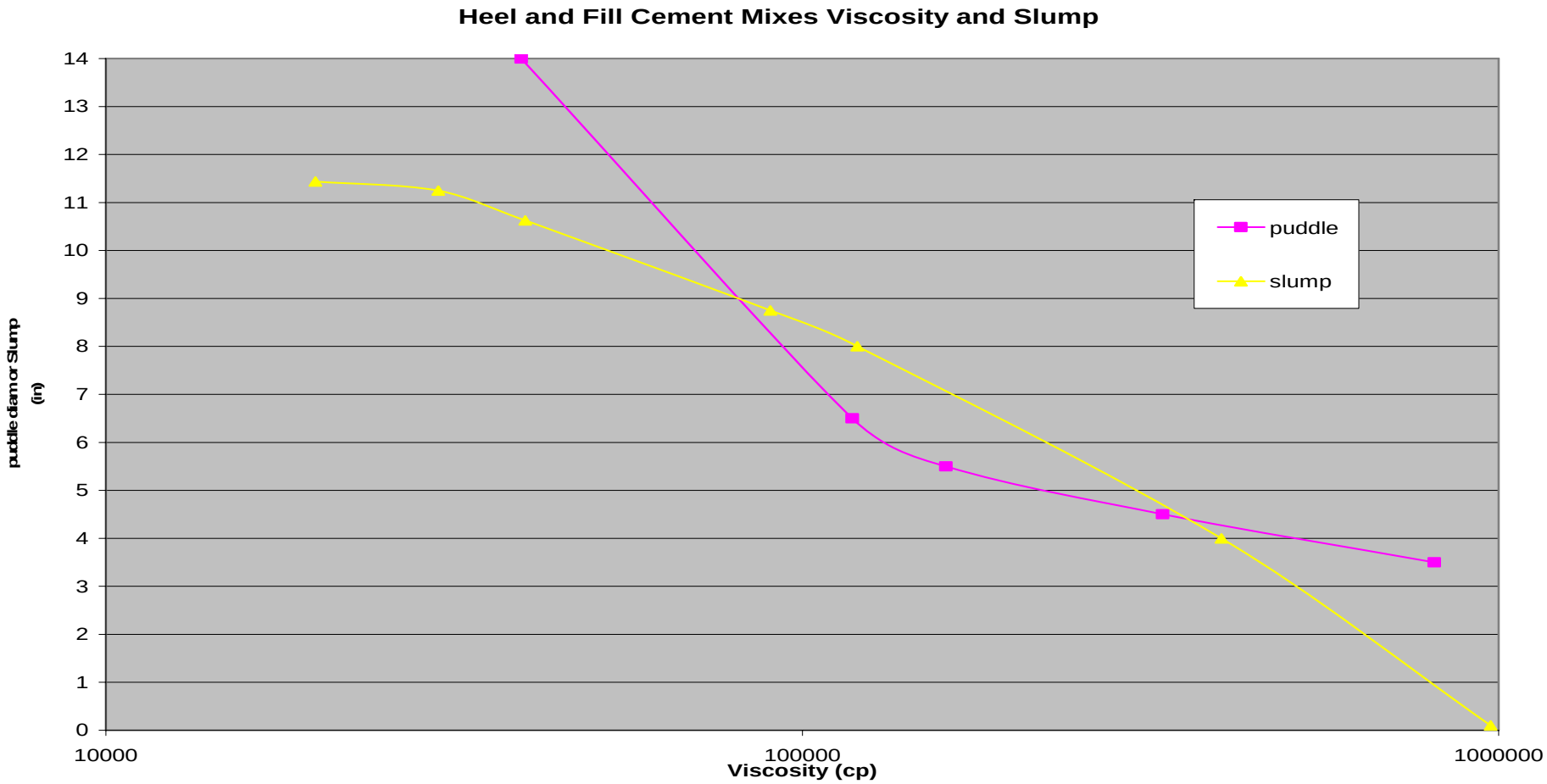

Figure 8 CLSM Viscosity from Viscometer, Slump and Flow test

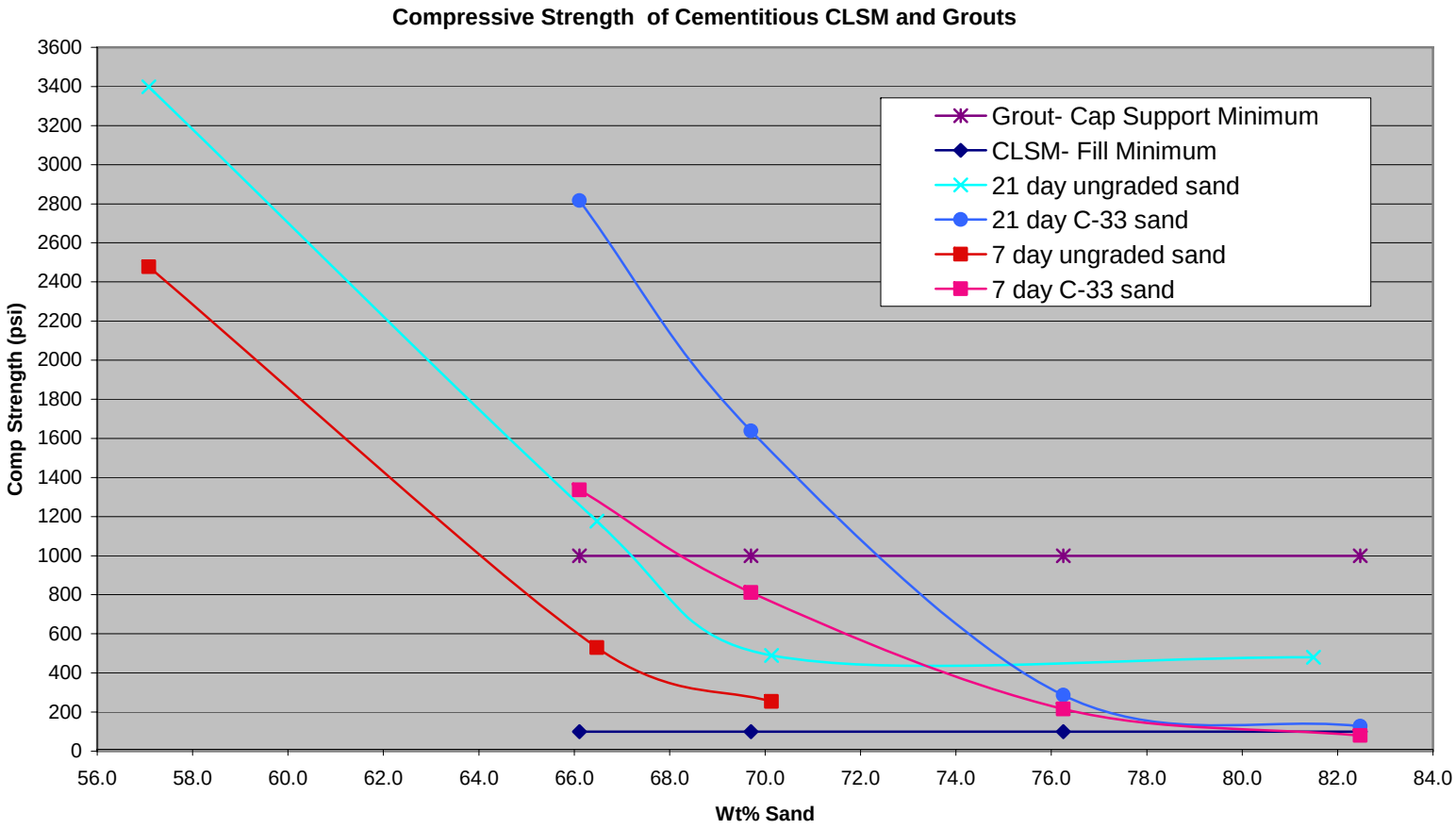

Figure 9 Compressive Strength and Sand Content of CLSM and Grout Mixes

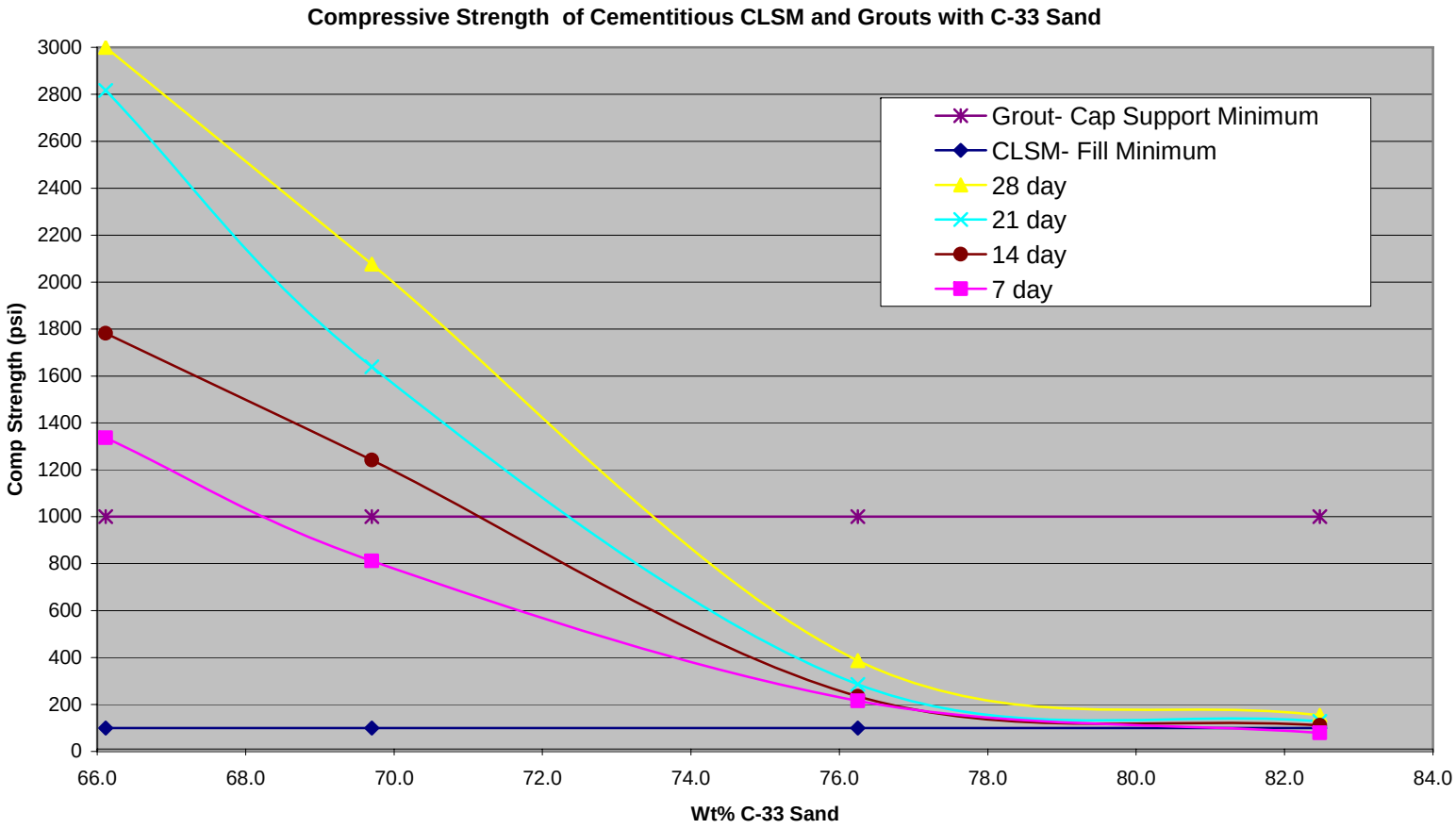

Figure 10 Compressive Strength and Graded C-33 Sand Content

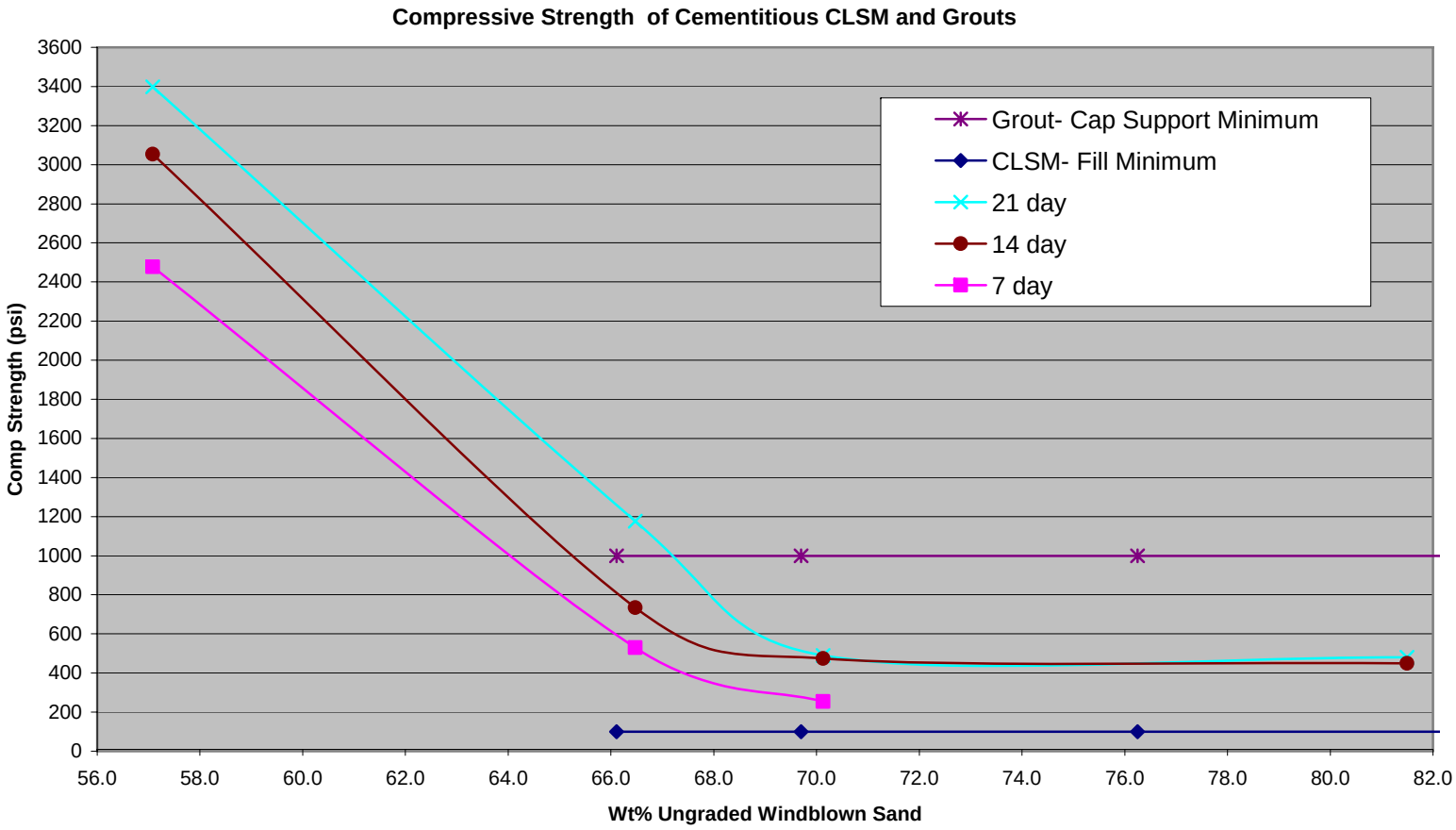

Figure 11 Compressive Strength of Ungraded Sand Mixes

6.2 Controlled Low Strength Material and Grout Placement Field Test

The INTEC Tank farm closure grouts mockup field testing simulated layer filling of the project tanks with low strength material (CLSM) to:

1. Evaluate low cost CLSM mixes to adequately fill large tanks with no cracking, bleed water, and heat build up.
2. Evaluate grout mixes with sufficient viscosity using placement techniques to adequately fill the top tank dome.
3. Evaluate the ability to pump lean CLSM or thick mixes over long distances.
4. Evaluate application alternatives of tank fill CLSM.
5. Access qualitatively overall Tank Farm Closure implementibility of filling with grout and CLSM.

This test was performed in accordance with construction specification (SPC-736) provided by CH2M♦WG Idaho, LLC (CWI) to supply and pump controlled low strength material (CLSM) to simulate filling of the Tank Farm Closure Project tanks. The construction specification met requirements of Contract No. 502833. Portage Environmental, Inc. (Portage) managed the test , Ovard Construction made and placed the treme tubes. Burns Concrete provided grouts and CLSM and Brundage Bone provided and operated a state of the art grout pumping truck with 129 foot boom. The table below lists tasks and responsibility.

Table 9 Service List for CLSM/Grout Pumpability and Placement Field Test

#	Service	Company
1	Manage Contractors and Field Test Operations	Portage
2	Supply a mock-up test area	Portage
3	Dig Trenches and Prepare Site	Ovard
4	Determine Grout Mixes	CWI, Burns
5	Supply, mix and deliver CLSM and grouts	Burns
6	Pump CLSM and grouts 120 feet	Brundage
7	Supply and install piping to simulate the tank fill pipe alternatives	Ovard
8	Sample Grout placements and Test	CWI
9	Core drill solidified layers of grout and CLSM	A Core
10	Analyze Cores	CWI
11	Cleanup of the mock-area after testing	Ovard
12	Document Test	CWI, Portage

6.2.1 Equipment

The Tank fill CLSM and closure grout field test used a high volume pump >60 yd3/hr (cubic yards per hour) and pump trucks with a > 120 ft. reach to test whether the specified CLSM and grouts were pumpable liquids and could be dropped with solids suspendable and no significant separation and reasonable self leveling.

6.2.1.1 Grout/CLSM Pump

A Schwing America S 47 SX grout pump with the 2525H-6 pump kit installed performed the test. The pump was tested near the maximum output of 213 cubic yards per hour. The pumping rate was well

above the 40 yd3/hr called for in the construction specification SPC-736. The delivery pressure was also much higher then the specified 150 psi. It was kept below the pump limit of 5000 psi, normally operating between 400-1200 psi for most placements. The pump was operated remotely. Pump rpm and pressure were monitored. Pump volume was estimated from the truck volume and timing of the delivery to give an approximate flow rate for each mix. These values are listed for each load in the tables below

6.2.1.2 Pump Truck

The Schwing pump truck had a net horizontal reach of 129.5-ft thus capable of delivering the CLSM in excess of the minimum requirement of 120-ft of horizontal reach to the positions shown in figure 11. Both a 4 inch and 5 inch high density rubber tubes nozzle- was used. The 4" was used for free dropping and treme tube application of CLSM. The 5" tube was used for dispensing the dome fill (final fill layer) and heel displacement (first layer) mixes. Positioning of the four section boom is entirely remote using radio control. Pump parameters are read from the remote device including pump rpm and pump pressure. Average pump flow rate for a load was calculated from pump time and truck volume and was not directly available. The mix truck with boom extended is shown in the figure 12: The pump operated between 1,200 and 1,700 rpm and was driven by the truck engine.

Figure 12 Pump Truck Boom Fully Extended Applying Grout Mix

6.2.1.3 "Treme" tubes

Two types of treme tubes were tested. Both used PVC plastic pipe one had drilled holes and other T fittings. The hole treme was 6 inch nominal diameter vertical schedule 80 PVC pipe 22 feet long with 3 inch diameter holes spaced at 12 inches (20 holes). Orientation of holes was staggered at 90 degrees shown in the schematic figure 11 and pictured in Figure 13.

The T Fittings treme was 4 inch nominal diameter vertical schedule 40 PVC pipe 22 feet in length with 4 inch diameter tees spaced at 16 inches (16 tees). Orientation of tee outlets staggered 90 degrees shown in the schematic figure 11 and pictured in Figure 14.

6.2.2 Trench Design

Three identical trenches were dug as diagramed in Figure 11. Each trench had a 3'x25' foot base. The sides were sloped at 45 degree giving a final foot print of 14'x36'. Each trench received 4 truck loads about 36 yd^3. The contents of each are given in Table 4. The filled trench volume is about 50 yd^3 thus each trench was filled

Figure 13 Three Mockup Trenches, numbered 3, 2, and 1 from left to right, 4" treme in #2 and 6" treme in #3

6.2.3 Measurements

Measurements were taken on each of the 12 batches and three modified half batches. Unit weight, air content and viscosity from puddle or slump test were obtained directly from 8 batches, from samples in 2"x2"x2" cubes and 2"x4" cylinders and from cores 20 days after placement. Properties of the grout/CLSM, operational parameters and physical properties of the application were measured and listed in Tables 9-11. Specific mock-up test measurements were.

1. Grout/CLSM properties

- Viscosity or Fluidity- (Flow test or slump test- inches),
- Density (specific gravity-g/cc or unit weight-lbs/ft^3)
- Air content (Vol %)

2. Operational pump properties

- Pumpability- a qualitative observation that the pump can handle the mixture and particles do not settle through the pump and pipe line and remain suspended under pressure.
- Pumped volume (yd^3)

- Pump pressure (Bar or psi)
- Pump speed (rpm)
- Pump time (min)

3. Physical properties of Placement:

- Layer height, layer width, layer thickness, (feet, inches)
- "Mounding"- difference in height over the surface area of the flow (inches).

6.2.4 Description of Mockup Grout/CLSM Test

The testing consisted of both CLSM drop tests for tank filling and heel displacement placements as diagramed in Figure 11. The testing simulated these three placements using CLSM for the fill and higher content cement grout for heel displacement and final layer dome fill. Twelve 9 yd^3 truck loads were applied, about 4 in each trench. Seven loads were dropped either freely or through treme tubes to simulate tank fill and seven were poured or placed. Although one of the seven was not a good mix and not much testing was done on it.

Grout will be used for the first 2-3 foot thick layer and CLSM for the fill. The testing simulated grout mixture placement by pouring and grout fill by dropping. There were four tests of more viscous grout mixtures for the first tank heel displacement layer. Three loads were placed with no time lapsed between each load to simulate multiple truck placement in or under un-solidified grout.

The CLSM for the actual tank fill will be placed in 3 to 4 foot thick layers. The testing simulated this by placing multiple layers of CLSM mixture by dropping. Layers varied around an average foot thick usually higher at the point of placement. At least four hours elapsed between each layer placement. At least 1 layer of one CLSM mixture specified in table below was placed using the three drop placement methods. The CLSM was contained by the trench, but could flow up to 25 feet horizontally in the trench.

6.2.4.1 Drop Tests Loads 1-5, 10/24

Brundage pumped CLSM mixtures through the pump truck piping and a 4 inch hose about 120 feet and dropped each over 20 feet both freely and contained through two different treme tube configurations. Burns supplied several CLSM mixtures three with entrained air content >20% similar to that used in the Glovebox Excavation Method fill in Pit 9. . We evaluated the flow and self leveling. All three trenches were used with two loads in trench one and two on the west side added at least 4 hours after the previous layers.

CLSM mixtures specifically designed for fill purposes were dropped free or through treme tubes. Three of the test mixtures contained a foaming agent to obtain pumpability and fluidity while keeping solids content high. Loads were sampled to measure dispersion effects as the mixture spread throughout the trench. Three loads were sampled and directly flow tested using the puddle test. Two loads had air content measured.

6.2.4.1.1 First Load (10/24/05, AM) Free Drop

The first CLSM trial was mix CLSM-1 the only mix with <100 lbs of Portland. This layer was emplaced with an approximately 25 foot free drop through a 4" hose. The mixture did not include any plasticizer. With only 48 gal/yd3 water it was too thick to pump. Slightly over a yard made it through the system approaching maximum pressure 5000 psi. The pump flow rate, 50 yd^3/hr, though the lowest seen in the test, exceeded the minimum required 40 yd^3/hr until pumping ceased. The pump had to be cleaned and was flushed with the remaining mixture after adding water.

The puddle diameter test on this mix one half hour after placement was 3" meaning essentially no slump and the mixture would have not been accepted. This was not unexpected since the mixture had no plasticizer. The lab tested mix had plasticizer and might have been pumpable.

About 60 gallons of water was added to the remaining mix in the truck and the mixture pumped easily. Significant free water was apparent on the surface which remained until the next placement in this trench in the afternoon. A set of three 2"x2"x2"samples were obtained from the trench both before and after the water was added to the mix. The puddle test on the mix after water was added was estimated since the free water was not a part of the sample. The pump pressure was about a thousand but the flow increased substantially to 160 yd^3/hr.

6.2.4.1.2 Second Load 10/24/05 AM, Drop through 4" treme tube

The second mix CLSM-3 was made with 100 lbs Portland, 200 pounds fly ash, and Darafill a foaming or air entraining agent made specifically for CLSM. The first third of the CLSM-3 layer was dropped through the 22 foot long 4" diameter Schedule 40 PVC pipe treme. ('Trench" figure above and figure of placement below). The pipe had 4 inch diameter tees with outlets at 16 inches spacing staggered at 90 degrees. As can be seen in the figure the outlet was more then adequate to handle the flow and the CLSM did flow down the trench. The entrained air mixture flowed freely. The treme tube reduced splattering but the CLSM did flow over half the trench distance. Pressure was about 430 psi giving a pump flow rate of 120 yd^3/hr. The 4" treme was damaged in removal from the first placement and was of no further use.

The remaining half of the second CLSM layer was free dropped. There was increased splattering but the CLSM did flow down the trench more rapidly flowing slightly over the edge of the first portion 4" treme placement. Pressure was reduced almost by half to 270 psi which reduced the flow to 80 yd^3/hr. The puddle test was 10.25" with a low unit weight due to the 23% entrained air of 105 lb/ft^3 or 1.68 g/cc. Samples were taken of both the treme placement and the free drop. Three 2"x2"x2" cubes were molded from samples near and far from the treme tube and near and far from the free drop impact point. Samples were also taken for 2x4 inch molds from the hose before placement.

Figure 14. Second Load CLSM with AEA Flowing from a 4" Treme Tube

6.2.4.1.3 Third Load 10/24/05 AM, Drop through 6" treme tube

The third mix CLSM-3a was almost identical to load 2 with 100 lbs Portland 200 pounds fly ash and foaming agent. The entire load was dropped through the 22 foot long 6 inch diameter vertical Schedule 80 PVC pipe. The 12 inch spaced 3 inch diameter holes are staggered at 90 degrees. The holes were sufficient to handle the higher flow then load 2. The treme tube reduced splattering allowing the grout to flow over the entire trench distance. Pressure was about double the previous load, 890 psi giving a pump flow rate of 130 yd^3/hr. The pipe remained in the trench and was used for subsequent applications of the dome fill grout the next day. This was one of the layers cored.

Figure 15 Load Three CLSM Flowing from 8 inch Treme Tube

Figure 16 CLSM Flow from 8” Treme Tube

6.2.4.1.4 Fourth Load (10/24/05, PM, Free Drop)

The fourth load used CLSM-2 with twice as much cementitous material, 600 lbs/yd^3 as both load 1 (CLSM 1) and load 2 and 3 (CLSM 3) 300 lbs/yd^3. It contained 150 lbs Portland 450 pounds fly ash and both plasticizer and foaming (air entrainment) agent. The entire CLSM-2 load was free dropped 20-25 foot. The mix was considered too fluid so no puddle measurements or unit weights were taken. Air content was targeted at 6% but was at least 16% as measured from the final density of solid samples. Pressure of 1550 psi was about double the previous load with the pump operating at maximum rpm. Pump flow rate was very high over 190 yd^3/hr. The liquid from the previous placement in the morning combined with this mix to give a several inch layer of free liquid in trench 1. Figure 22

Figure 17 Free Drop of Load Four CLSM Containing both AEA and Plasticizer

6.2.4.1.5 Fifth Load (10/24/05, PM, Free Drop)

The fifth load used a variation of the previous CLSM-2 mix. The 150 lbs Portland-450 pounds fly ash remained the same but the plasticizer was cut by 2/3. The entire CLSM-2a load was free dropped 20-25 foot in trench 2. The mix was less fluid then the previous with some trapped but little entrained air. The puddle measurement was 13" the highest reading measured of any mix. Unit weight was high due to the lack of air 123 lb/ft^3 or 1.97 g/cc. Air content was only 3.2% indicating the plasticizer seems to have eliminated any air entrainment effect. Pressure was about double the previous load, 1,550 psi with the pump operating at maximum rpm. The lack of air makes pumping more difficult. The pumping rate was very high over 190 yd^3/hr. The mix was self leveling and spread over the entire trench covering the second mix Figure 23. These two loads are the primary layers cored. The following layers would be removed prior to the coring. Samples were taken both near the drop point and at the edge of the layer. Samples were also obtained directly from the pump.

Figure 18 Load 5 CLSM Containing both AEA and Low Plasticizer

6.2.4.2 Top Layer Dome Fill Test Loads 6-8, 10/25, AM

Three similar grout mixes with significantly more cement were tested. The cement and fly ash contents were reversed from the previous tests, with 200 lbs cement and 100 lbs fly ash and the mix was designated CLSM 3-2. This gave a mix of higher strength and somewhat increased viscosity. Brundage pumped these more viscous mixtures under considerably higher pressure through a 5 inch hose (a 4 inch had been previously used).

All were pumped about 120 feet and dropped over 20 feet. Two were contained in the 6” treme tube with 3” holes taped forcing the grout to come out under the layer as it was being poured. One test placed the nozzle itself under the grout level. Burns supplied grout mixtures with both entrained air and plasticizer. These were the only mixes with higher cement than ash content. We evaluated the flow and pumping with the added back pressure of the grout. Only trench three was used with three placed on top

of the third load, CLSM 3, mix from the previous day. All the loads were placed within 1 hour with the second immediately following the first to test multiple truck pumping and logistics.

6.2.4.2.1 Sixth Load (10/25/05, 6" Treme Tube)

Two CLSM (CLSM 3-2) mixtures were pumped through the 6 inch diameter vertical Schedule 80 PVC pipe 22 feet long treme. The test was to investigate forcing a on the top of the fill into the dome area of the tank were the final fill elevation may be higher than the fill point. The bottom treme tube holes were plugged and capped except the lowest hole beneath the surface of the grout. Pumping continued until the hole was covered by about 1 foot of grout. The pumping of both loads was at maximum rpm and near maximum pressure. The first pump pressure reached 4500 psi and flowed at an average of 130 yd^3/hr. The air content was a little lower then targeted 10.5% but the mix was still pumpable. Measured unit weight 113 lb/ft3 or 1.81 g/cc was lower then calculated 121 lb/ft^3 or 1.94 g/cc.

Figure 19 Trench Three. 1st and 2nd application of Dome Fill Cement through bottom hole of 6" Treme

Figure 20 Trench Three; third in sequence of Load 6 (dome fill cement CLSM 3-2a) (Loads 6-8) after 6 yd^3.

6.2.4.2.2 Seventh Load (10/25/05, 6" Treme Tube)

A similar CLSM (CLSM 3-2a) mixture followed without stopping forcing more grout through the 6 inch diameter treme with the 3" hole beneath the surface. The grout was applied under the previous foot deep grout. Pumping at maximum rpm gave a pump pressure of 4,100 psi and a pump flow rate of about 170 yd^3/hr indicating a little greater fluidity and lower viscosity but more importantly no effect of the greater depth the grout was being forced through. The air content was not measured but was assumed to be the same as the load that follows based on the slightly greater ease of pumpng thus should be about 22

vol%. Unit weight was not measured at the site but that of the samples was 105 lb/ft^3 or 1.69 g/cc about the same as that calculated 106 lb/ft^3 or 1.71 g/cc.

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Figure 21 Trench Three, Load 7; CLSM 3-2a applied immediately following Load 6-

Figure 22 Trench Three; second in sequence applying Load 7 CLSM 3-2a through 6” Treme

Figure 23 Trench 3; third in sequence of Load 7 CLSM 3-2a showing layering over Load 6 and 3

6.2.4.2.3 Eighth Load (10/25/05, AM 5" supply hose)

Filling the dome using no treme tube was tested by placing the 5 inch supply hose in the previous placed layers from loads 6 and 7. Grout was pumped until the hose was covered by about 1 foot of material. A similar CLSM (CLSM 3-3) mixture as the two previous mixes with more entrained air, plasticizer and less water was used. The plasticizer (high-range water reducer) was added to the mix to increase flowablity while reducing the water content. Pumping at maximum rpm gave a pump pressure of 4,500 psi and a pump flow rate of about 200 yd^3/hr indicating the greater fluidity and lower viscosity. The air content was measured at 22 vol%. Unit weight was measured at 105 lb/ft^3 or 1.69 g/cc lower then that calculated value of 109 lb/ft3 or 1.74 g/cc. The sample solid density values matched the unit weight measured at the site. Loads 6, 7, and 8 filled trench three nearly full with a visually level surface. The surface was hard enough to support an individual's weight the following morning. Footprints as seen in the photograph below were made after 4 hours of set showing surface was still soft but with sufficient compressive strength to support individual.

Figure 24 Applying Load 8 Dome fill Grout in Trench 3; Application is through Pump Tube below the level of the grout

Figure 25 Trench Three after sequential application of CLSM 3-2a (dome fill cement) (Loads 6-8) footprints after 4 hours

6.2.4.3 Heel Displacement Test Loads 9-12, 10/25 PM and 10/26 AM

Four similar grout mixes with significantly more cementious material (called CLSM #4 mix) were used for testing initial heel displacement mixes. The mixes each had about 230 pounds cement and 470 pounds fly ash with slight changes in the water and plasticizer quantity. Brundage pumped these more viscous mixtures through a 5 inch hose about 120 feet with the nozzle 1-3 feet above the surface. This simulates pushing liquids and heel ahead of the mixture as had been demonstrated in the previous mockup (Nield 1998) Figure 2.

Successive loads placed the nozzle over previous layers to follow a controlled grout flow and visualize extent of mounding. Burns supplied grout mixtures with no entrained air and higher cement and ash content than previous grout and CLSM mixes. We evaluated the flow and pumping on previous layers both wet and those set the previous days. Only trench one and two were used with all placements on top of the CLSM mixes from the previous day. Two loads 9 and 10 were placed within 1 hour of each other. The last two loads 11 and 12 were placed the next day on top of these loads.

6.2.4.3.1 Ninth Load, 10/25/05, PM

Mix CLSM-4 has a higher content of cementitous material then previous grouts, CLSM -1, -2 and-3-1). No air entrainment agent was used. This CLSM 4-1 mix had the highest water content of the four heel

displacement mixes tested and was rather wet for heel displacement, puddle test was 7 inches. Pumping at maximum rpm gave a pump pressure of 1,640 psi and a pump flow rate of about 180 yd^3/hr indicating the greater fluidity and lower viscosity from the additional water. The air content was measured at 2.2 vol%. Unit weight was measured at 134 lb/ft^3 or 2.14 g/cc. This is higher then the calculated value of 131 lb/ft^3 or 2.10 g/cc. The sample solid density values were slightly higher then the unit weight measured at the site, 136 lb/ft^3 or 2.19 g/cc. Samples were obtained from the hose and after placement both near the hose and at the edge of the mound that formed. The mix was able to push the free water remaining from the previous days mixes away from the placement point in the manner desired to move heel toward the sump pump.

6.2.4.3.2 Tenth Load, 10/25/05, PM

Mix CLSM-4-2 had a similar amount of cementitous material as previous load with the water content reduced about 10%. The first portion of this mix had the lowest water content of any mix tested, 7.6 wt%. This mix was rather stiff for heel displacement with a low slump of 2.5 inches. Pumping was still possible with a pump pressure of, 1110 psi and a flow of about 130 yd^3/hr indicating sufficient fluidity and viscosity to pump. The air content was measured at 2.2 vol%. Unit weight was measured at 132 lb/ft^3 or 2.12 g/cc. This is lower then the calculated value of 136 lb/ft^3 or 2.18 g/cc. The sample solid density values were the same as those calculated. Samples were obtained from the hose and after placement both near the hose and at the edge of the mound that formed.

After about 3 yd^3 was pumped water was added to the mix bringing the water to over 8 wt%. The slump increased from 2.5 to 5”. The final 5 yd^3 were placed at a pump pressure of 1,210 psi and a pump flow rate of about 160 yd^3/hr. The density of the new mix was calculated to be 134 lb/ft^3 or 2.17 g/cc very close to that measured on the solidified samples 136 lb/ft^3 or 2.18 g/cc.

6.2.4.3.3 Eleventh Load, 10/26/05, AM

This load was placed on the previous mound from load 9 placed the previous day. The mound was used to provide a direction for the flow much like that of subsequent heel displacement placements to control flow and force heel to sump pump. Mix CLSM-4-3 had a similar amount of cementitous material as previous loads with the water content increased between that of load 9 and load to 10.5 wt%. This mix was considered acceptable for the 1st and 2nd heel displacement placements with a medium slump of 6.5 inches and a low puddle test of 5.5 inches. Flow was sufficient to extend 19.5 feet forming a mound 19.5 inches deep.

Two different pump speeds were tested to see what increased flow does to the placement. Using about half power at 1,500 rpm gave pump pressure of 1,000 psi and a pump flow rate of about 120 yd^3/hr indicating good fluidity and viscosity for pumping. The pump was turned to full power. Pressure doubled to 2,000 psi and flow also doubled to 240 yd^3/hr. Samples were obtained directly from the truck. The air content was measured at 2.5 vol%. Unit weight was measured at 133 lb/ft3 or 2.13 g/cc. This is close to the calculated value of 131 lb/ft^3 or 2.10 g/cc. The sample solid density values were higher than those measured or calculated 138 lb/ft^3 or 2.20 g/c. Samples were obtained directly from the truck before going through the pump and after placement both near the hose and at the edge of the mound that formed.

The sequence of photographs show the flow of the heel displacement mix as it mounds and flows down the trench. One can get an idea of the density of this mix formulated for the final stages of heel displacement.

Figure 26 Sequence in placing: Load 11 Heel Displacement Grout

6.2.4.3.4 Twelfth Load 10/26/05, AM

This load was placed on the previous mound from load 10 in trench two after a day of setting. Pictured below is that mound which had set without bleed to at least 100 psi. The two mounds from the two portions of that load were used to provide a direction for the flow much like that of the 4th and 5th heel displacement pours to control flow after it the first few placements or pours have moved the heel and finally force it to jet pump. Mix CLSM-4-4 had a similar amount of cementitous material as previous loads with 18 gallons of water added increasing water content to 10.9 wt%. This mix was more fluid then that used in load 11 but considered acceptable for final phase of heel displacement with a slump of 9.5 inches and a puddle diameter of 7".

Two different pump speeds were tested to see the effect on placement. Using about half power at 1500 rpm gave pump pressure of 1000 psi and a flow of about 120 yd^3/hr indicating good fluidity and viscosity for pumping. The pump was turned to 2/3 power. Pressure increased to 1240 psi and flow increased to 130 yd^3/hr. Samples were obtained directly from the truck. The air content was measured at 2.8 vol%. Unit weight was measured at 132 ft^3/yd or 2.12 g/cc. This is close to the calculated value of 130 ft^3/yd or 2.08 g/cc. The sample solid density values were higher than those measured or calculated 137 ft^3/yd or 2.19 g/c. Samples obtained for air and viscosity measurement were obtained directly from the truck had not gone through the pump. Samples after placement were taken both near the hose and at the edge of the mound that formed. Flow was sufficient to extend 23 feet forming a mound 9.5 inches deep and 8 foot wide.

6.2.5 Coring

Four Cores were taken under very difficult weather conditions 20 days after the October 24 and 25 placements on November 14th. Trench 1 and 2 had been partially excavated by removing the top harder heel-displacement grout layers so that only 2 CLSM layers remained in each trench. Trench 3 was almost full containing one air entrained CLSM load and 3 of the high cement dome fill mixes that had been successively placed within an hour. Trenches 2 (Middle) and 3 (East) were selected for cores. Trench 3 had three cores taken, since it had not been excavated and had the greatest number of layers, the first second and fourth core designated A, B, D. Trench 2 had one core taken the third one designated C

The first two cores were taken with a powered coring device. The coring device is 4" OD giving a 3.5" diameter core. The first core (A) was on the south end of the east trench #3. It was 58" to the trench floor and gave a core 46" long. The second core (B) was on the north end of same trench but only went 29" deep (giving a core length 21") due to difficulty in attaching the drill. The third and fourth cores had to be hand done due to low strength of the material. The strength of the material was insufficient to attach the powered coring machine. The hand coring device is 3" OD giving a 2.5" diameter core. The third core (C) was on the north end of trench 2. Its depth was 28" giving a core length 22". A final core (D) was taken in the middle of trench 3 extended 38" deep giving a core length of 21". The core data is summarized in Table 14.

Photos of the cores are shown. Layering cannot be seen and sections of low strength were destroyed in the coring process. The depth of the grout in each trench matches the record expected from the loads that were emplaced. Compressive strength is lower than that taken from wet samples.

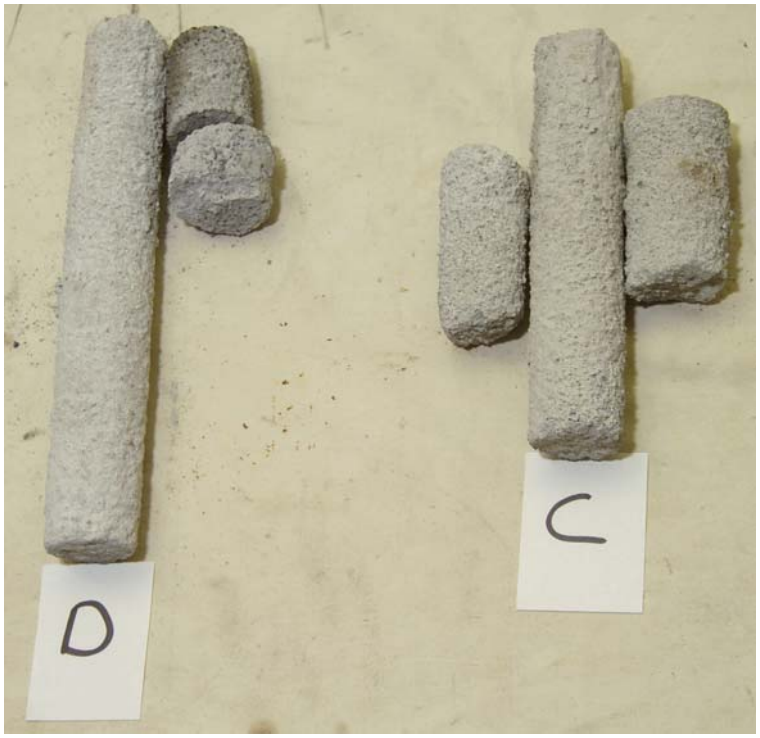

Figure 27 Fours Cores: A, B, D from Trench 3, and C from Trench 2

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Figure 28 Test Layouts and Treme Tubes Schematic.

Table 10. Summary of Mockup Test CLSM/grout Placement Data

Load	CLSM	Description-	Trench	Layer Depth	Layer width	Length of natural flow	Layer Volume	Total Trench Quantity
#	#	Drop Tests for Tank Fill	#	ft	ft	ft	yd3	yd3
1	1-1	Free Drop, low cement fill **no plasticizer no AEA** only mix not pumpable	1	3	3	3	1	1
1a	1-1a	Free Drop, low cement added water **no plasticizer no AEA, pumpable**	1	1.75	3.5	22	7	7
2	3-1	Drop though 4" Treme 4" Tee holes, mix similar to GEM fill, 1 to 2 Portland Fly Ash,, Air Entrainment Agent (AEA), no Plasticizer	**2**	0.8	3.5	14	2	2
2a	3-1	Free Drop, Second half of load 2,	**2**	1.2	4	25	6	6
3	3-1a	Drop though 6" Treme 3" Holes, Mix Similar to Load 2, High Air, AEA	**3**	1.8	4	25	9	9
4	2-1	Free Drop, 1 to 3 Portland Fly Ash, AEA high Plasticizer	1	1	5	25	8	16
5	2-1a	Free Drop, 1 to 3 Portland Fly Ash, AEA, low Plasticizer,	**2**	1.3	4	25	9	17
		Filling Dome						
6	3-2	Forced through 3" Hole 6" Treme, Dome fill 2 to 1 Cement Fly Ash, AEA	**3**	1.7	6	20	8	17
7	3-2a	Forced through 3" Hole 6" Treme, Dome fill 2 to 1 Cement Fly Ash, AEA	**3**	1.4	7.5	20	9	26
8	3-3	Forced with 5" hose below grout level, high cement, AEA, HRWR	**3**	1.75	7	20	9	35
		First Layer Heel Displacement						
9	4-1	1st Application of Heel Displacement Grout	1	5	6	8	9	25
10	4-2	1st Application of Heel Displacement Grout	2	4	4	7	5	22
10a	4-2a	2nd Application of Heel Displacement Grout	2	3	4	7	4	26
11	4-3	3rd or 4th Application of Heel Displacement Grout	1	1.6	8	19.5	8	33
12	4-4	Last Heel Displacement Grout Placement	2	2.4	4.5	23	9	35

Bold Trench Numbers of cored layers

Table 11. Summary of CLSM/Grout Mockup Pumping Operational Data

Load	Date	Time	CLSM	Mix Description	Viscosity	Drop Height	Unit Wt	Calc Unit Wt	Air	Pump Time	Pump Pressure	Pump Flow Rate	Cost Estimate	Vendor Estimate
#			#	**Drop Tests- Fill CLSM**	Inch	feet	lb/ft^3	lb/ft^3	Vol %	min	psi	yd^3/min	\$/yd^3	\$/yd^3
1	10/24	10:02	1-1	Free Drop no plasticizer	3	20-25	*130*	132	*2*	0.5	4900	130	60	93
1a	10/24	10:20	1-1a	Free Drop added water	*5*	20-25	*130*	129	*2*	2.5	1010	170	58	93
2	10/24	11:05	3-1	Drop through 4" Treme	10.25	22	105	102	23	1	430	120	67	93
2a	10/24	11:08	3-1	Free Drop GEM mix high air	*10*	20-25	*105*	102	*23*	4.3	270	80	67	93
3	10/24	12:03	3-1a	Drop through 6" Treme	*10*	22	*105*	101	*23*	4	890	130	67	93
4	10/24	3:20	2-1	Free Drop AEA and plasticizer	*20*	20-25	*105*	108	*16*	2.5	1550	190	97	106
5	10/24	4:16	2-1a	Free Drop AEA ,low plasticizer	13	20-25	123	125	3.2	3	930	180	87	106
				Dome Fill Placements- Grout										
6	10/25	10:08	3-2	Dome fill grout 6" Treme	8.5	22	113	121	10.5	3.7	4500	130	86	96
7	10/25	10:31	3-2a	Dome fill grout 6" Treme	*8*	22	*113*	122	*10*	2.7	4000	170	83	96
8	10/25	10:43	3-3	Dome fill grout 5" Nozzle	10.25	0	105	109	22	2.6	4500	200	82	96
9	10/25	3:32	4-1	Heel Displacement grout	8.5	1-3	134	131	*2*	3	1640	180	106	125
10	10/25	4:45	4-2	Heel Displacement grout	7	1-3	132	136	2.2	3.1	1010	130	107	125
10a	10/25	5:03	4-2a	Heel Displacement grout	*3*	1-3	132	136	2.1	1.5	1210	160	106	125
11	10/26	9:50	4-3	Heel Displacement grout	5.5	1-3	133	131	2.5	3	1510	180	107	125
12	10/26	10:45	4-4	Heel Displacement grout	7	1-3	132	130	2.8	4.3	1200	120	106	125

- *Italics*-Estimated Value

Table 12. Composition of CLSM and Grout Mockup Test Mixes

Load	CLSM	Mix Description	Water	Sand	Cem ent	Fly Ash	Water	Plastic izer	AEA	Samples	
#	#	**Drop Tests- Fill CLSM**	wt%				Gal/yd3	wt%		2x4	2x2x2
1	1-1	Free Drop no plasticizer	11	80	2.1	6.3	48	0	0		3
1a	1-1a	Free Drop added water	13	79	2.0	6.2	54	0	0		3
2	3-1	Drop through 4” Treme	12	76	3.8	7.8	41	0	0.015	12	6
2a	3-1	Free Drop GEM mix high air	12	76	3.8	7.8	41	0	0.015		6
3	3-1a	Drop through 6” Treme	12	76	3.9	7.8	43	0	0.015		6
4	2-1	Free Drop AEA and plasticizer	13	69	4.5	14	53	0.23	0.015		6
5	2-1a	Free Drop AEA ,low plasticizer	13	69	4.5	14	53	0.06	0.015	12	6
		Dome Fill Placements-grout									
6	3-2	Dome fill grout 6” Treme	11	78	7.2	3.7	45	0.07	0.014	6	
7	3-2a	Dome fill grout 6” Treme	11	78	7.2	3.8	42	0.06	0.014		6
8	3-3	Dome fill grout 5” Nozzle	9.2	79	7.6	3.7	32	0.07	0.014		12
9	4-1	Heel Displacement grout	11	69	6.6	13	48	0.17	0	6	7
10	4-2	Heel Displacement grout	7.6	73	6.2	13	34	0.16	0		12
10a	4-2a	Heel Displacement grout	8.2	73	6.1	13	36	0.16	0		15
11	4-3	Heel Displacement grout	10	69	6.5	13	44	0.17	0		21
12	4-4	Heel Displacement grout	11	69	6.5	13	46	0.17	0		21

Table 13. Properties of CLSM and Grout Mockup Test Mixes

			W/ PC	W/ Cem	PC/ FA	cem/ sand	AEA/ Cem	Plast/ Cem	28 day UCS		Density Calc	Density Meas
			Ratio						2x4	2x2x2	g/ml	
1	1-1	Free Drop no plasticizer	5.5	1.3	0.33	0.1	0	0	NA	364	2.11	2.09
1a	1-1a	Free Drop added water	6.4	1.6	0.33	0.1	0	0	NA	256	2.06	2.08
2	3-1	Drop through 4” Treme	3.2	1.1	0.49	0.15	0.001	0	210	313	1.64	1.84
2a	3-1	Free Drop GEM mix high air	3.2	1.1	0.49	0.15	0.001	0	NA	261	1.64	1.76
3	3-1a	Drop through 6” Treme	3.2	1.1	0.50	0.15	0.001	0	NA	330	1.62	1.78
4	2-1	Free Drop high air, plasticizer	2.9	0.73	0.33	0.26	0.001	0.01	NA	300	1.62	1.74
5	2-1a	Free Drop, low plasticizer	2.9	0.73	0.33	0.26	0.001	0.003	843	519	2.01	1.96
		Dome Fill Placements-grout										
6	3-2	Dome fill grout 6” Treme	1.6	1.1	1.95	0.14	0.001	0.007	767	NA	1.94	*1.70*
7	3-2a	Dome fill grout 6” Treme	1.49	0.98	1.90	0.14	0.001	0.007	NA	621	1.95	1.70
8	3-3	Dome fill grout 5” Nozzle	1.21	0.81	2.06	0.14	0.001	0.006	853	962	1.74	1.69
									2x2x 2			
9	4-1	Heel Displacement grout	1.7	0.57	0.50	0.33	0	0.009	2740	3460	2.10	2.19
10	4-2	Heel Displacement grout	1.24	0.41	0.49	0.26	0	0.009	1690	1630	2.18	2.19
10a	4-2a	Heel Displacement grout	1.34	0.44	0.49	0.26	0	0.009	NA	1370	2.17	2.19
11	4-3	Heel Displacement grout	1.60	0.52	0.49	0.29	0	0.009	2490	2650	2.10	2.20
12	4-4	Heel Displacement grout	1.67	0.55	0.49	0.29	0	0.01	2410	1980	2.08	2.19

Not Attempted

Table 14. Cores of Emplaced CLSM and Grout Mockup layers

Depth	Core		Load	W/Cem	PC/ FA	cem/ sand	28 day UCS		
46	A	**Trench 3 South side**	#	Ratio			2x2x2 psi	2x4 psi	7”x 3.5” psi
Top-7	A1	Dome fill grout 5” Nozzle	8	0.81	2.06	0.14	962	843	997
14	A2	Dome fill grout 6” Treme	6,7	0.98	1.90	0.14	621	767	1205
21	A3	Dome fill grout 6” Treme	6,7	1.1	1.95	0.14	621	767	520
28	A4	Dome fill grout 6” Treme	6,7	1.1	1.95	0.14	621	767	582
32		3.5” unusable section	3	1.1	0.50	0.15			
34		2.5” unusable section	3	1.1	0.50	0.15			
41	A5	6” Tube	3	1.1	0.50	0.15	330	NA	498
46		5.0” unusable section	3	1.1	0.50	0.15			
21	B	**Trench 3 North side**							
Top-4		4.0” unusable section	6,7	1.1	1.95	0.14			
11	B1	Dome fill grout 6” Treme	6,7	1.1	1.95	0.14	621	767	680
		3.0” unusable section	3	1.1	0.50	0.15			
	B2		3	1.1	0.50	0.15	330	NA	446
21	D	**Trench 3** mid. trench							
Top-4		4.0” unusable section							
9	D1	Dome fill grout 5” Nozzle	6,7	0.81	2.06	0.14	621	767	641
14	D2	Dome fill grout 6” Treme	6,7	0.98	1.90	0.14	621	767	700.
19	D3	Dome fill grout 6” Treme	8	1.1	1.95	0.14	962	843	941
21		2.0” unusable section							
22”	C	**Trench 2** mid. trench							5x2.5”
Top-5	C1	Free Drop GEM mix	5	0.73	0.33	0.26	519	843	763
10	C2	Free Drop GEM mix	5	0.73	0.33	0.26	519	843	482
15	C3	Free Drop GEM mix	5	0.73	0.33	0.26	519	843	715
17		Drop through 4” Treme	2	1.1	0.49	0.15			
22	C4	Drop through 4” Treme	2	1.1	0.49	0.15	261	210	266

NA Not Attempted

6.3 Test Evaluation

The INTEC Tank Farm closure grouts mockup test evaluated the ability to pump CLSM over long distance and to adequately fill large tanks. The CLSM should not crack, have no bleed water, and generate little heat. Table 15 summarizes the field test grout and CLSM applications.

A low cement CLSM without plasticizer was eliminated from consideration as not pumpable. Addition of water made it pumpable but resulted in some bleed water. Use of foaming or air entrainment agents (AEA) made other fill CLSM and capping grouts pumpable. Addition of both AEA and plasticizer was not necessary and both increases cost and can eliminate the air entrainment effect and resulted in one CLSM mixture that was too fluid. Addition of plasticizer and AEA allowed viscous dome fill CLSM mixes to be pumped.

Higher cementitious material containing grouts were pumpable and could be placed in thick layers to simulate the first and last applications of heel displacement as shown in the photos. These mixes had the greatest slope from the point of placement mounding several feet at the point of introduction. Sequential loads were pumped with afternoon loads a period of four hours elapsed between layer placements. Grout has set by this time with the layers though the grout bonds and is not distinct in the cores.

Three truck loads of higher cement dome fill grouts were placed at one time before setting successfully testing multiple truck placement and grout flow through a submerged tube. Multiple cores obtained though 1 CLSM layer and 3 dome fill grout layers in trench 3 had a higher strength then the core though 2 CLSM layers. All cores demonstrated sufficient strength for fill and some adherence of layers.

Eleven mixes were sampled for compressive strength. All CLSM mixtures met the 100 psi. minimum. A higher cement content grout tested for dome fill was close to 1,000 psi though it did not uniformly achieve this strength. Heel Displacement grouts had much higher proportion of cementitous material, no AEA and would meet all strength requirements desired.

Tank fill CLSM did not present significant implementibility problems especially with the added foaming or AEA. All specified grouts had hydraulic properties, with suspend-able solids and pump-able liquid-like material. Puddle test diameters of of 10 ¼ and 13 inch were measured. Set times were generally greater than 2 hours but less then 4. Aggregate remained in suspension save for some bleed water in non-plasticized mixes.

Separation as measured by the compressive strength ranged between 2 and 21% from samples near the tube and at the edge of the flow about 20 feet away. The use of a treme tube did not appear to influence separation. The relative percent deviation of compressive strengths for treme applied grouts was 17% and for the same mix appled with a free drop was 21%. The treme grout was slighty stronger at the edge of the flow than at the treme tube whereas the free drop was slightly stronger near the drop point then at the edge of the flow

Table 15. Summary of Pumping Cementitous Grout/CLSM Field Test

Trench Number	1	2	3	Total
Total Number of Loads	4	4	4	12
Total yd^3 in Trenches	33	35	35	103
Load numbers (**Grout bold**)	1,4,**9,11**	2,5,**10,12**	3,**6,7,8**	1-12
Primary Cement Type Cored	not cored	CLSM	**Grout**	
Load/layers cored	not cored	2,5	3,**6,7,8**	6
Loads Dropped through Treme	0	1	3	4
Samples Obtained	46	90	30	186

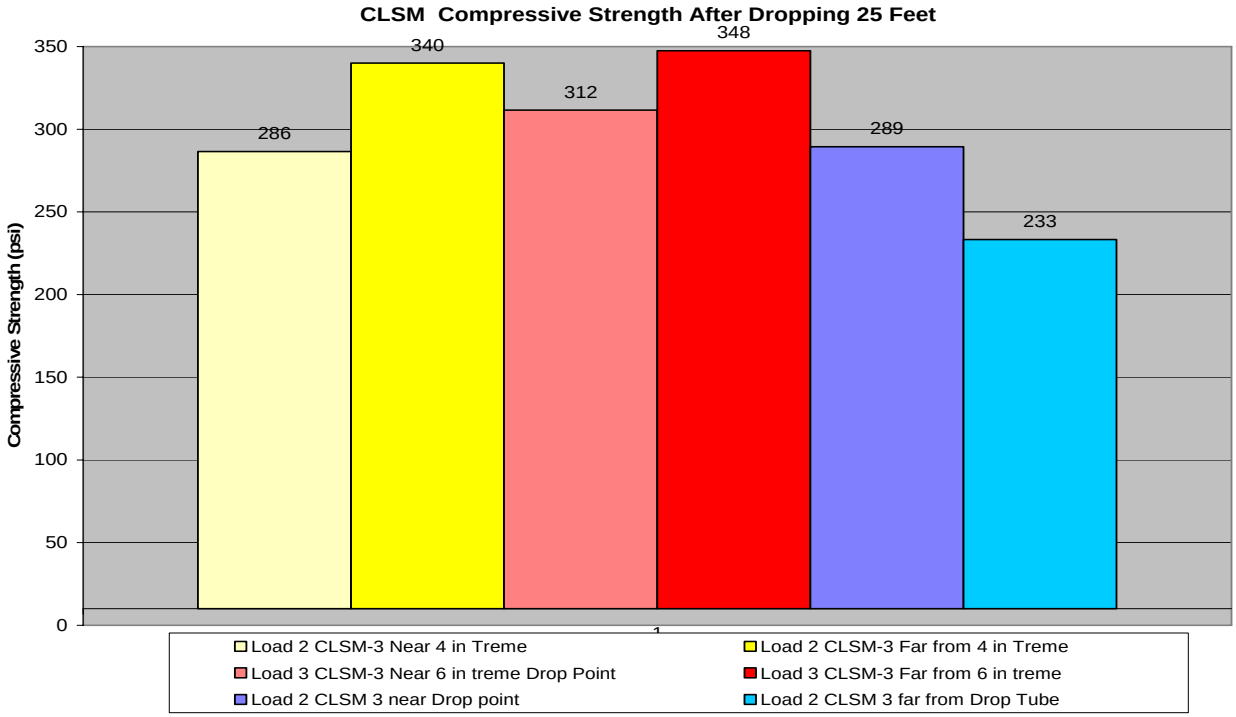

Figure 29 Segregation based UCS from Free and Treme Tube Drops

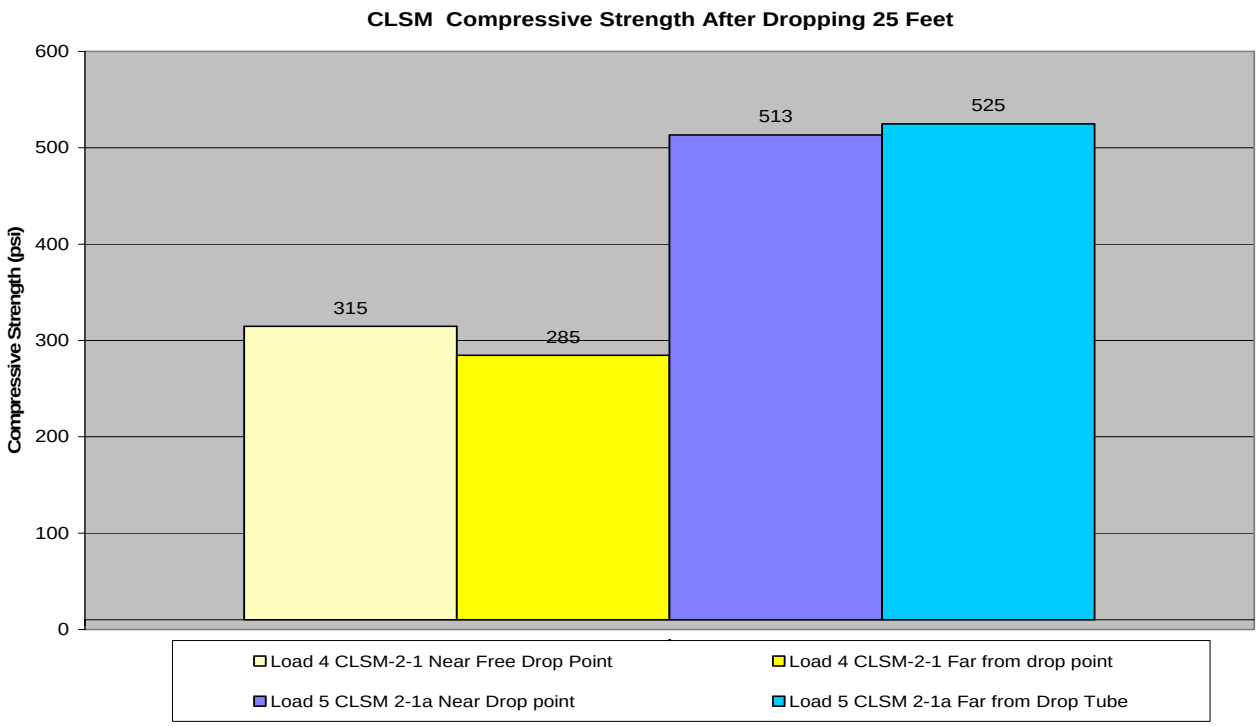

Figure 30 Segregation based on UCS from Free Drops of AEA and Plasticizer CLSM 2-1

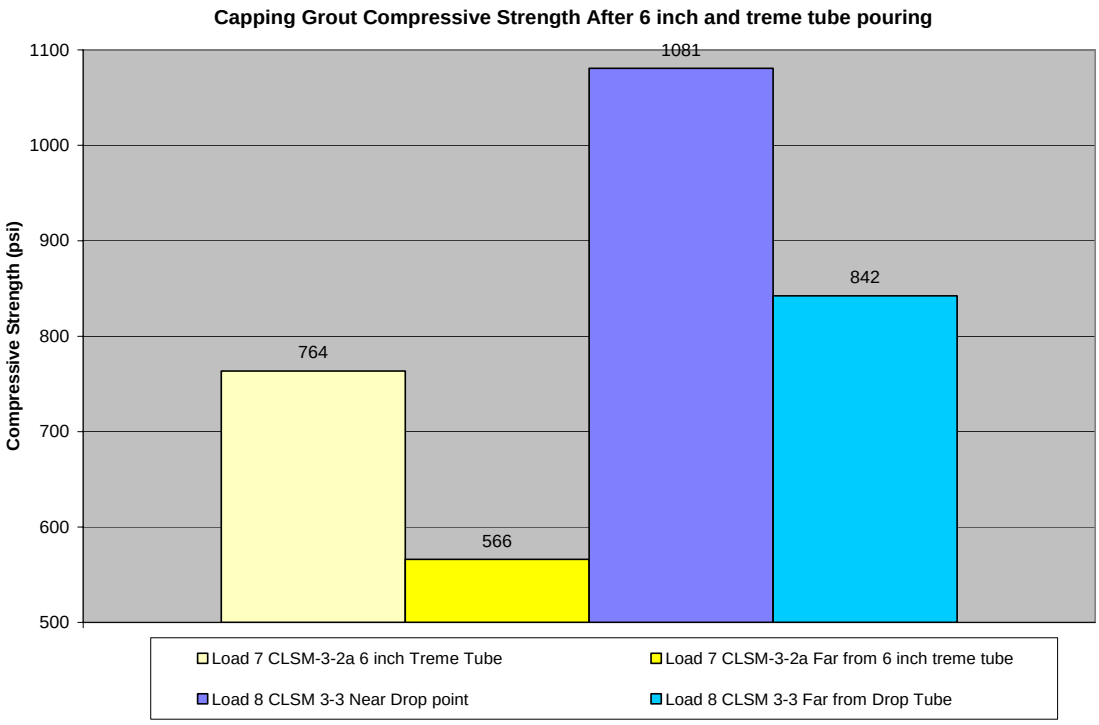

Figure 31 Segregation in Grout based on UCS from Free Drops of CLSM 3-2

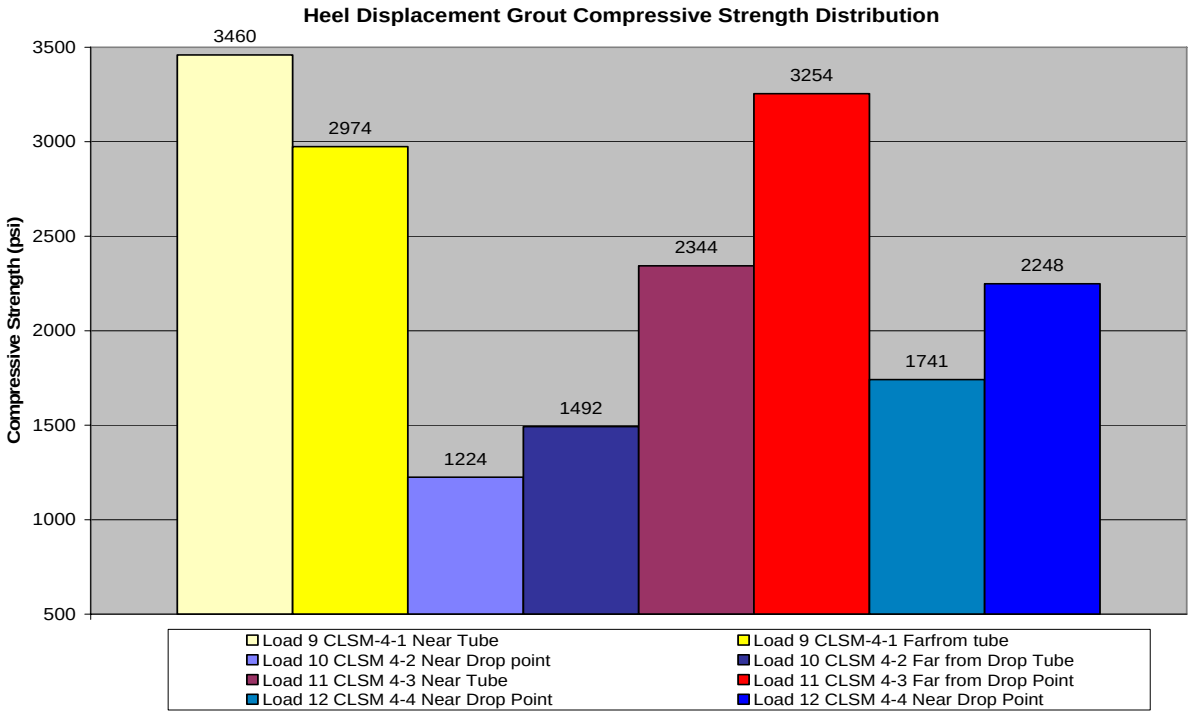

Figure 32 Distribution of UCS from Heel Displacement of CLSM 4

7. RECOMMENDATIONS AND CONCLUSIONS

Grouts and CLSM have been both lab and field tested for large tank application providing sufficient basis for their selection. All formulations consist primarily of sand, cement and fly ash. Separation was measured by the compressive strength in samples near the tube or discharge point and at the edge of the flow.

The controlled low strength material (CLSM) fill was pumpable and was free of separation and bleeding if AEA or plasticizer was used even in low cement (4%) CLSM mixes field tested. CLSM compressive strengths in excess of 100 psi can be achieved even with mixtures containing 70% ungraded, unwashed sand in laboratory tests. All field tested mixtures used C-33 graded sand. A 38 gallon mix with 76 wt% sand 4% cement 8% fly ash was successfully free dropped and applied through a 4" treme tube.

All mixtures field tested with some additive (foaming agent, AEA and/or plasticizer) did not separate or filter cake under pressure when being pumped at a wide range of pressures 270-4,900 psi, 120 feet distance, height of 25 feet and dropped. The CLSM spread evenly over the trench nearly 25 feet from the drop point. In cases with excessive water (Load 1a) and or combined additives (load 4 both AEA and high plasticizer) some bleed was seen though this was absorbed in subsequent layers.

The heel displacement grout primary effectiveness criterion is viscosity. A formulation suitable for heel displacement application similar to that field tested has higher cement content 6.5 wt%. Slump requirements for the heel displacement vary. The first two placements require a slump between 6" and 7½ ". The remaining placements require a slump between 9½" and 11". The test indicate that the water and plasticizer amounts in for this mix can be adjusted meet the slump requirements. The heel displacement grout containing sand (70 wt%) with fly ash (13 wt%) and low cement (6.5 wt%) also had sufficient compressive strength >1000 psi to be used for applications that may require the higher strength. Separation as measured by the compressive strength variations ranged from 6-33 relative percent deviation.

The primary effectiveness criteria for dome fill grout is viscosity. Lab tested formulation suitable for dome fill had high Portland contents, 8.9 wt%. More water would be needed when using ungraded, unwashed sand to make a pumpable mixture. The cementitous material (fly ash plus Portland) was decreased and ratio of fly ash to Portland reversed for the field test. This grout had properties needed to fill the dome in the top of the tank..

Mockup testing confirmed laboratory results and demonstrated useable mixtures for fill and heel displacement purpose. The mockup testing also comfirmed laboratory measurements to ensure modified mixtures would be pumpable, fill tanks evenly and be a cost effective material for tank farm closure. Operational parameters were recorded to estimate fill rates and equipment needs for the full scale tank fill operation. Modern radio control trucks with high capacity booms will allow both precise heel displacement application and fast fill of both tank and surrounding vaults. Cost were estimated both from raw material prices and vendor test estimates for a variety of mixtures. CLSM mixtures under 90\$/yd^3 should meet all tank fill requirements. Heel Displacement grout may be more costly 130\$/yd^3 due to higher cement contents.

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