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Summary of Hanford Tank Farm Closure Grout Testing Efforts for 2018

Mission Analysis Engineering
Process Integrity & Engineering

Supporting WRPS Closure & Interim Measures

February 21, 2019 Closure Forum

About Us

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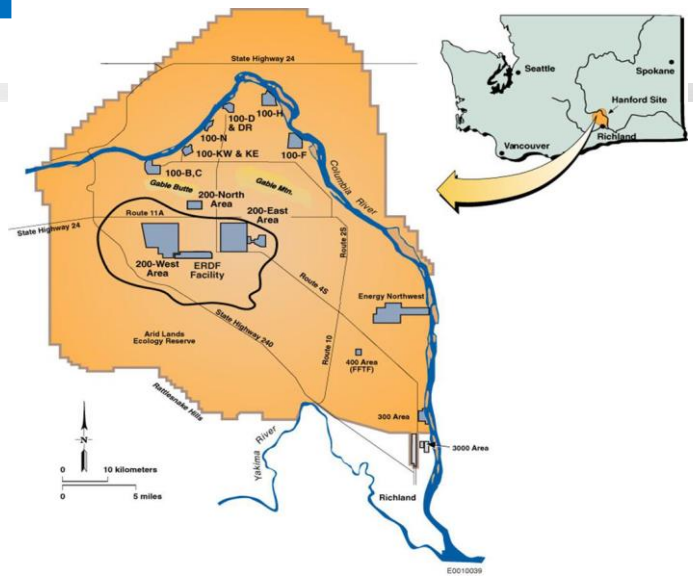
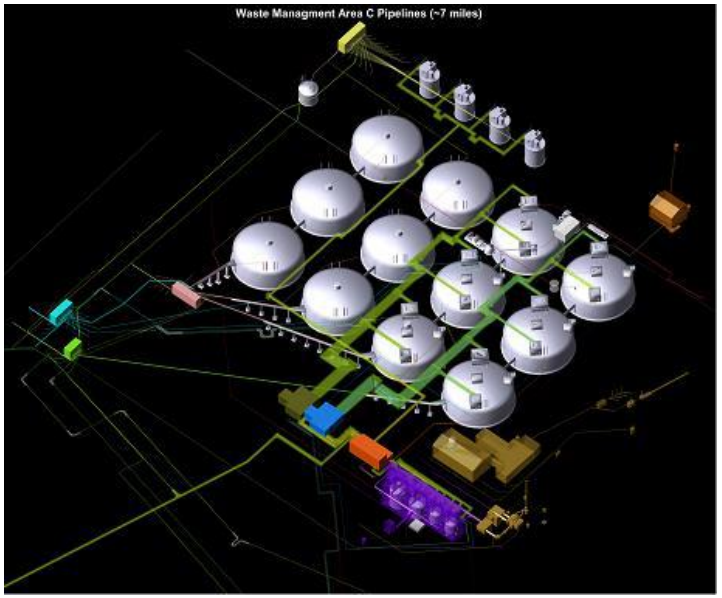
Overview

- **Background**
- Components of Grout Formulations
- General Testing Measures
- Highly Flowable Testing Measures & Results
- Bulk-Fill Testing Measures & Results
- Shrinkage Challenges
- Path Forward

Hanford WMA C Background





- Twelve 530,000-gallon tanks
- Four 55,000-gallon tanks
- Constructed 1944-46
- Retrieval operations completed 2017

FY 2018-2019 Closure Grout Testing Targets

Highly Flowable Closure Grout

Performance Objective	Requirement
Compressive Strength	> 200 psi at 28 days
Highly Flowable	≤ 15 seconds Efflux Flow Cone Time

Bulk-Fill Closure Grout

Performance Objective	Requirement
Non-Segregating	0 or 1 Visual Stability Index
Flowable	≥ 24 inch Slump Flow Spread
Minimal Bleed Water	< 0.1% by Volume (0% target)
Minimal Shrinkage	< 0.1%
Compressive Strength	> 200 psi at 28 days
Minimal Heat Generation	< 70°F Temperature Rise

Project Expertise

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Columbia Energy and Environmental Services

- Test plan and procedure
- Logistics and scheduling

Intermountain Materials Testing and Geotechnical

- Certified materials laboratory testing

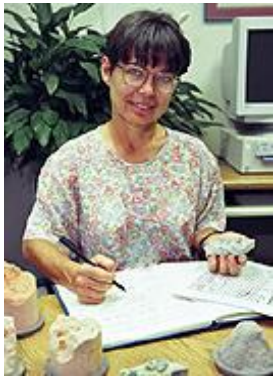
American Rock Products, A CRH Company

- Exploratory testing
- Materials

BASF The Chemical Company

- Admixtures

Renowned Experts Consulted



- Dr. Christine Langton
  - SRNL expert in concrete, grout construction materials, and low temperature isotope stabilization
  - Developed grout formulations to support tank and basin closures

- James Warner, PE
  - Industrial expert specializing in geotechnical applications of grouting
  - Over 50 years of experience developing solutions to foundation and structural problems

Renowned Experts Consulted

- Dr. Chadi El Mohtar
  - Geotechnical Engineering associate professor at University of Texas, Austin
  - Focuses on viscous flow within porous media under adverse conditions

- Dr. Donald Bruce
  - CPEng, RPG, RPEngG, and international consultant specializing in repair of concrete and Earthen structures
  - Over 45 years experience in civil, mining, and tunneling engineering

Grout History Across DOE Complex

- Compared 27 DOE Complex grouts:
  - 2 Oak Ridge tank treatment/closure formulas
  - 4 Savannah River tank closure formulas
  - 3 Idaho National Laboratory tank closure formulas
  - 5 Hanford Waste DST treatment/closure formulas from 1980's
  - 13 Hanford closure formulas from 1989 - 2017

Differences Between Hanford and Other Sites

- Arid environment with sandy soils
- Groundwater 200 - 400 ft below ground surface
- Complex waste
- Tri-Party Agreement regulatory requirements
- Availability of local materials
- Void filling for tanks and ancillary equipment

2009 Grout Testing Objectives at Hanford

1. Optimize waste stabilization and bulk-fill grout formulas
2. Minimize bleed water and segregation
3. Demonstrate scalability of the selected grout formulas

- Additional testing was recommended based on:
  - Visible bleed water
  - Grout segregation
  - Low batch yields

2018 Testing Efforts

July 11, 2018
Exploratory testing

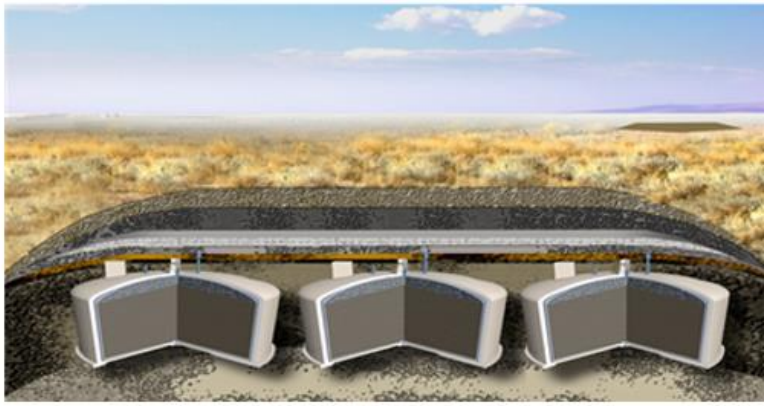
August 16, 2018
Highly flowable mock-up testing

November 9, 2018
Laboratory testing

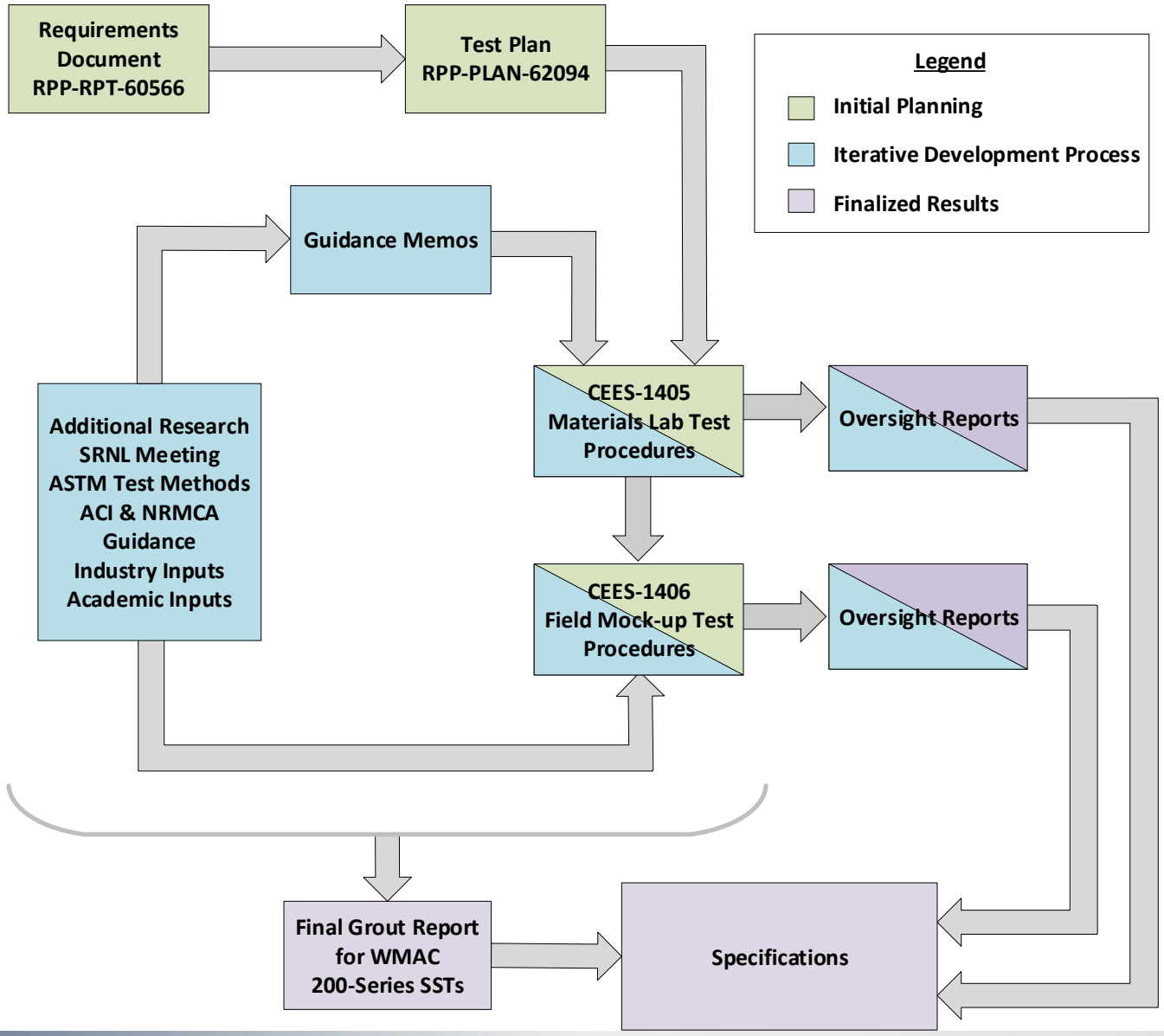
June 20, 2018
Laboratory testing

August 1, 2018
Laboratory testing

October 3, 2018
Exploratory testing



2018 Iterative Testing Approach



Types of Grout Formulas

	Bulk-Fill Grout	Highly Flowable Grout
Primary Function	• Self-leveling formulation to fill void spaces and isolate residual waste	• Low viscosity formulation to stabilize below-grade structures

Composition	• Aggregate
	  • Sand
	  • Pea Gravel
	• Cement
	• Fly Ash
	• Water
	• Admixtures
		• Cement
		• Fly Ash
		• Water
		• Admixtures

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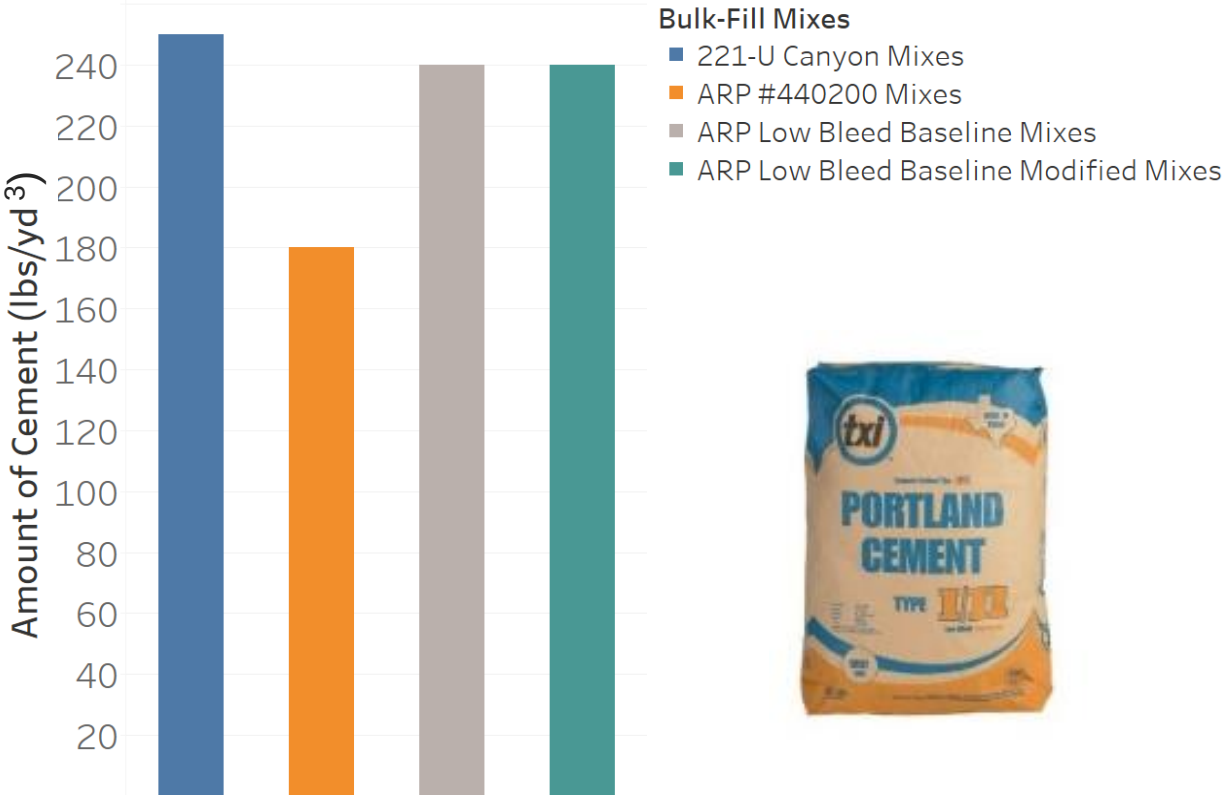
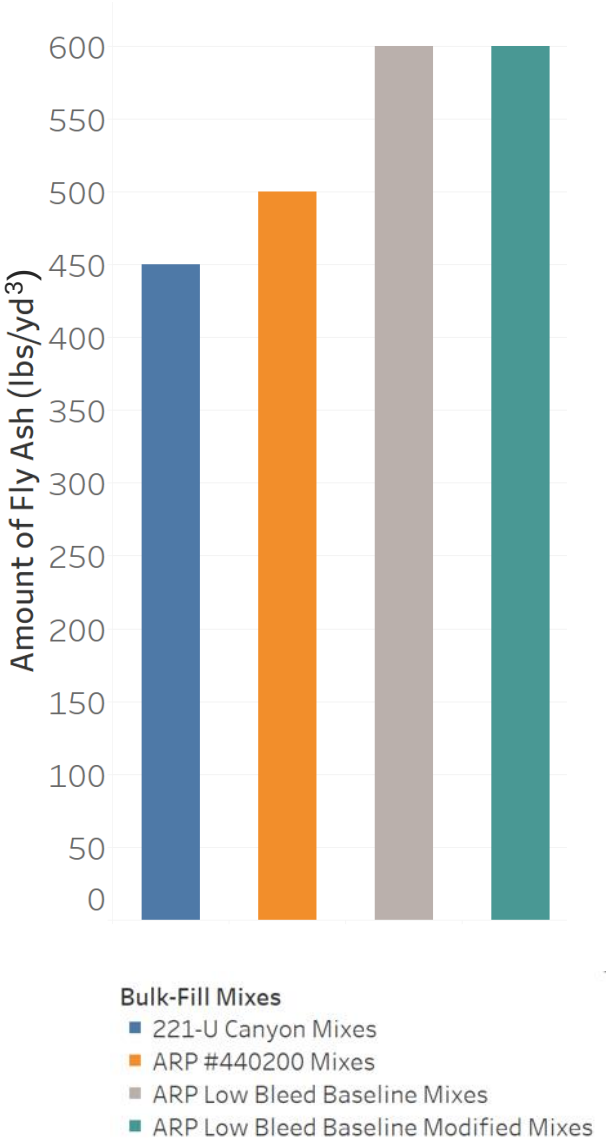
Portland Cement – ASTM C 150

- Provides cohesion and compressive strength to grout
- Type I: General purpose cement
- Type II: Lower heat of hydration than Type I



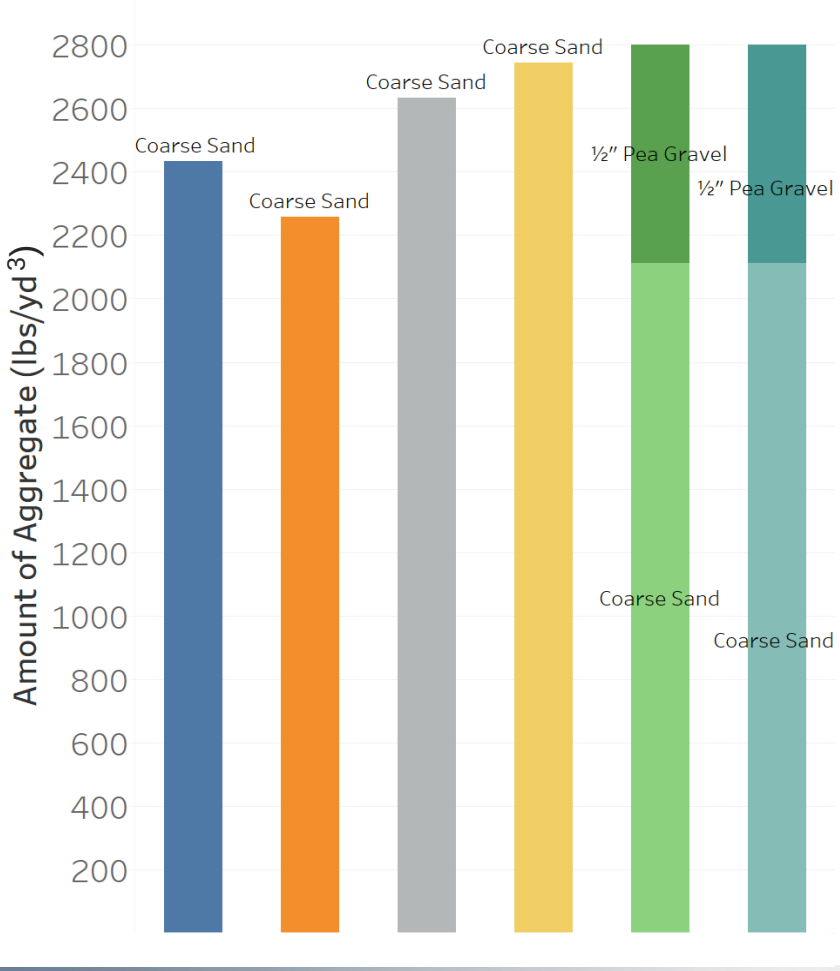
Classes C and F Fly Ash – ASTM C 618

- Coal combustion product composed of fine particles of burned fuel
- Advantages:
  - Reduces heat of hydration
  - Slows initial set time
  - Enhances flow
  - Increases long-term strength



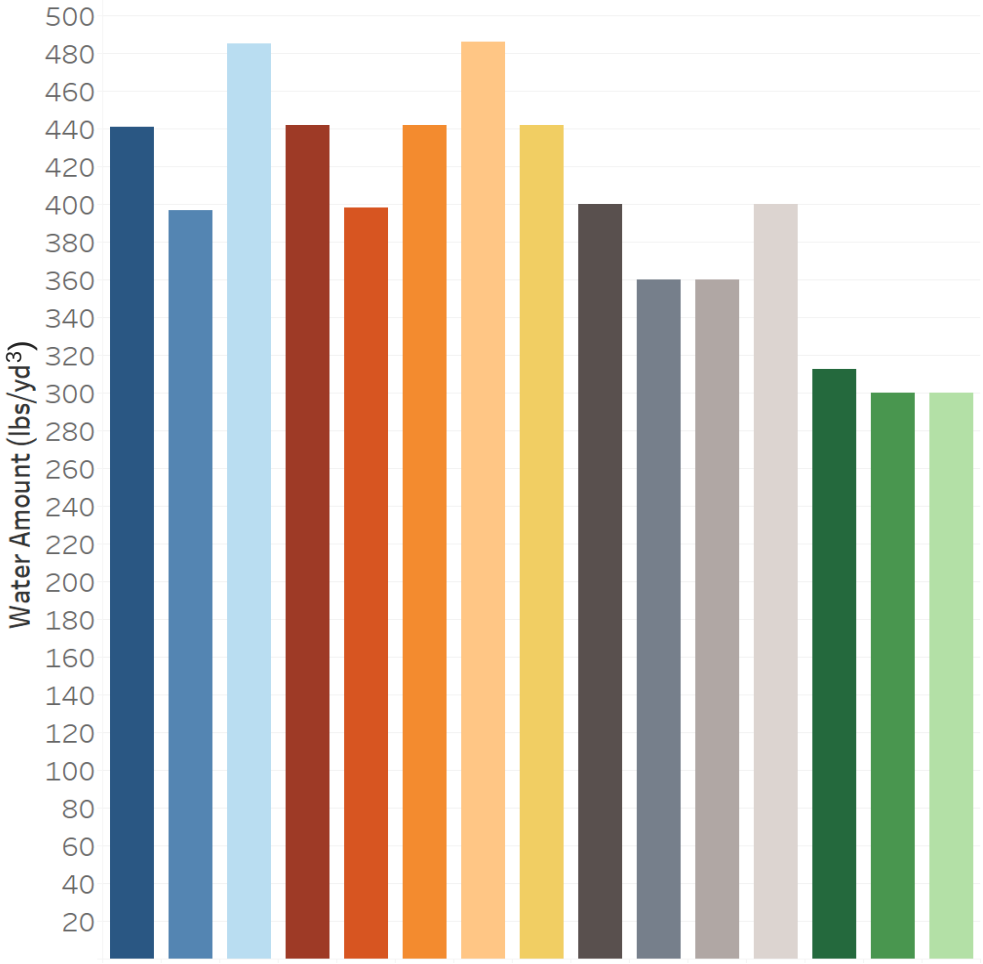
Aggregates – ASTM C 33

- Inert granular mineral material
- Economical, structural component



Water – ASTM C 1602

- Allows for hydration of the cementitious materials
- Ratio of water to cementitious materials impacts:
  - Strength
  - Durability
  - Porosity
  - Shrinkage



Chemical Admixtures – ASTM C 494

Retarding admixture: MasterSet Delvo

- Slows grout setting and allows for more transport and placement time

Superplasticizer: MasterGlenium 3030

- Reduces water required for desired flowability

Viscosity-modifying admixture: MasterMatrix VMA 358

- Increases resistance to segregation, controls bleeding, and enhances placement

Air-entraining admixture: MasterCell 25

- Lowers density, eliminates settlement, controls strength, reduces shrinkage, and lowers bleeding

Shrinkage Compensating Admixtures

MasterRoc FLC 100

- Reduces mixing water requirements, producing a flowable, non-segregating, non-shrinking grout
- Helps control bleed water

MasterLife SRA 035

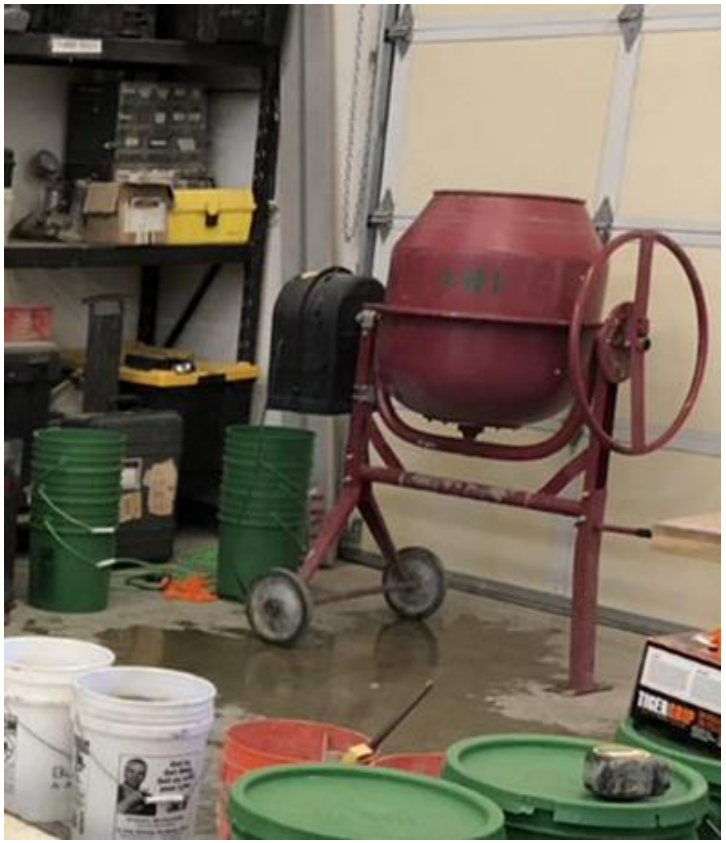
- Reduces drying shrinkage
- Reduces microcracking and drying shrinkage cracking

Savannah River Site Admixtures

- ADVA Cast 575 and EXP 958
- High-range water-reducers
- Properties began to degrade over time
- Used to achieve high compressive strength for the precast industry

Admixture Adjustment – ASTM C 192

- Perform slump flow test after:
  - 3-minute mixing period
  - 3-minute resting period
  - 2-minute mixing period
- Step-wise formula manipulation to adjust flowability and/or segregation



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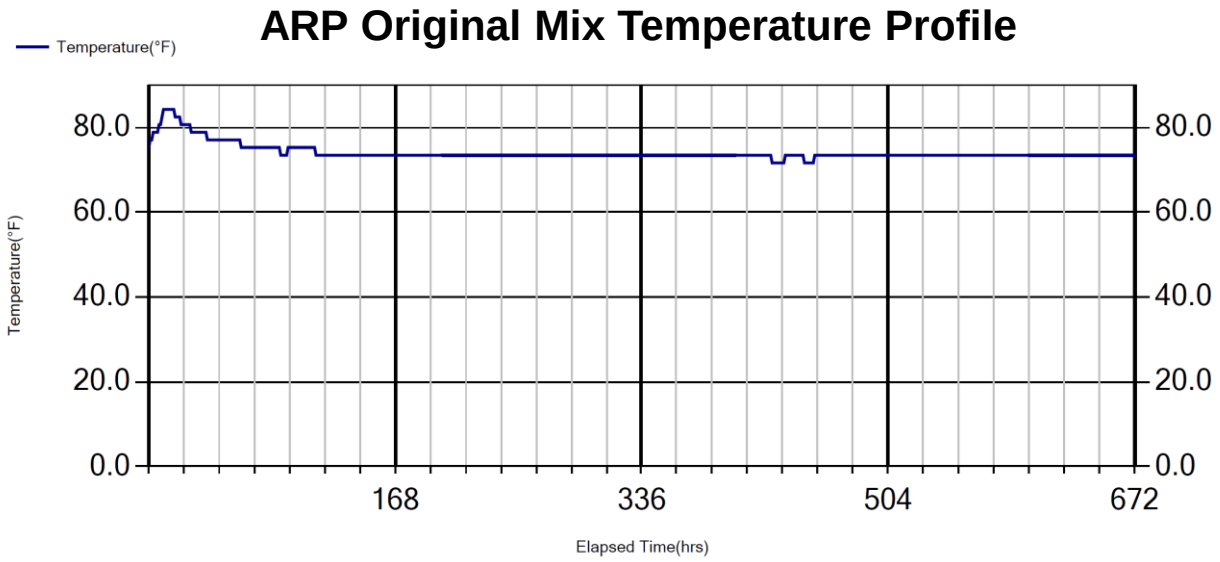
General Laboratory Testing Measures

- Curing temperature
- Compressive strength
- Yield
- Unit weight
- Air content

Curing Temperature

- Assuming initial temperature is 80 °F, temperature rise during curing < 70°F
- Provides flexibility in grout placement and better control of moisture evaporation



Compressive Strength – ASTM C 39

- Compressive strength > 200 psi at 28 days
- Provides long-term stability necessary to prevent subsidence

Yield (ASTM C 138), Unit Weight (ASTM C 231), and Air Content (ASTM C 940)

- Allows for project management and cost projections
- Actual yield measured compared to theoretical yield
  - Used for future project planning (volume of grout needed)

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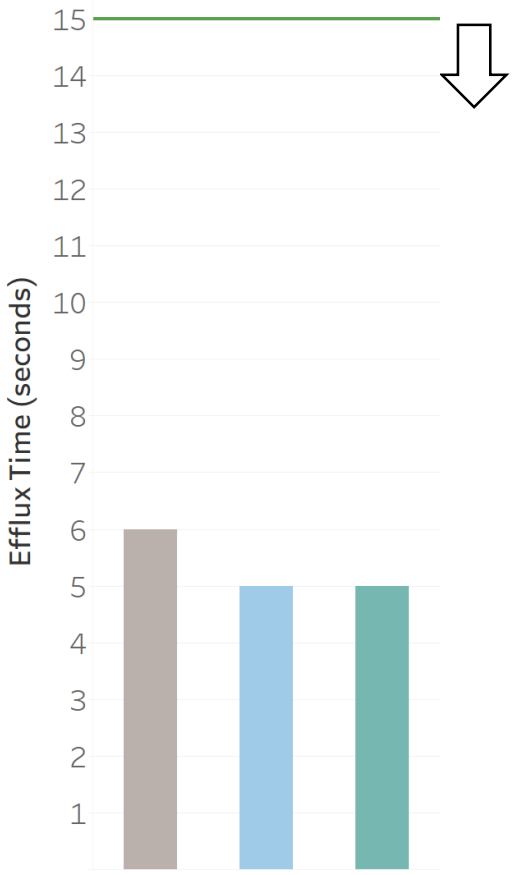
Highly Flowable Grout

Efflux Cone Test – ASTM D 6449

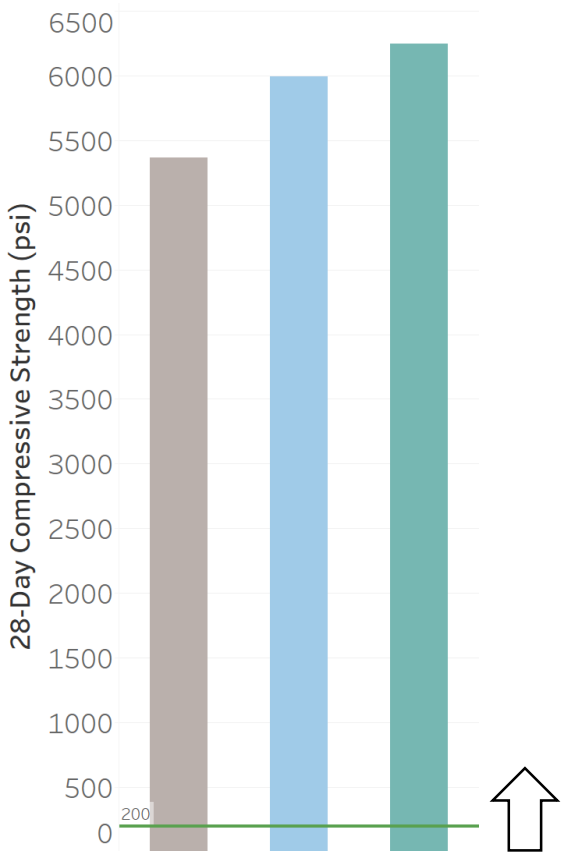
- Cone flow efflux time < 15 seconds
- Minimal efflux time is desired for grout capable of uniform flow

Highly Flowable Grout Laboratory Results

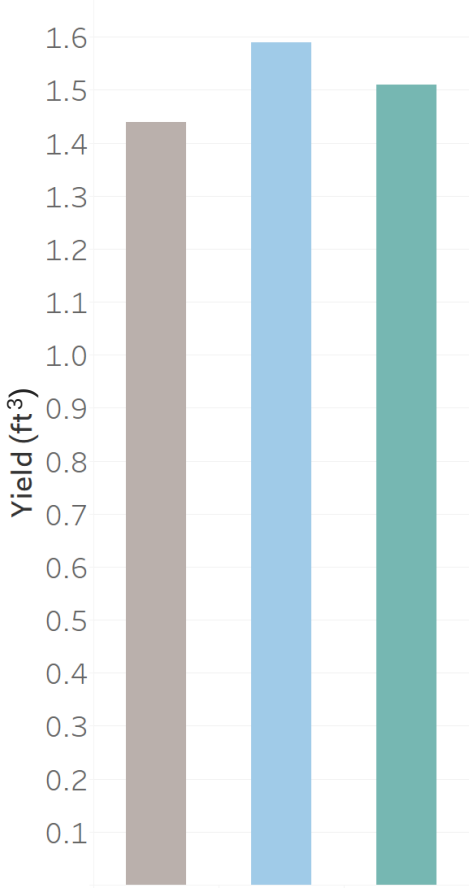
Efflux Flow Results



Compressive Strength Results



Yield Results

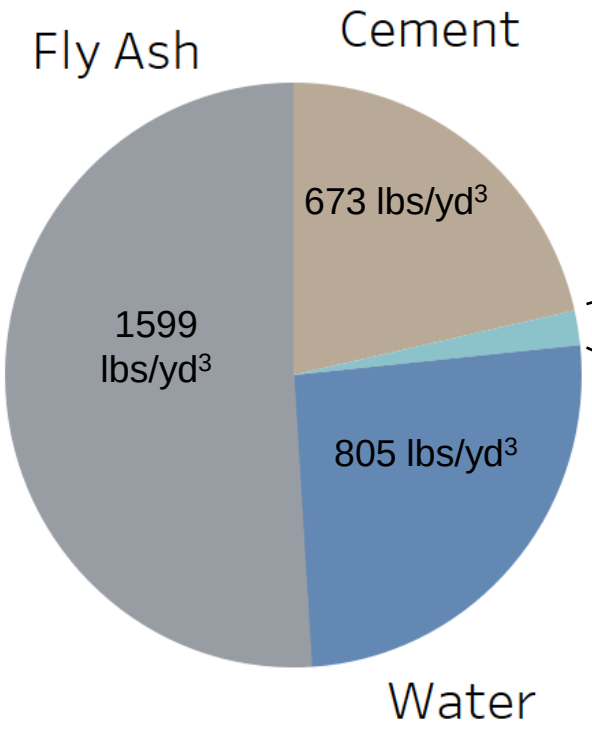


Mixes

- Idaho Pipe Grout Mix
- Idaho Pipe Grout -10% Water
- Idaho Pipe Grout +10% Water

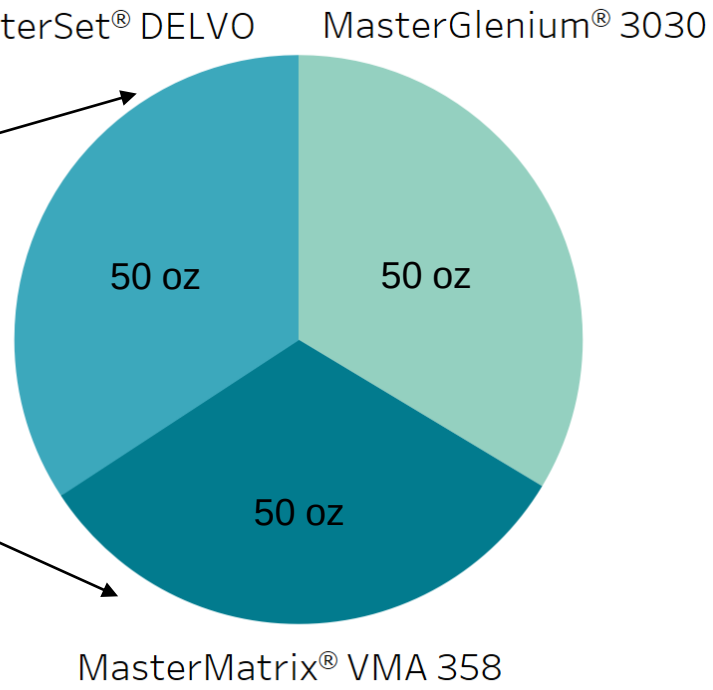
Final Highly Flowable Grout Formulation

Overall Formulation



Admixtures

Admixtures



Highly Flowable Grout Field Testing

Overview

- Background
- Components of Grout Formulations
- General Testing Measures
- Highly Flowable Testing Measures & Results
- **Bulk-Fill Testing Measures & Results**
- Shrinkage Challenges
- Path Forward

Bulk-Fill Grout

Bulk-Fill Laboratory Testing Measures

- Slump flow
- Visual stability index
- Bleed water
- Shrinkage

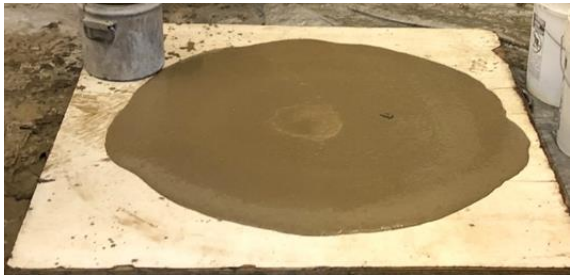
Slump Flow – ASTM C 1611

- Slump flow ≥ 24 inches
- Larger slump flow measurements indicate grout is flowable and self-leveling

Visual Stability Index – ASTM C 1611

- VSI of 0 or 1
- Allows grout to be pumped and placed without aggregate segregation

VSI = 0

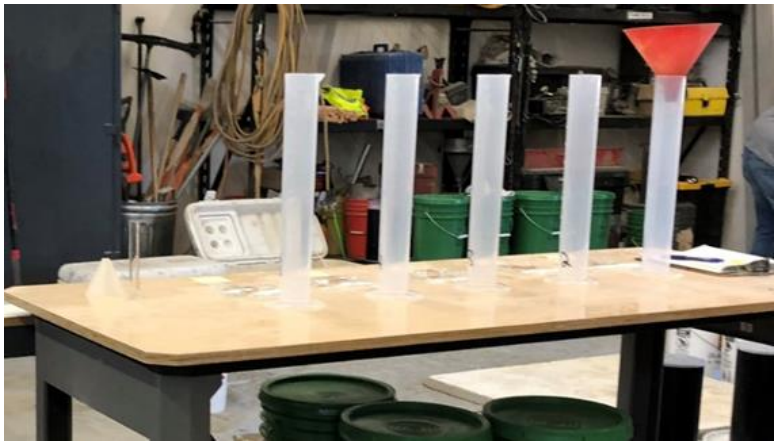


VSI = 1

VSI = 2

Bleed Water – ASTM C 940

- Minimal bleed water < 0.1% by volume (0% target)
- Reduces shrinkage due to water evaporation and limits the amount of potential cracking

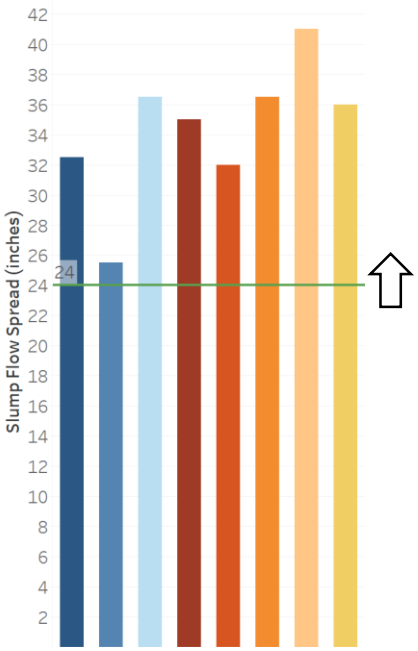


Shrinkage – ASTM C 1090

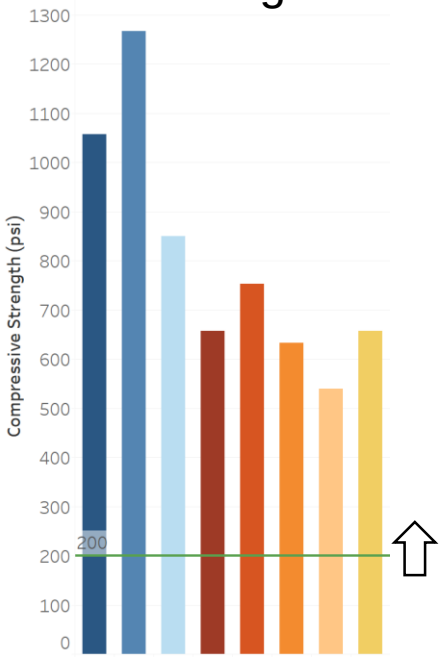
- Minimal shrinkage < 0.1%
- Reduces cracking and potential voids between grout and tank structure

Bulk-Fill First Testing Effort Results

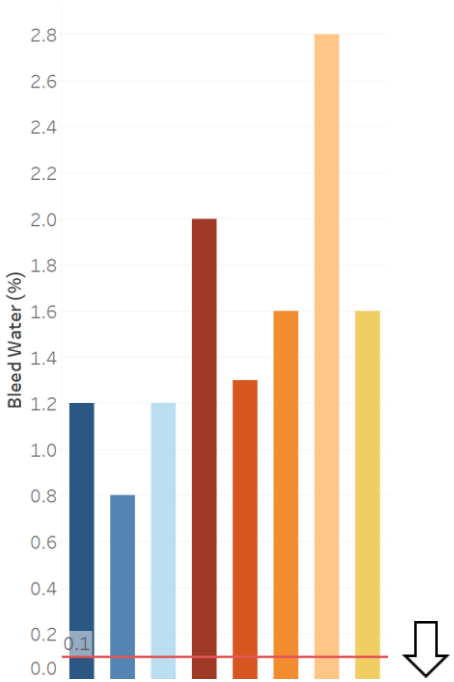
Slump Flow



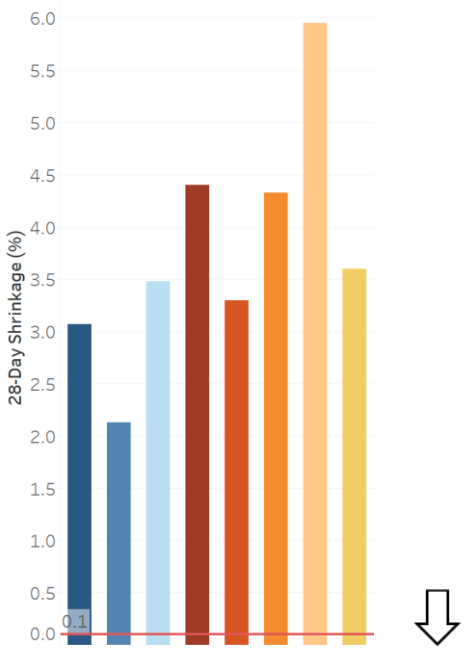
Compressive Strength



Bleed Water



28-Day Shrinkage

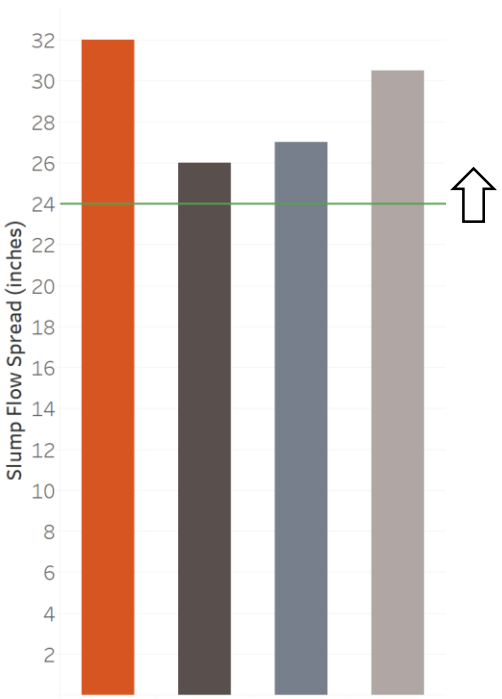


Batch	Slump Flow (in.)	VSI	28-Day Average Compressive Strength (psi)	Max Temperature Rise (°F)	Bleed Water (%)	28-Day Shrinkage (%)	Air Content (%)	Unit Weight (lbs/ft³)	Yield (ft³)
ARP #440200	35.0	1	657	9.2	2.0	4.40	0.6	136	1.3
ARP #440200 +10% Water	41.0	1	540	N/M	2.8	5.95	0.6	136	1.4
ARP #440200 -10% Water	32.0	0	753	N/M	1.3	3.30	0.7	140	1.3
ARP #440200 +25% VMA	36.0	1	657	N/M	1.6	3.60	0.5	139	1.4
ARP #440200 -25% VMA	36.5	1	633	N/M	1.6	4.33	0.5	138	1.4
221-U Canyon Mix	32.5	1	1057	12	1.2	3.07	0.5	139	1.4
221-U Canyon Mix +10% Water	36.5	1	850	N/M	1.2	3.48	0.6	137	1.5
221-U Canyon Mix -10% Water	25.5	0	1267	N/M	0.8	2.13	1.0	142	1.4

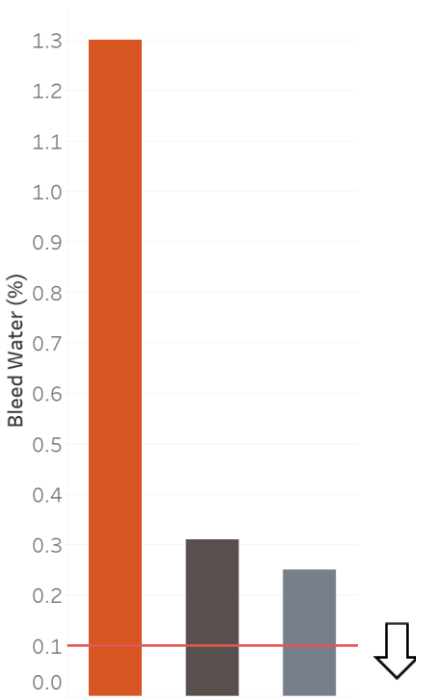
Bulk-Fill Mixes
- 221-U Canyon Mix
- 221-U Canyon Mix -10% water
- 221-U Canyon Mix +10% water
- ARP #440200 Mix
- ARP #440200 Mix -10% Water
- ARP #440200 Mix -25% VMA
- ARP #440200 Mix +10% Water
- ARP #440200 Mix +25%VMA

Bulk-Fill Second Testing Effort Results

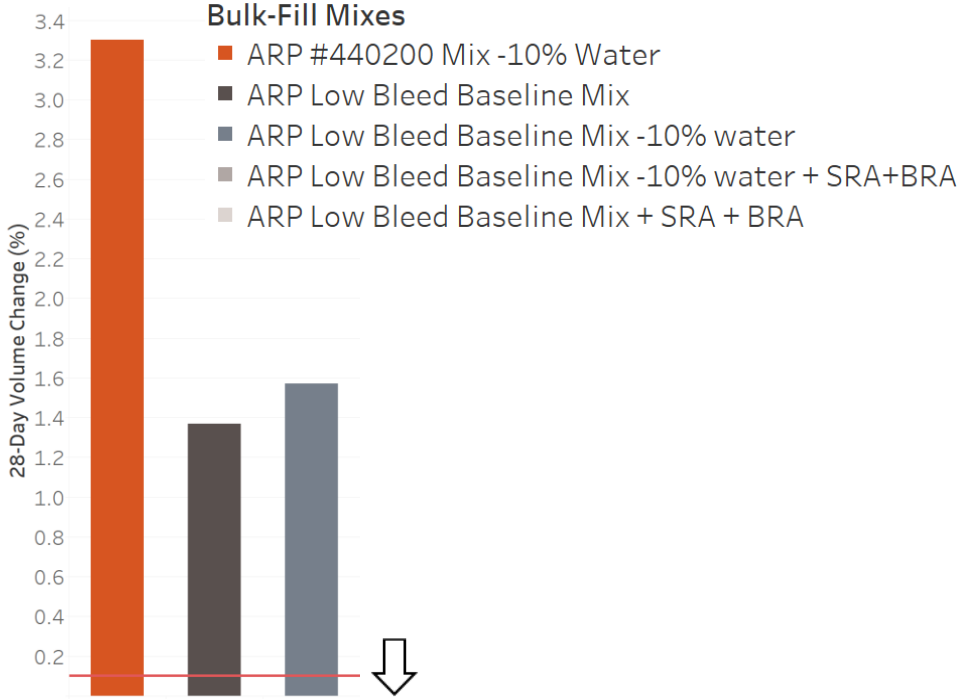
Slump Flow



Bleed Water



28-Day Shrinkage



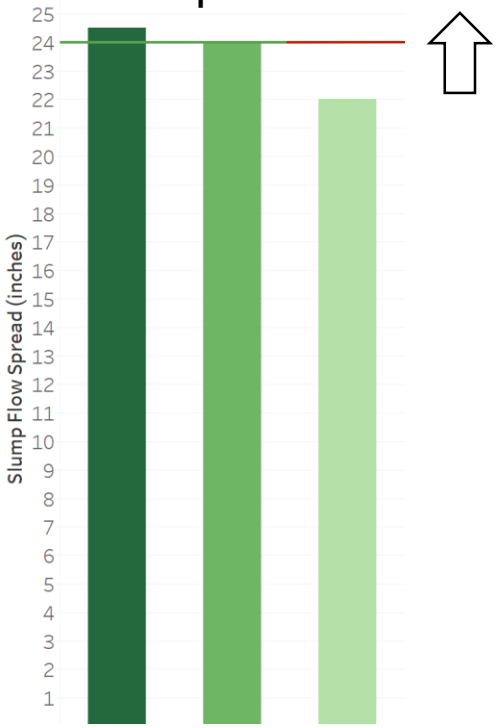
Batch	Slump Flow (in.)	VSI	Bleed Water (%)	28-Day Shrinkage (%)
ARP Low Bleed Baseline	26.0	0	0.31	1.4
ARP Low Bleed Baseline -10% Water	27.0	0	0.25	1.6
ARP Low Bleed Baseline +SRA +BRA	N/M	N/M	N/M	N/M
ARP Low Bleed Baseline -10% Water +SRA +BRA	30.5	2	N/M	N/M

Bleed Water Challenges and Solutions

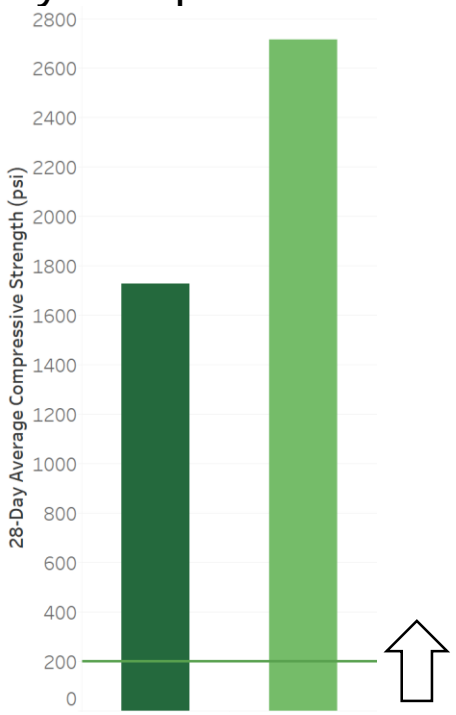
- Reduced amount of water in grout formulas
- Adjusted quantities of admixtures
- Tested via new standard
  - ASTM C 232 with modifications
  - Better represented field conditions

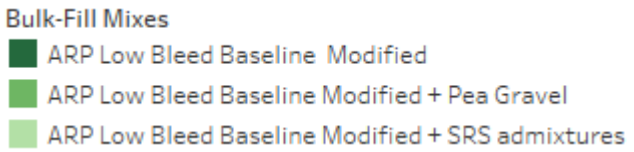
Bulk-Fill Third Testing Effort Results

Slump Flow



28-Day Compressive Strength





Batch	Slump Flow (in.)	VSI	Bleed Water (%)	28-Day Average Compressive Strength (PSI)	Max Temperature Rise (°F)	Air Content (%)	Unit Weight (lbs/ft³)
ARP Low Bleed Modified Baseline	24.5	0	0	1727	N/M	2.5	144
ARP Low Bleed Modified + Pea Gravel	24.0	0	0	2715	9	2.0	146
ARP Low Bleed + Pea Gravel + SRS Admixtures	22.0	N/M	N/M	N/M	N/M	N/M	N/M

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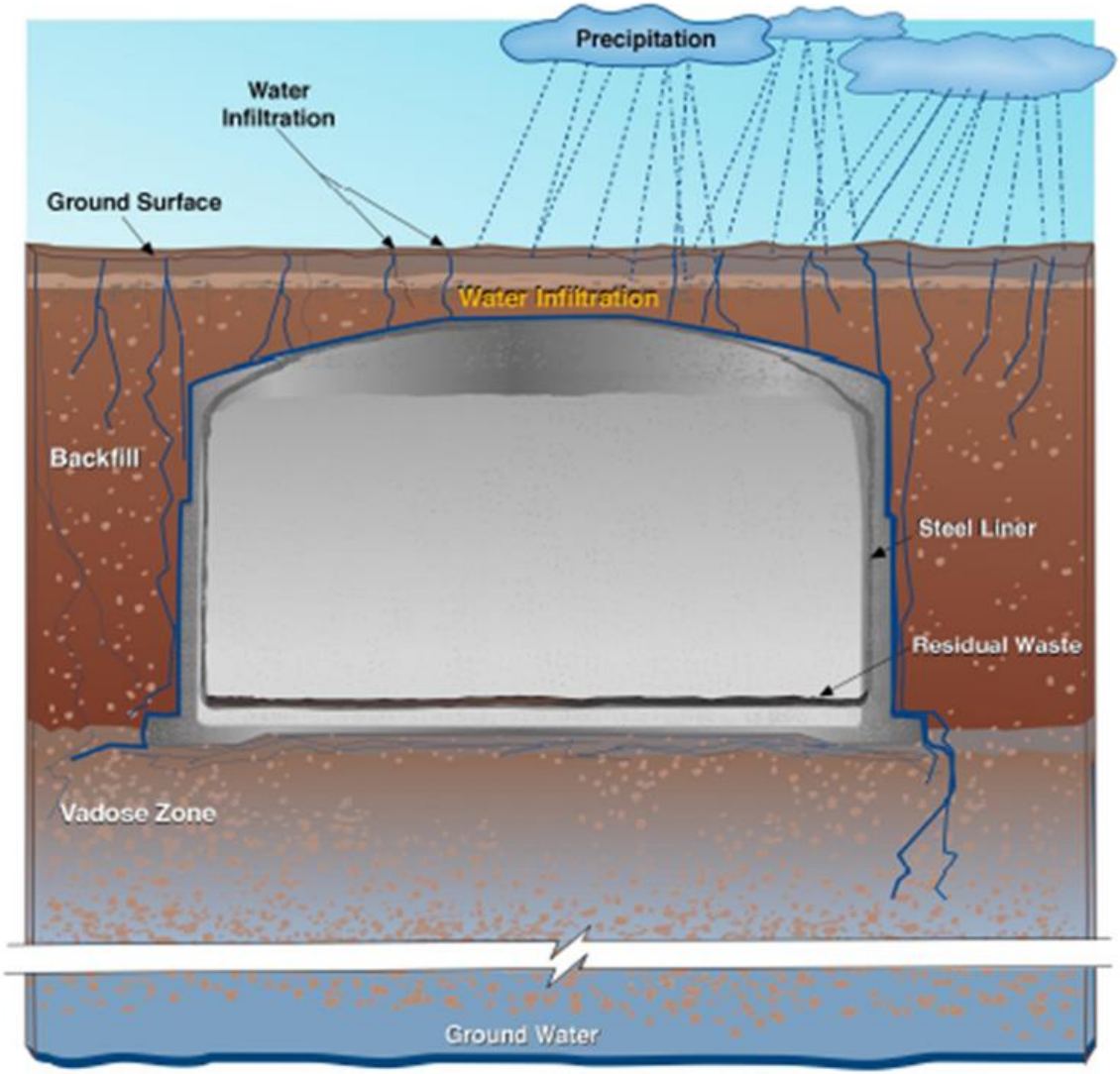
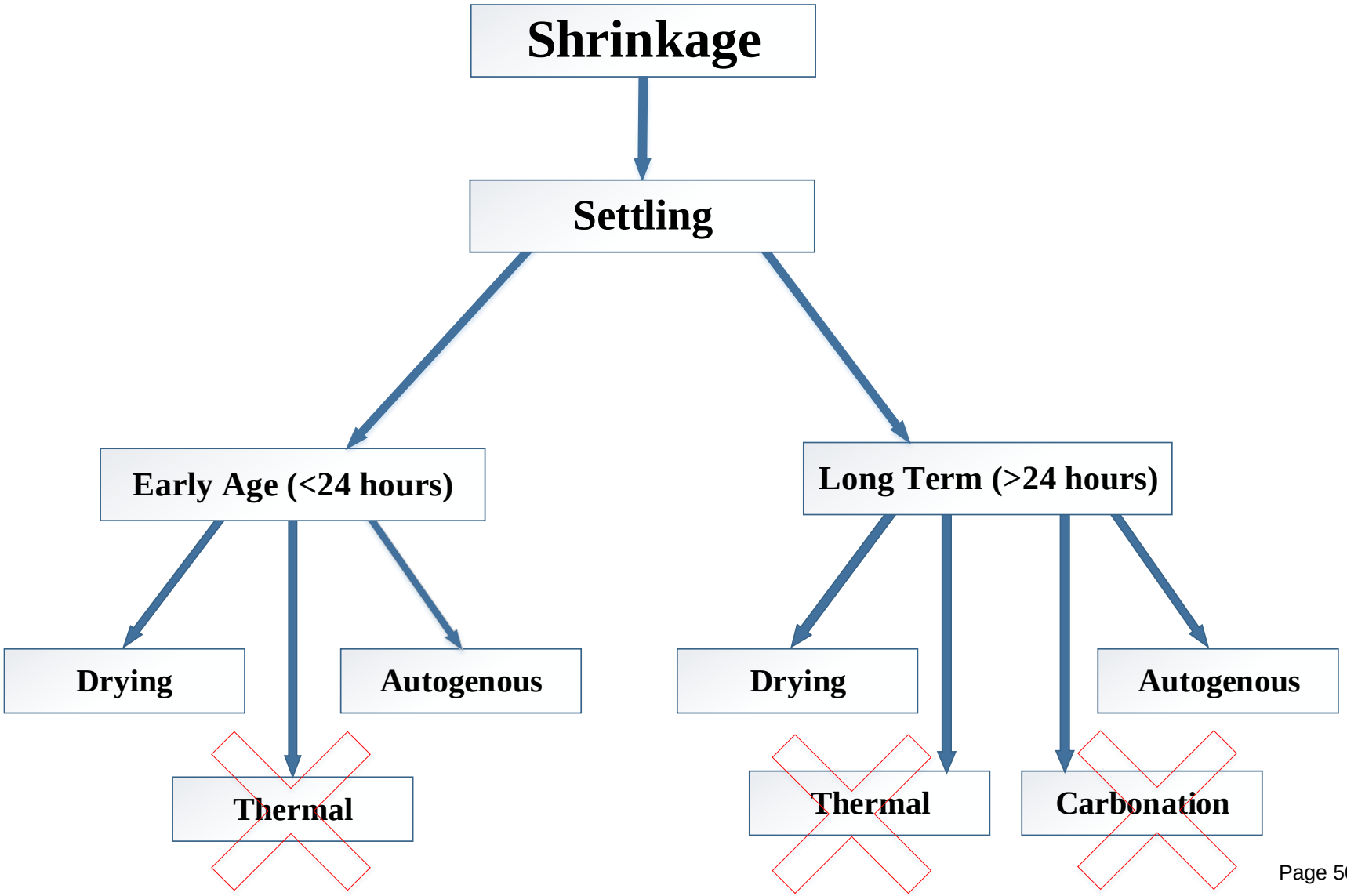
Importance of Shrinkage



Shrinkage Mechanisms



Efforts To Prevent Shrinkage

- Reduced amount of water in grout formulas
- Adjusted quantities of admixtures
  - Added shrinkage-compensating admixtures
- Added larger, rigid aggregates
  - Replaced 25% of sand with ½-inch range pea gravel

Conclusion

- Completed research to develop formulas
- Identified performance objectives
- Identified testing methods
- Conducted highly flowable testing and interpreted results
- Finalized a highly flowable grout formulation
- Conducted bulk-fill testing and interpreted results
- Solved bleed water challenge
- Working to solve shrinkage challenges

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Path Forward and Additional Testing

- Measure shrinkage using different standard (ASTM C 157)
  - Rectangular prism molds
  - Modifications to reflect field conditions
- Measure shrinkage using the same initial standard (ASTM 1090) to compare results
- Add additional Type K, M, and/or S admixtures for grout expansion if needed
- Measure shrinkage during mock-up testing

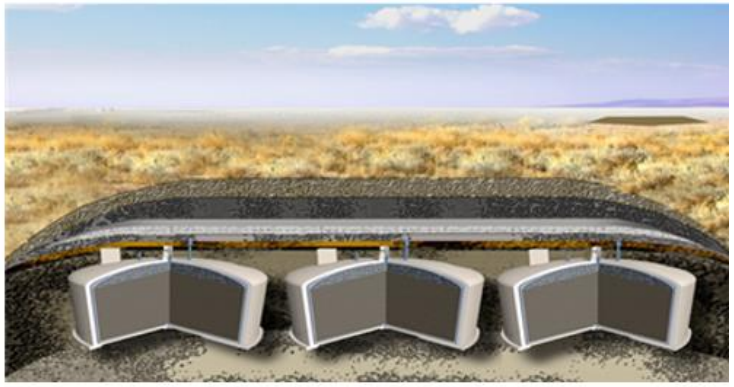
Questions?

Thank You

C-200 Series Closure Grout Development

Background Research → **Functional Performance Requirements** → **Testing Plan and Procedures** → **Grout Testing**

- DOE Complex past grout projects
- Industry standards
- Functional performance requirements



- Exploratory testing
- Laboratory testing
- Mock-up testing
- Test reports

WMA C Closure Efforts/Status

- Closure plans & regulatory approvals
  - WA Ecology comment resolution process for closure plans and other portions of the SST permit
  - Awaiting NRC comments on WMA C performance assessment
- Grout delivery for C-200 series tanks & ancillary equipment
  - Preliminary design ongoing
  - PrHa ongoing
- Grout formulation
  - C-200 series tanks & ancillary equipment
    - Highly-flowable selected
    - Bulk-fill ongoing materials testing for shrinkage
  - C-100 series tanks & ancillary equipment initiated
- WMA C facilities and equipment removal
  - Ongoing

Tank Closure Grout Formulas Across DOE Complex

washington river protection solutions

(wt/wt%)	Hanford GTF DST Slurry Feed test	Hanford GTF test PSW	Hanford GTF AP-102 test	PNNL-ORNL test for AN-106	US Army Corp Engrs	241-C-200's ATC ChemStabilization (HRC4)	241-C-200's ATC Bulk Fill (HRC8)	241-C-200's ATC Capping (HRC9)	2009 Hanford Closure Demo-ChemStabilization	2009 Hanford Closure Demo-Bulk Fill	2010 Hanford Closure Concept Bulk Fill	2010 Hanford Closure Concept Highly Flowable	Oak Ridge 1999 GAAT Waste via MPI	Oak Ridge 2001 OHF Tank Closure	SR Tnk 17F & 20F-ChemStabilization	SR Tnk 17F & 20F-Bulk Fill	SR Tnk 17F & 20F-Capping	SR Tnk 18F & 19F-Bulk Fill	INEEL-Highly Fluid	INEEL-Tank & Vault	INEEL-CLSM	241-AN-106A-Mix #1	241-AN-106A-Mix #2	PUREX Tunnel Structural Fill	221-U Canyon Closure	300 Area Pipeline/ARP #440200
Type I&II Portland Cement	6	41	21	5	9	6.12	2.06	7.54	3.04	5.62	5.68	22.87	7.02	1.32	33.53	4.3	16.23	3.38	22.03	6.38	2.56	8.72	32.21	9.99	6.99	5.32
Grade 100 Slag	47			47.5		5.7	5.76	5.66	9.03	0			23.6		5.18	0	0	5.68		9.77						
Class F Fly Ash	47	40	68	47.5	33.36	6.12	10.28	4.58	5.92	10.95	11.07	55.79	22.81	19.8		14.32		9.82	51.85	3.28	7.67	23.98	5.74	21.22	12.58	14.79
Silica Fume															2.23											
Quartz Sand ASTM C-33					39.42	68.76	69.39	68.15	69.78	71.95	72.72	0		76.9	40.27	65.89	67.42	48.42		69.4	79.24	48.56	42.43	56.01	68.07	66.74
Gravel #8 (3/8 in)																		21.64								
water					16.92	13.13	12.34	13.9	13	11.46	10.53	21.34	41.15	14.43	17.9	15.07	16.01	10.96	25.91	11.1	10.22	17.96	18.94	12.48	12.35	13.07
ASTM C494 Type F 1					0.14	0.03	0.03	0.03	0.07	0.01					0.46	0.41	0.34	0.09	0.16	0.07	0.18			0.04		
Medium Range Water Reducer																			0.08		0.13					
ASTM C494 Type B (Retarding)					0.01										0.39											
Foaming Agent (Rheocell 30)										0.01																0.01
ASTM C494 Type D2	0.01																							0.11		
ASTM C494 Type S Viscosity Modifier 3																								0.14		0.05
ASTM C260 Air-Entraining Admix (MB AE 90)																										0.02
Sodium Thiosulfate-Reducing Agent																0.05										
ELEMIX																						0.78	0.69			
Bentonite Clay/Attapulgite Clay		11	11		1.14								1.28													
Potter's Clay (Indian Red Pottery Clay)		8											4.15													
Water:Cement Ratio (W/C) in wt%	N/A	N/A	N/A	N/A	1.88	2.15	5.99	1.84	4.28	2.04	1.85	0.93	5.86	10.93	0.53	3.50	0.99	3.24	1.18	1.74	3.99	2.06	0.59	1.25	1.77	2.46
Water:Cementitious Material Ration (W:CM) in wt%	N/A	N/A	N/A	N/A	0.399433	0.731884	0.681768	0.781777	0.722624	0.691611	0.628657	0.271294	0.770167	0.683239	0.437225	0.809345	0.986445	0.580508	0.350704	0.571282	0.999022	0.549235	0.499078	0.399872	0.631068	0.649925

Highly Flowable Formulation