RECLAMATION

Managing Water in the West

Verification that Type V Cement is Required for CLSM with High Sulfate Soils

Research and Development Office
Science and Technology Program
Final Report ST-2015-2840-01

U.S. Department of the Interior
Bureau of Reclamation
Research and Development Office

December 2015

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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14. ABSTRACT

The study described in this report was authorized by the Bureau of Reclamation Research and Development Office, Science and Technology Program. The approved scope of work consisted of materials selection and mixture proportioning study for a CLSM mixture, performing short and long term compressive strength testing, data analysis, and preparation of a final report. The investigation was performed by personnel in the Concrete, Geotechnical and Structural Laboratory at Bureau of Reclamation's (Reclamation) Technical Service Center (TSC).

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Project and Document Information

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Peer Reviewer: I have reviewed the assigned items/sections(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer Veronica Madera Date reviewed 9/30/15
(Signature)

Acknowledgements

It is important to acknowledge several personnel for the success of this project: Bruce Schulte, Westin Joy, John (Bret) Robertson, John Buck, Mario Pereira, Brandon Poos, Veronica Madera, Ms. Kylie Fink and Ms. Ariel Voit. Dr. Jessica Torrey, and Dr. William Kepler, also provided additional project management support and technical guidance.

Acronyms and Abbreviations

ASTM – American Society of Testing and Materials
CLSM – Controlled Low Strength Material
LA – Low Alkali
CGSL – USBR's Concrete, Geotechnical and Structural Laboratory
NMSA – Nominal Maximum Size Aggregate
TSC – Technical Service Center
USBR – United States Bureau of Reclamation
w/cm – water to cementitious materials ratio

Executive Summary

This purpose of this project was to determine whether Controlled Low Strength Material (CLSM) produced with native soils containing sulfates will break down over time with or without the use of Type V cement. Several mixtures using soil with varying sulfate content and either Type I/II or Type V cement were made and tested for compressive strength at 7, 28, 56, 90, 180, 365 and 799 days. In general, CLSM containing Type I/II cement performed better than Type V cement, with the exception of when combined with soil containing 2.5% sulfates by mass. From the data produced during a three year period of time it appears that as long as the CLSM will not be exposed to excess water, either Type V or Type I/II cement can be used for "moderate" sulfate exposure with soils containing less than 2.0 percent by mass of water-soluble sulfate, or less than 150 ppm of dissolved sulfate in water.

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Introduction

This technical memorandum, prepared by the Concrete, Geotechnical and Structural Laboratory Group of the Bureau of Reclamation's Technical Service Center, in Denver, Colorado, discusses the results of the CLSM proportioning study.

This project consisted of performing a CLSM proportioning study using two different cementitious materials, Type I/II and Type V cement, and varying amounts of potassium sulfate added to crusher fines. Several trial batches were conducted to find the optimum proportions to target 7 day compressive strength of 100 psi with an 8 to 10 inch slump. Once the control proportions were determined, additional testing was performed to test the difference in compressive strength between CLSM produced at the two slump extremes. Additional trial batches were then designed to compare the use of Type I/II versus Type V cement with varying amounts of sulfate concentrations by weight of aggregate.

Background

The purpose of this project is to verify if there is a benefit to using Type V cement with Controlled Low-Strength Material (CLSM) made with native soils having high sulfate concentrations. CLSM, also known as flow fill, is commonly used for backfill along Reclamation pipelines and other structures. Current specifications require that CLSM use Type V (sulfate resistant) cement when contact with soils containing greater than 0.20 percent by mass of water-soluble sulfate, to mitigate sulfate attack. Sulfate attack is known to deteriorate cement paste when the sulfates in the soil react with the hydrated cement.

CLSM is used extensively throughout Reclamation, to possibly include over 100 miles of pipeline for the ongoing Navajo Gallup Water Supply Project. There is an economic and environmental benefit of using native soils in CLSM rather than the traditional ASTM C33 aggregates. Aggregates or soil make up approximately 75% of the volume of CLSM. Using native soils from the excavation instead of manufacturing and transporting aggregates can be not only a tremendous cost savings but a reduction in carbon production in the environment as well.

When concrete needs to have resistance to high levels of sulfates, Type V Cement is specified along with a minimum water/cementitious (w/cm) ratio, according to ACI 318-14 chapter 19 durability requirements [1]. Since CLSM is mixed with the high sulfate soils and placed at significantly higher w/cm ratios there may not be a benefit in using Type V cement and the extra expense of the specialty cement may not be needed.

This purpose of this project was to determine whether CLSM produced with native soils containing sulfates will break down over time with or without the use of Type V cement. The results of this study benefits not only the Navajo-Gallup project but also has Reclamation wide benefits as well.

Scope of Work

The scope of work for the project presented in this report contained the following main objectives:

1. Materials Selection
2. CLSM Proportioning Study
3. CLSM Compressive Strength Testing
4. Technical and Peer Review of preliminary report
5. Data Analysis and Checking
6. Final Report

Materials Selection

Detailed test results of all the materials used in this CLSM study are included in Appendix A.

Aggregate Selection

The first task of this research was to find the ideal native soil to use. This project required a soil that meets the current Bureau of Reclamation CLSM specifications and has extremely low sulfate content. The soil needed to meet ACI 318-14 criteria for the "S0" sulfate exposure category according to table 19.3.1.1, Exposure Categories and Classes. The definition of "S0" sulfate exposure is less than 0.10 percent by mass of water-soluble sulfate in the soil, or less than 150 dissolved sulfate in water, ppm.

For this study, the control CLSM mixture used material without any additional sulfate added to the mixture. Subsequent mixtures used increasing amounts of sulfate to meet the requirements of "S1", "S2", and "S3" sulfate exposures according to ACI 318 as shown in Table 1.

Table 1 – Sulfate Exposure Categories and Classes (adopted from ACI 318-14 table 19.3.1.1)

Class	Water-Soluble Sulfate in Soil, % by mass	Dissolved Sulfate in Water ppm	Sulfate Used in CLSM % by mass
S0	$SO_4^{2-} < 0.10$	$SO_4^{2-} < 150$	0.00
S1	$0.10 \leq SO_4^{2-} \leq 0.20$	$150 \leq SO_4^{2-} \leq 1500$	0.15
S2	$0.20 \leq SO_4^{2-} \leq 2.0$	$1500 \leq SO_4^{2-} \leq 10{,}000$	0.70
S3	$SO_4^{2-} > 2.0$	$SO_4^{2-} > 10{,}000$	2.5

Several samples of native soils were tested and none of them contained less than 0.10 Water-soluble sulfates (SO4). The Navajo Gallup Reach 12 A was under construction during this portion of the project. The CLSM supplier for Reach 12A elected to use crusher fines instead of soil for CLSM. Crusher fines met the current CLSM specification and also had a low sulfate concentration. Based on this information it was decided to use local crusher fines instead of native soils. The crusher fines were produced by Albert Frei and Sons, which is a local source of crusher fines. Physical property information for the crusher fines can be found in Appendix A.

Cementitious Materials

Two control mixes without any additional sulfate added to the crusher fines were made: one with Type I/II cement and the other with Type V cement. The Type I/II cement was provided by Holcim Cement and Mountain Cement supplied the Type V used for this study. Mill test reports are located in Appendix A.

CLSM Proportioning Study

Several trial batches were conducted to find the optimum proportions to target 7 day compressive strength between 50 and 150 psi, with an 8 to 10 inch slump without the addition of sulfates to the mixture. Once the optimum proportions were identified using both Type I/II and Type V cement, control mixes were batched. Additional CLSM mixtures were proportioned using the control proportions and increasing amounts of sulfates. For each batch, cylinders were cast using ASTM D4832-10, Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders [2]. Cylinders were kept in their molds and placed in the fog room for standard curing until time of testing. Table 2 summarizes CLSM mix proportions, physical properties and compressive strength. The batches were labeled using the following format: CLSM-(type of cement)-(percentage of sulfate added). For example CLSM with the label: “CLSM-I/II-.70” contains type I/II cement, and 0.70% additional sulfates.

The sulfates that were added to the crusher fines seemed to affect the water content and setting of the CLSM at higher dosages. Mixtures with added sulfates to achieve a sulfate concentration of 2.5% increased the water requirements considerably. CLSM also appeared to flash set so additional water and mixing was required to meet the slump requirements. It must be noted that the lower compressive strength corresponds with the higher water to cement ratio of these mixtures. Figure 1 illustrates the long term compressive strength of the mixtures tested.

Table 2 – CLSM Mixture Proportions, Physical Properties and Compressive Strength

	Type I/II Cement				Type V Cement			
MIX ID	**CLSM-I/II-0**	**CLSM-I/II-.15**	**CLSM-I/II-.70**	**CLSM-I/II-2.5**	**CLSM-V-0**	**CLSM-V-.15**	**CLSM-V-.70**	**CLSM-V-2.5**
Cast Date	8/28/2013	8/28/2013	8/28/2013	8/28/2013	8/28/2013	8/28/2013	8/28/2013	8/28/2013
Batch Size, cf	1.2	1.2	1.0	1.0	1.2	1.0	1.0	1.2
Cement Type/Source	Holcim, Type I/II LA	Holcim, Type I/II LA	Holcim, Type I/II LA	Holcim, Type I/II LA	Montain, Type V LA	Montain, Type V LA	Montain, Type V LA	Montain, Type V LA
Potassium Sulfate Type/Source	EMD PX1595-5	EMD PX1595-5	EMD PX1595-5	EMD PX1595-5	EMD PX1595-5	EMD PX1595-5	EMD PX1595-5	EMD PX1595-5
Aggregate Source	Albert Frei & Sons, Class 6 Base, Pit 6	Albert Frei & Sons, Class 6 Base, Pit 6	Albert Frei & Sons, Class 6 Base, Pit 6	Albert Frei & Sons, Class 6 Base, Pit 6	Albert Frei & Sons, Class 6 Base, Pit 6	Albert Frei & Sons, Class 6 Base, Pit 6	Albert Frei & Sons, Class 6 Base, Pit 6	Albert Frei & Sons, Class 6 Base, Pit 6
Mixture Proportions								
	Mass	**Mass**	**Mass**	**Mass**	**Mass**	**Mass**	**Mass**	**Mass**
	lbs/yd^3	**lbs/yd^3**	**lbs/yd^3**	**lbs/yd^3**	**lbs/yd^2**	**lbs/yd^3**	**lbs/yd^3**	**lbs/yd^3**
Water	574	581	582	674	567	589	581	690
Cement	212	201	202	186	198	202	201	187
Class 6 Base (Crusher Fines)	2965	2914	2920	2699	2872	2921	2900	2705
Sulfate	0.0	4.4	20.4	67.5	0.0	4.4	20.3	72.5
% of Sulfate to weight of aggregate	0.00%	0.15%	0.70%	2.50%	0.00%	0.15%	0.70%	2.50%
Total	3751	3700	3724	3626	3637	3716	3702	3655
w/c ratio	2.71	2.89	2.88	3.62	2.86	2.92	2.89	3.69
Physical Properties								
slump, inches	8.00	9.75	10.00	10.00	10.00	9.75	10.00	10.00
air, %	1.0	0.3	0.7	0.6	0.8	0.3	0.7	0.4
gravimetric air, %								
unit wt, (lbs/cf)	138.9	136.9	138.3	131.8	134.7	137.5	137.0	131.8
Temperature, F	-	66.0	66.0	65.0	-	64.0	66.0	66.0

Average Compressive Strength, psi								
	Type I/II Cement				Type V Cement			
MIX ID	**CLSM-I/II-0**	**CLSM-I/II-.15**	**CLSM-I/II-.70**	**CLSM-I/II-2.5**	**CLSM-V-0**	**CLSM-V-.15**	**CLSM-V-.70**	**CLSM-V-2.5**
7 day	155	145	155	70	100	125	110	75
28 day	220	190	195	80	130	150	125	55
56 day	195	200	190	75	160	180	170	90
90 day	295	225	235	90	160	205	180	100
180 day	290	240	220	100	180	205	195	110
365 day	265	260	240	115	195	210	150	165
779 day	327	290	290	150[1]	197	260	240	160

[1] Only 2 out of 3 samples could be tested

Values in red are questionable, strength decreases at 56 days

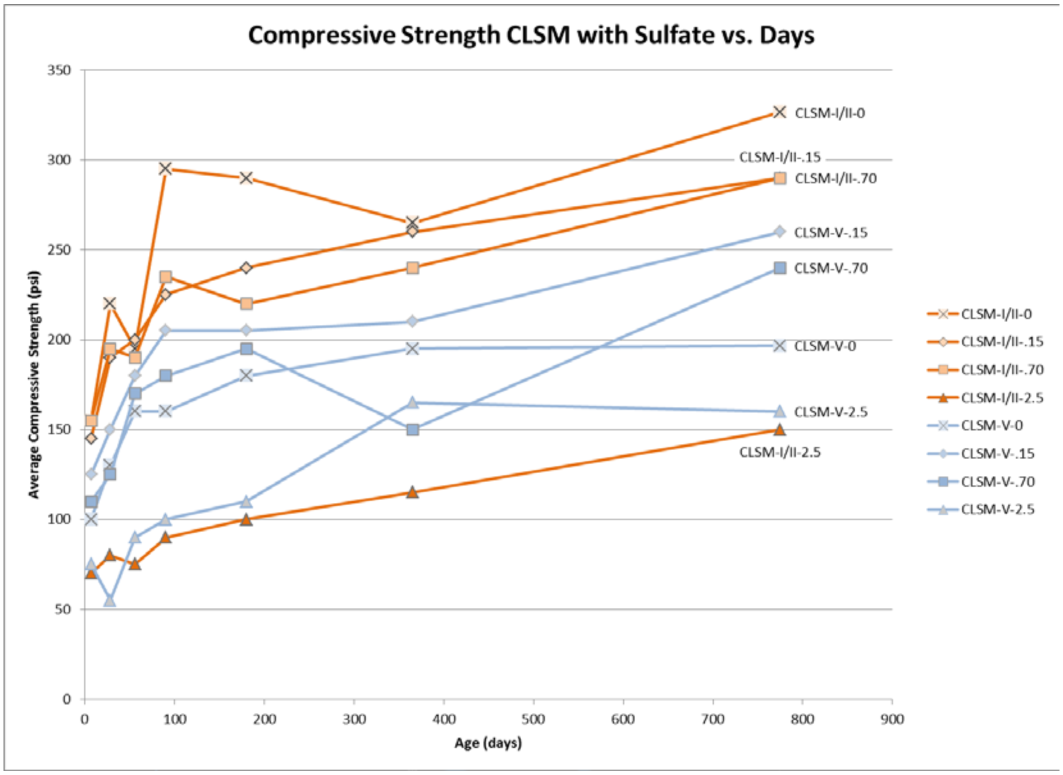


Figure 1 – CLSM Compressive Strength

Discussion

The CLSM compressive strength data shown in Figure 1is very inconsistent, however a general trend can be acknowledged. Testing CLSM is very difficult due to its low strength. It is difficult to remove CLSM specimens from their molds without damaging them and rendering them untestable. In addition, the degree of accuracy required for CLSM comparison is higher than it should be for such variable material. For example, ± 20psi for the compressive strength of concrete specimens made from the same batch and tested at the same age is not considered unusual, however for CLSM such variation can be the difference between acceptance or rejection for a material with a greater variability than structural concrete, especially if made with natural soils.

Also shown in Figure 1, is the strength difference between Type I/II and Type V cement. After the first year of this study, it was decided to closely investigate the compressive strength of the cement. Mortar cubes were made and tested using the two types of cement. Compressive strengths are presented in Table 3 and Figure 2.

Table 3 – Compressive Strength of 2- by 2-inch Cement Mortar Cubes

Compressive Strength of Hydraulic Cement Mortars (ASTM: C109/C109M)		
	Type I/II Cement	**Type V Cement**
Average Compressive Strength, psi		
7 day	5200	4580
28 day	6390	5330
56 day	6600	6250
180 day	6120	4880
365 day	6040	5920

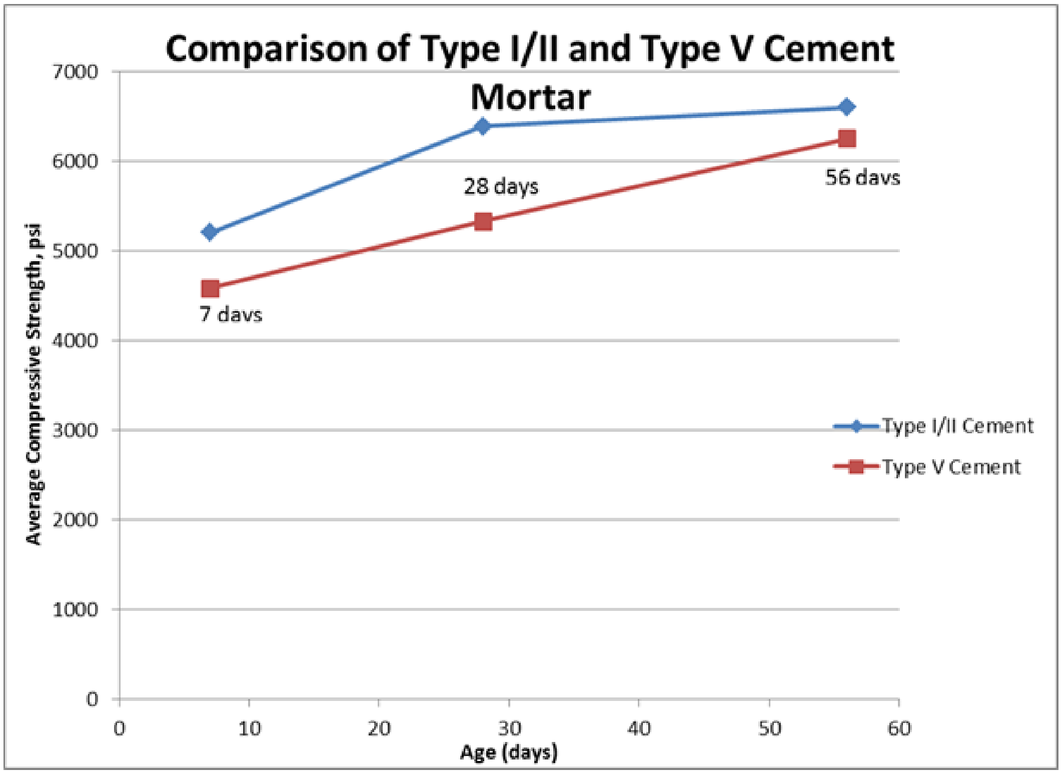


Figure 2 – Compressive Strength of Mortar Cubes

The mortar cube test data indicates that the compressive strength of the Type I/II cement is approximately 1000 psi higher at 28 days, which corresponds with the CLSM test data.

The most alarming observation of this CLSM study was the condition of the cylinders which were unintentionally exposed to excess moisture due to caps not fitting properly. The second cylinder for mixture CLSM I/II-2.5, which contained 2.5 % sulfates, fell apart when removed from the mold and was not testable, as shown in Figure 3.

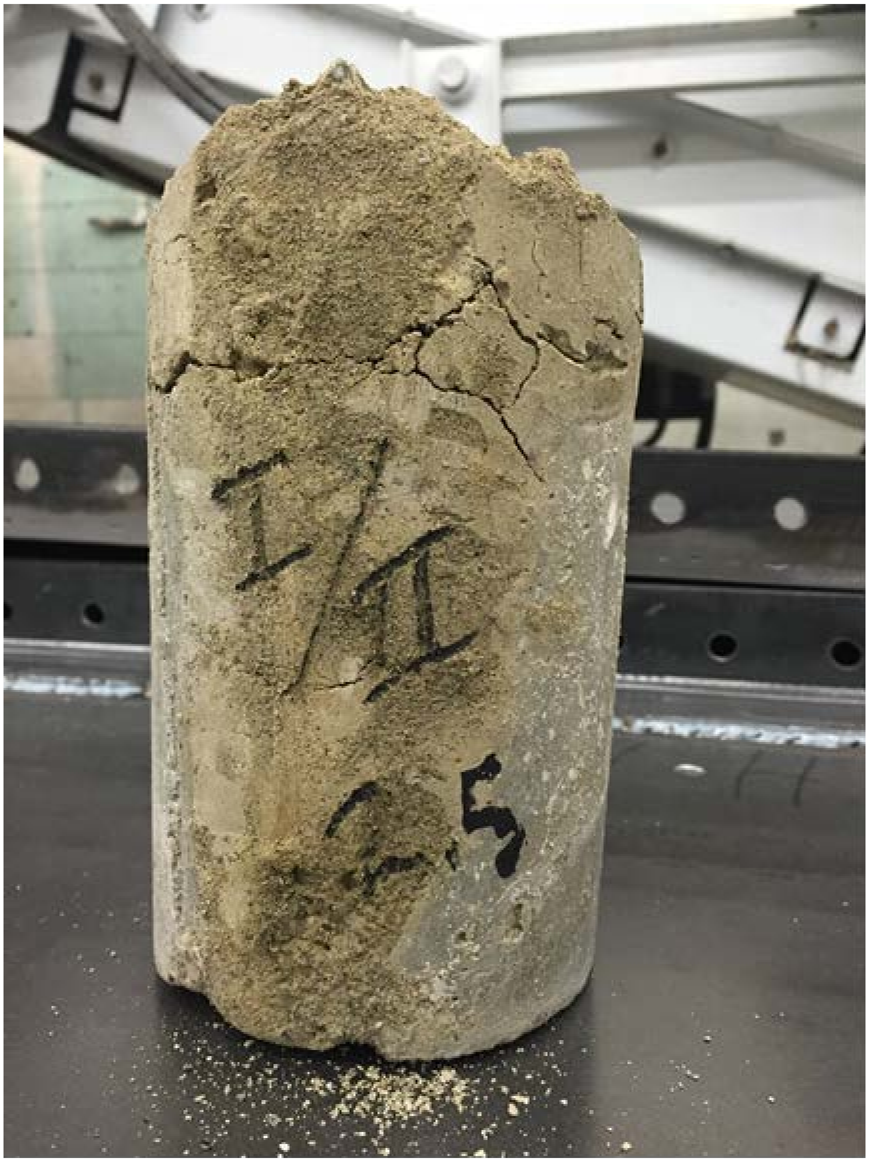


Figure 3 – Specimen CLSM I/II-2.5 which was exposed to excess water during curing

Conclusions

The purpose of this study was to verify that Type V cement is required for CLSM made with high sulfate soils. From the data produced during a three year period of time it appears that as long as the CLSM will not be exposed to excess water, either Type V or Type I/II cement can be used for "moderate" sulfate exposure with soils containing less than 2.0 percent by mass of water-soluble sulfate, or less than 150 ppm of dissolved sulfate in water.

The strength of the CLSM with greater than 2.0 percent by mass of water-soluble sulfate in the soil, is unpredictable with Type I/II cement, especially if there would be a source of water during service. The 2 year strength of the CLSM made with Type V cement and sulfates in this range appeared to decrease slightly;

therefore further investigation such as petrography of the CLSM specimens would be necessary to determine if either type of cement seems to mitigate sulfate damage to the cement paste when using soils with high sulfate contents.
Further investigation of CLSM for a longer duration and in moist environments is recommended, along with petrographic investigation. Fortunately, there are additional specimens available, from each mix tested, for petrographic investigation if funding is provided.

References

[1] ACI 318-14 Building Code Requirements for Structural Concrete and Commentary, Farmington Hills, MI: American Concrete Institute, 2014.

[2] Annual Book of ASTM Standards, Vol. 04.08 - Soil and Rock, West Conshococken, PA: ASTM International, 2010.

Appendix A. Material Test Results

Holcim

Material Certification Report

Material: Portland Cement
Type: I-II (ASTM C 150)

Test Period: 01-Oct-2011
To: 31-Oct-2011

Certification

Holcim cement meets the specifications of ASTM C 150 for Type I-II cement.

General Information

Supplier:	Holcim (US), Inc.	Source Location:	Ada Plant
Address:	14500 CR 1550 Ada, OK		14500 CR 1550 Ada, OK
Telephone:	(580)421-8915	Contact:	Theresa Hammons
Date Issued:	05-Dec-2011		

The following information is based on average test data during the test period. The data is typical of cement shipped by Holcim; individual shipments may vary.

Tests Data on ASTM Standard Requirements

Chemical			Physical		
Item	Limit[A]	Result	Item	Limit[A]	Result
SiO_2 (%)	-	20.6	Air Content (%)	12 max	5
Al_2O_3 (%)	6.0 max	4.8	Blaine Fineness (m^2/kg)	260 min	374
Fe_2O_3 (%)	6.0 max	3.0			
CaO (%)	-	64.3			
MgO (%)	6.0 max	1.6	Autoclave Expansion (%) (C 151)	0.80 max	0.00
SO_3 (%)[C]	3.0 max	2.9	Compressive Strength MPa (psi):		
Loss on Ignition (%)	3.0 max	2.1			
Insoluble Residue (%)	0.75 max	0.55	3 days	12.0 (1740) min	27.7 (4010)
CO_2 (%)	-	1.1	7 days	19.0 (2760) min	37.9 (5490)
Limestone (%)	5.0 max	3.4	28 days	28.0 (4060) min	50.3 (7300)
$CaCO_3$ in Limestone (%)	70 min	78	Initial Vicat (minutes)	45-375	144
Inorganic Processing Addition	5.0 max	0.0			
Potential Phase Compositions[D]:			Mortar Bar Expansion (%) (C 1038)	-	0.008
C_3S (%)	-	55			
C_2S (%)	-	17	Heat of Hydration: 7 days, kJ/kg (cal/g)[B]	-	332 (79)
C_3A (%)	8 max	8			
C_4AF (%)	-	9			
$C_3S + 4.75C_3A$ (%)	-	93.0			

Tests Data on ASTM Optional Requirements

Chemical			Physical		
Item	Limit[A]	Result	Item	Limit[A]	Result
Equivalent Alkalies (%)	0.60 max	0.38	False Set (%)	50 min	94

Notes

[A] Dashes in the limit / result columns mean Not Applicable.
[B] Test result represents most recent value and is provided for information only. Analysis of Heat of Hydration has been carried out by CTLGroup, Skokie, IL.
[C] It is permissible to exceed the specification limit assuming ASTM C 1038 Mortar Bar Expansion does not exceed 0.020 %.
[D] Adjusted per Annex A1.6 of ASTM C150 and AASHTO M85.
This data may have been reported on previous mill certificates. It is typical of the cement being currently shipped.

Additional Data

Inorganic Processing Addition Data	Base Cement Phase Composition

By ____________________
Quality Manager

Holcim

Material Certification Report

Material:	Portland Cement	Test Period:	01-Oct-2011
Type:	I-II (ASTM C 150)	To:	31-Oct-2011

Certification

Holcim cement meets the specifications of ASTM C 150 for Type I-II cement.

General Information

Supplier:	Holcim (US), Inc.	Source Location:	Ada Plant
Address:	14500 CR 1550 Ada, OK		14500 CR 1550 Ada, OK
Telephone:	(580)421-8915	Contact:	Theresa Hammons
Date Issued:	05-Dec-2011		

The following information is based on average test data during the test period. The data is typical of cement shipped by Holcim; individual shipments may vary.

Item	Result[A]	Item	Result
Type	-	C_3S (%)	57
Amount (%)	-	C_2S (%)	17
SiO_2 (%)	-	C_3A (%)	8
Al_2O_3 (%)	-	C_4AF (%)	9
Fe_2O_3 (%)	-		
CaO (%)	-		
SO_3 (%)	-		

By ____________________

Quality Manager

MOUNTAIN
CEMENT COMPANY
5 Sand Creek Rd.
Laramie, Wyoming 82070
(307) 745-4879

Certificate of Test

Portland Cement Type V
A.S.T.M. C 150 Designation: Type V Low-Alkali

Lot # 91-119
Date: 5/14/14

Chemical Analysis(%)-A.S.T.M. C 114

MgO	1.2
*SO_3	3.3
L.O.I.	2.40
Insol. Residue	0.59

Compound Composition - A.S.T.M. C 150

C_3A	4
$C_4AF + 2 \cdot C_3A$	20
Alkalies ($Na_2O + 0.658*K_2O$)	0.54
Inorganic Processing Add'ns	0.27
$CaCO_3$ in Limestone	86.2
% Limestone Additions	2.94

Physical Tests

Blaine Specific Surface - A.S.T.M. C 204	3940	cm^2/g
Air Content - A.S.T.M. C 185	7.2	vol. %
Autoclave Expansion - A.S.T.M. C 151	-0.03	%
Vicat Time of Set - A.S.T.M. C 191		
Initial Set	120	minutes
Final Set	240	minutes
Compressive Strength - A.S.T.M. C 109		
3 Day	4190	psi
7 Day	5160	psi
Lot # 60-90 28 Day	6420	psi

This cement has been sampled and tested in accordance with A.S.T.M. standard methods and procedures. Cement analysis are reported as oxides, in accordance with ASTM Test Method C114. Silicon dioxide (SiO_2) is present in the combined state as the compounds tricalcium silicate and dicalcium silicate, and not as crystalline silica. This cement contains processing additions which meet the requirements of ASTM C465. Compliance documents for these processing additions are available upon request. All test results are certified to comply with the type specification designated. We are not responsible for improper use or workmanship.

Bob Kersey
Chief Chemist

* In compliance with footnote D, Table 1, A.S.T.M. Standard Specification C 150 and A.A.S.H.T.O. Standard Specification M 85.

January 25, 2012

CTL | THOMPSON
MATERIALS ENGINEERS, INC.

Albert Frei and Sons, Inc.
PO Box 640
Henderson, Colorado 80640

Attention: Mr. Rick Foster

Subject: Physical Properties Testing
Class 6 Base Course, Pit 6 (ASTM)
Project No. CT15145.006-400

This report presents results of physical properties testing performed on material delivered to our laboratory in December, 2011. Representative samples delivered were identified as Class 6 Base Course, from Pit 6. Testing was performed to determine the materials compliance with (ASTM) specifications. The following testing was performed in general conformance with the applicable standards.

1) Sieve Analysis (Gradation)
2) Particle Analysis (Hydrometer)
3) Material Finer Than No. 200 Sieve by Washing
4) Specific Gravity & Absorption
5) Clay Lumps & Friable Particles – Coarse Fraction
6) Clay Lumps & Friable Particles – Fine Fraction
7) Sodium Sulfate Soundness – Coarse Fraction
8) Sodium Sulfate Soundness – Fine Fraction
9) Total Evaporative Moisture Content
10) Rodded Unit Weight & Voids
11) Loose Unit Weight & Voids
12) Los Angeles Abrasion
13) Fractured Faces
14) Liquid Limit
15) Plasticity Index
16) Maximum Density – Standard Effort
17) Maximum Density – Modified Effort
18) Hveem (R-value) Test
19) Swell
20) Standard Permeability
21) Modified Permeability
22) Soil Classification

A summary of the aggregate test results is attached, followed by the complete test results. Based on the test results, the material tested meets the ASTM specifications for class 6 base course. If you have any questions regarding this report, please call.

Respectfully submitted,

CTL | THOMPSON MATERIALS ENGINEERS, INC.

Daniel L. Barrett
Materials Lab Manager

Reviewed by:

COLORADO REGISTERED PROFESSIONAL ENGINEER DAMON B. THOMAS 30990

Damon B. Thomas, P.E.
Division Manager

DLB:DBT/dlb
Enclosures
1 copy sent
1 copy emailed: rfoster@albertfreiandsons.com

TABLE 1

Aggregate Qualification Summary - ASTM Specifications (ASTM C 33)

Albert Frei and Sons, Inc. - Pit 6, Class 6 Base

Project No. CT15145.006-400

Report Date: January 25, 2012

Sieve Analysis (ASTM C 136 & C 117)		
Sieve Size	**Passing (%)**	**Specification (%) (Table 703-3)**
3/4 inch (19 mm)	100	100
1/2 inch (12.5 mm)	94	-
3/8 inch (9.5 mm)	76	-
No. 4 (4.75 mm)	48	30-65
No. 8 (2.36 mm)	38	25-55
No. 16 (1.18 mm)	31	-
No. 30 (600 µm)	26	-
No. 50 (300 µm)	20	-
No. 100 (150 µm)	13	-
No. 200 (75 µm)	7.5	3-12
Particle Size Analysis (ASTM D 422)		
1 minute (37 µm)	6.5	-
4 minutes (19 µm)	5.0	-
19 minutes (9 µm)	3.6	-
60 minutes (5 µm)	2.4	-
7 hours 15 minutes (2 µm)	1.7	3% Max
25 hours 45 minutes (1 µm)	1.4	-

CTL | THOM... ENGINEERS, INC.

COLORADO REGISTERED PROFESSIONAL ENGINEER DAMON B. THOMAS 30990

Da... B. Thomas, P.E.

1/25/12

TABLE 1 (CONTINUED)

Aggregate Qualification Summary - ASTM Specifications (ASTM C 33)

Albert Frei and Sons, Inc. - Pit 6, Class 6 Base

Project No. CT15145.006-400 Report Date: January 25, 2012

Test		Results	Specification
Specific Gravity (ASTM C 127) Coarse Fraction		2.74	-
Absorption (ASTM C 127) Coarse Fraction		1.9%	-
Specific Gravity (ASTM C 128) Fine Fraction		2.71	-
Absorption (ASTM C 128) Fine Fraction		0.8%	-
Specific Gravity (ASTM C 127 & 128) Combined Fraction		2.73	-
Absorption (ASTM C 127 & 128) Combined Fraction		1.4%	-
Clay Lumps and Friable Particles (ASTM C 142) Coarse		0.3% Weighted Particles	2.0% Max
Clay Lumps and Friable Particles (ASTM C 142) Fine		0.8% Weighted Particles	3.0% Max
Sodium Sulfate Soundness (ASTM C 88) - Coarse		1% Weighted Loss	12% Max
Sodium Sulfate Soundness (ASTM C 88) - Fine		1% Weighted Loss	10% Max
Rodded Unit Weight & Voids (ASTM C 29)	Unit Weight	122 pcf	-
	Percent Voids	27%	-
	Tons per cubic yard	1.65 Tons /cu. yd.	-
Loose Unit Weight & Voids (ASTM C 29)	Unit Weight	113 pcf	-
	Percent Voids	32%	-
	Tons per cubic yard	1.53 Tons /cu. yd.	-
Los Angeles Abrasion (ASTM C 131)		36%	50% Max
Percentage of Fractured Particles (ASTM D 5821)		100%	-
Total Evaporable Moisture Content (ASTM C 566)		2.3%	-
Hveem Test (R-value) (ASTM D 2844)		85	-
Swell Test		-0.1%	-
Liquid Limit		NL	25 Max
Plasticity Index		NP	4 Max
Maximum Density @ Optimum Moisture (ASTM D 698)		137.5 pcf @ 8.0%	-
Maximum Density @ Optimum Moisture (ASTM D 1557)		139.0 pcf @ 7.0%	-
Standard Constant Head Permeability		1.88E-02 cm/s	-
Modified Falling Head Permeability		1.17E-03 cm/s	-
Soil Classification		A-1-a/b	-

CTL | THOMPSON ... ENGINEERS, INC.

COLORADO REGISTERED DAMON B. THOMAS 30990 PROFESSIONAL ENGINEER

Damon B. Thomas, P.E.

1/25/12

ATTACHMENT A

LABORATORY TEST RESULTS

PHYSICAL PROPERTIES OF AGGREGATES

Company Name: Albert Frei and Sons, Inc.
Material Source: Pit 6
Material Type: Class 6 Base

Project No. CT15145.006-400
Report Date: January 25, 2012

Sieve Analysis of Fine Aggregate
(ASTM C 136)

Sieve Size	Percent Passing Class 6 Base	Percent Passing (Table 703-3)
3/4 inch (19 mm)	100	100
1/2 inch (12.5 mm)	94	-
3/8 inch (9.5 mm)	76	-
No. 4 (4.75 mm)	48	30-65
No. 8 (2.36 mm)	38	25-55
No. 16 (1.18 mm)	31	-
No. 30 (600 µm)	26	-
No. 50 (300 µm)	20	-
No. 100 (150 µm)	13	-
No. 200 (75 µm)	7.5	3-12
1 minute (37 µm)	6.5	-
4 minutes (19 µm)	5.0	-
19 minutes (9 µm)	3.6	-
60 minutes (5 µm)	2.4	-
7 hours 15 minutes (2 µm)	1.7	3% Max
25 hours 45 minutes (1 µm)	1.4	-

Material Finer Than No. 200 Sieve by Washing
(ASTM C 117)

Initial Dry Weight (lb)	Final Dry Weight (lb)	Material Finer Than No. 200 Sieve (%)
13.49	12.48	7.5

Specific Gravity and Absorption of Coarse Aggregate
(ASTM C 127)

Oven Dry Weight (g)	SSD in Air Weight (g)	Submerged Weight (g)	Bulk Volume	Bulk (SSD) Specific Gravity	Absorption (%)
3267.5	3328.0	2112.0	1216.0	2.74	1.9

Fig. A-1

PHYSICAL PROPERTIES OF AGGREGATES

Company Name: Albert Frei and Sons, Inc.
Material Source: Pit 6
Material Type: Class 6 Base

Project No. CT15145.006-400
Report Date: January 25, 2012

Specific Gravity and Absorption of Fine Aggregate
(ASTM C 128)

Pycnometer Weight With Water (g)	SSD In Air Weight (g)	Pycnometer Weight With Sample (g)	Bulk Volume	Oven Dry Weight (g)	Bulk (SSD) Specific Gravity	Absorption (%)
679.4	500.0	994.6	184.8	496.1	2.71	0.8

Clay Lumps and Friable Particles in Aggregate
(ASTM C 142)

Sieve Size		Percent Grading of Sample	Weight Before (g)	Weight After (g)	Percent Loss	Weighted Percent Loss
Passing	Retained					
3/4 inch	3/8 inch	24	2000.9	1997.5	0.2	0.0
3/8 inch	No. 4	28	1007.4	998.4	0.9	0.3
Less Than No. 4		48	-	-	-	-

Total Percent Grading 100 Total Weighted Loss 0.3%

Clay Lumps and Friable Particles in Aggregate
(ASTM C 142)

Sieve Size		Weight Before (g)	Weight After (g)	Percent Particles
Passing	Retained			
No. 4	No. 16	25.0	24.8	0.8

Soundness of Coarse Aggregates by Use of Sodium Sulfate
(ASTM C 88)

Sieve Size		Percent Grading of Sample	Weight Before(g)	Weight After (g)	Percent Loss	Weighted % Loss
Passing	Retained					
3/4 inch	1/2 inch	6	670.8	659.6	1.7	0.1
1/2 inch	3/8 inch	18	330.0	321.8	2.5	0.4
3/8 inch	No. 4	28	301.5	300.5	0.3	0.1
Less Than No. 4		48	-	-	-	-

Total Weighted Loss: 1

Fig. A-2

PHYSICAL PROPERTIES OF AGGREGATES

Company Name: Albert Frei and Sons, Inc.
Material Source: Pit 6
Material Type: Class 6 Base

Project No. CT15145.006-400
Report Date: January 25, 2012

Soundness of Fine Aggregates by Use of Sodium Sulfate
(ASTM C 88)

Sieve Size		Percent Grading of Sample	Weight Before(g)	Weight After (g)	Percent Loss	Weighted % Loss
Passing	Retained					
No. 4	No. 8	10	100.0	96.4	3.6	0.4
No. 8	No. 16	7	100.0	96.6	3.4	0.2
No. 16	No. 30	5	100.0	96.0	4.0	0.2
No. 30	No. 50	6	100.0	95.9	4.1	0.2
Less than No. 50		20	-	-	-	-

Total Percent Grading of Combined Fractions: 100

Total Weighted Loss: 1

Bulk Density (Unit Weight) and Voids in Aggregates (Rodded Method)
(ASTM C 29)

Sample Weight (lbs)	Bucket Volume (ft^3)	Unit Weight (pcf)
40.14	0.333	120.5
40.48	0.333	121.6
41.28	0.333	124.0

Average Unit Weight: 122 pcf

Bulk Specific Gravity (OD) = 2.69
Voids in Aggregate Compacted by Rodding = 27%

Bulk Density (Unit Weight) and Voids in Aggregates (Loose Method)
(ASTM C 29)

Sample Weight (lbs)	Bucket Volume (ft^3)	Unit Weight (pcf)
37.68	0.3330	113.2
37.51	0.3330	112.6
37.68	0.3330	113.2

Average Unit Weight: 113 pcf

Bulk Specific Gravity (OD) = 2.69
Voids in Aggregate Compacted by Rodding = 32%

PHYSICAL PROPERTIES OF AGGREGATES

Company Name: Albert Frei and Sons, Inc.
Material Source: Pit 6
Material Type: Class 6 Base

Project No. CT15145.006-400
Report Date: January 25, 2012

Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

(ASTM C 131)

Grading	Initial Weight	Final Weight	Percent Loss
B	4996.6	3184.5	36.3

Determining the Percentage of Fractured Particles in Coarse Aggregate

(ASTM D 5821)

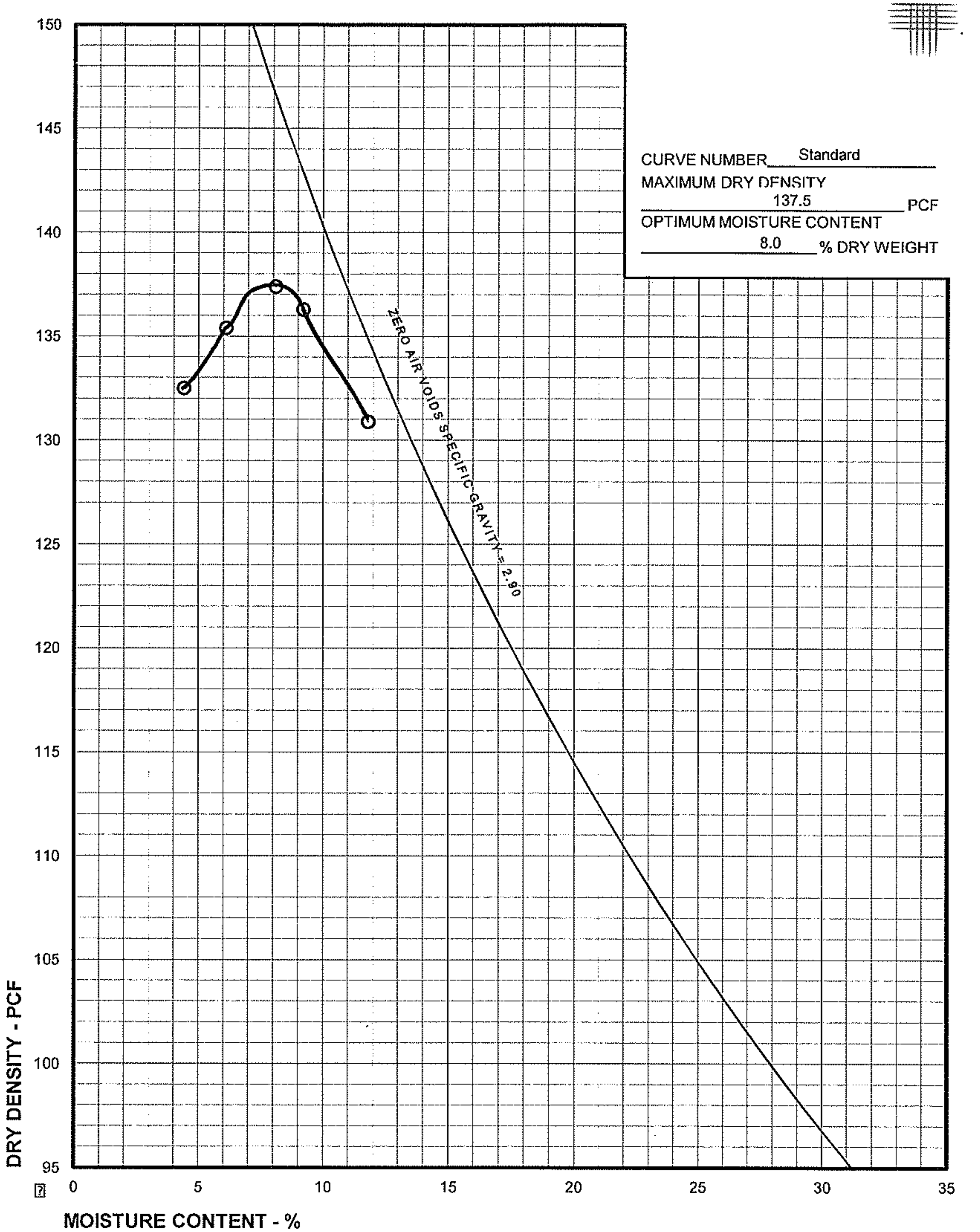
Initial Weight (g)	Weight of Fractured Particles (g)	Percent of Fractured Particles (minimum 2 faces)
1519	1519	100

Total Evaporable Moisture Content of Aggregates by Drying

(ASTM C 566)

Initial Weight (g)	Final Weight (g)	Moisture Content %
3370	3294.1	2.3

Fig. A-4



Sample Description Class 6 Base

Location

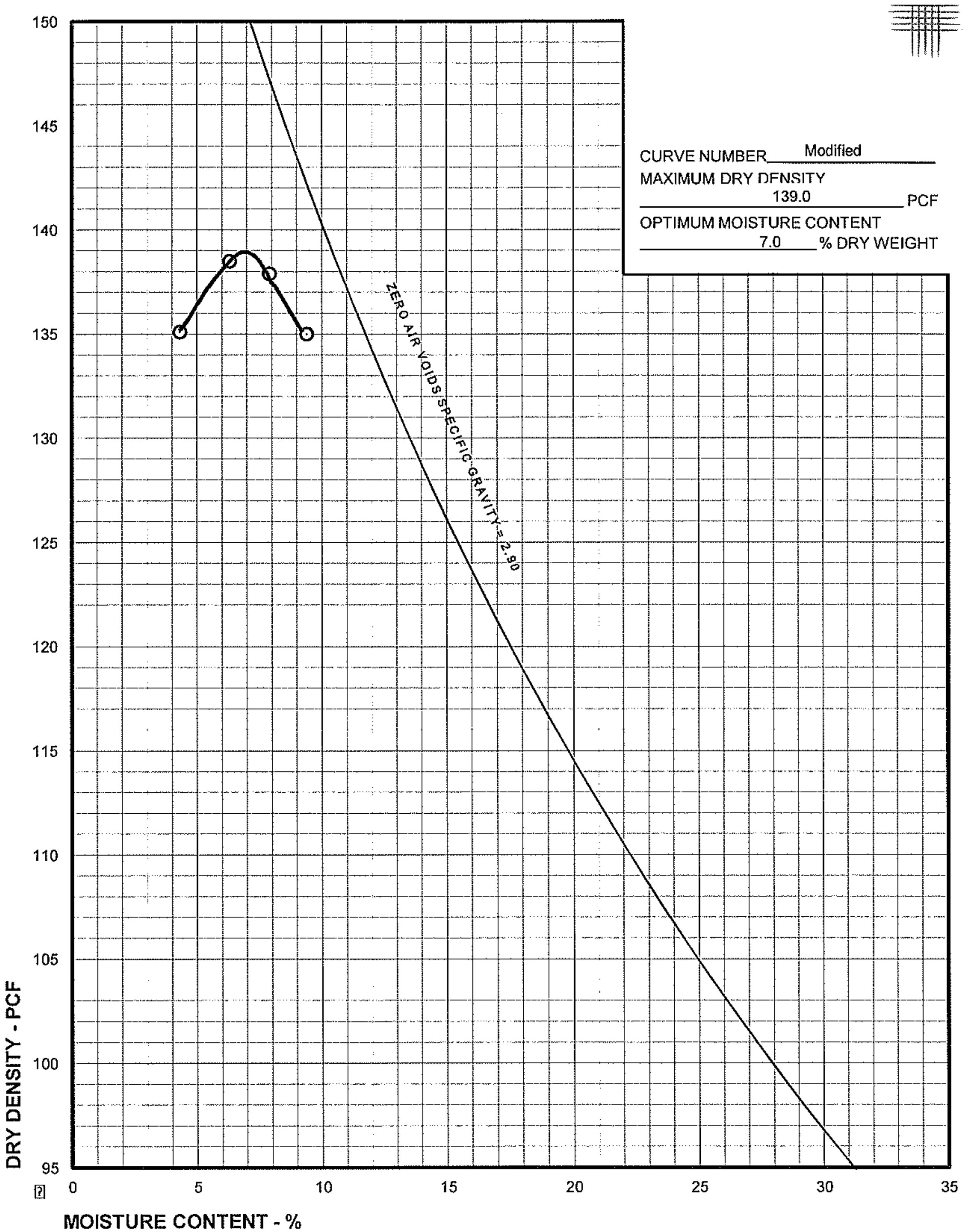
Compaction Test Procedure ASTM D 698 - 00 METHOD "C"

LIQUID LIMIT	NL	%
PLASTICITY INDEX	NP	%
GRAVEL	52	%
SAND	40	%
SILT AND CLAY	8	%

CompactionTest Results

Project No. CT15145.006-400

Fig.A-5



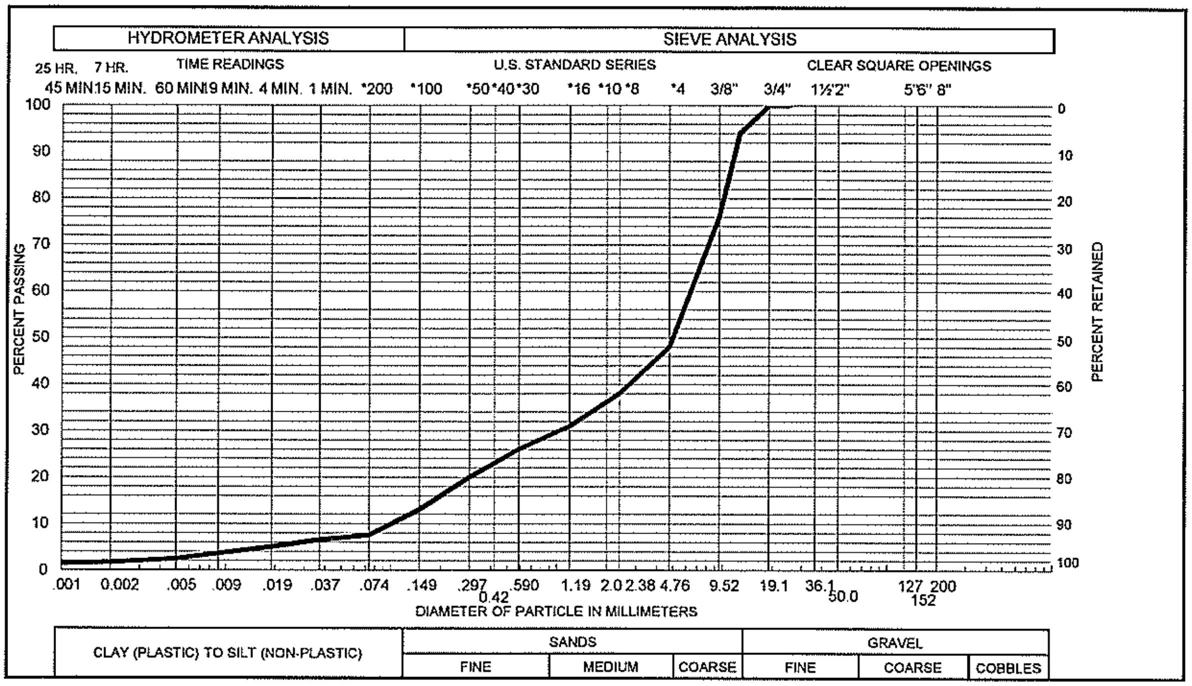
Sample Description Class 6 Base

Location

Compaction Test Procedure ASTM D 1557
METHOD "C"

LIQUID LIMIT	NL	%
PLASTICITY INDEX	NP	%
GRAVEL	52	%
SAND	40	%
SILT AND CLAY	8	%

CompactionTest Results



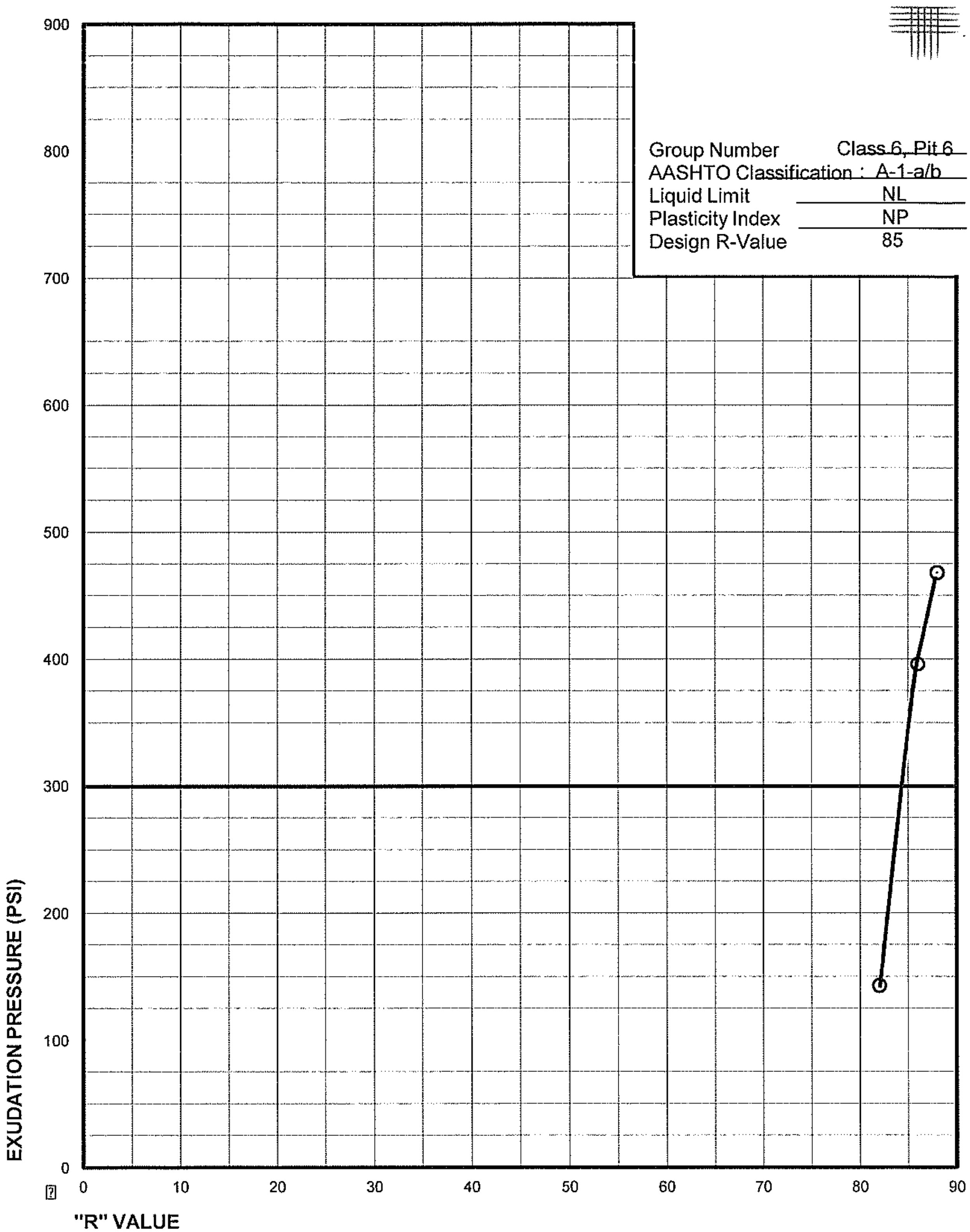
Sample of Class 6 Base
From Pit 6

GRAVEL 52 % SAND 40 %
SILT & CLAY 8 % LIQUID LIMIT NL %
PLASTICITY INDEX NP %

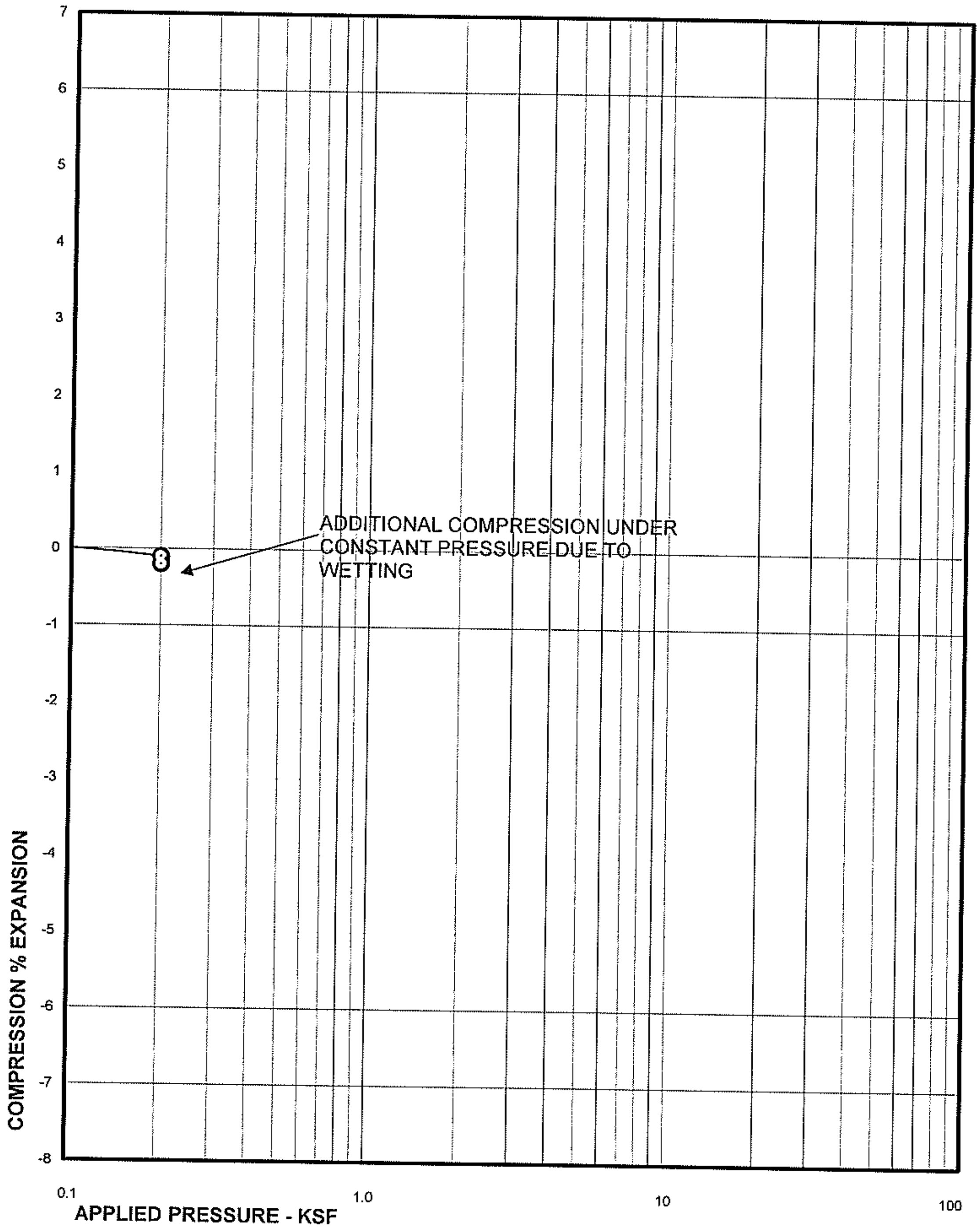
Project No.: CT15145.006-400

Gradation Test Results

Fig. A-7



Hveem Stabilometer Test Results



Sample of Class 6 Roadbase
From Pit 6

NATURAL DRY UNIT WEIGHT= 137.5 PCF
NATURAL MOISTURE CONTENT= 8.0 %

Swell Consolidation Test Results

FIG. A-9

Project No. CT15145.006-400

Constant Head Permeability

Project No.	CT15145.006	**Job Name:**	Al Frei	**Date:**	1/3/2012
Test Hole:		**Sample No**	CLASS 6 RB	**Depth:**	

Test System Data	
Sample Diameter (in), D:	8
Sample Length (in), L:	4
Sample Volume (ft^3), V:	0.1164
Permeameter Area (in2), A:	50.2655

Density Data	
Wet Soil/Mold, lbs.:	17.41
Mold Wt., lbs:	1
Wet Density, pcf:	141
Dry Density, pcf:	130.5

Moisture Data	
Before Test:	
Dish Number:	SP-66
Wet Wt., g:	2315.9
Dry Wt., g:	2157.8
Dish Wt., g:	196.4
Moisture, %:	8.1

After Test:	
Dish Number:	PUP
Wet Wt., g:	7892.8
Dry Wt., g:	7354.8
Dish Wt., g:	724.13
Moisture, %:	8.1

Sample De CLASS 6 RB Standard 137.5 @ 8%

95% at optimum

Calculation K=qL/Ath, where q = ml

Trial One			
Head, (in):	2	Permeability	
Time (s)	Outflow (ml)	ft/day	cm/s
77	250	56.76	2.00E-02
77	250	56.76	2.00E-02
77	250	56.76	2.00E-02
Head, (in):	4	Permeability	
Time (s)	Outflow (ml)	ft/day	cm/s
55	250	39.73	1.40E-02
49	250	44.59	1.57E-02
47	250	46.49	1.64E-02
Head, (in):	6	Permeability	
Time (s)	Outflow (ml)	ft/day	cm/s
38	250	38.34	1.35E-02
35	250	41.62	1.47E-02
34	250	42.85	1.51E-02
Head, (in):	4	Permeability	
Time (s)	Outflow (ml)	ft/day	cm/s
41	250	53.3	1.88E-02
41	250	53.3	1.88E-02
Trial Five			
Head, (in):	2	Permeability	
Time (s)	Outflow (ml)	ft/day	cm/s
62	250	70.49	2.49E-02
61	250	71.64	2.53E-02
61	250	71.64	2.53E-02

age Permeability: 53.16 1.88E-02

Constant Head Permeability

Project No.	CT15145.006	**Job Name:**	Al Frei	**Date:**	1/6/2012
Test Hole:		**Sample No.:**	CLASS 6 RB	**Depth:**	

Sample Description: CLASS 6 RB Modified 139.0 @ 7.0% 95% near optimum

Calculation: K=qL/Ath, where q = ml

Test System Data	
Sample Diameter (in), D:	8
Sample Length (in), L:	4
Sample Volume (ft^3), V:	0.1164
Permeameter Area (in2), A:	50.2655

Density Data	
Wet Soil/Mold, lbs.:	17.44
Mold Wt., lbs:	1
Wet Density, pcf:	141.3
Dry Density, pcf:	132.7

Moisture Data	
Before Test:	
Dish Number:	GRISHKO
Wet Wt., g:	2249.9
Dry Wt., g:	2125.7
Dish Wt., g:	196.7
Moisture, %:	6.4
After Test:	
Dish Number:	POP
Wet Wt., g:	8047.15
Dry Wt., g:	7459.22
Dish Wt., g:	724.13
Moisture, %:	8.7

Trial One			
Head, (in):	2	Permeability	
Time (s)	Outflow (ml)	ft/day	cm/s
70	25	6.24	2.20E-03
139	50	6.29	2.22E-03
Head, (in):	4	Permeability	
Time (s)	Outflow (ml)	ft/day	cm/s
90	50	4.86	1.71E-03
184	100	4.75	1.68E-03
Head, (in):	6	Permeability	
Time (s)	Outflow (ml)	ft/day	cm/s
122	50	2.39	8.42E-04
249	100	2.34	8.26E-04
130	50	2.24	7.91E-04
Head, (in):	4	Permeability	
Time (s)	Outflow (ml)	ft/day	cm/s
79	25	2.77	9.76E-04
153	50	2.86	1.01E-03
56	25	3.9	1.38E-03
Trial Five			
Head, (in):	8	Permeability	
Time (s)	Outflow (ml)	ft/day	cm/s
115	50	1.9	6.70E-04
231	100	1.89	6.67E-04
Trial Six			
Head, (in):	2	Permeability	
Time (s)	Outflow (ml)	ft/day	cm/s
87	10	2.01	7.09E-04
224	25	1.95	6.88E-04

Average Permeability: 3.31 1.17E-03

Corrosivity Tests Summary Report

2013-05-20

Sample Name	Measurement Date	Dilution Factor	Chloride Concentration (ppm)	Sulfate Concentration (ppm)	pH	Electrical Conductivity (μS)
Frei Class 8	2013-05-20	9.998	34.403	75.556	8.06	70.9

CUMULATIVE

7-1451 (9-86) Bureau of Reclamation	GRADATION ANALYSIS	Designation USBR 5325-___ Designation USBR 5330-___ Designation USBR 5335-___

SAMPLE NO. CRUSHER FINES	PROJECT CLSM - JANET	FEATURE
AREA	EXC. NO.	DEPTH

GRADATION OF GRAVEL SIZES

TESTED AND COMPUTED BY JB	DATE 5-31-13	% MOISTURE CONTENT OF +NO. 4 OVEN DRIED	WET MASS OF TOTAL SPECIMEN
CHECKED BY	DATE	% MOISTURE CONTENT OF -NO. 4 OVEN DRIED	TOTAL DRY MASS OF SPECIMEN 29.55

SIEVE SIZE		3" (75 mm)	1-1/2" (37.5 mm)	3/4" (19.0 mm)	3/8" (9.5 mm)	NO. 4 (4.75 mm)	PAN
MASS OF CONTAINER AND RETAINED MATERIAL			0.0				
MASS OF CONTAINER							
WET MASS RETAINED							
DRY MASS RETAINED			0.0	0.15	5.90	12.45	
DRY MASS PASSING				29.40	23.65	17.10	☑ lbm ☐ kg ☐ g
% OF TOTAL PASSING				99.5	80.0	57.9	

GRADATION OF SAND SIZES

WASHED

DRY MASS OF SPECIMEN 702.1 g	FACTOR = % TOTAL PASSING NO. 4 / DRY MASS OF SPECIMEN = 57.9 / 702.1 = .0824
DISH NO. 3	DRY MASS OF SPECIMENT (SIEVED)
SIEVING TIME	DATE

SIEVE NO.	MASS RETAINED (g)	MASS PASSING (g)	FACTOR X MASS PASSING = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
8	106.6	595.5		49.1	2.36 mm	
16	201.8	500.3		41.2	1.18 cm	
30	291.8	410.3		33.8	600 µm	
50	399.3	302.8		25.0	300 µm	
100	519.2	182.9		15.1	150 µm	
200	599.3	102.8		8.5	75 µm	
PAN	608.5					
TOTAL	0					

TESTED AND COMPUTED BY	DATE	CHECKED BY	DATE
JB	6-3-13		

HYDROMETER ANALYSIS

HYDROMETER NO.	DISPERSING AGENT	
STARTING TIME	DATE	AMOUNT mL

TIME	TEMP °C	HYD READ	HYD CORR	CORR READ	FACTOR X CORRECT READ = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
1 min							37 µm	
4 min							19 µm	
19 min							9 µm	
60 min							5 µm	AUXILIARY TESTS: USBR 5305-___ USBR 5300-___
7 h 15 min*							2 µm	
25 h 45 min*							1 µm	

TESTED AND COMPUTED BY	DATE	CHECKED BY	DATE

*Not required for standard test.

7-1589 (10-86)
Bureau of Reclamation

SPECIFIC GRAVITY DETERMINATION
(VOLUME METHOD)

Designation USBR 5320-__

SAMPLE NO.	PROJECT	FEATURE
1	CLSM TESTING	

SPECIMEN NO.	HOLE NO.	DEPTH ft ☐ m ☐
CRUSHER FINES		

TESTED BY	DATE	COMPUTED BY	DATE	CHECKED BY	DATE
JB	5-28-13	JB	5-28-13		

SPECIFIC GRAVITY SAMPLE SOAKED OVERNIGHT

	TRIAL NO. 1	TRIAL NO. 2
1. FLASK NO. 7		
2. MASS OF FLASK * +GLASS (g)	435.3	435.3
3. VOLUME OF FLASK * (cm^3)	953.16	953.16
4. MASS OF SPECIMEN (g)	590.4	590.4
5. MASS OF FLASK + SPECIMEN + WATER +GLASS (g)	1760.5	1760.9
6. TEMPERATURE OF WATER 19.8 °C (°C)	19.8 °c	21.4 °c
7. MASS OF FLASK + WATER = (5) - (4) (g)	1170.1	1170.5
8. MASS OF WATER IN FLASK = (7) - (2) (g)	734.8	735.2
9. ABSOLUTE DENSITY OF WATER AT TEMP (6) .998244 (g/cm^3)	.998244	.997904
10. VOLUME OF WATER IN FLASK = (8) / (9) (cm^3)	736.09	736.74
11. VOLUME OF SOIL = (3) - (10) (cm^3)	217.07	216.42
12. SPECIFIC GRAVITY = (4) / (11) **	2.72	2.73
13. AVERAGE		

*Calibration data from USBR 1030
**Implies that for water 1 g = 1 mL = 1 cm^3

GPO 852-303