ARKANSAS RIVER CORRIDOR

Appendix K: Geotechnical

ARKANSAS RIVER CORRIDOR, TULSA COUNTY, OKLAHOMA

Introduction

The Arkansas River is a water resource serving numerous nationally significant purposes. The river has historically served as a nationally significant resource for aquatic and terrestrial habitat of the nation's wildlife that live, breed, and migrate through the Arkansas River ecosystem. This includes federally endangered Interior Least Tern (Least Tern, *Sterna antillarum*), a nationally significant resource, and one federally threatened bird species, the Piping Plover (*Charadrius melodus*) as well as a plethora of native species and migratory waterfowl that support a healthy and functional riverine ecosystem. Keystone Lake and its dam located along the Arkansas River play vital roles in supporting the continued provision for these species, as well as many other purposes. In particular, the lake and dam provide flood risk management benefits, contribute to the eleven reservoir system operation of the McClellan-Kerr Arkansas River Navigation System, provide clean and efficient power through the associated hydropower plant, and provide a source of water for municipal and industrial uses. However, construction, operation, and maintenance of the Keystone Dam, lake, associated hydropower operations and other multi-purposes have significantly degraded the riverine ecosystem structure, function, and dynamic processes below Keystone Dam on the Arkansas River within Tulsa County, Oklahoma.

Purpose

This study is in response to the Section 3132 authorization of the 2007 WRDA. The purpose of this study is to evaluate the aquatic ecosystem restoration components of the October 2005 Arkansas River Corridor Master Plan (ARC Master Plan) and determine if there is a Federal Interest that aligns with the Corps of Engineers' ecosystem restoration mission.

Study Authority

The Arkansas River Corridor study is authorized in the Water Resources Development Act (WRDA) of 2007, Section 3132.

Section 3132. Arkansas River Corridor.

(a) IN GENERAL. – The Secretary is authorized to participate in the ecosystem restoration, recreation, and flood damage reduction components of the Arkansas River Corridor Master Plan dated October 2005. The Secretary shall coordinate with appropriate representatives in the vicinity of Tulsa, Oklahoma, including representatives of Tulsa County and surrounding communities and the Indian Nations Council of Governments.

(b) AUTHORIZATION OF APPROPRIATIONS. – There is authorized to be appropriated $50,000,000 to carry out this section.

Non-Federal Sponsor

Tulsa County is the non-federal sponsor for the Arkansas River Corridor feasibility study. An amended feasibility cost-sharing agreement was executed in May 2015.

Recommended Plan

Alternative 5 is the National Ecosystem Restoration (NER) Plan and includes construction of a pool structure at River Mile 530 to regulate flow in the Arkansas River, a rock riffle feature associated wetland plantings at Prattville Creek, and construction of a sandbar island near Broken Arrow, OK. With the implementation of the NER plan, more natural river flow would return to 42 river miles of the Arkansas River within the study area. The NER plan would provide approximately 2,144 acres of additional riverine habitat, nearly doubling the amount of currently available habitat under low flow conditions. Also five acres of restored wetlands, and three acres of reliable sandbar island habitat where none currently succeed, would be restored as part of the NER plan. Shoreline, river, backwater, slackwater, wetland, and sandbar island habitat quality would all be improved generating an overall increase in the ecosystem quality and carrying capacity of the corridor. Current operation of Keystone Dam would not be changed. Additional water and flow would remain within the existing banks of the river and would not increase the flood elevation, nor downstream or backwater flooding.

Geotechnical Investigations

Alternatives include two proposed dam sites, one located at Arkansas River Mile 531 and one at Arkansas River Mile 530. There have been two major phases of Geotechnical Investigations performed to date at these two proposed dam sites. River Mile 531 is the location of the original Reregulation Dam Constructed as part of the Keystone Dam Project which was constructed from December 20th, 1966 to August 16th, 1968 and demolished in 1985. There were a total of 31 borings advanced prior to construction of the original reregulation dam in 1966 as part of the initial design process. There have been a total of 3 borings advanced in 2008 near the alignment of the proposed dam at river mile 530. Plate K-1 is a location map which shows all of the borings to date near these proposed dam sites.

Soils at the Potential Dam Sites

Based on the investigations performed during design of the original Reregulation dam at River Mile 531, the soils within the river channel at the proposed dam site at River Mile 531 are mainly medium to coarse sands (SP), about 16 feet in thickness. On the left bank of the channel, the bank soils vary from 27 to 31 feet in thickness and are generally capped by 10-15 feet of sandy silts or silty sands underlain by medium to coarse sands (SP) with a thin stratum of pea sized gravel immediately above rock. Borings were not advanced on the right bank significantly outside of the river channel limits. However, Based on borings 12 and 13 near the right edge of the channel, the overburden is typically 15 feet or less comprised Sandy or silty soil (SM, SM-SP) with thin layers of gravel and clay immediately above rock. This overburden thickness is expected to increase an estimated 10-15 feet extending up the bank and further away from the channel limits.

Based on the 2008 investigations performed near the proposed dam site of River Mile 530, the soils within the river channel are approximately 10 feet thick and consists predominantly of loose fine to coarse grains sand with occasional gravel and clay lenses. On the left bank, soils are typically 18 feet thick and consists of silty sand with little gravel and occasional clay lenses. On the right bank, soils are approximately 35 feet thick and consist of 25 feet of sandy silt with some red clay lenses underlain by 10 feet of fine grained silty sand.

General Topography and Geology

The area is in the Osage Plains subdivision of the Central Lowlands physiographic province and consists of a series of irregular north-south trending sandstone and limestone capped ridges. Mature streams flow in wide valleys between the ridges. The bedrock strata are of sedimentary origin belonging to the Skiatook group of upper Pennsylvanian age.

Geology at the Potential Dam Sites

Bedrock at the proposed dam sites consist of shales and sandstones of the Coffeyville formation. The strata strike about N45E and dip 2^{o} in an upstream direction. The overall river valley is about 1-1/2 miles wide.

Design Details for Consideration- Founding Depth

Boring logs and as built drawings from the original reregulation dam indicate the top of rock to be approximately elevation 619.0 feet, NGVD 29. To reach firm and competent rock, the original structure was founded at elevation 610.0 feet NGVD29 to reach competent rock. Keystone Lake Design Memorandum # 89, Reregulating Dam, February 1966 indicates that blasting of rock was planned to reach a solid and continuous foundation. Construction records are not available to indicate if this blasting was needed. The design memorandum indicated that shale faces required protection with pneumatic concrete or other protection to protect from weathering prior to concrete placement. Based on a review of this available information, it is reasonable to assume any new structure will need to have a founding Elevation 610.0 – 615.0 feet NGVD29. It is likely that rock blasting or large excavation equipment will be required to reach this depth. Rock slopes can likely be excavated as steep as 6V:1H, and exposed shale will need to be protected from weathering until concrete is placed. An estimated 10-15 feet of overburden excavation may be required to reach top of rock.

Details for Consideration- River Mile 531 Dam Location

According to the 1986 Keystone Dam Periodic Inspection Report, when the original reregulation dam was demolished in 1985, it was removed only down to elevation 623.0 feet and concrete rubble from the demolition was placed downstream of the dam crest section. Figure K-1 shows the typical demolition detail. Figure K-2 contains a Google earth image aerial from 2005 which also shows some of the concrete rubble within the channel still visible at that time. Based on this information the location of the new proposed structure at River Mile 531 likely will need to be adjusted to be some distance away from the original reregulation dam structure remnants and rubble.

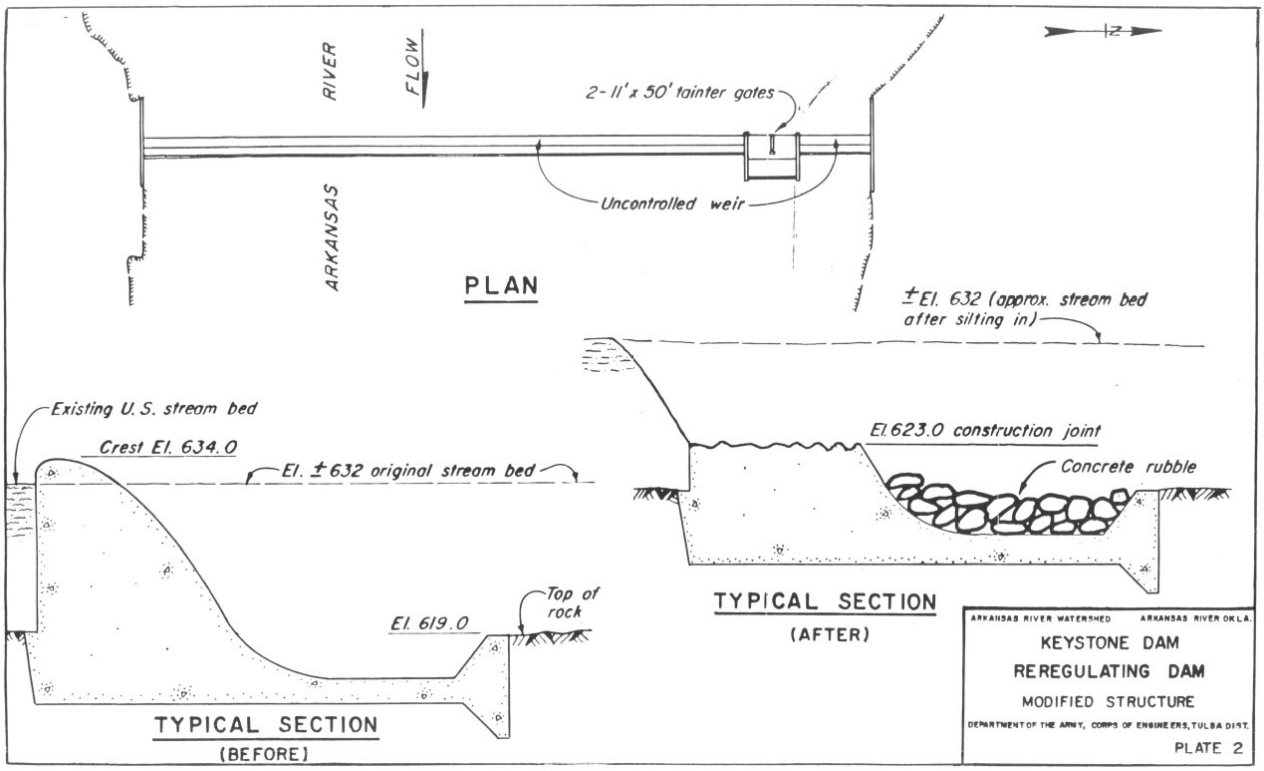


Figure K-1: Detail of demolition of original reregulation dam

Figure K-2: Aerial photo showing rubble within the channel from reregulation dam demolition

Design Details for Consideration- Additional Geotechnical Investigation Needs

While some investigations have been performed to date, additional investigations will be required to support design of the new structures. Additional investigations will be required at the River Mile 531 dam site to confirm locations and extent of the old reregulation dam remnants and rubble. Since the dam will likely need to be moved upstream or downstream of the original dam location some distance, additional investigations will be required to characterize the foundation rock along the actual dam alignment. It is reasonable to assume a minimum of 8 borings will be required at river mile 531, 4 within the channel and 2 at each abutment.

Since there have been only 3 borings advanced near the vicinity of the proposed dam alignment at river mile 530, it is reasonable to assume a minimum of 12 borings will be required at the proposed dam site at River Mile 530. It is recommended to conduct a minimum of 8 borings within the channel and 2 at each abutment.

Boring depths for these investigations will vary depending on the intent of each boring. For borings where intent is to confirm the elevation of top of rock within the channel, depths of 20 feet or less are likely. Borings intended to characterize the foundation rock within the channel or borings within the abutment may need to be on the order of 50 feet, with some portion of that being overburden drilling and some portion being rock coring. Lab testing will be required to characterize the foundation. All drilling through sediment within the channel or overburden shall include sampling and testing (insitu or laboratory) as needed for purposes of identifying cofferdam materials, cofferdam foundation, soil permeability and dewatering needs, as well as shear strength evaluation for excavation slope stability during temporary excavation. Pump tests may be considered to aid in dewatering system design.

Based on the unconfined compressive strength of the rock at the proposed sites from the 2008

investigations, the good structural performance of the original reregulation dam, and presence of the large upstream Keystone Dam Spillway (founded at similar elevation and rock formations), the proposed sites are anticipated to provide an adequate foundation for the proposed structures for bearing. Additional investigations may be needed to characterize the foundation rock for purposes of sliding stability. It should be noted that the design memorandum for the original reregulation dam included stability analyses based on a cohesion of 2 tsf and friction angle of 26° for sliding along bedding planes within the rock below the structure, although it is not cited how these design parameters were selected. While the foundation strength values may need to be confirmed for evaluating of the proposed structures as part of the design process, sliding stability is not anticipated to be a concern due to the low head expected.
In summary, while additional investigations are needed to progress the design process, the geotechnical and geologic information available for the proposed sites indicate these sites to be suitable for dam construction.

Design Details for Consideration- Construction Sequencing

There will be a need to sequence and plan construction to allow for channel flows at all times due to the typical operation of Keystone Dam. Releases from Keystone dam create highly variable flows and elevations within the river channel depending on inflow into the reservoir. During periods of no flood releases and no hydropower generation the river channel will be essentially dry with groundwater within the channel and banks near the channel bottom elevation. Typical hydropower releases from Keystone dam typically range anywhere from 6,000 cfs to 12,000 cfs resulting in Water depths of 4.4 feet and 6.0 feet respectively. Flood releases from Keystone Dam could have an impact to construction. Table K-1 shows a wide range of potential flood releases from Keystone Dam and the Corresponding Annual Chance of Exceedance (ACE), and water surface elevation/ depth at the proposed dam sites. It should be noted the elevations/ depths shown are with the proposed dam in place and gates open. Water surfaces would be approximately 4 feet higher for the condition with half of the dam built with gates open and the remaining half of the river closed off with a cofferdam for the second stage condition.

Table K-1: Flow depths at proposed dam sites for various discharges from Keystone Dam

				Minimum	Maximum
				Channel	Flow
ACE	ACE	Flow	Peak WSE	Elevation	Depth
(%)		(cfs)	(ft)	(ft)	(ft)
0.2%	(1/500)	490000	663.25	625.62	37.6
0.4%	(1/250)	300000	653.99	625.62	28.4
1%	(1/100)	205000	649.09	625.62	23.5
2%	(1/50)	155000	646.06	625.62	20.4
10%	(1/10)	90000	641.14	625.62	15.5
20%	(1/5)	40000	635.78	625.62	10.2

The cofferdams required for construction will be sized to achieve a balance between flood protection to the construction area and cost. It is likely that each dam will need to be built in two phases. The first phase will consists of construction of a cofferdam across part of the channel and subsequent construction of portions of the dam that will allow future flows. During this phase of work flows would be diverted towards the other side of the river not under construction.

A diversion or pilot channel may need to be constructed within the existing river channel to help facilitate flow diversion. A well point or other dewatering system will need to surround the excavation and construction area to permit construction within the cofferdam.

Upon completion of this phase of work, flows will then be diverted towards the newly constructed overflow portion of the dam, a cofferdam built around the remainder of the channel, new dewatering system installed, and the remainder of the structure constructed.

Upon completion of the entire structure, the remaining portions of the cofferdam will need to be removed. An example of first and second stage construction efforts with river diversion that may be required is shown in Figures K-3 and K-4.

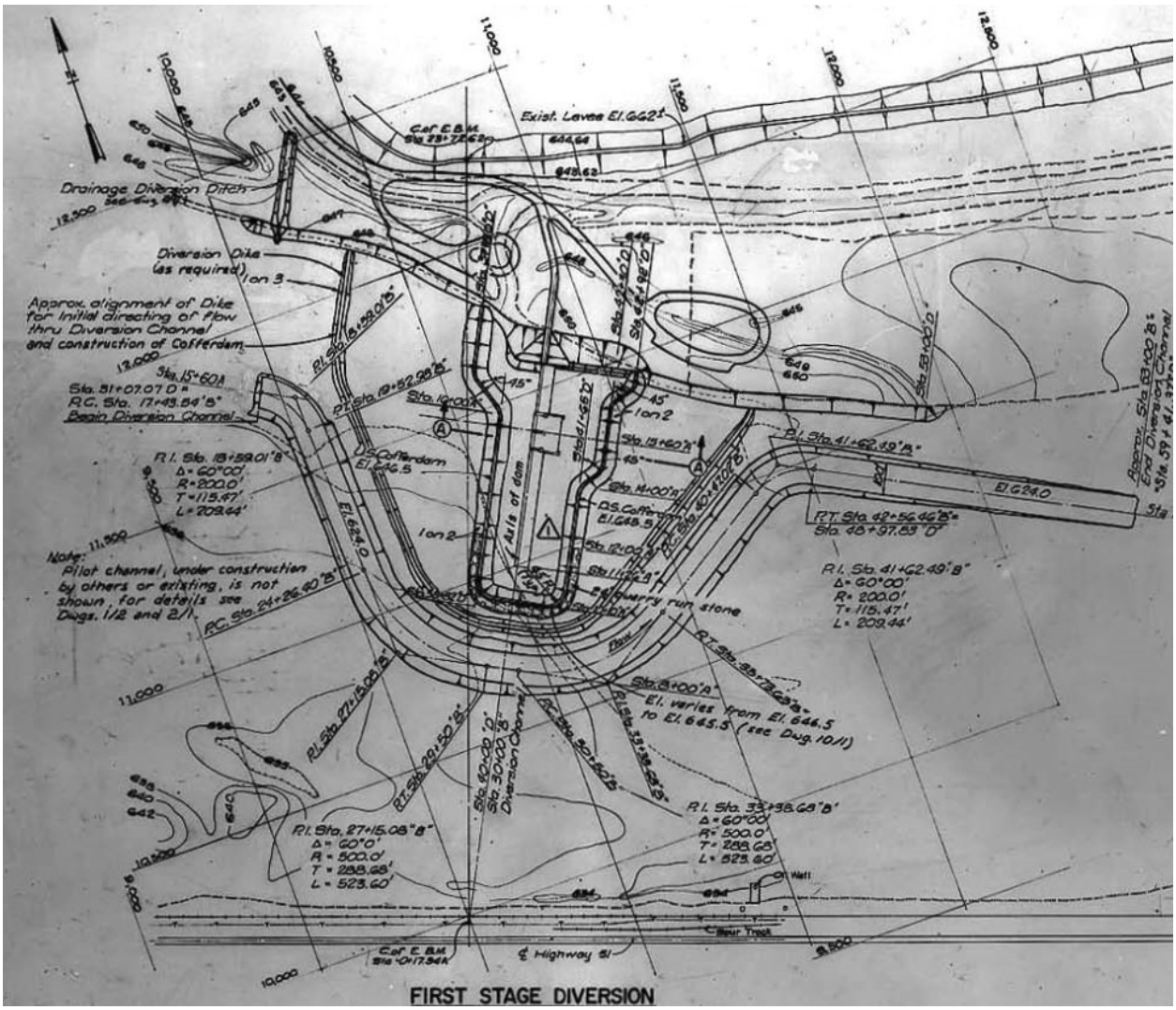


Figure K-3: Example first stage Diversion (Excerpt from Drawing 1070-C40-8/1)

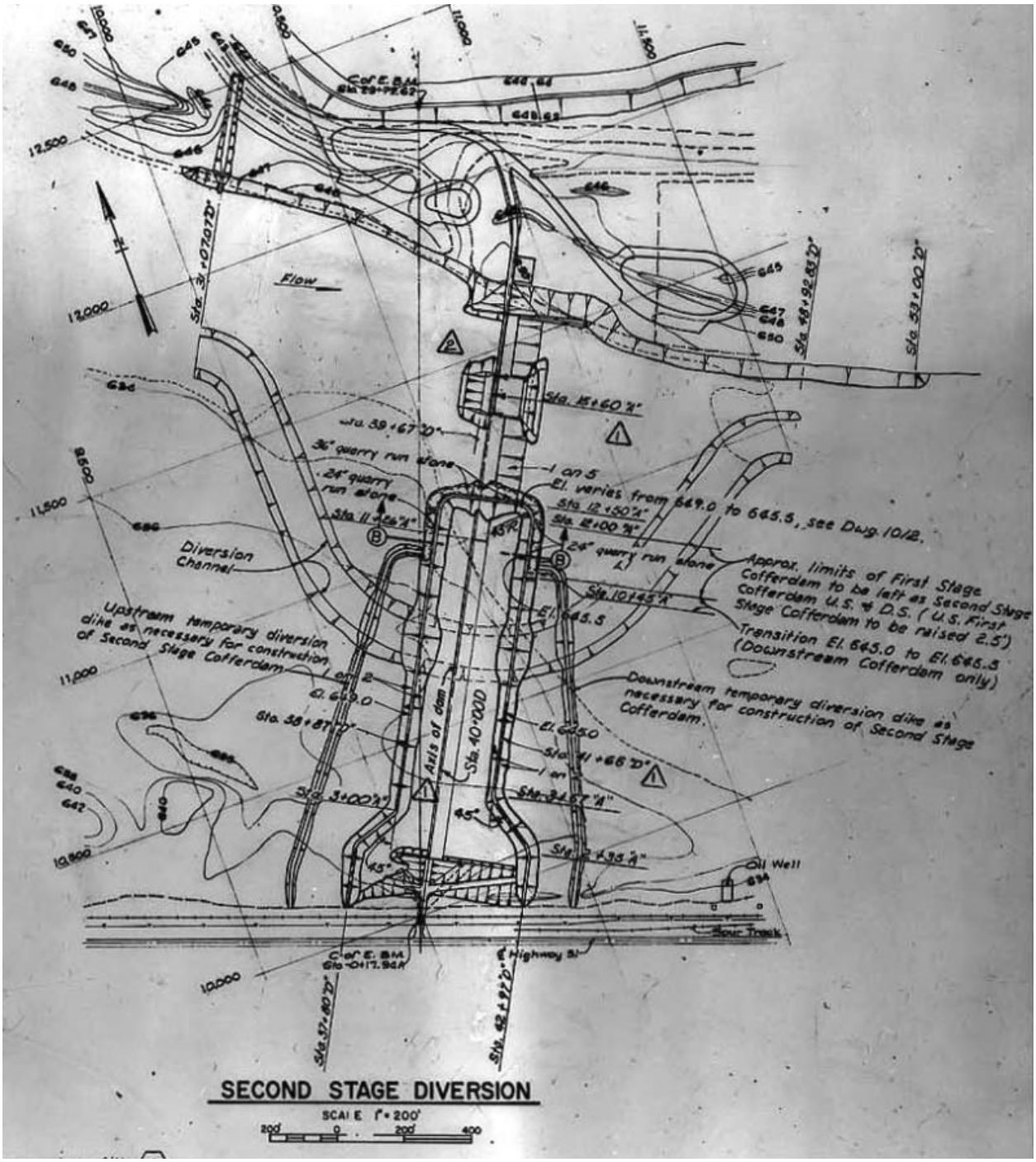


Figure K-4: Example second stage Diversion (Excerpt from Drawing 1070-C40-8/1)

The original Reregulation dam Design Memorandum indicates that permeability of the riverbed sands are on the order of 2 $X10^{-1}$ cm/s and $1x10^{-5}$ cm/s within the silty sands in the bank areas. The dewatering system for the original reregulation dam was comprised of a single stage wellpoint system with the header pipe set 14 feet above bedrock with wellpoints on a maximum spacing of 3 foot within the channel and 6 foot within the banks. Sump pumping was utilized to supplement the dewatering system.

Figure K-4 shows the temporary excavation and cofferdam to be at a 2H to 1V slope. Future investigations will need to evaluate if the current channel condition (with sedimentation) will require substantially different dewatering needs or excavation slopes, although it is not expected that the needs will be drastically different.

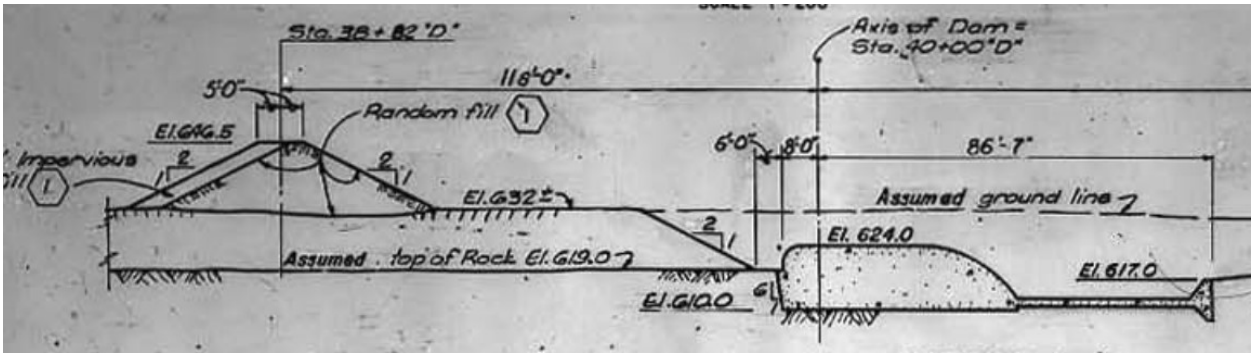


Figure K-4: Example temporary excavation and cofferdam construction as (Excerpt from Drawing 1070-C40-8/1)

Design Details for Consideration- Channel Slope Stability

Bank channel instability is not anticipated to be an issue due to the good performance of the channel slopes near the old reregulation dam (which had similar operating requirements of proposed structures). However, during design the channel banks should be evaluated for the potential for slope instability due to rapid drawdown from operations and for erosion of the channel banks due to wind and wave action within the pool upstream of the proposed structures. Geotechnical investigations performed in support of design should include characterizing the channel overburden and shear strengths for rapid draw down slope stability analyses. If determined to be needed, localized bank stabilization measures could be included in the vicinity of the pool control structures but this is not anticipated at this time.

Investigation Results

Detailed information from the 1960's and 2008 investigations are included on the following pages.

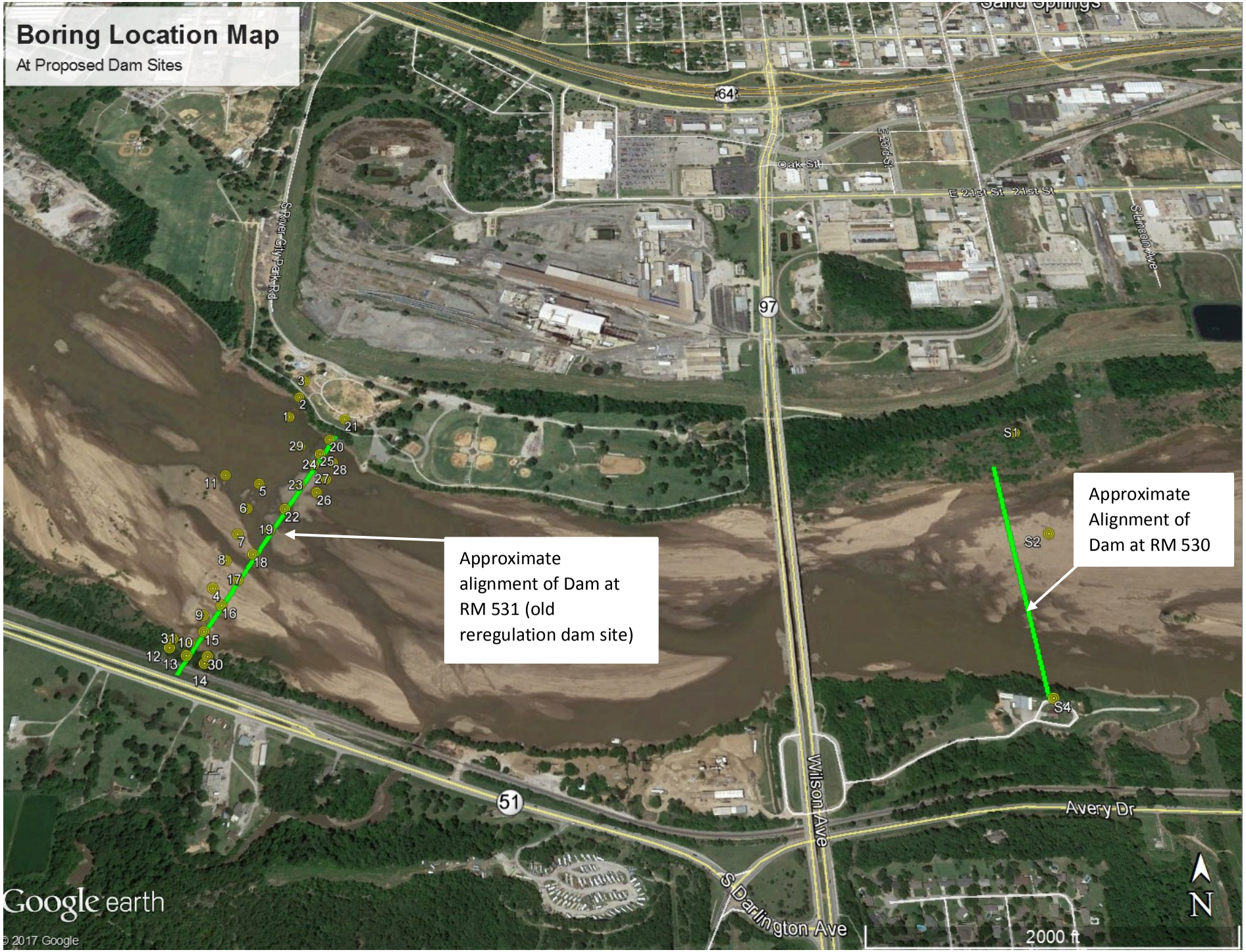
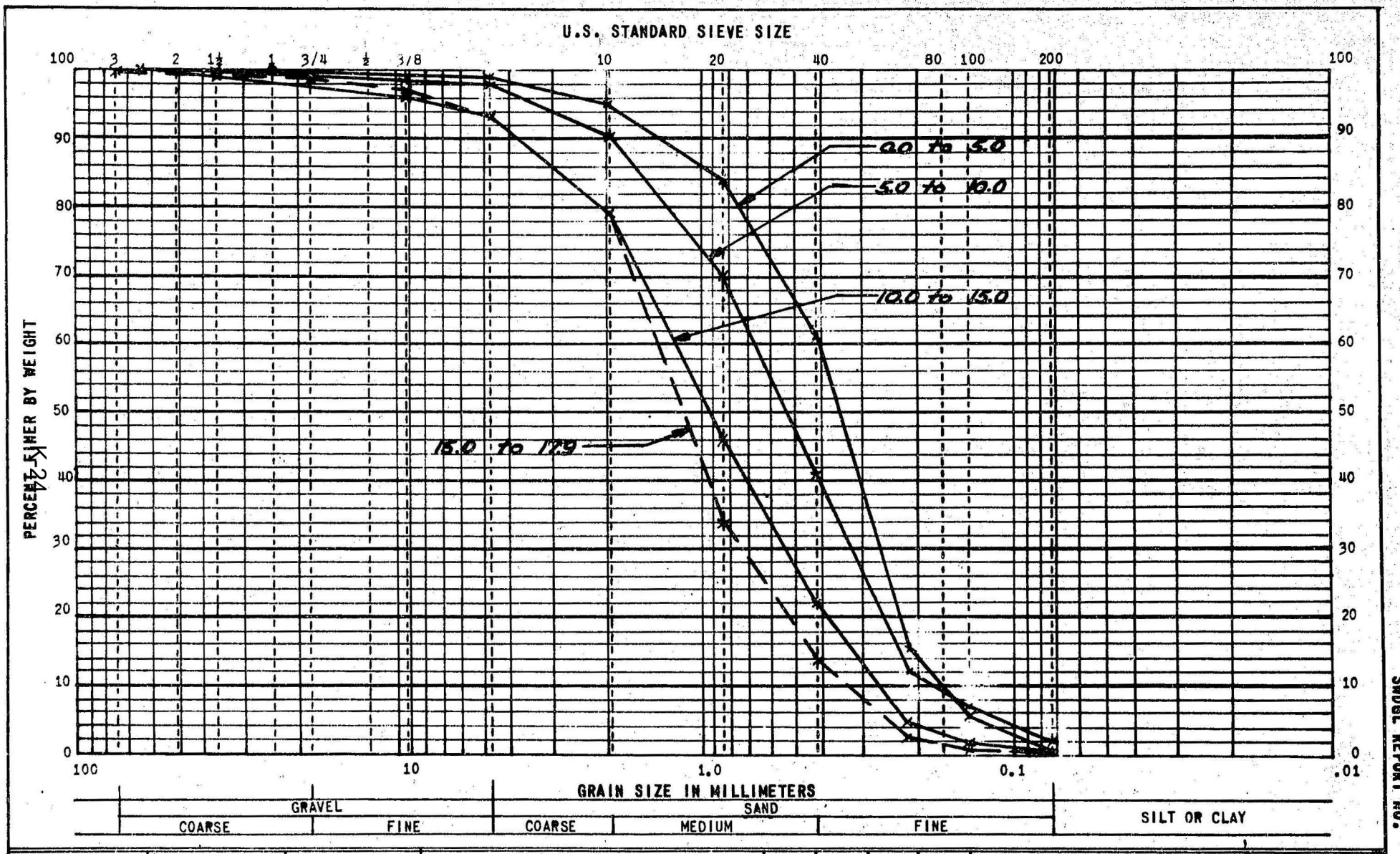


Plate K-1 Boring Location Map

Soils Test Results
(1960's borings)

SWD Form 137-J
Rev. 10 Jun 57



HOLE NO.	SWD SAMPLE NO.	DEPTH, FEET	CLASSIFICATION	LL	PL	PI	LS
		0.0 to 5.0	SP	NP			
		5.0 to 10.0	SP	NP			
		10.0 to 15.0	SP	NP			
		15.0 to 17.9	SP	NP			

GRADATION CHART

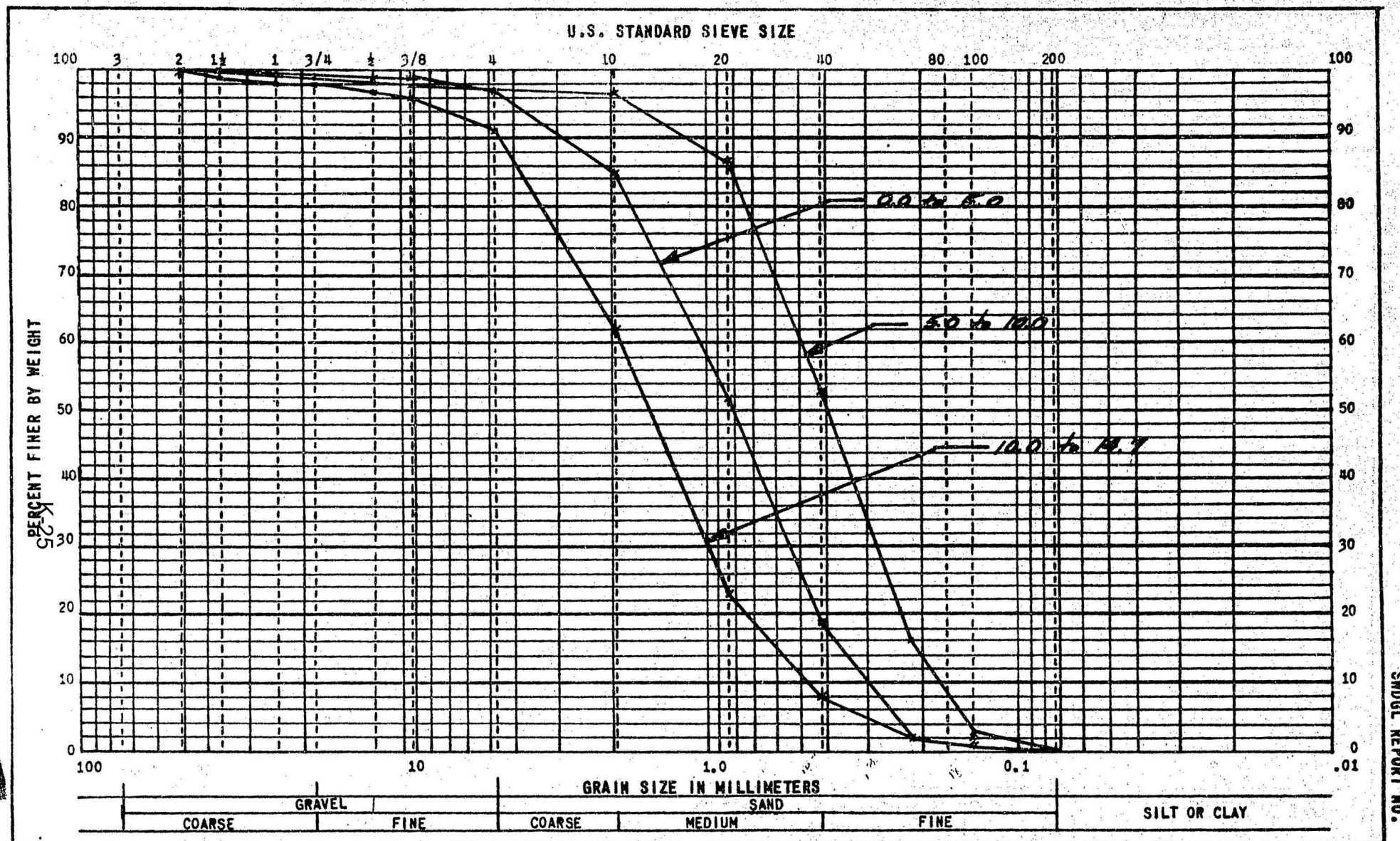
PROJECT: Design Memo No. 89

DISTRICT: Tulsa

TYPE MATERIAL: Arkansas River Sand

DATE: 24 April 64 PLATE NO: 1

SWDGL REPORT NO.



K-25

SWDGL REPORT NO.

HOLE NO.	SWD SAMPLE NO.	DEPTH, FEET	CLASSIFICATION	LL	PL	PI	LS
42A		0.0 to 5.0	SP	NP			
		5.0 to 10.0	SP	NP			
		10.0 to 14.7	SP	NP			

GRADATION CHART

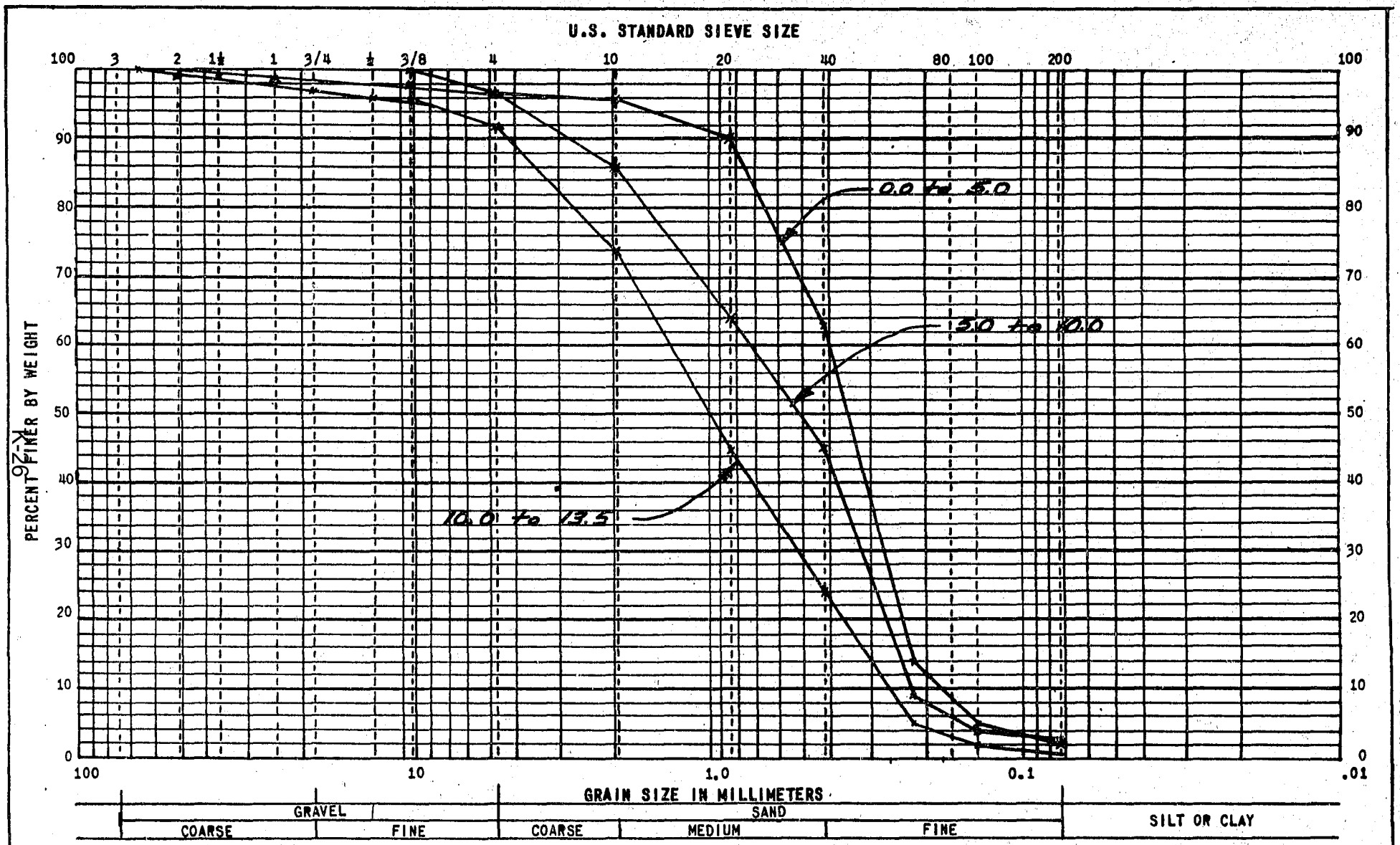
PROJECT: Design Memo No. 89

DISTRICT: Tulsa

TYPE MATERIAL: Arkansas River Sand

DATE: 24 April 64 PLATE NO: 2

SWD Form 137
Rev. 10 June 1957



HOLE NO.	SWD SAMPLE NO.	DEPTH, FEET	CLASSIFICATION	LL	PL	PI	LS
42B		0.0 to 5.0	SP	NP			
		5.0 to 10.0	SP	NP			
		10.0 to 13.5	SP	NP			

GRADATION CHART
PROJECT: Design Memo No. 89
DISTRICT: Tulsa
TYPE MATERIAL: Arkansas River Sand
DATE: 24 April 64 PLATE NO: 5

SWDGL REPORT NO.

Summary of Results
(2008 borings)

A total of 3 borings were advanced in 2008 near the alignment of the proposed dam at river mile 530. Included herein are the boring logs, soil test results, rock core unconfined compressive strength tests, photographs from unconfined compressive strength tests, and photographs of rock core for the three borings advanced in 2008.

Below is a summary of the 2008 boring locations

Boring ID	Latitude	Longitude
S1 *	N 36.12765	W 96.11081
S2	N 36.12585	W 96.11058
S4	N 36.12263	W 96.11125

* Coordinates for this location were estimated from available mapping

Below is a summary of the unconfined compressive strength tests from the 2008 investigations near the alignment of the proposed Dam in 2008.

Boring ID	Depth (ft)	Strength (psi)	Repaired Sample
S1	27.9-28.5	560	X
S1	45.2-45.8	1060	X
S2	21.4-22.0	740	X
S2	31.2-31.8	630	X
S4	40.0-40.6	70	
S4	71.1-71.75	580	X

Ignoring the outlier, the average unconfined compressive strength of the rock tests is about 715 psi, or 51 tons/ Ft^2. For planning purposes, the allowable bearing capacity of rock can be assumed to to be approximately 1/5 of the unconfined compressive strength, or 10 Tons/ Ft^2 (Reference Foundation Design by Wayne C. Teng, 1962). Based on these unconfined compressive strength tests, good structural performance of the original reregulation dam, and presence of the large upstream Keystone Dam Spillway (founded at similar elevation and rock formations), the proposed sites are anticipated to provide an adequate foundation for the proposed structures for bearing.

Rock Core Photographs from the investigations are included herein. The core photographs show the presence of some bedding planes and fractures as indicated on the logs and some weathered material. Field investigations also showed that the shales encountered could slake and weather over time due to exposure and it was necessary to wrap, seal, and wax core samples prior to testing to maintain integretity. Based on the Core Photographs and documentation included in design correspondence of the original Reregulation Dam, it is recommended that the final foundation surface rock for new structures be covered with protective concrete shortly after exposure and prior to placement of mass concrete. Vertical or near vertical shale excavation faces will likely need to be protected with pnuematic concrete, bituminous coatings, or some other sealant to prevent weathering and slaking. Future investigations should consider if bedding planes offer prefertential failure planes for global stability. It is still believed that the rock will offer a suitable foundation for the structures, but some protective measures maybe necessary as noted above.

Note: In order to test the rock core samples in accordance to ASTM standards, it was necessary to epoxy many of the specimens. The epoxy is of low strength and was only used to bond clean horizontal fractures. The epoxy is not believed to affect the results of the strength testing and this was demonstrated by the failure surfaces penetrating across the epoxy layer on several of the specimens.

Soils Test Results
(2008 borings)

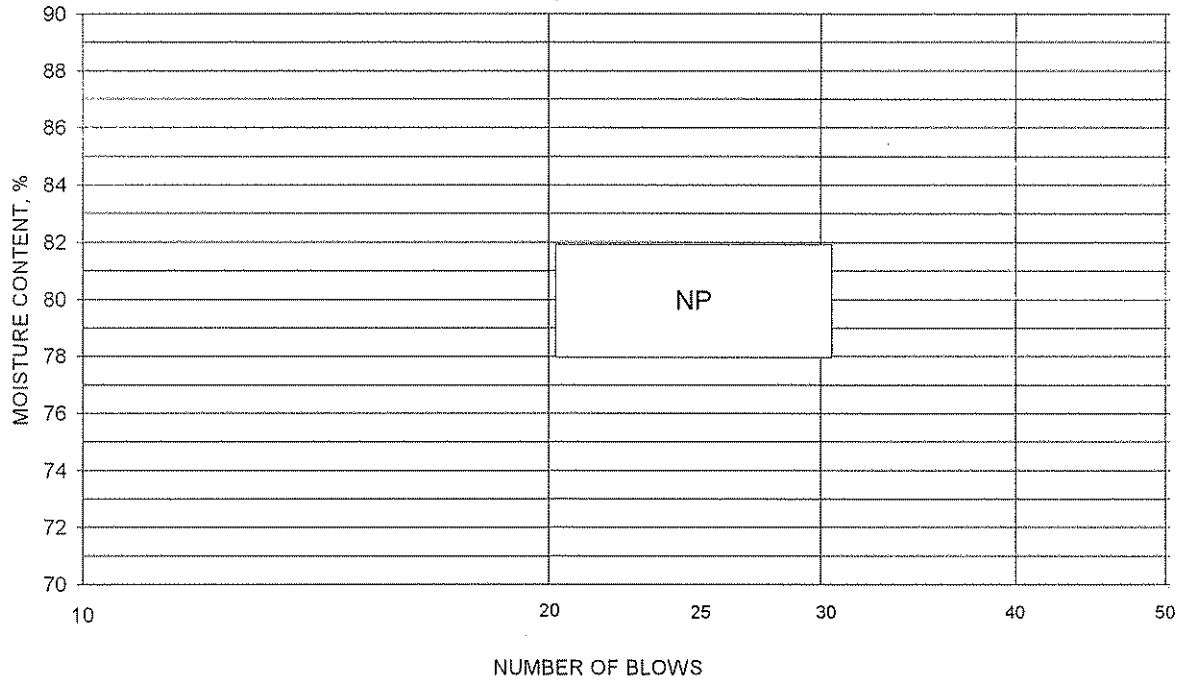
Fuller Mossberger Scott & May ENGINEERS

ATTERBERG LIMITS

Project	Arkansas River Drilling			Project No.	LX2007282
Source	S4, 30.0'-31.5'			Lab ID	4
Tested By	KWS	Test Method	ASTM D 4318 Method A	% + No. 40	4
Test Date	04-10-2008	Prepared	Dry	Date Received	03-26-2008

Wet Soil and Tare Mass (g)	Dry Soil and Tare Mass (g)	Tare Mass (g)	Number of Blows	Water Content (%)	Liquid Limit

Liquid Limit



PLASTIC LIMIT AND PLASTICITY INDEX

Wet Soil and Tare Mass (g)	Dry Soil and Tare Mass (g)	Tare Mass (g)	Water Content (%)	Plastic Limit	Plasticity Index

Remarks: _____

Reviewed By _____

Preparation Date: 10-98
Revision Date: 11-2000
File: LX2007282_LIM-4 Sheet: LIMIT

Fuller, Mossberger, Scott and May Engineers, Inc.

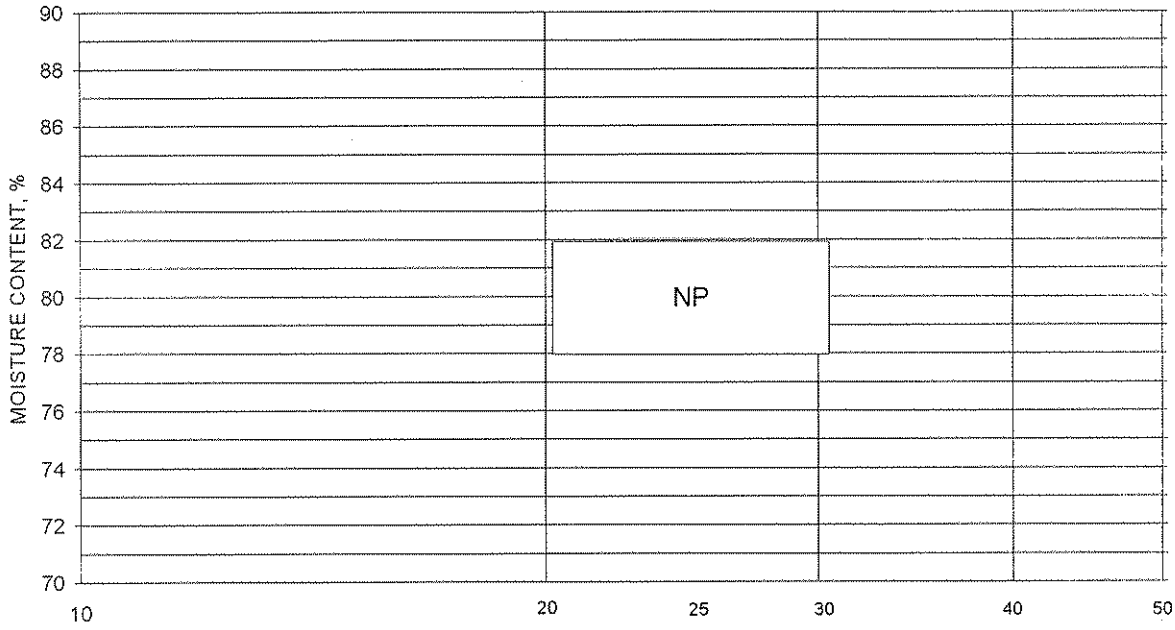
Laboratory Document
Prepared By: MW
Approved By: TLK

ATTERBERG LIMITS

Project	Arkansas River Drilling			Project No.	LX2007282
Source	S4, 5.0'-6.5'			Lab ID	3
Tested By	KWS	Test Method	ASTM D 4318 Method A	% + No. 40	1
Test Date	04-14-2008	Prepared	Dry	Date Received	03-26-2008

Wet Soil and Tare Mass (g)	Dry Soil and Tare Mass (g)	Tare Mass (g)	Number of Blows	Water Content (%)	Liquid Limit

Liquid Limit



PLASTIC LIMIT AND PLASTICITY INDEX

Wet Soil and Tare Mass (g)	Dry Soil and Tare Mass (g)	Tare Mass (g)	Water Content (%)	Plastic Limit	Plasticity Index

Remarks: _____

Reviewed By _____

Preparation Date: 10-98
Revision Date: 11-2000
File: LX2007282_LIM-3 Sheet: LIMIT

Fuller, Mossbarger, Scott and May Engineers, Inc.

Laboratory Document
Prepared By: MW
Approved By: TLK

Fuller Mossberger Scott & May ENGINEERS

Gradation Analysis
ASTM D 422

Project Name Arkansas River Drilling
Source S1, 10.0'-11.5'

Preparation Method ASTM D 1140 Method A
Particle Shape Rounded
Particle Hardness Hard and Durable
Sample Dry Mass (g) 509.02

Project Number LX2007282
Lab ID 1
Date Received 03-26-2008
Preparation Date 04-11-2008
Test Date 04-11-2008

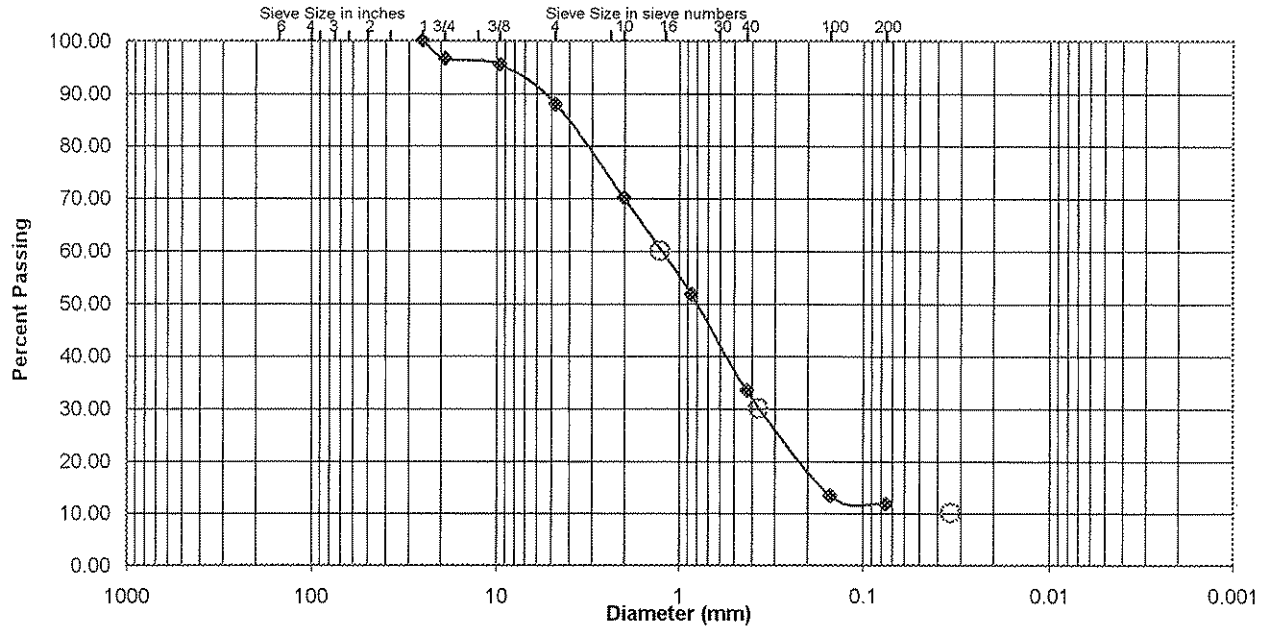
Analysis based on total sample.

Sieve Size	Grams Retained	% Retained	% Passing
1"	0.00	0.0	100.0
3/4"	17.74	3.5	96.5
3/8"	5.57	1.1	95.4
No. 4	38.55	7.6	87.8
No. 10	90.87	17.9	70.0
No. 20	93.18	18.3	51.7
No. 40	93.30	18.3	33.4
No. 100	101.72	20.0	13.4
No. 200	8.14	1.6	11.8
Pan	59.95	11.8	---

% Gravel	12.2
% Sand	76.1
% Fines	11.8
Fines Classification	N/A
D_{10} (mm)	0.0337
D_{30} (mm)	0.3667
D_{60} (mm)	1.2635
Cu	37.48
Cc	3.16

Classification
N/A

Particle Size Distribution



Comments

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Fuller Mossberger Scott & May ENGINEERS

Gradation Analysis

ASTM D 422

Project Name Arkansas River Drilling
Source S2, 0.0'-5.0'

Preparation Method ASTM D 1140 Method A
Particle Shape Rounded
Particle Hardness Hard and Durable
Sample Dry Mass (g) 432.07

Project Number LX2007282
Lab ID 2
Date Received 03-26-2008
Preparation Date 04-08-2008
Test Date 04-11-2008

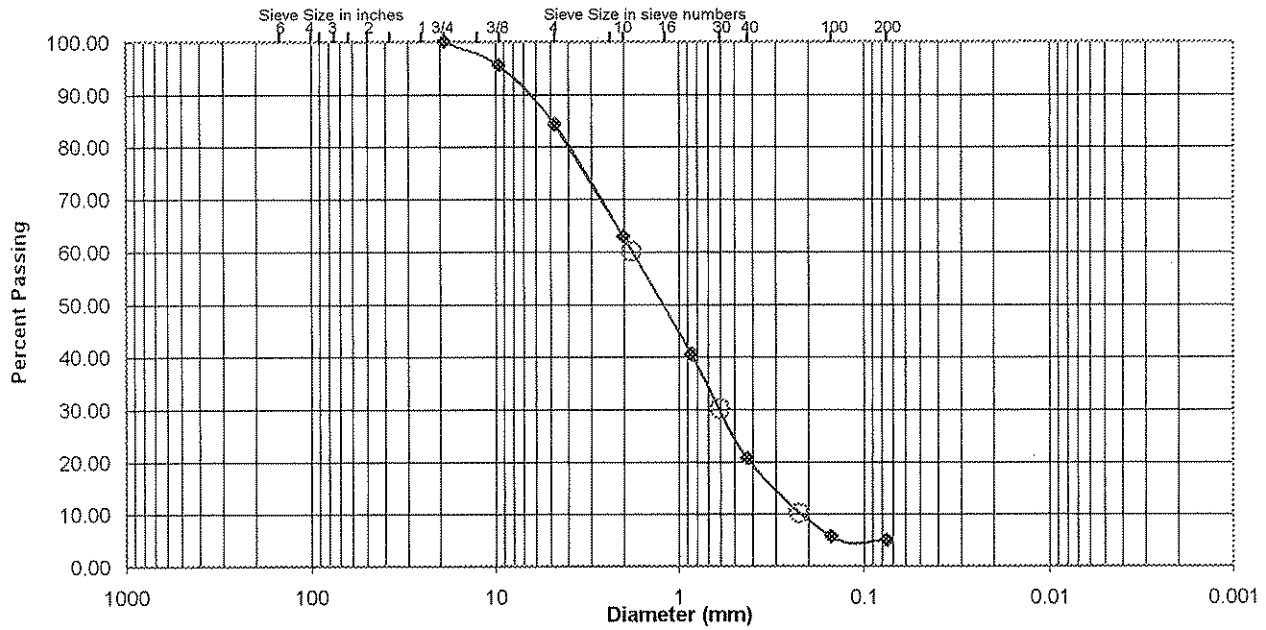
Analysis based on total sample.

Sieve Size	Grams Retained	% Retained	% Passing
3/4"	0.00	0.0	100.0
3/8"	19.50	4.5	95.5
No. 4	48.73	11.3	84.2
No. 10	92.78	21.5	62.7
No. 20	96.28	22.3	40.5
No. 40	85.95	19.9	20.6
No. 100	64.27	14.9	5.7
No. 200	3.52	0.8	4.9
Pan	21.04	4.9	---

% Gravel	15.8
% Sand	79.3
% Fines	4.9
Fines Classification	N/A
D_{10} (mm)	0.2229
D_{30} (mm)	0.6005
D_{60} (mm)	1.8006
Cu	8.08
Cc	0.90

Classification
N/A

Particle Size Distribution



Comments

Reviewed By

FULLER MOSSBARGER SCOTT & MAY ENGINEERS

Gradation Analysis
ASTM D 422

Project Name: Arkansas River Drilling
Source: S4, 5.0'-6.5'

Preparation Method: ASTM D 1140 Method A
Particle Shape: Angular
Particle Hardness: Hard and Durable
Sample Dry Mass (g): 182.91

Project Number: LX2007282
Lab ID: 3
Date Received: 03-26-2008
Preparation Date: 04-08-2008
Test Date: 04-08-2008

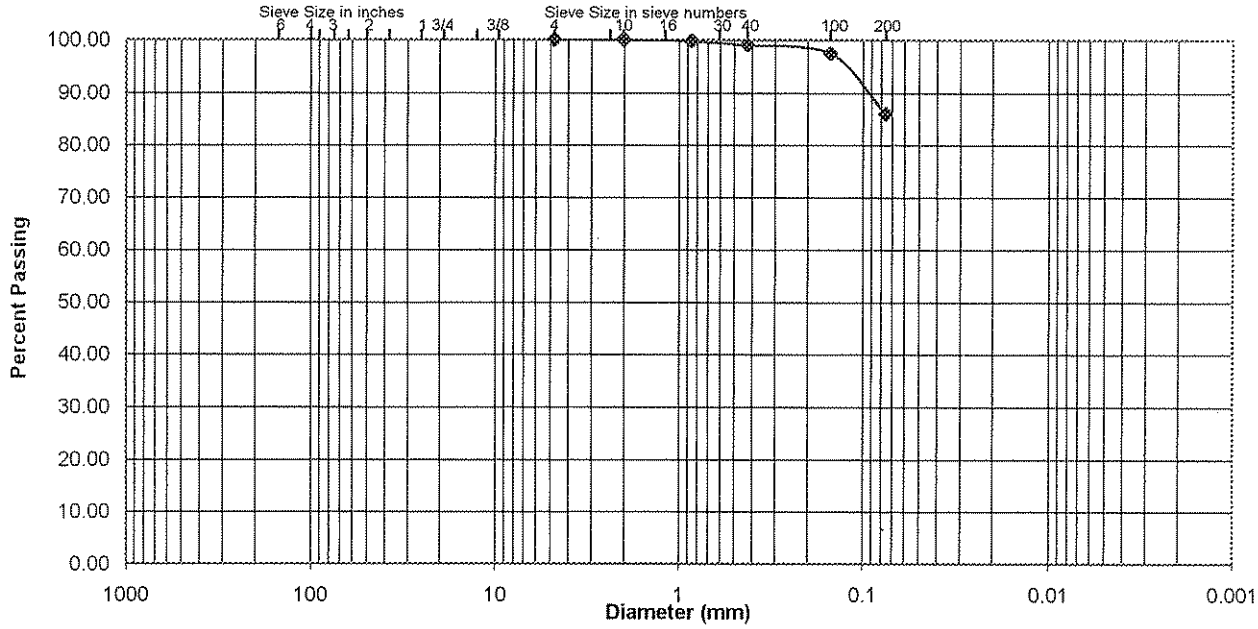
Analysis based on total sample.

Sieve Size	Grams Retained	% Retained	% Passing
No. 4	0.00	0.0	100.0
No. 10	0.06	0.0	100.0
No. 20	0.47	0.3	99.7
No. 40	1.23	0.7	99.0
No. 100	2.87	1.6	97.5
No. 200	21.12	11.5	85.9
Pan	157.16	85.9	---

% Gravel	0.0
% Sand	14.1
% Fines	85.9
Fines Classification	N/A
D_{10} (mm)	N/A
D_{30} (mm)	N/A
D_{60} (mm)	N/A
Cu	N/A
Cc	N/A

Classification: N/A

Particle Size Distribution



Comments

Reviewed By

Fuller, Mossbarger, Scott & May ENGINEERS

Gradation Analysis
ASTM D 422

Project Name: Arkansas River Drilling
Source: S4, 30.0'-31.5'

Preparation Method: ASTM D 1140 Method A
Particle Shape: Rounded
Particle Hardness: Hard and Durable
Sample Dry Mass (g): 286.03

Project Number: LX2007282
Lab ID: 4
Date Received: 03-26-2008
Preparation Date: 04-08-2008
Test Date: 04-11-2008

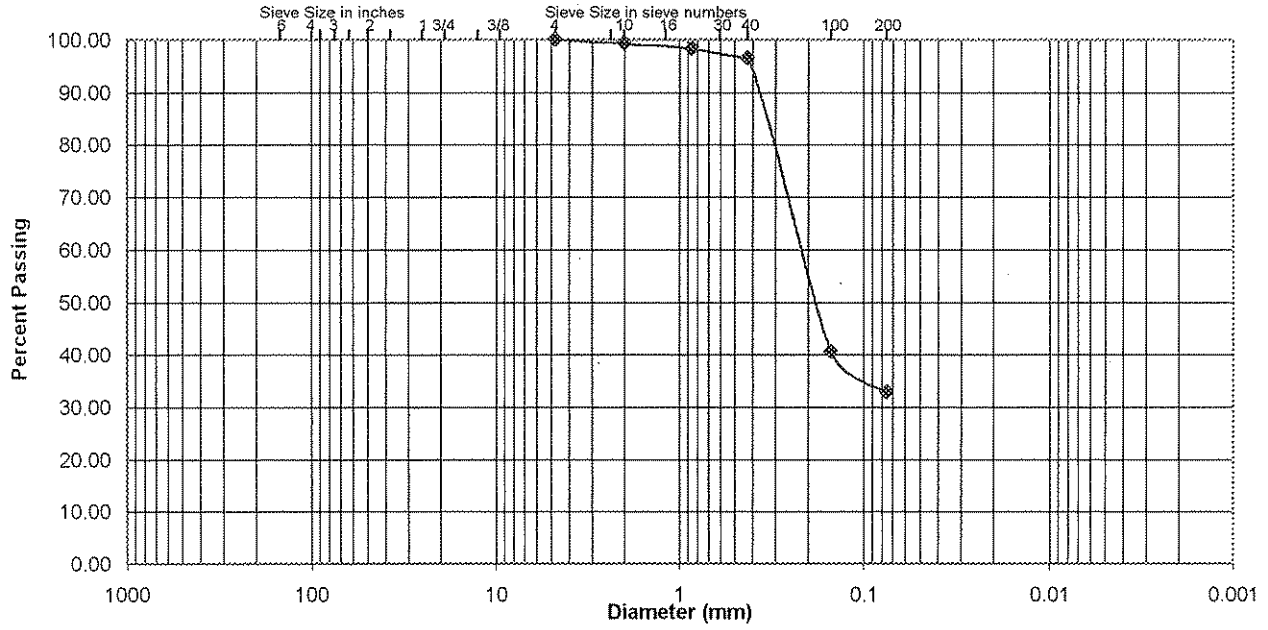
Analysis based on total sample.

Sieve Size	Grams Retained	% Retained	% Passing
No. 4	0.00	0.0	100.0
No. 10	2.06	0.7	99.3
No. 20	2.95	1.0	98.2
No. 40	5.28	1.8	96.4
No. 100	159.73	55.8	40.6
No. 200	22.20	7.8	32.8
Pan	93.81	32.8	---

% Gravel	0.0
% Sand	67.2
% Fines	32.8
Fines Classification	N/A
D_{10} (mm)	N/A
D_{30} (mm)	N/A
D_{60} (mm)	N/A
Cu	N/A
Cc	N/A

Classification: N/A

Particle Size Distribution



Comments

Reviewed By

Rock Core
Unconfined Test
Results
(2008 Borings)

Fuller Mossbarger Scott & May ENGINEERS

Unconfined Compressive Strength Of Intact Rock Core

ASTM D 2938

Project Name: Arkansas River Drilling
Project Number: LX2007282
Lithology: Shale, dark gray, soft
Lab ID: UCR-11
Hole Number: S1
Depth (ft/elev): 27.9' - 28.5'
Date Received: 03-26-2008

Temperature (°C): 19.8
Moisture Condition: As received, moist
Date Tested: 04-11-2008

Side Planeness	N/A	Height (in)	7.903	Wet Unit Weight (pcf)	153.7
Perpendicularity	N/A	Diameter (in)	3.187	Dry Unit Weight (pcf)	N/A
End Planeness	N/A	Area (in^2)	7.976	Moisture Content (%)	N/A

Dimensions were not confirmed.

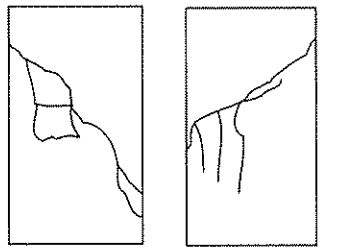
Loading Rate (lbf/sec): 20
Peak Load (lbf): 4460

Failure Type: Shear

Compressive Strength (psi): 560

Compressive Strength (tsf): 40

Failure Sketches



Comments: Fragile nature of specimen inhibited preparation. Dimensional tolerances were not confirmed.

Fuller Mossbarger Scott & May ENGINEERS

Unconfined Compressive Strength Of Intact Rock Core

ASTM D 2938

Project Name: Arkansas River Drilling
Project Number: LX2007282
Lithology: Shale, dark gray, soft
Lab ID: UCR-12
Hole Number: S1
Depth (ft/elev): 45.2' - 45.8'
Date Received: 03-26-2008

Temperature (°C): 19.8
Moisture Condition: As received, moist
Date Tested: 04-11-2008

Side Planeness	N/A	Height (in)	7.736	Wet Unit Weight (pcf)	155.1
Perpendicularity	N/A	Diameter (in)	3.278	Dry Unit Weight (pcf)	N/A
End Planeness	N/A	Area (in^2)	8.438	Moisture Content (%)	N/A

Dimensions were not confirmed.

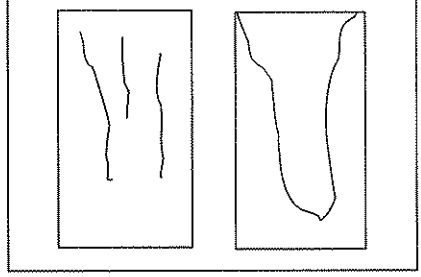
Loading Rate (lbf/sec): 20
Peak Load (lbf): 8940

Failure Type: Cone and Split

Compressive Strength (psi): 1060

Compressive Strength (tsf): 76

Failure Sketches



Comments: Fragile nature of specimen inhibited preparation. Dimensional tolerances were not confirmed.

Fuller Mossbarger Scott & May ENGINEERS

Unconfined Compressive Strength Of Intact Rock Core

ASTM D 2938

Project Name: Arkansas River Drilling
Project Number: LX2007282
Lithology: Shale, dark gray, soft
Lab ID: UCR-13
Hole Number: S2
Depth (ft/elev): 21.4' - 22.0'
Date Received: 03-26-2008

Temperature (°C): 19.8
Moisture Condition: As received, moist
Date Tested: 04-11-2008

Side Planeness	N/A	Height (in)	6.703	Wet Unit Weight (pcf)	153.7
Perpendicularity	N/A	Diameter (in)	3.284	Dry Unit Weight (pcf)	N/A
End Planeness	N/A	Area (in^2)	8.472	Moisture Content (%)	N/A

Dimensions were not confirmed.

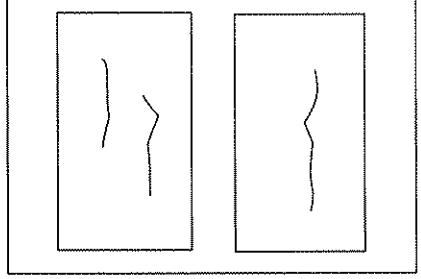
Loading Rate (lbf/sec): 20
Peak Load (lbf): 6280

Failure Type: Undetermined

Compressive Strength (psi): 740

Compressive Strength (tsf): 53

Failure Sketches



Comments: Fragile nature of specimen inhibited preparation. Dimensional tolerances were not confirmed.

Fuller Mossbarger Scott & May ENGINEERS

Unconfined Compressive Strength Of Intact Rock Core

ASTM D 2938

Project Name: Arkansas River Drilling
Project Number: LX2007282
Lithology: Shale, dark gray, soft
Lab ID: UCR-14
Hole Number: S2
Depth (ft/elev): 31.2' - 31.8'
Date Received: 03-26-2008

Temperature (°C): 19.8
Moisture Condition: As received, moist
Date Tested: 04-11-2008

Side Planeness	N/A	Height (in)	8.248	Wet Unit Weight (pcf)	155.1
Perpendicularity	N/A	Diameter (in)	3.297	Dry Unit Weight (pcf)	N/A
End Planeness	N/A	Area (in^2)	8.536	Moisture Content (%)	N/A

Dimensions were not confirmed.

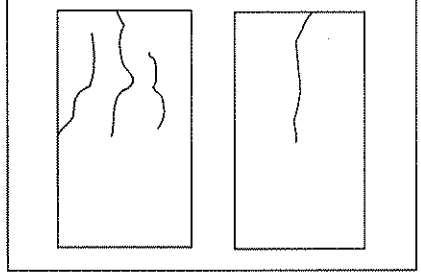
Loading Rate (lbf/sec): 20
Peak Load (lbf): 5360

Failure Type: Undetermined

Compressive Strength (psi): 630

Compressive Strength (tsf): 45

Failure Sketches



Comments: Fragile nature of specimen inhibited preparation. Dimensional tolerances were not confirmed.

Fuller Mossbarger Scott & May ENGINEERS

Unconfined Compressive Strength Of Intact Rock Core

ASTM D 2938

Project Name: Arkansas River Drilling
Project Number: LX2007282
Lithology: Shale, dark gray, very soft
Lab ID: UCR-15
Hole Number: S4
Depth (ft/elev): 40.0' - 40.6'
Date Received: 03-26-2008

Temperature (°C): 19.8
Moisture Condition: As received, moist
Date Tested: 04-11-2008

Side Planeness: N/A
Perpendicularity: N/A
End Planeness: N/A
Dimensions were not confirmed.

Height (in): 6.809
Diameter (in): 3.376
Area (in^2): 8.953

Wet Unit Weight (pcf): 143.3
Dry Unit Weight (pcf): N/A
Moisture Content (%): N/A

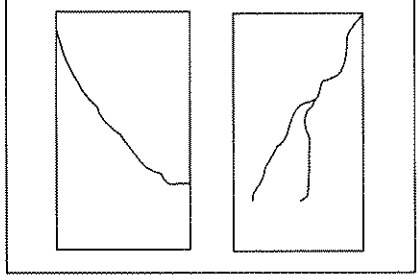
Loading Rate (lbf/sec): 20
Peak Load (lbf): 630

Failure Type: Shear

Compressive Strength (psi): 70

Compressive Strength (tsf): 5

Failure Sketches



Comments: Fragile nature of specimen inhibited preparation. Dimensional tolerances were not confirmed.

Fuller Mossbarger Scott & May ENGINEERS

Unconfined Compressive Strength Of Intact Rock Core

ASTM D 2938

Project Name: Arkansas River Drilling
Project Number: LX2007282
Lithology: Shale, dark gray, soft
Lab ID: UCR-16
Hole Number: S4
Depth (ft/elev): 71.10' - 71.75'
Date Received: 03-26-2008

Temperature (°C): 19.8
Moisture Condition: As received, moist
Date Tested: 04-11-2008

Side Planeness	N/A	Height (in)	8.063	Wet Unit Weight (pcf)	155.7
Perpendicularity	N/A	Diameter (in)	3.321	Dry Unit Weight (pcf)	N/A
End Planeness	N/A	Area (in^2)	8.662	Moisture Content (%)	N/A

Dimensions were not confirmed.

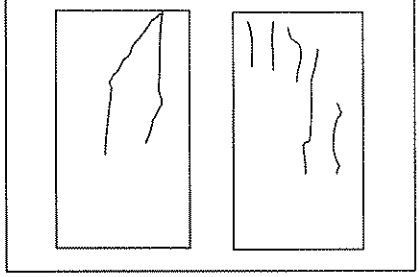
Loading Rate (lbf/sec): 20
Peak Load (lbf): 5010

Failure Type: Undetermined

Compressive Strength (psi): 580

Compressive Strength (tsf): 42

Failure Sketches



Comments: Fragile nature of specimen inhibited preparation. Dimensional tolerances were not confirmed.

Rock Core
Unconfined Test
Photographs
(2008 Borings)

Fuller Mossbarger Scott & May ENGINEERS

Photo Report

Project Name Arkansas River Drilling
Project Number LX2007282
Lithology Shale, dark gray, soft
Lab ID UCR-11
Hole Number S1 Depth (ft) 27.9' - 28.5'
Test Type Unconfined compressive strength

As Received

Core Preparation

Fuller Mossbarger Scott & May ENGINEERS

Photo Report

Project Name Arkansas River Drilling
Lithology Shale, dark gray, soft
Hole Number S1 Depth (ft) 27.9' - 28.5'
Test Type Unconfined compressive strength

Project Number LX2007282
Lab ID UCR-11

Core Preparation

Post Test

Fuller Mossbarger Scott & May ENGINEERS

Photo Report

Project Name Arkansas River Drilling
Project Number LX2007282
Lithology Shale, dark gray, soft
Lab ID UCR-11
Hole Number S1
Depth (ft) 27.9' - 28.5'
Test Type Unconfined compressive strength

Post Test

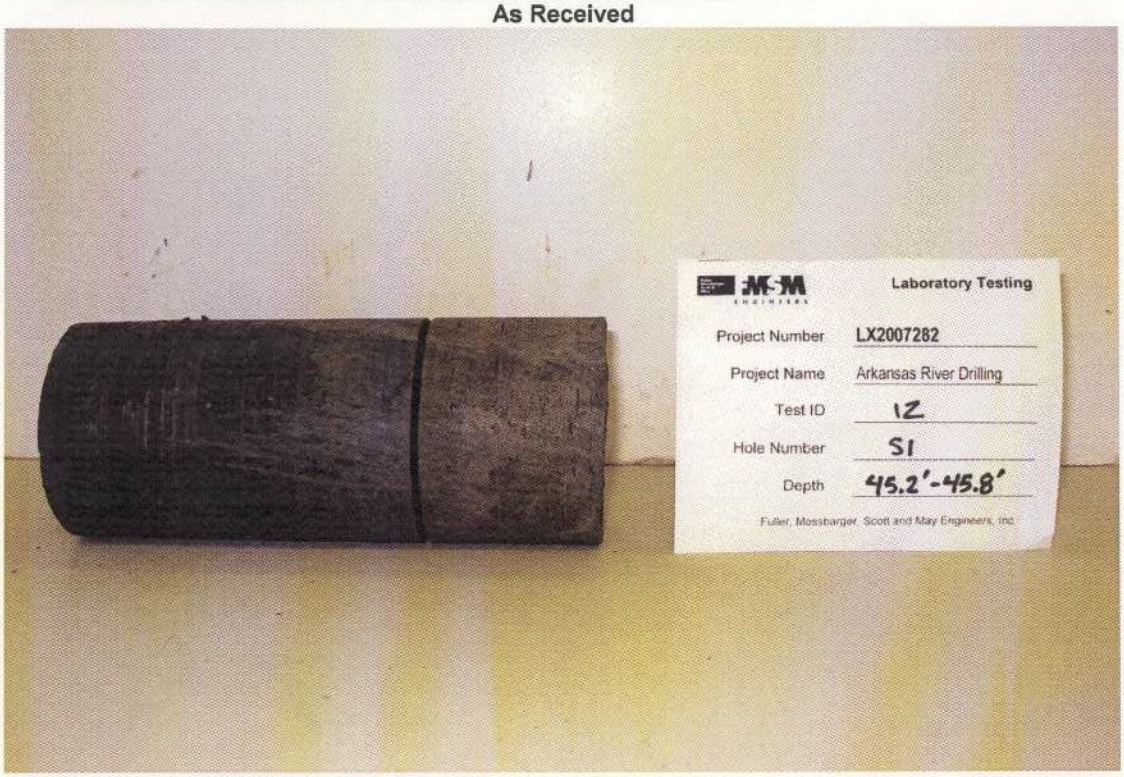
Fuller Mossbarger Scott & May ENGINEERS

Photo Report

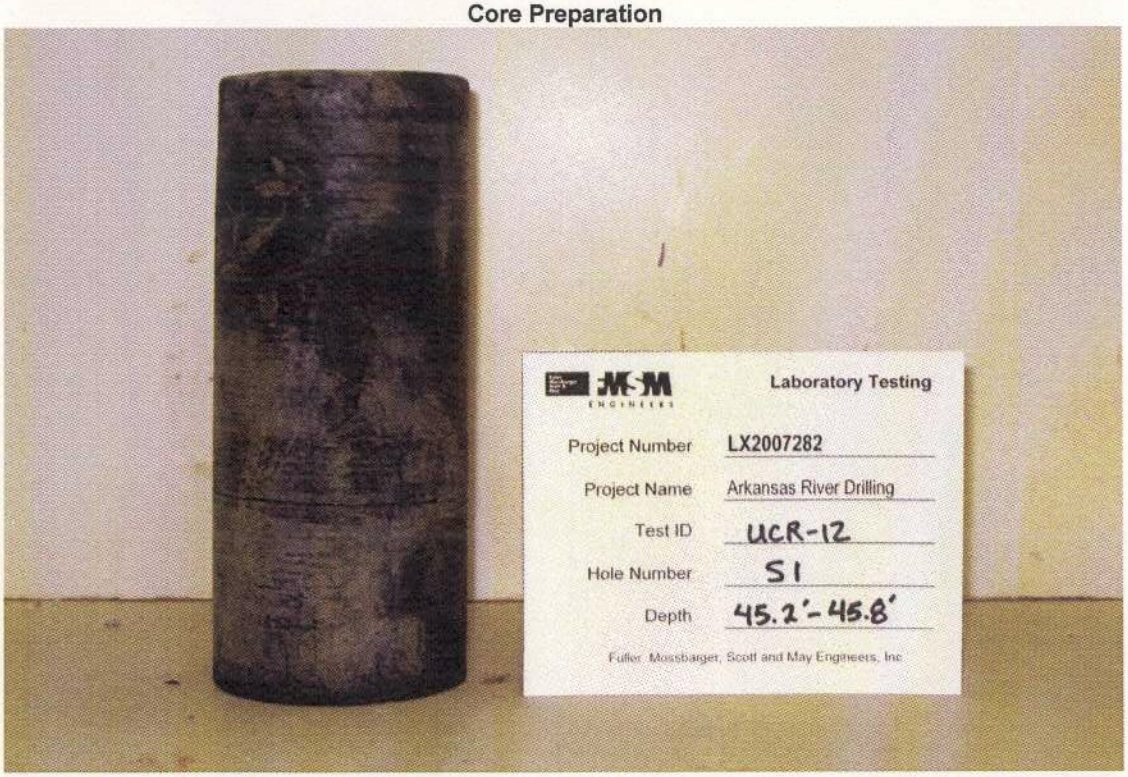
Project Name Arkansas River Drilling
Lithology Shale, dark gray, soft
Hole Number S1 Depth (ft) 45.2' - 45.8'
Test Type Unconfined compressive strength

Project Number LX2007282
Lab ID UCR-12

As Received



Core Preparation

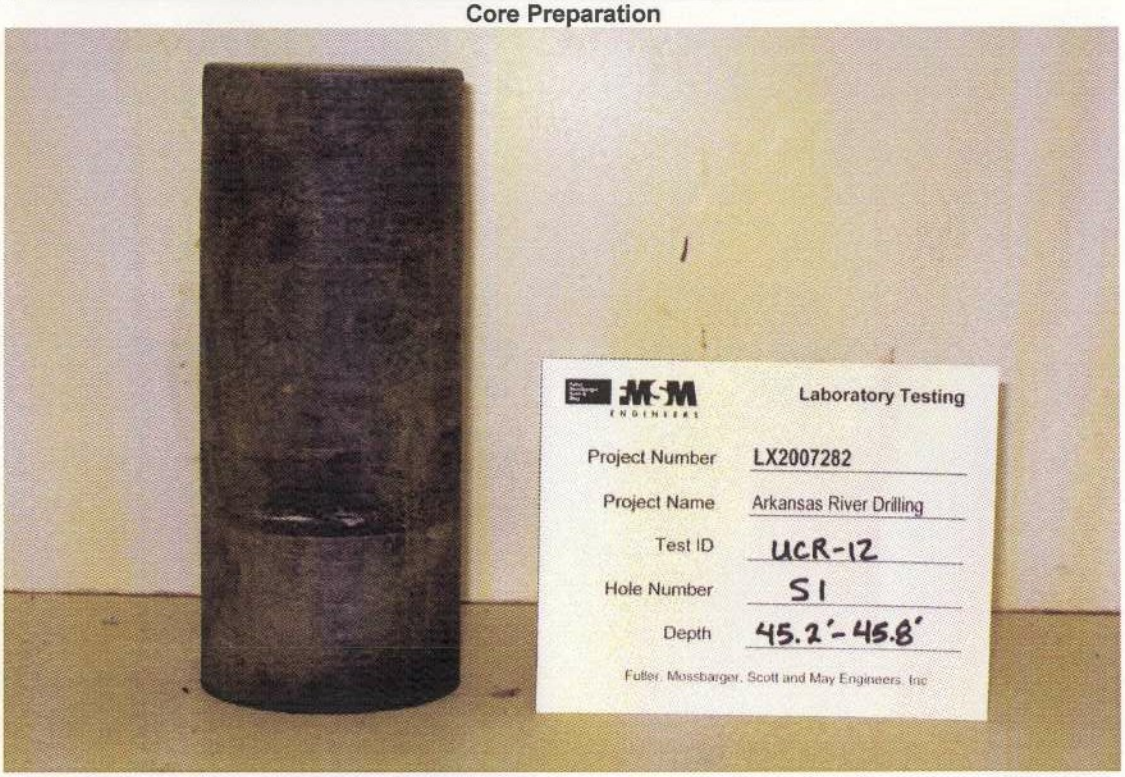


Fuller Mossbarger Scott & May ENGINEERS

Photo Report

Project Name Arkansas River Drilling
Project Number LX2007282
Lithology Shale, dark gray, soft
Lab ID UCR-12
Hole Number S1 Depth (ft) 45.2' - 45.8'
Test Type Unconfined compressive strength

Core Preparation



Post Test

Fuller Mossbarger Scott & May ENGINEERS

Photo Report

Project Name Arkansas River Drilling
Project Number LX2007282
Lithology Shale, dark gray, soft
Lab ID UCR-12
Hole Number S1
Depth (ft) 45.2' - 45.8'
Test Type Unconfined compressive strength

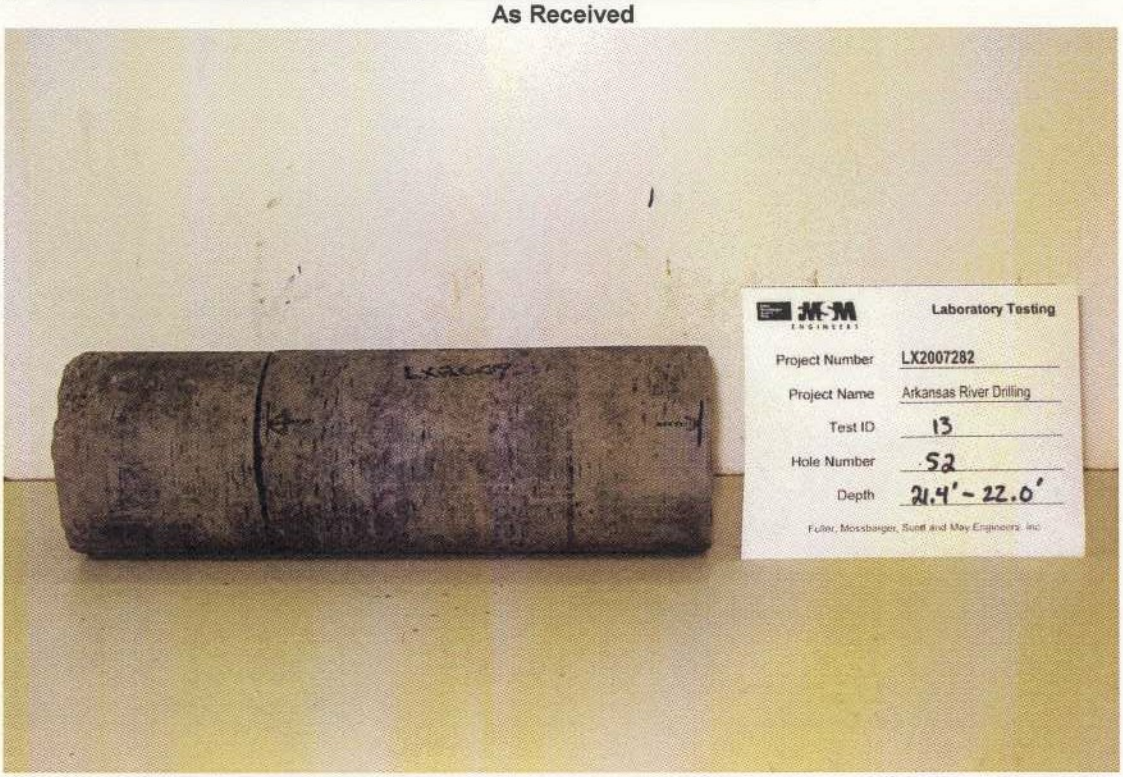
Post Test

Fuller Mossbarger Scott & May ENGINEERS

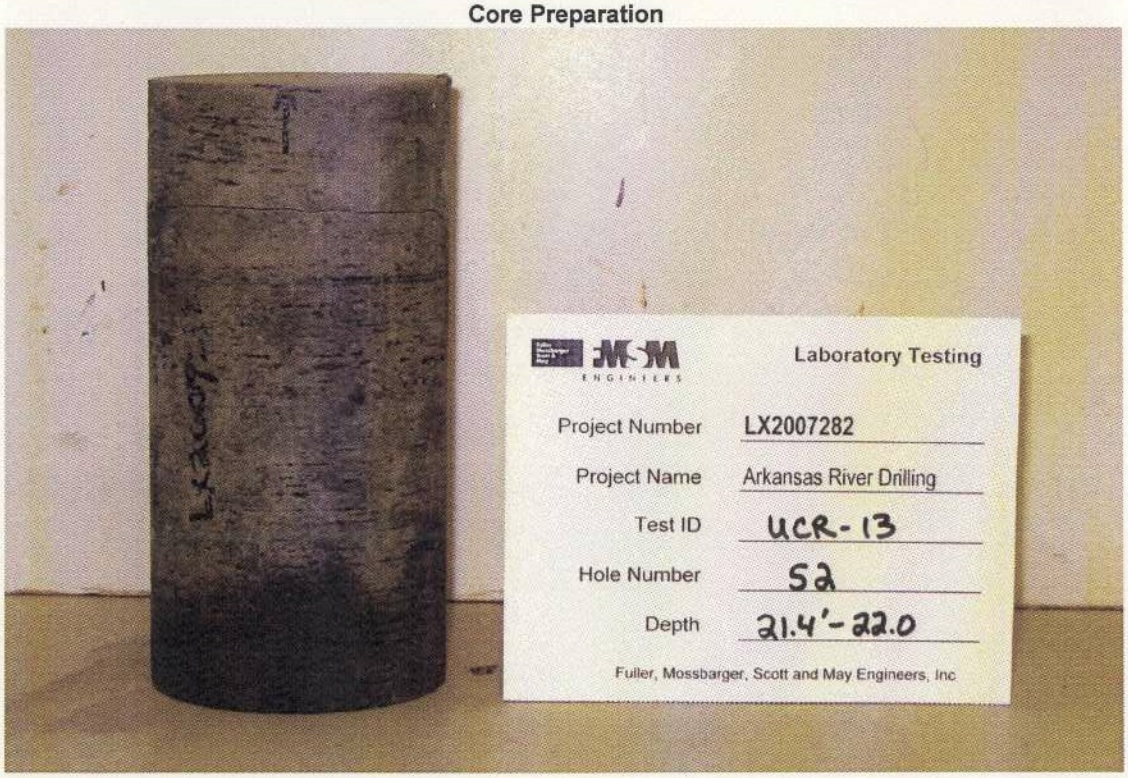
Photo Report

Project Name Arkansas River Drilling
Project Number LX2007282
Lithology Shale, dark gray, soft
Lab ID UCR-13
Hole Number S2 Depth (ft) 21.4' - 22.0'
Test Type Unconfined compressive strength

As Received



Core Preparation



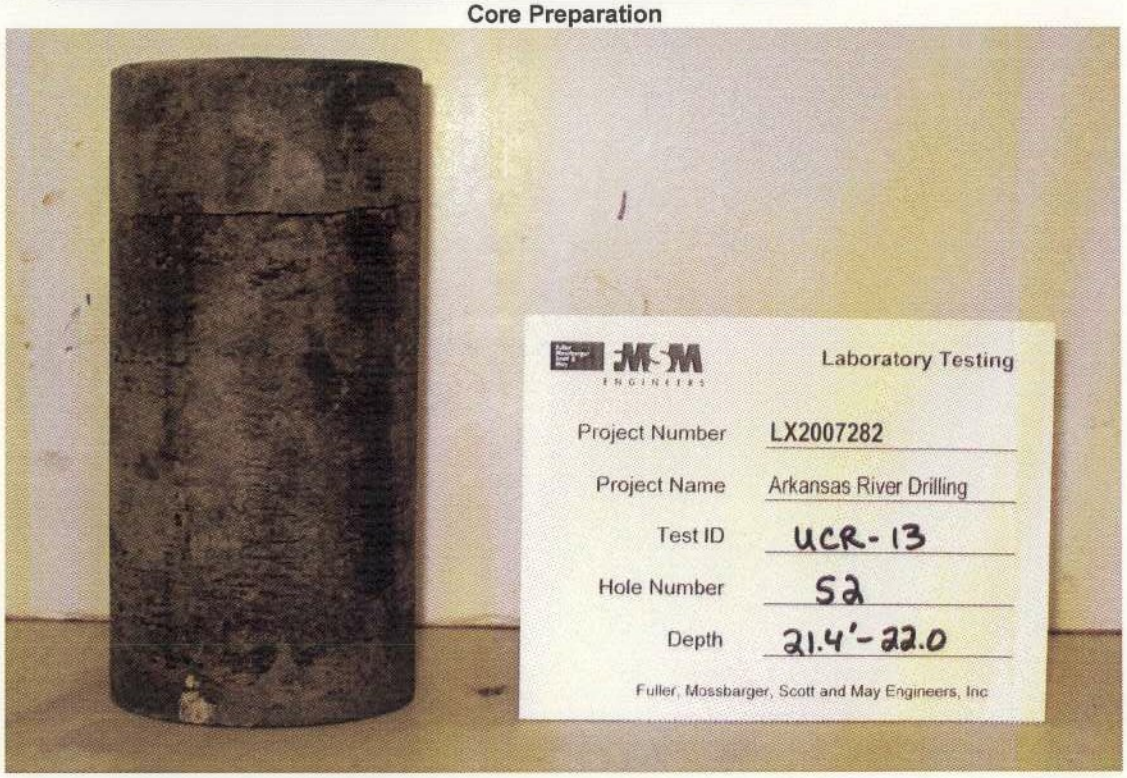
Fuller Mossbarger Scott & May ENGINEERS

Photo Report

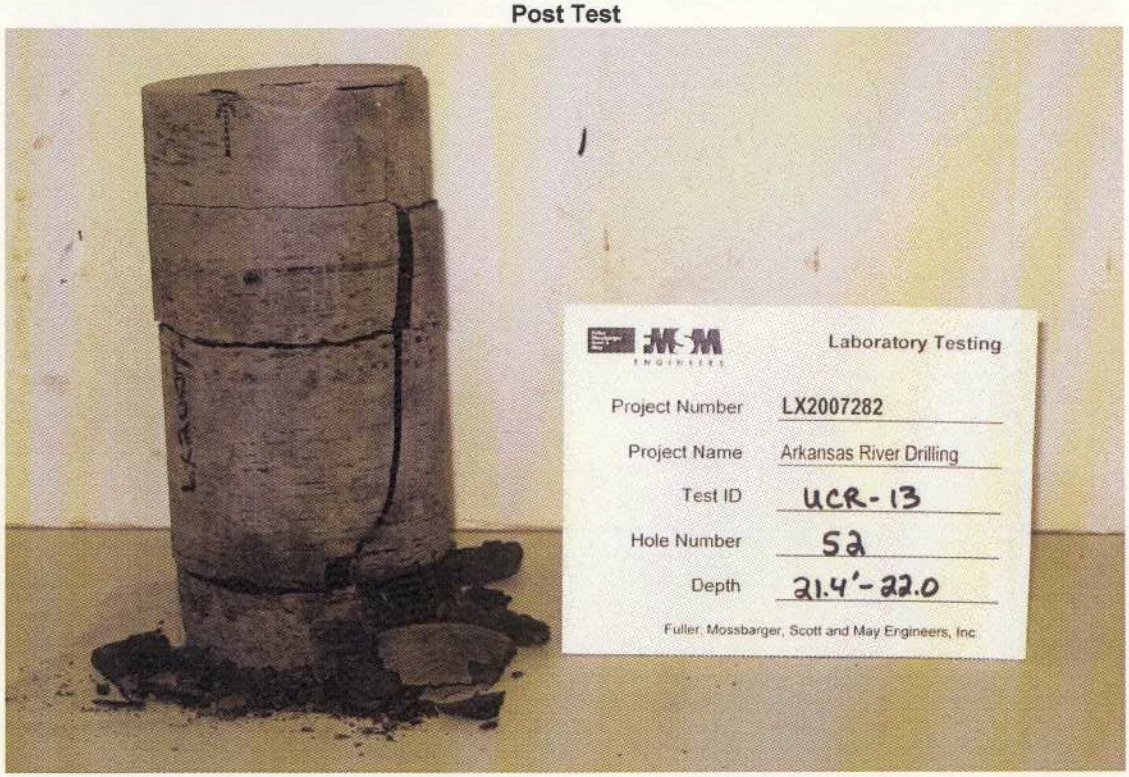
Project Name Arkansas River Drilling
Lithology Shale, dark gray, soft
Hole Number S2 Depth (ft) 21.4' - 22.0'
Test Type Unconfined compressive strength

Project Number LX2007282
Lab ID UCR-13

Core Preparation



Post Test

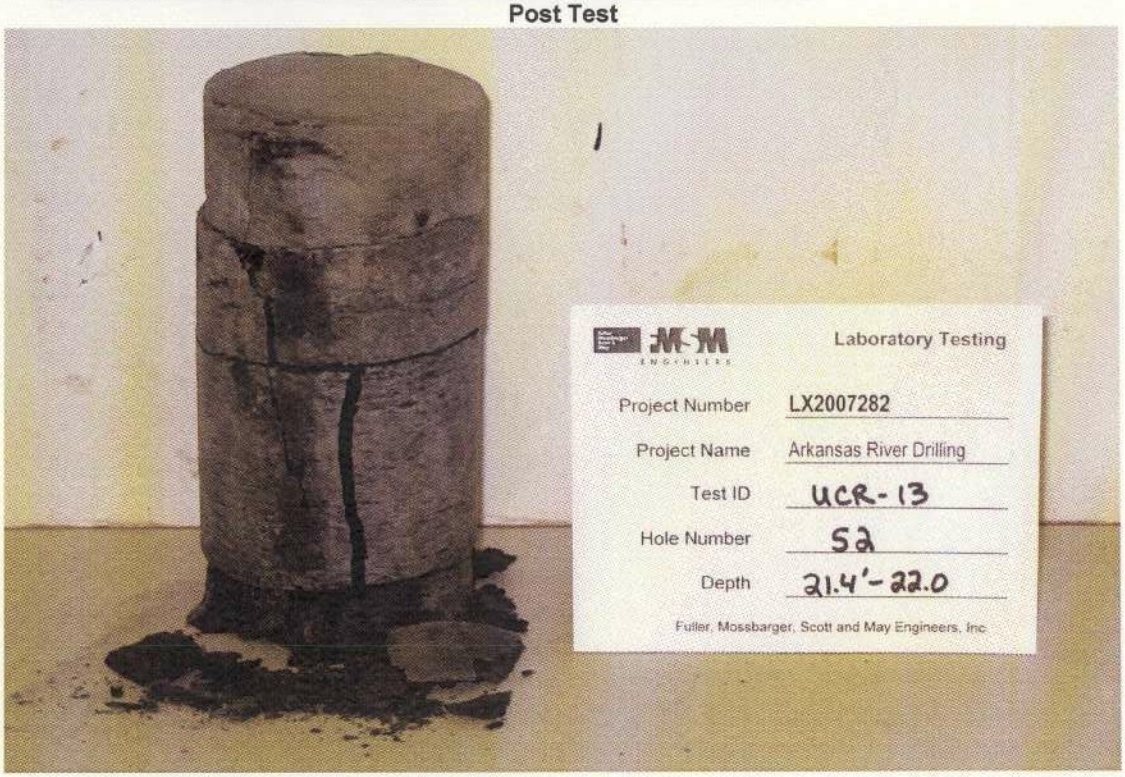


Fuller Mossbarger Scott & May ENGINEERS

Photo Report

Project Name Arkansas River Drilling
Project Number LX2007282
Lithology Shale, dark gray, soft
Lab ID UCR-13
Hole Number S2
Depth (ft) 21.4' - 22.0'
Test Type Unconfined compressive strength

Post Test



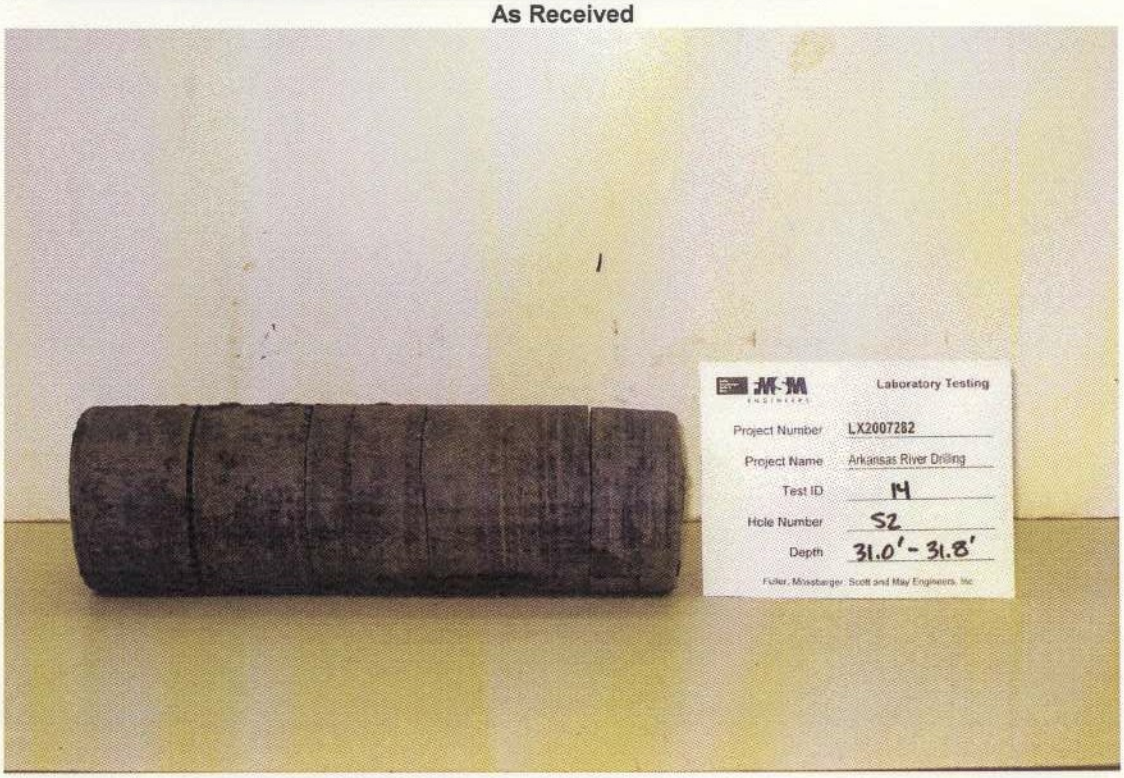
Fuller Mossbarger Scott & May ENGINEERS

Photo Report

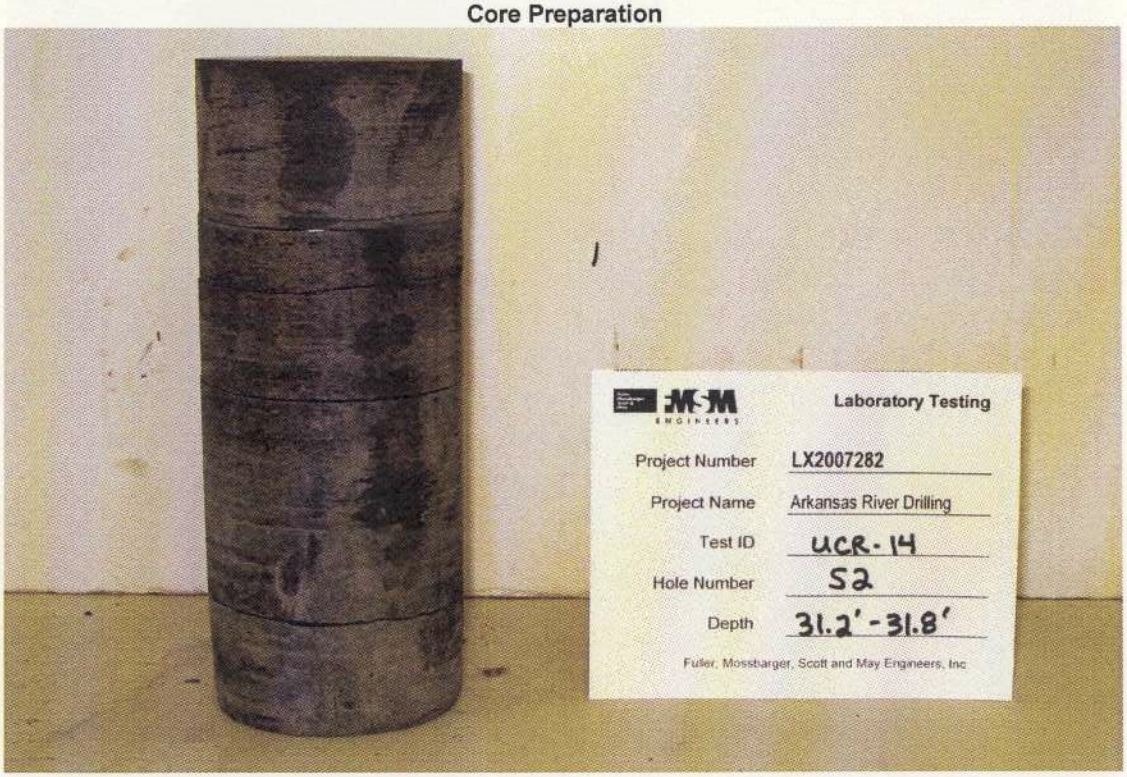
Project Name Arkansas River Drilling
Lithology Shale, dark gray, soft
Hole Number S2 Depth (ft) 31.2' - 31.8'
Test Type Unconfined compressive strength

Project Number LX2007282
Lab ID UCR-14

As Received



Core Preparation



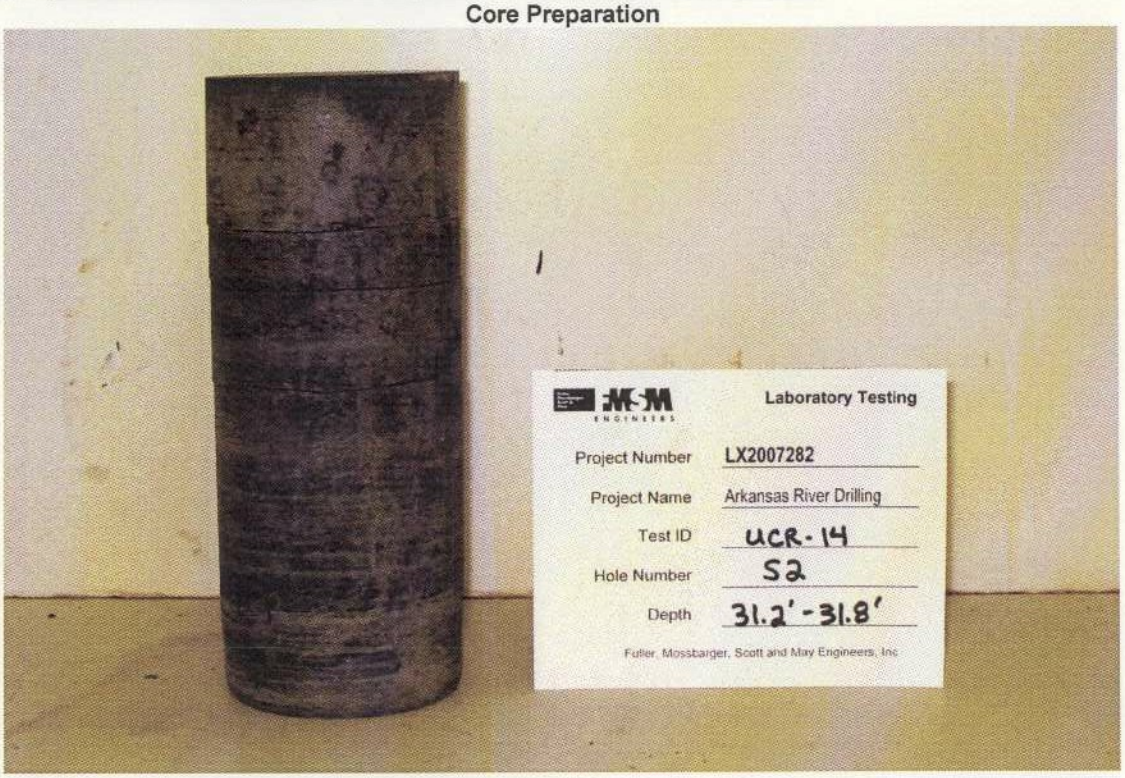
Fuller Mossbarger Scott & May ENGINEERS

Photo Report

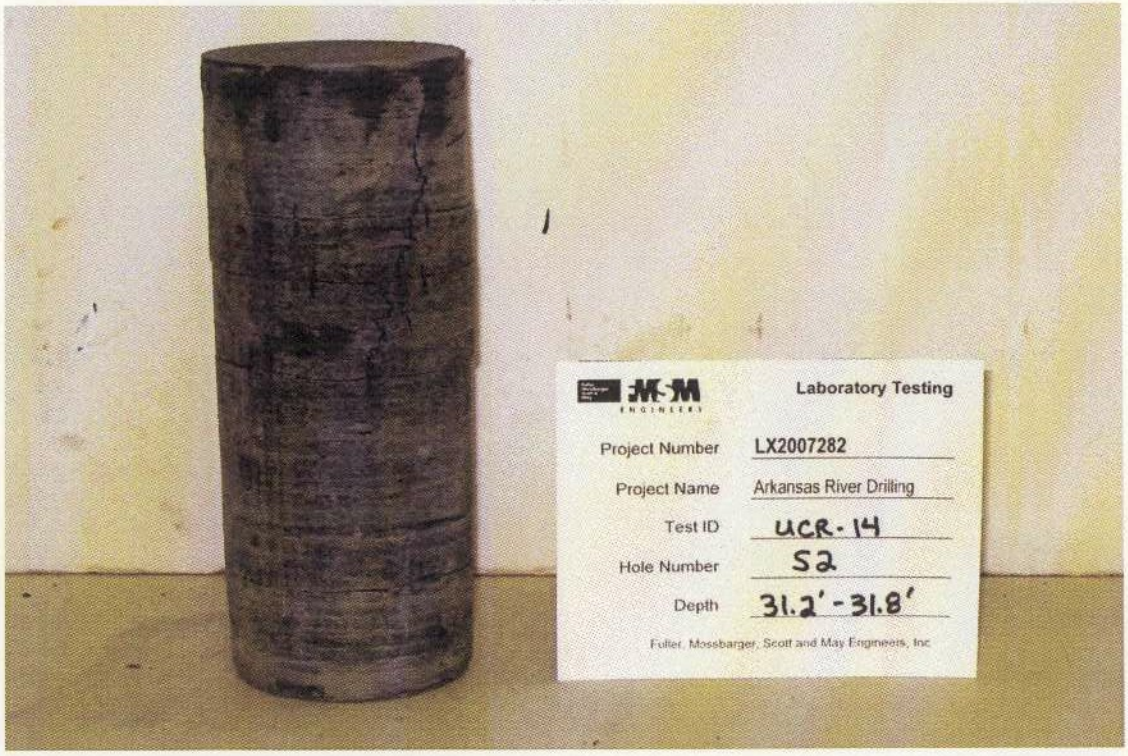
Project Name Arkansas River Drilling
Lithology Shale, dark gray, soft
Hole Number S2 Depth (ft) 31.2' - 31.8'
Test Type Unconfined compressive strength

Project Number LX2007282
Lab ID UCR-14

Core Preparation



Post Test

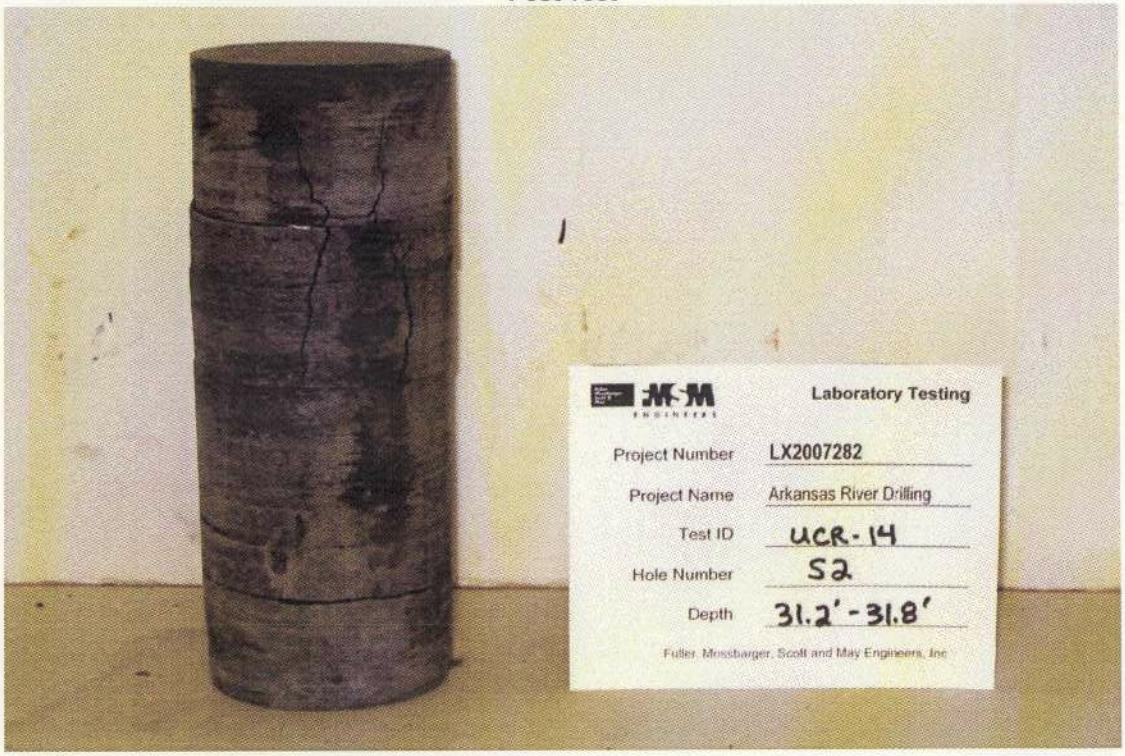


Fuller Mossbarger Scott & May ENGINEERS

Photo Report

Project Name Arkansas River Drilling
Project Number LX2007282
Lithology Shale, dark gray, soft
Lab ID UCR-14
Hole Number S2 Depth (ft) 31.2' - 31.8'
Test Type Unconfined compressive strength

Post Test



Fuller Mossbarger Scott & May ENGINEERS

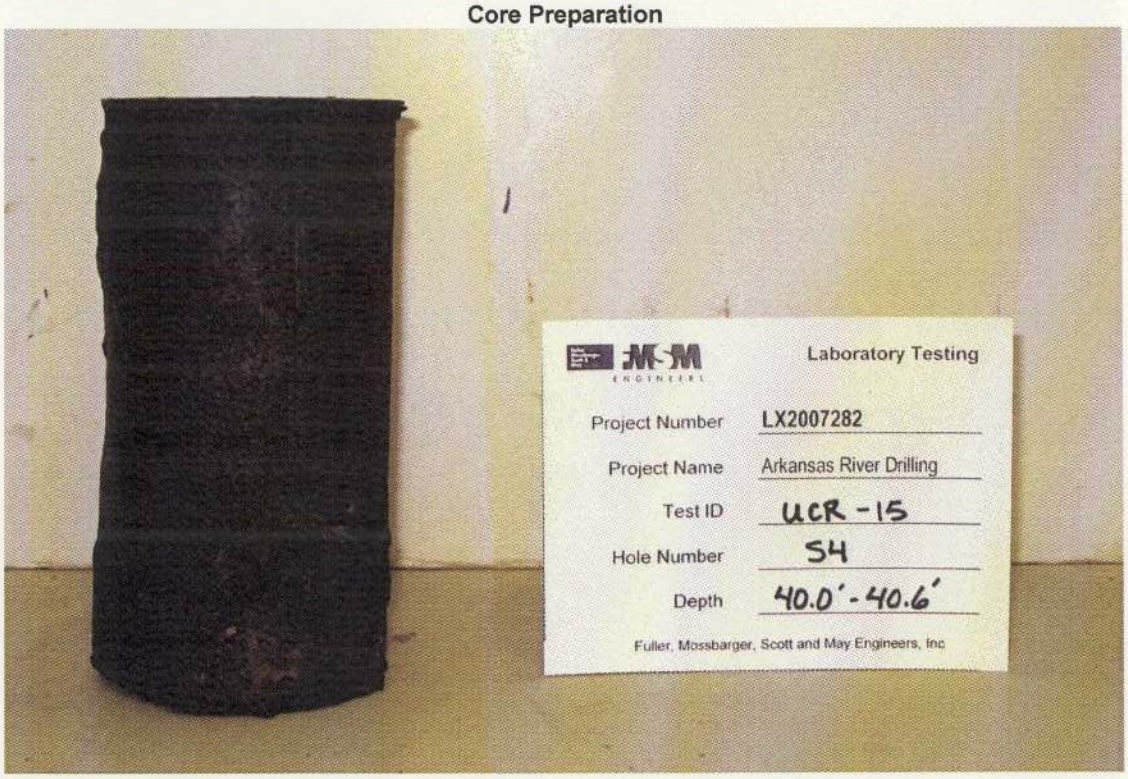
Photo Report

Project Name Arkansas River Drilling
Lithology Shale, dark gray, very soft
Hole Number S4 Depth (ft) 40.0' - 40.6'
Test Type Unconfined compressive strength

Project Number LX2007282
Lab ID UCR-15

As Received

Core Preparation



Fuller Mossbarger Scott & May ENGINEERS

Photo Report

Project Name Arkansas River Drilling
Lithology Shale, dark gray, very soft
Hole Number S4 Depth (ft) 40.0' - 40.6'
Test Type Unconfined compressive strength

Project Number LX2007282
Lab ID UCR-15

Post Test

Post Test

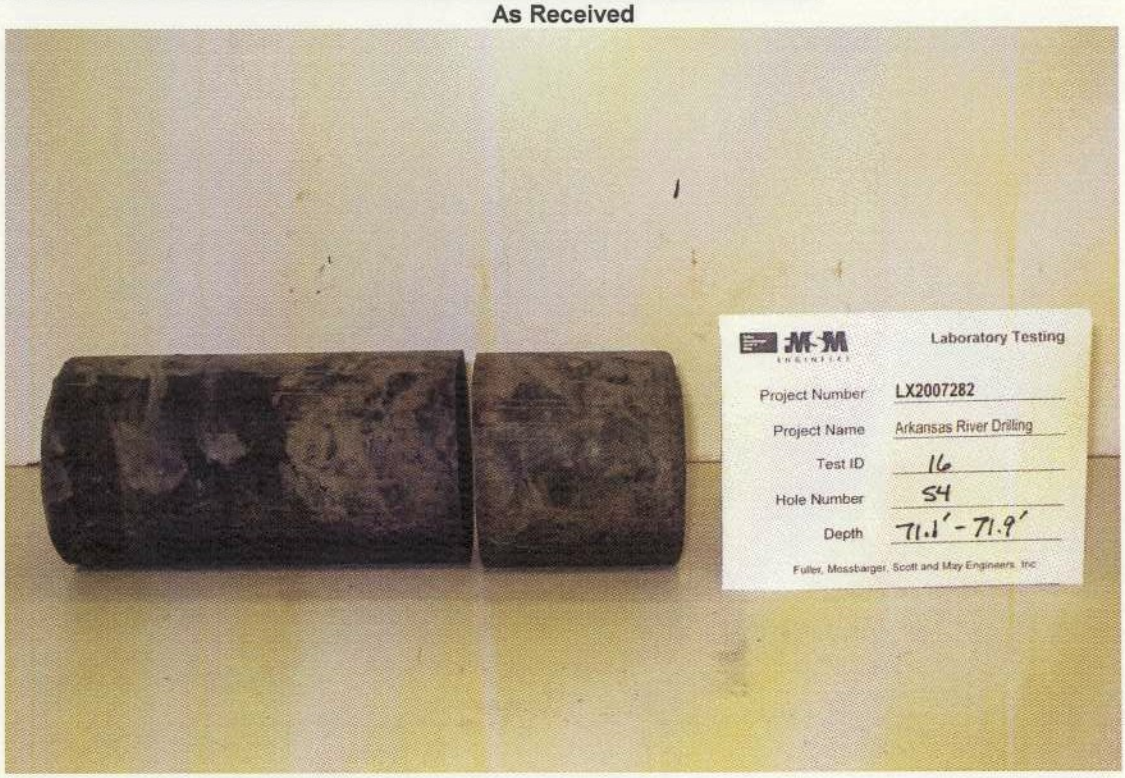
Fuller Mossbarger Scott & May ENGINEERS

Photo Report

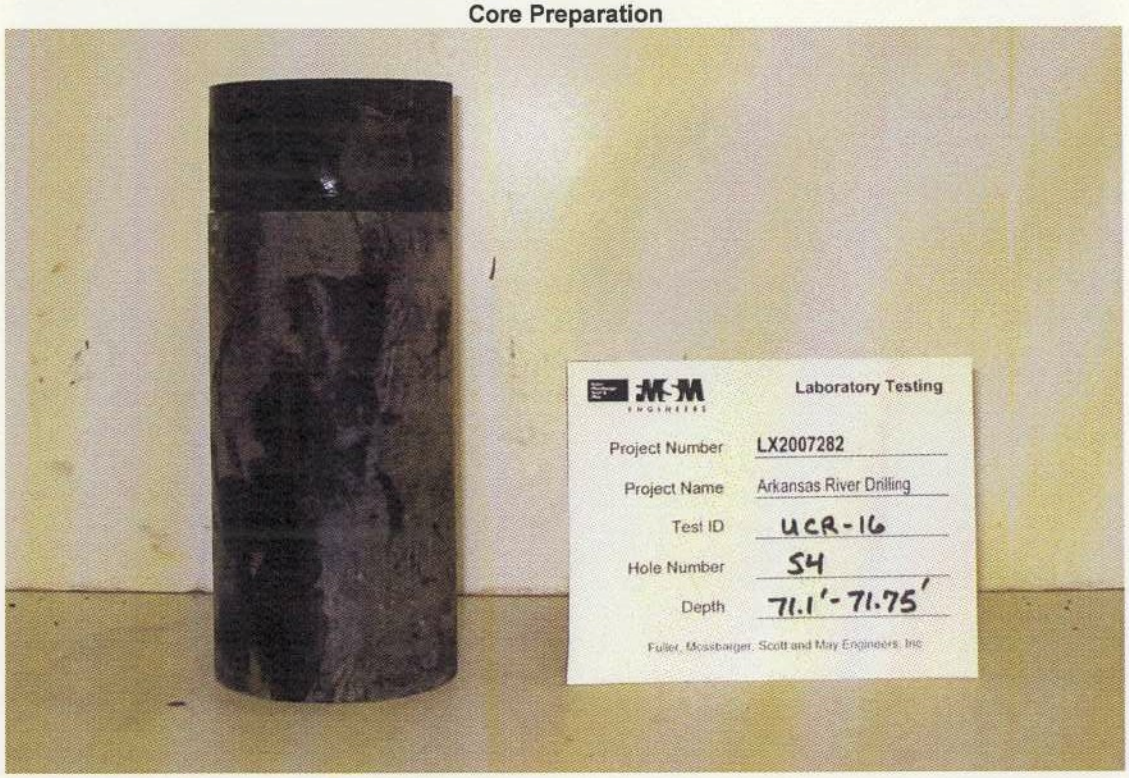
Project Name Arkansas River Drilling
Lithology Shale, dark gray, soft
Hole Number S4 Depth (ft) 71.10' - 71.75'
Test Type Unconfined compressive strength

Project Number LX2007282
Lab ID UCR-16

As Received



Core Preparation



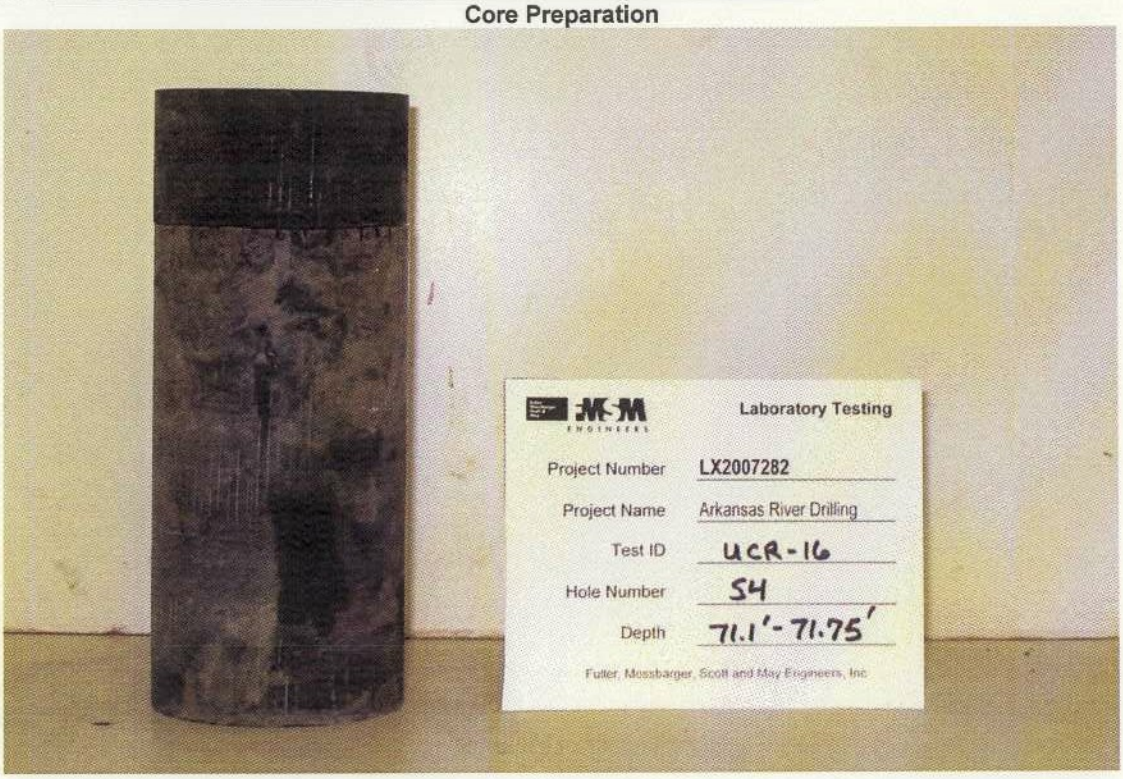
Fuller Mossbarger Scott & May ENGINEERS

Photo Report

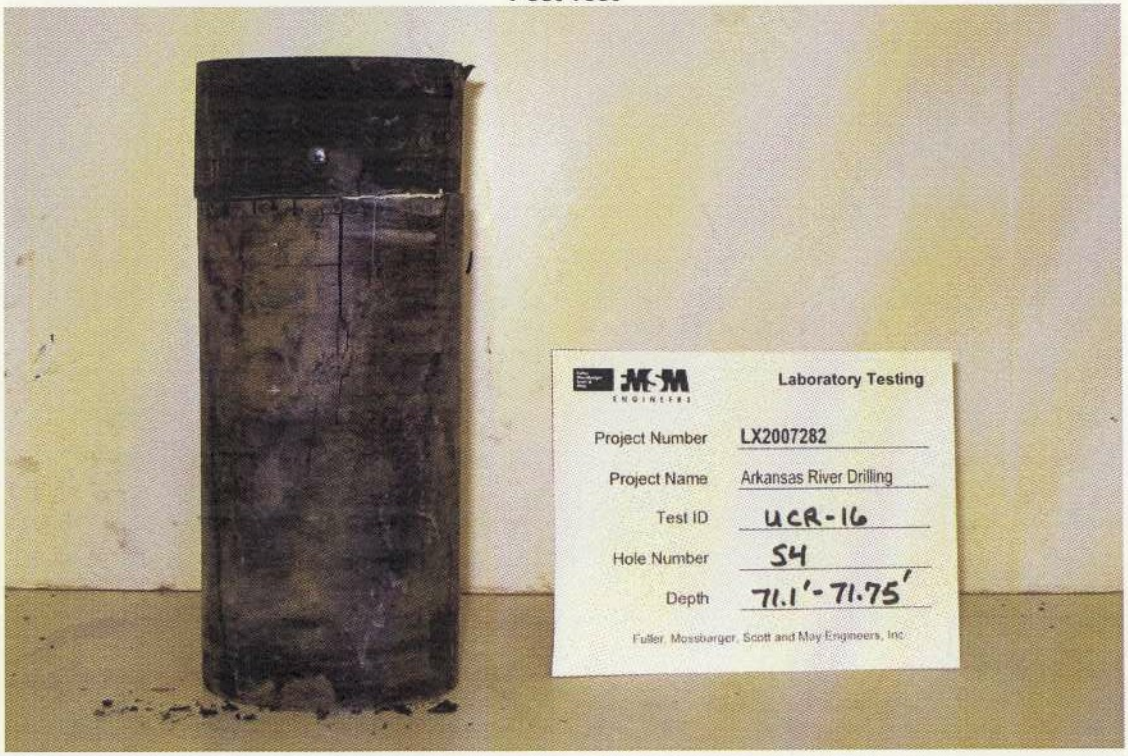
Project Name Arkansas River Drilling
Lithology Shale, dark gray, soft
Hole Number S4 Depth (ft) 71.10' - 71.75'
Test Type Unconfined compressive strength

Project Number LX2007282
Lab ID UCR-16

Core Preparation



Post Test



Fuller Mossbarger Scott & May ENGINEERS

Photo Report

Project Name Arkansas River Drilling
Lithology Shale, dark gray, soft
Hole Number S4 Depth (ft) 71.10' - 71.75'
Test Type Unconfined compressive strength

Project Number LX2007282
Lab ID UCR-16

Post Test

Photographs of Rock Core
(2008 borings)

Boring ID

S-1

Figure 1 -- 25-30 feet

Figure 2 – 30-35 feet

Figure 3 – 35-40 feet

Figure 4 – 40-45 feet

Figure 5 – 45-50 feet

Figure 6 – 50-55 feet

Figure 7 – 55-60 feet

Boring ID

S-2

Figure 1 – 10.5 - 15.5 feet

Figure 2 – 15.5 - 20.5 feet

Figure 3 – 20.5 - 25.5 feet

Figure 4 – 25.5 - 30.5 feet

Figure 5 – 30.5 - 35.5 feet

Figure 6 – 35.5 - 40.5 feet

Figure 7 – 40.5 - 45.5 feet

Figure 8 – 45.5 - 50.5 feet

Boring ID

S-4

Figure 1 – 35-40 feet

Figure 2 – 40-45 feet

Figure 3 – 45-50 feet

Figure 4 – 50-55 feet

Figure 5 – 55-60 feet

Figure 6 – 60-65 feet

Figure 7 – 65-70 feet

Figure 8 – 70-75 feet