Date:	6/20/13	Project:	French Creek Fish Barrier	Prepared By:	JJR
Rev. No.	0	Office:	Bozeman	Checked By:	JDE
Rev. Date:		Calc. No.	FC-FB-02	Approved By:	
Subject:	Geotechnical Analysis				

French Creek Fish Barrier: Geotechnical Stability

Table of Contents

1 Purpose And Objectives

The purpose of this calculation brief is to verify the proposed earthen embankment, to be built as part of the French Creek Fish Barrier, satisfies appropriate geotechnical design criteria. The analyses performed within this calculation brief are intended to provide a geotechnical assessment of the proposed design. In this light, the potential for slope failure, excessive seepage gradients and potential for unsuitable foundation materials are addressed. Design conditions are listed below with each design criteria expressed as minimum required Factors-of-Safety (FOS):

1) During and end construction slope stability, FOS > 1.3;
2) Long-term static slope stability, FOS > 1.5;
3) Pseudo-static seismic slope stability, FOS > 1.0 - 1.2;
4) Liquefaction Potential, FOS > 1.2; and
5) Piping Potential, FOS > 1.5.

2 Back ground

This report is intended to perform as an appendix to the Final Design Report for the French Creek Fish Barrier Design Documents and therefore the overall project background and objectives will not be discussed herein. Discussion of background and data will be limited to those items that are directly related to this evaluation. General data sources will be presented in this section whereas detailed discussions of data and interpretation will be presented in the Method Section of this report.

An earthen embankment is proposed as part of the French Creek Fish Barrier. The embankment is approximately 10 feet in height, a top width of 8 feet, and 3H:1V sides slopes. The fish barrier structure is approximately 175 feet, the entire width of the French Creek flood plain which is bounded by steep hillsides . The crest elevation of the embankment is 5911.93 feet.

The operational pool elevation upstream of the fish barrier is estimated just above 5907.19 feet, the weir crest elevation. The maximum pool elevation during the 100 year run-off event is designed to be 5910.92, one foot below the embankment crest. The tail-water elevation downstream of the fish barrier is designed anticipated to be approximately 5902.08 feet during the 100-year design event. Therefore the maximum head differential across the embankment is estimated to be 8.84 feet.

The embankment crest elevation and maximum pool elevation used in this report are slightly higher than those discussed above. This evaluation assumes an embankment elevation of 5912.25 ft and a 100-year pool elevation of 5911.25 ft. The difference of 0.3 feet will not significantly affect the results and conclusion of this analsysis.

3 METHODS

Geotechnical evaluation of the proposed earthen embankment was performed to determine whether the proposed structure would be geotechnically stable during the construction and operational period. The analyses considers five design criteria address the embankment during critical periods during the life of the structure. These scenarios were based the understood standards of practice for engineered embankments. Site conditions and material characteristics were interpreted from published geologic maps, site observations, and laboratory testing.

3.1 Design Basis

Five design conditions were defined, as introduced previously, the conditions are as follows:

1) During and end construction, FOS > 1.3;
2) Long-term static slope stability, FOS > 1.5;
3) Pseudo-static seismic slope stability, FOS > 1.0 - 1.2;
4) Liquefaction Potential, FOS > 1.2; and
5) Piping potential, FOS > 1.5.

3.2 Site Conditions

As reported by the Montana Bureau of Mines and Geology (MBMG), geologic maps encompassing the proposed site suggest the immediate geology consists of Middle Proterozoic deposits of the Missoula Group. In brief, the Missoula Group is described as interlayered quartzite and siltite. Based on field observations, the creek deposits are likely a coarse grained alluvial gravel system interbedded with colluvium from the adjacent hillsides, overlaid with 1-2 feet of organics and vegetation. The native bedrock is possibly shallow in this reach of the creek, quartzite and siltite are relatively very resistant to erosion. Therefore the alluvial gravel may be relatively shallow and shallow bedrock may create an impermeable boundary beneath the embankment.

Nearby to the Northwest, in an adjacent creek bed and hillside, are Pleistocene glacial deposits, described as poorly sorted bouldery gravel and sand deposited by glacial melt water.

3.3 Stability Model and Parameters

3.3.1 Material Characteristics

Two potential borrow sources were identified for the compacted embankment fill material. The first borrow source is located 3.5 miles to the northeast along Big Hole Road, and is labeled source #1. The second borrow sources is located 4.5 miles to the northeast along Big Hole Road and is labeled source #2. Laboratory testing was performed on bulk samples retrieved from the borrow sources. The following laboratory tests were performed on the bulk samples:

1) Particle Size Analysis (ASTM D422);
2) Standard Proctor Compaction (ASTM D698); and
3) Ridgid-wall permeability (ASTM D5856).

Source #1 is classified as a poorly graded gravel with silt and sand (GP-GM). The maximum dry density is 142.5 pcf with an optimum moisture content of 5.4%. The hydraulic conductivity for a specimen compacted to 95% of the Standard Proctor density is 5.39 ft/day. Source #2 is classified as a Poorly Graded Gravel with Sand (GP). The maximum corrected dry density is 132.2 pcf with an optimum moisture content of 8.3%. The hydraulic conductivity for a specimen compacted to 95% of the Standard Proctor density is equal to 2.3 feet/day. Laboratory data sheets are included in Attachment A. A conservative friction angle of 32 degrees is assumed for the compacted embankment fill (Sources #1 or #2). For a well compacted GP-GM or GP, compacted to 95% of the standard proctor, a conservative friction angle is 35 degrees.

Based on site observations, the *in-situ* foundation materials are probably alluvial gravels. The alluvial gravels are anticipated to have been deposited directly onto the native bedrock. Typical horizontal hydraulic conductivity values for an alluvial gravel deposit may range between 350 – 750 feet per day, where the vertical hydraulic conductivity may be 20% of the horizontal. Typical strength characteristics of alluvial gravel ranges between 32 – 37 degrees. Since the density and character of the materials is unknown, a conservative value of 32 degrees is used for the stability analyses

3.3.2 Seepage Evaluation

A steady state seepage model was used to estimate the elevation of the steady state phreatic surface through the embankment and the magnitude of the vertical hydraulic gradient at the toe. SeepW/, a 2D finite element seepage program, was used for the calculations. The model assumes the maximum water surface elevation of 5,911.25 (5910.92 final design El.) feet on the upstream side, one foot beneath the embankment crest. The steady state analysis assumes the maximum water surface elevation is maintained long enough for steady state seepage to develop through the embankment.

An example of the estimated steady state phreatic surface is shown in Attachment B, this phreatic surface is incorporated into the Long-term slope stability calculations discussed in the next section. Gradients calculated near the toe of the embankment are used to estimate the vertical seepage gradients. Several models were performed to check the sensitivity of the toe gradient to the foundation permeability and conductive thickness. A gradient equal to unity, is the limit of vertical equilibrium. The calculated FOS against piping, is therefore, the inverse of the hydraulic gradient. The calculated FOS against piping at the toe of the embankment ranges between 3.0 to 4.0 for a range of foundation conductivities and thicknesses. Attachment B includes a table summarizing the calculated FOS's for the respective thicknesses and hydraulic conductivity.

3.3.3 During/End of Construction Evaluation

Rapid excavation or fill placement in/on soft low permeable materials can result in the buildup of excess pore water pressures. Excess pore water pressure reduces material strength and may cause slope or bearing failure during and immediately after construction. The materials beneath the proposed embankment are anticipated to be relative dense and permeable alluvial gravels; therefore, excess pore water pressure is not anticipated. The anticipated foundation material precludes the necessity of a during construction stability evaluation.

3.3.4 Long-term Stability Evaluation

The FOS against slope failure for the proposed embankment was calculated using the limiting equilibrium slope stability software Slope/W. The phreatic surface estimated for the maximum pool elevation was used along with the previously discussed strength characteristics. The resulting calculated FOS (FOS=1.6) exceeds the recommended minimum of 1.5. Model output is included in Attachment B.

3.3.5 Pseudo-Static Seismic Evaluation

Based on design guidance set forth in Chapter 7520 of the Forest Service Manual, Dam Planning, Investigation, and Design, a detailed seismic analysis is not performed for the following reasons:

1) Anticipated foundation materials beneath the embankment are not anticipated to be subject to liquefaction, as discussed above, they likely medium dense alluvial gravels;
2) The embankment fill material is specified to be compacted to 95% of the standard proctor:
3) The embankment slope are equal to or flatter than 3H:1V;
4) For this site location the maximum horizontal bedrock (lithified material) acceleration is 0.07g for the 10% probability of exceedance in 50 year earthquake (USGS). The peak ground acceleration is used to estimate the seismic coefficient, k_s, which is used in the Limit Equilibrium slope stability model. (EPA, 1995 and Duncan and Wright, 2005)

   $$k_s = 0.5 * a_{max}$$

   Therefore, the seismic coefficient used to evaluate stability of the foundation materials is, k_s = 0.035g. The estimated seismic coefficient is less than 0.20g.
5) The static long-term factor of safety is greater than 1.5, Section 3.3.4;
6) The free board at the time of the earthquake is at least 3 to 5 percent of the embankment height. The free board for the 100-year design flow is one foot. Approximately 10% of the embankment height.

4 RESULTS AND DISCUSSION

Of the recommended geotechnical design conditions, FOS's were calculated for the two most critical, piping and long-term slope stability, FOS = 3.0 and FOS = 1.6, respectively. The calculated FOS's for these two conditions exceeded recommended minimum values of 1.5, for both. The remaining conditions were discussed above and rigorous analyses were preempted.

The results of this analysis provides an evaluation of the geotechnical stability of the proposed embankment to be built as part of the French Creek Fish Barrier. The assumptions made in this analysis should be confirmed during construction by a competent geotechnical engineer.

5 REFERENCES

Duncan, J.M. and Wright, G. (2005). Soil Strength and Slope Stability, John Wiley and Sons, Inc. Hoboken, New Jersey.

United States E.P.A. (1995). RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities, Office of Research and Development, Washington D.C.

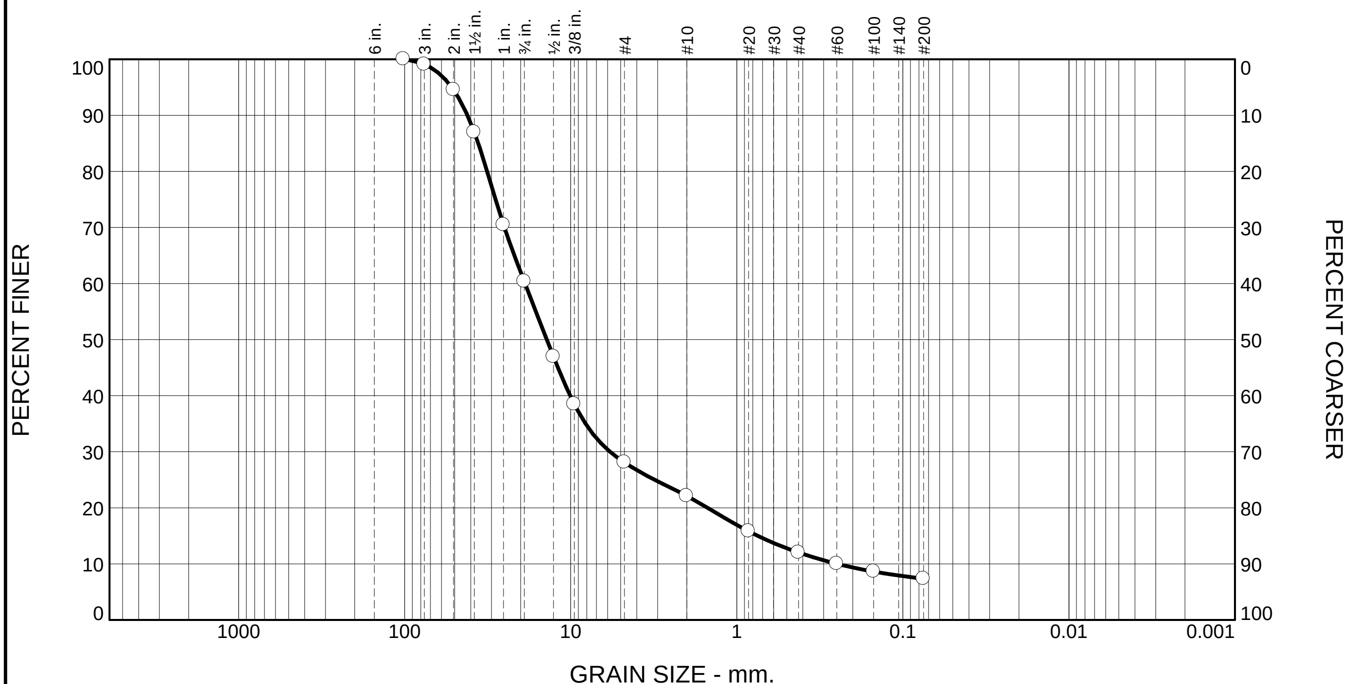
U.S. Forest Service (2011). FSM 7500 - Water Storage and Transmission, Chapter 7520 – Dam Planning, Investigation, and Design.

6 DOCUMENT REVISION SUMMARY

Revision No.	Author	Version	Description	Date
Rev 0	JR	0	Preliminary Evaluation	6/21/13
Rev 1				

ATTACHMENT A

Particle Size Distribution Report



% +3"	% Gravel Coarse	% Gravel Fine	% Sand Coarse	% Sand Medium	% Sand Fine	% Fines Silt	% Fines Clay
1	39	32	6	10	5	7	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
4"	100		
3"	99		
2"	95		
1 1/2	87		
1"	70		
3/4"	60		
1/2"	47		
3/8"	38		
#4	28		
#10	22		
#20	16		
#40	12		
#60	10		
#100	9		
#200	7.4		

* (no specification provided)

Material Description

Atterberg Limits (ASTM D 4318)

PL= LL= PI=

Classification

USCS (D 2487)= AASHTO (M 145)=

Coefficients

D_{90}= 41.8834 D_{85}= 36.0670 D_{60}= 18.8368
D_{50}= 13.9391 D_{30}= 5.7976 D_{15}= 0.7483
D_{10}= 0.2477 C_u= 76.04 C_c= 7.20

Remarks

Date Received: 5-13-13 **Date Tested:** 5-21-13

Tested By: LD/NG

Checked By: NG

Title:

Source of Sample: Source 1 **Date Sampled:** 5-12-13

Sample Number: G13578

Pioneer Technical Services, Inc.

106 Pronghorn Trail, Suite A - Bozeman, MT 59718

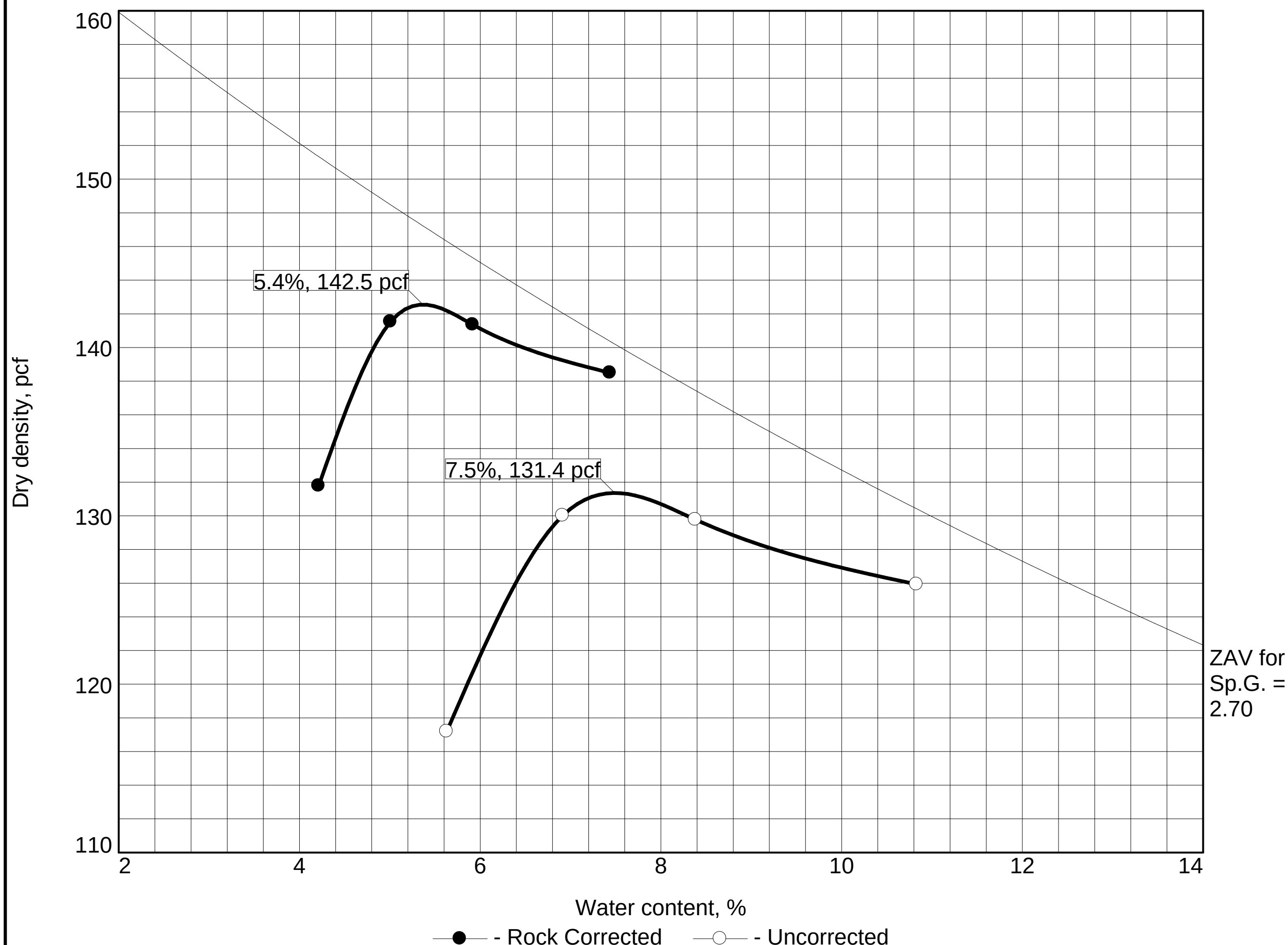
Ph. 406-388-8578 - Fax 406-388-8579

Client:

Project: French Creek Fish Barrier

Project No: **Figure**

COMPACTION TEST REPORT



Test specification: ASTM D 698-07 Method C Standard
ASTM D 4718-87 Oversize Corr. Applied to Each Test Point

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > 3/4 in.	% < No.200
	USCS	AASHTO						
				2.65			38	7.6

ROCK CORRECTED TEST RESULTS	UNCORRECTED	MATERIAL DESCRIPTION
Maximum dry density = 142.5 pcf	131.4 pcf	
Optimum moisture = 5.4 %	7.5 %	

Project No. **Client:**

Project: French Creek Fish Barrier

Source of Sample: Source 1 **Sample Number:** G13578

Remarks:
Specific gravity is assumed

Pioneer Technical Services, Inc.
106 Pronghorn Trail, Suite A - Bozeman, MT 59718
Ph. 406-388-8578 - Fax 406-388-8579

Figure

Tested By: LD **Checked By:** NG

HYDRAULIC CONDUCTIVITY FOR RIGID-WALL TEST SAMPLES
FALLING HEAD Method D
ASTM D 5856

Client:

Project: French Creek Fish Barrier

Sample Source #1

Specific Gravity: **2.65**

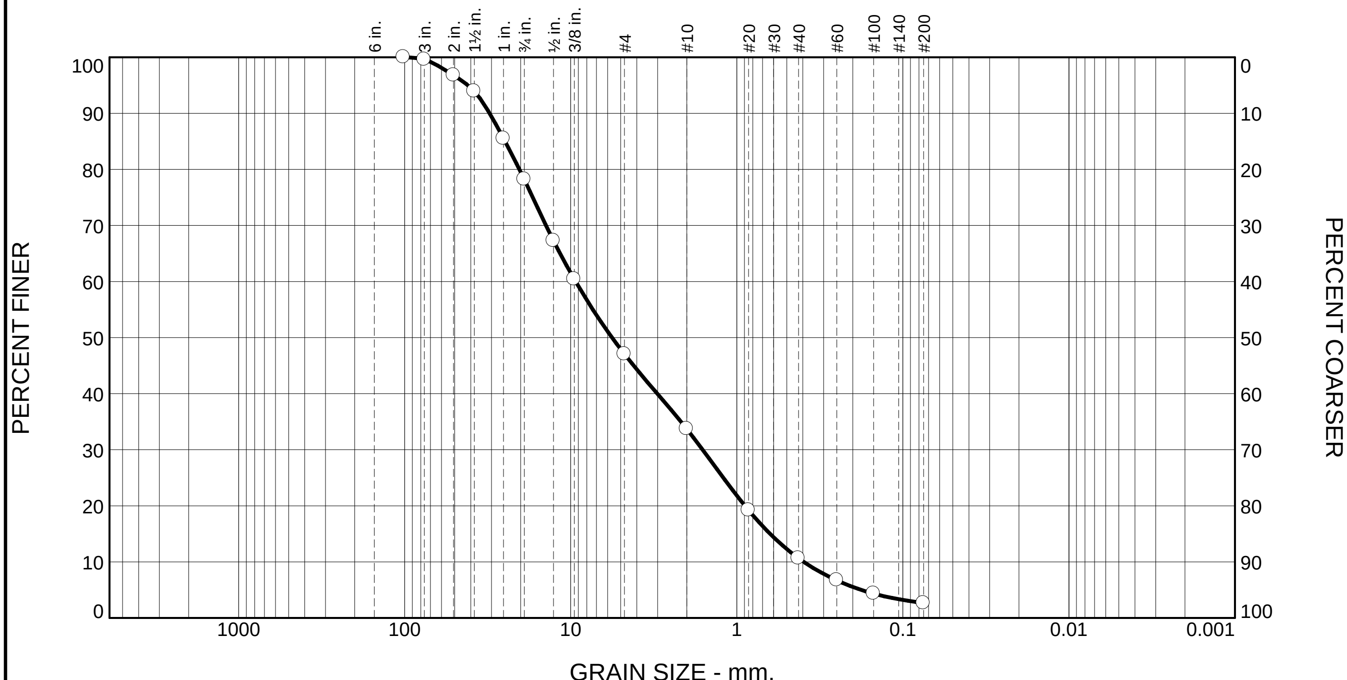
Dry Density (pcf):	124.8	% Max. ASTM D-698: 95%		
Specimen Length (cm):	11.64	Specimen Diameter (cm):	15.24	Area of Standpipe (cm^2): 0.912
Height Burrett bottom to bench (cm)	40.64	Height Outlet Above Bench (cm):	25.4	
Length of Burrett Scale (cm)	54.5			

Increment Number	Initial Reading Influent (cm^3)	Final Reading Influent (cm^3)	Time Increment (min.)	Applied Pressure Differential (psi)	Initial Head (cm)	Final Head (cm)	Average Hydraulic Gradient (cm/cm)	Hydraulic Conductivity (cm/sec)	Hydraulic Conductivity at 20 C (cm/sec)
1	0	45.1	0.68	0.0	69.74	19.59	3.84	1.8E-03	1.9E-03
2	0.1	45	0.68	0.0	69.63	19.70	3.84	1.8E-03	1.8E-03
3	0	45.2	0.68	0.0	69.74	19.48	3.83	1.8E-03	1.9E-03
4	0	45	0.68	0.0	69.74	19.70	3.84	1.8E-03	1.8E-03
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20	Average Hydraulic Conductivity of Last Four Test Increments =					**1.9E-03**	**cm/sec**		
21	k = (aL/At) ln (h1/h2)								
22									
23									
24									
25									

Water Content Before Test	
Tare #	
Wet Soil + Tare	4548
Dry Soil + Tare	4248
Tare Weight	0
Water Content	7.06
Source	Specimen

Water Content After Test	
Tare #	
Wet Soil + Tare	4966
Dry Soil + Tare	4592
Tare Weight	406.2
Water Content	8.93
Source	Sample

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	22	31	13	23	8	3	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
4"	100		
3"	100		
2"	97		
1 1/2	94		
1"	86		
3/4"	78		
1/2"	67		
3/8"	60		
#4	47		
#10	34		
#20	19		
#40	11		
#60	7		
#100	4		
#200	2.7		

* (no specification provided)

Material Description

poorly graded gravel with sand

Atterberg Limits (ASTM D 4318)

PL= **LL=** **PI=**

Classification

USCS (D 2487)= GP **AASHTO (M 145)=**

Coefficients

D_{90}= 30.7764 D_{85}= 24.8688 D_{60}= 9.3426
D_{50}= 5.6392 D_{30}= 1.6057 D_{15}= 0.6294
D_{10}= 0.3953 C_u= 23.63 C_c= 0.70

Remarks

Date Received: 5/13/13 **Date Tested:** 5/20/13
Tested By: LD/NG
Checked By: NG
Title:

Source of Sample: Source #2 **Date Sampled:** 5/12/13
Sample Number: G13579

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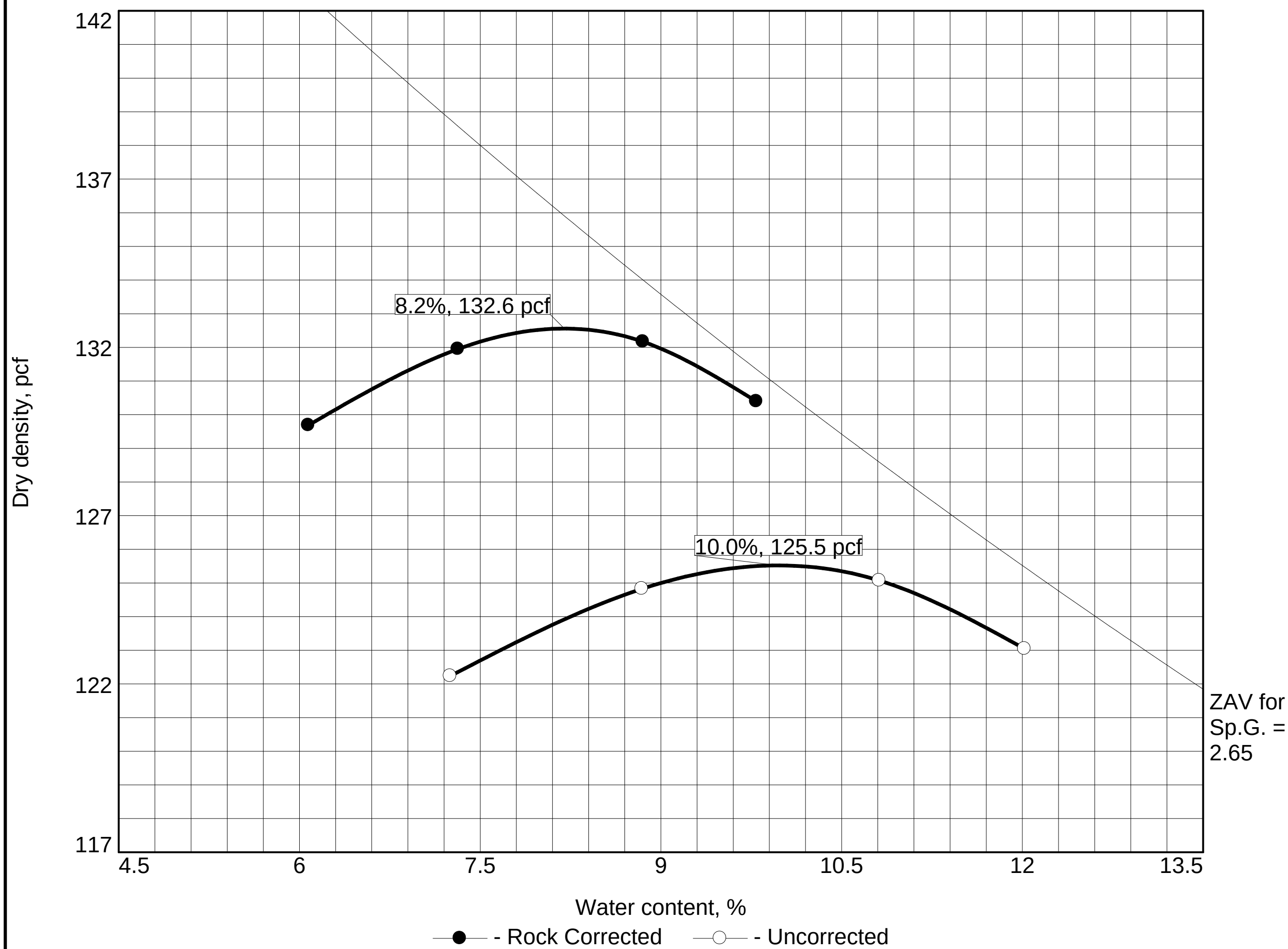
106 Pronghorn Trail, Suite A - Bozeman, MT 59718
Ph. 406-388-8578 - Fax 406-388-8579

Client:
Project: French Creek Fish Barrier

Project No: **Figure**

COMPACTION TEST REPORT



Test specification: ASTM D 698-07 Method C Standard
ASTM D 4718-87 Oversize Corr. Applied to Each Test Point

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > 3/4 in.	% < No.200
	USCS	AASHTO						
	GP			2.65			22	2.7

ROCK CORRECTED TEST RESULTS	UNCORRECTED
Maximum dry density = 132.6 pcf	125.5 pcf
Optimum moisture = 8.2 %	10.0 %

MATERIAL DESCRIPTION

poorly graded gravel with sand

Project No. **Client:**

Project: French Creek Fish Barrier

Source of Sample: Source #2 **Sample Number:** G13579

Remarks:

Specific gravity is assumed

Pioneer Technical Services, Inc.
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Figure

Tested By: NG **Checked By:** NG

HYDRAULIC CONDUCTIVITY FOR RIGID-WALL TEST SAMPLES

FALLING HEAD Method D

ASTM D 5856

Client: | Project: French Creek Fish Barrier

Sample: Source #2

Specific Gravity: **2.65**

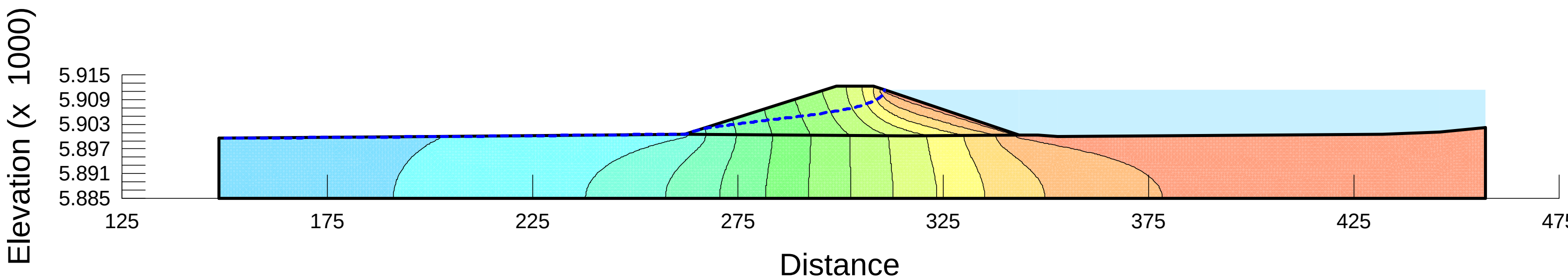
Dry Density (pcf):	119.2	% Max. ASTM D-698:	95%		
Specimen Length (cm):	11.64	Specimen Diameter (cm):	15.24	Area of Standpipe (cm^2):	0.912
Height Burrett bottom to bench (cm)	40.64	Height Outlet Above Bench (cm):	25.4		
Length of Burrett Scale (cm)	54.5				

Increment Number	Initial Reading Influent (cm^3)	Final Reading Influent (cm^3)	Time Increment (min.)	Applied Pressure Differential (psi)	Initial Head (cm)	Final Head (cm)	Average Hydraulic Gradient (cm/cm)	Hydraulic Conductivity (cm/sec)	Hydraulic Conductivity at 20 C (cm/sec)
1	0	45	1.53	0.0	69.74	19.70	3.84	8.0E-04	8.0E-04
2	0	45	1.62	0.0	69.74	19.70	3.84	7.6E-04	7.6E-04
3	0	45	1.83	0.0	69.74	19.70	3.84	6.7E-04	6.7E-04
4	0	45	1.86	0.0	69.74	19.70	3.84	6.6E-04	6.8E-04
5	0	45	1.53	0.0	69.74	19.70	3.84	8.0E-04	8.0E-04
6	0	45	1.58	0.0	69.74	19.70	3.84	7.8E-04	7.8E-04
7	0	45	1.43	0.0	69.74	19.70	3.84	8.6E-04	8.6E-04
8	0	45	1.52	0.0	69.74	19.70	3.84	8.1E-04	8.1E-04
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20	Average Hydraulic Conductivity of Last Four Test Increments =					**8.1E-04**	**cm/sec**		
21	k = (aL/At) ln (h1/h2)								
22									
23									
24									
25									

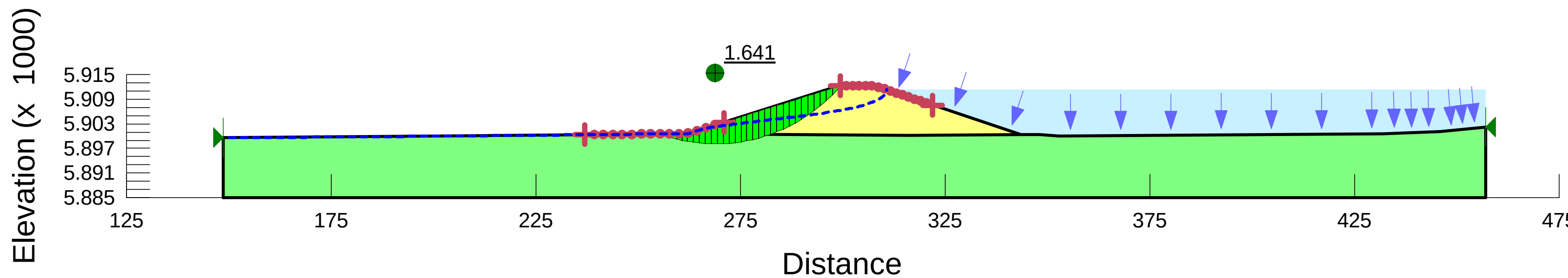
Water Content Before Test	
Tare #	
Wet Soil + Tare	4452
Dry Soil + Tare	4059.5
Tare Weight	0
Water Content	9.67
Source	Specimen

Water Content After Test	
Tare #	
Wet Soil + Tare	4902
Dry Soil + Tare	4445
Tare Weight	407.5
Water Content	11.32
Source	Sample

ATTACHMENT B



Elevation (x 1000)
5.915
5.909
5.903
5.897
5.891
5.885
125
175
225
275
325
375
425
475
Distance


1.641
Elevation (x 1000)
5.915
5.909
5.903
5.897
5.891
5.885
125
175
225
275
325
375
425
475
Distance