Alaska Department of Transportation & Public Facilities

Dalton Highway 9 to 11 Mile
Expedient Resistivity Permafrost Investigation

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13. ABSTRACT (Maximum 200 words)

This project performed capacitive coupled resistivity surveys over a roadway reconstruction project in Interior Alaska, for the determination of permafrost extent. The objective was to ascertain the ability of an expedient earth resistivity survey system to effectively obtain permafrost information to be utilized for design. This section of roadway traverses ice-rich discontinuous permafrost terrain, and to prevent costly long term thaw-settlement, thermal mitigation was included in the form of subsurface extruded polystyrene rigid board insulation. To insure optimal installation of the thermal protection, an effective method was needed to determine the location and depth of frozen soil. Two transects were surveyed along the existing roadway surface for nearly the full length of the project. In addition, continuous soil samples were drilled at select portions of the project for ground-truth of the survey results. Lastly, sub-grade soils samples were collected during excavation of the ice-rich cuts areas for further correlation with survey results.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
	AREA			
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
	VOLUME			
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
	TEMPERATURE (exact degrees)			
^{o}F	Fahrenheit	5 (F-32)/9	Celsius	^{o}C
	or (F-32)/1.8			
	ILLUMINATION			
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm^2	square millimeters	0.0016	square inches	in^2 m^2
square meters		10.764	square feet	ft^2 m^2
square meters		1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
	VOLUME			
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3 m^3
	cubic meters	1.307	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
	TEMPERATURE (exact degrees)			
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Expedient Permafrost Resistivity Investigation

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Preface

This report and field work were completed by Kevin Bjella, Research Civil Engineer, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), and performed under a Cooperative Research and Development Agreement with Alaska DOT&PF.

The author gratefully acknowledges Alaska DOT&PF personnel for their support during the field work of this project. The author would also like to thank Dr. Edel Cortez (CRREL) for his review of this report, and Marc Beede (CRREL) and Art Gelvin (CRREL) for their valuable field assistance.

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1. EXECUTIVE SUMMARY

Ground ice is detectable with surface based geophysical methods. Measuring the electrical resistivity of earth materials (sediments and rock) allows for accurate delineation between frozen vs. thawed materials, and ice-rich vs. ice-poor materials. This application is particularly useful for determining the gross ground ice content of permafrost. The goal of this project was to determine if capacitive-coupled earth resistivity (CCR) could be utilized to determine the optimal locations and depth for thaw-prevention measures to be installed on a roadway reconstruction project in Interior Alaska. This project demonstrated that CCR can efficiently be utilized to determine areal extent and depth to permafrost under an roadway embankment, and the information can be effectively presented to aid project planners and engineers dealing with permafrost issues in roadway design.

2. INTRODUCTION

Frozen earth materials generally have greater electrical resistance than non-frozen earth materials, and in the case of permanently frozen soil, or permafrost, the resistivity is magnitudes higher than non-frozen or thawed soils. Traditionally, electrical earth resistivity is measured by inserting electrodes into the soil along a limited distance transect, which is time consumptive for long distance surveys. Capacitive-coupled earth resistivity allows for the rapid acquisition of subsurface electrical resistivity measurements. It has been shown that CCR will allow for distinguishing between ice-rich vs. ice-poor permafrost, and frozen vs. non-frozen soils (Bjella 2013 and 2013b; Calvert 2002; De Pascale 2008). However it is not well understood if the resolution of this system can provide a cost effective tool that could be used during design and/or re-construction of linear engineering projects. For these types of infrastructure projects, depth to permafrost, ice content, and lateral extent must be adequately quantified to insure costly thaw-settlement does not occur.

In the summer of 2012, the Alaska Department of Transportation (AKDOT&PF), Northern Regions Office partnered with the Cold Regions Research and Engineering Laboratory (CRREL) to undertake a test utilizing CCR. This test was conducted over a section of roadway currently undergoing reconstruction at 9-11 Mile Dalton Highway. The goal was to ascertain how the CCR could aid this reconstruction effort and determine extent and depth to ice-rich permafrost sediments. Additionally, seven boreholes were drilled along the project by CRREL for ground truth of the resistivity survey.

3. BACKGROUND

3.1 Permafrost

The permafrost of Interior Alaska is discontinuous laterally, and ranges in depth from tens of feet to nearly 200 feet. It is located at the bottom of valleys and lower slopes, and reaches higher elevations of north facing slopes. In valley bottoms, the permafrost is primarily composed of sand and gravels which have been deposited on the bedrock, and these sediments are overlain by wind deposited and water deposited sediments, primarily of silt size (loess). The wind deposited silt can be host to a many types of massive ice features such as; segregation ice up to inches in thickness, and feet in width and length; and wedge ice many feet in width, and tens of feet in depth and length.

On the lower and upper reaches of the slopes, the loess is deposited directly on the bedrock and weathered bedrock. The silt sequences can reach thicknesses of 60 ft. or more in valley bottoms, and they progressively thin when moving to the tops of the slopes. In general the high elevations are thawed on the south facing slopes while frozen on the north facing slopes. If south facing slopes are frozen, the thickness will be less than on the north facing slope.

The permafrost in discontinuous regions is warm at approximately -2.0 to -1.0°C. The thermal regime that protects this natural state from thawing is delicate, and often the construction and existence of any infrastructure will disrupt this balance and begin thaw to some depth. Thawing of ground ice provides for remobilization of the sediments, causing settlement, which in the case of roadways and airfields, results in depressions at the surface. Thaw settlement can be destructive requiring annual maintenance to insure operability, and overall decreases the life of the infrastructure.

3.2 Electrical Resistivity

One measurable characteristic of earth materials is conductivity, or inversely, resistivity. Electrical resistivity has been used for decades to image the subsurface where contrasts in resistivity are present. In permafrost terrain, the change of state from water to ice provides this contrast. At temperatures of -1°C frozen silt is approximately 1.5 times more resistive than if the soil was thawed, and at -5°C it is approximately 5.0 times more resistive than if the soil is thawed (Hoekstra 1974). Resistivity measurements in the CRREL Permafrost Tunnel in Fox have shown that depending on the moisture (ice) content of frozen silt, resistivity can vary from 1000 ohm-m, to 100,000 ohm-m.

Overall, resistivity surveys show good delineation between ice-rich and ice-poor soils, and between frozen and thawed zones. Most commonly resistivity is measured by pounding metal electrodes into the ground (galvanic coupling). Connections are made to these stakes and DC electric current is injected through one electrode pair, while the resultant voltage is measured at a separate electrode pair. This is often termed electrical resistivity tomography (ERT). This type of survey, although providing comparatively high resolution and great depth, is very time consuming and limits the practical length of a resistivity survey.

A relatively new method, capacitive-coupled resistivity (CCR) utilizes an AC current that is transmitted through a dipole antenna transmitter (Tx) dragged along the ground surface. The cable is capacitive- coupled to the ground surface, resulting in a measureable voltage at the dipole antenna receiver (Rx), which is also capacitive-coupled to the ground surface. The distance between the transmitter and the receiver determines the depth of measurement, and for expediency, up to five receivers are pulled in tandem resulting in simultaneous measurement of five depth intervals. The receivers are interconnected with insulated cables that act as the antenna, and the same type of insulated cable is attached at either end of the transmitter to act as antenna. The manufacturer creates two lengths of cables, 5-m and 10-m. To obtain deeper intervals, the rope separating the receiver array from the transmitter is lengthened and the same transect is repeated. The entire system can be pulled by a person walking, by a motor vehicle, snow machine, or ATV, and very good correlation has been shown between ERT, CCR, and borehole drilling (Schnabel 2013).

3.3 Purpose

For the reconstruction project at 9 -11 Mile Dalton Hwy, multiple sections were scheduled to have the surface elevations lowered to decrease the grade. It was anticipated this ‘cutting’ would penetrate frozen material, subjecting possibly many feet of frozen ground to thawing during establishment of the new annual thaw depth, and most probably causing much thaw settlement. To mitigate these affects, the plan was to decrease the annual thaw depth at these sections with the installation of subsurface rigid board insulation (Figure 1). It was theorized that CCR may provide an expedient method to survey the top of permafrost in a continuous manner, quickly identifying the locations where the cut locations would encounter permafrost and insulation should be installed.

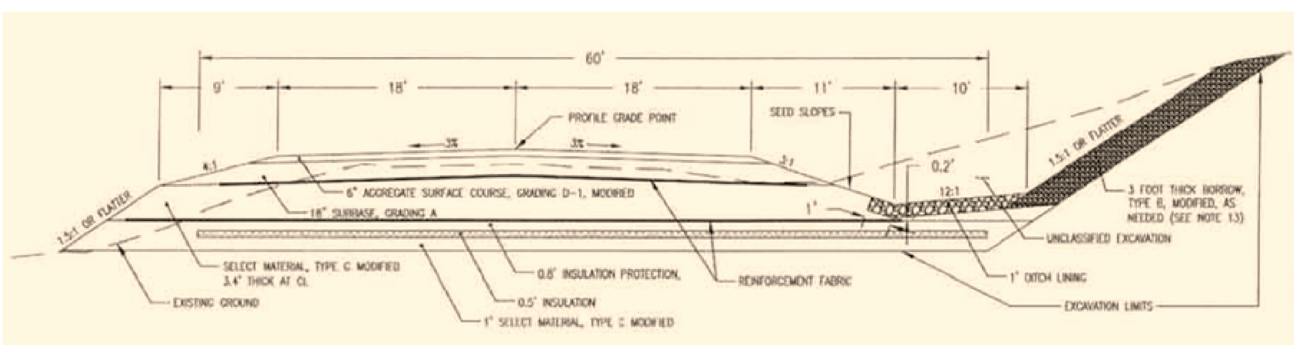

Figure 1. Roadway profile with insulation board (AKDOT&PF)

4. **METHOD**

4.1 Survey

The survey route consisted of nearly the entire reconstruction project. The Beginning-of-Project (BOP) was 433+93 and the End-of-Project (EOP) was 587+00 (Figure 2). Due to traffic control procedures the day of our survey, it was impractical to begin at the BOP and therefore the survey started at 440+00, stopping at EOP.

We conducted two passes utilizing the 10-m dipole configuration. The first pass utilized a rope separation of 5-m, and with five receivers this provides a potential total depth of survey of 9-m (29.5-ft). The second pass utilized a rope separation of 25-m, which provides a potential total depth of survey of 17-m (55-ft). The total length of the entire system behind the pulling vehicle (Figure 3) with the 5-m rope is 50-m (164-ft), and with the 25-m rope is 70-m (230-ft).

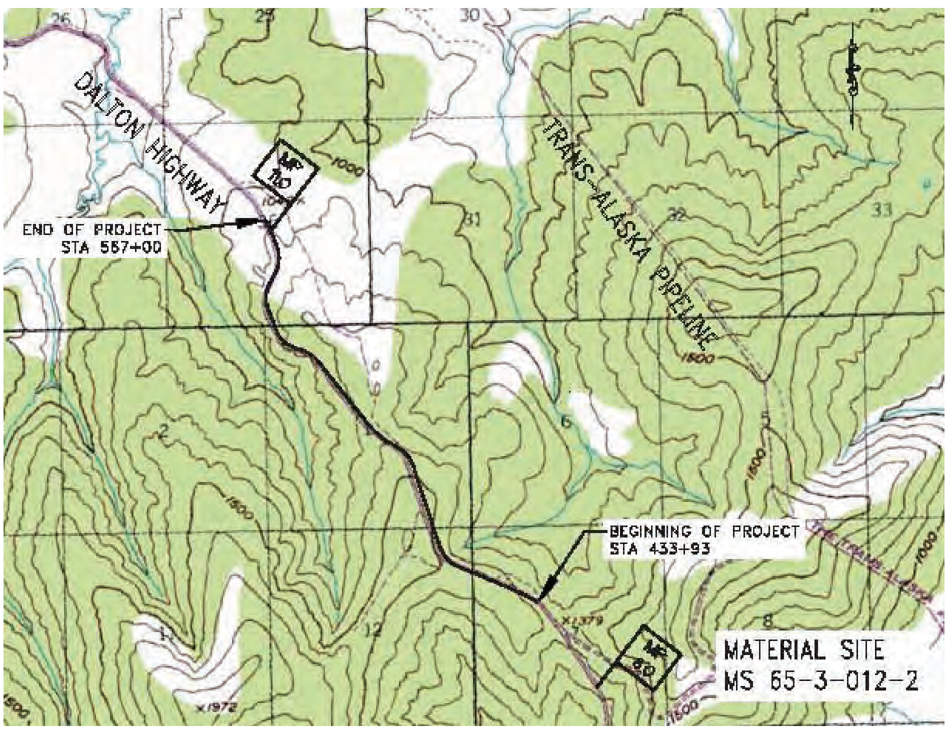

Figure 2. Route location for the CCR survey.

Figure 3. Photo taken during the survey with five receivers in the foreground and behind the black towing vehicle, and the transmitter in the background with the ATV guide at the very end of the system.

Our goal was to survey along the center line of the roadway as much as possible, but due to heavy equipment and pilot-car traffic, we primarily surveyed the right or north-bound lane. Also, because of the excessive length of the total array, the system cannot directly track behind the pulling vehicle and tends to ‘cut’ the short radius curves by tracking into the opposite lane. We were able to counter this some degree by providing a ‘tail’ guide consisting of a person riding an ATV guiding the rear of the array with an attached rope. This was only an issue on curves to the left where the system would tend to track to the opposite lane. For curves to the right, generally there existed a windrow of dirt at the road edge caused by road grading operations, and that prevented the array from sliding into the ditch.

4.2 Post Processing

Post processing produces a cross-section that extends along the length of the survey, and down to the surveyed depth, and is called a ‘pseudo-section’. The image consists of color contours showing transitions from more conductive to more resistive regions. Processing consists of downloading the collected file from the controlling unit to a field PC, the file is then formatted for the inversion program taking approximately 5 to 10 minutes, and then the inversion process takes approximately 2 to 5 minutes per file depending on collection parameters. Field viewable pseudo-sections can therefore be available within 10 to 15 minutes of the end of the survey. This can allow for in-the-field route adjustments if required. Further processing is usually done in the office to compare and compile individual transects and transform the data into a useful report format to include topography and project specific horizontal stationing.

The inversion software used for this survey was RES2DINV by Geotomo, and the specific approximate solution was conducted with an least-squares averaging algorithm. This algorithm takes the apparent measured resistivity from the OhmMapper system at each location and depth, compares that value to the other values around it, and performs iterations to fill the gaps between the measured points, providing a more complete view of what exists in the subsurface. Other than very high resistivity values (which were expected), no unusual occurrences were encountered requiring alternate processes or routines. It should be noted that the value for earth resistivity (ohm-m) plotted by the software is subject to intervening very high and very low values measured during collection, such as culverts, cables, subsurface water, etc.. These very local extreme values can skew the overall values of the pseudo-section, and data points such as these can be filtered if excess 'noise' occurs. One last note, the approximate center of the array is where the data is collected and referenced, and because of the long length of the array, survey psuedo-sections illustrate data before the actual referenced beginning point of the survey (440+00), and the data will stop just before the actual referenced ending point of the survey (565+00). This does not affect the recorded position of the data as the system and software are referenced to the operator position, and the collected data is accurately displayed based on this reference.

5. **RESULTS**

5.1 Standard Processing

Common practice is to view pseudo-sections with colored contours that illustrate changes in resistivity values from one region to the next. With frozen ground, this resistivity gradation exists in reality as changes in temperature will affect the unfrozen moisture content of the sediment. As the temperature decreases with increasing depth into the permafrost, more of this unfrozen water is entrained as ice and the resistivity value increases.

Complete standard pseudo-sections for each pass are shown in Figure 4 and 5. In Figure 6 the two passes are combined into a single pseudo-section, and in Figure 7 apparent resistivity readings for each receiver are plotted in descending order of depth. This type of plot provides the ability to see the subtle resistivity changes vertically and laterally, and also serves to compare the results of two or more passes for continuity. All of these plots demonstrate that good correlation was achieved between the two passes.

The results indicate highly resistive ground is located under most of the entire project. Noticeable high resistivity sections are located at: BOP to 454+00, 464+00 to 520+00, and 528+00 to EOP. The middle section appears to have a greater density of high resistivity, which also appears to be closer to the road surface. Low resistivity sections are shown at 454+00 to 464+00, and 520+00 to 528+00.

The existing roadway embankment in the vicinity of 460+00 curves to the right and is on a cross-slope from left to right. Although the roadway embankment fill is deeper on the right than on the left, the fill depth was not greater than the reach of either pass of the OhmMapper. Therefore the data taken from 454+00 to 464+00 measured high conductivity with no trace of high resistivity, and this was interpreted as thawed ground. After 500+00 the remaining roadway embankment is on a cross-slope from right to left, and the fill section depth is greater on the left side of the roadway than the right. An S-curve exists at this location, starting with a curve to the left over deep fill. At this location the system tracked well into the oncoming lane, and the high conductivity with no trace of high resistivity is interpreted to be due to measurements through excessive embankment fill depths.

To validate these results, seven boreholes were drilled on 11 September 2012. These holes were drilled utilizing a Geoprobe 7822 Direct Push drill. Core was generally not taken while drilling through the roadway embankment fill, but upon attainment of significant increase in drilling resistance coring would be initiated. Selected samples were retrieved for gravimetric moisture content analysis. The late summer season thaw depth under the roadway embankment averaged approximately 3.0-m (10.0-ft.), and the moisture (ice) contents ranged from 4.8% to 101%. The bore logs are included in Appendix A.

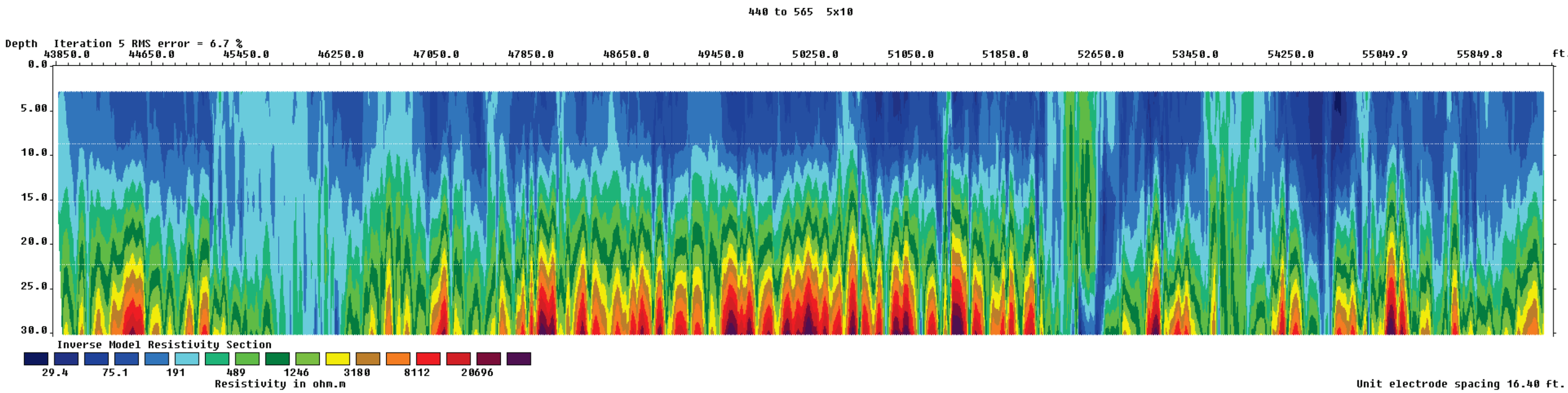

Figure 4. First pass starting at 440+00 and ending at EOP. The measured depth interval was from approximately 8 to 30 feet.

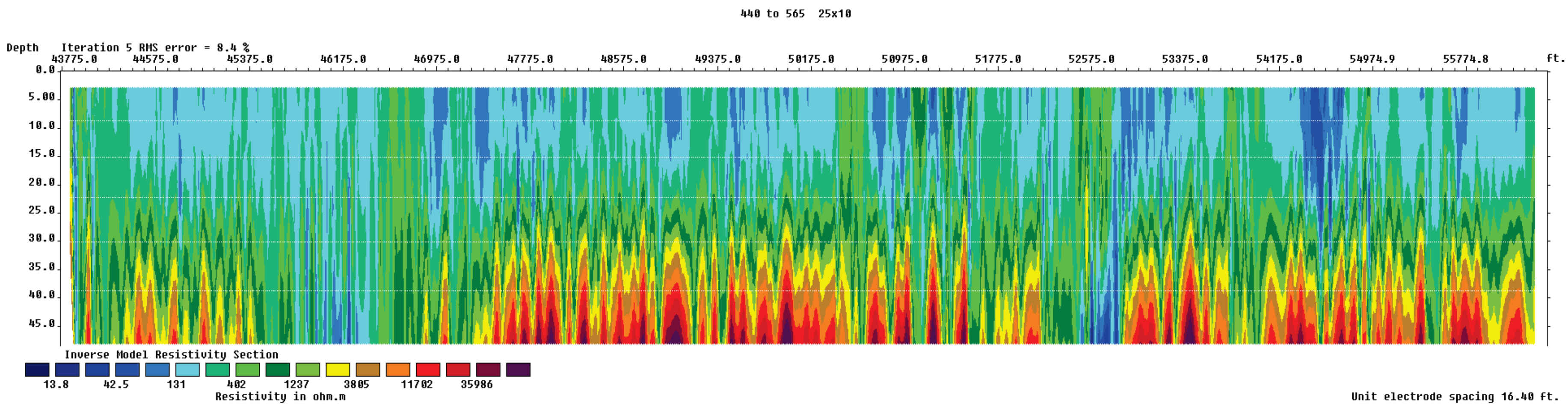

Figure 5. Second pass starting at 440+00 and ending at EOP. The measured depth interval was from approximately 30 to 50 feet.

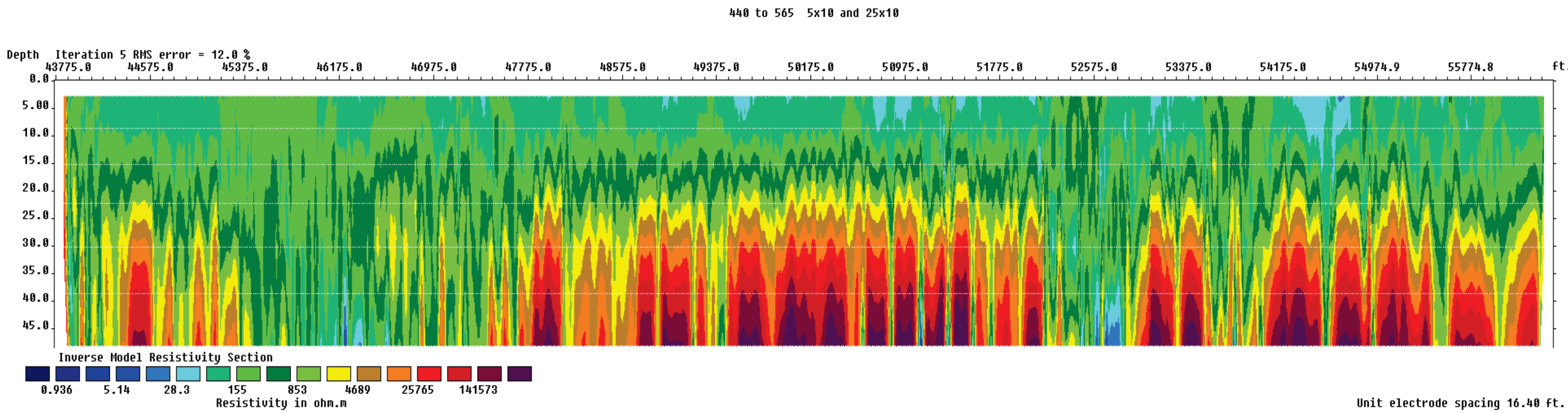

Figure 6. Combined first and second pass.

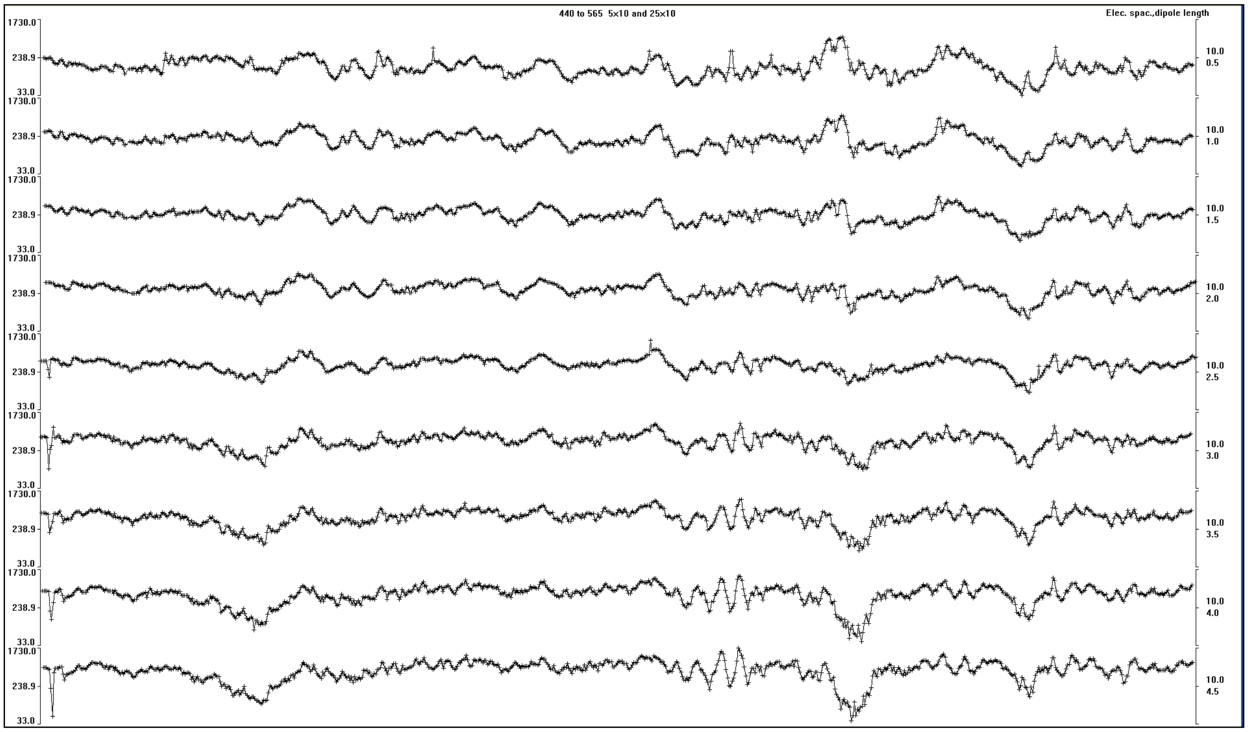

Figure 7. Apparent resistivity data plot for each receiver. Nine total depth levels are shown due to the deepest depth receiver on the first pass being redundant with the shallowest depth on the second pass.

5.2 Additional Processing

The standard results presented in the previous section illustrate the ability of the system to rapidly collect permafrost information over great distances in short amounts of time. However, for this particular application of determining extent of frozen ground within a certain depth under the roadway surface, the horizontally flat (no topographic correction) and color contour pseudo-sections are limited in the information that can conveyed.

Utilizing the Plan and Profile images for this project provided by DoT, topography data was extrapolated and included into the inversion process. The result is a topographically accurate pseudo-section which was then overlaid onto the Plan and Profile images. Additionally, the inversion color scheme was altered to illustrate a definitive change from thawed (seasonally thawed layer) to frozen (permafrost table). A gradational blue color scheme was chosen for all contours with less than 100 ohm-m, and a gradational red color scheme was chosen for all contours with greater than 100 ohm-m. The results are shown in Appendix B with the CRREL borehole locations also illustrated.

Based on the information provided by this survey, and also the project engineer's knowledge of the permafrost conditions encountered during ditch back-slope excavation, specific locations were called out for the installation of the insulation board. The sections and roadway width extent are listed in Table 1.

Table 1. Determined locations and extent for insulation board (AKDOT&PF Change Order #3, 17 October 2013).

Station to Station		Installation
475+50	*481+50	Full Width
513+50	514+50	Right Side
515+50	520+50	Left to Right Ditch
522+00	524+00	Right Ditch
529+00	533+00	Right Ditch
541+00	546+50	Full Width

* Extended to 483+00 during excavation

5.3 Road Construction

Site visits were made by CRREL during the cutting of the sub-grade on 26 April, 2 May, 3 May, and 6 May 2013. Specifically we observed nearly the entire cut on the top of 9-Mile Hill, and samples were taken at select locations for correlation with the resistivity and borehole drilling. The air temperature during the visit of 6 May was no lower than 4°C (40°F), and wedge ice and isolated ice-rich soil was thawing readily in the sun, with dripping and sloughing down the cut slopes. However, it was globally observed during the four hour site visit that sediments directly adjacent to and directly above massive wedge ice were not exhibiting ice-rich thawing behavior, indicating these are ice-poor sediments. Four hand drilled core samples were taken at various depths adjacent to and above wedge ice in this large cut, and the gravimetric moisture contents ranged from 27% to 34%.

Borehole #3 was drilled on the right side of the roadway at station 477+00 (the top of 9 Mile Hill) and encountered massive ice (foliated ice) from the top of permafrost at 3.0-m (10.0-ft). to bottom-of-hole at 5.2-m (17.0-ft). Figure 8 is a photograph of this ice wedge exposed on the right side of the cut during the excavation and prior to covering of the back-slope. It can be seen that the surrounding sediment is not dripping, sloughing, or running onto the ice and sediment below. Figure 9 is a photograph of wedge ice further down-station and still at the 9 Mile Hill cut on the left side. Again although the air temperature is well above freezing, these sediments are not exhibiting ice-rich thawing behavior. These very low moisture content sediments can help to explain the undulating nature of the high resistivity sections seen in the pseudo-sections.

Figure 8. Wedge ice exposed on the right side at station 477+00. Tracing the wedge in the floor of the cut revealed with wedge was cut at an oblique angle.

Figure 9. Close up view of wedge ice further down-station from Figure 8, and on the left side. The surrounding sediments are not dripping and sloughing although the temperature is well above freezing.

6. CONCLUSIONS

The CCR system allowed for the determination of many parameters of permafrost associated with the Dalton Highway 9 to 11 Mile reconstruction project. Most importantly the presence (thawed vs. frozen areas), the depth to the permafrost table, the horizontal and vertical extent, and also the moisture content. The ground truth information collected via borehole drilling was critical to ascertain the credibility of the initial interpretation of the processed data, and most importantly for this project was the determination of the average depth of the permafrost table under the roadway surface.

It was discovered that with some effort, the pseudo-sections could be overlaid on the Plan and Profile images, which greatly aided the decisions involved with the insulation board change order. By plotting the pseudo-sections with two discrete color bands, one band corresponding to the thawed state, and the other band corresponding to the frozen state, the resistivity provided information that was useful to those managing the project.

The first pass alone would have fulfilled the scope-of-work for this project, however two passes were conducted allowing for us to come to this conclusion with 100% assurance. If the same type of information was needed for a similar project where the permafrost table was at a depth equal to or greater than the bottom limit of the first pass, or 9.0-m (30-ft.), a second pass would be recommended, or one pass be completed with the longer separation between the receiver array and the transmitter.

It was found that collecting data along a specific portion of the roadway embankment, in this case the northbound lane, was problematic due to the array length for the survey. Roadway surveys in the future should have additional personnel available and staged at key locations along curves, to insure the array remains in the specified portion.

7. RECOMMENDATIONS

We recommend an additional test be conducted on another ice-rich permafrost roadway or runway reconstruction project. Although this test appears to have been very successful and useful for designers and construction managers at AKDOT&PF, we feel the full benefit of a survey such as this could be obtained if the data was collected earlier in the design phase of the project. The best scenario would be that this information is collected prior to final borehole drilling, allowing the opportunity for ground truth of the CCR data (which is needed in all cases), and would allow the opportunity for follow-on CCR surveys if further broad scale information is needed.

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9. **APPENDIX A**

Soil Classification

The soils classification system for this report utilizes certain features from the Unified Soil Classification System (USCS), ASTM methods D-2487 (Classification of Soils for Engineering Purposes), D-2488 (Description of Soils, Visual-Manual Procedures), and the Description of Classification of Frozen Soils by Linell and Kaplar (1966). The identification of the following characteristics are listed in the order they are reported:

- Density or consistency (when available)
- Color
- Minor constituents
- Major constituents
- Trace constituents
- Geologic characteristics (if applicable)

Color is used to distinguish between different soil layers, or to indicate the degree of weathering and/or oxidized state. Major, minor, and trace constituents of a soil are determined by visual-manual procedures or by measurement. Major constituents are those comprising more than 50% of the soil mass, minor constituents comprise 15% to 50% of the soil mass and are modifiers of the major constituents. Trace constituents are those comprising less than 12% of the soil mass. Visual ice descriptions are used to determine the degree of excess ice and

Table 2. Description and Classification of Frozen Soils.

<table>
<tr><td rowspan="3">Segregated ice is not visible by eye</td><td colspan="2">Friable, poorly bonded. Material is easily broken up</td><td>Nf</td></tr>
<tr><td rowspan="2">Well bonded, Soil particles strongly held together by ice</td><td>Excess ice</td><td>Nbe</td></tr>
<tr><td>No excess ice</td><td>Nbn</td></tr>
<tr><td rowspan="4">Segregated ice is visible by eye < 50%</td><td colspan="2">Individual ice crystals</td><td>Vx</td></tr>
<tr><td colspan="2">Ice coatings on soil particles</td><td>Vc</td></tr>
<tr><td colspan="2">Stratified or distinctly oriented ice formations</td><td>Vs</td></tr>
<tr><td colspan="2">Random or irregularly oriented ice formations</td><td>Vr</td></tr>
<tr><td rowspan="2">Ice > than 2.5cm in thickness</td><td colspan="2">Ice visible, >50%</td><td>ICE + inclusions</td></tr>
<tr><td colspan="2">Individual layer</td><td>ICE</td></tr>
</table>

After – Linell and Kaplar, “Description and Classification of Frozen Soils”, International Conference on Permafrost, Purdue University, November 1963.

Table 3. Drill log abbreviations:

fine	f.
medium	med.
coarse	cse.
slightly	sl.
with	w/
dark	dk.
light	lt.
occasional	occ.
frequent	freq.
trace	tr.
interbedded	int.
not applicable	NA
air rotary	AR
tricone	TC
downhole hammer	DH
weathered	wx
fragment	frag.
sample	smpl

Subsurface Drill Log
Borehole BH-1 445+00

Project: AK DoT Dalton Hwy 9-11 Mile
Location: Left edge of roadway surface
Date: 11-Sep-12
Time: 1100
Air Temp: 50°F

Total Depth: 12.5 ft.
Logged By: K. Bjella
Drilling Contractor: CRREL
Drilling Method: Macro-Corer
Note: Frozen at 10 ft.

Depth (ft) 0.0	Froz.	Sample #	Recov. %	Moist. g/g %	Drill Method	Description
0.5					MC	Select Fill for Roadway
1					↓	
1.5						
2						
2.5						
3						
3.5						
4						
4.5						
5			100		↓	
5.5					MC	
6					↓	
6.5						Base Coarse Select Fill
7						Grey Silt
7.5						
8						
8.5						
9						
9.5						
10			100		↓	
10.5	↓				MC	Grey/Tan Silt
11					↓	
11.5		S-1		48.0		Ice-rich Wx Bedrock (Vc ~ 20%, Vr ~ 15%)
12						
12.5	↓	S-2	100	34.8	↓	BOH - Wx Bedrock
13						
13.5						
14						
14.5						
15						
15.5						
16						
16.5						
17						
17.5						
18						
18.5						
19						
19.5						
20						
20.5						
21						
21.5						
22						
22.5						

Subsurface Drill Log
Borehole BH-2 460+00

Project: AK DoT Dalton Hwy 9-11 Mile
Location: Right edge of roadway surface
Date: 11-Sep-12
Time: 1200
Air Temp: 50°F

Total Depth: 18.0 ft.
Logged By: K. Bjella
Drilling Contractor: CRREL
Drilling Method: Direct Push and Macro-Corer
Note: No Frozen Material

Depth (ft)	Froz.	Sample #	Recov. %	Moist. g/g %	Drill Method	Description
0.0						
0.5					DP	Select Fill for Roadway
1						
1.5						
2						
2.5						
3						
3.5						
4						
4.5						
5						
5.5						
6						
6.5						
7						
7.5						
8						
8.5						
9						
9.5						
10						More Resistance to Pounding - Base Coarse Select Fill (?)
10.5						
11						
11.5						
12						
12.5						
13						
13.5						
14						
14.5						
15						
15.5						
16						
16.5						Refusal with Direct Push
17					MC	Chx to Macro Corer -Wx Bedrock - Schist
17.5						
18		S-1	100	4.8		BOH - In Wx Bedrock
18.5						
19						
19.5						
20						
20.5						
21						
21.5						
22						
22.5						

Subsurface Drill Log
Borehole BH-3 477+00

Project: AK DoT Dalton Hwy 9-11 Mile	Total Depth: 17.0 ft.
Location: Right edge of roadway surface	Logged By: K. Bjella
Date: 11-Sep-12	Drilling Contractor: CRREL
Time: 1300	Drilling Method: Direct Push and Macro-Corer
Air Temp: 50°F	Note: Frozen at 10 ft. - No Samples

Depth (ft) 0.0	Froz.	Sample #	Recov. %	Moist. g/g %	Drill Method	Description
0.5					DP	Select Fill for Roadway
1					↓	
1.5						
2						
2.5						
3						
3.5						
4						
4.5						
5						
5.5						
6						
6.5						
7						
7.5						
8						
8.5						
9						
9.5						
10					↓	Refusal using Direct Push
10.5	↓				MC	Chx to Macro - Corer, Massive Ice - Foliated (ICE)
11					↓	
11.5						
12						
12.5						
13						
13.5						
14						
14.5						
15			100		↓	Massive Ice - Foliated (ICE)
15.5					MC	
16					↓	
16.5						
17	↓		100		↓	BOH - Massive Ice - Foliated (ICE)
17.5						
18						
18.5						
19						
19.5						
20						
20.5						
21						
21.5						
22						
22.5						

Subsurface Drill Log
Borehole BH-4 501+00

Project:	AK DoT Dalton Hwy 9-11 Mile	Total Depth:	18.5 ft.
Location:	Right edge of roadway surface	Logged By:	K. Bjella
Date:	11-Sep-12	Drilling Contractor:	CRREL
Time:	1430	Drilling Method:	Direct Push and Macro-Corer
Air Temp:	45°F	Note:	Frozen at 10 ft.

Depth (ft) 0.0	Froz.	Sample #	Recov. %	Moist. g/g %	Drill Method	Description
0.5					DP	Select Fill for Roadway
1						
1.5						
2						
2.5						
3						
3.5						
4						
4.5						
5						
5.5						
6						
6.5						
7						
7.5						
8						
8.5						
9						More Resistance to Pounding - Base Coarse Select Fill (?)
9.5						
10						
10.5						Very High Resistance to Pounding - Frozen Material
11						
11.5						
12						
12.5						
13						
13.5						
14						
14.5						
15					↓	Refusal using Direct Push
15.5					MC	Chx to Macro - Grey Silt with Visible Ice (Vx ~ 35%, Vs ~ 20%)
16		S-1		79.0		
16.5						
17						
17.5						
18						
18.5	↓	S-2	100	68.0	↓	BOH - Grey Ice-Moderate Silt (Vx ~ 10%, Vs ~ 10%)
19						
19.5						
20						
20.5						
21						
21.5						
22						
22.5						

Subsurface Drill Log
Borehole BH-5 525+50

Project: AK DoT Dalton Hwy 9-11 Mile	Total Depth: 19.5 ft.
Location: Right edge of roadway surface	Logged By: K. Bjella
Date: 11-Sep-12	Drilling Contractor: CRREL
Time: 1600	Drilling Method: Direct Push and Macro-Corer
Air Temp: 50°F	Note: Frozen at 16.0 ft.

Depth (ft) 0.0	Froz.	Sample #	Recov. %	Moist. g/g %	Drill Method	Description
0.5					DP	Select Fill for Roadway
1						
1.5						
2						
2.5						
3						
3.5						
4						
4.5						
5						
5.5						
6						
6.5						
7						
7.5						
8						
8.5						
9						
9.5						
10						
10.5						
11					↓	Refusal using Direct Push - Base Coarse Select Fill (?)
11.5					MC	Chx to Macro - Grey Silt Ice-Rich (Vx ~ 25%, Vs ~ 15%)
12						
12.5						
13						
13.5						
14						
14.5			100		↓	
15					MC	
15.5						
16						
16.5						
17		S-1		54.8		
17.5						
18						Wx Bedrock - Schist
18.5						
19		S-2		35.0		
19.5	↓		100		↓	BOH - In Wx Bedrock Ice-Moderate (Vx ~ 10%)
20						
20.5						
21						
21.5						
22						
22.5						

Subsurface Drill Log
Borehole BH-6 539+00

Project:	AK DoT Dalton Hwy 9-11 Mile	Total Depth:	14.5 ft.
Location:	Right edge of roadway surface	Logged By:	K. Bjella
Date:	11-Sep-12	Drilling Contractor:	CRREL
Time:	1700	Drilling Method:	Direct Push and Macro-Corer
Air Temp:	50°F	Note:	Frozen at 11.0 ft.

Depth (ft) 0.0	Froz.	Sample #	Recov. %	Moist. g/g %	Drill Method	Description
0.5					DP	Select Fill for Roadway
1					↓	
1.5						
2						
2.5						
3						
3.5						
4						
4.5						
5						
5.5						
6						
6.5						
7						
7.5						
8						
8.5						
9						
9.5						
10						
10.5						
11					↓	Refusal using Direct Push
11.5	↓				MC	Chx to Macro - Ice with Silt Inclusions (ICE + Inclusions)
12		S-1		101	↓	Ice-Rich Grey Silt (Vx ~ 25%, Vs ~ 20%)
12.5						
13						
13.5						
14		S-2		64.0		
14.5	↓		100		↓	BOH - Ice (foliated?) (ICE)
15						
15.5						
16						
16.5						
17						
17.5						
18						
18.5						
19						
19.5						
20						
20.5						
21						
21.5						
22						
22.5						

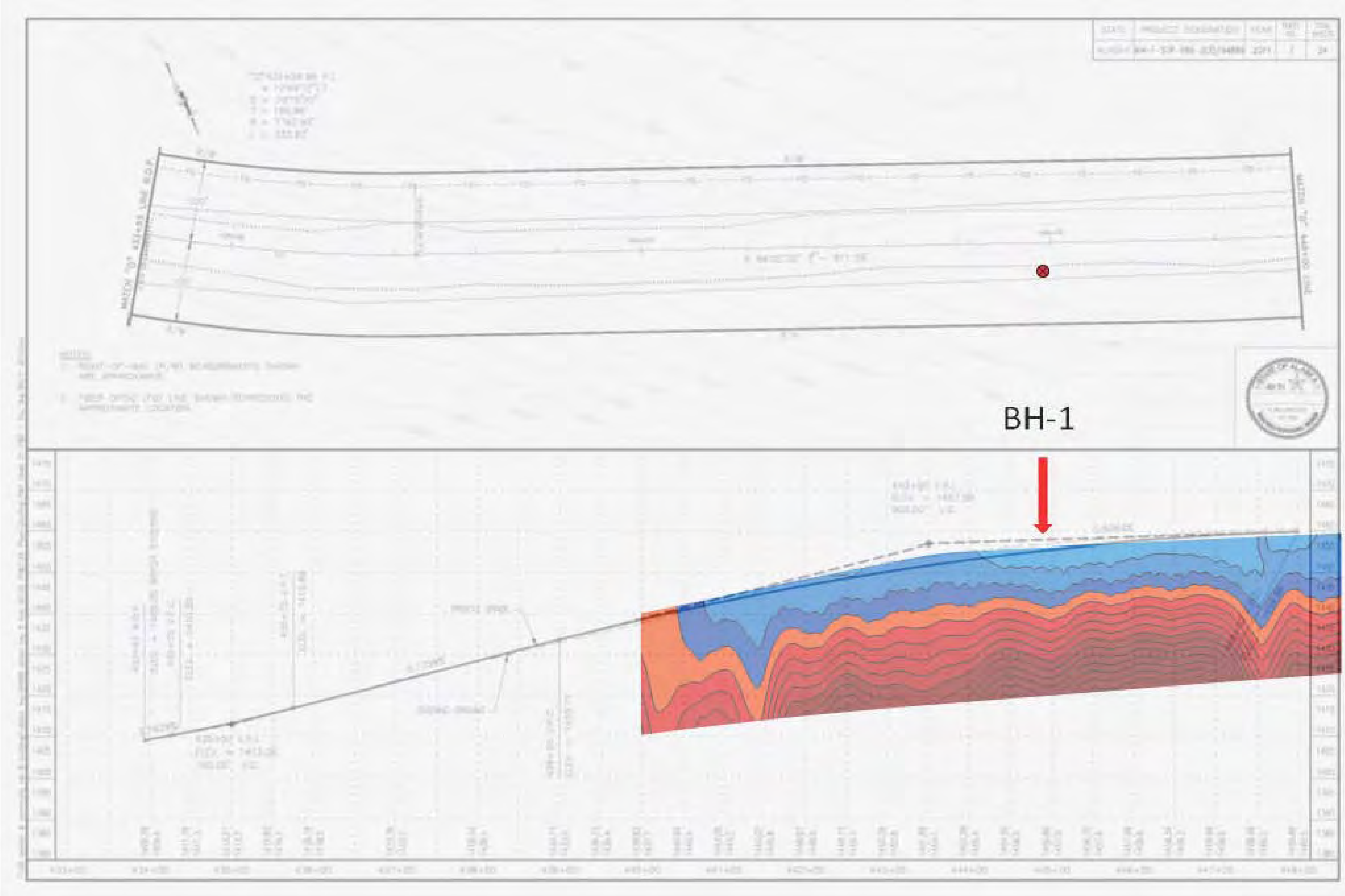
Subsurface Drill Log
Borehole BH-7 553+00

Project: AK DoT Dalton Hwy 9-11 Mile	Total Depth: 14.5 ft.
Location: Right edge of roadway surface	Logged By: K. Bjella
Date: 11-Sep-12	Drilling Contractor: CRREL
Time: 1800	Drilling Method: Direct Push and Macro-Corer
Air Temp: 45°F	Note: Frozen at 9.5 ft.

Depth (ft) 0.0	Froz.	Sample #	Recov. %	Moist. g/g %	Drill Method	Description
0.5					DP	Select Fill for Roadway
1					↓	
1.5						
2						
2.5						
3						
3.5						
4						
4.5						
5						
5.5						
6						
6.5						
7						
7.5						
8						
8.5						
9						
9.5					↓	Refusal using Direct Push
10	↓				MC	Chx to Macro - Silt with Ice Lenses (<5mm) (vx ~ 10%, Vs ~ 40
10.5					↓	
11		S-1		73.0		
11.5						
12						
12.5						
13						Massive Ice - 1.5 ft. in thickness (ICE)
13.5						
14		S-2		58.0		Grey Silt Ice-Moderate (Vs ~ 25%)
14.5	↓		100		↓	BOH - ice Moderate Grey Silt (Vx ~ 20%, Vs ~ 30%)
15						
15.5						
16						
16.5						
17						
17.5						
18						
18.5						
19						
19.5						
20						
20.5						
21						
21.5						
22						
22.5						

10. **APPENDIX B**

Following pages….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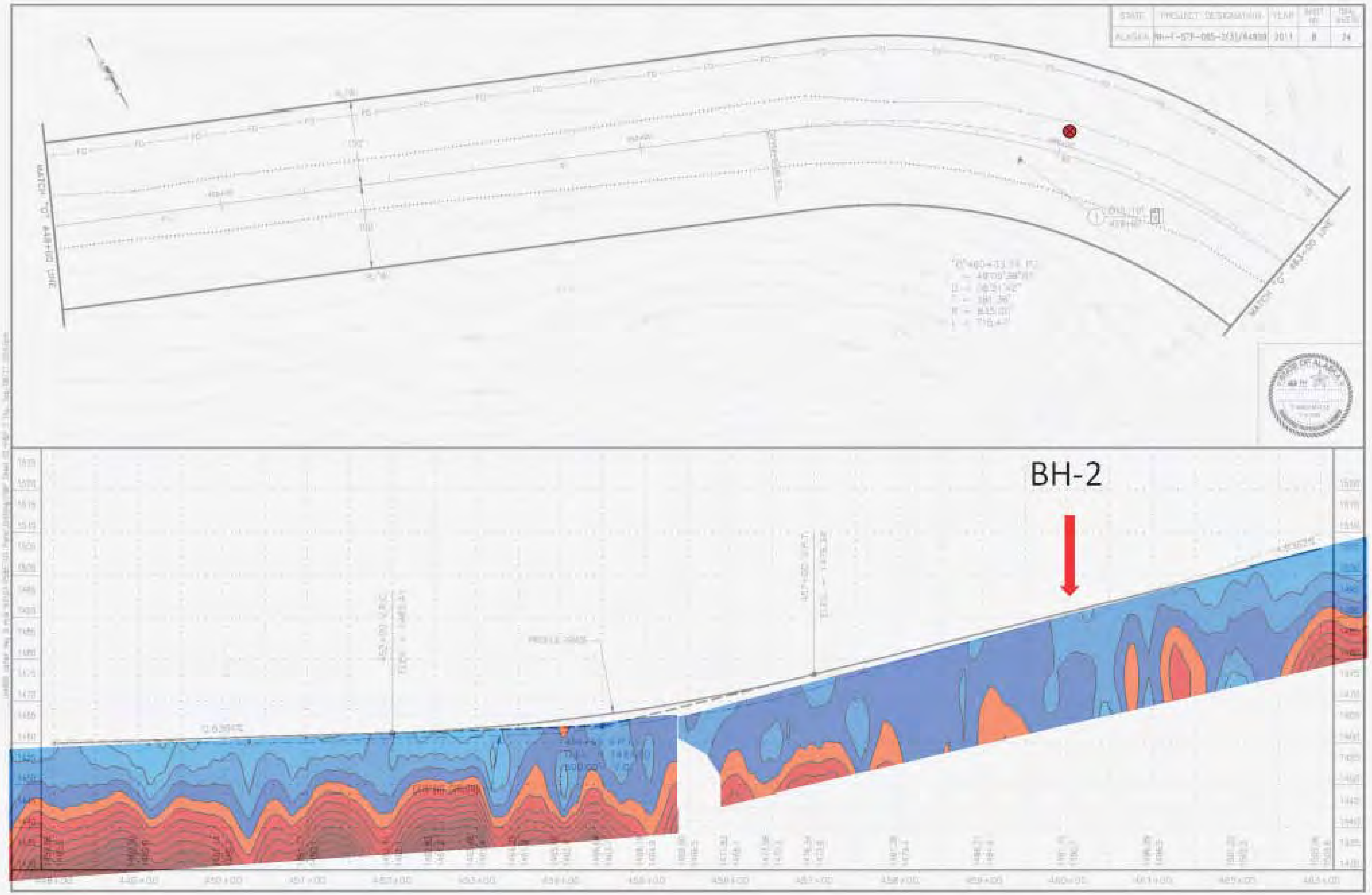
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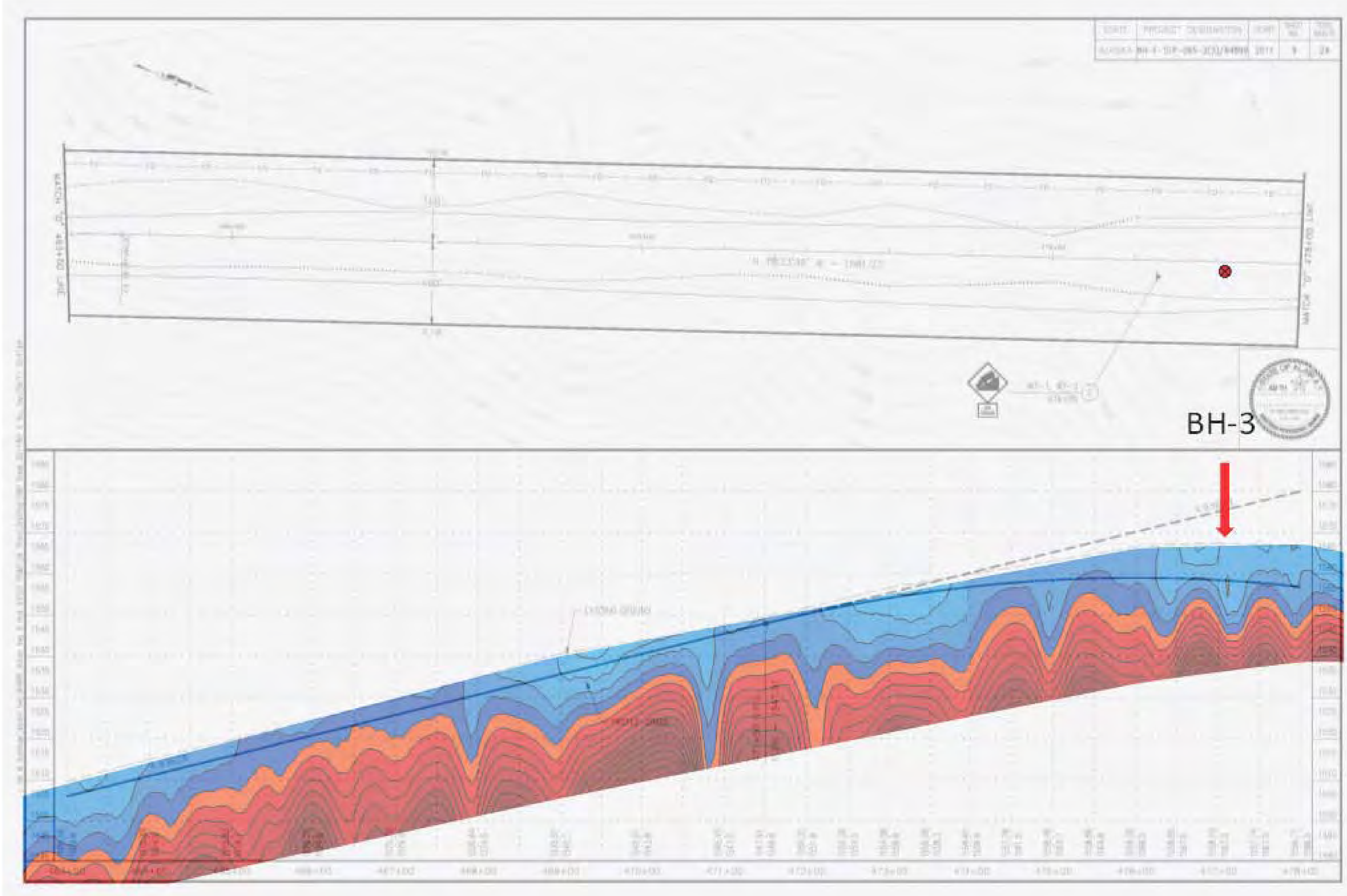
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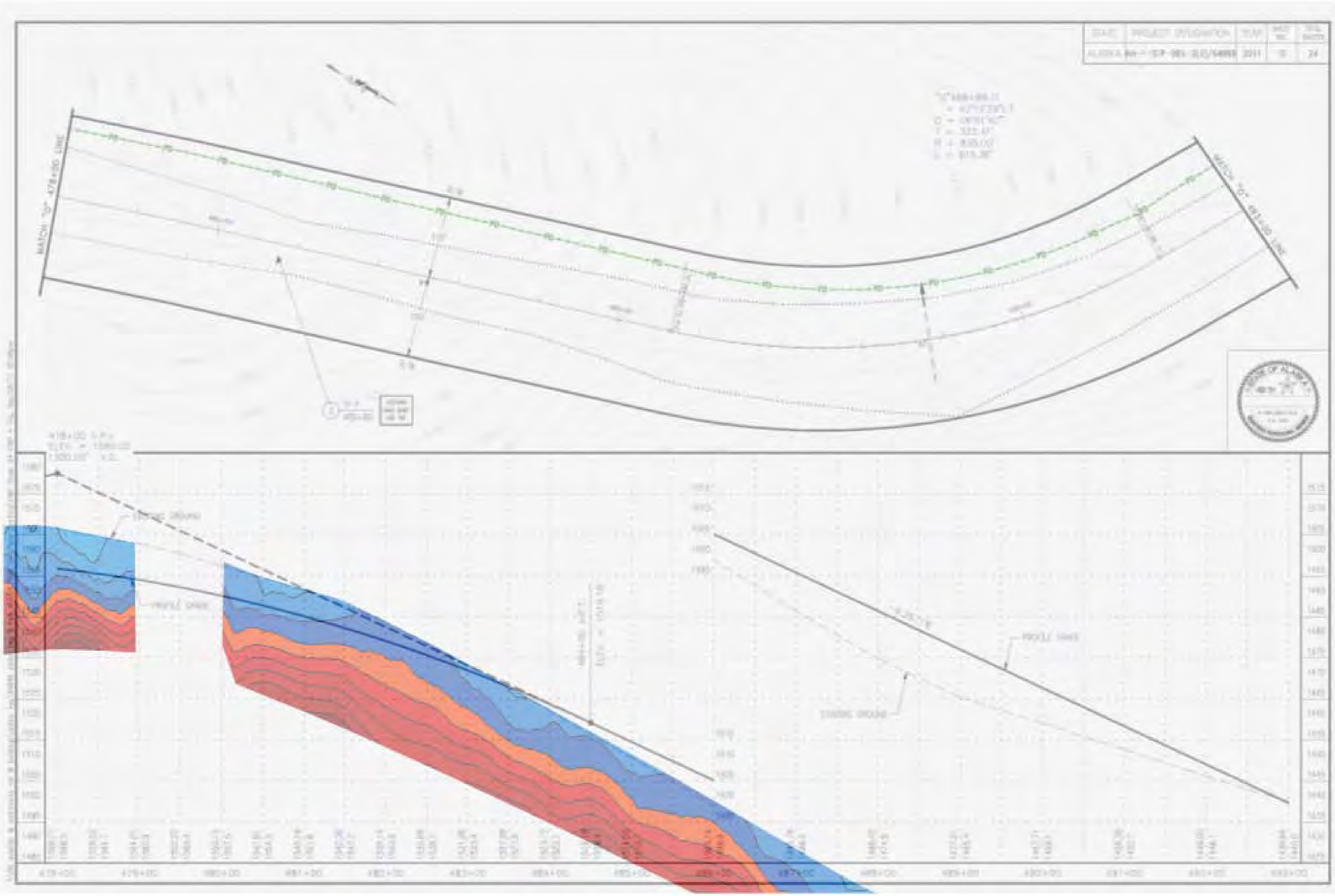

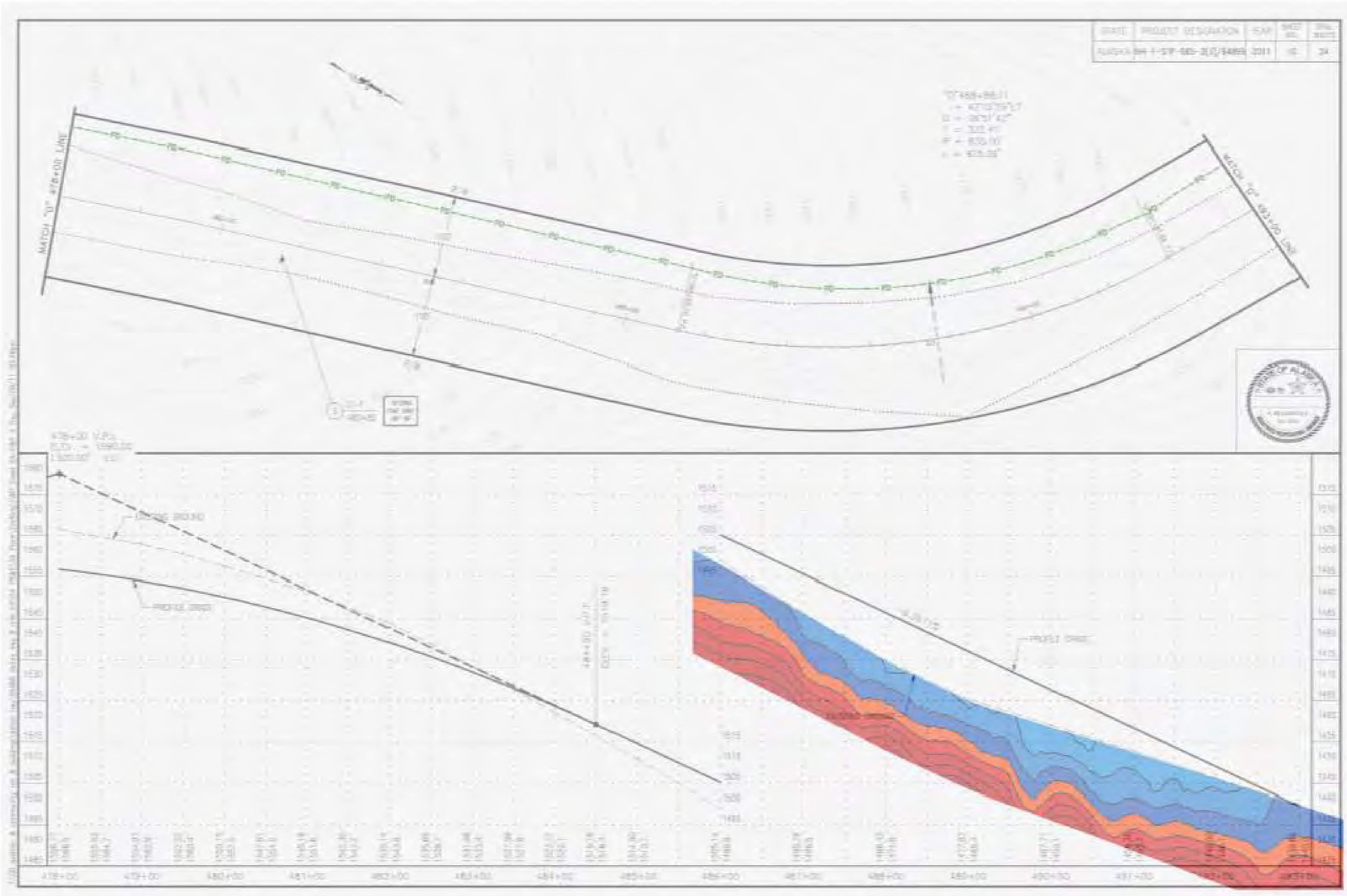

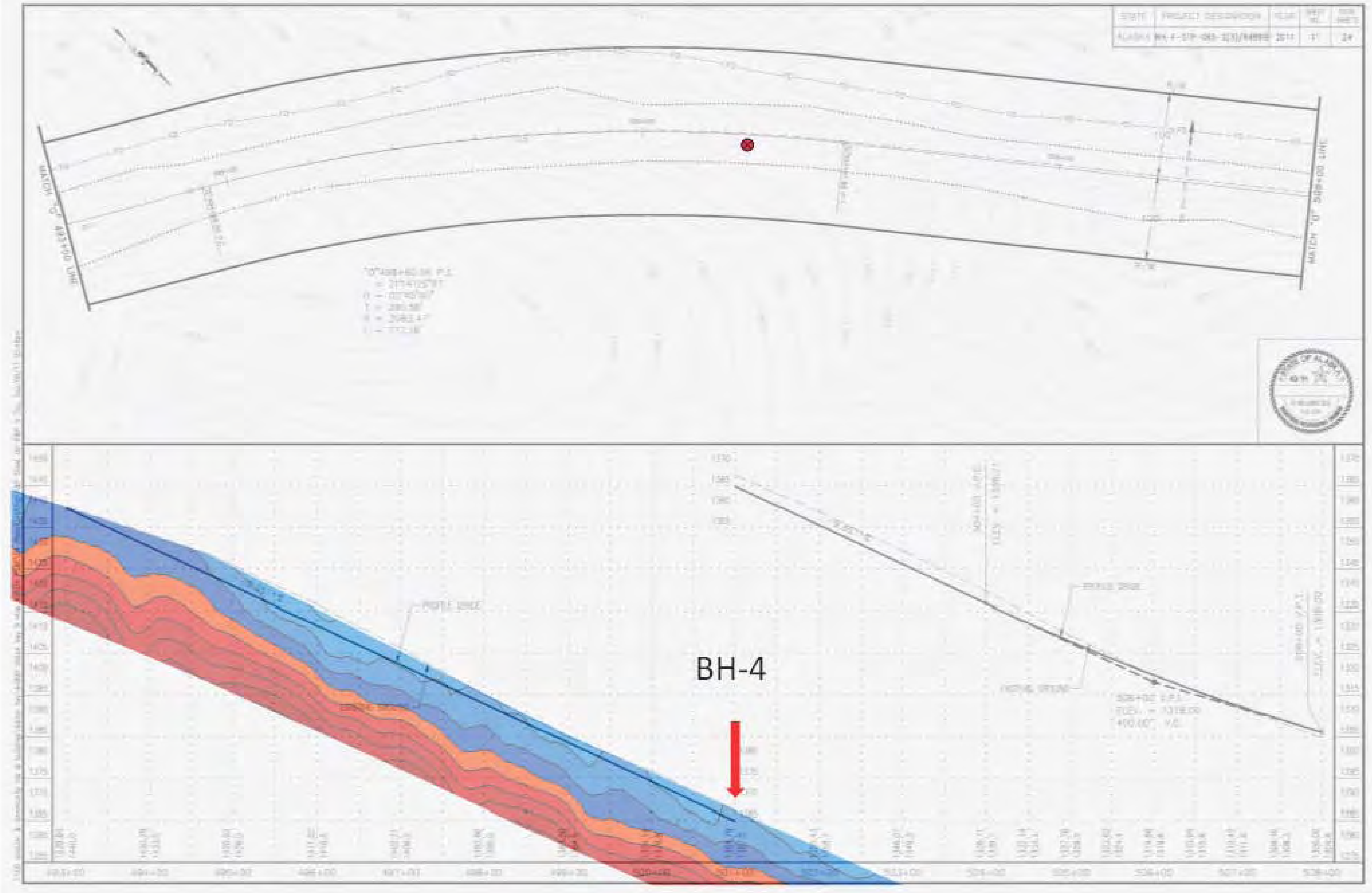

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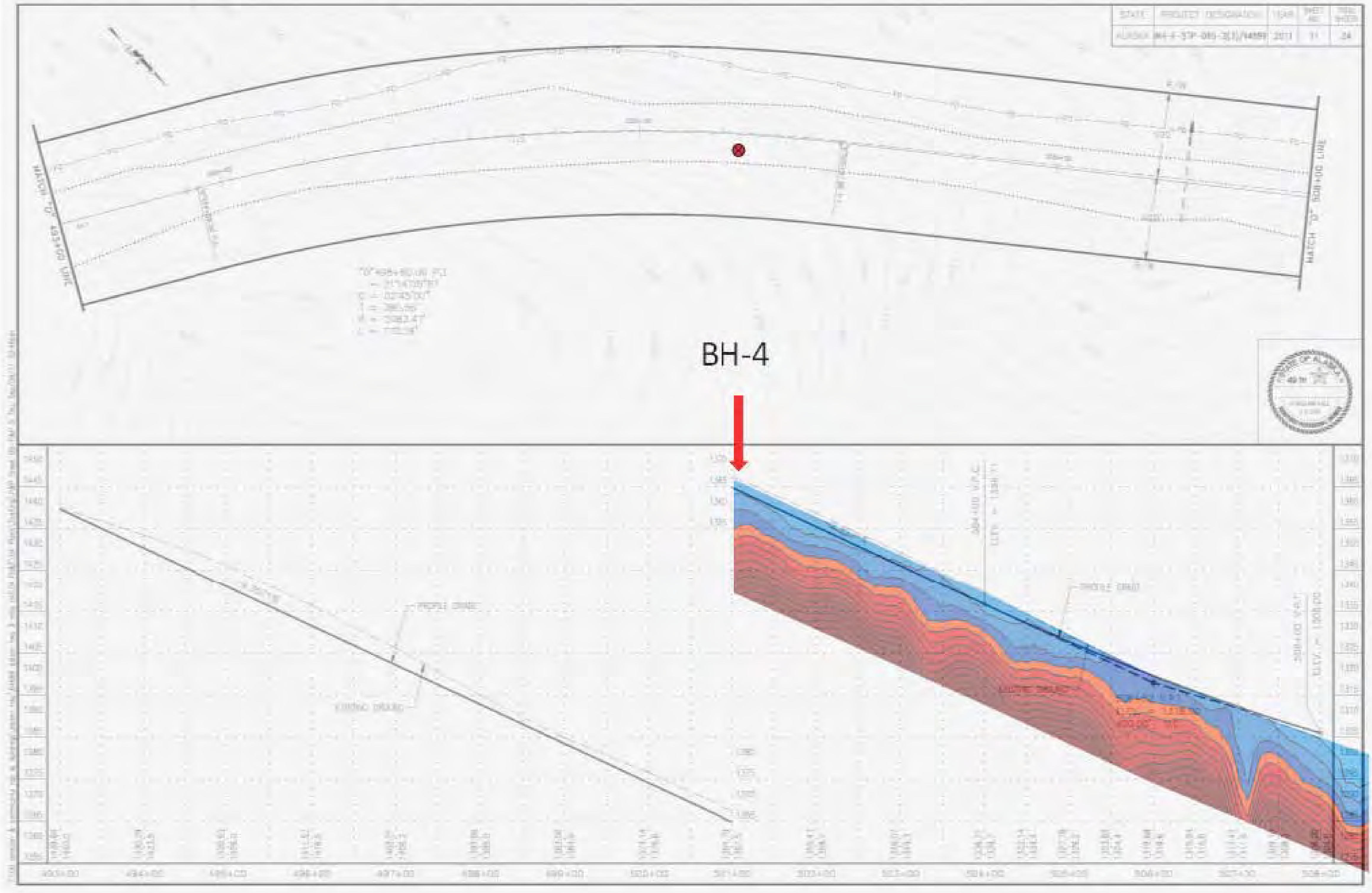
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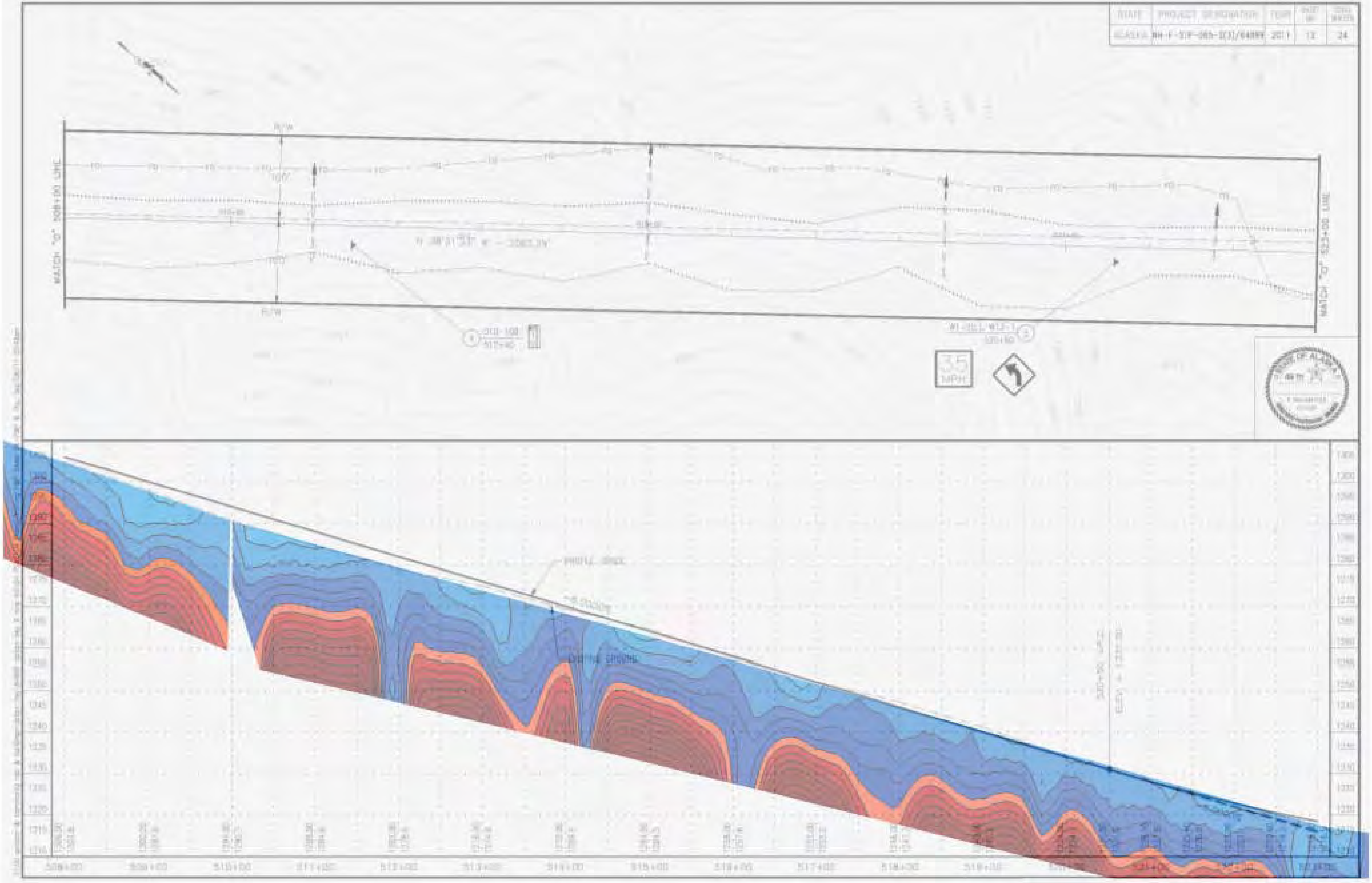
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ALASKA
R/W
35 MPH
PROFILE GRADE
EXISTING GROUND
508+00
509+00
510+00
511+00
512+00
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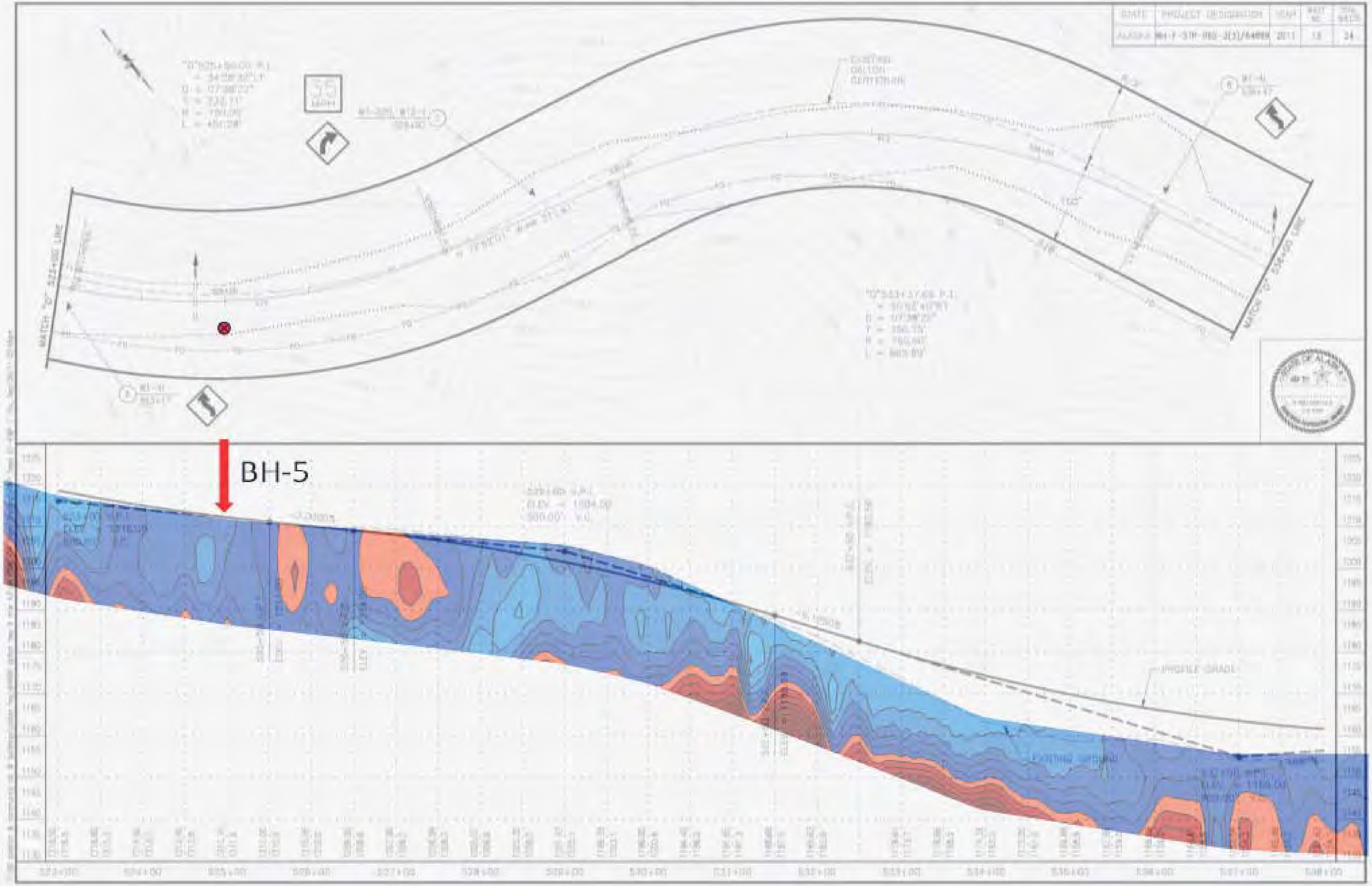
516+00
517+00
518+00
519+00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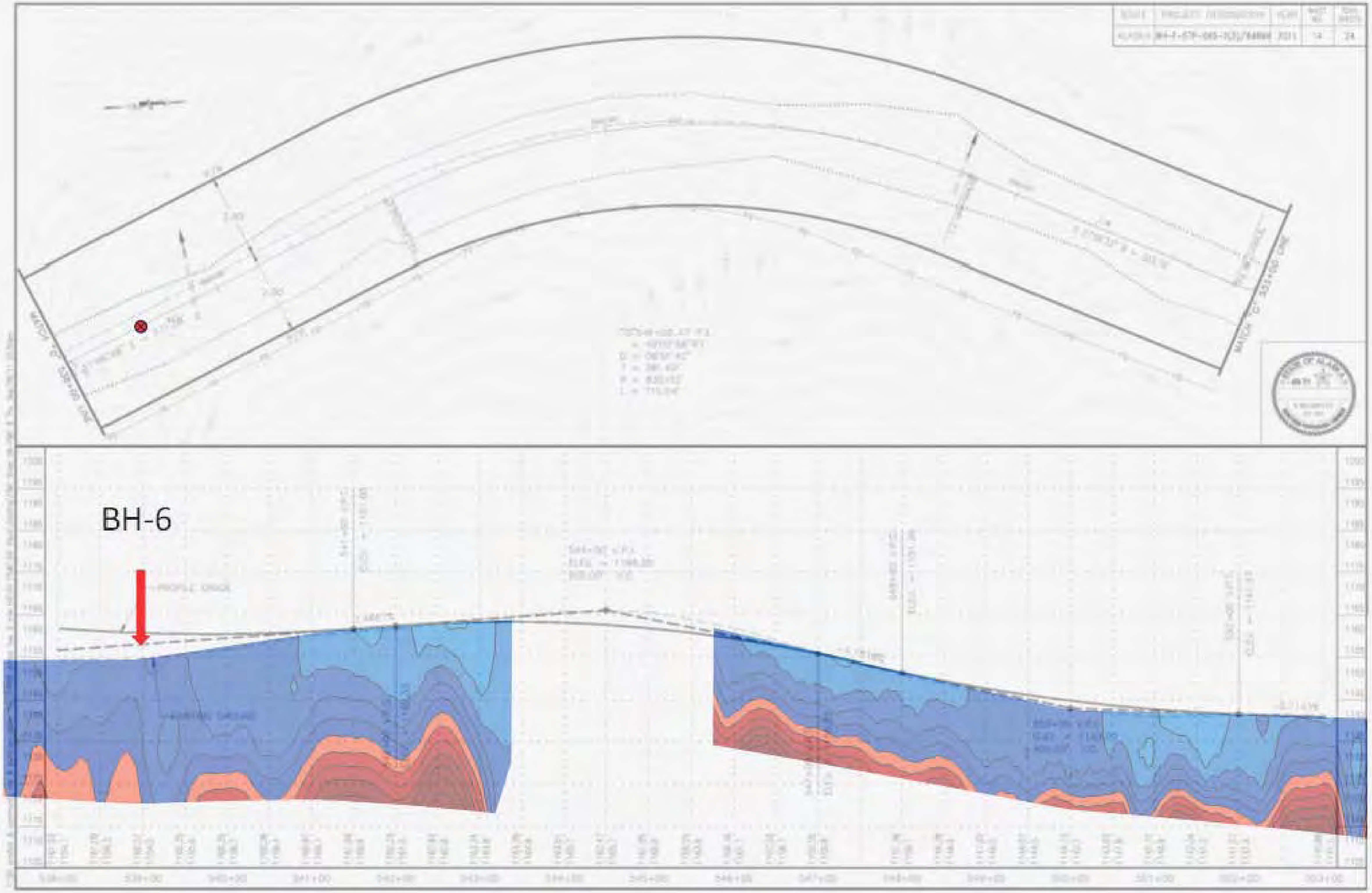
EXISTING DALTON CENTERLINE
PROFILE GRADE
EXISTING GROUND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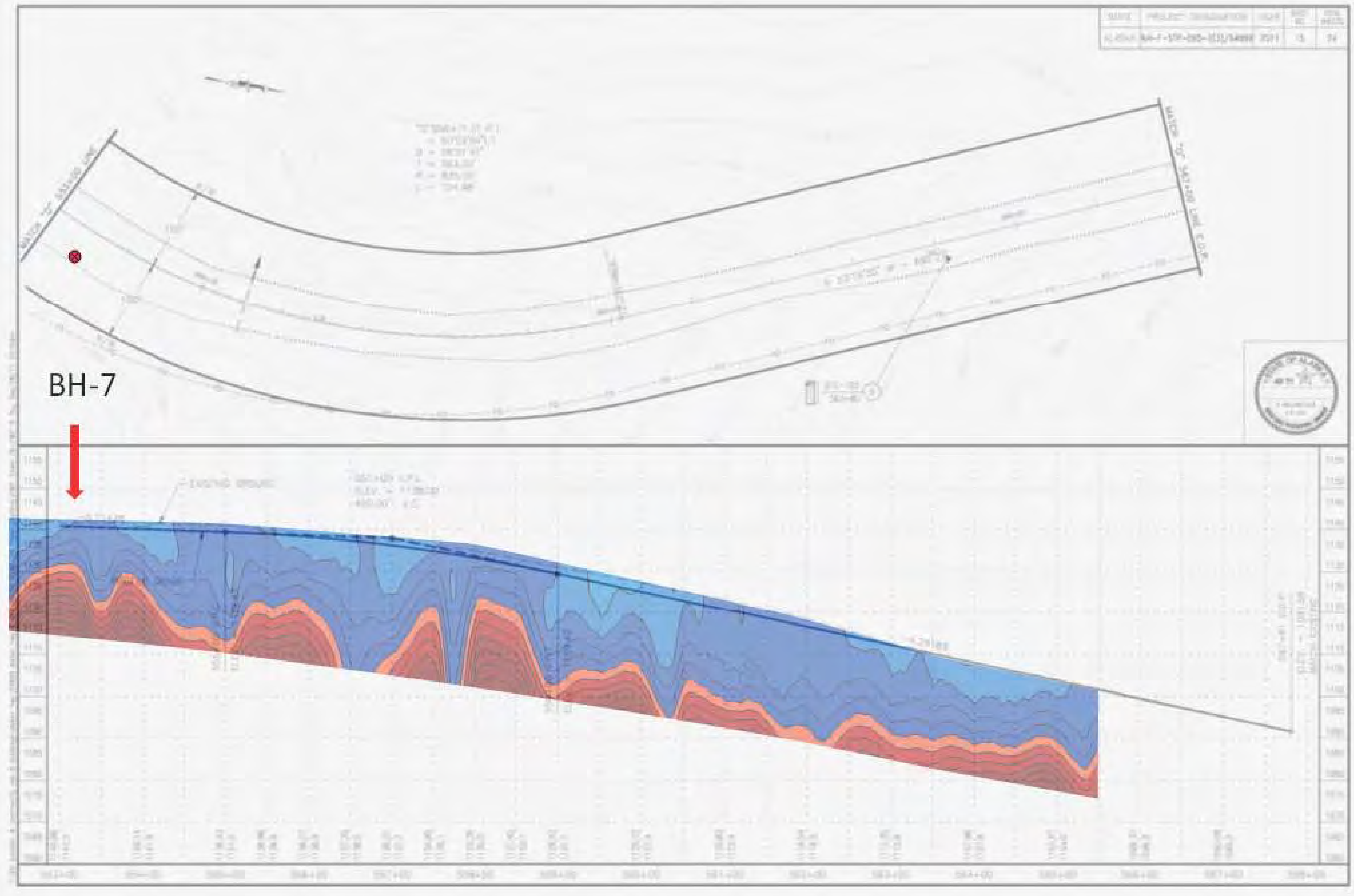
PROFILE GRADE
EXISTING GROUND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EXISTING GROUND