THERMAL MODELING OF ANCHORAGE DRIVEWAY CULVERT WITH ADDITION OF

INSULATION TO PREVENT FROST HEAVING

By

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Abstract

A predominate problem in cold regions, and specifically in Anchorage, Alaska, is frost heaving pavement above culverts in residential driveways. The culvert increases heat loss in the subgrade materials during winter months and allows the soils below the culvert to freeze, which is not an issue if the underlying soils are non-frost susceptible material. However, there are numerous locations in Anchorage and other parts of Alaska where the underlying soils are frost susceptible which result in frost heaving culverts under driveways that cause damaged pavement and culvert inverts that are too high. The seasonal heave and settlement of culverts under driveways accelerates pavement deterioration. A model of this scenario was developed and several insulation configurations were considered to determine a suitable alternative for preventing pavement damage from heaving culverts. The model used material properties for typical Anchorage area silty sand. The model showed that insulation could be used below culverts to prevent differential frost heave at the culvert. In addition, this technique uses typical construction materials and is reasonable for a typical residential dwelling contractor to complete during the construction of the home.

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1.0   Introduction

Engineers working in cold regions are presentenced with several unique challenges to cover during their design process. One of these challenges is associated with frost heave when designing pavement sections. For soils to frost heave, there need to be three key components, which are frost susceptible soils, freezing temperature, and water. It typically is not reasonable to completely remove the water from the subsurface, so cold region engineers design pavement section to remove the frost susceptible soils or to prevent them from freezing by the use of insulation. Another, more cost effective approach is to create a pavement section that will allow the subgrade to freeze evenly so that differential heaving in the pavement section is minimized so that the road will remain smooth. Both are appropriate design methods for pavement sections. However, if a culvert is required in the road section there is an increase in heat loss surrounding the culvert. The increased heat loss can result in an accelerated rate of heaved in the soils under the culvert leading to a raised section of pavement above the culvert that causes frost jacking. In a typical street section the effects culvert heave can be reduced by adding a tapered section of non-frost susceptible material on either side of the culvert to spread the differential amount of heave over a longer distance. However in a typical driveway, there is not adequate space between the culvert and the existing street to provide a taper to reduce the differential heave to a manageable amount. Since a tapered approach is not typically construable for a residential driveway, the budgets are relatively small, there is a low traffic volume and slow speeds a typical pavement section for a residential dwelling does not incorporate a pavement section designed to prevent frost heave of a culvert. Most culverts are installed to the proper elevation for the correct drainage of the project site with no consideration of the underlying soils and the potential frost heave. Similar to the street culvert, the driveway culvert causes increased heat loss which allows for the underlying soils to be exposed to the freezing conditions. If the underlying soils are frost susceptible, the culvert could heave at a different rate than the rest of the driveway creating a raised section above the culvert and cracking with repeating events over several winters, accelerating the rate of deterioration of the pavement.

The scope of this study will be to develop an appropriate configuration for driveway pavements sections with culverts in the Anchorage, Alaska area, to prevent differential frost heave of the culvert. The hypothesis of this study is that insulation can be used to develop a reasonably constructible solution to preventing differential frost heave above driveway culverts.

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2.0   Literature Review

There are not very many studies related to the prevention of frost heave over a culvert that pertain to a residential driveway. Most of the studies that were reviewed related to larger scale projects such as streets, highways, and trains. CTC & Associates (teamed with the Minnesota Department of Transportation) conducted a literature search and surveyed representatives from transportation agencies in cold-climate states in the United States and provinces in Canada that may have experience with heave and dips near the centerline culverts (directly above the culvert) during cold weather, and practices to mitigate them (LRRB, 2016). Several of the respondents to the survey indicated that the differential frost heave was the result of the improper application of or the lack of a tapered fill section during installation. The study concluded that by using the frost wedges (taper), the frost heaves of the road surface can be evened out along a stretch of road to such extent that the elevation of the road surface is made to change so smoothly that the pavement will not fissure as a result of frost heaving of the culvert (Taivainen, 1967-8). Several of the respondents referred to experience with a taper method but none the respondents had experience with using insulation to mitigate the differential frost heave and only one respondent had plans to test a culvert section with insulation designed to prevent frost heave.

A study by the Underground Space Center at the University of Minnesota (Duquennoi, C. & Sterling, R. L. 1991), was completed on the frost heave patterns of an insulated culvert. The study installed three insulated culverts. The culverts consisted of a 24-inch inside diameter concrete culvert that was insulated with expanded polystyrene insulation on the outside of the culvert with thicknesses of 1 inch, 2 inches, and 3 inches. The study compared the insulated culverts to an uninsulated culvert, which showed that there was less slope variance, as described in American Association of State Highway and Transportation Officials (AASHTO) Guide (AASHTO 1993a), above the insulated culvert when compared to the uninsulated culvert. This study shows that insulation can be used to help mitigate the frost heave differential with the use of insulation, however concrete culverts are not typically used for a residential culvert especially with external insulation.

3.0   Driveway Pavement Section

3.1   Driveway Pavement Section Design Method

The pavement section that was selected for this study was designed using the Design of Pavement Structures recommendations presented in the AASHTO guide (1993). The AASHTO method is an empirical method based on field performance from road tests completed by AASHTO and theoretical values based on soil properties. For the road tests, a panel of highway performance assessors were used to rate the driving conditions over the life of the road. The assessors were required to provide a value between 0-5 to rate the road with 0 being undriveable and 5 being a perfect ride. The assessors also provided the lowest acceptable value for driving. These values were correlated to the change in Pavement Serviceability Index (PSI) which represents the allowed deterioration of the road over its life before repairs or replacement are required. The PSI was adjusted for the type of road, location of the road, and frost heave. The PSI and other values were used to produce an empirical equation, shown below, for use in design of flexible pavements.

$$\log_{10}(W_{18}) = Z_R S_0 + 9.36 \log_{10}(SN + 1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \log_{10}(M_R) - 8.07 \qquad (1)$$

Where:

    W_{18} = Number of 18-kip equivalent single axle loads (ESALs)

    Z_R = Standard normal deviate

    S_0 = Standard deviation

    ΔPSI = Change in serviceability level from traffic and frost heave

    M_R = Effective roadbed soil resilient modulus (psi)

    SN = Structural number

The values used in the design equation were chosen to represent similar conditions to a driveway in Anchorage, Alaska and are derived from numerous tables, figures, and correlations presented in the Federal Highway Administrations (FHWA) NHI-05-037 Geotechnical Aspects of Pavements (FHWA, 2006). First, ESALs were estimated based on the driveway traffic classification of the proposed road using Table 11.3 from Huang (1993). The design reliability factor is simply the z-value based on the probability that the road will last the entire design life.

A design reliability level of 80% was chosen for this project resulting in a Z_R of -0.841 from linear interpolation of a standard statistics table. Values of 50-80 % are recommended by AASHTO (FHWA, 2006) for the design reliability level of local residential streets. The design reliability level was modified by a standard deviation amount to account for the uncertainty and variation in the design conditions and soil properties. AASHTO recommends a standard deviation of 0.45 for flexible pavements (Huang, 1993). The recommended value for ΔPSI from traffic and frost heave is 2.2 for low traffic roads and driveways. The design equation also uses the resilient modulus which may be estimated using an empirical correlation with California Bearing Ratio (CBR). Sukumaran (2002) presents four common correlations between CBR and M_R. The two that yield the most conservative values for M_R were chosen for this design. For CBRs less than 5, Equation 2 was used and for CBRs greater than or equal to 5, Equation 3 was used.

$$M_R(psi) = 1500 * CBR \tag{2}$$
$$M_R(psi) = 2555 * CBR^{0.64} \tag{3}$$

The U.S. Army Corps of Engineers suggests field CBR values from 5 to 15 for low plasticity silts, 20 to 40 for well-graded sands, and 60 to 80 for well-graded gravels (FHWA, 2006). Considering the effects of thaw-weakening, CBR values of 25 and 0.2 were conservatively chosen for Municipality of Anchorage (MOA) Type 2 fill and Anchorage area silty sand. The CBR values are typically whole numbers, however it was assumed a CBR of 1 for the silty sand that was reduced in strength by 80% due to saturated conditions during the thawing process. The MOA Type 2 fill gradation specification is shown in Table 1. A gradation of Anchorage area silty sand is attached in the Appendix. The silty sand gradation was completed by Northern Geotechnical Engineering, Inc. *d.b.a.* Terra Firma Testing and also used in "Applicability of Two Soil Thermal Conductivity Models for Anchroage Road Material" from Cody Kreitel.

Footnote:
Kreitel, Cody, J. (2013). *Applicability of Two Soil Thermal Conductivity Models for Anchroage Road Material.* University of Anhchorage Alaska, Anchorage Alaska.

Table 1: Municipality of Anchorage Type 2 Fill Gradation

Sieve Size	Percent By Mass Passing
8"	100
3"	70-100
1-1/2"	55-100
3/4"	45-85
#4	20-60
#10	12-50
#40	4-30
#200	*2-6
0.02	0-3

*In Addition to the grading limit listed above, the fraction of material passing the #200 sieve shall not be greater than fifteen percent of that passing the #4

Equation 1 was solved to find a structural number for each layer which was compared to a structural number found from Equation 4, below.

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 + \cdots + a_i D_i m_i \tag{4}$$

Where:

a_i = Layer coefficients

m_i = Drainage coefficients

D_i = Thickness of layer

The general procedure is to use equation 1 to determine the required overall structural number to protect the subgrade. The layer thickness is adjusted so the sum of the structural numbers of the layers are greater than the structural number required to protect the underlying layers. The layer coefficients used in equation 4 for each layer were found from the resilient modulus of that layer using Equation 5 (FHWA, 2006).

$$a_i = 0.14 * \sqrt[3]{\frac{M_R}{30000}} \tag{5}$$

The drainage coefficient was derived from recommendation in FHWA (2006) that relates the quality of drainage for each layer to the percent of time that the layer's moisture level approaches saturation. To determine the drainage coefficients it was assumed fair quality of

drainage (water removed within one week) and moisture levels approaching saturation more than 25% of the time. With these numbers determined, the thickness of the pavement section was adjusted in order to provide an appropriate driveway pavement section.

3.2 Driveway Pavement Section

Following the AASHTO design method described above, a driveway pavement section was completed. A Microsoft Excel spreadsheet was created to solve the AASHTO equations and was designed to have the ability to add multiple layers in the pavement section. The resulting pavement section design is presented in Figure 1. This study utilized only a two-layer design consisting of asphalt/leveling course and MOA Type 2 fill above the subgrade.
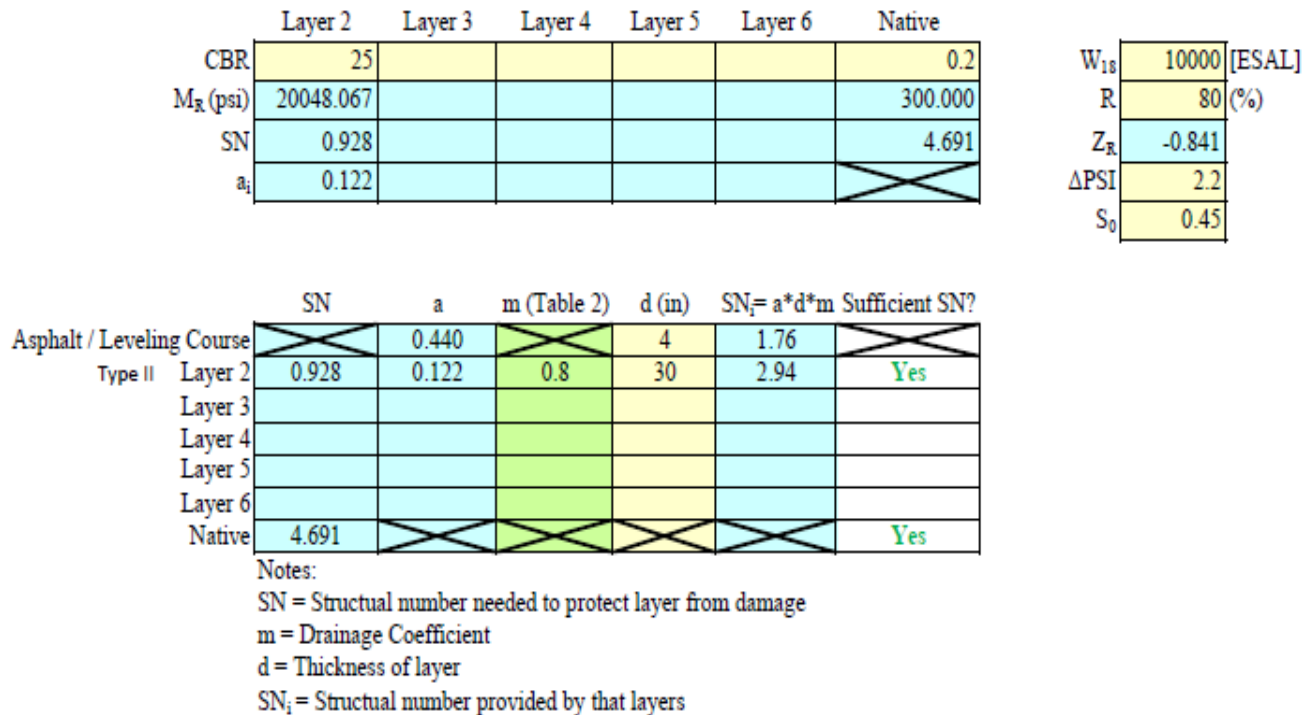
	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Native			
CBR	25					0.2	W_{18}	10000	[ESAL]
M_R (psi)	20048.067					300.000	R	80	(%)
SN	0.928					4.691	Z_R	-0.841	
a_i	0.122					✕	ΔPSI	2.2	
							S_0	0.45	

	SN	a	m (Table 2)	d (in)	SN_i= a*d*m	Sufficient SN?
Asphalt / Leveling Course	✕	0.440	✕	4	1.76	✕
Type II Layer 2	0.928	0.122	0.8	30	2.94	Yes
Layer 3						
Layer 4						
Layer 5						
Layer 6						
Native	4.691	✕	✕	✕	✕	Yes

Notes:
SN = Structual number needed to protect layer from damage
m = Drainage Coefficient
d = Thickness of layer
SN_i = Structual number provided by that layers

Figure 1: AASHTO Driveway Pavement Design Calculations

The following table (Table 2) is the driveway pavement section from the calculations shown above. A permeable geotextile fabric is recommended by AASHTO to be placed at the base of the recommended pavement sections detailed in Table 2 in order to create a fines barrier.

Table 2: Driveway Pavement Section

Thickness	Material
2 inches min.	Asphalt concrete
2 inches max.	NFS leveling course
30 inches	MOA Type 2
	Geotextile (recommended by AASHTO)
	Silty Sand (Frost Classification: F3)

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4.0   Thermal Analysis

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In order to evaluate the depth of frost penetration into the subgrade, a thermal analysis of the pavement section described above was completed. The thermal analysis was completed using the software Temp/W produced by Geostudio.

4.1   TEMP/W (GeoStudio 2012)

Numerical modeling is a non-invasive and relatively expeditious technique, using mathematics to simulate actual physical processes. This technique allows the user to manipulate initial site conditions and predict future site conditions. However, because the model analysis is based on user defined material properties, the results generated are only as accurate as the data that is initially input into the model. Furthermore, averaged values for material properties are often used in the modeling process to limit the complexity of the model, and allow for a more manageable data set. These generalizations do not account for the small-scale variations (both vertical and horizontal) which often occur in earth materials. Therefore, results obtained from numerical models should not be viewed as absolutes, but can be used along with other site-specific data to help guide design efforts.

TEMP/W is a two-dimensional, finite-element analysis software program that can model thermal changes in the subsurface due to a variety of environmental factors. TEMP/W can also be used to compute the transient distribution of subsurface temperatures (*i.e.,* temperature change with respect to time). As we describe below in more detail, the analysis was split the into four sequential steps, with each step representing a different stage of the development of the analysis

4.2   Model Configuration

A subsurface model was created to represent a cross-sectional area under a typical Anchorage driveway in TEMP/W's graphical user interface. As TEMP/W is a two-dimensional software program, the model was constructed as a cross-sectional model representing the centerline of the driveway.

The model is divided into individual units known as "regions". The region dimensions are designated by the user, and allow the user to assign various material properties to the model. The regions are subsequently divided into smaller units known as "elements" during a process known as "meshing". TEMP/W generates an "element mesh" (i.e., grid), which allows the

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program to relate information contained within each element to the surrounding elements during the temporal analyses. Each element is composed of the most basic model units known as "nodes" (*i.e.,* corner points), which link each element to one another within each region, and between surrounding regions.

4.3   Model Materials and Boundary Conditions

For the thermal analysis five different materials were identified and applied in the thermal model, representing one native subgrade (silty sand) and four materials associated with the construction of the driveway pavement section (asphalt concrete, leveling course, type 2 fill and insulation). Each material was assigned representative values for thermal conductivity and volumetric heat capacity, which were selected from Andersland and Ladanyi (2004), Dore, G., & Zubeck, H., K. (2009), and Farouki (1981). A material was assigned to each region of the model during each step of the analysis. The material properties applied are shown in Table 3.

Table 3: Material Properties for Temp/W

| | Thermal Conductivity | | Volumetric Heat Capacity | | | |
	Unfrozen	Frozen	Unfrozen	Frozen	Insitu Vol. Water Content	Dry Unit Weight
Material:	BTU/hr/ft/°F	BTU/hr/ft/°F	BTU/ft^3/°F	BTU/ft^3/°F	ft^3/ft^3	pcf
Pavement	10.4	10.4	33.46	33.46	0	140
Leveling Course	1.2	1.52	26.59	28.9	0.12	125
AS&G TYPE 2	1.2	1.66	26.59	28.9	0.12	125
Silty Sand	1.3	1.31	38	29	0.15	120
Insulation	0.17	0.17	0.6	0.6	0	2

Boundary conditions are used to define the external conditions that affect the temperature within the model, and are in essence what define the direction that energy (*i.e.,* heat) will move within the system. Boundary conditions are used by TEMP/W to calculate the heat energy flux gradient within a problem set. Boundary conditions are user defined, therefore for this study the most recent year (2016) climate data for Anchorage, Alaska was used as the surface boundary conditions. The climate data was downloaded from the NOAA online weather data website to produce the temperature graph shown in Figure 2.
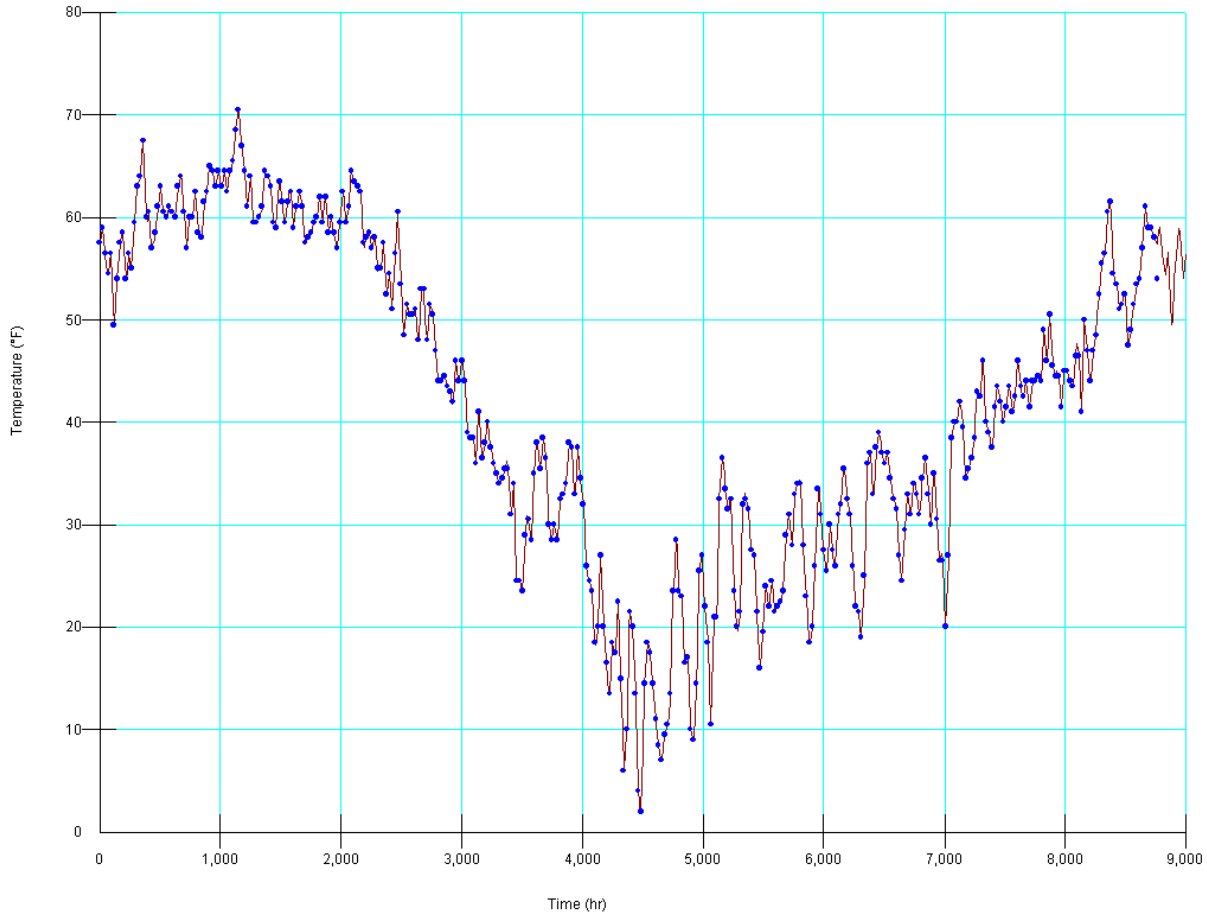
Figure 2: Average Temperature for Each Day in Anchorage, Alaska in 2016

4.4   Analysis Procedure

The analysis procedure was split into four sequential steps. The steps are detailed below:

Step One – Generation of Model – The first step of the thermal analysis was to create a steady-state thermal analysis on the modeled subsurface soils to generate a preliminary thermal gradient across the profile. This step does not represent any given point in time, but provides the analysis an approximate "starting point", thus minimizing the time required to bring the model into equilibrium.

Step Two – Generation of Transient Temperature Gradient Profile – In this step a transient analysis was completed on the model generated during step one. A boundary condition at the surface of the model was applied using Anchorage climate data. The climate boundary condition applies seasonal temperature fluctuations to the ground surface of the modeled

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subsurface soils and generates a representative thermal gradient for the soil profile (prior to any construction). A constant temperature was applied to the bottom of the model. The model was ran for ten annual cycles of the climate cycle (one year) to ensure the thermal gradients generated in each cycle were stable (the temperature at any given time and point is not changing significantly, less than four inches, with each additional cycle). The constant temperature was adjusted if the thermal gradients were not stable. Each time cycle was broken down into 120 time steps (one calculation every month) to reduce the required calculation time and maintain a manageable file size while maintaining enough time steps to provide accurate results.

Step Three – Generation of Transient Temperature Gradient Profile for Pavement Section and culvert – In step three, the driveway pavement section and culvert were added to the model. A boundary condition at the culvert was applied using the same Anchorage climate data. The model was again ran for ten annual temperature cycles to determine the long term effect of the construction.

Step Four – Generation of Transient Temperature Gradient Profile for Pavement Section, culvert and insulation – Step four uses the model created in step 3 with the addition of insulation. A total of four configurations of insulation were modeled to determine the insulation that resulted in a frost line at the culvert similar to the rest of the pavement section. The model for each insulation configuration was again ran for a total of ten annual temperature cycles to allow the model to reach equilibrium.

5.0   Results

The following sections show the results of each step in the thermal model analysis.

5.1   Steady State Model and Temperature Gradient

The first step of the thermal analysis was to create a model. There are several regions in the model to allow for the addition of the pavement section, culvert, and insulation. However, in the steady-state analysis, all regions are assigned the silty sand material to represent the site prior to any construction. Shown in Figure 3 is the steady state model with the climate condition applied to the surface (green line with dots) and the constant subsurface temperature at depth (red line with dots) applied to the bottom.
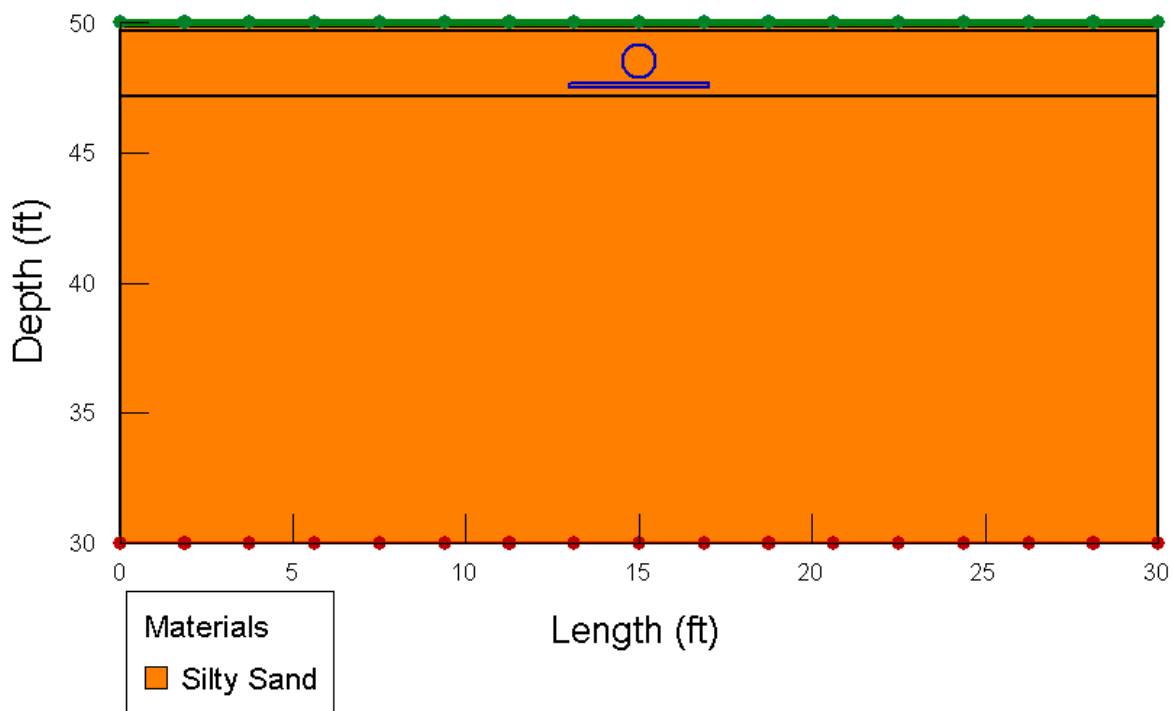
Figure 3: Thermal Analysis Steady State Model

A mesh was created to for the modeling process using TEMP/W's automatic meshing algorithm. The mesh size is reduced near the culvert and insulation to more accurately calculate the changing conditions as shown in Figure 4.
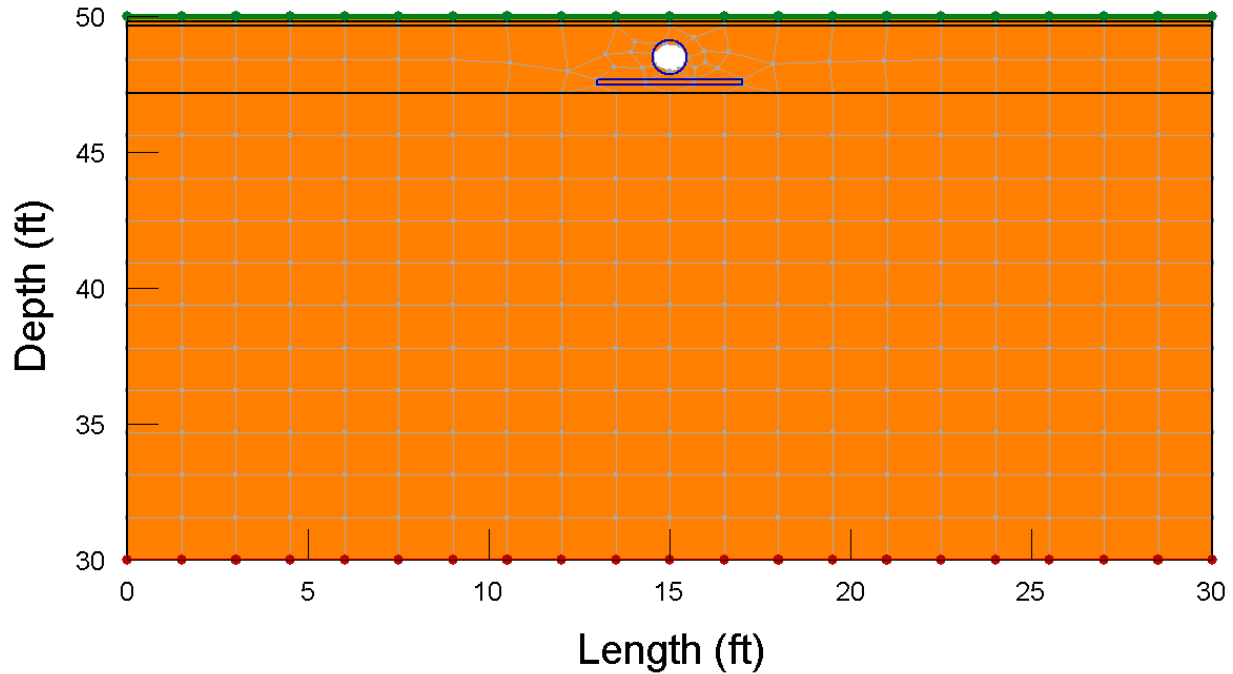
Figure 4: Thermal Analysis Model Mesh

With the model and mesh created, a transient model can be completed. As described above the transient model was ran for 10 climate cycles (10 years). From now on the cycles will be referred to in years. This step verifies that the model is stable and should be representative of the shallow active layer that is of interest. It can be seen that there is very little change in the maximum frost depth (blue dashed line) between the first year to the ninth year as shown in Figures 5 and 6 respectively. The ninth year was used due to the cycle starting in the summer so the tenth year does not reach maximum frost depth. It should be noted that the spot where the future culvert is to be located is not yet open but appears white due to the small element sizes in this area.
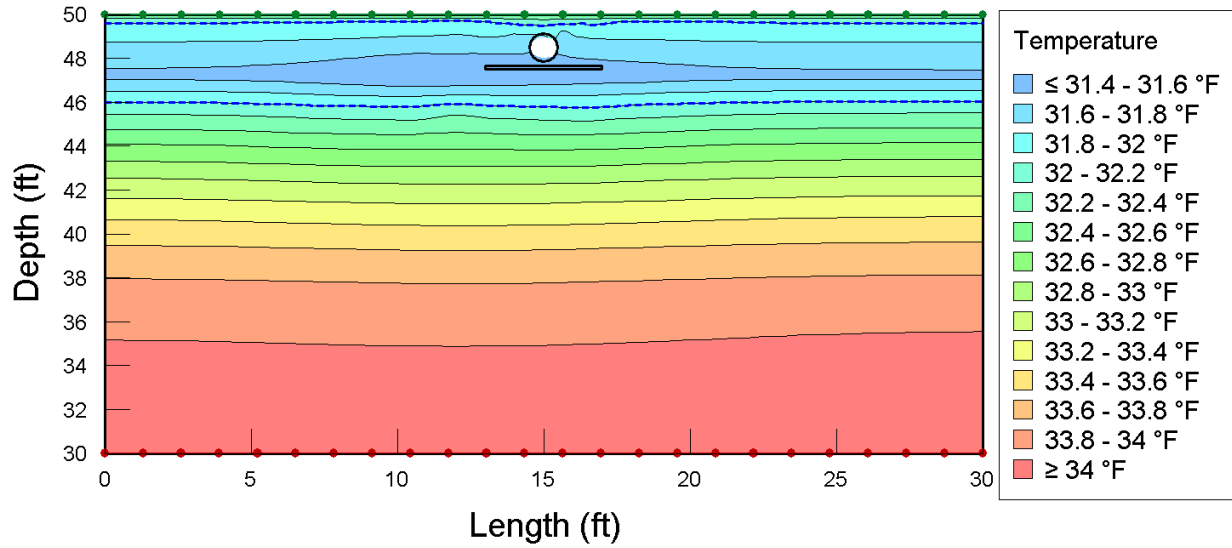
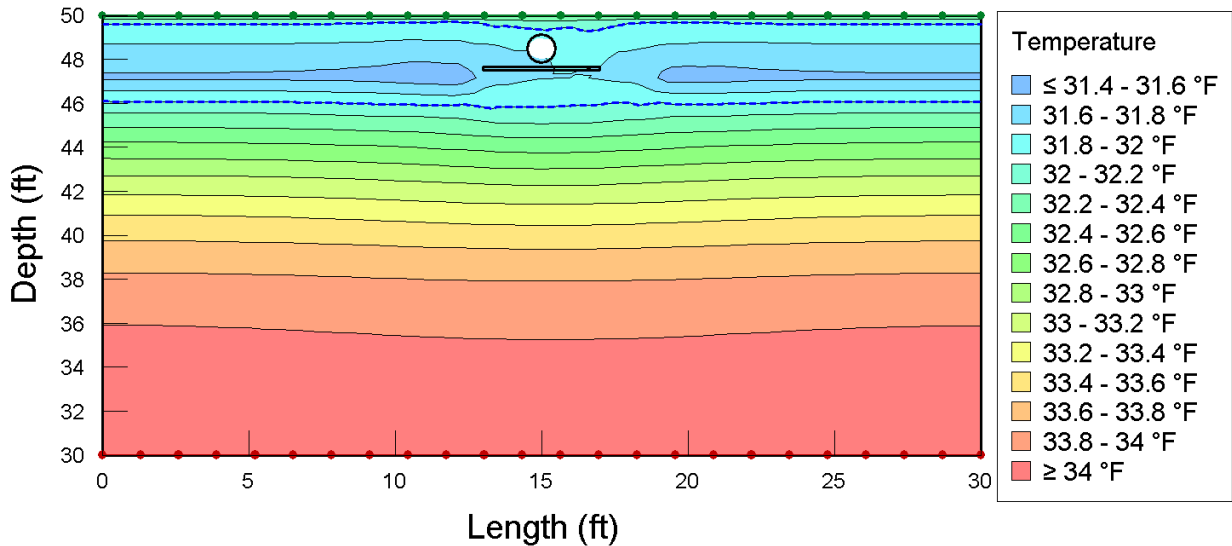**Figure 5: Temperature Gradient (Year 1, Day 274)**

Figure 6: Temperature Gradient (Year 9, Day 273)

5.2   Thermal Analysis with Pavement and Culvert without Insulation

With a stable model the thermal analysis proceeded to step three. As showing in Figure 7, the driveway pavement section consisting of asphalt, leveling course, MOA Type 2 (AS&G Type 2) and the culvert was added with the respective materials assigned. The climate condition was also applied to the culvert.
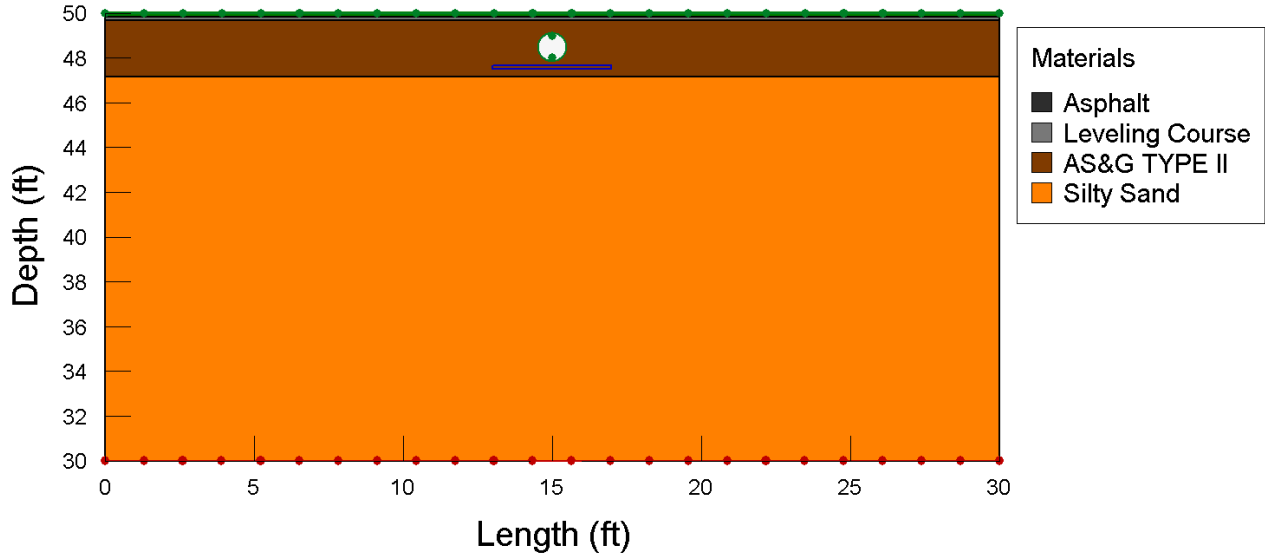
Figure 7: Thermal Analysis Model with Pavement Section and Culvert

The model was set up to complete 10 more years in addition to the steady state analysis (0 to 9 years) so this transient model is from year 10 to year 19. Figures 8 and 9 show the frost depth for year 10 and 19 respectively.
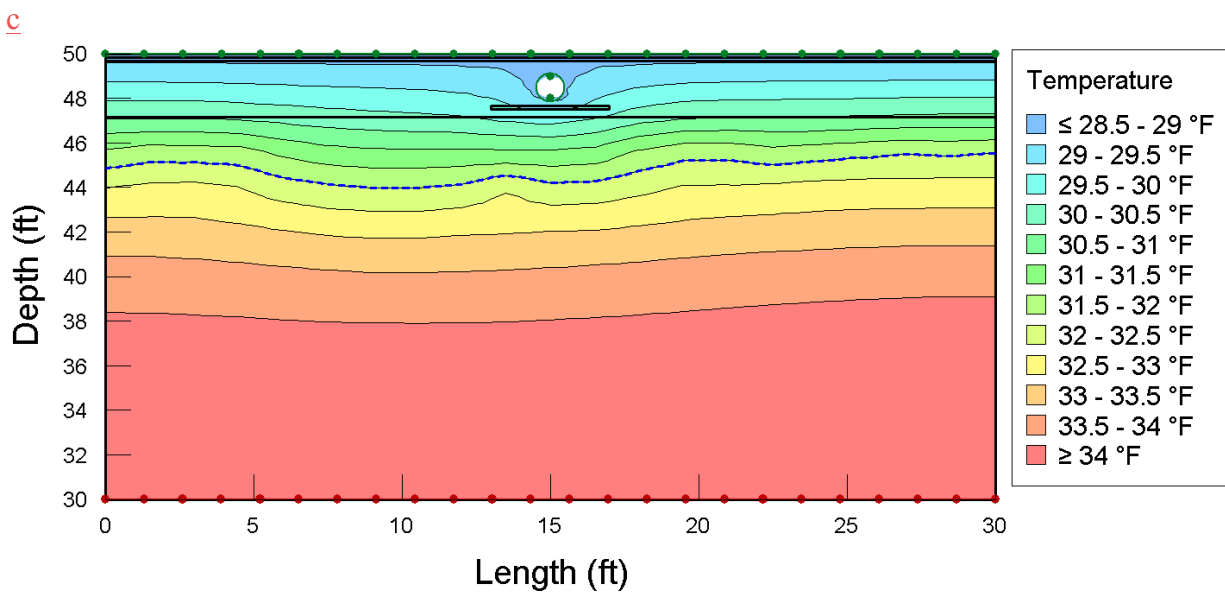

Figure 8: Temperature Gradient with Pavement Section and Culvert (Year 10, Day 243)
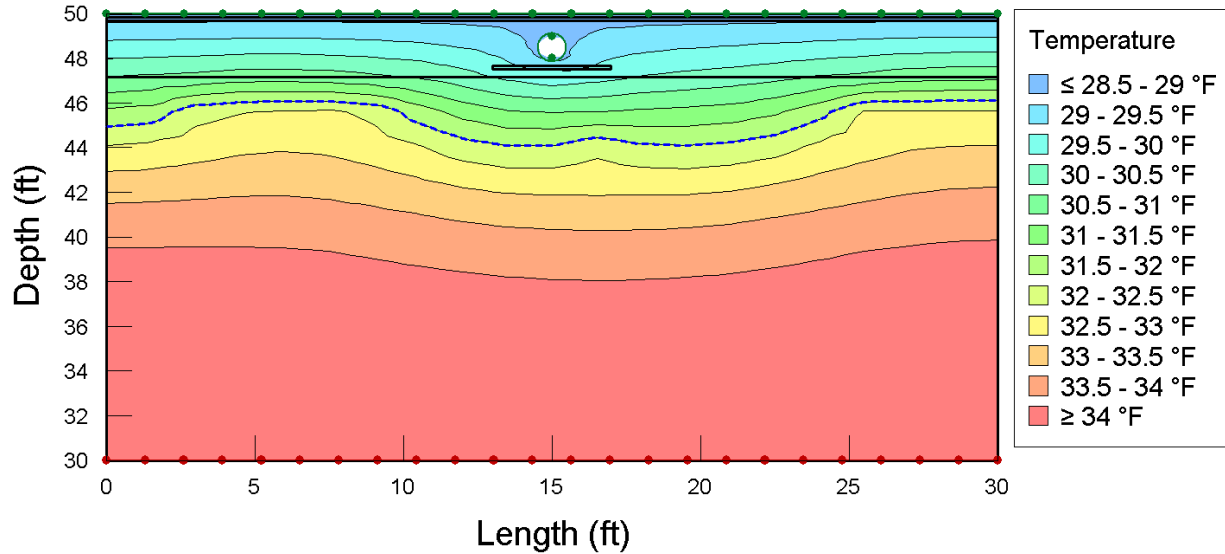
Figure 9: Temperature Gradient with Pavement Section and Culvert (Year 19, Day 243)

5.3   Thermal Analysis with Pavement, Culvert, and Insulation

The final step was to complete a thermal analysis of the pavement section including the culvert and insulation. As showing in Figure 10, the driveway pavement section consisting of asphalt, leveling course, MOA Type 2 (AS&G Type 2), insulation and the culvert was added with the respective materials assigned. The climate condition was also applied to the culvert as before. This analysis was continued after the 10 year cycle of the area undeveloped, therefore it is also based on years 10 through 19.
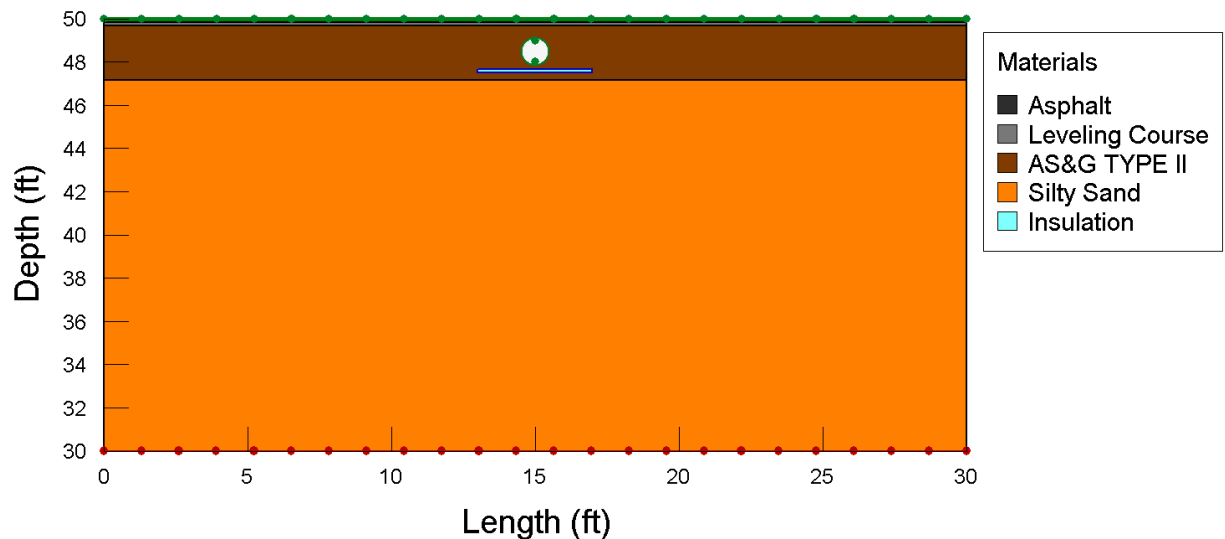

Figure 10: Thermal Analysis Model with Pavement, Culvert, and Insulation

The first insulation configuration consisted of two-inch thick insulation four feet wide applied four inches below the culvert. Figures 11 and 12 show the frost line associated with year 10 and 19 respectively of the thermal analysis.
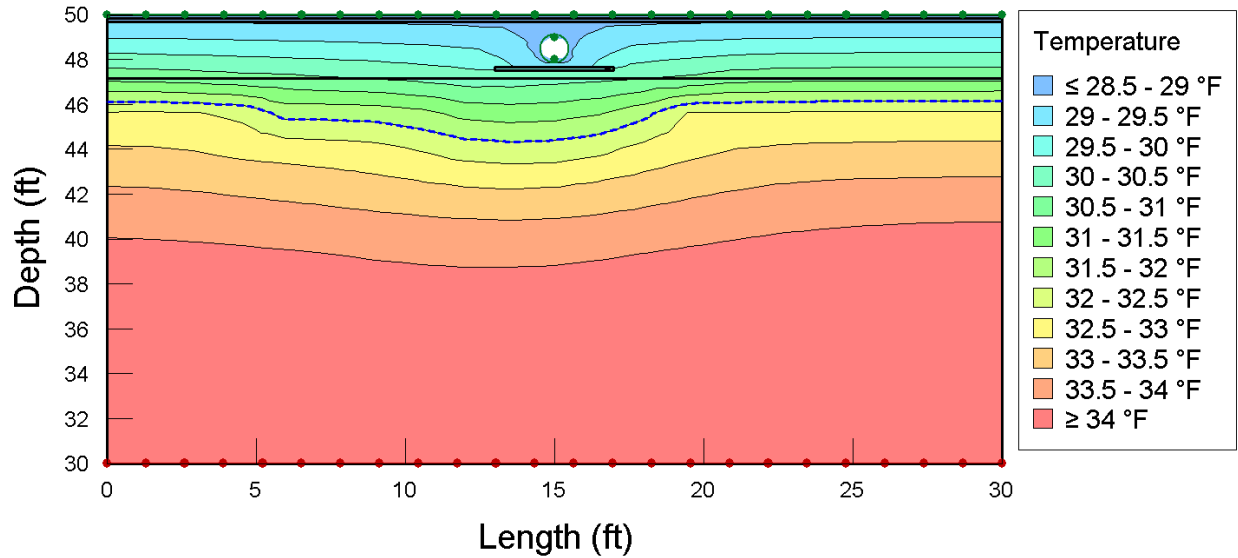

Figure 11: Temperature Gradient with Pavement, Culvert, and Insulation (2"x4')(Year 10, Day 243)
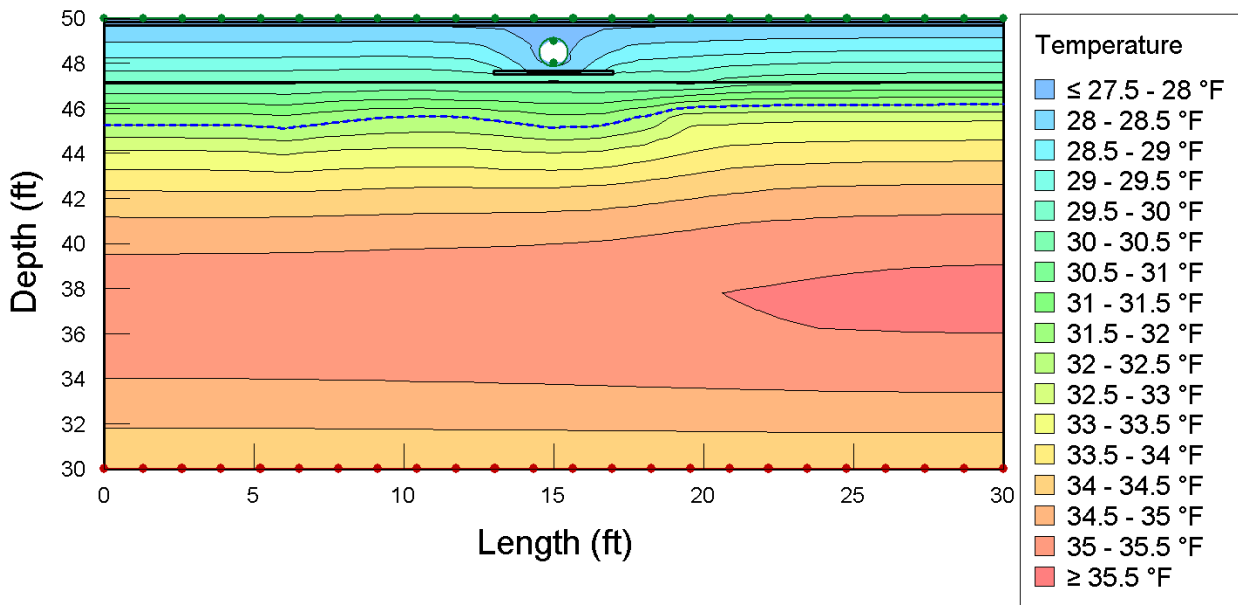

Figure 12: Temperature Gradient with Pavement, Culvert, and Insulation (2"x4')(Year 19, Day 243)

The temperature gradient still show a dip in the frost line below the culvert, so more insulation was added. An additional two inches was added to the thickness for a total of four-

inch thick insulation at four feet wide. Figures 13 and 14 show the temperature gradient with this insulation configuration at years 10 and 19 respectively.
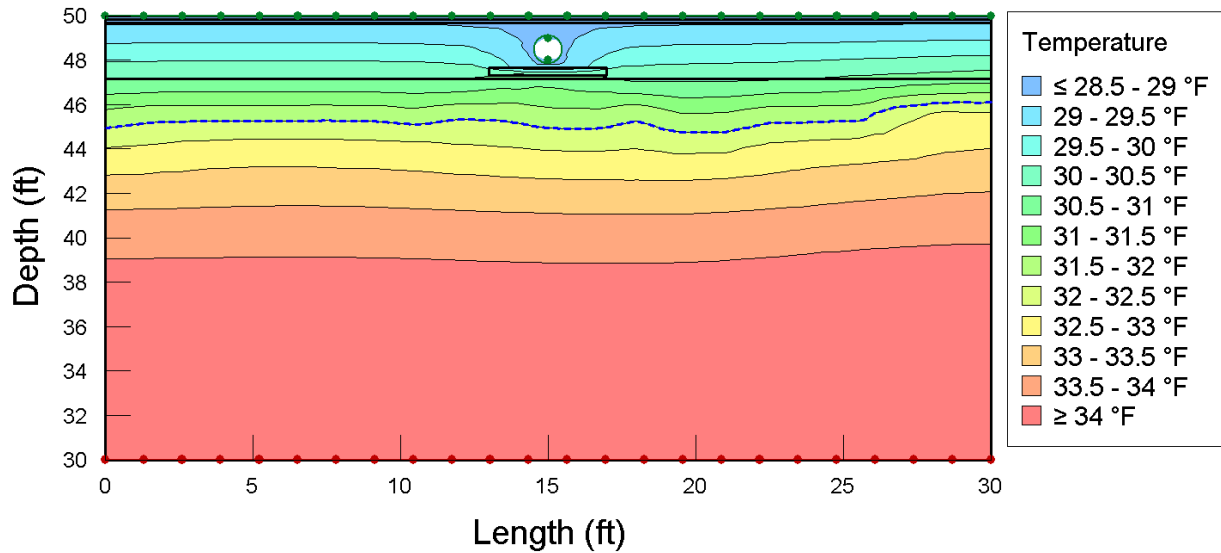

Figure 13: Temperature Gradient with Pavement, Culvert, and Insulation (4"x4')(Year 10, Day 243)
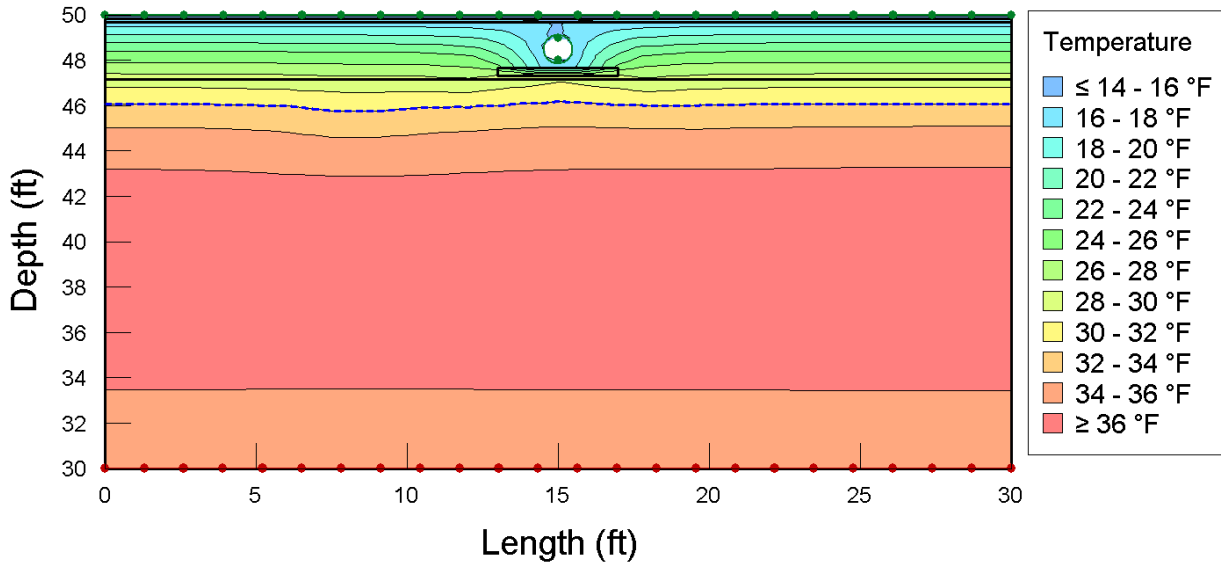

Figure 14: Temperature Gradient with Pavement, Culvert, and Insulation (4"x4')(Year 19, Day 243)

The insulation configuration shown above leveled out the frost line across the pavement section. However, to provided additional information and options of insulation a thermal analysis was also completed on the insulation thickness of two inches and eight feet wide as shown in Figures 15 and 16 for the year 10 and 19 respectively. In addition, a fourth thermal analysis was

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completed with the insulation being four inches thick and eight feet wide, which is shown in Figures 17 and 18 for the year 10 and 19 respectively.
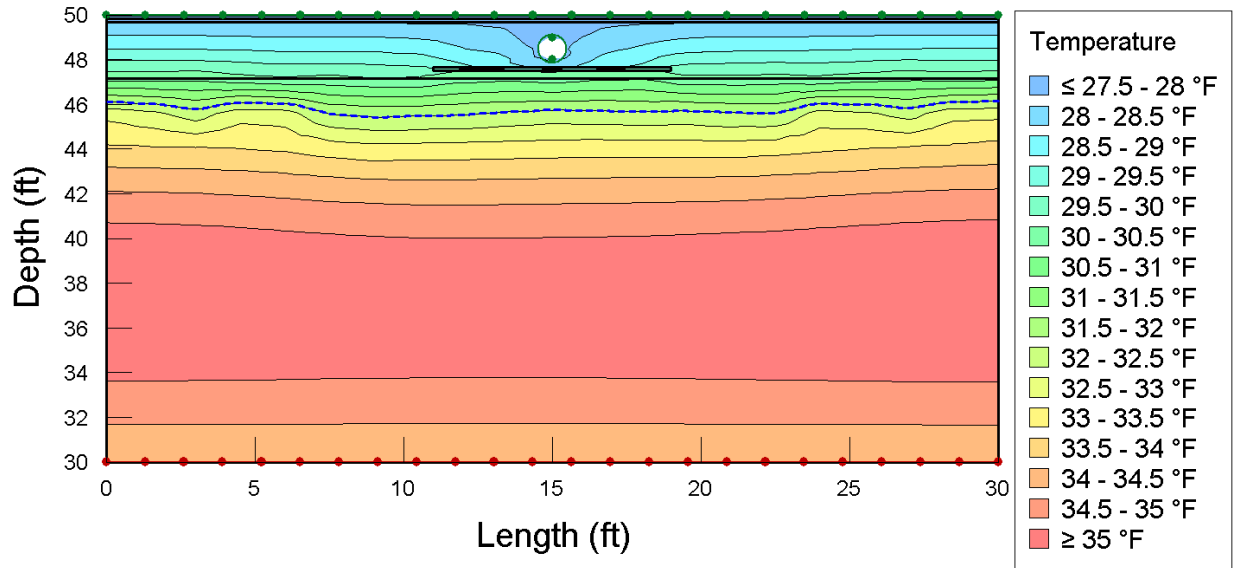

Figure 15: Temperature Gradient with Pavement, Culvert, and Insulation (2"x8')(Year 10, Day 243)
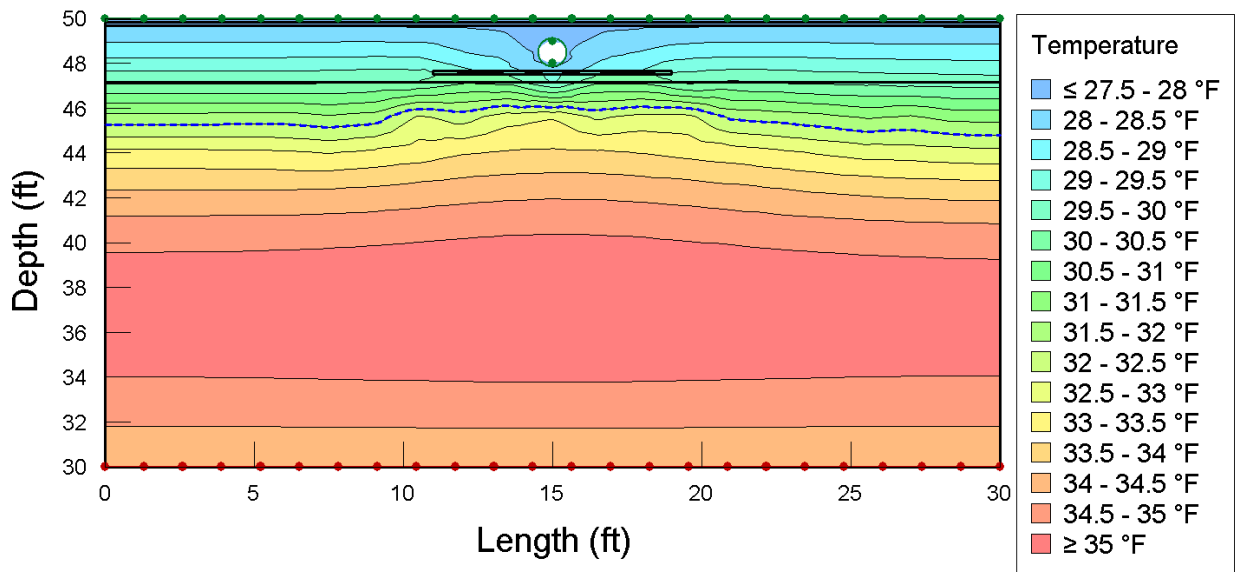

Figure 16: Temperature Gradient with Pavement, Culvert, and Insulation (2"x8')(Year 19, Day 243)
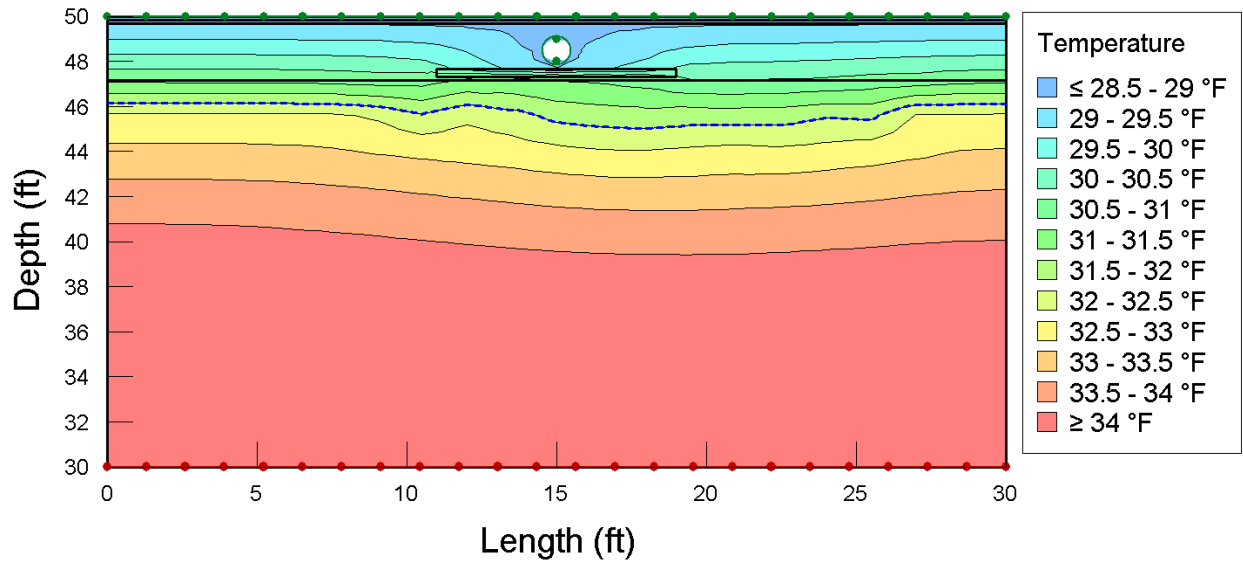
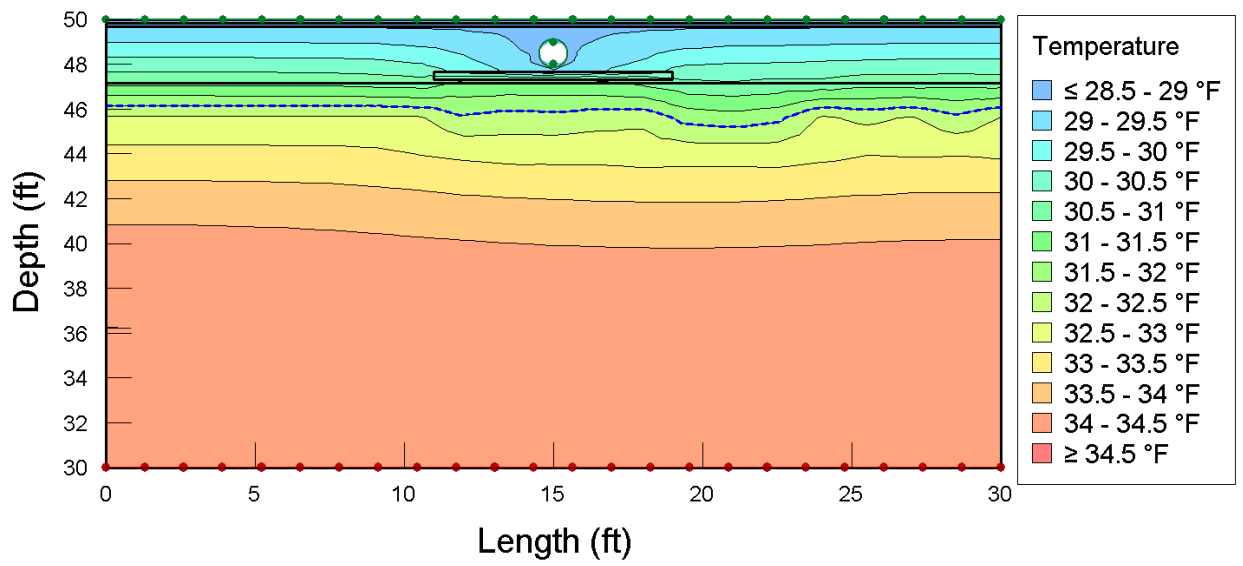**Figure 17: Temperature Gradient with Pavement, Culvert, and Insulation (4"x8')(Year 10, Day 243)**

Figure 18: Temperature Gradient with Pavement, Culvert, and Insulation (4"x8')(Year 19, Day 243)

6.0   Discussion

The results of the thermal analysis appeared to be reasonable. In the steady state analysis the frost line continued to return the similar position over the simulated 10 years. The frost line was approximately 10 feet below the ground surface, which is a realistic frost depth for the Anchorage, Alaska area. When the pavement section and culvert were added to the model, as expected the frost depth increased at the culvert compared to the rest of the pavement section by approximately two feet. The frost line did change over the 10 years, which is expected to be related to the addition of the climate boundary in the culvert.

It was apparent that the addition of the insulation reduced the difference in frost depth below the culvert compared to the rest of the pavement section. The thermal analysis for the insulation configuration of two-inch thick by four feet wide reduced the frost differential to approximately one foot. When two inches of insulation was added creating a four-inch thick by four feet wide the first year resulted in a reduction of frost difference to approximately one foot by at the change over 10 year there was almost no change in the frost depth.

The additional thermal analyses increased the insulation width to eight feet wide. The two-inch thick by eight feet wide insulation resulted in approximately a half a foot of differential frost depth for the first year however in the 10 year was still approximately a half a foot of differential frost depth but the frost depth below the culvert was less than the surrounding pavement section. The result of an additional two inches of insulation (four-inch thick by eight feet wide) was approximately a half a foot of differential frost depth for both the first and 10 year cycle.

7.0   Conclusions

As a result of the driveway pavement design and thermal modeling, it is apparent that the addition of a culvert to a driveway or any road creates differential frost depths between the culvert and the rest of the pavement section. Depending on the subgrade soils, the differential frost depths could lead to varying level of frost heave either making the driveway unpleasant to drive on and/or deteriorate the pavement section at an accelerated rate. The thermal model shows that insulation could be used to reduce the differential frost depths, and is a constructible option for residential driveway culverts.

8.0   Recommendations

This culvert configuration should be expanded upon using different soil road section thickness/culvert depths. In addition to varying depths a study could be completed on the effects of the culvert diameter. It is expected that the larger diameter will require a wider insulated section but no additional thickness. It would be beneficial to typical homeowners if a general culvert insulation guideline were completed, as most residential design and construction budgets do not allow for a thermal analysis of a culvert in the driveway.

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Appendix

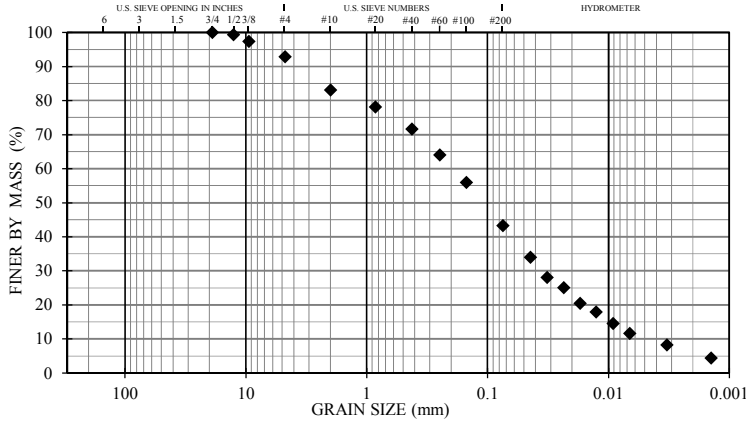## Anchorage Silty Sand Gradation Report

NORTHERN GEOTECHNICAL ENGINEERING, INC. / TERRA FIRMA TESTING

Laboratory Testing   Geotechnical Engineering   Instrumentation   Construction Monitoring Services   Thermal Analysis

PROJECT CLIENT:	**CJK**	% GRAVEL	**7.2**	USCS **SM**
PROJECT NAME:	**MS Project**	% SAND	**49.6**	USACOE FC **F3**
PROJECT NO.:	**MS Project**	% SILT/CLAY	**43.2**	% PASS. 0.02 mm **22.6**
SAMPLE LOC.:	**Anchorage Silty Sand**	% MOIST. CONTENT	**0.0**	% PASS. 0.002 mm **5.9**
NUMBER/ DEPTH:	**Anchorage Silty Sand**	UNIFORMITY COEFFICIENT (C_u)		**38.9**
DESCRIPTION:	**Silty sand**	COEFFICIENT OF GRADATION (C_c)		**1.3**
DATE RECEIVED:		ASTM D1557 (uncorrected)		**N/A**
TESTED BY:	**CJK**	ASTM D4718 (corrected)		**N/A**
REVIEWED BY:	**CJK**	OPTIMUM MOIST. CONTENT. (corrected)		**N/A**

PARTICLE SIZE ANALYSIS ASTM D422 / C136

COBBLES	GRAVEL		SAND			SILT or CLAY
	Coarse	Fine	Coarse	Medium	Fine	

MOISTURE-DENSITY RELATIONSHIP ASTM D1557

SIEVE ANALYSIS RESULT

SIEVE SIZE (mm)	SIEVE SIZE (U.S.)	TOTAL % PASSING	SPECIFICATION (% PASSING)
19.00	3/4"	**100**	
12.70	1/2"	**99**	
9.50	3/8"	**97**	
4.75	#4	**93**	
2.00	#10	**83**	
0.85	#20	**78**	
0.43	#40	**72**	
0.25	#60	**64**	
0.15	#100	**56**	
0.075	#200	**43.2**	

HYDROMETER RESULT

ELAPSED TIME (MIN)	DIAMETER (mm)	TOTAL % PASSING
0		
0.5		
1	0.0442	33.9
2	0.0324	28.0
4	0.0235	25.1
8	0.0172	20.4
15	0.0127	17.9
30	0.0092	14.5
60	0.0067	11.5
250	0.0033	8.2
1440	0.0014	4.3
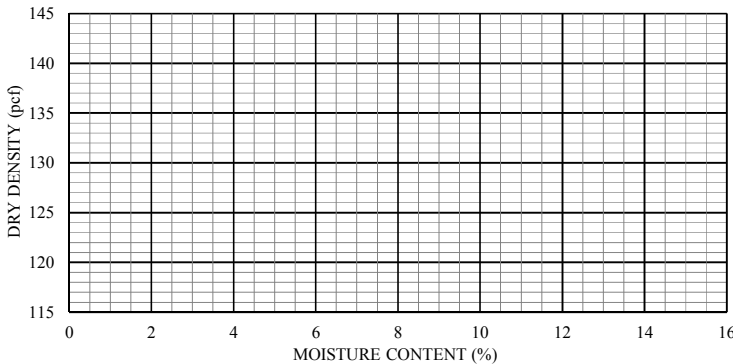
HYDRAULIC COND. (ASTM D2434)	**N/A**
DEGRADATION (ATM T-313)	**N/A**
PLASTICITY INDEX ASTM 4318	**N/A**

The testing services reported herein have been performed to recognized industry standards, unless otherwise noted. No other warranty is made. Should engineering interpretation or opinion be required, NGE-TFT will provide upon written request.

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