4370 Contractors Common
Livermore, CA 94551
Tel: 925-999-9232
Fax: 925-999-8837
info@geothermusa.com

November 16, 2016

PAR Electrical Contractors, Inc.
70 Fuller Rd.
Chicopee, MA 01020
Attn: Stephanie Labbe, Project Manager

Re: Suggested Thermal Resistivity Values for Design
Trench Thermal Resistivity Study, Northern Pass Transmission Line Project

We are pleased to submit the following report of the summary of our findings of the applicable thermal resistivity (TR) values for the native soils along the proposed cable route. The findings are based on the following:

- Review of the borehole logs
- Soil descriptions
- Water table (where available)
- Blow count (N value where applicable)
- Reconstituted dry density of samples (where applicable)
- Thermal dryout characterization
- Measured 'as received' moisture content
- Critical moisture content

We reviewed the following information you provided:

- Design max conductor temp is 70 °C.
- Typical trench detail
- Full depth FTB with Rho of 100 @ 0% or 80 @ 1% (mix design from InTerra) with a 6" layer of 1000-psi lean concrete.
- Standard trench width of 2'-9"
- Cable spacing C to C of 18" with 3" surround of FTB
- Shallowest depth per cover requirement is 51" to bottom of trench.

We have assumed the total heat output of the cables to be ~50 W/m (~15 W/ft.).

Background – Factors affecting soil thermal resistivity:

Thermal resistivity depends on soil composition, texture, water content, density, and various other factors to a lesser degree. This complex inter-relationship does not lend itself to a simple formula, rather a thermal probe test must be carried out in the field (in-situ) or on soil samples in undisturbed condition. Laboratory tests should only be performed on intact, undisturbed samples, and the results correlated with *in situ* values.

Soil Composition

Soil is a composite consisting of solid mineral grains, typically only making point-to-point contact, and pore space filled with water and air. The thermal resistivity of a soil mass is a function of the intrinsic resistivity of its components.

Texture

This refers to the soil grain size, shape, and particle size distribution. Since most of the heat is conducted through the solid particles and their contacts, the resistivity is minimized for soil particle mixtures that maximize these contacts. In engineering applications, it is often sufficient to qualitatively categorize a soil by a visual description using accepted adjectives to indicate the fractional amount of each component (i.e. gravel, sand, silt, clay).

Water Content

The major influence on the thermal resistivity is the moisture content. In a dry state the spaces between the solid mineral grains are filled with air (~4500 ºC-cm/W). As water (~165 ºC-cm/W) replaces air, the soil resistivity is substantially lowered (as much as 3 to 7 times). This is depicted by the 'thermal dryout curve' (thermal resistivity vs. soil moisture content). A soil that is better able to retain its moisture, as well as being able to efficiently re-wet when dried, will have better thermal performance characteristics. The soil water content is expressed as a percentage of the weight of water to the dry weight of soil solids, as determined by oven drying at 105 ºC.

Dry Density

Soil densification improves soil grain contacts and displaces air therefore reducing the resistivity, most notably at low moisture contents. Well-graded soils are potentially more-dense because smaller grains can efficiently fill the spaces between the larger particles. Dry density is expressed as the ratio of the dry weight of the soil solids to the total volume.

Organic Content

Soil containing organic material such as peat (fibrous or amorphous), vegetation, root-matter, etc. will exhibit high thermal resistivity even in moist condition and significantly higher in totally dry condition.

Results and Comments:

Our selection of the 'applicable thermal resistivity' values were based on the above factors for each soil type. The 'as received' moisture content and most importantly, the *'critical moisture content'* derived from dryout curves was used. Critical moisture content is defined as the moisture content below which the linear relationship between resistivity and moisture content becomes asymptotic. In granular non-cohesive soils such as sand and gravel, this is well define as the 'knee of the curve'. For cohesive soils such as silt, clay and organic soils, the shape of the curve is more parabolic and the knee of the curve is vague. In addition, the in-situ and/or the 'as received' moisture content of the sample was taken into consideration. For example: if the 'as received' moisture content of a granular sample was measured to be only 5%, and if the water table was at or above the samples depth, we can assume that the in-situ moisture content is much higher. In some cases, the loss of moisture can be attributed to sample porosity (hydraulic conductivity), sampling technique, storage and transportation.

We have added a column on the Excel data sheet that you provided. This gives the suggested thermal resistivity (TR) values for the 'Trench' and 'Trenchless' sections along the cable route(s). There are numerous locations where the suggested TR values are higher (some significantly higher) than 100 °C-cm/W. The locations or sections where the TR values are significantly higher will be the 'pinch-point' - commonly referred to as 'hot-spots'. These may need special attention with respect to the size of the backfill envelope and/or the quality of the backfill material.

We assume an Ampacity program ('in-house' or a 'commercially available') will be used to optimize the cable/trench/backfill design to satisfy the Ampacity.

Open Trench Installation

For the shallow burial depth of ~1.5m (5-ft), we understand the entire trench will be backfilled with FTB with thermal resistivity of 100 °C-cm/W in totally dry condition. Based on the suggested native soil thermal resistivity, if the Ampacity is not satisfied, you may consider using a backfill with lower thermal resistivity. This may be necessary for 'hot-spot' mitigation where other options may not be practical or cost-effective. We will be pleased to discuss this option with you.

HDD/Trenchless Installation

We assume the cables will be installed in some type of casing (steel, HDPE, PVC, FRP) and the annulus will be filled with a thermal grout with thermal resistivity significantly lower than the native soil at that elevation. We will be pleased to discuss thermal grout design and performance with you.

Ambient Temperature

A thermal survey (in-situ thermal testing) was not conducted and therefore, ambient temperature values can be obtained from local and national agencies such as USGS (US Geological Survey), airport authority, environmental agency or other relevant publications. Maximum recorded ambient temperature at the proposed burial depth of the cables should be used for the rating.

Please contact us if you have any questions or wish to discuss this report.

Geotherm USA

Deepak Parmar