The Effect of Raw Material Source on Concrete Duct Bank Thermal Resistivity

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***Abstract* – Past experiments provided a method of determining concrete thermal resistivity using the constituents of the concrete mix. At that time material from only one source was used in the experiments. The question was raised whether the source of the sand or cement would affect the thermal resistivity of the concrete. This paper describes an experiment designed to determine whether the source of the sand and cement would affect the thermal resistivity of a concrete mix. The experiment performed determined that the source of the raw material will affect the thermal resistivity of concrete. This paper describes the experiment and includes the analysis of the gathered data. The experiment showed that the source from which both sand and cement was procured does have an effect on the final resistivity of concrete, and will affect the resistivity values that are used when determining the ampacity of cables encased in concrete duct banks.**

***Index Terms*-- Cable Ampacity, Duct Bank Design, Soil Moisture, Soil Properties, Thermal Conductivity, Thermal Stability, Thermoresistivity, Underground Cable Design.**

I. INTRODUCTION

The thermal resistivity of concrete surrounding cables is important in determining the ampacity of the encased cables. Past experimentation derived a set of equations that could be used in determining the thermal resistivity of concrete duct banks if the proportions of water, cement, and fly ash were known [1]. Equation (1) was found to determine the thermal resistivity of a concrete-sand-water mix, if x is the water to cement ratio (w/c) and y is the thermal resistivity in cm˚C/W.

$$y = 139.4x^2 - 214.6x + 115.37 \tag{1}$$

Equation (2) is then used to find the prediction interval for the mix, y_0 is added and subtracted from y in Equation (1) to find the 95% prediction interval for any concrete mix with a w/c ratio of x.

$$y - 2.262\sqrt{17.149\left(5.75 - 35x + 95.8x^2 - 111x^3 + 46.3x^4\right)} \le y_0 \le y + 2.262\sqrt{17.149\left(5.75 - 35x + 95.8x^2 - 111x^3 + 46.3x^4\right)} \tag{2}$$

For a cement-sand-fly ash-water mix, Equation (3) was found to predict the thermal resistivity [1].

$$y = 114.34x_1^2 - 176.02x_1 - 0.08444x_2 - 64.421x_3 + 72.709x_1x_3 + 142.68 \tag{3}$$

Where:
x_1=water/cement ratio
x_2=water content in lb/yd^3
x_3=fly ash/cementitious ratio
y=thermal resistivity in cm-°C/W

The prediction interval is found using Equation (4) and adding y_0 to y in Equation (3).

$$y_0 = 2.447\sqrt{7.6535(1+Z)} \tag{4}$$

The value of Z is found using Equation (5) and the matrices X0 and W are found using Equations (6) and (7).

$$Z = X_0^{'} W X_0 \tag{5}$$

$$X_0 = \begin{bmatrix} x_1^2 \\ x_1 \\ x_2 \\ x_3 \\ x_1 x_3 \\ 1 \end{bmatrix} \tag{6}$$

$$W = \begin{bmatrix} 46.2963 & -55.5556 & 0 & 0 & 0 & 13.88889 \\ -55.5556 & 70.35174 & 0 & 6.122449 & -10.2041 & -18.8776 \\ 0 & 0 & 0.000102 & 0 & 0 & -0.03929 \\ 0 & 6.122449 & 0 & 20.40816 & -27.2019 & -4.59184 \\ 0 & -10.2041 & 0 & -27.2019 & 45.35147 & 6.122449 \\ 13.88889 & -18.8776 & -0.03929 & -4.59184 & 6.122449 & 20.90816 \end{bmatrix} \tag{7}$$

The sand and cement used to derive these empirical equations was procured from a local source in Colorado. The question remained whether the source of the raw material used in the concrete mix would affect the thermal resistivity of the concrete. An experiment was designed to answer this question, and the results of this experiment is included in this paper.

II. EXPERIMENT DESIGN

To determine the effects of the raw material source, cement and sand samples were procured from five different locations.

Location 1: California
Location 2: Colorado
Location 3: Missouri
Location 4: North Carolina
Location 5: Pennsylvania

A single factor, five treatment experiment was designed where the treatments were the factor was the location of the source material and each of the five locations was an individual treatment.

Four concrete samples were prepared for each of the treatments, twenty samples in all, using identical concrete mixes. The concrete mixes used are shown in Table I [2]. The concrete samples were then left to cure for 28 days. It was found that one of the concrete samples from California was not correctly mixed and resulted in a sample that was not usable for testing. It was discarded and not used in the analysis of the experiment.

After 28 days the thermal resistivity of the concrete samples was tested in random order [3][4]. The results are shown in Table II.

TABLE I
CONCRETE MIXES USED FOR EXPERIMENT 1

Sample Number	*Source*	*w/c*	*Water (lbs/yd^3)*	*Cement (lbs/yd^3)*	*Sand (lbs/yd^3)*
1	Location 1	0.6	385	242	2440
2	Location 1	0.6	385	242	2440
3	Location 1	0.6	385	242	2440
4	Location 1	0.6	385	242	2440
5	Location 2	0.6	385	242	2492
6	Location 2	0.6	385	242	2492
7	Location 2	0.6	385	242	2492
8	Location 2	0.6	385	242	2492
9	Location 3	0.6	385	242	2203

10	Location 3	0.6	385	242	2203
11	Location 3	0.6	385	242	2203
12	Location 3	0.6	385	242	2203
13	Location 4	0.6	385	242	2203
14	Location 4	0.6	385	242	2203
15	Location 4	0.6	385	242	2203
16	Location 4	0.6	385	242	2203
17	Location 5	0.6	385	242	2440
18	Location 5	0.6	385	242	2440
19	Location 5	0.6	385	242	2440
20	Location 5	0.6	385	242	2440

TABLE II
TEST RESULTS: SAMPLE THERMAL RESISTIVITY CM˚C/W

	Sample Number				
Sample	*1*	*2*	*3*	*4*	*Mean Resistivity (cm˚C/W)*
Location 1	54.3	56.9	57.3	Discarded	56.2
Location 2	36.0	35.2	36.4	39.1	36.7
Location 3	49.7	46.1	50.3	48.4	48.6
Location 4	38.8	35.8	41.9	41.3	39.4
Location 5	41.7	41.2	42.3	40.7	41.5

III. ANALYSIS OF RESULTS

The method used to analyze the experimental data was a single factor analysis of variance. Since one sample of concrete from the California sources was not included in the analysis and unbalanced design analysis was used [5]. The data in Table II was plotted on a normal distribution graph shown in Fig. 1. The data appear to be reasonably normally distributed with similar variances.

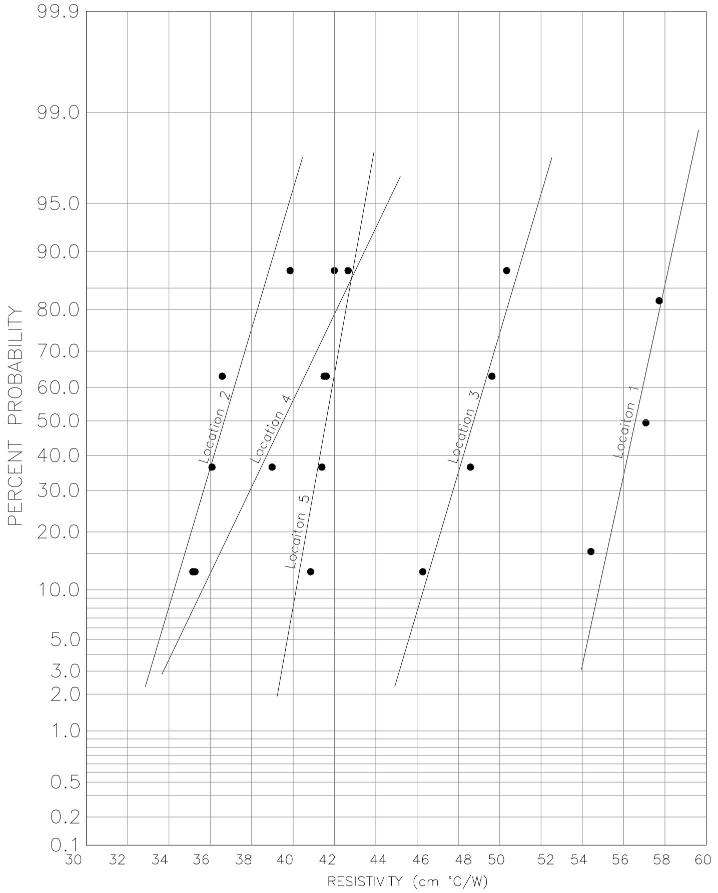

Fig. 1. Data on Table II shown on a normal distribution plot.

The results of the analysis of variance is shown in Table III.

TABLE III
ANALYSIS OF VARIANCE FOR DATA IN TABLE II.

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	*F_0*	*$F_{0.05,4,14}$*
Resistivity	854.5	4	213.62	61.04	3.89
Error	49.0	14	3.50		
Total	903.5	18			

The null hypothesis is that there is no difference in resistivities between the different treatments, and the resistivities from all the sources are essentially the same. The alternative hypothesis is that there is a difference between the resistivities of the different treatments. Table III shows that the statistic F_0 derived from the experimental data is 61.04. The F distribution test statistic is 3.89. Since 61.04>3.89 the null hypothesis must be discarded and the alternative hypothesis accepted. There appears to be evidence from this experiment that the location from which raw materials are procured affects the resistivity of the concrete.

Subsequent analysis was done to determine if the contributions of both sand and cement contributed to the variation in thermal resistivity between material sources. The cement and sand from Colorado and Missouri were tested independently. Nine samples of Cement were prepared from the cement from Colorado and the cement from Missouri. They were left to cure for 28 days and the thermal resistivity was tested in random order. The results of the tests are shown in Table IV.

TABLE IV
RESISTIVITY OF CEMENT SAMPLES IN CM˚C./W

Sample	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Mean Resistivity (cm˚C/W)*
Location 2	93.0	96.9	107.1	95.3	99.5	88.0	93.0	86.6	107.4	96.3
Location 3	87.1	85.9	88.4	94.6	85.4	91.2	91.3	89.7	84.6	88.7

A two-sample t-test (a statistical test done to compare two population means, by comparing small sample means, to determine if the population means are statistically different) was done on the data in Table IV [5]. The t-statistic from the data was 2.8, and the $t_{0.025,16}$ test statistic (statistic with a single-tail significance level of 0.025 and 16 degrees of freedom) was found to be 2.11. Since 2.8>2.11, for a 5% significance level the null hypothesis must be rejected and it may be seen that there is a difference between cement resistivities of the samples from Colorado and the samples from Missouri.

Three samples of dry sand and three samples of sand with an 11% moisture content were prepared from sand procured from Colorado and from sand procured from Missouri. The sand samples were tested in random order. The results of the tests are shown in Table V

TABLE V
RESISTIVITY OF CEMENT SAMPLES IN CM˚C/W

Sample	*1*	*2*	*3*	*Mean Resistivity (cm˚C/W)*
Location 2 Dry	283.5	276.8	277.2	279.1
Location 3 Dry	277.8	272.8	256.7	269.1
Location 2 11%	64.6	58.5	53.2	58.8
Location 3 11%	72.1	78.8	70.1	73.7

A two-sample statistical t-test was done for the dry samples and for the samples with 11% moisture content. For the dry samples the t-statistic from the data was found to be 1.5 and the t test statistic was 3.7. Since 1.5<3.7 to a 5% significance level, there is no evidence to reject the hypothesis that the resistivities of the samples from Colorado and Missouri have the same thermal resistivities. After moisture is added, however, the conclusion changes. For the 11% moisture samples the t-statistic from the data was found to be 3.0 and the t test statistic was 2.6. Since 3.0>2.6, to a 5% significance level the null hypothesis must be rejected and the alternative hypothesis that there is a difference between the resistivities of the sand from the two sources must be accepted.

IV. CONCLUSIONS

The mean resistivities shown in Table II show that the resistivity of the concrete mix from the California source were 1.5 times the resistivity of the samples from the Colorado sources. The values calculated in Equations (1) and (3) may need to be corrected, and may be 1.5 times those calculated in these equations depending upon the source of the material. Since there is a difference in resistivity of concrete due to the types of sand that is available at every location, the results of Equations (1) and (3) are only applicable for locations where the sand and cement is of similar resistivity at that procured in Colorado. The highest resistivity seen during this experiment exceeded the values calculated in Equations (1) and (3) by a factor of 1.5.

Testing of cement and sand individually appeared to show that dry sand is nearly the same resistivity no matter the source. However, after moisture is added, there is a difference between the resistivities of material from different sources. Variation between both sand and cement qualities from material procured from different sources both contribute to differences between the final concrete resistivities.

When concrete duct banks are being used, and an accurate estimate of thermal resistivity is needed, the best course of action will be to procure sand and cement from the source of the concrete. This material should be used to produce test samples to determine the thermal resistivity of the concrete that will be used in the final design. If known, exact samples of the proposed concrete mix can be prepared and tested to determine the expected resistivity of the concrete that will be used for the duct banks. Several samples should be prepared of the mix and tested, and the mean value of the samples should be used for the resistivity of the concrete. This value can be used in Neher-McGrath calculations for any cables encased in the concrete. If desired, equations similar to Equations (1) and (3) can be derived from the samples taken from any source.

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BIOGRAPHIES

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