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SOIL AND BACKFILL MATERIAL OF ENVIRONMENTAL FRIENDLY THERMAL PROPERTIES

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ABSTRACT: The rate at which heat is transferred through the earth is a phenomenon that affects the environment. In arid and semi-arid areas environmental weather changes show temperature ranges of more than 15 degrees. The nature of substrata or subsurface soil determines the temperature variations at any given time of the day. Gain and release of heat are generally slow but mainly dependant on the constituents of the ground. It is believed that clay content of backfill material can be a significant factor to control temperature during evening and early morning times. Investigations of heat gain and release including temperature changes were studied for soils commonly used. Range of optimum clay content associated with convenient evening weather will are highlighted.

Keywords: Temperature, Clay, Expansive soil, Mixtures, Heat

1. INTRODUCTION

1.1 General

The thermal properties of soils are key parameters in the design of engineering projects where heat changes and/or temperature variations are involved. Flow of heat through soils consisting of solid grains or particles, water and air attracted considerable amount of research in many disciplines. The heat dissipation around underground high voltage cables is related to actual thermal properties of soil. Major failures of high voltage underground cables took place during summer times in Riyadh city, Saudi Arabia as a result of inappropriate backfill material [1].

Works of reference [2] showed that the thermal resistivity for fine sand in dry state is varying from 260 to 360 ^{o}C-cm/watt and for coarse sand varies from 160 to 250 ^{o}C-cm/watt. They found that black cotton soils and fly ash could have thermal resistivity values as high as 1120 and 1100 ^{o}C-cm/watt respectively. Reference [3] studied the effects of many parameters on the thermal conductivity. These included grain-size distribution, particle shape, porosity, degree of saturation and mineral content. A model was constructed to predict the thermal conductivity based on above mentioned parameters.

Reference [4] stated that thermal conductivity increased with the increase of soil density and water content. It was also observed that the increase of salt contents is associated with the decrease in thermal conductivity. It was found that the sand had higher values of thermal conductivity than the clay loam for the same salt type and concentrations.

1.2 Heat Transfer Theories

The study of unidirectional conduction of heat transfer is expressed by Fourier simple equation.

$$q = - kA\,(d\theta/dx) \qquad (1)$$

Where:
q = the rate of heat along x axis
A= cross –sectional area
$d\theta/dx$ = the temperature gradient.
K = the thermal conductivity of the material.

Thermal needles or probes simulate a line source of heat input in a homogenous medium. After a short period of time the temperature rise is found function of the heater power, and the medium thermal conductivity. This could be stated mathematically as:

$$\delta\theta/ \delta t = \alpha\,(\delta2\theta/ \delta r^2+ 1/r \quad \delta \theta/ \delta r) \qquad (2)$$

Applying boundary conditions the above equation can be solved to give the following relationship:

$$\Delta\theta = (Q/4л\, k) \quad \log_e \; t_2/t_1 \qquad (3)$$

The plot of this equation will give a straight line with a slope equal to (Q/4 л k). The thermal resistivity is equal to 1/k . The above approach is typical to the approach followed by Hukseflux Thermal Sensors for their TP-02 Nonesteady state probe for thermal conductivity measurements [5].

1.3 This study

This research study is aimed at measuring temperature changes and rates of change for environmental friendly clay sand mixtures to be used in design for coastal areas where extremely high temperature changes are reported. The behavior of heat gain and heat loss is studied based on the change of temperature over time. This study is designed to help municipal engineers to specify a fill material to be used for coastal green parks and green areas in general so that a comfortable temperature or weather is attained at the right time. During hot summer times the subsurface ground gain heat and will not be cool until long time after sunset. Mixtures of sand and Alqatif clay are studied in order to select an optimum clay sand mixture that will help quick cooling of ground to create a comfortable weather. This property can also be used for quick heating in the early mornings of cold winter.

The ambient and soil temperature in degrees Celsius for some selected regions in Saudi Arabia are given in Table 1 below:

Table 1. Metrological data from selected parts of Saudi Arabia

Temp/ Region	Hofuf	Riyadh	Yanbu	Khurais
Monthly Normal Max Temp. (hottest month)	45	43	39	42
Monthly Normal Max Soil Temp. (1m below ground)	31	31	32	-
Highest recorded temperature	49	49	49	52

From Meteorological & Seismic data SAES-A-112 [6]

The temperature can go as high as 50 ºC in some parts of the Kingdom of Saudi Arabia.

2. MATERIAL AND METHODS

This section describes the material and methods used for preparing compacted sand clay mixtures. The clay was obtained from Al-Qatif town in the eastern province of Saudi Arabia. Al Qatif clay is classified as highly plastic clay (CH). This clay is proposed for use in clay sand liners for various environmental applications.

Several research studies were performed to characterize and evaluate this type of clay. Al Qatif clay is classified in accordance with ASTM D 2487 as highly plastic clay (CH). This clay is known of its high expansion and shrinkage properties. Several research studies were performed to characterize and evaluate this type of clay [7] to [9].

The standard proctor maximum dry density is measured at 11.5 to 12 kN/m^3 [10]. The optimum moisture content is reported as 30 to 32%. Al Qatif clay indicated liquid limit of 130 to 150 with plasticity index in the order of 60 to 70 [11]. The sand material used is generally poorly graded sand [12] with a coefficient of uniformity of 1.737 and coefficient of curvature of 1.078. The specific gravity of the sand used is 2.66.

3. EXPERIMENTAL PROGRAM

The investigation program included four sets of samples prepared in cylindrical moulds 75 mm in diameter and 50 mm height in order to assess the rate of gain and loss of heat for sand backfill and clay sand mixtures with 10%, 20% and 30% clay content. All soils were prepared at the maximum dry density and optimum moisture content as obtained in a standard proctor test.

All samples were supplied with 5TE Decagon sensors connected to Em50 data logger. The sensors were set to record the electrical conductivity, volumetric water content and temperature at 10 minutes interval. In order to reduce heat losses 5 cm thick polystyrene was used to rap the cylindrical sample and allow heat gain and loss from a single direction. Temperature controlled oven was used to expose the soil samples to heat at a constant temperature.

The oven was set to keep the temperature constant at 30, 40 and 50 degrees simulating selected three common levels during summer times in Saudi Arabia. The soil samples were allowed to gain heat in the oven for a period of 24 hours. After gaining the oven heat the samples were allowed to loose heat in room temperature (22 ºC degrees) for a 24 hour period.

Figure 1. 5TE Decagon Sensor

Figure 2. Em50 data loggers used for 5TE sensors

4. RESULTS AND DISCUSSIONS

The test results indicated that different sand clay mixtures behave differently with regard to gain and loss of heat. The rise and fall of temperature is function of many parameters that include clay mineralogy, texture, porosity and density of soil. The scope of this study is limited to comparison between soils of the same dry density and mineralogy but with different clay contents and different range of temperature variations. The first feature we can observe from the test results is the non-smooth changes in gaining temperature for sand as compared to sand clay mixtures and the extra time needed to achieve a target temperature. This can be attributed to excessive voids filled up with air. Filling up the sand with small amount as little as 10% of clay will be sufficient to achieve a smooth profile. The time needed for sand backfill to gain the ambient hotter temperature is much more than the time needed for different clay sand mixtures. Figures 3 and 4 show the differences of gain and loss of heat for the sand alone and for sand with 30% clay. 12 hours were sufficient to increase the temperature from 20 degrees to 28 degrees for the 30% clay soil as compared to 21 hours needed for the sand alone.

The sand alone was also found cooling slower when compared with 30% clay soil. In order to achieve a predictable quick drop and increase in temperature clay need to be added at a certain percentage. This amount depends on the clay minerology and other factors. For this specific type of soil amounts of 10% can be sufficient. The trend of gaining temperature in sand alone was repeated when elevating temperature from 20 to 40 and 50 degrees. All other mixtures presented smooth curves. The time needed to heat up and cool down is variable and is function of the clay content and the temperature range. The cooling time is generally shorter when the range of temperature is low. The time needed to drop the temperature from 40 to 20 is estimated at 6 hours compared to more than 12 hours when temperature is cooled from 50 to 20 degrees.

When heating the soil the air in the pores is highly affected and the sand alone may behave in a different way. The amount of air seems to be a key element in the heat transfer within unsaturated soil material. Rate of cooling may be faster in sand alone when the temperature range is high. The thermal conductivity of air, water and sand at different ranges of temperature govern the cooling and heating time. Example of thermal conductivity at 25 degrees centigrade for the three phase's involved are given in Table 2.

Table 2 Typical thermal conductivity values for selected material

Material	Thermal conductivity at 25 degrees in W/(m K)
Sand, dry	0.15 - 0.25
Sand, moist	0.25 - 2
Sand, saturated	2 - 4
Clay, dry to moist	0.15 - 1.8
Clay, saturated	0.6 - 2.5
Air, atmosphere	0.024

The values given in Table 2 can be used as a guide to compute or predict the range of cooling or heating time. The actual cooling and heating time need to be investigated in the laboratory based on a simulation model of the clay sand mixture constituents. The results of this investigation indicated that the time for cooling or heating is very sensitive to the range of temperature selected, air voids and path of heat (that is to say cooling or heating). We strongly recommend that municipal authorities to specify minimum clay content and specify the predicted cooling and heat up times for the regions concerned.

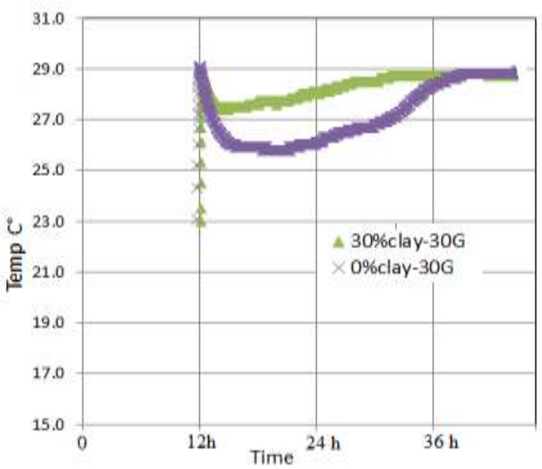

Figure 3. Gain of heat for 30% clay content and sand only at 30 degrees Temperature.

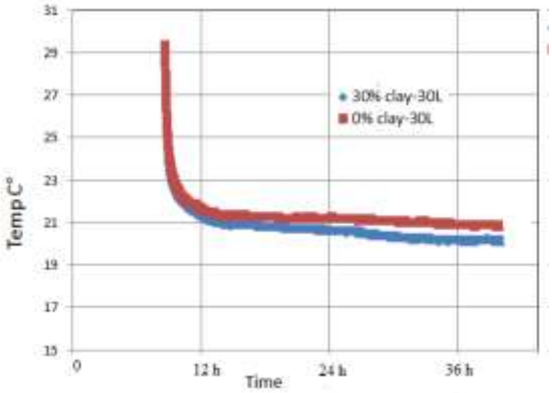

Figure 4. Loss of heat for 30% clay content and sand only at 30 degrees Temperature.

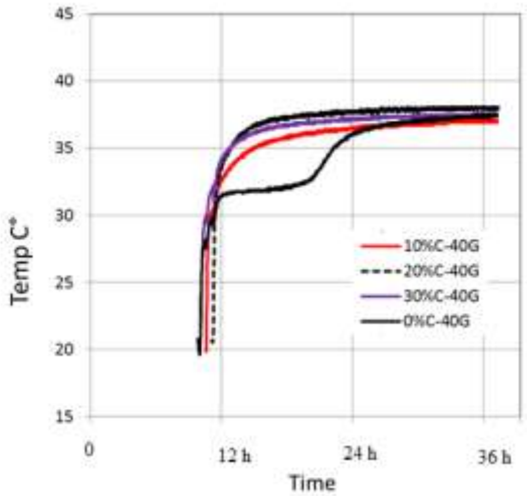

Figure 5. Gain of heat for all clay sand mixtures at 40 degrees Temperature

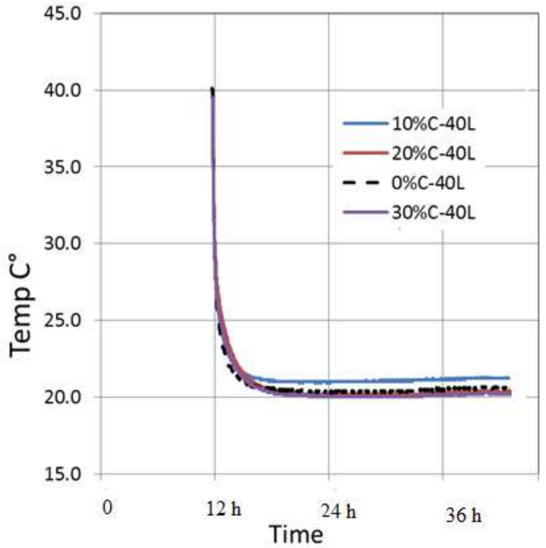

Figure 6. Loss of heat for all clay sand mixtures for 40 to 20 degrees Temperature

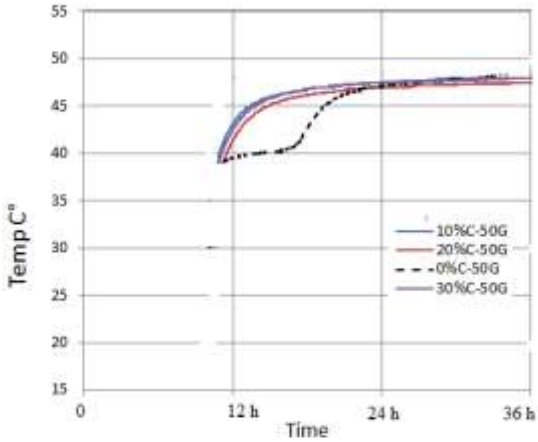

Figure 7. Gain of heat for all clay sand mixtures at 50 degrees Temperature.

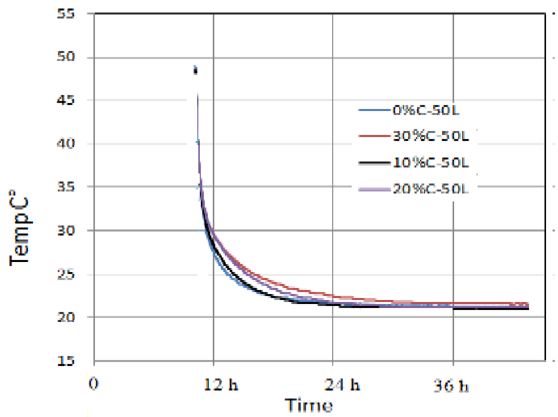

Figure 8. Loss of heat for all clay sand mixtures for 50 to 20 degrees Temperature.

5. CONCLUSION

The different sand clay mixtures behave differently with regard to gain and loss of heat. The test results indicated non-smooth changes in gaining temperature for sand as compared to sand clay mixtures. Filling up the sand with small amount as little as 10% will be sufficient to achieve a smooth profile.

The time needed for sand backfill to gain the ambient hotter temperature is much more than the time needed for different clay sand mixtures.

The time needed to heat up and cool down is variable and is function of the clay content and the temperature range.

It is strongly recommend that municipal authorities to specify minimum clay content and specify material with known predicted cooling and heat up times for the regions concerned.

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