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In-situ Thermal Conductivity of Rocks for Srinagar H.E. Project, U.P.

by

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Introduction

Thermal conductivity of geological strata is of great importance to scientists, meteorologists, agronomists and engineers. From engineering point of view, the information is of significant value for projects involving buried cables, electrodes, construction of roads etc. particularly regarding problems related to flow of heat through the medium.

The conventional steady state heat flow method requires samples to be collected and transported to the laboratory, causing disturbance to the structure and constituents of the matter. Also, this method requires a long wait for thermal gradient to stabilize causing moisture movement within the sample. These effects are more prominent in case of soils. To overcome these shortcomings as instrument was designed, developed and fabricated at CSMRS for measurement of in-situ thermal conductivity by 'Transient Method' (Sudhindra et al, 1988). The instrument was used successfully in soils for earth electrode sites of High Voltage Direct Current transmission projects for the first time.

The present work relates to measurement of in-situ thermal conductivity of rocks for Srinagar H.E. Project, U.P. It is proposed to build a 90 meter high concrete gravity diversion dam on Alaknanda river 6 km.

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Srinagar town in Uttar Pradesh. Thermal properties of foundation rocks namely in-situ thermal conductivity, laboratory measurements of specific heat, coefficient of linear expansion alongwith density were required as design parameters for taking into account thermal effects during and after the construction of the dam. However, work relating to tests other than thermal conductivity being outside the scope of this paper, have not been discussed. The proposed dam and its appurtenant structures are located within a complexly folded fractured sequence of quartzite and metabasic. The dam axis has been so chosen that the dam foundation between the axis and 200 m downstream in the entire river bed and even down to 40 m depth can be accommodated within quartzite. Only a small portion of plunge pool area and the top of the dam would be in metabasic. As seen by surface exposures and exploratory drifts, the quartzite- metabasic contact is invariably sheared but does not show any signs of chilling/ backing/corrosion of margins or thermal metamorphic effect on either rock unit.

The quartzite have been divided into (a) Recrystallised (b) Massive and (c) Thinly bedded and fractured. The metabasic also have been classified into three, namely (a) Massive (b) Foliated and (c) Thinly foliated and sheeted. The metabasic rock range in composition from epidiorite to amphibolite. On the basis of competence and degree of jointing these subunits are further classified into (a) Massive quartzite and massive metabasic exposed in 25% of dam area (b) The recrystallised quartzite and foliated metabasic exposed in 65% of dam area and (c) Thinly bedded and sheared metabasic which is exposed in 10% of dam area. The extent of weathering in these rocks is not very deep laterally into the abutment or very deep vertically below overburden.

Principle

If an infinitely long line source of heat is embedded in an infinite *homogeneous isotropic medium* then the radial flow of heat away from the source is governed by (Baver et al, 1972) :

$$\partial T = k\left[\left(\frac{\partial^2 T}{\partial r^2}\right) + \frac{1}{r}\left(\frac{\partial T}{\partial r}\right)\right] \qquad (1)$$

Where 'T' is the temperature of the medium at a time 't', 'k' is thermal diffusivity of the medium and 'r' is the distance from the line source.

For thermal conductivity measurements, the infinite long line source is approximated by a long electrically heated wire enclosed in a cylindrical probe. The probe is introduced into the medium. Heating current is supplied to the wire and consequent rise in temperature is measured using suitable temperature sensors adjacent to the wire.

The temperature rise $(T - T_o)$ at a radial distance 'r' from the source is given by,

$$T - T_0 = \left[q/(4\pi K)\right]\left[-Ei(-r^2/4kt)\right] \tag{2}$$

Where 'q' is the heat induced per unit time per unit length of the source, 'k' is the thermal conductivity of the medium and 'T_o' *is temperature* at $t = 0$ and

$$-Ei(-r^2/4kt) = \int_{r^2/4kt}^{\infty}\{(1/u)\exp(-u)\}\,du$$

$$= -\gamma - \ln(r^2/4kt) + (r^2/4kt) - \frac{(-r^2/4kt)^2}{4} + \cdots\cdots$$

is approximately the exponential integral for small values of $r^2/4kt$ where 'u' is a variable of integration and 'γ' is Euler's constant (0.5772...).

For the tests employing larger observation time and smaller probe radius $r^2/4kt \ll 1$, hence all terms after the logarithmic term may be neglected. Thus,

$$T - T_0 = \left[q/(4\pi K)\right]\left[-\gamma - \ln(r^2/4kt)\right]$$

$$T - T_0 = \left[q/(4\pi K)\right]\left[c + \ln t\right] \tag{3}$$

where 'c' is a constant.

Equation (3) may be rewritten as.

$$T = \left[q/(4\pi K)\right]\left[c + \ln t\right] + T_0$$

$$= \left[qc/(4\pi K)\right] + T_0 + \left[q/(4\pi K)\right]\ln t \tag{4}$$

$$= \left[qc/(4\pi K)\right] + T_0 + \left[2.303\,q/(4\pi K)\right]\log_{10} t \tag{5}$$

The graph between T and Log_{10} t gives the straight line having a slope 2.303 $q/(4\pi k)$ and intercept $qc/(4\pi k) + T_o$. Thus the slope obtained from the curve,

$$S = 2.303\, q/(4\pi K)$$

or the thermal conductivity of the medium,

$$K = 2.303\, q/(4\pi S)$$

substituting the value of heat I^2R introduced into the probe in place of q, we get,

$$K = 0.1834\, I^2 R/S \text{ W/m °C} \quad (6)$$

where 'I' is the current in Amperes passing through the heater of the probe, 'R' is specific resistance of the heater in ohms/m.

Preparation

Selection of a proper location for conducting tests is very important as the value of thermal conductivity may vary according to the texture and moisture content of the medium. A location selected should be such that it represents the strata expected to be encountered during the execution of the project. After selection of the location, test points are marked such that these represent the location. The number of test points depend on the size of the location.

In rocks, specially in fractured and weak ones, it is very difficult to get a smooth and straight hole. If the diameter of the hole is nearly same as that of the probe, good thermal contact between the probe and the medium is difficult to obtain because of the presence of thin layer of air and it is not easy to fill this gap. Therefore, a hole of diameter slightly bigger than that of the probe is drilled up to 1.1 m depth.

Method

The probe is made from 20 mm dia. 1 m long aluminium rod. It consists of an electrical heater along its axis and three Platinum Resistance Temperature Detectors placed at equal distance. It is inserted into the hole and fine powder of same type of rock obtained from the location are poured around it. A little amount of water is also added to obtain better thermal contact between the probe and the medium. The probe is left for 10 to 15 minutes so that it attains the temperature of the medium. After that a known amount of constant electric current is passed through the probe heater and temperature is observed with respect to time at different depths using multichannel digital temperature indicator. The data thus obtained is

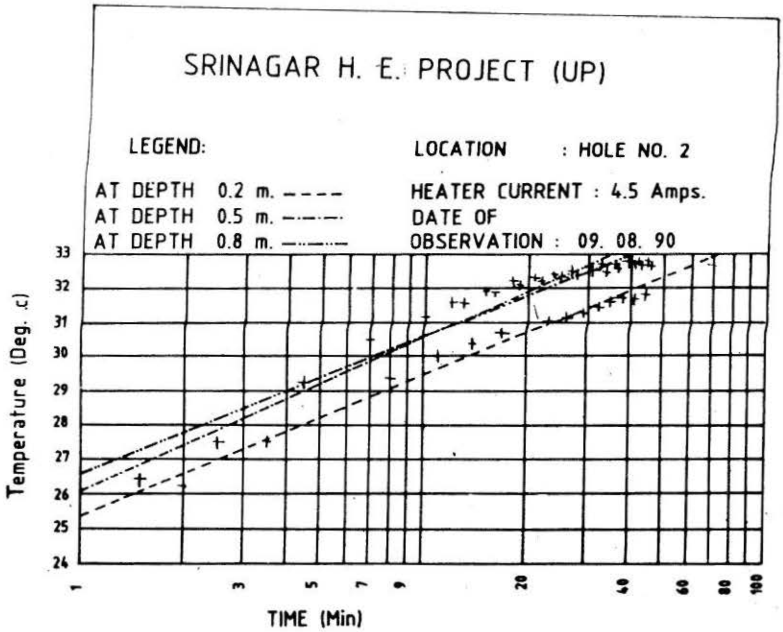

FIGURE 1. Temperature Vs. Log. Of Time Plot (I Phase)

plotted to obtain the slope of the temperature vs. Log of time curve and the thermal conductivity of the medium is calculated using equation (6).

Field Work

Holes of 1.1 m. depth and 25 mm. diameter were drilled in the rock. Coarse sand of same type of rock obtained from the nearby river was used to fill the gap and for obtaining thermal contact between the probe and the medium. The thermal conductivity of the rock was determined using the above described method.

Field data obtained from the in-situ thermal conductivity tests conducted during the first phase in the month of August'90 was processed on computer with the help of a software specially developed for the purpose. Theoretically, temperature vs. Log of time graph should be linear in ideal conditions (Farouki, 1986). The graphs obtained from field data for some of the tests points had shown non-linearity to a great extent (fig. 1). The trend of deviation from the ideal linear relationship indicated loose contact or presence of air between the probe and the rock. Therefore, during the second phase of work in the month of March'91, a little amount of water

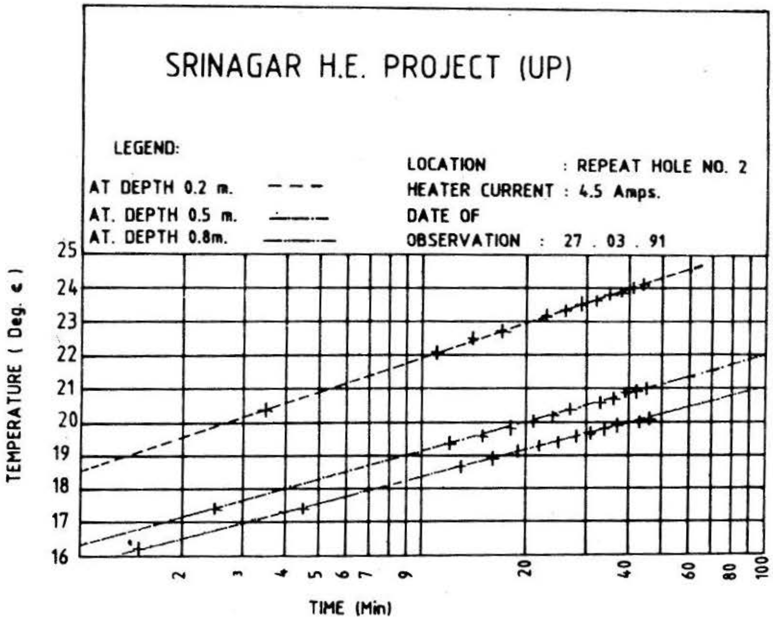

FIGURE 2. Temperature Vs. Log. Of Time Plot (II Phase)

was added to the sand filled into the hole to provide better thermal contact. Several field trials were carried out to check the repeatability, reliability and accuracy of the tests. Tests were conducted at the same point without changing experimental variables to check reproducibility. Heat was induced at different rates in different tests at same test point. Also, observations were taken for both heating and cooling cycles for checking the accuracy. It was observed from the graphs obtained from the set of data of March'91 that significant improvement could be achieved with better thermal contact (fig. 2). The fresh graphs have shown linear relationship near to that in ideal condition.

During August'90, 16 Thermal Conductivity tests were conducted at 15 test points at three different locations and existing drifts. Out of these 7 were conducted in Quartzite and 9 in Metabasic rock. While in the month of March'91, 19 tests were conducted at 15 test points out of which 12 were in Metabasic and 7 in Quartzite. The field data obtained from these tests was processed with the help of computer for calculation of slope between temperature and log of time and determination of thermal conductivity. The results are given in Tables 1 and 2.

TABLE 1

Results of Insitu Thermal Conductivity Tests of Rocks During The Month of August'90.

Rock Type : Quartzite

Test Point No.	Thermal Conductivity (W/m Deg.C)			
	Depth from ground level			
	0.2m	*0.5m*	*0.8m*	*Average*
6	5.99	5.05	4.91	5.31
7	3.61	3.45	3.60	3.56
8	5.20	4.05	5.24	4.83
9	5.61	5.65	5.62	5.63
10	3.69	3.80	4.74	4.08
11	3.30	2.31	3.40	3.00
13	5.62	5.42	3.94	4.99

Value of Thermal Conductivity for Quartzite:

Minimum - 2.31 W/m Deg.C
Maximum - 5.99 W/m Deg.C
Average - 4.49 W/m Deg.C

Rock Type : Metabasic

Test Point No.	Thermal Conductivity (W/m Deg.C)			
	Depth from ground level			
	0.2m	0.5m	0.8m	Average
1	2.16	2.18	2.17	2.17
2	2.42	2.34	2.43	2.39
3	2.44	2.42	2.29	2.38
4	2.39	2.40	2.46	2.42
5	2.08	2.09	2.06	2.08
12	2.88	2.90	2.87	2.88
14	2.00	2.72	2.41	2.38
15	2.19	2.18	2.17	2.18

Value of Thermal Conductivity for Metabasic:

Minimum - 2.00 W/m Deg.C
Maximum - 2.90 W/m Deg.C
Average - 2.37 W/m Deg.C

Analysis of Results

The values obtained for in-situ thermal conductivity in March'91 for Metabasic rock are higher than those obtained in the month of August'90 due to better contact between the probe and the medium. However, values obtained for quartzite rock are lower in the month of March'91 than those obtained during August'90. This may be attributed to the lower moisture content present in the strata. It was observed that the water level was only few cms below the ground level during the month of August'90 while it was 2 to 3 meter below ground in the month of March'91.

TABLE 2
Results of Insitu Thermal Conductivity Tests of Rocks During The Month of March'91.

Rock Type : Quartzite

Test Point No.	Thermal Conductivity (W/m Deg.C)			
	Depth from ground level			
	0.2m	0.5m	0.8m	Average
6	4.28	4.97	5.88	5.04
7	4.11	3.50	3.38	3.66
8	2.06	2.89	4.26	3.07
9	3.47	4.49	5.09	4.35
16	4.07	4.44	5.00	4.50
10	2.69	4.25	4.47	3.80
13	4.95	5.16	4.45	4.85

Value of Thermal Conductivity for Quartzite:

Minimum - 2.06 W/m Deg.C
Maximum - 5.88 W/m Deg.C
Average - 4.32 W/m Deg.C

Rock Type : Metabasic

Test Point No.	Thermal Conductivity (W/m Deg.C)			
	Depth from ground level			
	0.2m	0.5m	0.8m	Average
1	2.62	2.68	2.70	2.67
2	2.51	2.67	2.89	2.69
3	2.23	2.87	2.90	2.67
4	2.64	2.62	2.71	2.66
5	3.21	3.13	3.47	3.27
12	2.39	2.62	2.57	2.53
14	2.93	3.06	3.05	3.01
17	4.02	3.51	3.63	3.72
18	2.82	2.63	2.84	2.76

Value of Thermal Conductivity for Metabasic:

Minimum - 2.23 W/m Deg.C
Maximum - 4.02 W/m Deg.C
Average - 2.87 W/m Deg.C

TABLE 3
Typical Values of Thermal Conductivity of Rocks

Rock Type	Thermal Conductivity (W/m Deg.C)
Basalt	1.68 - 3.61
Gabbro	2.52 - 3.78
Quartzite	3.11 - 7.94

(Source : Manual of Applied Geology for Engineers, Institute of Civil Engineers, London, pp. 50)

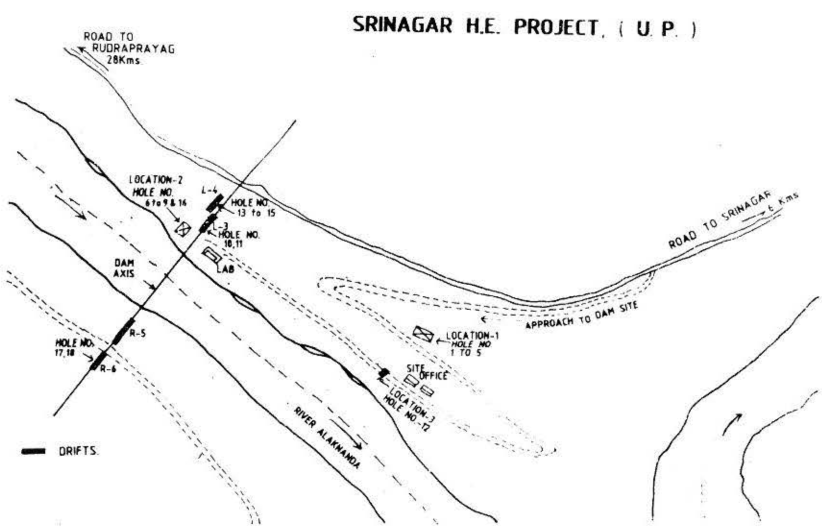

FIGURE 3. Location of Insitu Thermal Conductivity Tests At Srinagar H.E. Project, U.P.

Different values at different depths may be attributed to the condition of the strata around the test point. Denser and closely packed strata gave higher values in comparison to the loosely packed one. The amount of clay, organic matter or air voids present also reduce the thermal conductivity. The values also depend on ambient temperature and weather conditions.

Values of thermal conductivity for metabasic rock may be taken as 2.67 W/m °C for test points 1 to 4 (fig. 3). The value obtained at test point No. 5 i.e. 3.27 W/m °C is comparable with the values obtained at test points No. 14 and 17 i.e. 3.01 and 3.72 W/m °C respectively. However, values obtained at test points No. 12 and 18 are comparable with those obtained at test points 1 to 4.

Thermal conductivity values obtained for quartzite rock range from 2.06 to 5.88 W/m °C with an average of 4.32 W/m °C. However, thermal conductivity at test point No. 8 depth 0.2 m and 0.5 m and that at test point No. 10 depth 0.2 m are 2.06, 2.89 and 2.69 W/m °C. This may be attributed to the highly fractured nature of the rock. Also some of the holes were filled with tightly packed material and had to be redrilled. Enlargement of hole while redrilling has also resulted in reduced thermal conductivity values. If these lower values are omitted the resultant values range from 3.38 to 5.88 W/m °C with an average of 4.43 W/m °C. Keeping in view the lower water table these results are in agreement with earlier one. The results obtained are well within the range specified in the data from literature as shown in Table 3.

Conclusions and Scope for Future Work

The probe originally designed for use in soils has proved to be reliable in all the tests conducted in both types of rocks. The results obtained from several field trials and tests conducted during the second phase of work have shown significant reproducibility and accuracy of the measurement and hence the reliability near to that in ideal conditions. The results obtained in different conditions have shown variation as expected.

The present work had been restricted to depth upto one meter from the ground level. Also, some problem was faced in drilling holes of small diameter. Hence, more work is required to be done for improvement of the instrument, so that it can be used in commonly available drill holes of standard diameters. This will also enable measurements at deeper layers of the earth's crust.

The insitu thermal conductivity tests may prove to be useful for determination of rate of dissipation in geological strata in underground excavation, tunnelling, nuclear waste disposal, buried cables and earth electrodes and construction of roads and other projects.

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List of Symbols

δ - Delta
π - Pi
γ - Gama