# *Supplementary Note on Work of Caron and Szuk*

Before this bulletin went to press, communications were received from Claude aron, Chief of the Research Laboratory of Solétanche, Paris, and Geza Szuk of the ungarian Scientific Institute for Structural Engineering, Budapest. These communica-ons resulted from a Seminar by Correspondence organized by Professor L'Hermite 1 behalf of RILEM on moisture-measurement in materials and structures. They are considerable importance with respect to the condition of moisture in sands and soils ıd to electric and thermal resistivity of soil-water systems.

Caron investigated the possibility of using the thermal probe (1) as a nondestructive ethod of moisture determination. He employed a thermal probe of 2 mm outside dia-eter and 120 mm length containing an electric heating wire and a thermocouple. Heat-g was done by a 6-volt battery regulated with a rheostat so that the heating current re-ained constant at 300 or at 600 milliamp. The increase in temperature of the needle a function of time was measured with an electronic voltmeter (Philips GM 6010).

The water content of a soil specimen is related to its thermal resistivity; the resis-ity is represented by the slope of the line obtained if the thermocouple voltage is otted as the ordinate and the log of time as the abscissa. One selects the straight rt of the curve between 1 and 10 min.

Figure 4 (reproduced herein as Fig. 1) of Caron's paper (2) gives the water content a sand as a function of the tangent of the slope of the experimental temperature-log ne curve. The relationship is very good for low moisture contents. The method may so be applied to determine the porosity of saturated sands.

The paper by Caron elicited the following discussion, written by Geza Szuk:

"Caron discusses in his paper results obtained with the method of moisture deter-nation based on thermal conductivity. When evaluating the diagrams, it is striking ıt the tangent (tg 0.46) of the sample with a water content of 4.77 percent does not em to fit into the other results of the test series.

"In the first section of straight lines determining the tangents, scatter is noteworthy ere the measured points are not in accordance with the straight lines. Caron is of opinion that this scatter is due to the heating of the probe and can be neglected.

"In Figure 1, the relation between tg $\alpha$ and the percentage of moisture can be seen, tted as a continuous curve.

"If the diagram in Figure 1 is plotted on the basis of the actual experimental data, a rked inflection is observed at 5.3 percent of water (Fig. 2, Curve 1). This phenome-1 can also be observed in Figure 1 of Caron's paper.

"The diverging values, measured in the first period of the straight lines determining tangents, are doubtless a consequence of the heating period. But if the character of s scatter is better investigated, it is found that stopping times for the scatter first in-ase with increase of moisture percentage and later, after a maximum between 5 and ercent, begin to decrease (Table 1).

"Plotting these times against the percentage of humidity (Curve 2) a very interesting l-shaped curve is obtained. This curve has no peak, because there is no data be-en 4.77 and 6.55 percent. Comparing Curves 1 and 2, it is found that the inflection nt of the tg curve (Curve 1) appears at the same place where the peak of Curve 2 ht to be (5.3 percent).

"If the scatter is due solely to heating, it would have another character. It seems bable that this phenomenon is connected with other properties of the sand becoming .

"With our conductimetric measurements, it was found that by increasing the mois-e content, the electrical resistance curve of the sand shows an inflection at a cer-1 moisture percentage (3).

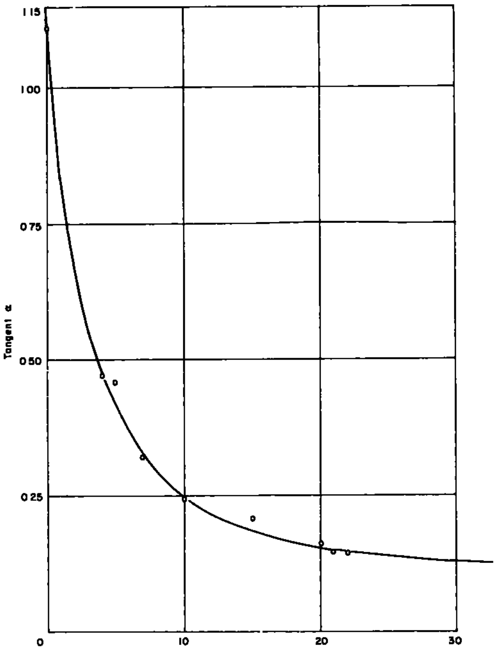


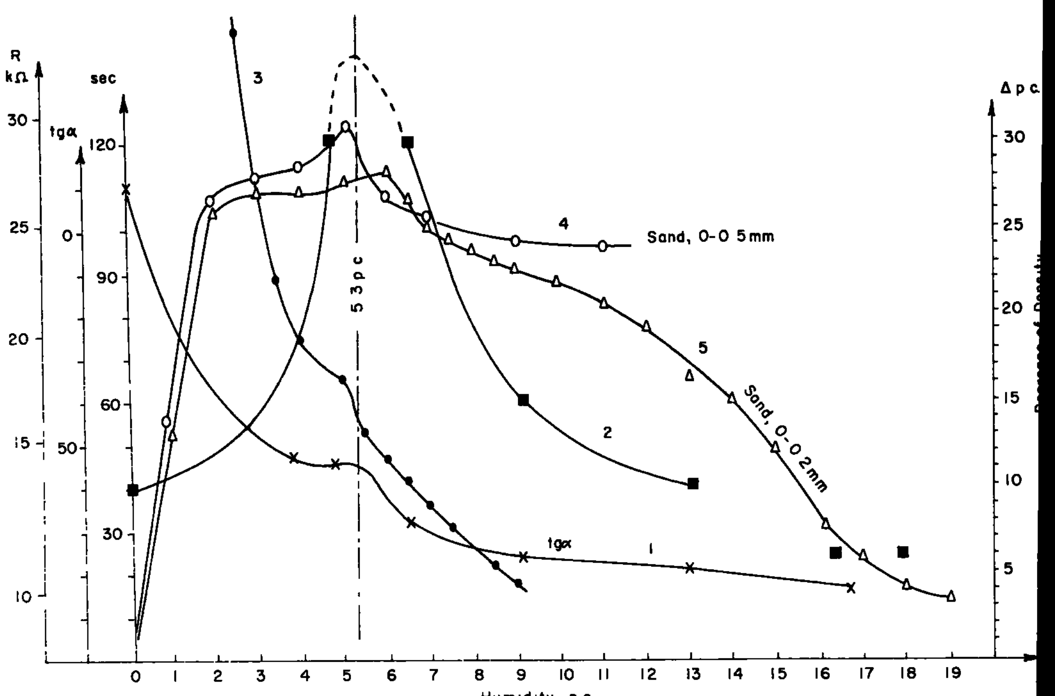

Figure 1. Water content of sand as function of tangent **α**.

**TABLE 1**

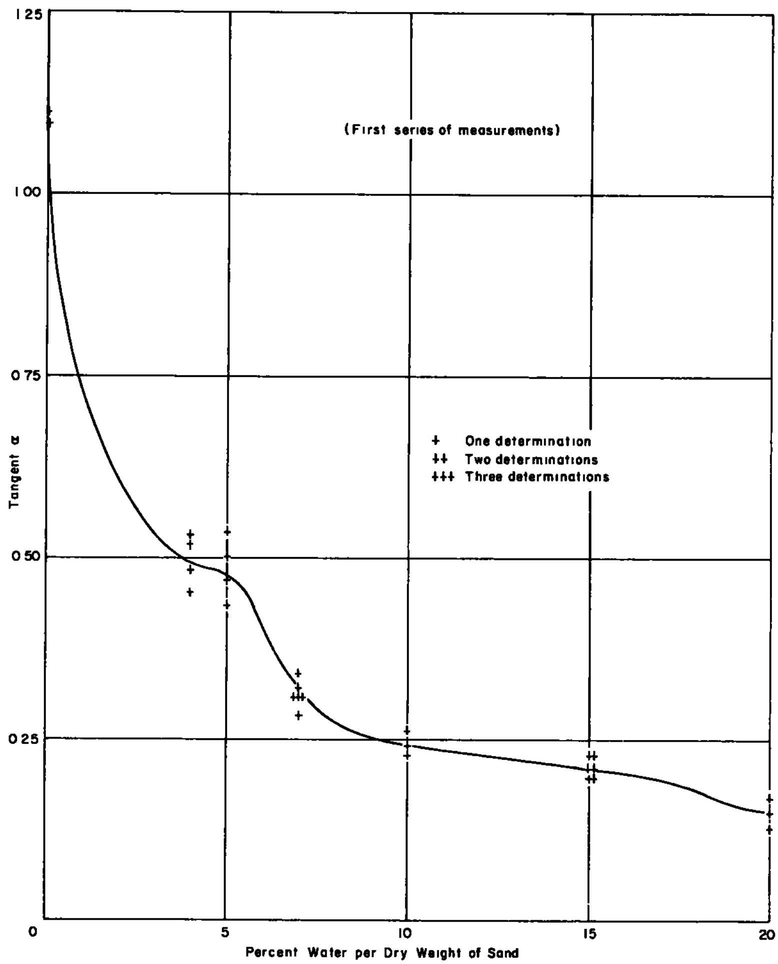
| $H_2O$ (%) | tg α | End of Scatte (min) | (sec) |
|---|---|---|---|
| 0 | 1.11 | 0 | 40 |
| 3.85 | 0.47 | - | - |
| 4.77 | 0.46 | 2 | 00 |
| 6.55 | 0.32 | 2 | 00 |
| 9.1 | 0.245 | 1 | 00 |
| 13.0 | 0.205 | 0 | 40 |
| 16.65 | 0.160 | - | - |
| 18.00 | 1.145 | - | - |

"This point was called wetting point a it has been proved that this point determines the water requirement of the aggr gate.

"The resistance curve of 0- to 0.5-m sand is shown in the diagram as Curve 3 With this size, the inflection is found to at 5 percent. Plotting the curve of dens decrease relative to the dry sand materi of similar size above the curve against t moisture content (Curve 4), a very valu




Fi ure 2. Electric, the l, and ot r properti of sand as function of water conte




gure 3. Variation of probe heating as function of moisture content of sand, first series of measurements.

lation is obtained; that is, decrease of the density shows a maximum value at the in-ction point of the conductimetric curve.

"These measurements were taken with 0- to 0.5-mm Danube sand. Considering above statements, a relation between these phenomena is very probable. In the dia-am, the curve of change in density of 0- to 0.2-mm Danube sand is also plotted. As can be seen, the peak of the diagram is shifted in direction of the higher percentage moisture. This phenomenon was observed also when the wetting point of the sand s determined conductimetrically.

"Caron used 0- to 0.4-mm sand for his experiments. With this grading, the wetting int and the minimum of density has to be in a somewhat higher moisture zone than s found in our experiments with material of 0.5-mm size.

"Caron's curves show indeed irregularities at 5.3 percent. It would be interesting repeat the test with 0- to 0.4-mm sand of 5.3 percent moisture content, as it could ove our suppositions."

Caron's response to the observations by Szuk was as follows:

"Your contribution to the conference on the measurement of water content by electric sistivity and your comments on our own report have been of greatest interest to us.

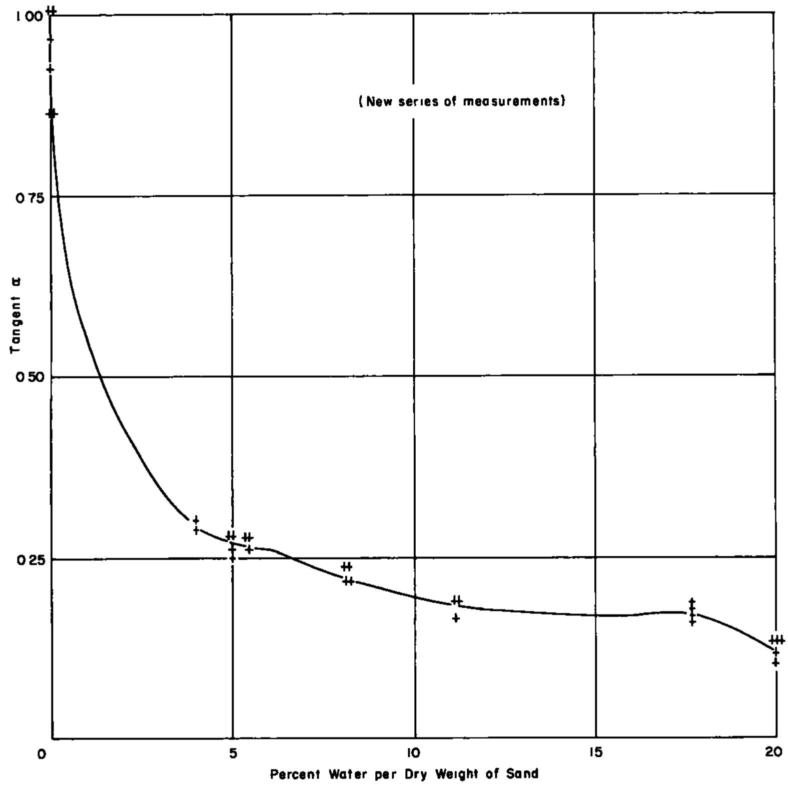



Figure 4. Variation of probe heating as a function of moisture content of sand, ne
series of measurements.

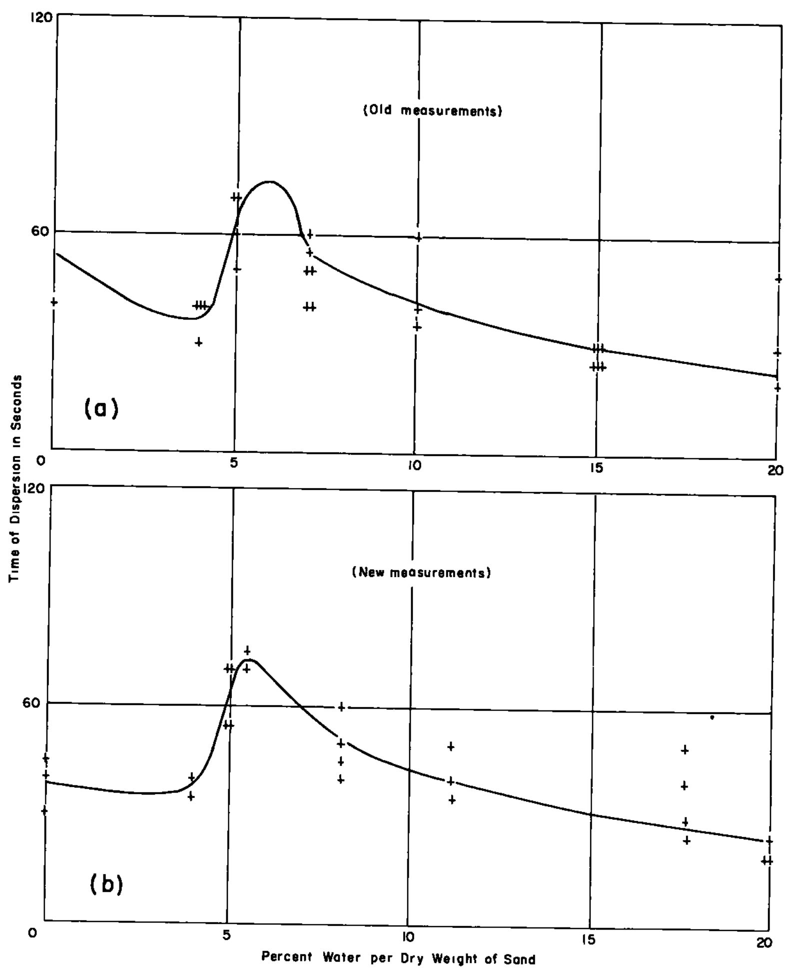
"The discontinuity that you have observed on the curve representing the electric c ductivity as a function of the moisture content and that you have interpreted as repre sentative of the water required for wetting of the material (sand or silt) is indeed ve interesting.

"Interpreting several water content curves by variation of the thermal capacity w we had given in our report, you have found a double discontinuity:

1. The curve that represents the rate of heating as a function of the water conte would flatten out in the vicinity of the content required for wetting in analogy with th respective observation in the case of electric resistivity.
2. The curve that represents the time passed before the heating curve becomes linear as a function of the water content exhibits a maximum just at the water conte required for wetting. To give you more information on these two phenomena, we ar sending you our complete series of measurements. On the four curves that will be cussed subsequently, we have reported the water content as a percentage of the dry weight of the material which in all cases is a sand that passes the 0.4-mm sieve.

<u>Curve of the Slope of the Temperature-Log Time Relationship as a Function of the Moisture Content</u>

"Figure 3 gives all the data obtained in the original investigation, of which only a portion was reported in our previous communication. Figure 4 gives a new series c data obtained with another thermal probe. One can notice a slight tendency of infle at a water content of about 5 percent, but we do not dare to be as categorical about t as in your measurements on electric resistivity, since we recognize the lower sens tivity of our thermal method.




ure 5. Variation of time of dispersion as function of water content of sand, (a) old measurements, and (b) new measurements.

rve of the Time of Dispersion as a Function of the Water Content

"As in your communication, we designate as time of dispersion the time passed be- e the plots of the temperature versus log time become linear; that is, before they in to obey the theoretical law. We have found that the first points do not align them- ves with the data taken after 1 min. It is possible to draw a straight line through these t points. This line has a different slope than the theoretical straight line obtained ween 1 and 10 min. The time of dispersion has been defined by us as the time at ch these two lines cross. Precise determination of the dispersion time is obviously ossible, since the first straight line is quite ill-defined. Consequently, the inter- t is also ill-defined and so is the curve resulting from plotting the dispersion times sus the moisture content.

'Nevertheless, despite this fact which is true not only for our first determinations . 5a) but also for our second series (Fig. 5b), one can obtain a type of bell-shaped ve whose maximum is in the vicinity of the water percentage required for the wetting ne sand. Therefore, a discontinuity appears to exist at the moment at which the l-water-air system passes from what is essentially a two-phase sand-air system which the water has not yet wetted the sand grains completely and formed a continu- water phase) to a three-phase sand-air-water system. This discontinuity will be more important, the finer the particle size of the material."

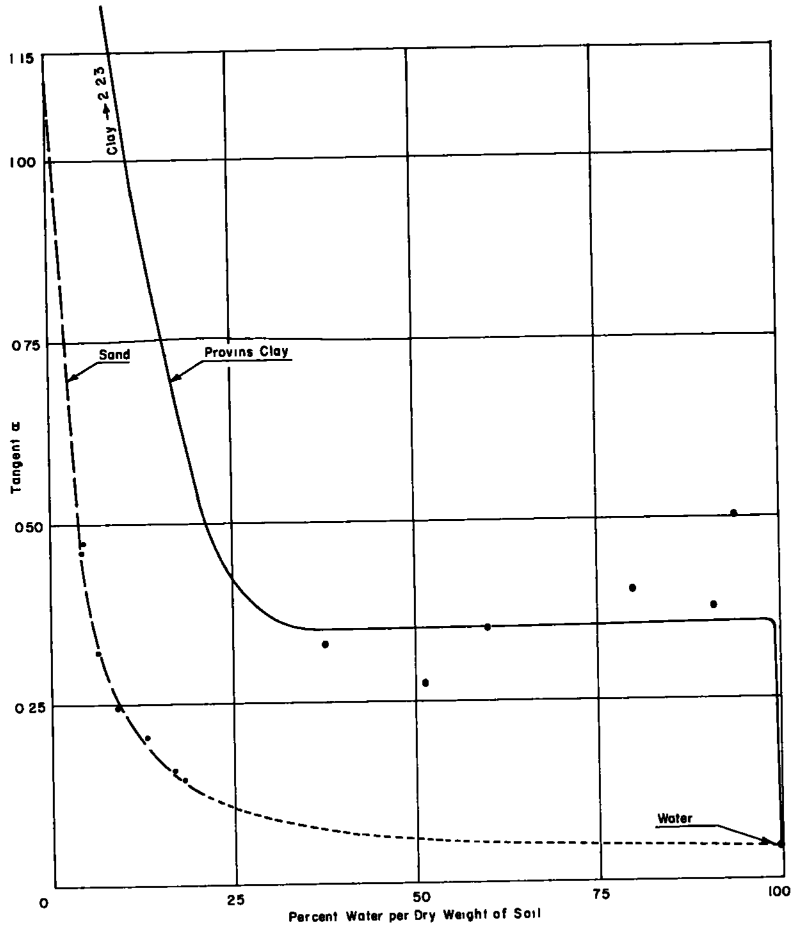



Figure 6. Tangent α as function of water content of sand and clay.

It should be very enlightening with respect to the controversy on the thermal moi ture movement in sands to reanalyze available data by taking the findings of Caron a Szuk into account and also to run new experiments with sands having moisture conte that straddle those at which the observed discontinuity occurs.

Caron also attempted to apply the method of moisture determination by means of thermal resistivity tests in the case of clay soils. He made numerous determinatio of the same precision as those on sand. However, on plotting the tangents of the he ing-log time curve versus the moisture contents, two anomalies were observed:

"Instead of the points defining a continuous curve as in the case of sands, there a points that deviate considerably. The tangent values, which are proportional to the thermal resistivities, are very high even for very low clay contents (with 75 g of cl or 10 g of bentonite per liter of water, one obtains tangent values that are ten times larger than those for pure water).

"At first we thought that small air bubbles entrained in the clay suspension came contact with the hot thermal probe and formed some insulating patches. However, carefully de-aired suspensions gave the same high values. We thought to have foun an explanation in the high viscosity of the clay suspensions which are pseudo-liquid which convection phenomena may occur. As a matter of fact, if one applies the sa method to glycerine, one finds a tangent value that is fifteen times larger than that water although the specific heat of glycerine is about 40 percent less. On the other

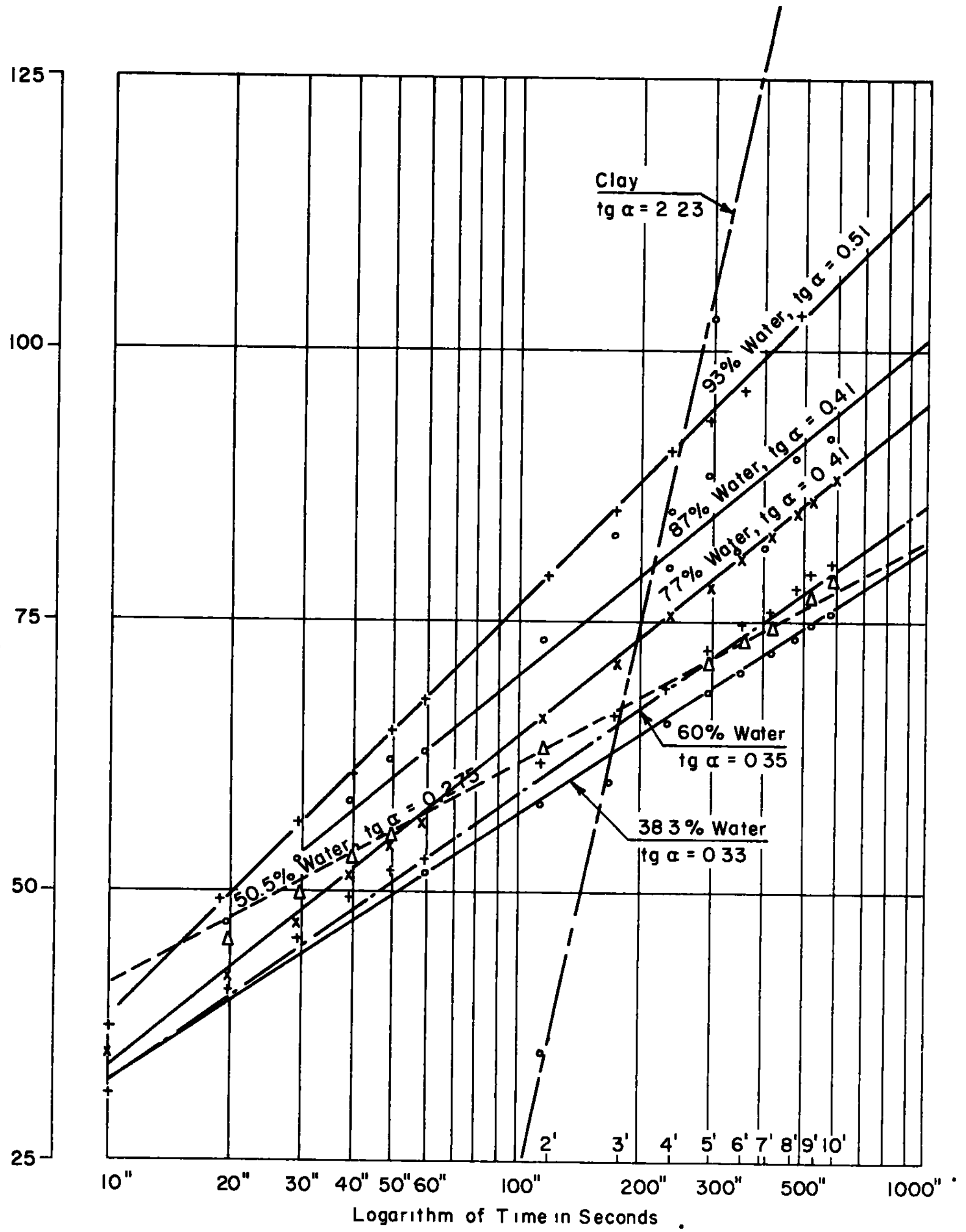



Figure 7. Thermocouple readings in Provins clay at various water contents.

d, the tangent value found with a viscous sodium silicate solution was ten times her than that for water.

"Measurement of moisture content by thermal diffusion seems to be feasible only if particles are not affected by convection currents of the medium. Such a conclusion only be tentative. More extensive studies must be undertaken to clear up this anomus behavior of clays.

"But if the viscosity of the medium causes this anomaly, why do the data for pure er fall so well in the extrapolated curve for sands (see Fig. 6)? If it is the interstitial water that must be able to move freely and not be bound to the particles, why does the glycerine, which is so much more viscous than water, show anomalous behavior? The problem remains in its fullness and much research is necessary to resolve it."

The findings of Caron with respect to the doubling of the thermal resistivity of wate by the addition of 1 g of bentonite per liter and the increase to ten times the water valu by dispersion of 75 g of Provins clay in a liter of water are of greatest interest with respect to the problem of thermal and moisture conduction in clay-water systems (Fig 7). Giving due consideration to the large body of thermal resistivity data on clay soils collected by Sinclair, Buller, and Benham (4) and analyzed by Winterkorn (5) and keep ing in mind that the average thermal resistivity of clay minerals at random orientatio should be quite close to and possibly less than that of water, the tremendous increase in the thermal resistivity of water by the presence of dispersed clay, as observed by the thermal probe test, must be due to either or both, the disturbance of the water structure by the presence of the clay particles and a special geometric arrangement o the clay particles in the vicinity of the thermal probe. In view of the magnitude of the change in thermal resistivity, it is felt that its most probable cause is a circular arrangement of the clay platelets at a small distance from the probe surface in the shap of a cylinder that is concentric with the thermal probe. Such a structure could functi as a thin wall and impede the loss of heat from the water phase between it and the sur face of the probe, in a manner similar to that described and analyzed already by Fourier (6). However, as Caron states, this problem deserves further thorough experimental investigation and theoretical evaluation.

## REFERENCES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