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# THE INFLUENCE OF ACCESS HOLE PARAMETERS ON NEUTRON MOISTURE PROBE READINGS

by

Willy V. Abeele

## ABSTRACT

Computing soil moisture content with a neutron probe requires use of a calibration curve that considers the thermal neutron capture cross section of the hole liner as well as the hole diameter. The influence of steel, polyvinyl chloride, and aluminum casings that fit 0.051 to 0.102-hole diameters was determined by comparison with neutron probe readings in uncased holes of corresponding diameters. Eccentricity of probe location was considered a potentially significant variable. The relationship between hole diameter and count rate also was investigated. The experiment was run in disturbed Bandelier tuff with an average dry density of 1.2 $g\cdot cm^{-3}$ and moisture content of 1.3 to 35.5% by volume. The casing material and hole diameter influenced the probe readings significantly, whereas eccentric location of the probe did not. Regression analyses showed an almost perfect inverse linear correlation between hole diameter and count rate.

## I. INTRODUCTION

Fast neutrons emitted by a radiation source in a moisture probe are slowed mainly by elastic scattering. This slowing depends largely on the amount of hydrogen present, since neutron energy loss is inversely proportional to the mass of a colliding nucleus. The amount of hydrogen detected is, in turn, a good indication of the moisture content of an inorganic soil.

The neutrons, slowed to thermal velocities by successive collisions, diffuse randomly without losing any more energy, unless they are absorbed or captured by nuclei with high thermal neutron capture cross sections, such as chlorine, cadmium, lithium, boron, and to a lesser extent iron, manganese, and potassium (International Atomic Energy Agency). These elements are undesirable in soils whose moisture is measured using a fast neutron source, as soil moisture is deduced from the number of thermalized neutrons that reach the detector. Elements with high absorption cross sections reduce this number, so the count rate might lead to gross underestimation of the water content. If an access tube contains nuclei with high thermal neutron capture cross sections, or the access hole is too large, a very different calibration curve from that provided by the manufacturer is needed.

The probe contains a fast neutron source and a slow neutron detector. During the collision process, the change of neutrons direction (scattering angle) and thermalization (slowing down) transfers kinetic energy to the target nucleus. If the scattering angle is $\theta$, the general formula is

$$E_a - E_s = \frac{2A(1-\cos\Theta)E_a}{(A+1)^2} ,$$

where $E_a$ and $E_s$ are, respectively, the neutron energy before and after the collision and A is the atomic weight of the nucleus. From this equation, one can conclude that all of a neutron's kinetic energy can be lost in a head-on collision with a hydrogen nucleus. Increased atomic weight of the nucleus increases a neutron's remaining kinetic energy following a collision with that specific nucleus.

## II. METHODS

Often one must measure soil moisture with a neutron probe in access holes whose liner materials or diameters differ substantially from those the manufacturer considers ideal. The nuclear probe tested was a Troxler Electronic Labs, Inc. (Model 1255SN835). The instrument was accompanied by a calibration table of count ratio vs moisture content by volume in inorganic soils. This calibration is valid only if a thin-walled aluminum irrigation pipe of 0.051-m outside diameter is used as an access hole. Use of any casing at all for deep holes drilled in solid rock might well be uneconomical. For moisture monitoring purposes, pipes often are installed vertically in deep pits that then are backfilled. The slightest bending of a narrow pipe makes it impossible for the probe to reach its destination. The problem might not have occurred if a larger diameter hole and/or a stronger pipe material had been used.

If the hole diameter is significantly greater than the probe diameter, eccentricity of probe location must be considered an additional variable. The influence of steel, polyvinyl chloride (PVC), and aluminum casings that fit 0.051-, 0.060-, 0.063-, 0.076-, 0.102-, and 0.113-m diameters was determined by comparison with results obtained in uncased holes of corresponding diameters by positioning the probe alternately at the center and at the edge of the hole. The experiment was conducted in crushed Bandelier tuff (a volcanic ash) whose average dry density was 1.2 g $cm^{-3}$. Ten drums were filled with the tuff whose respective moisture ratios by volume were 0.013, 0.044, 0.063, 0.092, 0.102, 0.183, 0.200, 0.262, and 0.355. Homogeneity was achieved in each drum by mixing known amounts of water and dry tuff in a cement mixer. The final moisture ratio by weight was determined by oven drying 10 selected samples. Multiplying these values by the measured tuff density gave the moisture ratio by volume. Access pipes of the smallest diameter were driven into each drum and the tuff inside the pipe removed. Five consecutive counts were then taken and averaged. Then pipes of the next larger diameter were driven into the tuff, the inner pipe and entrapped tuff were removed, and successive counts were read. Nuclear measuring devices generally are calibrated in count ratios rather than absolute counts, to eliminate errors arising from drifts in the electronic system. The count ratio is acquired by dividing the standard count, measured with the probe in its shield, into the test count.

## III. RESULTS

Eccentric location of the neutron probe in the access tubes did not influence the count ratio significantly. Regression analysis showed an almost perfect inverse linear correlation between hole diameter and count ratio, but only over a rather small (0.051- to 0.102-m) hole diameter range. Steel and PVC pipes of three different diameters were sealed off at the bottom and put in a water tank. In them also, there was a strong inverse linear correlation between the count ratio and the 0.060- to 0.127-m hole diameter. The correlation coefficient was -0.9961 for the PVC pipes and -0.9970 for the steel pipes.

Table I indicates count ratio (CR) dependence on hole diameter (d) at nine different moisture ratios by volume (MVR). At 0.051- to 0.102-m hole diameters, there is a good inverse linear correlation between hole diameter and count ratio. The coefficient of correlation (r) is computed to indicate the inverse correlation in this case (r is negative!).

Table I

Estimated Count Ratio (CR) as a Function of Hole Diameter (d) in Meters for a Given Moisture Ratio by Volume (MRV)

$$CR = a + b\,(d)$$

| MRV | a | b | $r^2$ | r |
|---|---|---|---|---|
| 0.013 | 0.122 | -0.555 | 0.843 | -0.918 |
| 0.044 | 0.153 | -0.220 | 0.637 | -0.798 |
| 0.063 | 0.234 | -0.545 | 0.986 | -0.993 |
| 0.092 | 0.300 | -0.627 | 0.990 | -0.995 |
| 0.102 | 0.391 | -1.006 | 0.980 | -0.990 |
| 0.183 | 0.621 | -1.896 | 0.996 | -0.998 |
| 0.200 | 0.612 | -1.693 | 0.994 | -0.997 |
| 0.263 | 0.822 | -2.377 | 0.998 | -0.999 |
| 0.355 | 1.056 | -3.536 | 0.998 | -0.999 |

If the same data are plotted using the count ratio as an independent variable and the corresponding moisture ratio by volume as the dependent variable, with the hole diameter and casing material held constant, a strong correlation again appears as Table II shows. These equations permit good estimation of the moisture ratio by volume from the count ratios obtained.

TABLE II

Estimated Moisture Ratio by Volume (MRV) Based on Count Ratio (CR)

$$MRV = a + b\ (CR)$$

| Casing | Hole Diameter | a | b | $r^2$ | $CL_{0.95}$ |
|---|---|---|---|---|---|
| Aℓ | 0.051 | -0.030 | 0.420 | 0.997 | 0.0085 |
| Aℓ | 0.063 | -0.030 | 0.444 | 0.995 | 0.0106 |
| Aℓ | 0.076 | -0.034 | 0.475 | 0.996 | 0.0098 |
| Uncased | 0.051 | -0.026 | 0.422 | 0.993 | 0.0127 |
| Uncased | 0.060 | -0.027 | 0.435 | 0.993 | 0.0124 |
| Uncased | 0.063 | -0.028 | 0.444 | 0.992 | 0.0132 |
| Uncased | 0.076 | -0.029 | 0.468 | 0.993 | 0.0128 |
| Uncased | 0.102 | -0.032 | 0.527 | 0.988 | 0.0160 |
| PVC | 0.060 | -0.053 | 0.686 | 0.994 | 0.0116 |
| PVC | 0.113 | -0.131 | 1.597 | 0.981 | 0.0204 |
| Fe | 0.076 | -0.045 | 0.648 | 0.991 | 0.0142 |
| Fe | 0.102 | -0.058 | 0.762 | 0.981 | 0.0204 |

Tables I and II together permit good estimation of the moisture ratio by volume in any 0.051- to 0.102-m-diameter uncased hole from the measured count ratio. This cannot be done quite so easily for cased holes, because the measured count ratios depend also on the thickness of the casing material.

Results from aluminum-cased holes were very similar to those from uncased holes of equal diameter. This is demonstrated clearly by the similarity of the equations pertaining to uncased and aluminum-cased holes of the same diameter. However, the thermal neutron capture cross sections of iron and chlorine in steel and PVC pipes, respectively, were so high that the results deviated substantially from those expected in uncased holes. Regression lines, though, could be fitted with coefficients of determination (on the regression of MRV on CR) that were not appreciably different whether the hole was uncased or cased with aluminum, steel, or PVC. The coefficients of determination decreased slightly in PVC- and steel-cased holes larger than 0.076 m in diameter, but even then, they remained higher than 0.98. This indicates that, given an adequate calibration curve, one can find a good linear fit between actual and estimated moisture content by volume.

Table II also indicates that for uncased or aluminum-cased holes of 0.076-m diameter or less, the slope of the curves diverges moderately when MRV is plotted against CR (Fig. 1.) Given larger diameters or steel or PVC casings, slope divergence increases.

The count ratios used in the regression analysis were obtained by averaging five count readings and dividing them by the standard count. A coefficient of variation was based upon the standard deviation associated with each average count ratio. Careful evaluation of the coefficient of variation shows that it does not increase significantly with hole diameter and reaches a high of 1.64% in the 0.113-m PVC-cased hole. This can be considered another indication that centering the probe in the hole is unimportant. The 95% confidence limits on the regression equations has been computed for an estimated moisture ratio by volume of 0.02. The results are shown in Table II under the headings $CL_{0.95}$.

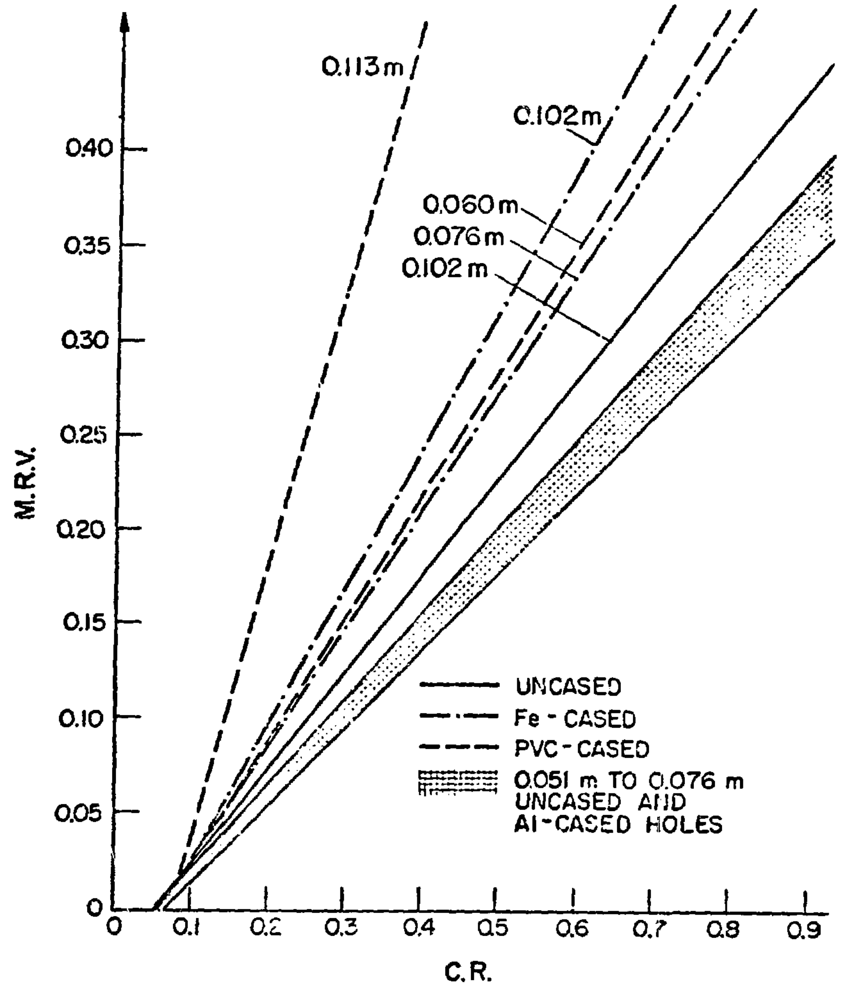

Fig. 1.
Moisture ratio by volume in function of count ratio (diameter is indicated on the curves).

## REFERENCE

International Atomic Energy Agency; NEUTRON MOISTURE GAUGES, Technical Report Series No. 112, Vienna, 1970.