NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE of HYDROLOGY

REPORT No 7 JUNE 1969

INSTALLATION OF ACCESS TUBES AND CALIBRATION OF NEUTRON MOISTURE PROBES

by

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INSTITUTE OF HYDROLOGY
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by C. W. O. Eeles

ABSTRACT

The neutron back-scattering method has very great advantages in the determination of soil moisture content. The results obtained, however, can be easily rendered invalid by faulty calibration methods and incorrect installation of access tubes. This report describes the routine method developed at the Institute in an attempt to overcome these problems.

1. INTRODUCTION

The use in the United Kingdom of the neutron moisture meter has become firmly established in research which requires the determination of changes in soil moisture content.

The neutron scattering equipment consists of a probe containing a source of high energy neutrons with a detection system for low energy neutrons, and a scaler or ratemeter. The neutron source is usually Americium-Beryllium which has a low gamma output, a long half-life and emits fast neutrons with an energy of the order of 3 MeV. The source and detector are lowered into an access tube in the ground and a fast neutron flux is set up in the soil. The hydrogen nuclei, which are present mainly in the molecules of soil water, moderate the fast neutrons by elastic collisions to the thermal energy that these particles would have at ambient temperature. The thermal ("slow") neutrons form a 'cloud' which stabilises in about a microsecond, and the rate at which back-scattered thermal neutrons arrive at the detector can be related directly to the moisture content of the soil by either field or theoretical calibration.

The detectors in equipment in current use are either a boron trifluoride proportional counter or a lithium glass scintillation detector. The latter has the advantage of approximating to a 'point' detector, but requires more complex electronics than the counter and appears to offer vertical resolution of soil layers which is little better than a short proportional counter with a centre-placed source. Modern electronics has brought the scaler and ratemeter to comparable sizes and the only disadvantage of the former is the higher power consumption which makes a larger battery pack necessary. The advantage of the greater precision of a scaler is therefore obtained at the expense of somewhat greater weight. Although the initial cost of neutron scattering equipment is high, there are very considerable advantages to be gained from its use in determining moisture content.

The gravimetric method of moisture determination involves the removal of a soil sample from the site. Inevitably this procedure changes the natural soil moisture regime so that samples taken at a later date must be taken some distance away. Errors are inevitable at every stage of the process particularly in the determinations of volumes and weights, and the selection and maintenance of the temperature and time for which samples are dried. Furthermore the gravimetric method cannot be regarded as an absolute method because of the complexity of the distinction between 'free' and 'bound' water. Another disadvantage of the method is that it is expensive in time and labour, although the capital outlay for equipment is much less. In sharp contrast the neutron method can be very precise and is repeatable without further disturbance to the soil after the emplacement of an access tube. The time taken per reading is comparatively short so that the number of sites which can be sampled is greater, and these can be sampled to depths which would be impracticable with the gravimetric method.

Indirect, tensiometric methods (e.g. resistance blocks and porous pot tensiometers) suffer from several drawbacks. The most serious problem is that direct contact by the instrument with the soil is difficult to maintain. The changing impedance of this contact alters the time taken by the block (or porous pot) to reach equilibrium with the soil moisture. This time is also affected by the different hydraulic conductivities of the block and soil. There is also a variable amount of hysteresis between the drying and wetting cycles in the media.

The very great advantages of the neutron back-scatter method are:

a) the same soil is determined each time
b) consequent upon (a), background errors are constant and moisture differences can be measured very accurately
c) the precision of the method (assuming good electronics) is dependent upon the number of counts or the time constant; this can be calculated and checked, and can be set as required for given circumstances.

The advantages are lost however, if the access tubes are incorrectly installed, giving rise to unknown biases, or if the calibration is incorrect. The routine methods developed by the Institute of Hydrology in an attempt to overcome the problems involved are briefly described in this paper.

2. ACCESS TUBES

Aluminium, aluminium alloy, brass and stainless steel tubes are all currently used in Britain (Bell and McCulloch, 1966). The factors affecting choice of a particular material are soil chemistry, durability and depth of installation and the need to obtain the maximum count rate. Aluminium is the most "transparent" material to thermal neutrons; brass reduces the count rate slightly but might be less corrodible in an alkaline soil. Stainless steel is the most durable material but due to the large neutron absorption cross-section of iron this gives a considerably reduced count rate; it has the advantage that tubing is strong enough to be flush coupled to reach greater depths than the available standard lengths of other metal tubing will allow.

The access tubes used by the Institute of Hydrology are seamless aluminium alloy tubes, $1\frac{3}{4}$ in outside diameter, 16 s.w.g. wall, closed by a tapered plug of the same material (Fig. 1A). The conical nose of the plug assists the location of the tube as it is forced down the hole and presses back into the side any stones that may be projecting. The tapered shank of the plug tends to spread the tube mouth and so makes a very tight metal to metal seal. Bostik Outdoor sealant is placed on the inner taper to act as a second seal, making the tube completely waterproof. The tube inside diameter is approximately $\frac{1}{8}$ in greater than the $1\frac{1}{2}$ in diameter of the neutron probes used. The tube is usually of such a length that a standard length, say 5 cm, protrudes above the surface, but in some circumstances this is made to be either more or less.

In the field the top of the tube is closed by a rubber bung which has a perforated container of self-indicating silica gel suspended below it to absorb any interior condensation. Over the outside of the tube exposed above the ground, a short sleeve of 2 in tubing is fitted to prevent farm animals from removing the bung.

3. DISTURBANCE OF SOIL SYSTEM

Provided care is taken not to alter the surface structure of the soil during routine readings with neutron moisture meters, the only changes suffered by the soil system are due to the installation of the access tube. This work must be carried out using a routine which, if followed closely, will ensure the emplacement of the tube with little damage to the surrounding soil matrix and none to the tube. It is absolutely essential that the access tube should fit as tightly as possible to prevent water running down the tube from the surface, and to avoid errors in moisture determination caused by air or water filled gaps between the access tube and the soil. Nevertheless, undue compression of the soil around the tube must also be avoided because the zone nearest to the access tube influences the reading most.

Methods of access tube insertion using a simple hand-operated soil auger are unsatisfactory for a variety of reasons and should be avoided. The presence of stones can cause the hole to deviate from the vertical by deflecting the auger bit, and if a stone is forced aside a cavity may be made in the side of the hole, affecting the density of the cloud of thermal neutrons differently in varying moisture conditions. The repeated movement of the auger up and down the hole when removing soil from the bottom tends to enlarge the top of the hole. This leaves room for water to run down the side of the tube, making it necessary to backfill from the surface and gives the soil immediately surrounding the tube a different density and structure. This affects the moisture retention of the soil matrix, and will alter the distribution of thermal neutrons surrounding the radioactive source leading to errors in the determination of moisture content. Mechanical augers share the disadvantages of hand augers and also cause much more disturbance due to churning with caught-up stones, compression, oversizing, etc.

4. TOOLS, ACCESSORIES AND PROCEDURES FOR INSTALLING ACCESS TUBES BY HAND

The tools used for the insertion of access tubes must be brought to and used at the selected site with as little disturbance to the soil surface as possible. Access tubes should be installed in dry conditions, preferably prior to the growing season. This may not be practicable however, and in wet conditions, or when there is an easily disturbed surface litter layer under trees, the soil surface around the hole must be protected by the use of duckboards. The whole operation requires maximum care and skill, because a badly installed tube will result in permanently biased readings.

The 3ft guide tube is shown in the ground at the top of a hole in Plate 1. An auger is in the tube while the ground surface immediately surrounding the tube is protected by a duraluminium plate. In the background is the lifting apparatus for extracting the tubes. In the foreground is a 6ft auger with C-spanners, and behind this is a similar length guide tube together with the access tube ready for emplacement. The other tools are the rammer, tube cutter and tube extractor.

The method depends on the auger which is worked through a steel guide tube (Fig. 2) of the same diameter as the access tube. The auger is worked ahead of the cutting edge of the guide tube so that little or no disturbance is caused to the surrounding soil. Auger and guide tube are advanced in alternation until the appropriate depth is reached when the guide tube is removed and replaced by an access tube.

To insert a 1.75 in access tube, a hole some 6 in deep is first made in the soil using a 1.375 in auger, and this is done through a 1.875 in hole in a 2 ft x 2 ft dural plate placed on the ground so as to protect the soil surface around the hole. The auger is withdrawn, cleared of soil and the 3 ft guide tube is inserted into the hole to a depth of 6 in, care being taken to ensure that the tube is vertical. The hole is then augered out through the guide tube to 6 in beyond its cutting edge, the auger is removed and the guide tube hammered down 6 in with the rammer (i.e. to the bottom of the augered section), the dimensions of which are shown in Fig. 3. The loose soil is taken out by auger (through the guide tube), and the hole augered another 6 in beyond the cutting edge of the guide tube, and so on until the hole has reached the required depth. If the hole is to be more than 3 ft deep the first guide tube is replaced by the 6 ft tube when 3 ft is reached. The extension rods for the augers are three feet long and so this determines the length increments for the guide tube set (i.e. auger lengths 3ft 6 in, 6 ft 6 in, 9 ft 6 in, etc., guide tube lengths 3 ft, 6 ft, 9 ft, etc.).

The guide tube must not be driven beyond the augered hole because the compression and disturbance to the surrounding soil is greatly increased by the compacted soil forced into the tube. It is not desirable to withdraw the guide tube unnecessarily because the sides of the hole are disturbed and the top becomes widened beyond the diameter of the access tube. Backfilling round the top of the installed access tube is not an acceptable procedure for reasons given in Section 3.

As the hole is drilled a careful record should be kept of the depths of changes in the profile, and types of soil passed through at each horizon.

The last guide tube used should be taken down about the full length required for the access tube, and the augered hole one or two inches beyond this to allow for debris falling down when the guide tube is removed and the permanent tube installed. The guide tube can sometimes be removed easily by twisting and pulling the tube by means of the tommy bar, but in some soils it has to be hauled out with block and tackle. It is essential to rotate the tube while applying the lift and particularly so when withdrawing from wet, heavy clay. It is essential that great care be taken to avoid enlarging the diameter of the hole during this operation.

The access tube should require ramming gently to get it down, but not so vigorously as to make a hole in the tube with any stone that is projecting, to buckle the tube or bell it out at the top. When the tube is down as far as it will go the top is cut off to the correct height, and any burrs remaining removed. The site is then cleared of tools and soil from the hole, and a marker is left to enable the tube to be found again.

Flints, stones and rocks in the soil either offer an immovable barrier or move but cannot be brought up through the guide tube by the auger. Small flints and shale have the latter effect, and, if embedded into soils where compression would be minimal, the only course open is to drive the guide tube down about 6in or a foot and hope that the stone is either cut or forced into the tube. The tube must then be withdrawn and cleared by hammering the side of the tube. Large flints and small rocks can sometimes be broken up *in situ* by using a long round bar of mild steel with a chisel point which is worked through the guide tube. More elaborate power driven equipment may be necessary in extremely dry dense soils, or where large rocks are encountered (Kozachyn and McHenry, 1960, Richardson, 1966). Where there is any doubt the hole should be abandoned and re-sited a few yards away; the abandoned hole should be backfilled.

5. ACCESS TUBE EXTRACTION

There are occasions when it is necessary to withdraw an access tube, as for example, during the course of field calibrations. A special extractor is required as it is very easy to damage the relatively soft metal; this tool is shown in Fig. 1B. When the extractor is screwed up tight in the tube the rubber pads are vertically compressed and expand at the edges, so gripping the tube wall. The tube may then be extracted in the same way as the guide tube.

6. SURFACE LAYER MEASUREMENTS

One difficulty with the neutron method is obtaining readings in the top 20 cm of soil. The density of the 'cloud' of thermal neutrons, which is in dynamic equilibrium over the zone of importance, is affected by the probe approaching the surface where there is a loss of fast and thermal neutrons from the soil system. By using one of the so-called 'neutron reflectors' the density of the thermal neutron 'cloud' in the soil can be increased; however, this is not a measure of the moisture present but only of the backscattering property of the reflector. Even if the reflector is made from material of high atomic mass, and can return fast neutrons to the soil, the geometry is no longer spherically symmetrical about the source. Therefore, using this method the normal depth calibration curve cannot be used since there is either an increased background count, or the shape and hence the density of the thermal neutron 'cloud' has been altered giving another false moisture reading.

This can be avoided by using the soil trays developed at the Institute of Hydrology (Bell, in preparation). These comprise a specially made fibreglass tray filled with surface soil; when not in use the tray is kept in a hole lined round the sides with a concrete ring near the access tube. The tray surface is level with the ground surface. The tray is 10 cm deep and 46 cm in diameter, the appropriate crop is grown in it, and the bottom is perforated and designed to maintain hydraulic continuity with the soil below when it is in the concrete holder. The soil in the tray thus has the same density, chemistry and approximate moisture content as the top soil layer in the vicinity. The tray has a central tube which enables it to be fitted over the access tube when readings are to be taken, thus the tray effectively doubles the thickness of the surface 10 cm soil layer and enables the normal calibration to be applied for readings taken 10 cm below the true ground surface. For neutron probes with an extended vertical geometry, e.g. those employing a bottom placed source and a BF_3 counter, a deeper tray might be required.

7. CALIBRATIONS

Two main problems arise when considering the calibration of neutron moisture meters. The first is that the count rate in a soil of given composition is dependent not only on the water content, but also upon the dry bulk density (Fig. 4). Although hydrogen is the soil element which predominantly affects the density of the slow neutron cloud, all elements have to some degree a scattering and an absorption cross-section for neutrons. Thus, different densities of soil matrix create different probabilities of thermalising collisions, i.e. the total capture and scattering cross-sections of the soil matrix are changed if the weight of dry soil per unit volume is changed. It therefore appears that the count rate is a function of dry density as well as moisture. From the curves it can be seen that there is little difference in <u>slope</u> over any normal range of moisture change, so that working in terms of moisture differences rather than absolute values produces very little error if density is neglected and a single curve is used. The shape of the curves varies with the detection system and source-detector geometry of different equipments (Bell and McCulloch, 1968). Current opinion is inclined to accept the effect of dry bulk density of the soil on calibration curves as described above, but it is very difficult to establish experimentally due to various errors which inevitably occur with both field and laboratory determinations.

The second problem is that a curve is affected by the chemistry of the matrix and the presence of certain trace elements with high absorption cross-sections reduces the neutron count. These effects can be dealt with theoretically (Ølgaard, 1965) but this involves very precise and expensive chemical analyses of elements for each level in the soil at each site at which readings are to be taken.

The theoretical method also requires at least two experimentally established calibration points and it is therefore considered that unless the very extensive and detailed chemical analyses are already available, empirical field or laboratory calibration is more practicable. The variation of counts due to the radioactive random decay process in the source can be dealt with quite simply by statistical formulae (Bell and Eeles, 1967).

8. LABORATORY CALIBRATION

This is possible with some soils if they satisfy two criteria:

(i) they do not swell and shrink with moisture change, i.e. they are low in clay minerals and organic content

(ii) they are fairly homogeneous as regards chemistry and density, and not highly textured.

Gravels and sandy soils satisfy these criteria. A watertight drum at least five feet in diameter and at least five feet deep is required, together with a thoroughly air dried four ton sample of the soil. The procedure of sampling, air drying and packing of the drum to constant density provides a number of problems and is expensive. However, it does provide two (and possibly three) very accurate calibration points which can be regarded with a confidence not always possible with field calibrations. Count rates are established for the known moisture values for the air dry and saturated conditions, after which the drum is allowed to drain to equilibrium over several weeks. A full count rate profile is then obtained and this is equated with a moisture profile established by sampling the drum as it is systematically emptied of soil.

9. FIELD CALIBRATION

A field calibration is the simplest method of calibration if the effect of soil dry bulk density is clearly appreciated. It does, however, involve sampling at different moisture contents throughout the year, and so it is a very lengthy process to obtain the complete set of curves. These represent all the soil in a defined area and depth, for which it may be assumed that calibration is affected predominantly by density variations, with a fairly constant chemistry. To derive even one curve for one soil at an effectively constant dry bulk density is a long and difficult job. These curves do not have to be corrected for 'bound water' in the soil matrix as do theoretically derived curves, and this is one of many advantages of the field calibration.

A temporary access tube is inserted in the ground near to the intended position of the permanent access tube. The neutron probe is lowered to the required depth and a statistically suitable count accumulated by the scaler. The tube is then removed and at least six 'undisturbed' soil cores are taken centred at the reading depth, and surrounding the tube position in as close a circle as possible. The soil corer used in this relatively undisturbed sampling technique is shown in Fig. 5. Plate 2 shows a four inch 'Jarrett' auger which is marked by tape at the depths at which samples are to be taken; it is used to open a hole to these depths. The Institute corer in front of this is then used to take the soil sample. The corer is shown with the P.V.C. liner exposed between it and the cutting shoe. An actual sample is next to this with one end trimmed and the other end still with the surface grass attached to the soil core. The P.V.C. liner retains the sample but care must be taken to drive the corer to exactly the correct distance so as not to compress the sample. A groove on the outside of the corer barrel shows where the top of the P.V.C. liner is in relation to the soil surface, and the corer should not be driven beyond this mark. The six soil cores are then processed gravimetrically to obtain the mean moisture volume fraction and dry bulk density. Once calibration curves have been established for a particular instrument then other instruments can be intercalibrated very easily by comparing field readings, but only if the probes have similar source detector geometries and systems. It is vital that compression of the cores does not occur as this will change the apparent moisture content and density against which the count rate is to be plotted.

10. LOGGING ACCESS TUBES

Readings can be taken as often as required providing that care is taken not to disturb the site surface. Where the ground is likely to be compacted and surface vegetation destroyed by repeated visits, then the tube should be approached in a manner to prevent this disturbance, e.g. on duckboards. Routine procedures to reduce incidental errors should be used at each site and on each occasion when taking readings. Under normal circumstances readings are best taken at 10 cm intervals overlapping the zones of importance and so producing a running average of the moisture profile. When the pattern of moisture variation has been determined over a period, readings are concentrated in the zone of moisture change so defined.

The preset count or time is set on the scaler according to the expected moisture range in a profile to give the required precision (Bell and Eeles, 1967), and the readings are converted to count rates which are then expressed as a ratio to the count rate in the transport shield; this ratio procedure compensates for drift in the electronics or change in performance which might otherwise cause sudden or progressive spurious 'moisture changes'. All readings are recorded on field sheets (Fig. 6) on which the relevant site and equipment details are also noted.

The equipment must be checked periodically because of possible long term drift in the electronics. For equipment employing a scintillation detector a graph of count rate in the transport shield (or some other standard) is plotted against the pulse discrimination setting of the scaler. Increasing this voltage setting progressively cuts off from the scaling circuit pulses caused by gamma photons, thermal, epithermal and fast neutrons in that order.

As the setting is increased the initial count rate drops sharply, and then the graph levels off to form a 'plateau' due to the large proportion of thermal neutrons counted. The count rate again falls sharply as the counting threshold is moved into higher energy ranges. From its shape the curve is called a 'plateau' curve, and the scaler discriminator is set at the voltage connected with the middle of the plateau so that the main component of the count rate is thermal neutrons. The discriminator can be adjusted to give a particular count rate, e.g.

the count rate in water, but this must be on the stable part of the 'plateau'.

The corresponding curve for a proportional counter is a plot of count rate against anode voltage. Here the high energy neutrons are detected first at low anode voltages, so that the curve initially rises sharply and levels off when the thermal neutron detection threshold is reached. The curve rises steeply again as the gammas start adding to the count rate.

To ensure that readings taken in comparable conditions over a period are consistent it is essential to check the 'plateau' curve regularly, and to reset the discriminator or anode voltage if necessary.

11. CONCLUSION

The importance of taking every care in the installation of neutron access tubes cannot be over emphasised as a reading bias introduced here is not easily detected. Similarly, disturbance to the moisture regime arising from changed surface conditions due to trampling by careless operators during logging may cause serious errors.

Although the instrument precision is good the accuracy of the calibration curve is affected by errors in the moisture determination. All errors must be kept to a minimum by carrying out the work of calibration with extreme care.

The establishment and maintenance of good routine procedures should prevent these faults, and lead to reliable results provided that the field procedures of assistant staff are checked frequently.

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Ølgaard, P.L. 1965. On the theory of the neutronic method for measuring the water content in the soil. *Danish Atomic Energy Commission, Riso Report 97.*

Richardson, B.Z. 1966. Installation of soil moisture access tubes in rocky soils. *J. Soil Wat. Conserv.*, *21*, *4*, 143-145.

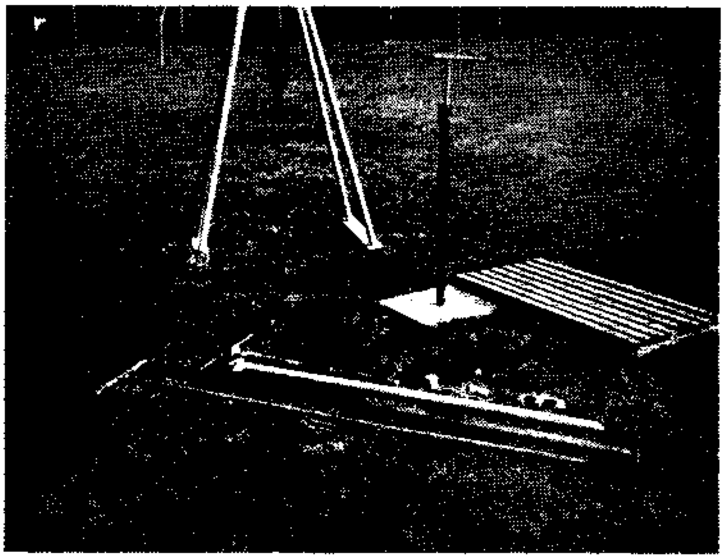


Plate 1. Acess tube installation equipment.

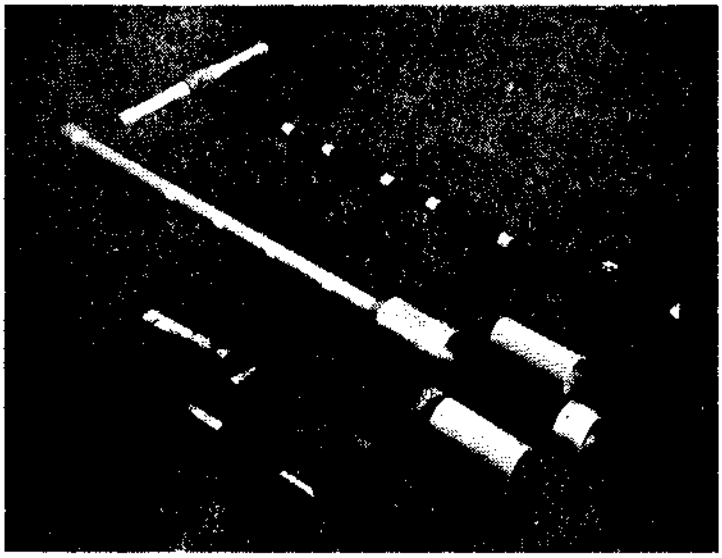
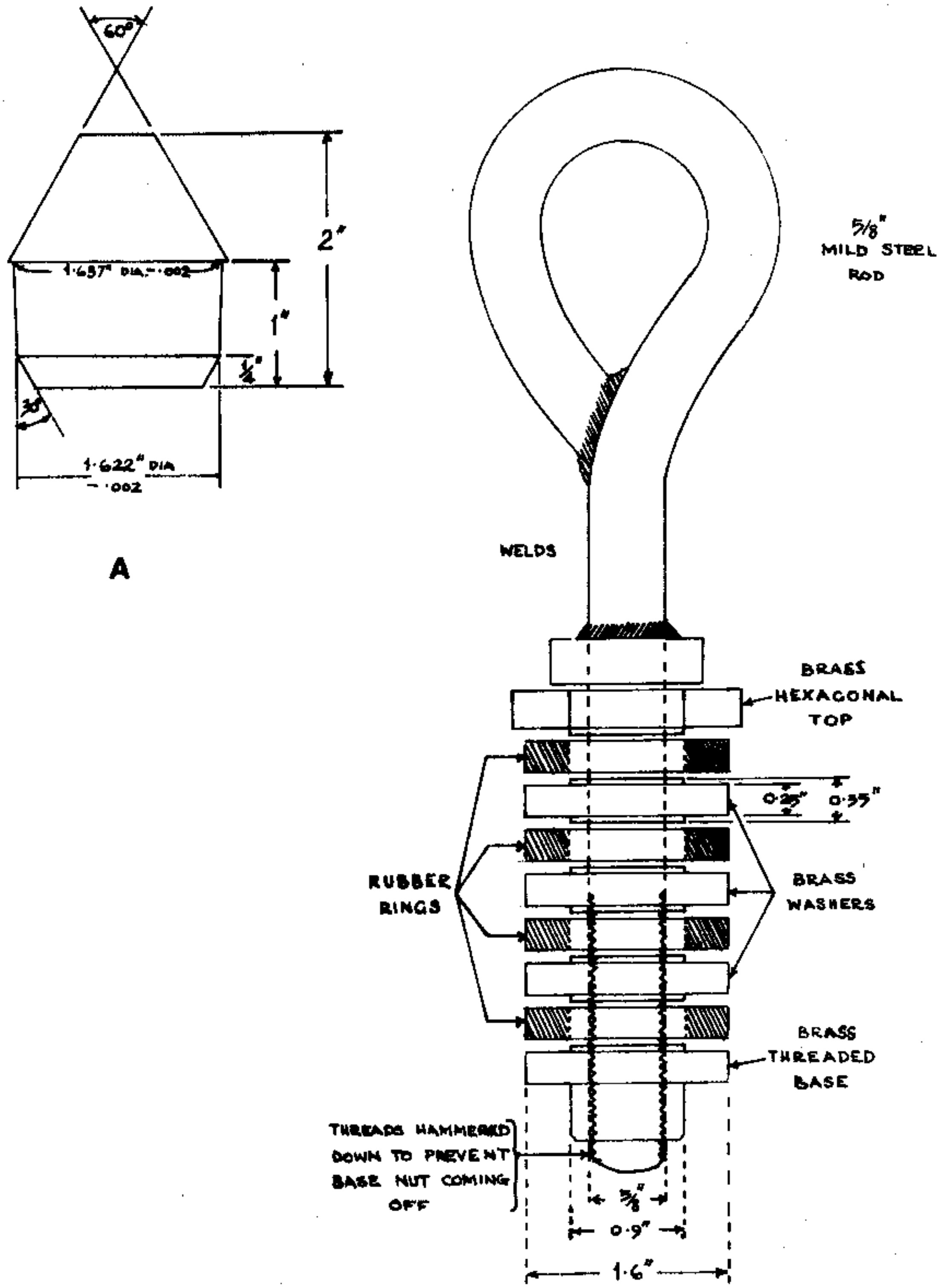


Plate 2. Equipment for obtaining relatively undisturbed soil cores of known volume.



A

B

Fig. 1

A: Tapered Plug to Seal Bottom of Access Tube

B: Access Tube Extractor

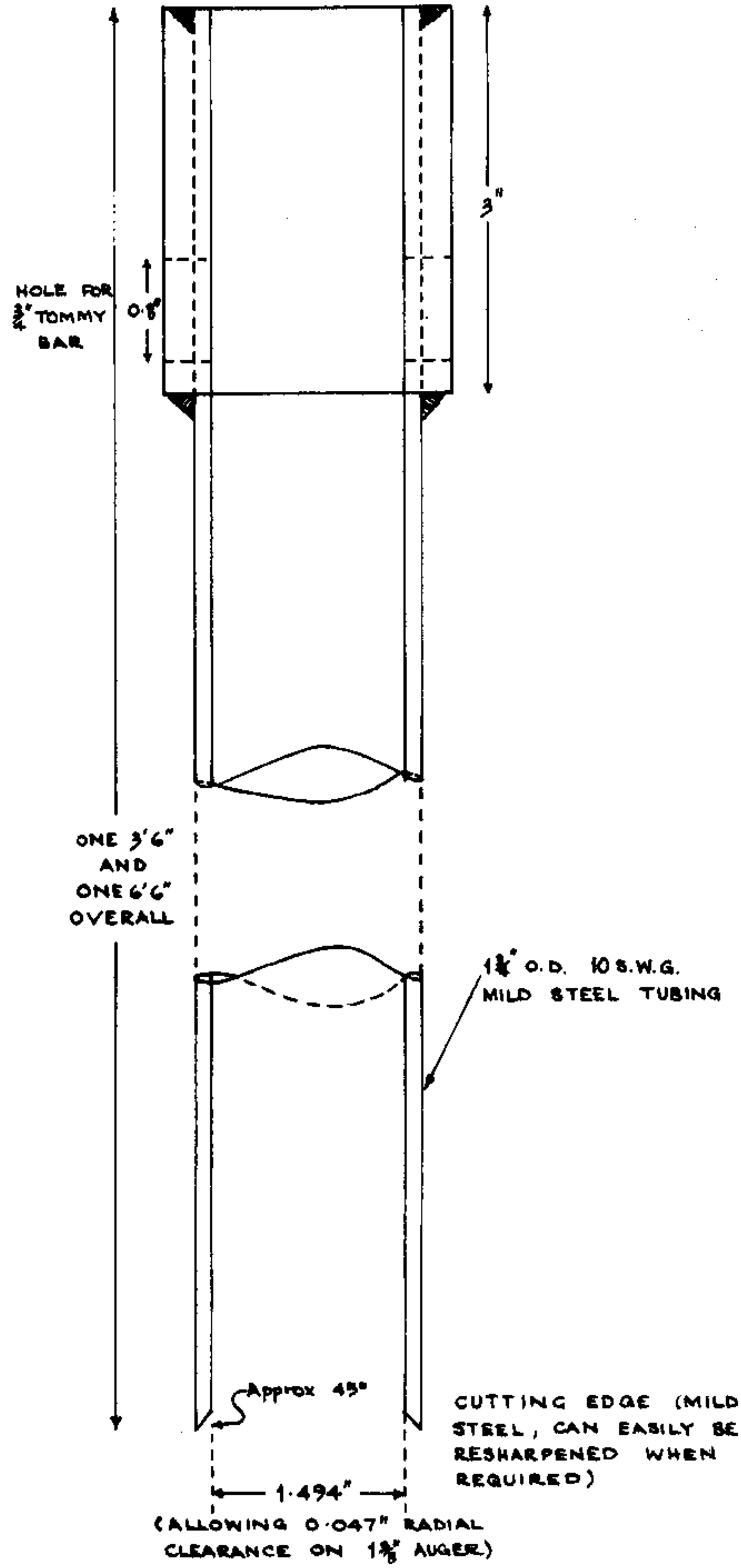


Fig. 2 Steel Guide Tube for Auger

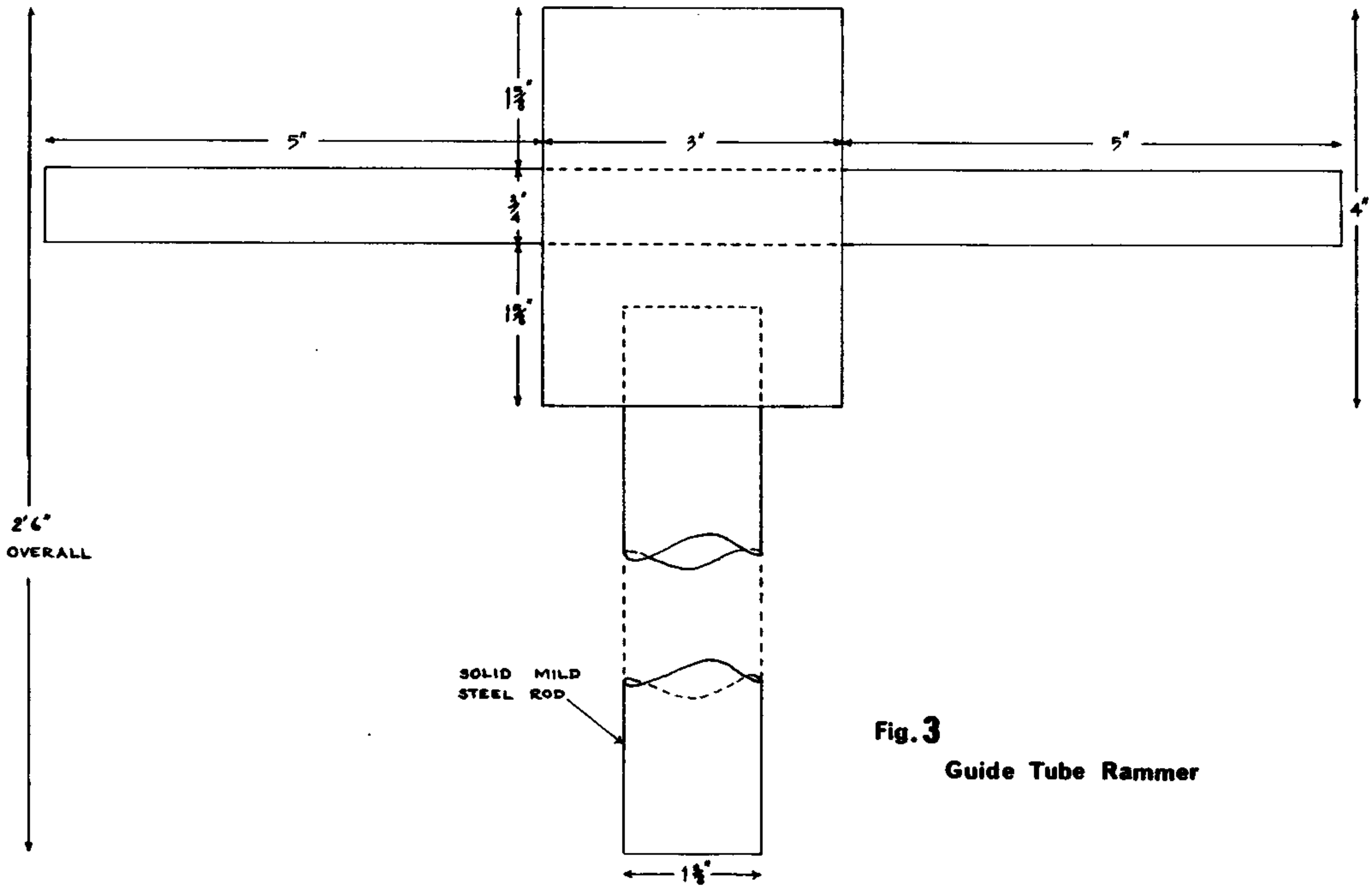


Fig. 3

Guide Tube Rammer

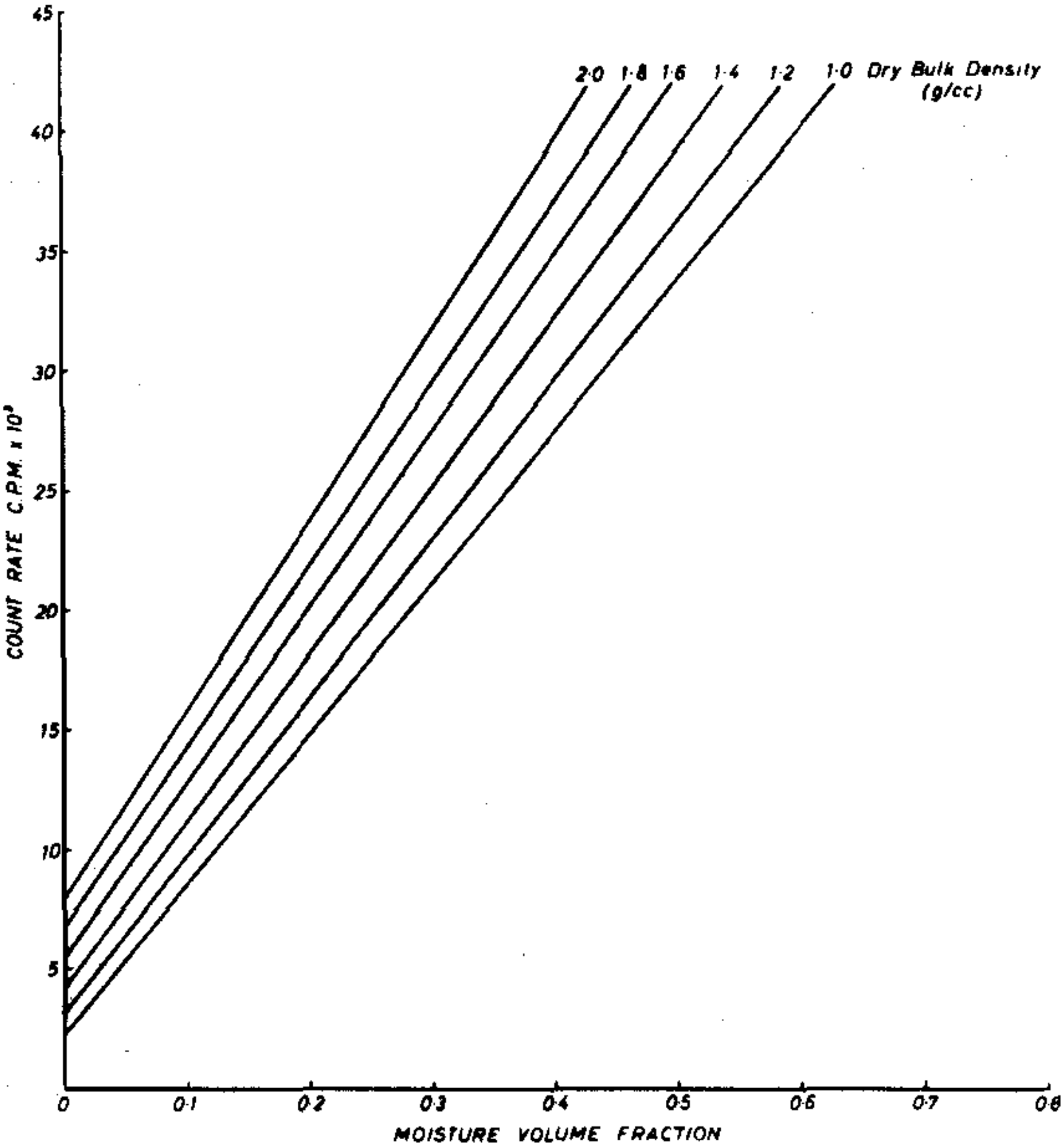
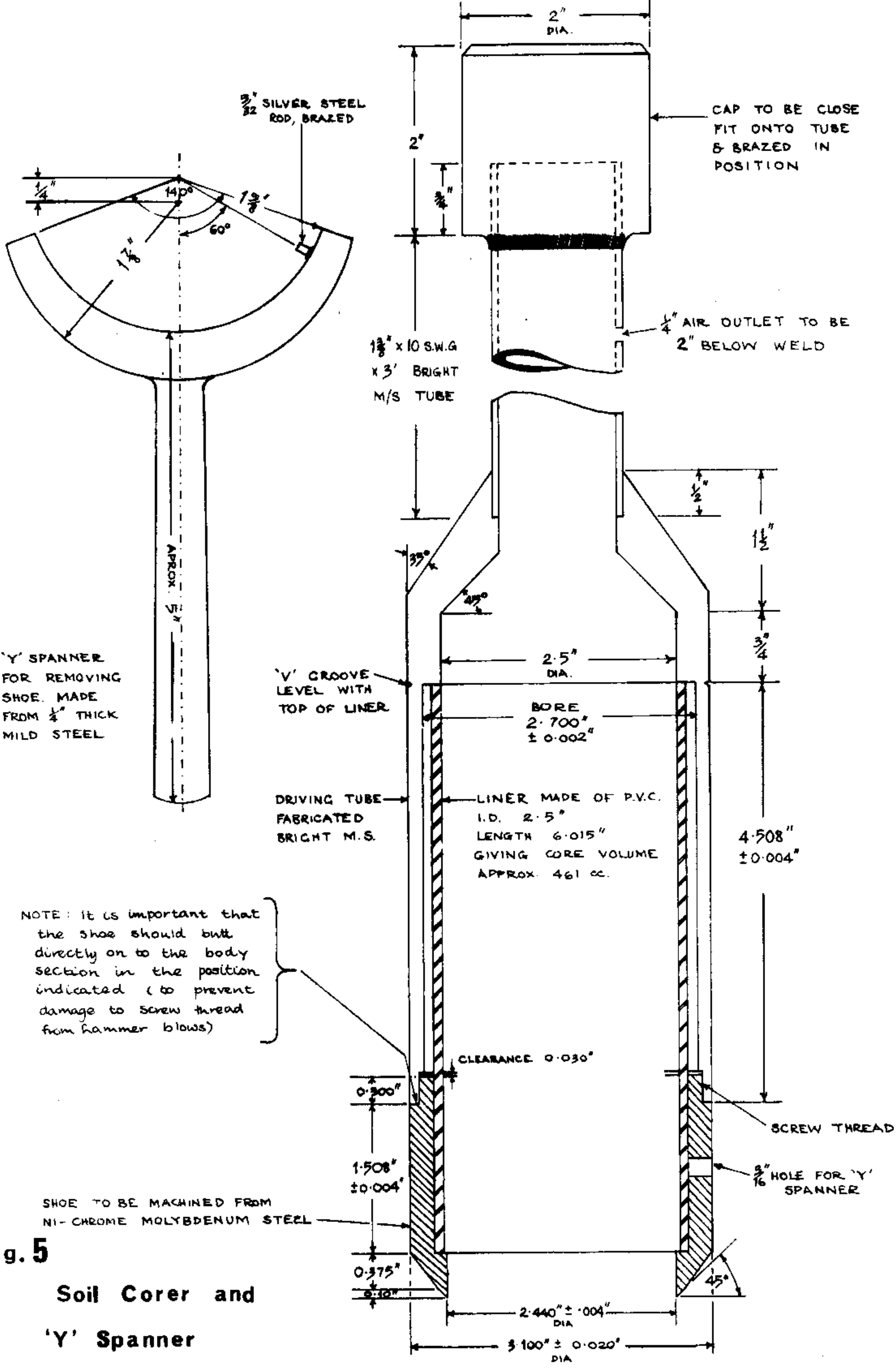


FIG 4. THEORETICAL CALIBRATION CURVES SHOWING THE EFFECT OF DRY BULK DENSITY

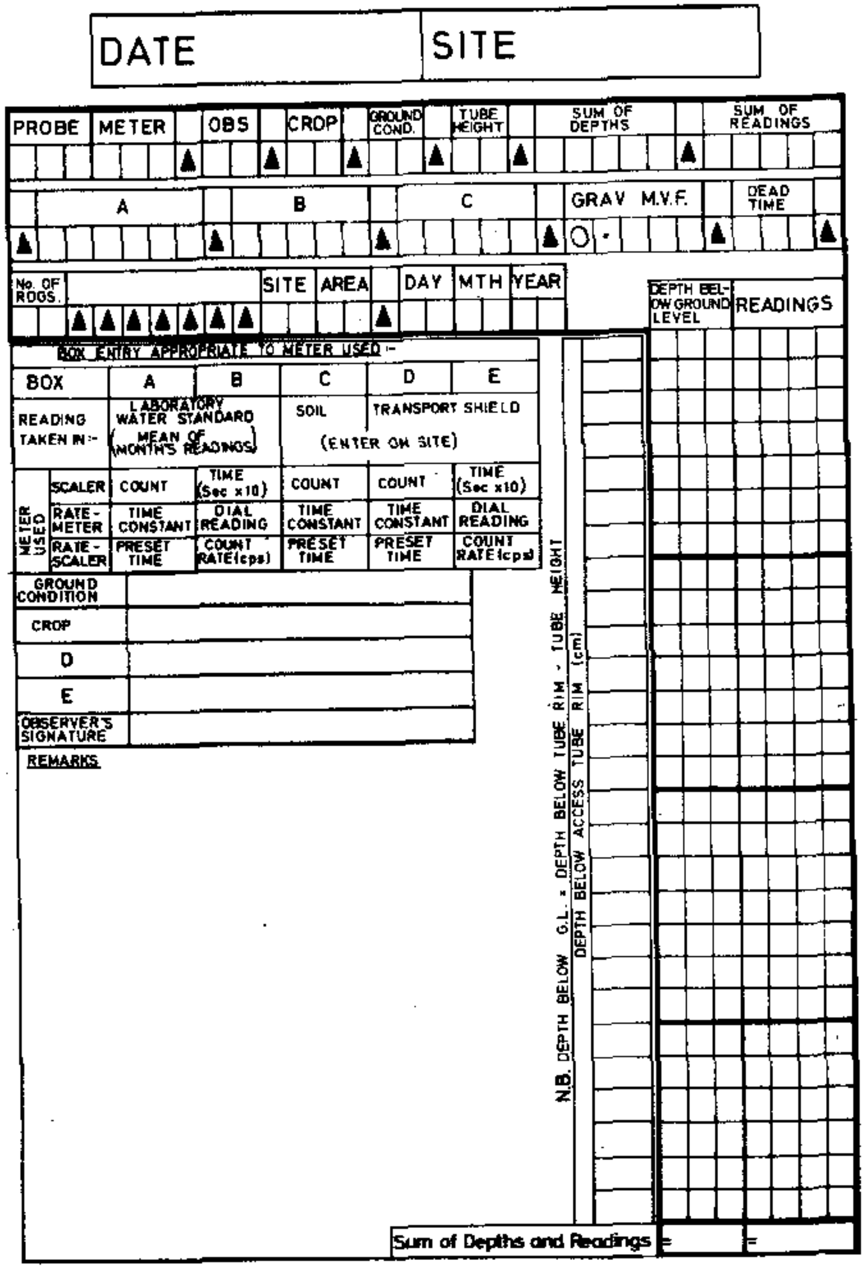


NOTE: It is important that the shoe should butt directly on to the body section in the position indicated (to prevent damage to screw thread from hammer blows)

Fig. 5

Soil Corer and 'Y' Spanner

NEUTRON SCATTERING FIELD DATA FORM No 71-2



DATE | SITE

PROBE | METER | OBS | CROP | GROUND COND. | TUBE HEIGHT | SUM OF DEPTHS | SUM OF READINGS

A | B | C | GRAV M.V.F. | DEAD TIME

No. OF RDGS. | SITE | AREA | DAY | MTH | YEAR

BOX ENTRY APPROPRIATE TO METER USED:-

BOX		A	B	C	D	E
READING TAKEN IN:-		LABORATORY WATER STANDARD (MEAN OF MONTH'S READINGS)		SOIL	TRANSPORT SHIELD (ENTER ON SITE)	
METER USED	SCALER	COUNT	TIME (Sec x10)	COUNT	COUNT	TIME (Sec x10)
	RATE-METER	TIME CONSTANT	DIAL READING	TIME CONSTANT	TIME CONSTANT	DIAL READING
	RATE-SCALER	PRESET TIME	COUNT RATE(cps)	PRESET TIME	PRESET TIME	COUNT RATE(cps)

GROUND CONDITION

CROP

D

E

OBSERVER'S SIGNATURE

REMARKS

N.B. DEPTH BELOW G.L. = DEPTH BELOW TUBE RIM - TUBE HEIGHT

DEPTH BELOW ACCESS TUBE RIM (cm)

DEPTH BELOW GROUND LEVEL | READINGS

Sum of Depths and Readings = =

FIG. 6A

Instructions for entries in the field

1. Enter in the appropriate box in the heavy rimmed area the appropriate codes or values for:-

   (i) Probe
   (ii) Meter
   (iii) Tube height, ie. the height of the access tube rim above ground level.
   (iv) C
   (v) If no core sample taken (for separate thermogravimetric determination of MVF for top 15 cm), enter 0.000 in "GRAV MVF". Leave blank if core taken. No separate code is necessary to show that a core has been taken.

2. Enter in the appropriate box (outside the heavy rimmed area) in words or numbers:-

   (i) Site
   (ii) Date
   (iii) Standard count at site (D and E).
   (iv) Ground conditions.
   (v) Crop
   (vi) Observer's signature.
   (vii) Any relevant remarks eg. "access tube damaged".
   (viii) Reading depths below access tube rim.

3. Enter meter readings and their depths below ground level.

Instructions for entries on return to office

Enter codes for:-

(i) Observer
(ii) Crop
(iii) Ground conditions.
(iv) Site and Area.
(v) Day, month and year.

Enter values for:-

(i) Sum of depths (excluding gravimetric depth).
(ii) Sum of readings (excluding gravimetric value).
(iii) A and B.
(iv) Gravimetric MVF, where relevant.
(v) Dead time of ratemeter, where relevant.
(vi) Number of readings taken with probe (ie. excluding gravimetric value).

Observation Units:-

Danbridge and EAL:-	time for preset count (sec x 10).
Ratescaler :-	count rate in counts per second (c.p.s.).
Ratemeter :-	c.p.s., as read from dial, not corrected for dead time.
Depth units :-	centimetres
Dead time :-	microseconds

(NB. No decimals to be used).

FIG. 6B

FIELD SHEET

REPORTS OF THE INSTITUTE OF HYDROLOGY

Available on application to the Librarian

Report No 6	1969	"A feasibility study and development programme for continuous dilution gauging", by P. H. Hosegood, M.K. Bridle and P. W. Herbertson
Report No 7	1969	"Installation of access tubes and calibration of neutron moisture meters", by C. W. O. Eeles
Report No 9	1971	"River level sampling periods", by P. W. Herbertson, J. R. Douglas and A. Hill
Report No 10	1971	"User's testing schedule for the Wallingford probe system", by P. M. Holdsworth
Report No 11	1971	"Report on precipitation", by J. C. Rodda
Report No 13	1971	"A computer program to use orthogonal polynomials in two variables for surface-fitting", by D. Richards
Report No 14	1972	"A system for processing data from autographic recorders", by J. R. Douglas
Report No 16	1972	"Peat Hydrology"