Instructions for the fabrication of thermocouple cables for measuring ground temperatures

Johnston, G. H.

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INSTRUCTIONS FOR THE FABRICATION OF THERMOCOUPLE CABLES FOR MEASURING GROUND TEMPERATURES

BY

G. H. JOHNSTON

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INSTRUCTIONS FOR THE FABRICATION OF THERMOCOUPLE CABLES FOR MEASURING GROUND TEMPERATURES

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G. H. Johnston

For a number of years the Division of Building Research has been involved in the measurement of ground temperatures relative to studies of frost penetration, permafrost and general construction problems that require a knowledge of subsurface temperature variations. Several types of instrumentation have been used but ground temperature measurements have generally been made with thermocouples. The accuracy and reliability of such measurements can be affected by a number of factors, many directly related to the fabrication of the circuitry and the use of the measuring equipment. Studies have been carried out to evaluate the source and magnitude of error introduced by some of these factors and modifications have been incorporated into the design of the installations in an attempt to eliminate or reduce these errors. This paper describes the fabrication of a complete thermocouple assembly (Figure 1) developed by and at present used by the Division.

Basically, the thermocouple cable consists of copper-constantan duplex wires placed in an oil-filled plastic pipe for protection against damage and moisture. To facilitate field measurements the cable is attached to a switching arrangement in a weatherproof switch box. Using the instrumentation described in the following paragraphs it should be possible to obtain temperatures accurate to at least ±0.5°F and in many cases to ±0.3°F if care is taken in the fabrication of the installation and the use of the reading instruments. Two types of reading instruments, a portable precision potentiometer and an electronic temperature indicator, and instructions for their use in the field, have already been described (1, 2).

THERMOCOUPLE CIRCUIT

When two lengths of different metals are joined at both ends and the junctions subjected to different temperatures, a small electromotive force is set up in the circuit causing a current to flow. These junctions are known as thermocouples. The electromotive force generated is a function of the temperatures and the properties of the metals. Temperatures are obtained by measuring the difference in electromotive force between a junction of known temperature, i.e. a reference junction, and one of unknown temperature. In the usual thermocouple circuit, when temperatures are measured with a portable potentiometer, the reference junction is immersed in a bath of water and finely crushed ice which will maintain a constant temperature of 32°F. If an electronic temperature indicator is used, the temperature of the reference junction, which is incorporated into the instrument circuit, is compensated for automatically. A diagram showing the complete thermocouple circuit from the ground temperature junction to the reading instrument is given in Figure 2.

If extremely long leads are necessary for an installation, it may be desirable to use a "long lead" circuit as shown in Figure 3. This circuit has two advantages:

1. it cuts down the resistance of the circuit so that more sensitive determinations can be made with a potentiometer;

2. it is more economical since constantan wire is quite expensive.

One important disadvantage of the long lead circuit is that, because it has only one common constantan conductor from the junction box to the switch box, the entire cable will be out of commission should this one wire be cut or damaged.

It is important that all ground temperature installations be adequately protected from the effects of moisture and weather to prevent corrosion and possible "short circuits." Care must be taken in the use of switches and connectors and in making connections, particularly with regard to eliminating or reducing thermal gradients at terminal points where considerable error can be introduced. In general, the fabrication of reliable temperature measuring instrumentation requires good workmanship and good materials.

<u>Thermocouple Wire</u>

Copper wire can be manufactured to high standards of uniformity and purity. Because constantan wire is less homogeneous, errors can develop due to temperature gradients in the wire. The calibration and quality of commercially available thermocouple wire is normally satisfactory but care should be taken to ensure that good grade copper-constantan wire of proper calibration (1938) is always used. Premium grade or "special accuracy" wire can be purchased at a slightly greater cost.

For most ground temperature installations, 20-ga duplex wire is recommended. This wire has two conductors, one copper and one constantan, individually encased in polyvinyl chloride with an over-all covering of polyvinyl chloride. (Wires having various types and combinations of coating materials are also available.) Although polyvinyl-covered wire is suitable for the ground temperature cable, it has not been satisfactory when used for lead wires because the polyvinyl coating tends to crack and peel when subjected to flexing at below freezing air temperatures. Lead wires having an outer jacket of asbestos and an inner jacket of teflon are used under these conditions. These coatings do not break in cold weather and are highly resistant to abrasion and rough use which they may receive if dragged from one location to another or if coiled and uncoiled.

The sensitivity of a portable potentiometer is greatly affected if the external resistance of the thermocouple circuit is greater than about 30 ohms. This factor becomes extremely important if the temperatures to be measured are close to the reference junction temperature of 32°F. The size of the wire, therefore, limits the length of wire that can be used. Normally, for installations having a length of 75 ft or less, 20-ga wire is satisfactory. For those greater than 75 ft, but not longer than 200 ft, 16-ga wire is used. When an electronic temperature indicator is used, however, much greater lengths of 20-ga wire can be used because the sensitivity of this instrument is not affected by the resistance of wire lengths normally used in ground temperature work.

Multi-conductor cables of various wire gauges are now available and are most convenient for fabricating thermocouple cables.

Switches and Connectors

To avoid the tedious task of connecting individually many thermocouple leads to an instrument when readings are desired, a rotary selector switch is normally used. When a switch is inserted into a thermocouple circuit a junction will be created at each switch point. If the switch is made of uniform material and the temperature of each switch point is the same, this effect will cancel out. For accurate readings, therefore, adequate precautions must be taken to insulate or protect the switches against thermal gradients. In addition, only copper leads should be attached to the switch points as copper is likely to have properties similar to those of the material used for the switch points.

Leeds and Northrup rotary selector switches (type 31-3) are used by the Division. These can be obtained in various combinations of one to six poles with twelve points per pole. They are totally enclosed, thus assuring clean contact surfaces. The stationary contacts are made of solid silver and the brushes are of durable silver alloy.

Particular attention must be given to all connections to reduce or eliminate all possible effects caused by thermal gradients that may exist at these points. For example, constantan-to-constantan connections should not be soldered or joined by connectors made of a different metal, such as brass, because a temperature-measuring junction is set up at that point. (Solder, for instance, has similar properties to copper wire.) In such cases, only connectors made of solid constantan (of the same grade as the wire) should be used or a connection made by simply twisting the constantan wires tightly together.

Simple clamp-type connectors and terminal blocks have been developed to ensure a positive connection of copper and constantan wires for use in making connections between the switch box and the reading instruments in the field. These consist of small bakelite blocks which are attached to the jaws of the clamp upon which copper and constantan wires are wound individually (Figure 4). These wires are mated with wires wound on similar blocks fastened together (with the wires insulated from one another) and mounted in the switch box. The clamps used are battery booster cable clips which can be obtained at hardware or electrical stores. Details of the construction of the bakelite blocks are given in Figure 5.

CABLE FABRICATION

Duplex Wire

The thermocouple cable refers to that portion of the installation from the lowest thermocouple junction in the ground to the switch box. The number of duplex wires in the cable will depend on the number of points in the ground at which the temperature is desired - one duplex wire for each point. Each duplex wire in the cable is cut to a length equal to the distance from the ground surface to the point in the ground where the temperature is to be measured plus the distance from the ground surface to the switch box. This last should be a minimum of 5 ft to allow some flexibility in positioning the switch box at the site.

To make a thermocouple junction, take one end of the wire and strip back the outer insulation for about 1 in. Strip about 3/4 in. of the covering from each of the copper and constantan conductors. Thoroughly clean each wire with emery cloth or scrape with a knife and twist the ends tightly together for about 3/8 in. cutting off any jagged ends of wire. With a hot soldering iron "sweat" lead-tin, resin core solder between the twists of the thermocouple tip. To complete the junction, dip the tip in electrical insulating enamel. Two or three dippings are required, allowing the enamel to harden fully after each dipping.

As each length of wire is cut, it should be identified by a small, numbered metal tag attached to each end of the wire. When the duplex wires have been cut and the thermocouple junctions prepared, all the wires are bound tightly together with electrician's or similar tape so that the thermocouple points are spaced at the intervals corresponding to the depths in the ground at which temperatures are to be measured.

The complete wire assembly is then inserted in a length of flexible polyethylene hose (Canadian Government Specifications Board, Spec. No. 41-GP-5A) which is free of any cuts or breaks. The hose is cut so that it is about 1 ft shorter than the longest wire in the cable.

Two methods have been used to place the cable in the hose depending on the length of the installation. An electrician's "fish" tape can be inserted in the hose from the upper end through to the bottom where the tape is securely fastened to the top end (thickest) of the cable by electrician's tape and strong cord. The fish tape and wire should overlap by at least 5 ft. The fish tape is then pulled back through the hose. For long lengths (>100 ft) a light cord attached to a tightly rolled ball of paper or a cork slightly smaller than the inside diameter of the hose can be blown through the hose with compressed air. A heavier cord or 14-or 16-ga steel wire can then be pulled through, attached to the thermocouple string and pulled back to the upper end of the hose. A little light oil poured into the hose will lubricate the walls and facilitate pulling the cable through the hose.

The size of polyethylene hose required will depend on the number of duplex wires in the cable. Hose with an inside diameter of $\frac{1}{2}$ in. will hold about six 16-ga or twelve 20-ga duplex wires and 3/4-in. inside diameter hose will hold about twelve 16-ga or twenty 20-ga duplex wires, depending on the type and thickness of insulation covering the wire.

The duplex wires are positioned in the hose so that the lowest thermocouple point is about 3 in. above the lower end. Each of the duplex wires in the cable will extend about 15 in. above the top of the hose. A lucite or brass plug (Figure 6) is then driven into the hose and securely held in place by hose clamps, thus sealing the lower end of the hose. The lowest thermocouple point can be fastened to the plug with cord so that the thermocouple junctions will not be displaced when the assembly is coiled for shipment. The 0-ft depth (ground surface) should be well marked on the outside of the hose so that the installation can be properly positioned in the ground.

Multi-conductor Cable

Multi-conductor thermocouple cables which contain from 6 to 56 pairs of thermocouple wire are now available in both 16- and 20-ga wire sizes (others on special order). These cables vary in outside diameter, depending on the number of wires, from about 0.5 in. for a 6-pair cable to about 1.2 in. for a 56-pair cable of 20-ga wire. A 14-pair cable of 20-ga wire with polyvinyl chloride insulation on individual wires, aluminum-backed MYLAR tape wrapped around the bundle of conductors, and an over-all covering of polyvinyl chloride has an external diameter of about 0.65 in. This cable will fit inside a 3/4-in. I.D. polyethylene hose. The multi-conductor cable is usually placed in a hose to protect it against damage during shipment and against moisture when installed in the ground.

To fabricate the thermocouple junction the outer covering on the multi-conductor cable is cut and stripped back for a distance of 2 in. at each point along the cable corresponding to the depth at which temperatures are to be measured. The pair of wires (copper and constantan) in the cable, which are numbered, colour-coded and concentrically wound next to each other are selected, cut and their covering stripped back for about 3/4 in. Care must be taken to avoid cutting or damaging any of the other wires in the cable. The thermocouple point is then made, following the directions given previously. The junction is pushed back into the bundle of conductors and a coating of glyptol applied over the break in the cable. The joint is then tightly taped over the break in the cable.

When fabrication of all thermocouple points in the multi-conductor cable has been completed, the cable is then inserted into the protective polyethylene hose and the lower end of the hose plugged as previously described.

Long Lead Installation

For the long lead circuit, the thermocouples are prepared exactly as described previously but the lengths of duplex wire (or multi-conductor cable) required for each thermocouple will be the length measured from the junction box to the point in the ground where the temperature is to be measured. The junction box is usually placed in the cable about 5 to 10 ft above the ground surface mark. At the junction box, copper lead wires are spliced to each of the duplex copper wires and all the duplex constantan wires are spliced to a common constantan wire. It is suggested that 16- or 14-ga constantan wire be used for the common constantan lead to cut down the resistance of the circuit. The copper and constantan lead wires run from the junction box to the switch box. Details of the construction of the junction box are shown in Figure 7.

Prior to making the splice, the duplex and lead wires are placed inside suitable lengths of polyethylene hose. The lead wires are pulled through the junction box and the splice is made at the lower end of the junction box.

To splice the copper wires together at the junction box, strip back the covering from each wire for $1\frac{1}{2}$ in. Carefully clean each wire with emery cloth. For each splice slip a length of plastic tubing over one of the wires, long enough to cover the completed splice. Next, cross the wires in the middle of the bared section and wind one wire around the other $1\frac{1}{2}$ times at long spacing, then 5 times at short spacing. Sweat solder well into the twisted junction and coat with glyptol. Slip the plastic tubing over the splice and securely tape it in place. When all coppers have been joined, bind them together with tape.

For the constantan junction, bare $1\frac{1}{2}$ in. of each of the duplex constantans and about 3 in. of the common lead wire. With the duplex wires closely grouped, tightly bind them together by winding the common constantan around them. Then tape the splice well.

When the splices are completed, they are positioned inside the junction box. The lower fitting is then tightly screwed into place and the polyethylene hose securely fastened to the fittings at each end with clamps. The complete assembly is given a coating of waterproofing compound. When installed in the field, the junction box must be buried at least 3 ft below the ground surface so that a constant temperature will be maintained while readings are being taken.

SWITCH BOX FABRICATION

Most ground temperature installations are located so that the switching arrangement is subjected to extremes of winter and summer conditions. A switch box was specially designed to protect the switches and wire connections from the effects of weather, in particular from corrosion and moisture. The relatively large mass of metal surrounding the switch terminals will also help to damp out temperature differences that can introduce errors at the terminals. Details of the switch box assembly are shown in Figures 8 and 9. It consists of a length of 6-in. steel pipe sealed on the bottom (except for the entry port for the wires) and supported on three pipe legs. A removable cover permits access to the switches mounted inside. All external parts of the switch box are given at least two coats of an automobile type finish paint to prevent rusting.

Depending on the number of thermocouple points, one or two rotary selector switches can be housed in this switch box. If only one rotary switch (12 points - single pole) is required, it is mounted at the centre of the switch plate. If two single pole switches or one double pole switch are necessary, then a lever action toggle switch is required to change from one rotary switch to the other or to change from one pole to the other on the single rotary switch having 2 poles. Details for mounting two rotary single pole switches and a toggle switch are shown in Figure 10. The terminals that connect the lead wire from the reading instrument to the thermocouple junction (switch) wires are also mounted in the switch box. The switch mounting plate has a diameter slightly smaller than the inside diameter of the switch box and is made of 1/4-in. thick bakelite. It is secured to the inner lugs on the switch box by three screws.

COMPLETING THE INSTALLATION

To join the thermocouple cable to the switch box, the wires extending above the top of the hose must be carefully fed up through the opening in the base of the switch box. The hose is then drawn up over the fitting that protrudes below the base of the switch box. It is then secured to this fitting by means of two hose clamps and the connection is coated with a waterproofing compound. The wires should be drawn up through the fitting with care so that their insulation is not cut or damaged. The rotary switches and toggle switch (if required) are mounted on the bakelite plate.

The outer covering on each duplex wire is then carefully peeled off for about 4 in. making sure the covering on the individual wires is not damaged. The insulation on each conductor is then stripped back for about 1 in. Both copper and constantan wires should be well cleaned with emery cloth. The copper wires are then soldered (lead-tin resin core) to the switch points in order, according to their depth from the ground surface, i.e. the duplex wire from the thermocouple junction at the ground surface or the closest one to the ground surface is attached to switch point 1, the next deepest thermocouple is attached to switch point 2, etc. Any sequence may be used but it is of utmost importance that the identity (depth) of the thermocouple point connected to a particular switch point be carefully noted. All constantan wires are tightly bundled together ready to be attached to the common lead to the switch box terminal block.

A 36-in. length of copper-constantan duplex wire is used as the connecting lead from the terminal block to the switch. About 24 in. of each of the copper and constantan conductors, from which the insulation has been stripped and the wires well cleaned with emery paper, are wound on the terminal block. At the other end, 4 in. of the outer covering are carefully peeled back and 1 in. of the copper wire and 2 in. of the constantan wire bared and cleaned. The copper lead is soldered to the terminal lug on the switch body. The constantan lead is inserted in the bundle of constantans from the ground thermocouple junctions and the 1 in. or longer portion protruding from the bundle is then tightly wrapped around the bundle; no solder should be used at this connection. The entire constantan connection is then dipped in glyptol, carefully covered with "spaghetti" (plastic tubing) and wrapped with tape so that the bare conductors will not come in contact with any of the copper wires or the switch box housing. To ensure that each thermocouple circuit is functioning and has been connected to the correct switch point, the resistance of each circuit should always be checked with an ohm-meter. So long as the measuring junctions in the ground are 2 ft apart, or greater, they can be readily identified by this method.

The switch plate is then carefully placed in the switch box to avoid damage to the wires and secured to the brackets on the inside wall. The cover plate is then placed on the switch box and secured by means of the brass thumb screws which tighten the cover against a rubber gasket in the rim of the box - thus sealing the installation.

The cable and switch box are filled with a high quality transformer oil (e.g. Voltesso No. 35) using a vacuum pump.

Details of the arrangement for filling the installation with oil are shown in Figure 11. The vacuum pump is connected to a special fitting in the wall of the switch box. The oil provides additional protection to the switch points and terminals in the switch box and will also reduce convection currents within the cable. If the cable and the switch box are to be shipped separately, the cable can be filled with oil by connecting the pump to the top of the hose. The top end of the hose is plugged similar to the bottom end to prevent leakage during shipment. In this case, the hose should be cut so that it is about 6 in. longer than the longest wire in the cable. When the switch box and the cable are connected in the field, the switch box should be filled with oil to at least the top of the switch plate.

FIELD INSTALLATION OF CABLE

The complete assembly, i.e., thermocouple cable and switch box can be shipped as a unit to the field. In most cases, however, it will be found convenient to ship the cable and the switch box as individual components to be connected after the cable has been installed in the ground.

At the site the cable should be stretched out for its full length and straightened to remove all kinks caused by coiling for shipping. If installed in below-freezing temperatures, it should be uncoiled and straightened in a warm environment and carried or dragged to the site.

Short cables (15 ft or less) are normally installed in test pits or boreholes by simply pushing the cable to the depth desired (in a borehole) or by fixing it in place in a groove about 1 ft deep in the wall of the pit. The groove and test pit are then carefully backfilled, with the original excavated material, to about the original density. The borehole is backfilled with material similar to that removed during drilling. For longer cables, which are usually installed in boreholes, a weight (10 to 20 lb) must generally be tied to the bottom end of the cable to keep it straight while it is lowered into the hole. Care should be taken in backfilling the hole to ensure that, as far as possible, the cable is encased by soil so that air currents will not circulate down the hole alongside the cable from the ground surface, and that surface water will not fill the hole around the cable.

TAKING READINGS

The installation described has been designed to minimize the time required to connect the measuring instrument when taking readings in the field, while ensuring that positive and trouble-free connections will be obtained. This has been found to be particularly important under winter conditions when the measuring instrument must be transported and connections made at an exposed field location.

The plate cover of the switch box must be removed. The clamp connector and its lead which has been transported with the measuring instrument, already connected to it, can then be quickly clamped to its mating terminal block on the switch mounting plate in the switch box. The clamp must be placed in such a way as to connect copper to copper and constantan to constantan. This problem can be eliminated if the terminal block is so shaped when it is made that only one clamp position is possible. When the necessary readings have been obtained, the connector clamp is removed and the cover of the switch box replaced.

REFERENCES

1. Johnston, G. H. The measurement of ground temperatures using a modified portable potentiometer. National Research Council, Division of Building Research, Technical Note No. 329, March 1961.

2. Johnston, G. H. The measurement of ground temperatures using a modified electronic temperature indicator. National Research Council, Division of Building Research, Technical Note No. 330, March 1961.

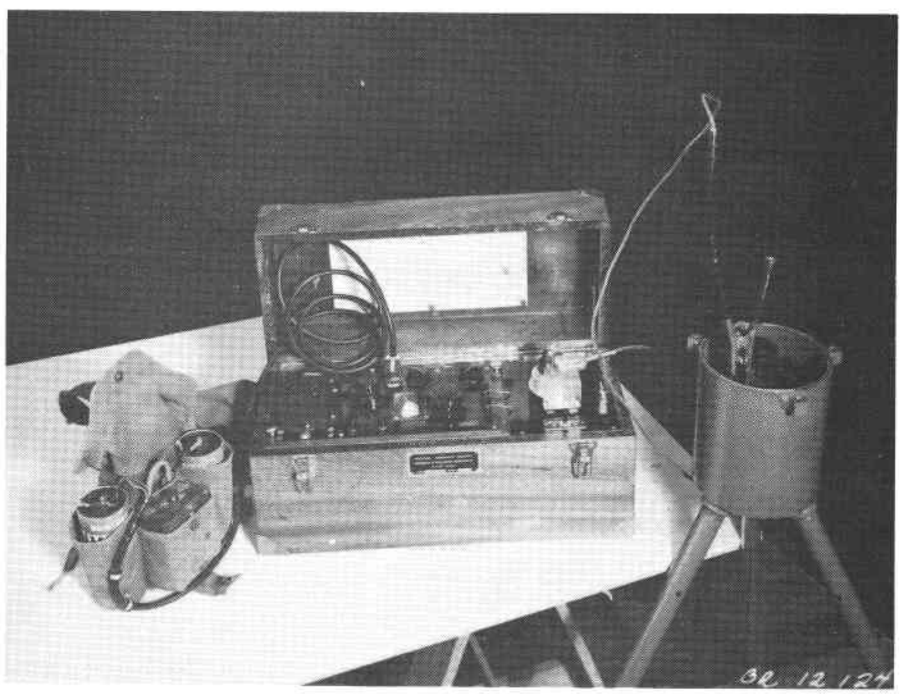


Figure 1   Ground temperature installation
thermocouple cable and switch box

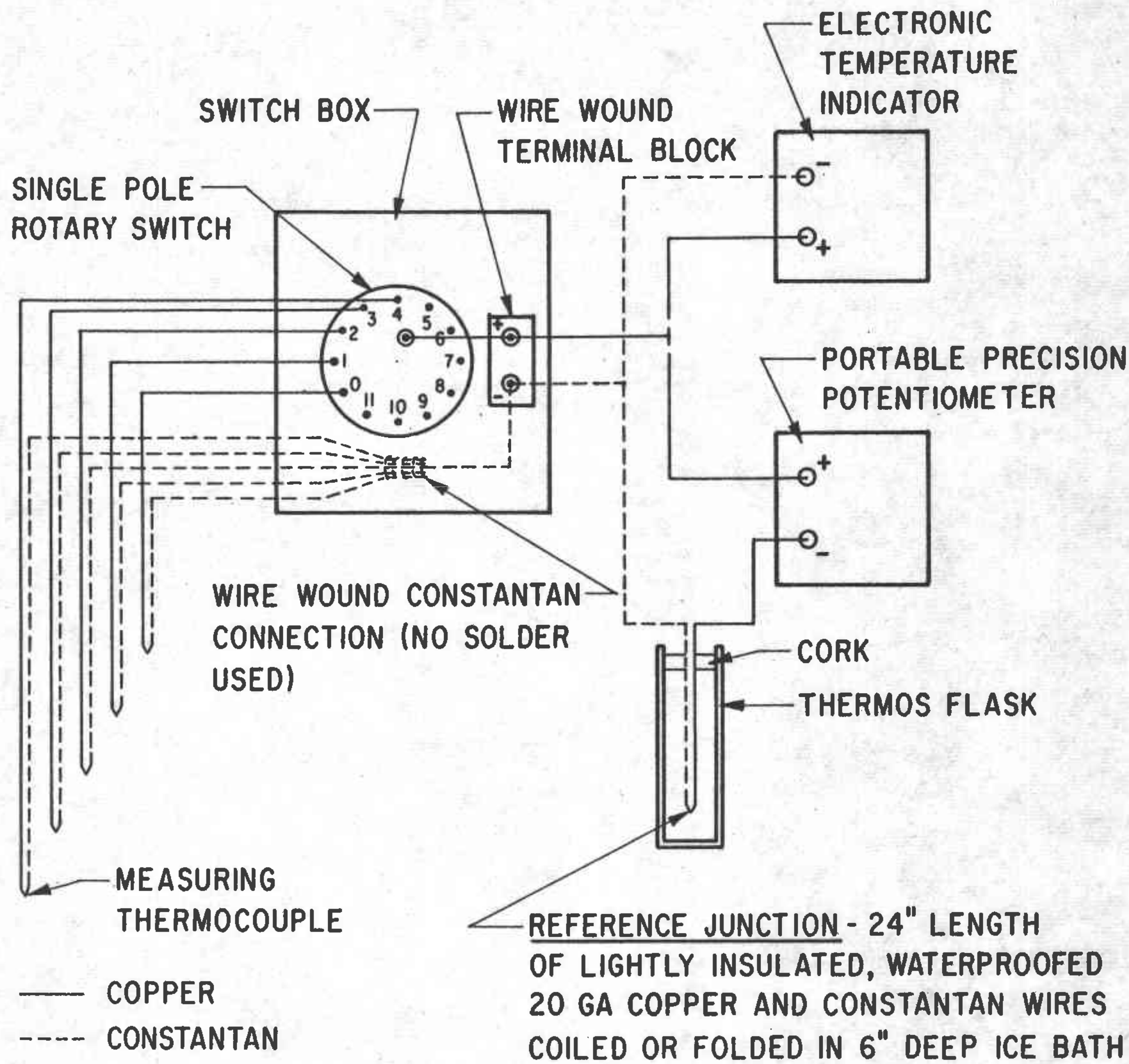


FIGURE 2
CIRCUIT FOR GROUND TEMPERATURE THERMOCOUPLE INSTALLATION

BR. 2952-1

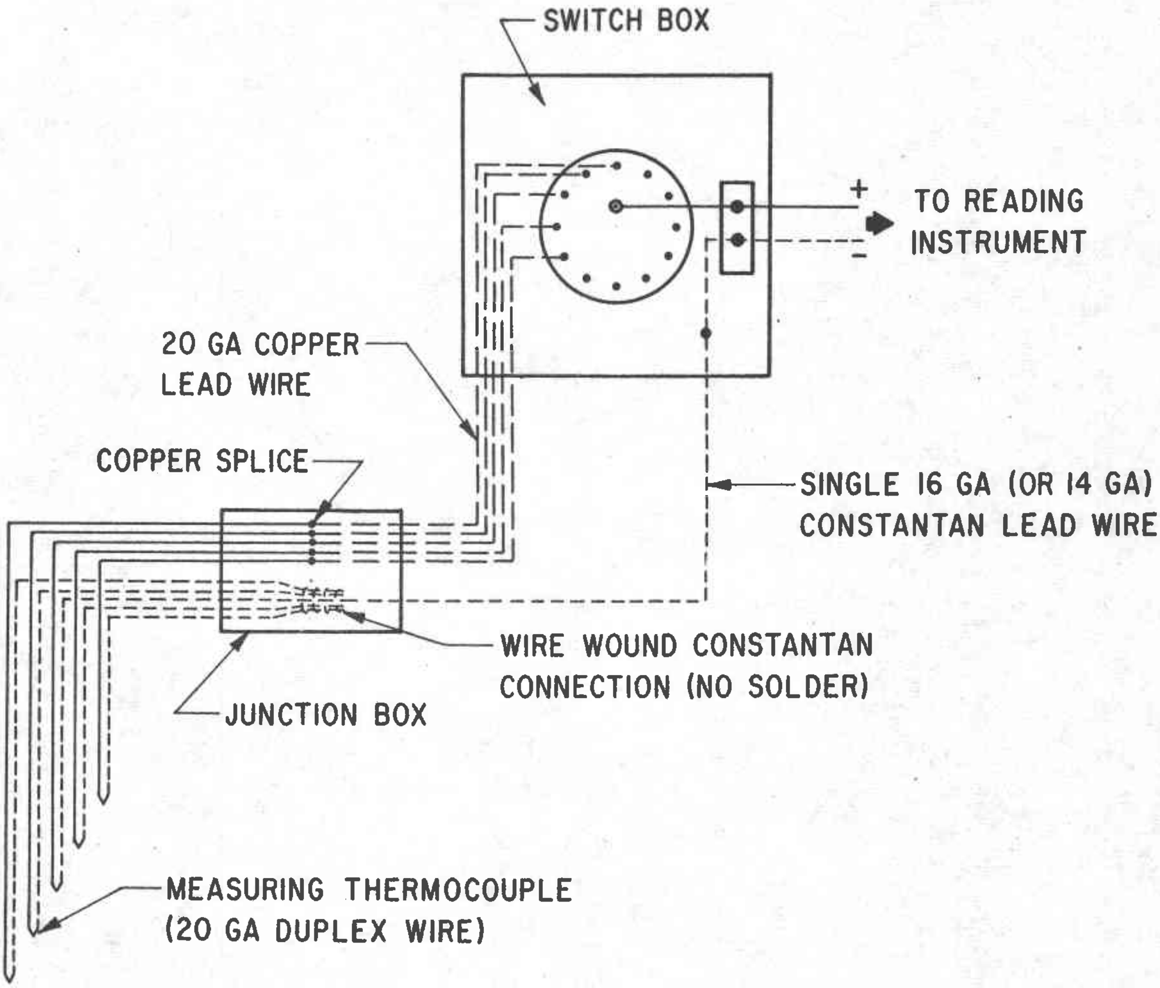


FIGURE 3
LONG LEAD THERMOCOUPLE CIRCUIT

BR. 2952-2

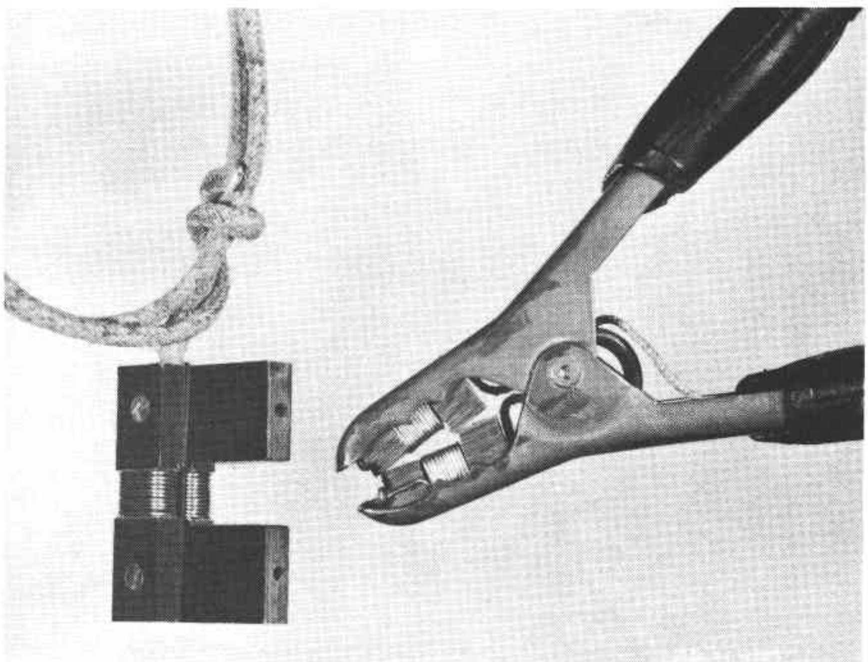


Figure 4 Wire-wound clamp connector and switch box terminal block

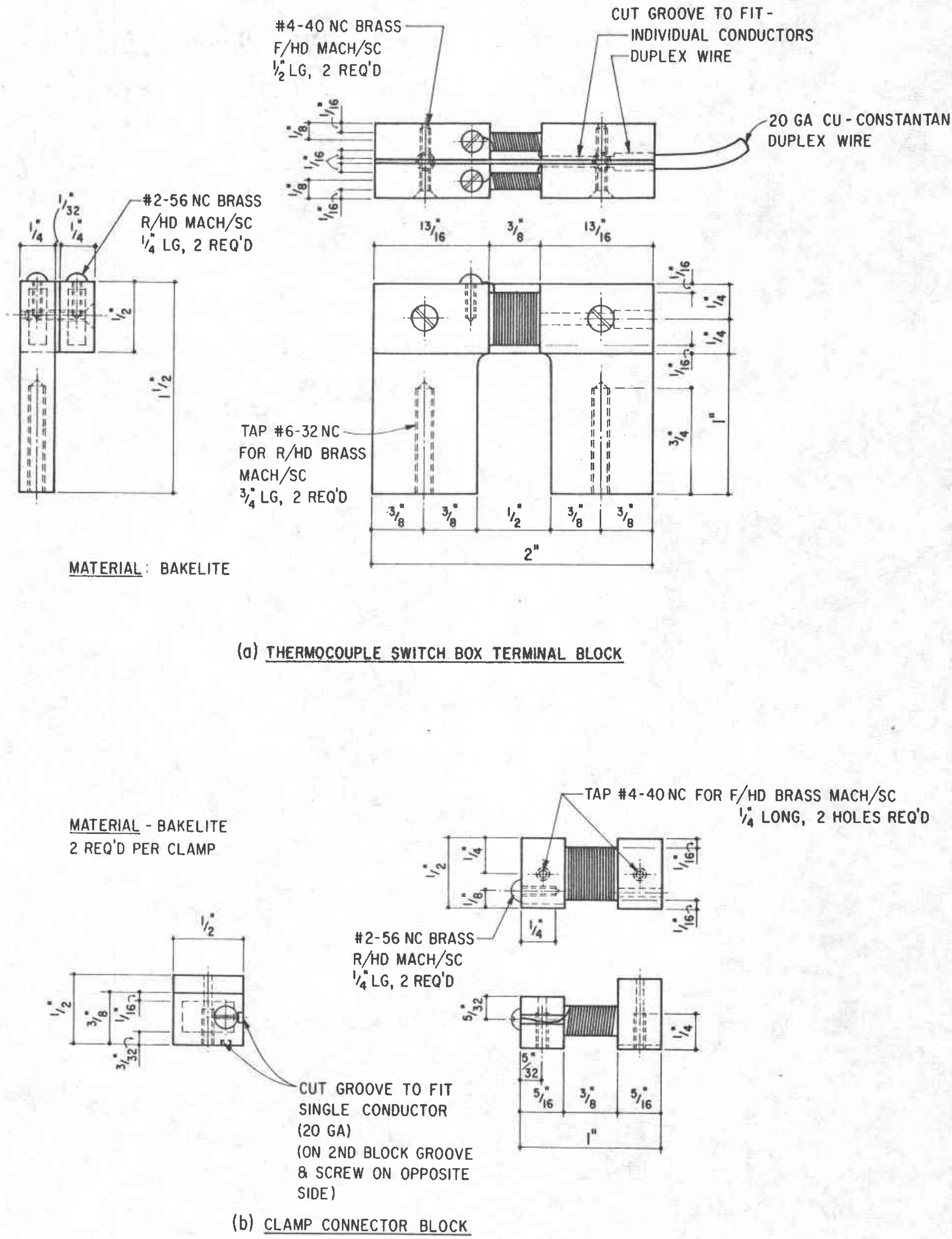


FIGURE 5 DETAILS OF THERMOCOUPLE WIRE WOUND CONNECTORS

BR 2952-5

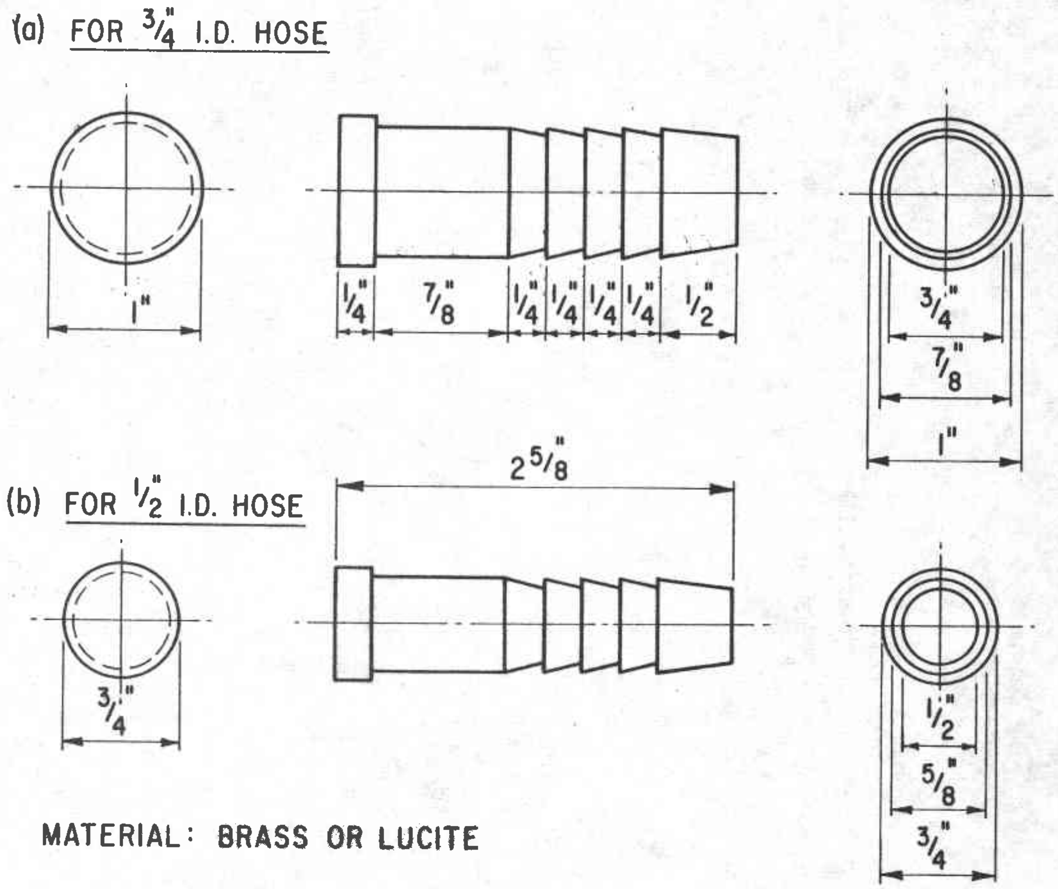


FIGURE 6
PLUG FOR THERMOCOUPLE CABLE

BR. 2952-4

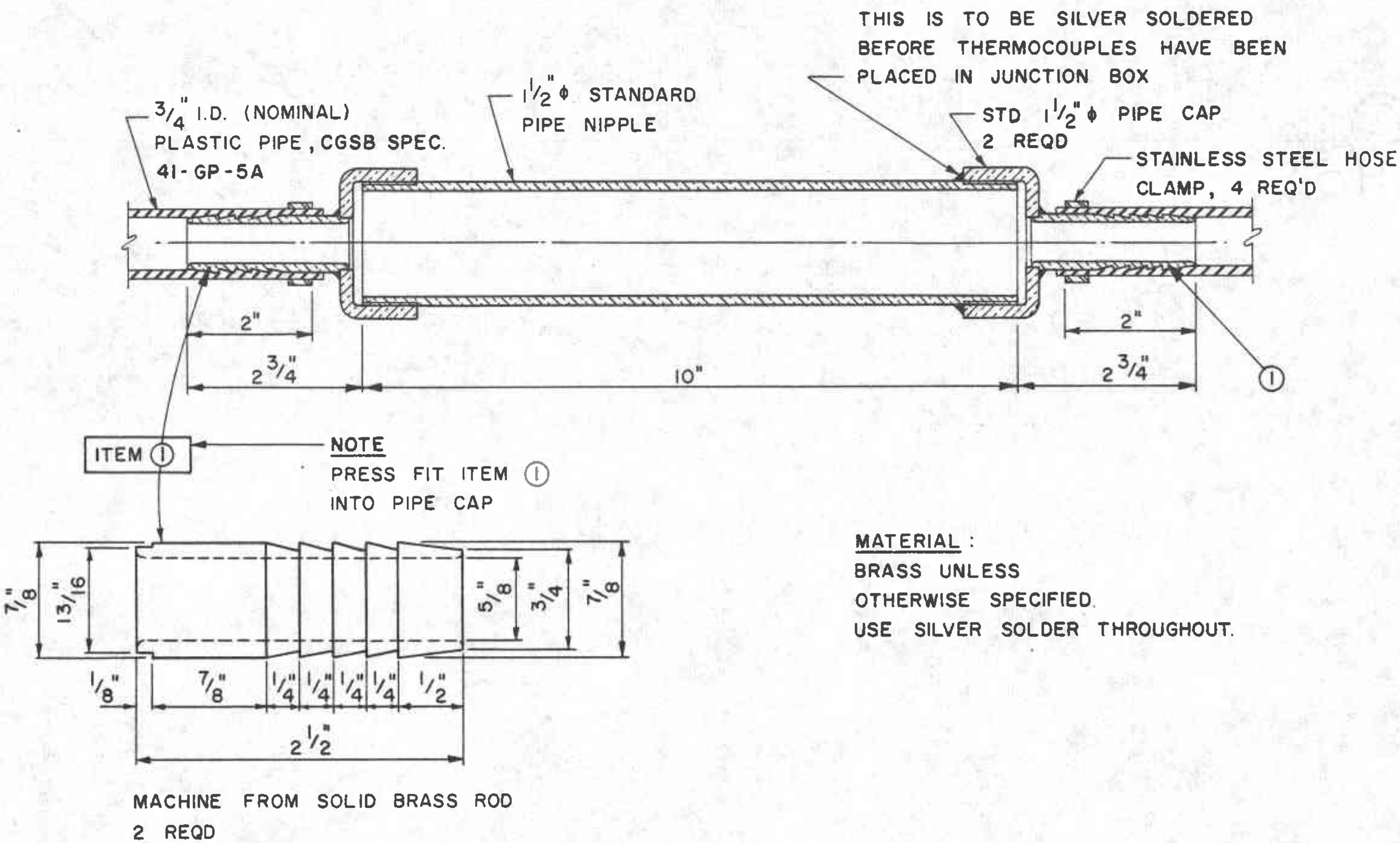
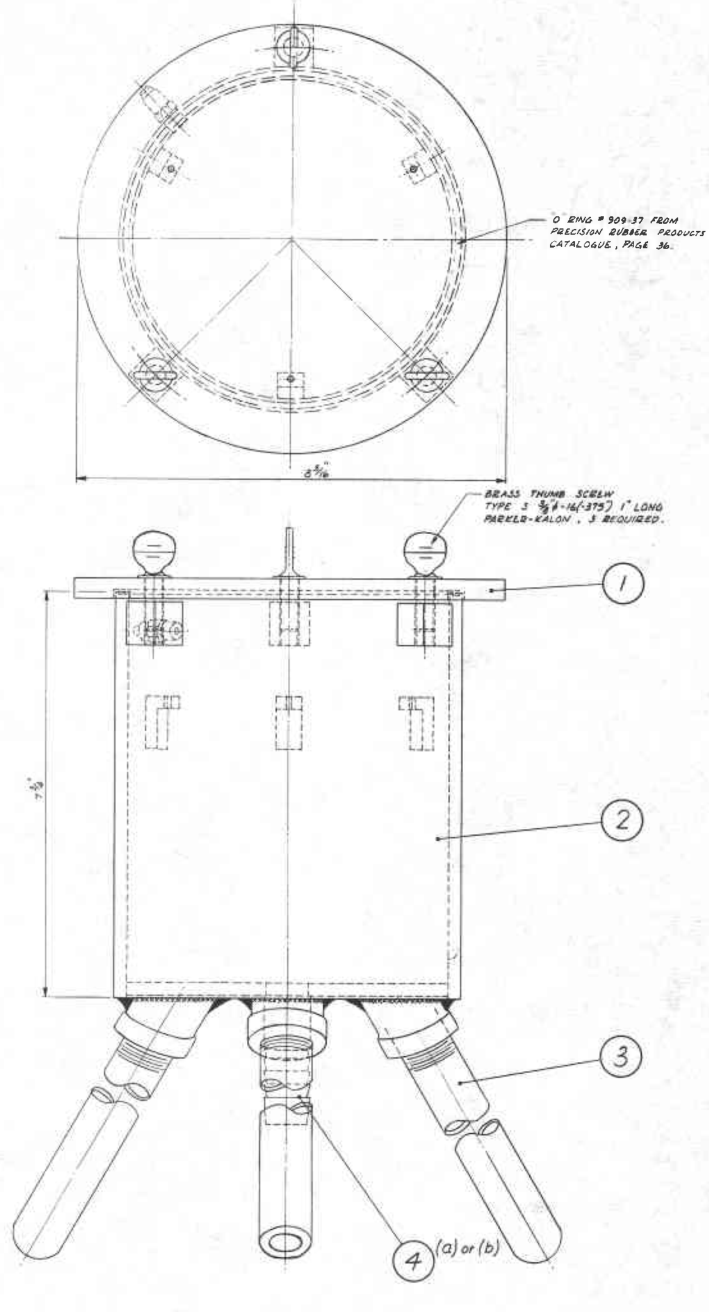


FIGURE 7
JUNCTION BOX FOR LONG LEAD THERMOCOUPLE INSTALLATION



ASSEMBLY

NOTE:

ALL EXTERIOR SURFACES TO BE CLEANED OF RUST & FOREIGN MATTER & GIVEN EITHER-

1. A BAKED ON EPOXY RESIN COATING OR
2. ONE COAT OF IRON OXIDE PRIMER-CGSB SPEC. 1-GP-81 & ONE COAT OF AUTOMOTIVE TYPE EXTERIOR ENAMEL

FIGURE 8

ASSEMBLY OF WEATHERPROOF THERMOCOUPLE SWITCH BOX

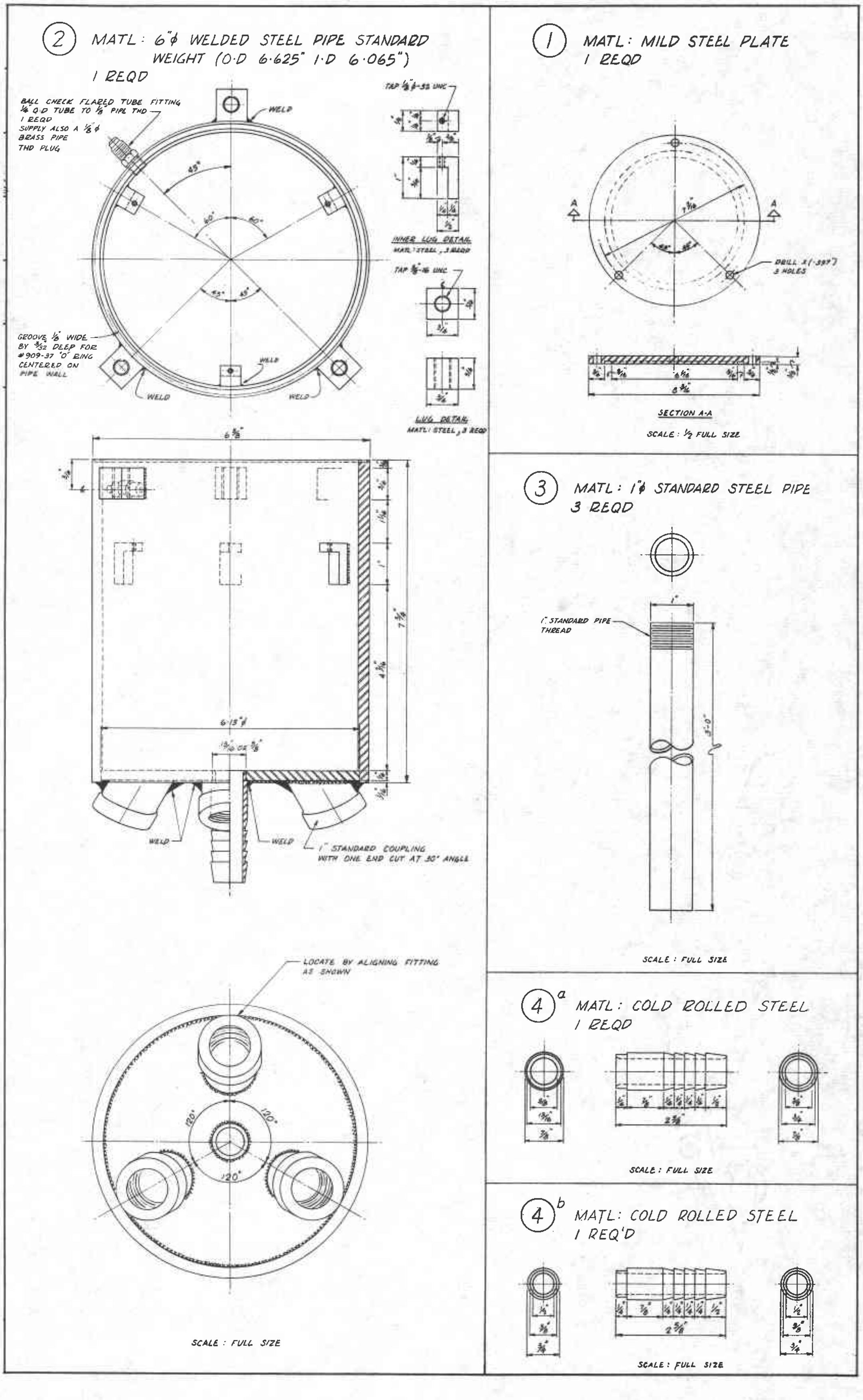
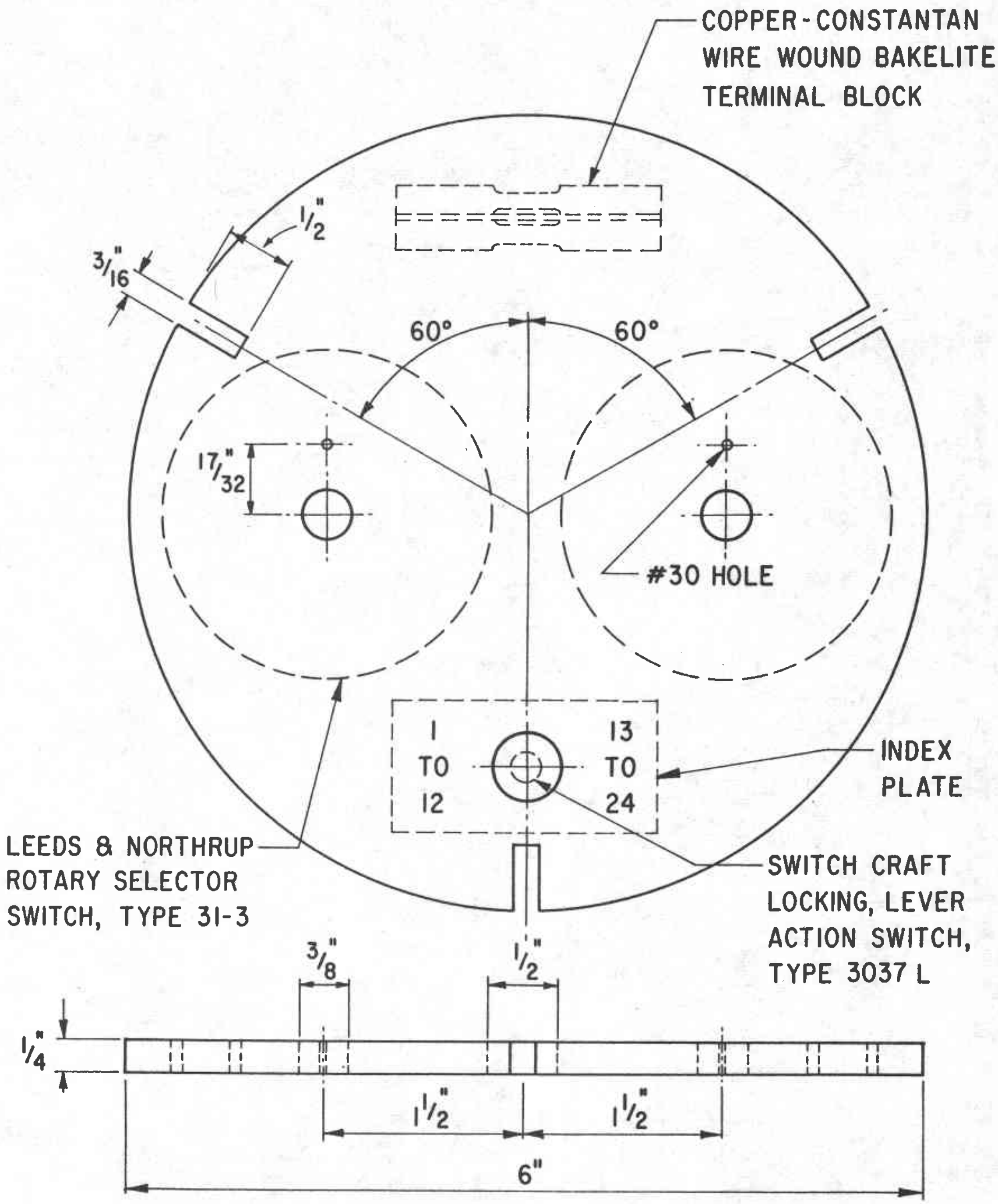


FIGURE 9
DETAILS OF WEATHERPROOF THERMOCOUPLE SWITCH BOX

BR 1719-2



MATERIAL: BAKELITE

FIGURE 10
SWITCH MOUNTING PLATE FOR THERMOCOUPLE SWITCH BOX

BR. 2952-5

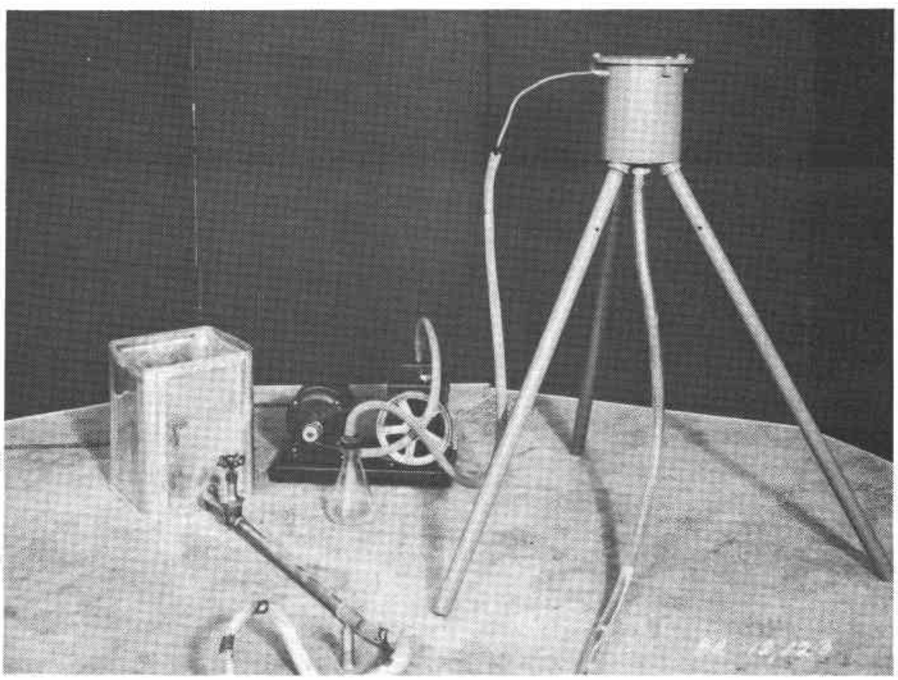


Figure 11   Equipment set-up for filling installation with oil