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MEASUREMENT OF TEMPERATURES AND

FROST PENETRATION IN PAVED OR UNPAVED

AREAS WITH THERMOCOUPLES

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MEASUREMENT OF
TEMPERATURES AND FROST PENETRATION
IN PAVED OR UNPAVED AREAS
WITH THERMOCOUPLES

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1. Background and Scope. Records of air, pavement and ground surface, and subsurface temperatures are needed from widely distributed geographical areas, in order to improve knowledge of and methods of estimating frost penetration and thaw conditions beneath various types of pavements and for various soil conditions. The results will be used in the design of pavements, utilities, building footings, and other construction. This report describes equipment, installation and a general observational program for obtaining pavement and ground temperature records and for measuring depth of frost penetration under either paved or unpaved areas. Two types of installations are described:

a. First Order (Regional) Stations. These installations provide continuous 24-hour records of temperatures above and below the surface and are intended to provide sufficient data for adequate comparison of actual with theoretical temperature conditions, and for study of the coefficient of surface temperature transfer. Because of their greater expense and the volume of detailed data provided by each, these stations are intended to be limited in number. They should be chosen to give a wide but selective coverage of geographical latitudes and of climatic conditions, for flexible and rigid pavement types and for general ground cover conditions.

b. Second Order Stations. These installations provide either weekly or twice weekly records of temperatures below the surface, and by correlation with the freezing point of soil moisture for the particular material, a record of the progressive freeze and thaw of the subgrade may be obtained. These stations are relatively inexpensive and are intended to be installed in greater number than the first order stations in order to give wide statistical coverage of geographical locations, climatic conditions, soil types, pavement types, ground cover conditions, etc.

The two most commonly used methods of predicting depths of frost penetration are based on computing the Air Freezing Index for the particular area and then either (1) estimating frost penetration using an empirical relationship between Air Freezing Index and frost penetration or (2) computing frost penetration using existing mathematical formulae, in which are introduced thermal characteristics of the affected materials such as pavement, base course and subgrade, and the Air Freezing Index*.

*The Air Freezing Index is the number of degree days between the highest and lowest points on the cumulative degree days-time curve for one freezing season. Each degree in any one day that the daily mean air temperature varies from 32°F. is called a degree day. The degree days are minus when the daily mean air temperature is below 32°F. and plus when above.

Method (1) is presently used by the Corps of Engineers to estimate frost penetration beneath pavements as shown in Figures 1 and 2. The method has its limitations as the relationship between Air Freezing Index and frost penetration shown on Figure 2 is based on observation at both rigid and flexible paved areas with non-frost susceptible bases of varying gradation, density and water content. Thus, in order to take proper account of the influence of these variables and to apply the method to diversified soil conditions it is necessary to resort to Method (2) or to obtain additional information on the relationship of Freezing Index and frost penetration for a wide range of conditions. The thermal equations used in Method (2) all include a correction factor applied to the Air Freezing Index to account for difference between air temperature and pavement or soil surface temperature. This correction factor known as the "surface transfer coefficient" varies with such items as degree of surface roughness, surface color, velocity of air, duration and intensity of sunshine, rainfall and evaporation.

Investigational data obtained at a First Order Station will permit evaluation of the "surface transfer coefficient" and will provide additional empirical data on the relationship between Air Freezing Index and frost penetration. A Second Order Station will also provide data on the latter relationship and indirectly will permit determination of a correction factor to apply to the Air Freezing Index in order for the predicted and observed depths of frost penetration to correspond.

2. Equipment.

a. General. The following principal items of equipment are required:

(1) First Order Station

(a) Sixteen (16) thermocouple assemblies
(b) One (1) sixteen point temperature measuring device and automatic recorder giving readings accurate to ± 0.6°F.
(c) 800 L. F. Duplex copper and constantan (1938 Calibration) thermocouple wire.
(d) 40 L. F. black iron pipe, 1 1/2 inch.
(e) 50 L. F. Polyvinyl Chloride plastic tubing, 0.535" I.D. and 0.030" wall thickness.

(2) Second Order Station

(a) Twelve (12) thermocouple assemblies
(b) One (1) twelve position selector switch and waterproof box.
(c) One (1) portable potentiometer giving readings accurate to ± 0.6°F.
(d) 600 L. F. Duplex copper and constantan (1938 Calibration) thermocouple wire.
(e) 40 L. F. black iron pipe 1 1/2-inch.
(f) 50 L. F. Polyvinyl Chloride plastic tubing, 0.535" I.D. and 0.030" wall thickness.

The lengths of thermocouple wire, pipe and plastic tubing given in above lists are approximate and should be modified to fit field conditions.

b. Thermocouple Assemblies. The principal advantages which lead to the selection of thermocouples for measuring subsurface temperatures are: (1) low volumetric heat capacity making them sensitive to sudden temperature changes, which is desirable near pavement surface, (2) ease of installation, (3) ability to determine subsurface temperatures with no interruption of traffic and (4) relatively low cost as compared to thermistors or resistance thermometers. Each thermocouple assembly should consist of a single pair of continuous (unspliced)* thermocouple wires with the pair of wires fused at one end, as shown in Figure 3, to form the temperature sensitive junction and with the wires fastened at the other end to the temperature measuring device or selector switch. Thermocouples may be made up in accordance with the procedure outlined in Figure 3 or may be purchased factory-assembled. The wire should consist of No. 20 gage duplex copper and constantan (1938 Calibration).

3. Location of Stations. The selection of locations for the temperature measuring installations should be made so as to encompass to as great a degree as possible the variables which are known to affect the penetration of freezing temperature. For pavements these variables are (1) air temperature, which may vary markedly within a region or state due to such factors as latitude, altitude, or proximity to the ocean or other large body of water, (2) exposure to sun i.e., north or south side of slope or shading of trees at roadside, (3) exposure to wind, (4) rainfall, (5) snowfall and snow cover, (6) type of pavement and surface texture and color, (7) type, thickness, density and water content of base course materials, (8) type, density and water content of subgrade soil, (9) relative frost susceptibility of subgrade soil, (10) freezing point of soil moisture, (11) depth to ground water table and (12) flow of ground water, i.e., side hill slopes. Using the above list of variables as a guide, areas for temperature installations should be selected to obtain data for what is considered to be the more typical conditions to permit wider application of the data. In addition, it may be desirable to investigate extreme conditions where they may be controlling.

It is highly desirable to locate the Second Order temperature measuring installations as near as practicable to an existing First Order weather station. This will make available reliable climatological data in addition to temperature and rainfall information which will prove invaluable in analysis of results. If it is not possible to locate in close proximity to an existing weather station, it will be necessary to install a recording thermograph in a louvred stand, five feet high of the type used by the U. S. Weather Bureau. This may, for example, be located at the edge of the highway. The stand should also include a glass bulb thermometer which can be read to the nearest 1/2°F. for use in periodically checking the accuracy of the thermograph. Since over-surface thermocouples are provided at First Order Stations, the use of a thermograph is not necessary at these stations, although it is considered desirable.

*If longer runs than 50 feet are necessary heavier gage lead wire may be spliced to the thermocouple wires to reduce resistance, but this should not be done unless absolutely necessary.

4. Installation of Electrical Temperature Measuring Equipment.

a. General. Thermocouple installation methods, as discussed in the following paragraphs, apply to both First Order (Regional) Stations and Second Order Stations with the exception that over-surface thermocouples will be omitted from the latter stations. Normally, when maximum depth of frost penetration is desired, installations should be near enough to the center of the pavements to minimize any effect of insulation from pavement shoulders normally not plowed free of snow during the winter months. At First Order Stations it is preferable to locate the thermocouples for measuring the air temperatures directly above the subsurface temperature installation. This precludes using the area for traffic and removal of snow by plowing, so that such stations will either be at specially constructed test areas or blocked off portions of pavements such as adjacent to highway offices.

b. Position of Thermocouples. Over-surface thermocouples at First Order Stations should be placed 1/8-inch, 1-inch, 6-inches and 5-feet above the pavement surface; these may be attached to a wooden stand, with the thermocouple extending at least 4 inches from the vertical member of the stand. If necessary to dampen short-period temperature fluctuations, each thermocouple junction above the pavement should be inclosed in a glass glycerin-filled vial approximately 1/4 inch in diameter and 1-1/2 inches long, the protective plastic covering being removed. Each thermocouple should be sheltered against the direct rays of the sun; however, air circulation in the vicinity of each thermocouple end should not be restricted. The wooden stand should also be so located that shadows are not cast over the area beneath which subsurface thermocouples are located. It is recommended that the first four subsurface thermocouples be placed at 1/8, 1, 3 and 6 inch depths. The remaining 8 of the 16 thermocouples should be evenly spaced below the 6-inch depth to at least one foot below the maximum estimated depth of frost penetration in the most severe winter. Average depths of frost penetration below paved areas kept free of snow and underlain by non-frost susceptible base materials may be estimated by use of Figures 1 and 2. Maximum depths of frost penetration range from about 12 to 15 inches greater than average values in areas where the Normal Freezing Index is greater than 500 degree-days and 15 to 18 inches as the Normal Freezing Index decreases from 500 to 200 degree-days. At areas where the Normal Freezing Index is less than 200 degree-days, the actual frost penetration may exceed the average penetration by as much as about 30 inches during extreme cold winters.

(1) New Construction - Thermocouples installed where new construction is under way should have the thermocouple measuring junctions placed at the desired level and the excavated material backfilled and compacted to the dry unit weight of the surrounding material. Density and water content determinations should be made at a minimum of three depths; continuous determinations are desirable. Full soil data should be obtained, including gradations, Atterberg Limits and position of ground water table, if any.

(2) Old Construction - Installation procedure for old construction is to excavate a test pit to the desired depth with density and

water content determinations being made during excavation at a minimum of three depths, with continuous determinations preferred. Again, full soil data should be recorded. Thermocouple measuring junctions should be inserted into undisturbed material in the side of the pit, preferably for a horizontal distance of approximately one foot. The soil should be in intimate contact with the covering of the thermocouple unit. Upon installation, the test pit should be backfilled carefully to the same density and condition that existed originally.

(3) Thermocouple Leads. - Thermocouple leads should be brought from the installation to the switch box at a minimum depth of approximately one foot below pavement surface. The thermocouple wires should be threaded loosely within plastic tubing to reduce the tendency toward breakage of the vertical portions of leads by frost heaving, while the plastic tubing (containing the thermocouple leads) should be threaded through a black iron pipe over its principal length of run to prevent damage from traffic. A diagram of a typical installation of thermocouples in a paved area is shown in Figure 4.

c. Selector Switch Box and/or Automatic Recorder. At Second Order Stations, a suitable weatherproof box should be constructed at the pavement shoulder to house the selector switch for thermocouple leads. This box should be located above the ground surface for accessibility and should be of rugged construction, well anchored into the ground. The use of a six-foot high security fence with barbed wire on angle brackets and locked gate around area is considered essential to protect equipment from vandalism.

The automatic recorder at First Order Stations will require a 115-volt A. C. power supply. It will be necessary to house the recorder in a heated building, or the recorder itself may be heated by a built-in heating unit and insulated.

5. Observational Program.

a. Temperature Records. - Air and subsurface temperature records at the First Order Stations should be obtained on approximately 30 minute cycles by thermocouples and recorder and generally continuous air temperatures should be obtained by thermograph at installations not in close proximity to U. S. Weather Bureau Station. Subsurface temperature records at Second Order Stations should be obtained once or twice weekly at the same hour on each day of readings. Thermograph record of air temperature should be obtained at all installations not in vicinity of Weather Bureau Station. Where Weather Bureau records are utilized an air temperature should be obtained by use of a bulb thermometer at the same time as subsurface temperature readings. Plots of depth versus temperature shall be made as shown in Figure 5. By interpolation, the depth of penetration of 30, 31, 32 and 35°F. temperatures are plotted for the season or year as shown on Figure 6.

b. Explorations. - During the period of maximum frost penetration, test pits shall be made to determine the depth of actual frost penetration, in the same materials and within 10 feet of the location of the thermocouples and at the same distance as the thermocouples from the shoulders. The depth of frost penetration in conjunction with the daily temperature readings will provide a check of the freezing temperature of the soil moisture for the material where the installation is situated. It is also desirable to check the temperature of the soil exactly at the bottom of the frozen layer by inserting a temperature-measuring element several inches into the side of the test pit with the aid of a probe. Moisture contents of both frozen and unfrozen material should be obtained over the depth of the test pit. Density measurements are also desirable.

At installations where the ground water table is located within 15 feet of the surface, ground water observation wells should be installed to approximately that depth with filter material placed around the bottom of the well. It is essential that the well be sealed from infiltration of water either at the pavement surface or from the base course. Readings of ground water level should be obtained prior to and during the freezing period and during the frost melting period at approximately weekly intervals. Where the depth to ground water is less than the depth of frost penetration, freezing of water in the observation well will prevent reading throughout the freezing period.

c. Laboratory Tests for Freezing Point of Soil Moisture. - Previous laboratory studies* have indicated that the freezing point of soil moisture is generally below 32°F. with the depression in the freezing point being greatest in the finer-grained clay soils. For a given soil the freezing point decreases with decrease in water content. Most investigators attribute the depressed freezing point of soil moisture to (1) soluble salts in the pore water and (2) the adsorption forces by which the water is held by the soil grains. Pore water at the centers of the interstices, at greater distance from the grains, is considered to freeze at a higher temperature than the water closer to the grains, with the adsorbed or "solid" water layer held tightly on the surface of fine soil grain having a freezing point considerably below 32°F.

The freezing point of soil moisture can be determined in the laboratory by freezing a small sample of soil of known density and water content and observing the temperature change at the center of the specimen by means of a thermocouple. #30 or #24 thermocouple wire should be used in order to assure sufficiently rapid response. Readings should be accurate to 0.1°F. A precision potentiometer similar to a Leeds and Northrup, Type K-2, can be used, taking successive readings as the specimen is slowly cooled. The temperature continues to drop gradually as 32°F. is passed, supercooling occurring. However, when the water in the voids starts to crystallize there is an abrupt rise in temperature, followed by a short period of time when the

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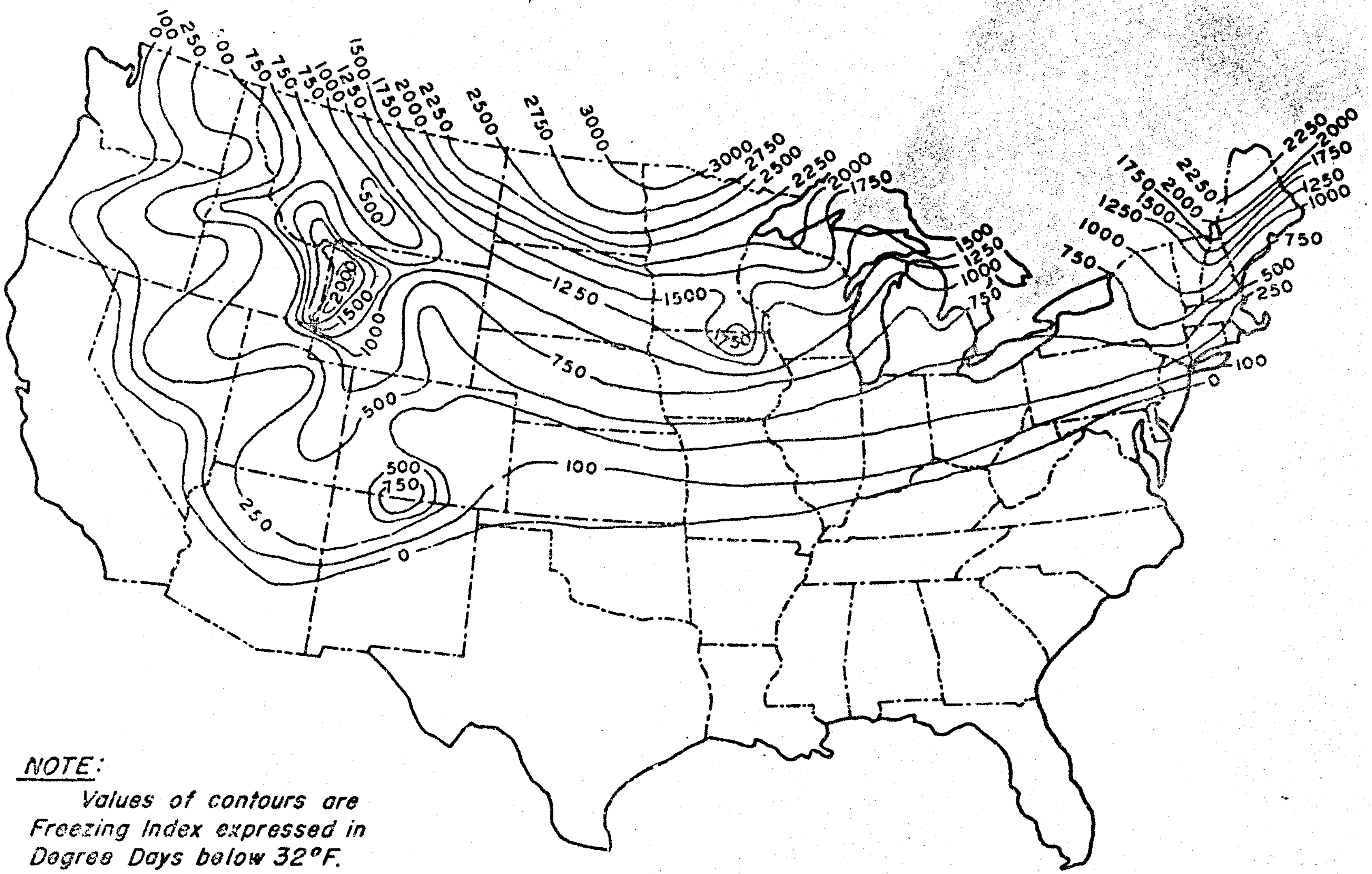
* For summary of results see Highway Research Board Special Report 1, Frost Action in Roads and Airfields, 1952

temperature remains relatively constant. This period of little temperature change is attributed to the release of latent heat from the soil moisture. This constant temperature is the freezing point of a large percentage of the moisture in the soil.

In comprehensive soil temperature studies it is desirable to perform laboratory freezing point tests for correlation with the thermocouple and test pit observations. However, if attempted, the necessity for thorough analysis of the effects of such factors as moisture content, density, soil mineral characteristics, and dynamics of the freezing process should be anticipated, for proper evaluation.



NOTE:

Values of contours are Freezing Index expressed in Degree Days below 32°F.

FREEZING INDEX DATA INFLUENCING FROST ACTION

FIGURE 1

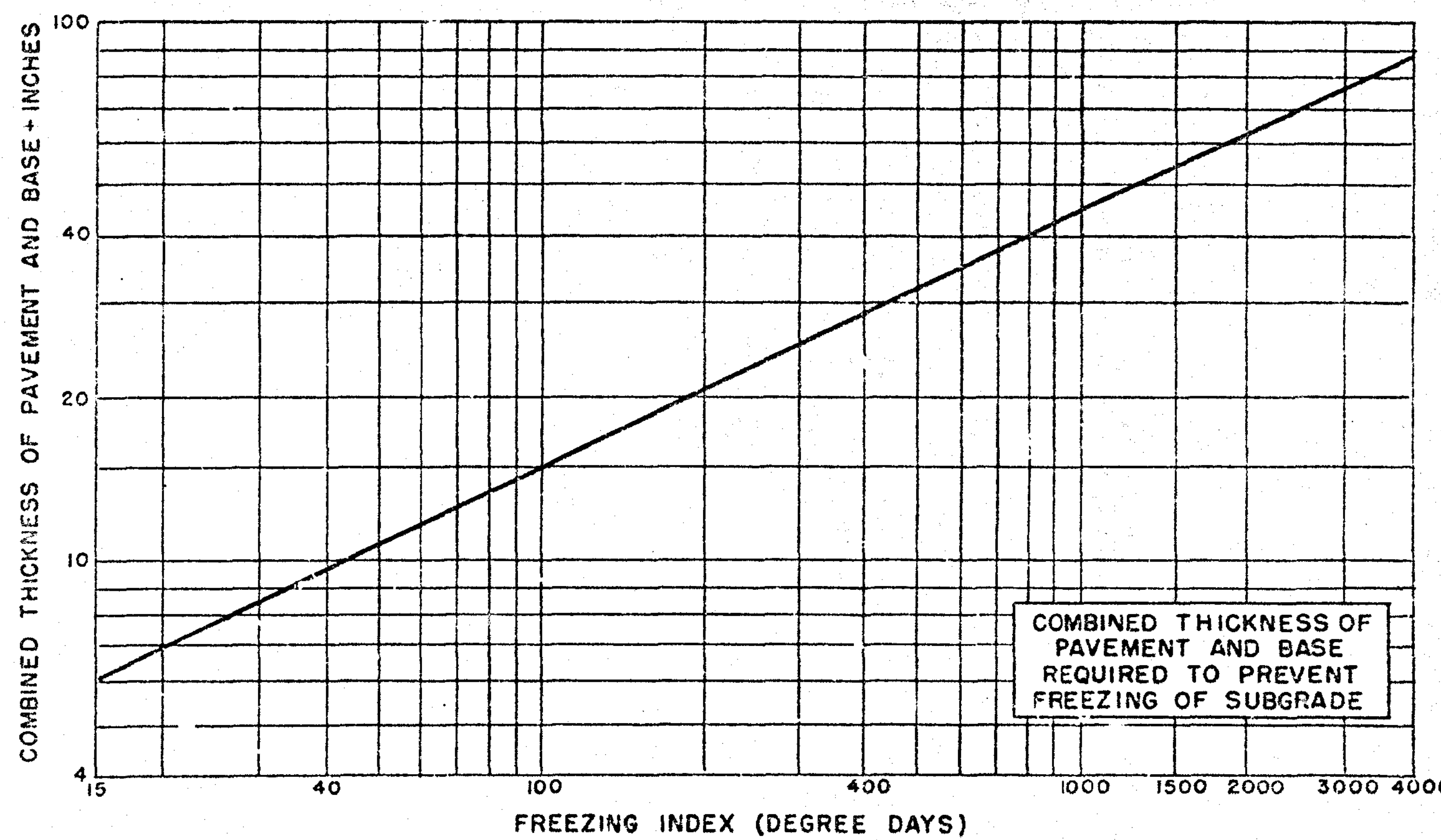
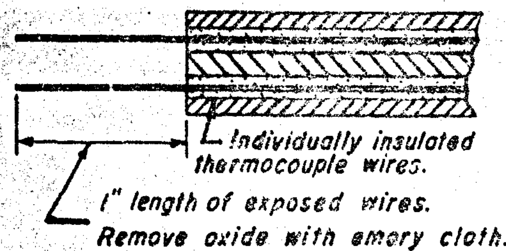
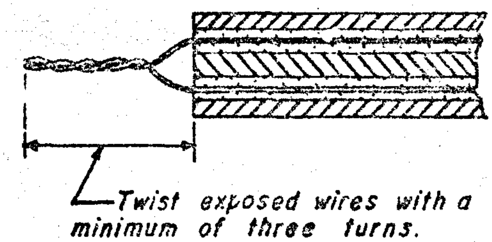

COMBINED THICKNESS OF PAVEMENT AND BASE - INCHES
100
40
20
10
4
15
40
100
400
1000
1500
2000
3000
4000
FREEZING INDEX (DEGREE DAYS)
COMBINED THICKNESS OF PAVEMENT AND BASE REQUIRED TO PREVENT FREEZING OF SUBGRADE

FIGURE 2

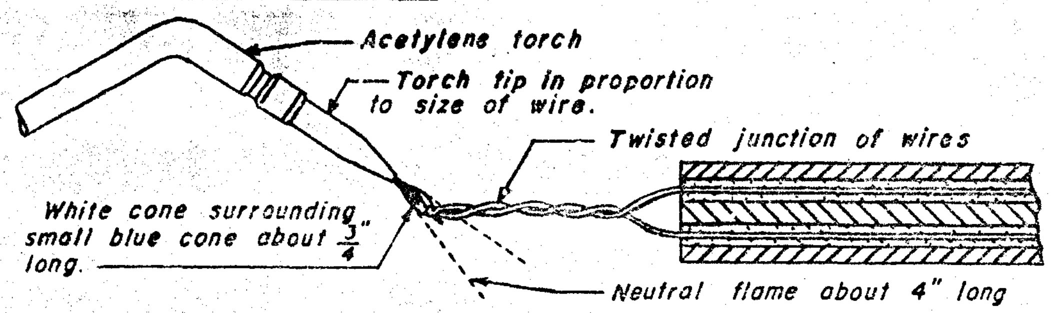
STEP 1 - CUTTING WIRE



STEP 2 - TWISTING WIRE

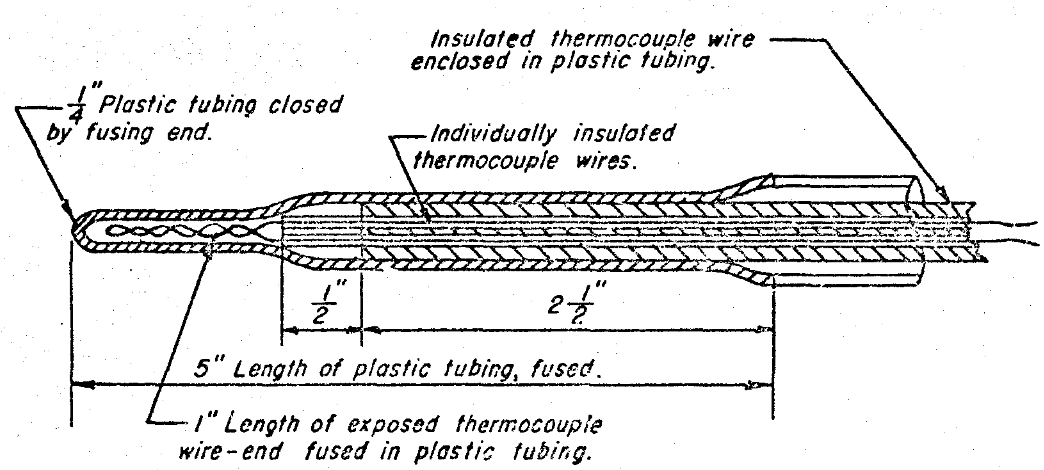


STEP 3 - WELDING WIRE



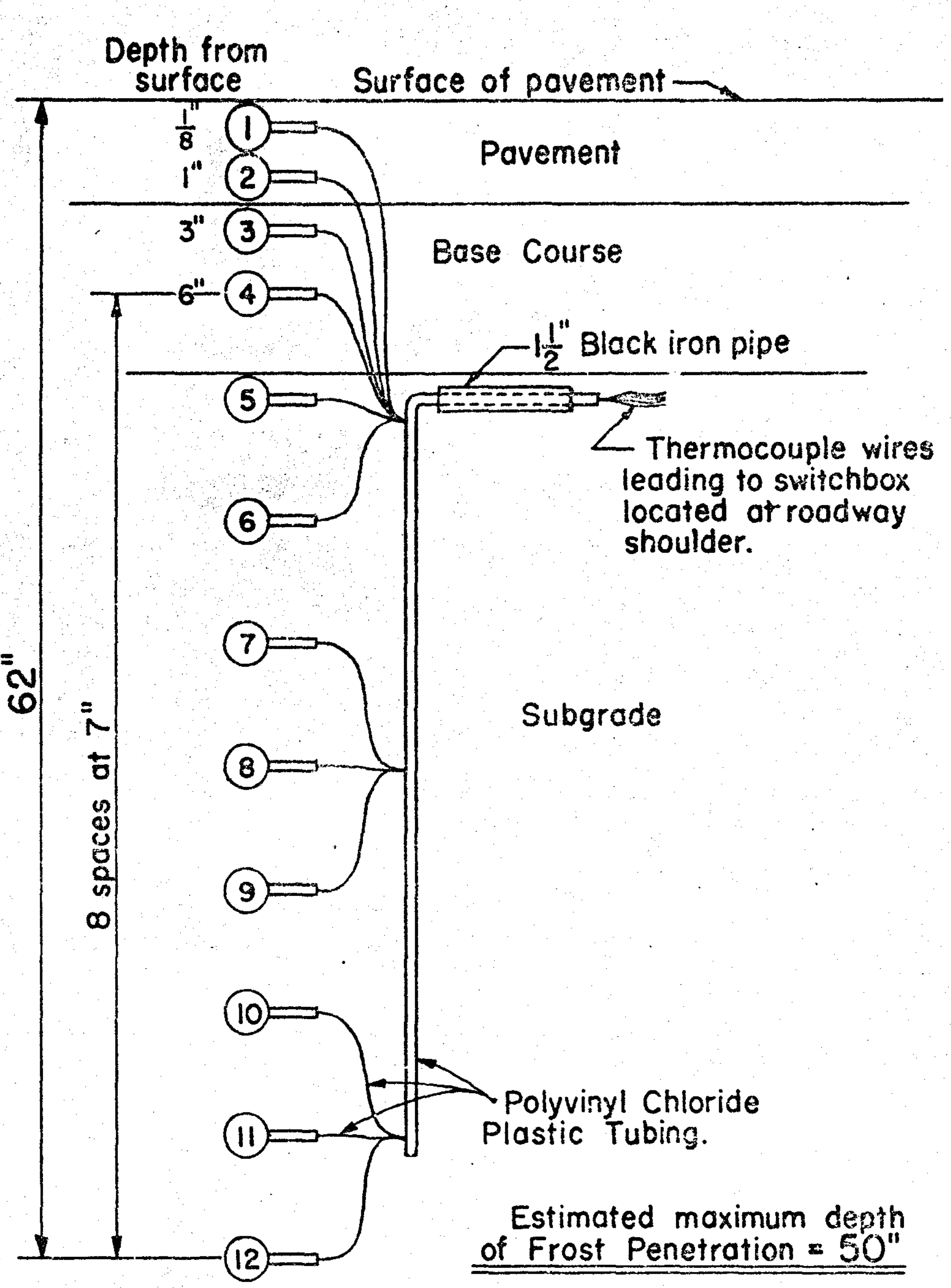
PROCEDURE: Hold twisted junction of wires in flame at tip of white cone until both wires are bright red, then dip in fluxing mixture consisting of 6 parts of fluorspar to 1 of borax. (Borax may be used alone) Place in flame until both wires reach melting point at same time, then revolve weld in flame until both metals flow together forming a ball weld at the tip. Use a moderately hot flame to avoid burning. The junction may also be made with silver solder.

STEP 4 - ENCASING WELDED WIRE



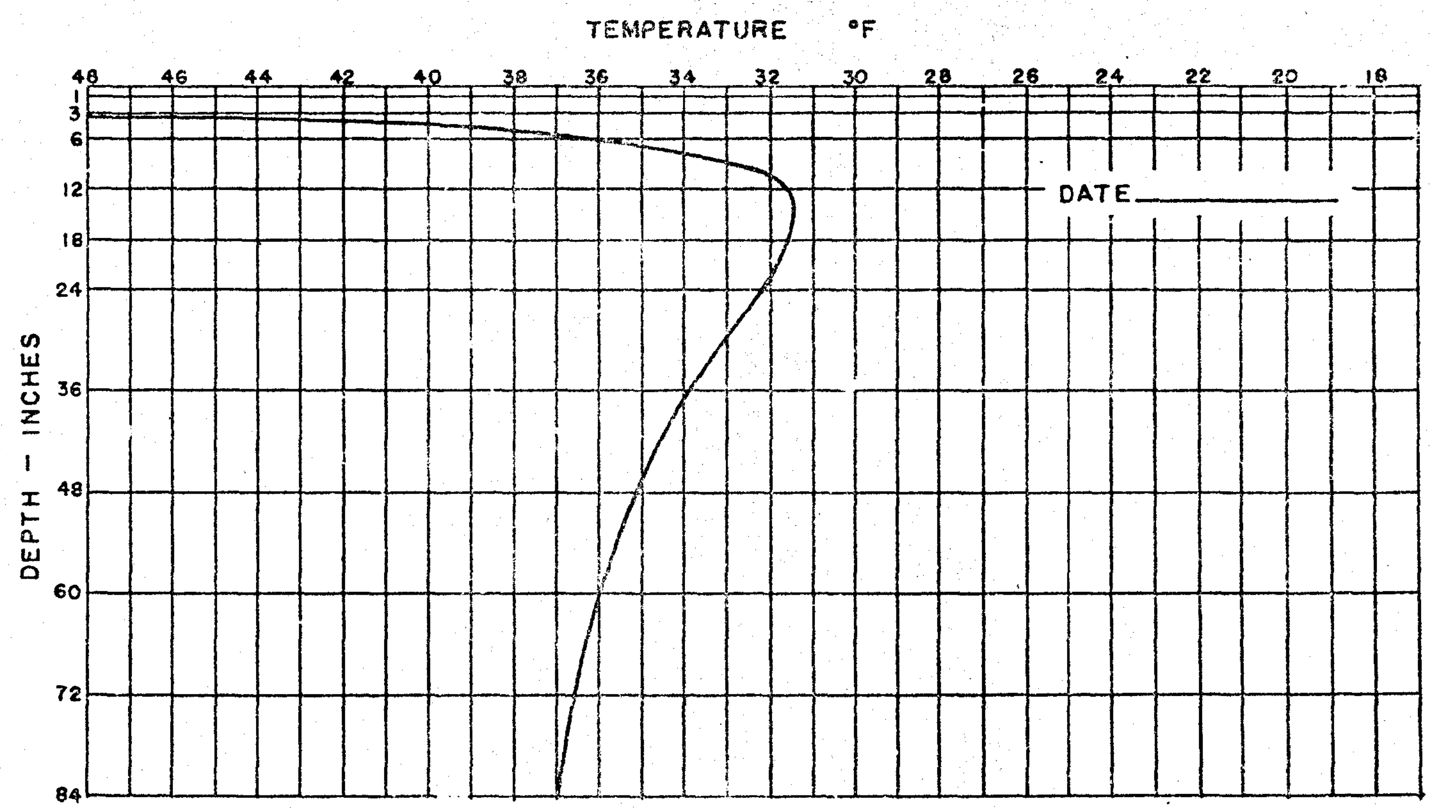
THERMOCOUPLE CONSTRUCTION

FIGURE 3



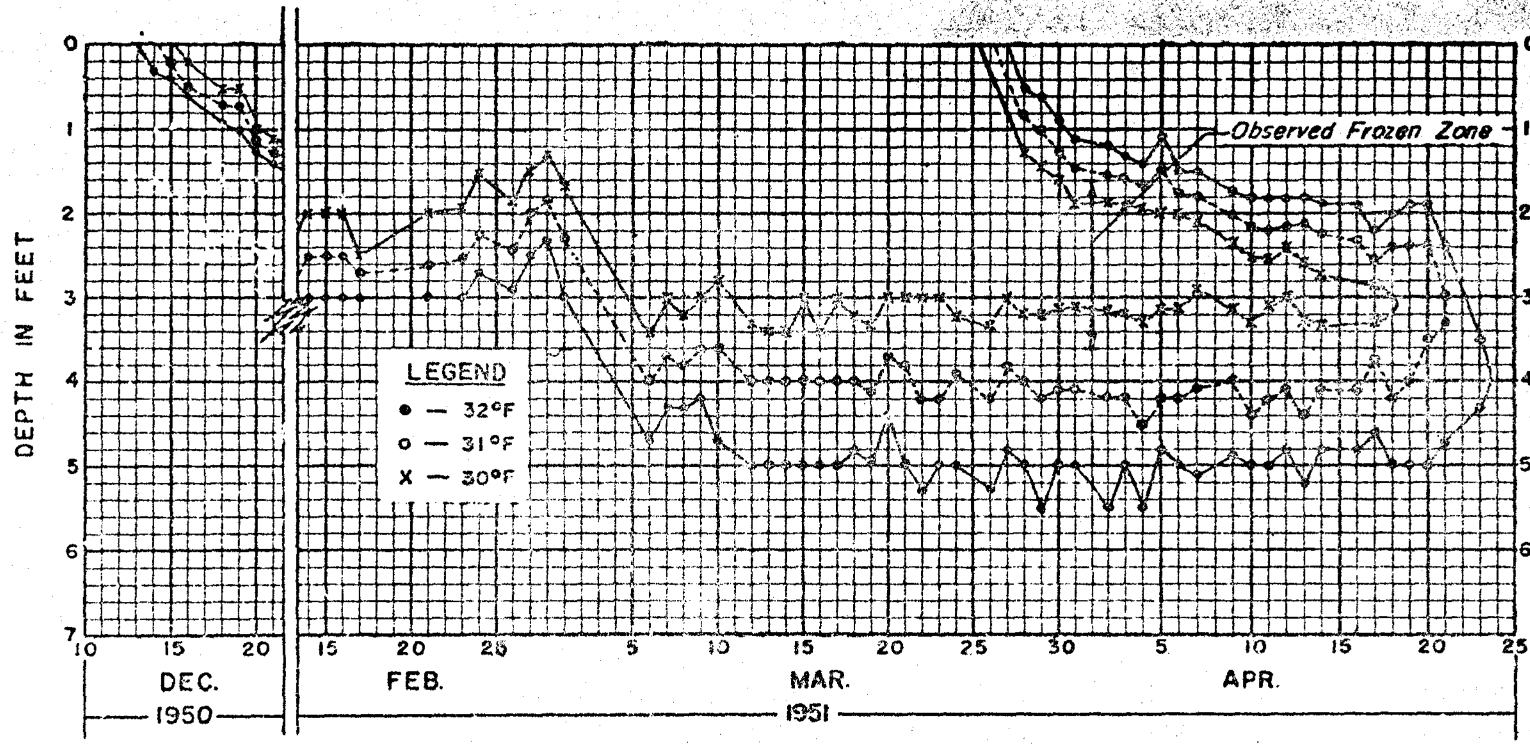
Typical Installation of Subsurface Thermocouples in Paved Area.......

FIGURE 4



TYPICAL DAILY PLOT
of
SUBSURFACE TEMPERATURES vs. DEPTH

FIGURE 5



TYPICAL PLOT
of
TEMPERATURE PENETRATION VS TIME

FIGURE 6

APPENDIX A

Equipment Notes

1. Thermocouples. - Thermocouples are thermo-electrical thermometers consisting of two wires of different metals or alloys joined at each end to form an electric circuit; the two junctions of dissimilar wire constitute a thermocouple. When both junctions are at the same temperature no difference in potential exists in the circuit, but when the temperature is different at both junctions, a potential difference is generated in the circuit which is nearly directly proportional to this temperature difference. Thus, the thermocouple provides the thermo-electric voltage which, when measured with a suitably calibrated potentiometer, can then be translated into temperature units. The temperature-indicating potentiometer is calibrated for use with a particular set of metals or alloys, a definite reference junction temperature and a particular temperature range. The thermocouple junction that is maintained at a particular reference temperature, usually 0 Degrees Centigrade, is designated as the cold or reference junction; the thermocouple junction at the unknown temperature which is to be measured is designated as the measuring junction. Usually, any number of measuring junctions are arranged in an assembly, with one or more reference or cold junctions forming couples with the several measuring junctions which are connected to the temperature-indicating potentiometer in series through selector switches.

The selected gage of the thermocouple wire depends on the type of installation and the rate of change of temperature to be measured. Where the distance from the thermocouple junction and the potentiometer is 50 feet or somewhat greater, #20 gage wire is generally specified because of lower internal resistance. Lighter wire is preferable where rapid changes in temperature are to be recorded; therefore, there is some advantage in using #24 gage wire directly beneath the pavement surface. Advantages of the heavier gage wire are: (1) ease with which the thermocouple junctions can be made and (2) greater strength. The latter is obtained, however, with some loss in flexibility.

The temperature measuring junction, made up as shown in Figure 3 of the basic specification, is protected against corrosion by hermetically sealing the junction for a distance of approximately five inches in 1/4-inch transparent plastic tubing having a wall thickness of 1/16-inch and a total length of about 2 1/2 feet. This seal is made by softening the plastic tubing in a glycerin bath at a temperature of approximately 300°F., inserting the junction into the tube and then compressing the tube around the junction for the length of five inches until the plastic has cooled. Caution should be exercised not to injure the junction or wires by excessive pressure. From the installation point to the switch box, the thermocouple group is loosely encased in 0.535-inch I.D. Polyvinyl Chloride plastic tubing having an 0.030-inch wall thickness (similar or equal to plastic tubing having the trade name of "Rextrude"). Where installed under traffic areas, the latter is also enclosed in a 1 1/2-inch black iron pipe from the switch box to the temperature measuring location. This arrangement protects the thermocouple wires from injury due to vehicle traffic, permits the wires to yield during heave without rupturing, and produces a watertight unit. The emittance point of each individual junction unit from the "Rextrude" is also sealed with asphalt-asbestos mastic and the joint covered with waterproof electrical tape.

2. Thermocouple Metals or Alloys. - The various types of commercial thermocouples are constructed from a few basic metals or alloys, several combinations of which are: Copper-Constantan,* Chromel-Alumel, Chromel-Constantan, Platinum-Platinum and Rhodium. Copper-Constantan is considered the best combination because (a) the range of temperature that can be measured covers the required range for normal air and subsurface temperature measurements, (b) due to its having a shorter range than other combinations, greater accuracy may be obtained, and (c) the cost is relatively low.

3. Potentiometers. - To measure the difference in potential of the thermocouples and to translate the voltage into temperature, a calibrated potentiometer is used. Several types of instruments are available from various manufacturers, the choice being dependent on the type of installation. Regardless of type chosen, the following requirements are recommended: (1) A total range of 4 mv. or 200°F., suggested range (-) 50 to (+) 150°F., and (2) the instrument calibrated for copper-constantan thermocouples. Various types of equipment are listed below:

a. Portable Potentiometer. - Portable potentiometers are manually-operated, self-contained units with galvanometer and standard dry batteries as a power source with a built-in automatic compensating reference junction which eliminates the need of a cold junction and with direct reading scales calibrated in either millivolts or temperature degrees. Use of this equipment is simple, and the accuracy is ±0.6°F. The precautions necessary in the use of this type of potentiometer are that the standard cell contained in the unit must be protected from freezing and that the extent of leads from the installation to the instrument is usually limited to approximately 50 feet. Somewhat greater lengths may be permissible by the use of heavy gage lead wire to which a short length of finer wire may be spliced with the thermocouple junction made in the finer wire. This potentiometer is recommended for use at Second Order Stations.

b. Recording Potentiometers. - More elaborate units are available for permanent or semi-permanent installation. These units require a 115 volt A.C. power supply and have to be sheltered in a heated building to protect the standard cell. Usually units of this type function by means of electronic systems. These instruments are usually direct reading, may have various numbers of manually operated switches for any number of thermocouples, and may also be automatic recording, taking continuous readings. The accuracy of this instrument is ± 0.6°F. Advantages of this type are simple adjustment, rapid and direct reading, and lengths of leads from thermocouple to potentiometer have no effect. The disadvantages are high initial cost and no gain in accuracy. This potentiometer is recommended for use at First Order Stations.

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*Constantan is an alloy consisting of 55% copper and 45% nickel.

c. Precision Potentiometers. - A precision potentiometer is a laboratory instrument. Installations of this type, in addition to the potentiometer, require a standard cell, a two-volt storage battery, galvanometer, switch box, and 115-volt alternating current supply. Equipment must be used in relatively dust-free and vibration-free heated quarters. This instrument is not recommended for field installations except where instrument is to be kept in a field office with an adjacent test section.

d. Temperature Measuring Units.

(1) First Order Stations. Temperature measuring units for the First Order Stations should be of the stationary type which operate on a 115-volt A.C. power supply and automatically provide a continuous temperature record. These units usually consist of a potentiometer, balancing unit consisting of a convertor and amplifier which actuates a two-phase balancing motor, and a recording unit. These instruments are made to record various numbers of readings depending on the design of the unit. Sixteen point recorders are recommended for First Order Stations. Frequency of readings and chart speeds are variable depending on the manufacturer's design. Reference junctions may be of the automatic compensating type, built into the instrument, or a constant temperature bath may be used. Use of a constant temperature bath for a reference is not recommended due to the difficulties in maintaining a constant temperature over long periods of time. Installation of these temperature-measuring units is quite simple and once in operation the only maintenance required is changing of charts, replacement of dry cell batteries and periodic lubrication. Precautionary steps must be taken to prevent the standard cell in the potentiometer circuit from freezing. This may be done by housing the instrument within a heated shelter or by installation of a heating unit within the instrument itself.

(2) Second Order Stations. Temperature measuring instruments for Second Order Stations should be battery-operated portable potentiometers which are self contained units requiring an operator to obtain the temperature measurements. They may be moved from one location to another to investigate temperatures at several stations. Usually automatic reference junction compensation is built into the instrument. The dial for reading the temperatures is calibrated in temperature degrees. For operation, the operator opens the lid, unclamps the galvanometer, sets its zero, standardizes the circuit and connects the leads. To obtain a reading he turns the potentiometer knob until the galvanometer point comes to zero and then reads the temperature scale. The only maintenance is occasional cleaning and dry cell replacement. As in the automatic or stationary units, this instrument also uses a standard cell in the circuit which must be protected from freezing. This protection may be accomplished by using the instrument in heated quarters such as a heated vehicle or by connecting the standard cell remotely or by the operator carrying it on his person.

4. Switches. - Switches may be obtained from manufacturers of potentiometers and should meet the following requirements:

(1) Enclosed contact surfaces.
(2) Contact resistance of 0.001 ohms or less.
(3) Thermal electromotive force less than 1.0 microvolts.
(4) Maximum conductance less than 0.03 microhenry.
(5) Capacitance between segments less than 0.5 micro-micro farads

When installation is to be made out-of-doors, the switch should be installed in a weatherproof box for protection from dust, dirt and moisture, and the contact surfaces should be cleaned frequently.

5. Equipment Suppliers. - Electrical temperature-measuring equipment and information pertaining thereto may be obtained from the following manufacturers:

a. Leeds and Northrup Co.
4907 Stenton Avenue
Philadelphia 44, Penna.

b. General Electric Corp.
Schenectady, New York

c. Wheelco Instrument Co.
Harrison and Peoria Streets
Chicago 7, Illinois

d. Minneapolis-Honeywell Regulator Co.
Brown Instruments Division
Wayne and Roberts Avenues
Philadelphia 44, Penna.

e. The Foxboro Company
Foxboro, Massachusetts

f. Tagliabue Instruments Division
Weston Electrical Instruments Corp.
614 Frelinghuysen Avenue
Newark 5, New Jersey

g. Rubicon Company
Ridge Avenue at 35th Street
Philadelphia 32, Penna.

6. Approximate Cost. - The cost of electrical temperature measuring equipment for the two proposed stations as given below is approximate only. The actual cost would depend upon the particular type of equipment selected and the supplier.

FIRST ORDER (REGIONAL) STATIONS

a. Special sixteen (16) point temperature measuring device and automatic recorder. S/E Leeds and Northrup Speedomax, Catalog 60366, Special 16-point Model S, Speedomax type G, indicating temperature recorder, temperature range - 30° to +170° or -1.2 to 3.2 mv. $1,300.

b. 800 L.F. No. 20 gage, duplex copper and constantan (1938 Calibration), enamel and asbestos wrap, on each wire, Neoprene over-all. 112.

c. 40 L.F. Black iron pipe, 1 1/2-inch. 48.

d. 50 L.F. Polyvinyl Chloride plastic tubing, 0.535" I.D. x 0.030" wall 2.

e. 40 L.F. Polyvinyl Chloride plastic tubing, 1/4" O.D. x 1/16" wall 2.

Total $1,464.

SECOND ORDER STATIONS

a. Single Range Portable Potentiometer S/E Leeds and Northrup 8663 Special Temperature range -30 to +170°F. or -1.2 to + 3.2 mv. 280.

b. Selector Switch, Double-pole, 12 position S/E Leeds and Northrup Switch No. 31-3-0-2. 15.

c. 600 L.F. No. 20 gage, duplex copper and constantan (1938 Calibration), enamel and asbestos wrap on each wire, Neoprene over-all. 84.

d. 40 L.F. Black iron pipe, 1 1/2-inch. 48.

e. 50 L.F. Polyvinyl Chloride plastic tubing 0.535" I.D. x 0.030" wall. 2.

f. 30 L.F. Polyvinyl Chloride plastic tubing, 1/4" O.D. x 1/16" wall. 2.

Total $431.

Note: The 1946 price of a Friez #505 thermograph was $110 which generally would be in addition to above listed items.

END

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