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NEW ENGLAND DIVISION
CORPS OF ENGINEERS, WAR DEPARTMENT
BOSTON, MASSACHUSETTS

REPORT
ON
FROST INVESTIGATION
1944 - 1945

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1. SYNOPSIS

The frost investigation program, including studies at ten airfields, was authorized by the Chief of Engineers by letter to the Division Engineer, New England Division dated 7 July 1944, subject: "Frost Investigation". Frost investigation at five additional airfields in the Missouri River Division was authorized by the Chief of Engineers in 1st Indorsement to letter dated 24 August 1944, from the Division Engineer, Missouri River Division, to the Chief of Engineers, subject: "Frost Investigation". The combined investigations included studies at 15 airfields with varying subsurface conditions located in the northern part of the United States. The purpose of the investigation was to establish criteria and methods for the design of airfield pavements where conditions are conducive to frost action, both in theaters of operation and in the United States, and to establish criteria and methods for evaluation of airfield pavements where subgrade soils or base courses experience frost action. Extensive field and laboratory tests were conducted together with theoretical and mathematical studies. At three of the airfields traffic tests with wheel loads ranging from 7,000 to 60,000 lbs. were conducted. The results of frost investigations made at Dow Field, Bangor, Maine, in 1943-1944 for the Pavement Evaluation Program, including results of traffic tests, have been utilized in this investigation. Based upon the studies performed, a method of design of flexible and rigid pavements over subgrades susceptible to frost action has been included in the Ad Interim Engineering Manual as Part XII, Chapter 4, entitled "Frost Conditions, Airfield Pavement Design". The design is applicable for evaluation of airfield pavements where subgrade soils or base courses experience frost action.

2. INTRODUCTION

a. AUTHORIZATION. The frost investigation program was authorized by the Chief of Engineers by letter to the Division Engineer, New England Division, dated 7 July 1944, subject "Frost Investigation". The New England Division was assigned the responsibility for organizing the program at ten airfields, obtaining the cooperation of the Missouri

River Division and Great Lakes Division in the program, and analyzing and reporting on all the investigations. A Frost Effects Laboratory was established in the New England Division by direction of the Chief of Engineers, as stated in circular letter No. 3221, dated 11 August 1944, with the immediate purpose of carrying out the frost investigation program and such other frost investigations as may be requested by the Chief of Engineers and the various Divisions and Districts. In addition to this authorization an investigation of frost action at five airfields within the Missouri River Division was authorized by the Chief of Engineers in the 1st Indorsement to the letter dated 24 August 1944, from the Division Engineer, Missouri River Division, to the Chief of Engineers, subject: "Frost Investigation".

b. PURPOSE. The purpose of the frost investigation was to provide test data and analyses to:

(1) Establish criteria and methods for the design of airfield pavements where conditions are conducive to frost action, both in theaters of operation and in the United States.

(2) Establish criteria and methods for the evaluation of airfields pavements where subgrade soils or base courses experience frost action.

The purpose of this report is to unify and summarize the results of observations and tests made at various airfields in the U.S. and to present design and evaluation criteria resulting from a study of the accumulated data.

c. SCOPE. This report presents a summary of the studies, the observations and tests made, and the conclusions based upon these data including Part XII, Chapter 4, Ad Interim Engineering Manual. The work presented herein includes the data obtained in the investigations conducted in 1944 and 1945. The results of the investigations made at Dow Field in 1943-1944 for the Pavement Evaluation Program and reported in "Report on Frost Investigations and Pavement Behavior Tests, Dow Field, Bangor, Maine", dated January 1946, are summarized with the data obtained for this investigation. The program for 1944-1945 consisted of the following phases:

(1) A review and analysis of previous investigations of frost action.

(2) The performance of laboratory controlled tests to determine coefficients of heat transfer of various soils.

(3) The observation and testing of the effect of frost action during the winter of 1943-1944 and 1944-1945 under paved and turfed airfield areas.

(4) The review and analysis of the results of investigations performed.

The laboratory controlled tests consisted of an investigation of the thermal conductivity of unfrozen cohesionless soils at different densities and water contents under controlled temperatures to assist in the prediction of depth of frost penetration into cohesionless soils for design purposes.

The observation and testing of the effect of frost action were studied at 15 airfields located in northern United States as shown in map on Plate 1. A total of 32 test areas were investigated at these airfields. Seventeen test areas had flexible pavements and eleven test areas had rigid pavements. Four turfed areas were investigated adjacent to paved test areas. The individual test areas were selected to encompass as closely as possible the full range of the following variables influencing frost action:

(1) Air temperature ranging from mild to extreme in severity.

(2) Ground water table varying from an elevation near the surface of the pavement to an elevation greater than 90 feet below the pavement surface.

(3) Precipitation prior to freezing period varying from light to relatively moderate.

(4) Base and subgrade materials varying in water content from relatively dry to saturated.

(5) Subgrades varying from a plastic fat clay to a nonplastic silty gravelly sand.

(6) Base materials varying from a plastic sand-clay-gravel to a crushed rock.

(7) Rigid and flexible pavements.

(8) Pavement designs which would support light to heavy aircraft.

Ten airfields were selected for obtaining the minimum data believed basic for an understanding of the effect of frost action at the site. These less comprehensive studies consisted of the following:

(1) Observation of frost action in base and subgrade materials.

(2) Measurement of frost heave, ice lenses, density, and water content variations in the base and subgrade materials.

(3) The correlation of these data with precipitation, ground water table, type of pavement, and soil types.

The airfields selected to obtain the data described above were:

(1) Otis Field, Sandwich, Massachusetts.

(2) Houlton Airfield, Houlton, Maine.

(3) Bismarck Municipal Airfield, Bismarck, North Dakota

(4) Casper Airfield, Casper, Wyoming.

(5) Fargo Municipal Airfield, Fargo, North Dakota.

The same tests, with the addition of water infiltration and subsurface temperature measurements, were made at five additional airfields located in the Missouri River Division. The investigations at these airfields were conducted independently of the frost investigation program by the Boston District:

(1) Sioux Falls Airfield, Sioux Falls, South Dakota.

(2) Fairmont Airfield, Fairmont, Nebraska.

(3) Great Bend Airfield, Great Bend, Kansas.

(4) Garden City Airfield, Garden City, Kansas.

(5) Pratt Airfield, Pratt, Kansas.

The following five airfields were selected for a more comprehensive investigation consisting of additional tests and observations:

(1) Dow Field, Bangor, Maine.

(2) Presque Isle Airfield, Presque Isle, Maine.

(3) Truax Field, Madison, Wisconsin

(4) Pierre Airfield, Pierre, South Dakota.

(5) Watertown Airfield, Watertown, South Dakota.

The additional tests and observations conducted at these airfields were as follows:

(1) Traffic tests at Dow, Pierre, and Truax Airfields, to determine the load carrying capacity of the pavement during the frost melting period.

(2) Temperature measurements of the pavement, base, and subgrade by means of thermocouples or mercury thermometers or both (omitted at Truax Field).

(3) Investigation of turfed area adjacent to the pavement test areas with and without snow cover (omitted at Truax Field).

(4) Plate bearing tests and in-place C.B.R. tests.

(5) Detailed laboratory tests on pavement, base, and subgrade samples.

d. DEFINITIONS. The description of the tests and analysis of results involve a specialized use of certain terms and words. These words and terms are defined for use in this report as follows:

(1) TEST AREA. The test area is the portion of the airfield selected for observations and investigations.

(2) TRAFFIC TEST AREA. The traffic test area is the portion of the test area subjected to traffic tests.

(3) TEST LANE. A test lane is the portion of the traffic test area subjected to a specific number of repeated wheel loads per day.

(4) TURNAROUND. A turnaround is the portion of the traffic test area used for turning traffic equipment.

(5) PASS. A pass is one movement of the traffic test equipment over a test lane.

(6) TRAFFIC. Traffic is the operation of making passes of the testing equipment over the traffic test areas.

(7) COVERAGE. One coverage is one application of a definite wheel load over each point in a given test lane.

(8) CYCLE. One cycle of coverages equals the coverages applied during one day.

(9) PAVEMENT. The term pavement is defined as a covering of a prepared or manufactured product superimposed upon a subgrade or base to serve as an abrasive and weather resisting structural medium.

(10) BASE. The term base applies to the course of specially selected soils, minerals, aggregates, or treated soils placed and compacted on the natural or compacted subgrade.

(11) SUBGRADE. The term subgrade applies to the natural soil in place or to fill material upon which a pavement or base is constructed.

(12) FLEXING. Flexing is the visible spring or vertical elastic movement of the pavement under a moving wheel load.

(13) MAP CRACKING. Map cracking is the development of a definite crack pattern in the pavement surface under the action of repeated loadings. Map cracking is dis-

tinguished by the formation of continuous connected cracks enclosing polygonal pavement segments.

(14) CONSOLIDATION. Consolidation is the increase in unit weight per unit volume, or decrease in volume of a given weight of a material due to the action of applied loadings. Consolidation is condidered to be synonymous with compaction in this report.

(15) PERMANENT OR VERTICAL DEFORMATION. Permanent or vertical deformation is the accumulative non-elastic part of the total vertical movement of the surface of the pavement which remains after the load is removed.

(16) FROZEN SOIL. Frozen soil is referred to in this report as follows:

(a) Homogeneous Frozen Soil. A homogeneously frozen soil is a soil in which all the water in the soil is frozen within the natural voids existing in the soil, without observable accumulation of ice lenses of frost forms exceeding in volume such natural void spaces.

(b) Stratified Frozen Soil. A stratified frozen soil is a soil in which a part of the water in the soil is frozen in the form of observable ice lenses, occupying space in excess of the original soil voids.

(17) ICE CRYSTALS. The formation of ice particles found in the pores of homogeneous frozen soil is referred to as ice crystals.

(18) ICE LENSES. Ice lenses are the ice formations in stratified frozen soil occurring in repeated layers essentially parallel to each other and normal to the direction of heat loss.

(19) FROZEN ZONE. The limits of depth within which the soil is frozen is referred to as the frozen zone.

(20) FROST PENETRATION. The maximum depth from the sur-

face to the bottom of the frozen soil.

(21) DEPTH OF FREEZING TEMPERATURE PENETRATION. The depth of freezing temperature penetration is the maximum depth below the surface of freezing temperature.

(22) FROST ACTION. Frost action is the accumulation of water in the form of ice lenses in the soil under natural freezing conditions.

(23) FROST HEAVE. Frost heave is the raising of the pavement surface due to the accumulation of ice lenses. The amount of heave in most soils is approximately equal to the cumulative thickness of ice lenses.

(24) FROST SUSCEPTIBLE SOIL. Frost susceptible soil is a soil in which frost action is possible. Any soil which contains three per cent or more by weight of grains smaller than 0.02 mm. diameter shall be considered susceptible to frost action.

(25) NON-FROST SUSCEPTIBLE MATERIALS. Non-frost susceptible materials are crushed rock, sand and gravel, gravel, slag, cinders, or any other cohesionless material in which frost action is not possible.

(26) DEGREE DAY. Degree day for one day is the algebraic difference between 32° Fahrenheit and the daily mean temperature. The degree day is plus when the daily mean temperature is below 32° Fahrenheit and minus when above. For any one day there are as many degree days as there are degrees Fahrenheit difference in temperature between the mean temperature for the day and 32° Fahrenheit. Cumulative degree days-time curve is obtained by plotting the cumulative degree days versus time.

(27) FREEZING INDEX. Freezing index is a measure of the combined duration and magnitude of below-freezing air temperatures occurring during any given winter and is the maximum ordinate of the degree days-time curve.

(28) NORMAL FREEZING INDEX. Normal freezing index is computed for normal air temperatures based upon a long period of record, usually 10 years or more.

(29) GROUND WATER TABLE. The ground water table is the free water surface nearest to the ground surface.

(30) DENSITY. Density is the unit dry weight in pounds per cubic foot.

(31) NORMAL PERIOD. The normal period is the time of the year when the foundation materials are not effected by frost action.

(32) WATER CONTENT. Water content is the ratio, expressed as a percentage, of the weight of water in a given soil mass to the weight of solid particles.

(33) DEGREE OF SATURATION. The ratio, expressed as a percentage, of the volume of water in a given soil mass to the total volume of intergranular space. Percent saturation is synonymous with degree of saturation in this report.

e. ACKNOWLEDGEMENT. These studies are based upon fundamental relations developed and presented by previous investigators, particularly S. Taber, A. Casagrande, P. C. Rutledge, and G. Beskow.

This investigation was conducted under direction of personnel of Office of Chief of Engineers by personnel of the New England Division, assisted by personnel of the Great Lakes Division and Missouri River Division.

Dr. A. Casagrande of Harvard University and Dr. P. C. Rutledge of Northwestern University acted in the capacity of consultants.

Acknowledgement is made to the U. S. Weather Bureau for weather data used and to the Post Engineers at various test locations for assistance given in performing tests.

3. REVIEW OF LITERATURE.

All available literature on subject matter related to frost phenomena was studied. A list of the articles and publications reviewed is included in the bibliography of this report. Most of the publications listed have influenced the general development of laboratory and field procedures for frost investigations. Several of the articles are not in agreement with recent investigations, but are included as a record of previous studies. Many of the publications are now out of print. The asterisk used in the bibliography indicates that a copy is on file at the Frost Effects Laboratory, New England Division, Boston, Massachusetts.

4. DESCRIPTION OF FROST ACTION.

Frost action is defined as the physical phenomena by which layers or lenses of ice are built up within a soil mass. Three conditions must occur simultaneously for these ice layers to form. These are as follows:

a. SOIL. Frost action within a soil is a function of its void size which may be conveniently expressed as a function of grain size. In this investigation, any soil which contains three per cent or more by weight of grains smaller than 0.02 mm. is considered frost susceptible and a soil in which frost action is possible.

b. WATER. Frost action depends upon the availability of water either by virtue of an adjacent ground water table, a capillary supply, or water within the soil voids.

c. TEMPERATURE. Frost action within soils requires the maintenance of freezing temperature slightly below the surface of ice lens formation. The greatest accumulation of ice will occur when the penetration of the freezing temperature is slow; a rapid penetration may result in few or no ice lenses.

The process of frost action may be described as follows: The water in the void spaces becomes cooled below the normal freezing temperature of water. This supercooled water has a high molecular attraction to ice crystals. Thus the supercooled water travels to ice crystals, which form in the larger voids, solidifying upon contact. This process repeated forms an ice lens. A single lens will continue to grow in thickness, always against the direction of heat transfer, until the formation of a lens at a lower elevation cuts off the source of water, or until the temperature rises above freezing.

Frost heaving is directly associated with frost action and is the visible evidence on the surface that ice lenses have formed in the soil mass. The frost boils as referred to by highway engineers are caused by a rapid thawing of an area of severe frost action beneath a flexible pavement. Such thawing occurs largely from the surface down and the excess water liberated from the thawed area is prevented from draining downward by the still frozen underlying soil and ice layers. The excess water causes the thawed soil to become exceedingly soft. Likewise the pumping of water from joints in concrete slabs during the spring may be the result of excess water in the subgrade liberated from thawed ice layers.

5. AIRFIELDS INVESTIGATED.

a. LOCATIONS. The fifteen airfields selected for this investigation are located in the New England Division, Great Lakes Division, and Missouri River Division. These airfields comprise the varied conditions of soil, temperature, rainfall, and ground water that would be required for comparative study in an investigation of this nature.

The following tabulation, in addition to the geographical location map shown on Plate 1, summarizes the airfield locations, elevations, and general physiography:

AIRFIELD	LOCATION NORTH LAT.	 WEST LONG.	AGENCY	ELEV. ABOVE MSL	PHYSIOGRAPHY
Presque Isle Presque Isle, Maine	47°	68°	New England Div.	500	Glaciated region of rolling hills
Houlton Houlton, Maine	46°	68°	New England Div.	470	Narrow valley flanked by high hills
Dow Bangor, Maine	45°	69°	New England Div.	170	Glaciated region of rolling hills
Otis Camp Edwards, Mass.	42°	70°	New England Div.	120	Flat outwash plain
Truax Madison, Wisconsin	43°	89°	Great Lakes Div.	860	Low level marsh
Pierre Pierre, South Dakota	44°	100°	Missouri River Division	1720	Ravines to predominating flat plateau

AIRFIELD	LOCATION		AGENCY	ELEV. ABOVE MSL	PHYSIOGRAPHY
	NORTH LAT.	WEST LONG.			
Casper Casper, Wyoming	43°	107°	Missouri River Division	5320	Gullies to rolling hills mountains to south
Watertown Watertown, South Dakota	45°	97°	Missouri River Divison	1730	Flat to rolling
Fargo Municipal Fargo, North Dakota	47°	97°	Missouri River Division	900	Bed of ancient lake - very flat
Bismarck Municipal Bismarck, North Dakota	47°	101°	Missouri River Division	1650	Ascending and descending benches
Sioux Falls Sioux Falls, South Dakota	44°	96°	Missouri River Division	1420	Flat flood plain
Fairmont Fairmont, Nebraska	41°	98°	Missouri River Division	1630	Flat plain
Great Bend Great Bend, Kansas	39°	98°	Missouri River Division	1890	Wide flat valley
Garden City Garden City, Kansas	38°	101°	Missouri River Division	2880	Flat to slightly undulating prairie land
Pratt Pratt, Kansas	38°	99°	Missouri River Division	1950	Gently rolling prairie land interspersed with low knolls and occasional shallow ponds or "buffalo wallows"

b. DESCRIPTION OF AIRFIELDS.

(1) GENERAL. A description of each airfield at which tests were conducted is presented in the following paragraphs. Weather data, grain size curves, classification of the base and subgrade materials, typical logs, and other pertinent data for each airfield are presented in Figures 1 to 6 on Plates 2 to 8 inclusive and in Table 1. The location of the test areas at each airfield is shown on Plates 9 and 10. The selection of airfields was based upon particular characteristics such as weather, ground water, and other conditions which would influence frost action. These conditions are noted for each airfield.

(2) PRESQUE ISLE AIRFIELD. This site was selected due to detrimental frost action experienced during previous winters. The airfield is located in the northeastern part of Maine in the city of Presque Isle. The region is hilly and glaciated. The normal freezing index, based on a 31-year record, is 2061. Three test areas representing portland cement concrete, bituminous concrete pavements, and turfed surfaces were selected for investigation. The rigid pavement, seven inches thick, is constructed on 30 to 36 inches of sand and gravel base; the flexible pavement, four inches thick is constructed on 24 to 30 inches of sand and gravel base. The subgrade is a frost susceptible clayey silt, sand, and gravel mixture (GC) with 10 to 35 per cent by weight finer than 0.02 mm. grain size. The ground water table is slightly below six feet in depth, except during the frost melting period when it rises to about two feet below the pavement surface. During the winter of 1942-1943 approximately 500 square yards of runway pavement heaved. Planes using the airfield during 1943 and 1944 were generally 30,000-pound and 65,000-pound gross plane weight. The number of landing and take-off cycles was irregular and ranged from 5 to 25 per day.

(3) HOULTON AIRFIELD. This site is in Aroostook County, Houlton, Maine. The terrain and weather are similar to Presque Isle Airfield. Houlton Airfield is located in a narrow valley flanked on the sides by relatively high hills. The normal freezing index is 1780 based on a 41-year record. Two test areas were selected. One test area is located on the parking apron and has a soil cement base with 1-1/2 inches of bituminous concrete wearing course. The other test area, located on the N-S runway, has six inches of sand and gravel base underlying four inches of bituminous concrete wearing course. The subgrade is a frost susceptible silty sand and gravel (GF) with 6 to 15 per cent by weight finer than 0.02 mm. grain size. The ground water table was generally below the explored depth of six feet. No serious heaving or pavement failures due to frost action have been noted during the operation of the airfield. During the winter of 1942-1943 plane traffic was moderately heavy and consisted of 60,000-pound gross weight planes. Smaller plane weights of 12,000 to 30,000 pounds were general in 1941 and 1942.

(4) DOW FIELD. This site was selected because of detrimental frost action during previous winters and the availability of data obtained from previous frost study at this airfield. Dow Field is located two miles west of the city of Bangor, Maine. The region consists of rolling terrain with hills composed of a thin mantle of slightly gravelly silt (glacial till) overlying bedrock. In the low areas the glacial till is overlain by a layer of silty clay. The normal freezing index is 1275

on the basis of a ten-year record. Four test areas consisting of portland cement concrete, bituminous concrete, and turfed surfaces were selected. The rigid pavement, seven inches thick, overlies 15 inches of sand and gravel base. The flexible pavement, 3.5 inches thick, overlies 24 to 36 inches of sand and gravel base in one test area and in the other test area 28 to 63 inches of sand and gravel base. The subgrade underlying pavements and turfed areas is generally a silty clay (CL) with 40 to 97 per cent by weight finer than 0.02 mm. grain size. The ground water table is from four to six feet below the surface and rises to a depth of one to four feet during the frost melting period. Frost action was studied at Dow Field in three test areas as a part of the Pavement Evaluation Program during the winter, spring, and summer of 1944. During this previous investigation, a glacial till subgrade (GC) was encountered in addition to the silty clay (CL) subgrade. The most frequent use of the airfield was between May 1942 and December 1943 by all types of aircraft. The majority of planes were of 30,000 to 60,000 pounds gross weight and made approximately 14 cycles of landings and take-offs per day.

(5) OTIS FIELD. Otis Field, selected because of previous occurrences of frost action, is located within the limits of Camp Edwards, Massachusetts. The site is of glacio-fluvial origin and is part of an extensive outwash plain. The area is generally flat consisting of extensive deposits of variable sands and gravels with occasional boulders. Winter temperatures at Otis Field are fairly mild, with a normal freezing index of 202 based on a 21-year record. The test area is located in a cut section on the NE-SW runway. The flexible pavement, five to seven inches thick, overlies a non-uniform subgrade generally comprising intermixed pockets of sands, silts, and gravels resulting in several gradations of frost susceptible soils located from about one to three feet below the pavement surface. The subgrade at greater depths consists of fine to medium sand with occasional gravel and small quantities of silt. Ground water was not encountered at an explored depth of 15 feet. Frost action was observed in January 1943 when pavement heaves had developed at several locations on the paved runways. Differential heaves of three to six inches occurred in unsealed portions of the bituminous concrete pavement. Traffic at Otis Field has been mainly by 30,000-pound planes during operations by the Army from January 1942 to January 1944 with average operations of 45 cycles of landings and take-offs per day. Since May 1944 the Navy has used the field more intensively by 12,000 to 15,000-pound planes, making 200 to 250 cycles of landings and take-offs per day. Occasionally, planes of 60,000-pound weight use the airfield.

(6) PIERRE AIRFIELD. Pierre Airfield, approximately

three miles northeast of the city of Pierre, South Dakota, is located on a relatively level plateau about two miles north of the Missouri River. The normal freezing index is 1294 on basis of 46-year record and the ground water table is at a depth greater than 25 feet from the surface. This airfield was selected to determine the effects of frost in an area having a low annual precipitation, low water table, and naturally dry subsurface soil conditions. Three test areas consisting of portland cement concrete, bituminous concrete, and turfed surfaces were selected for investigations. The rigid pavement, seven inches thick, was constructed on 7 to 14.5 inches of sand and gravel base. The flexible pavement, 5.5 inches thick, overlies a sand and gravel base of 6 to 15.5 inches thickness. The subgrade is a mixture of clay, silt, and sand (CL) susceptible to frost action. No serious heaving of pavements or pavement distress due to frost action has been noted during the period of operation of the airfield. Traffic has consisted of 30,000 to 60,000-pound planes making from five to more than 200 landing and take-off operations per day during period December 1942 through September 1943.

(7) CASPER AIRFIELD. Casper Airfield is located approximately eight miles northwest of the city of Casper, Wyoming. This site was selected to determine the effects of frost in an area having a comparatively low annual precipitation, an extremely low water table, and dry subsurface conditions. The general terrain of the airfield site is substantially flat. The general weather conditions in the airfield region are moderate with the normal freezing index of 532 based on a five year average. Two test areas were selected. One test area on the apron consists of portland cement concrete pavement, seven inches thick, placed directly on a compacted frost susceptible sand and sandy clay subgrade. The other test area consists of a flexible pavement taxiway section constructed of five inches of asphaltic concrete on 7 to 13 inches of sand and gravel base. The ground water table is in excess of 90 feet below the surface of the airfield. Pavement heave or distress due to frost action has not been serious at this airfield. During the period beginning November 1942 and ending October 1944, traffic operations consisted principally of 50,000-pound gross plane weights making an estimated 95 landing and take-offs per day.

(8) WATERTOWN AIRFIELD. Watertown Airfield is located adjacent to the northwest city limits of Watertown, South Dakota. The general terrain of the airfield site varies from flat to rolling. Winter temperatures are generally severe with a normal freezing index of 1742 based on a 40-year record. Three test areas were selected. The portland cement concrete area consists of an eight-inch slab constructed directly

on the subgrade which consists principally of frost susceptible silty, clayey sand (SF-OL). The bituminous concrete test area, consists of five inches of asphaltic concrete overlying eight inches of sand and gravel base. The turfed area was similar to the subgrade underlying the pavements. The subgrade consists of a frost susceptible silty clayey sand (SF-OL). A well defined water table at approximately 12 feet below the surface exists in the gravelly materials found in the deeper subgrade. No serious heaving of the pavement or pavement failures due to frost action have been observed. The airfield traffic during 1943 and 1944 consisted of approximately 100 landings and take-offs per day by planes generally of 60,000 pounds gross weight.

(9) FARGO MUNICIPAL AIRFIELD. Fargo Municipal Airfield is located approximately 1.5 miles northwest of the northwest city limits of the city of Fargo, North Dakota. The airfield is located on a generally smooth, flat plain, originally the bed of an ancient glacial lake. Winter temperatures at Fargo Airfield are the most severe of all the 15 airfields investigated. The normal freezing index, based on a 63-year record, is 2646. One test area was investigated which consisted of 1.5 inches of bituminous concrete wearing surface constructed over a soil cement base course having a thickness of approximately 6.5 inches. A sub-base of sand and clay material (CL-SF), approximately 15 inches in thickness, overlies about eight inches of black clay with sand gravel and cinders (OH-CH). The subgrade is a medium fat to fat clay (CH). The ground water table during the freezing period varies from five to seven feet in depth below the pavement. During the frost melting period it rises to a depth of three feet. The sub-base and subgrade materials are considered susceptible to frost action. A moderate amount of frost action occurred during this investigation but is not considered detrimental to the pavement. Aircraft operations on the airfield began in 1941. Traffic has been mainly by small and medium size commercial planes with occasional use by 30,000 and 60,000-pound gross weight planes. Intensity of operations has been approximately 30 landings and take-offs per day.

(10) BISMARCK MUNICIPAL AIRFIELD. Bismarck Municipal Airfield is located south of the southeast limits of the city of Bismarck adjacent to Fort Lincoln, North Dakota. The airfield site is on a relatively flat, elevated bench about two miles east of the Missouri River. Winter temperatures are extreme with a normal freezing index of 2552 based on a 69-year record. One test area of bituminous concrete pavement located on a runway was selected for investigation. The pavement is 4.5 inches thick and was constructed on a six-inch sand and gravel base course and approximately three feet of frost susceptible silt and fine

sand (CL-ML) subgrade. A deeper subgrade is composed of sand and gravelly materials to a depth of approximately 12 feet where a very compact clay is encountered. This results in the formation of a perched water table at a depth of about 12 feet below the surface. The normal elevation of natural ground water is approximately 40 feet below the surface. Prior to the period of frost investigation, no indications of frost heaving or other major pavement changes due to frost action have been noted. Traffic prior to September 1943 consisted principally of commercial airline planes making six landings and take-offs per day. Since that period traffic has increased to an average of 20 landing and take-offs per day, principally by planes of 8,000 to 12,000 pounds and 30,000 to 60,000 pounds gross weight.

(11) TRUAX FIELD. Truax Field is located on a low-lying level area forming one of the upper reaches of the marshes along the Yahara River and Lakes Mendota and Morona at Madison, Wisconsin. The winter temperatures are severe with a normal freezing index of 1227 based on a 43-year record. Three test areas were selected. Two test areas consisted of bituminous concrete and one consisted of portland cement concrete pavements. The bituminous concrete pavement, 2.5 inches thick, is constructed on a crushed rock base, and a sandy clay and gravel (GF) sub-base. The two flexible pavement test areas, located on a runway and taxiway, differ in the thickness of base and sub-base. The taxiway test area has eight inches of base and 15 to 17 inches of sub-base. The runway test area has 20 inches of base and 21 to 31 inches of sub-base. The portland cement concrete test area, located on the parking apron, consists of a six-inch slab which was constructed on a base of sand-clay-gravel (GF) varying from about three to five feet in thickness. The original subgrade is a silty clay (CL) with lenticular deposits of fine sand occurring at varying elevations. The ground water table is fairly uniform throughout the field, normally varying from six to eight feet below the pavement surfaces. No data on frost action at the field had been obtained prior to the investigation covered by this report. Since completion in December 1942, the airfield has been used by most types of military planes at 10 to 100 cycles per day including 30,000 and 60,000-pound gross weight planes.

(12) SIOUX FALLS AIRFIELD. Sioux Falls Airfield is located northwest of the city of Sioux Falls, South Dakota. The airfield is located in a flat flood plain just above the Big Sioux River. Levee construction along the north and northwest side of the airfield protect the airfield from flood waters of the Big Sioux River. Severe winter weather conditions are indicated by a normal freezing index of approximately

1100 based on a 46-year record. Two test areas were selected. One is on a taxiway pavement of two inches of bituminous concrete with approximately 9.5 inches of gravel, sand, and clay base overlying 12 inches of select soil sub-base (CL). The subgrade soils consist of a mixture of clay, silt, and sand (CL-CH). The second test area is located on the portland cement concrete apron. The concrete pavement was placed directly upon the frost susceptible compacted subgrade. The normal elevation of ground water is approximately nine feet below the surface. During flood stage the level of the Big Sioux River is above the surface elevation of the airfield. However, no appreciable back drainage through subterranean water courses has been recorded. No severe pavement distress due to frost action has been observed. A previous investigation of frost conditions existing under a taxiway pavement at this airfield was made in March 1944. Excavations made at that time indicated the presence of appreciable ice lenses extending from the top of the subgrade to a depth of approximately three feet. Traffic during the period from June 1942 through the date of this report has consisted of approximately 45 landings and take-offs per day with aircrafts ranging from 5,000 to 35,000 pounds gross plane weight.

(13) FAIRMONT AIRFIELD. Fairmont Airfield is located on a level plain approximately two miles south of the town of Fairmont, Nebraska. Moderate winter weather conditions are indicated by a normal freezing index of 581 based on a 46-year record. The test area consisted of an eight-inch portland cement concrete pavement constructed directly on a silty clay (CL-CH) subgrade. The ground water is located approximately 90 feet below the pavement surface. Airfield traffic started in May 1943. To the date of this report there were approximately 75 landings and take-offs per day by planes ranging in weight from 5,000 to 60,000-pounds gross plane weight.

(14) GREAT BEND AIRFIELD. Great Bend Airfield, approximately three miles west of the city of Great Bend, is located in the wide, flat valley of the Arkansas River. Winter temperature conditions in the airfield region are extremely variable, with extremes of very mild to occasionally severe winters. The 46-year normal freezing index is only 28. One test area consists of a seven-inch portland cement concrete pavement constructed on a six-inch sandy gravel base. The subgrade consists principally of a silty clay (CL) and sandy silt (CL-SF). The water table ranged from 12 to 15 feet below the surface during the period of this investigation. No pavement failure due to frost action has been observed. Traffic has consisted of light to heavy planes up to 120,000 pounds gross plane weight making approximately 100 landings and

take-offs per day.

(15) GARDEN CITY AIRFIELD. Garden City Airfield, approximately nine miles southeast of Garden City, Kansas, is located on flat to slightly undulating prairie land with the Arkansas River approximately one mile south and west of the airfield. The 44-year normal freezing index is 56. One test area was selected and is located on a runway pavement consisting of bituminous concrete having a thickness of 1.5 inches constructed on a sand, gravel, and clay (SC) base course with a thickness of approximately 10.5 inches, overlying a silty clay (CL) subgrade. Ground water elevation is more than 90 feet below the surface. Pavement distress due to frost action has not been previously recorded at this airfield. In a previous investigation made on the airfield pavement in January 1944, the presence of ice lenses and frost formations were observed in the subgrade. The freezing index for the 1943-1944 season was approximately 244. Aircraft operation began on this airfield on 15 January 1943. Operations until 15 December 1944 have consisted of approximately 1,000 landings and take-offs per day by light weight planes, and 15 landings and take-offs per month by 30,000 to 60,000 pounds gross weight planes.

(16) PRATT AIRFIELD. Pratt Airfield is located approximately three miles north of the city of Pratt, Kansas, on a gently rolling prairie land interspersed with low knolls and occasional shallow ponds. Mild winter weather conditions are indicated by the 46-year normal freezing index of 28. One test area was selected and is located on a taxiway pavement consisting of a seven-inch design thickness of portland cement concrete, overlying a silty sand cushion (SF-CL) of average thickness of three inches, but ranging from zero to 12 inches. The subgrade consists of a silty clay (CH-CL). The ground water elevation in the airfield region is approximately 90 feet below the surface. The sand cushion tends to pond water after periods of precipitation. The source of the water in the sand cushion is believed to be surface water infiltrating through cracks and joints in the pavement, and also acting at the juncture of the pavement and turf shoulder. Aircraft traffic began on this airfield in July 1943. Traffic during the operational period has consisted principally of 35,000 and 120,000-pounds gross plane weights. The average daily traffic during the period of operation has been approximately 130 take-offs and landings per day.

c. TYPES AND CONDITION OF PAVEMENT. The types of pavement, thickness of pavements, and the condition of the surfaces of the pavements of each test area at all airfields prior to investigations, are briefly summarized as follows:

AIRFIELD	THICKNESS (inches) AND TYPE OF PAVEMENT	CONDITION
Presque Isle		
Test Area A	7 P.C.C.	Good - Few small cracks and depressions.
Test Area B	4 B.C.	Good - Few small cracks and depressions.
Dow Field		
Test Area A	7 P.C.C.	Poor - About 40 per cent of area cracked due to previous tests and frost action.
Test Area B and C	3.5 B.C.	Good - Scattered longitudinal cracks along construction lanes.
Houlton		
Test Area A	1.5 B.C. 6 Soil Cement	Good - Minor cracking and minor depressions.
Test Area B	4 B.C.	
Otis		
Test Area A	5 to 7 B.C.	Good - Minor cracking and minor depressions.
Truax		
Test Area A and B	2.5 B.C.	Good - Minor Cracking.
Test Area C	6 P.C.C.	Good - Minor cracking and depressions.
Pierre		
Test Area A	7 P.C.C.	Good - Few cracks, minor ponding condition.
Test Area B	5.5 B.C.	Good - Minor cracking and depressions, ponding.
Casper		
Test Area A	7 P.C.C.	Good - Minor cracking.
Test Area B	5 B.C.	Fair - Numerous small depressions and minor cracks, ponding.

AIRFIELD	THICKNESS (inches) AND TYPE OF PAVEMENT	CONDITION
Watertown		
Test Area A	8 P.C.C.	Good - All joints sealed, few cracks.
Test Area B	5 B.C.	Good - Minor depressions and ponding.
Fargo		
Test Area A	1.5 B.C. 6.5 Soil Cement	Transverse cracking and minor deformations. Area sealed in good condition prior to start of tests.
Bismarck		
Test Area A	2 to 4.5 B.C.	Fair - Checking and minor cracks. Minor depressions and ponding.
Sioux Falls		
Test Area A	2 B.C.	Good - All cracks have been sealed.
Test Area B	6 P.C.C.	Good - All joints and cracks sealed and maintained.
Fairmont		
Test Area A	8 P.C.C.	Good - Minor cracking, some seepage through joints and ponding after heavy precipitation.
Great Bend		
Test Area A	7 P.C.C.	Fair - Pavement cracking occurred in areas subject to concentrated traffic.
Garden City		
Test Area A	1.5 B.C.	Good - Minor depressions causing some ponding after heavy precipitation.
Pratt		
Test Area A	7 P.C.C.	Good - Some cracking and seepage.

d. BASES. Sand and gravel base courses of GW classification, predominate the test areas and range in average thickness from 6 to 48 inches. In every test area the grain size distribution curves indicate that all base materials except for small fractions thereof contain more than three per cent finer than the 0.02 mm. size. At Truax Field the subbase, underlying the crushed rock base, contains a higher percentage of material passing the 0.02 mm. size than any of the GW base material encountered because of its sandy clay content. At Presque Isle Airfield four inches of crushed rock overlies a sand and gravel base in Test Area B. Soil cement base course, six inches thick, is located under the bituminous concrete wearing surface in Test Area A at Houlton and Fargo Airfields. One test area each at Otis, Casper, Sioux Falls, Fairmont, and Watertown Airfields has pavements constructed directly on frost susceptible subgrades. The description, classification, and grain size curves for bases in each test area are shown in Figures 1 and 2 on Plates 2 to 8 inclusive.

e. SUBGRADES. A wide range of subgrade soils is found in the test areas. Predominant are the silty clayey sands and gravels of GC and CL classification. Occasional CH material was encountered in test areas of the Missouri River Division. All subgrade soils are frost susceptible with 3 to 97 per cent finer by weight than 0.02 mm. in size. Figures 1 and 2 on Plates 2 to 8 inclusive show description, classification, and grain size curves of the predominating subgrade soils.

f. DRAINAGE. The surface and subsurface drainage facilities at the several test areas are summarized in the following tabulation:

AIRFIELD	TEST AREA	SURFACE DRAINAGE	SUBSURFACE DRAINAGE
Presque Isle	A	Surface runoff from pavement collected by catch basins in valley in apron area.	Base course continued through shoulder to edge of fill on one edge.
	B	Surface runoff from pavement and shoulder collected by shallow turf or rock gutters which drain to a catch basin at end of taxiway.	6-inch open joint pipe, 4-foot depth backfilled with sand and gravel at outside edge of surface treated gravel shoulders.

AIRFIELD	TEST AREA	SURFACE DRAINAGE	SUBSURFACE DRAINAGE
Dow	A	Surface runoff from ℄ pavement collected by catch basins located 75 feet from ℄ and spaced 225 feet longitudinally.	8-inch non-reinforced concrete open joint pipe, 4-foot depth backfilled with bank-run sand and gravel.
	B and C	Surface runoff from ℄ pavement collected by catch basins located at edge of pavement spaced 225 feet and catch basins at edge of bit. treated shoulders and at 250 feet from ℄ in turfed area.	Open joint pipe at bit. conc. pvt. edges and skip pipe at 175 feet from ℄ runway at bit. surf. treated shoulder edges.
Houlton	A	Surface runoff from apron collected in ditch at pavement edges.	Open joint pipe, 5-foot depth, to intercept sidehill seepage at east edge. Backfilled with sand and gravel.
	B	Surface runoff from ℄ pavement collected by combination drains and catch basins at runway edges and ditches along outside edge of landing strip.	Open joint pipe, 5-foot depth, at edges of bit. conc. runway. Backfilled with sand and gravel.
Otis	A	Surface runoff collected by longitudinal turf swales located 160 feet from ℄ runway with catch basins to closed joint pipe.	6-inch non-reinforced open joint pipe laid in 2-foot wide trenches at edge of pavement, backfilled with well graded sand and gravel. Pipe inverts are about 4 feet below pavement edge.
Truax	A	Surface runoff from ℄ of pavement to edge of shoulder collected by catch basins in shallow gutter at shoulder edge.	None
	B	Surface runoff from ℄ of pavement to edge of shoulder collected by catch basins in shallow gutter at shoulder edge.	Perforated tile pipe in trenches filled with coarse sand at edges of pavement. Top 2 inches is clay top soil.
	C	Surface runoff from pavement and adjoining turfed area collected by catch basins in turfed area at low points.	Trench filled with sand and gravel and containing a V.C. pipe with open joints along south edge. None at north edge.
Watertown	A and B	Surface runoff drains to open shallow swale at edge of pavement.	None

AIRFIELD	TEST AREA	SURFACE DRAINAGE	SUBSURFACE DRAINAGE
Casper	A	Surface runoff collected by catch basins located in shallow swale in pavement area.	None
	B	Surface runoff collected by shallow swale at edge of pavement.	None
Fargo	A	Surface runoff from pavement collected by combination drains at pavement edges.	Combination drains backfilled with coarse aggregate located in shoulder with open joint pipe in trench.
Bismarck	A	Surface runoff collected by shallow swale at edge of shoulders.	None
Pierre	A and B	Surface runoff collected by shallow swale at edge of shoulders.	None
Sioux Falls	A and B	Drainage of airfield principally by surface runoff. Temporary ponding relieved by seepage into subsurface permeable strata.	None
Fairmont	A	Drainage provided by surface drainage and by comprehensive storm sewer system.	None
Great Bend	A	Drainage secured by drainage ditches and by drainage into sump ponds.	None
Garden City	A	Drainage secured by surface drainage and storm sewer system. Interceptor drainage ditch protects the paved areas from water draining from higher area.	None
Pratt	A	Drainage secured by surface drainage and a storm sewer system.	None

g. WEATHER. Of the 15 airfields investigated, Fargo Airfield has the greatest normal freezing index. The 15 airfields are tabulated to show the range from mild to extreme winter conditions as measured by the freezing index and the approximate dates of the normal freezing period:

AIRFIELD	NORMAL FREEZING INDEX	CONDITION	NORMAL FREEZING PERIOD
Fargo	2646	Extreme	1 Nov. - 1 Apr.
Bismarck	2552	Extreme	1 Nov. - 1 Apr.
Presque Isle	2061	Extreme	10 Nov. - 1 Apr.
Houlton	1780	Severe	15 Nov. - 1 Apr.
Watertown	1742	Severe	1 Nov. - 20 Mar.
Pierre	1294	Severe	15 Nov. - 15 Mar.
Dow	1275	Severe	1 Dec. - 25 Mar.
Truax	1227	Severe	20 Nov. - 15 Mar.
Sioux Falls	1100	Severe	20 Nov. - 14 Mar.
Fairmont	581	Moderate	20 Nov. - 2 Mar.
Casper	532	Moderate	20 Nov. - 20 Mar.
Otis	202	Moderate	15 Dec. - 1 Mar.
Garden City	56	Mild	20 Dec. - 6 Feb.
Great Bend	28	Mild	2 Jan. - 6 Feb.
Pratt	28	Mild	3 Jan. - 6 Feb.

Precipitation during the three months prior to the freezing period has been considered to determine its effect on water table and saturation of the subgrade during this critical period. The normal precipitation was greatest at Otis Field where a total of 13 inches was measured for three months prior to the start of freezing. The airfields are tabulated to show the comparative rainfall:

AIRFIELD	NORMAL TOTAL PRECIPITATION DURING 3 MONTHS PERIOD PRECEDING FREEZING (in Inches)
Otis	13
Dow	11
Presque Isle	10
Houlton	9
Truax	7
Fairmont	6.5
Pratt	6.3
Sioux Falls	5.5
Great Bend	5.3
Casper	4.4
Watertown	4.4
Garden City	4.1
Fargo	3.7
Bismarck	2.6
Pierre	2.4

Snowfall was greatest in the New England region where Presque Isle Airfield had a cumulative total above 100 inches. Snowfall became less toward Houlton (75 inches), Dow (60 inches) and Otis (18 inches) airfields. Snowfall at the midwestern airfields ranged from 5 to 35 inches cumulative total for the 1944-1945 winter.

6. RESULTS

The field explorations, measurements, observations, field tests, and investigations at each field were generally conducted during the following periods:

(1) Prior to freezing or normal

(2) Freezing

(3) During frost melting

(4) After frost melting

The period prior to freezing or normal period, generally in the summer or early fall, is considered in this report as the basis of comparison. With the data available for the four periods, a comparison of the test results and investigations may be made and the variations from the normal noted. In the following paragraphs the various tests and investigations conducted during the above periods are described and the location of results are indicated.

a. TESTS FOR SOIL CLASSIFICATION. Laboratory test, including sieve analysis, hydrometer analysis, Atterberg limits, and specific gravity were conducted on representative samples of base, subbase, and subgrade materials at all airfields for classification purposes. The soils were classified in accordance with the soil classification for airfield projects by A. Casagrande as outlined in Chapter XX, Engineering Manual, (March 1943). The specific purpose for grain size distribution curves was to determine whether or not the base, sub-base, or subgrade materials were frost susceptible. Grain size curves and classification data for typical materials and typical logs for each test area are shown in Figures 1 and 2, Plates 2 to 8 inclusive. A summary tabulation of the results of tests, including Atterberg limits, Cassagrande soil classification, and range in percentage of particles finer than 0.02 mm. is included in Table 1.

b. TESTS FOR AVAILABILITY OF WATER FOR FROST ACTION.

(1) PRECIPITATION. Precipitation data for the various airfields were obtained from either the U.S. Weather Bureau Station nearest the airfields or from the A.A.F. Weather Officer at the specific airfield. Cumulative rainfall for the months of September through December and cumulative snowfall for months of November through March are shown in Figures 4 and 5 respectively on Plates 2 to 8 inclusive. Tabulation of the record of precipitation for the three months prior to the freezing period for all airfields is included in Table 1.

(2) GROUND WATER. Ground water elevations in both the subgrade and base were obtained by means of observation wells in the base and subgrade. These measurements were augmented by excavation of test pits. The readings in the wells were obtained during the normal period and to the end of frost melting period. Depth of ground water from the surface of the pavement is plotted against time in Figure 6, Plates 2 to 8 inclusive, for comparison with the profile of base and subgrade. Tabulation of the average depth of the water table from the surface of the pavement during the normal, freezing, and frost melting period is included in Table 1.

(3) WATER CONTENT AND DENSITY. Water content and density determinations of the base and subgrade materials were obtained in test pits excavated during the normal period, freezing period, frost melting period, and after the frost melting period when the subsurface conditions had returned to normal, generally in May or June. The specific time for the excavation of the test pits was based on previous weather data and the progress of freezing weather. The variation in average density and average water contents for the representative subgrade and base materials during these periods is shown graphically for all test areas in Figure 9, Plates 2 to 8 inclusive. Results are also summarized in Table 1.

(4) DEGREE OF SATURATION. The degree of saturation of of the base and subgrade materials during the normal, freezing, and frost melting periods were computed from the density, water content, and specific gravity of the various materials. Variation in the degree of saturation during these periods is shown in Figure 9, Plates 2 to 8 inclusive. The average degree of saturation of the base and subgrade materials during the various testing periods is summarized in Table 1.

c. TESTS FOR TEMPERATURE. Measurements were made, or obtained from other sources, of air temperatures at all airfields investigated.

At 17 test areas, measurements of subsurface temperature were made. The following paragraphs contain pertinent comments on these observations:

(1) AIR TEMPERATURES. The air temeratures were obtained from either the nearest U. S. Weather Bureau Station or the A.A.F. Weather Officer at the airfield. These were supplemented at some fields by U.S.E.D. thermographs located at the test areas. For each airfield air temperature data in the form of degree day curves from 1 November 1944 to 1 May 1945 and normal curve for same period are shown in Figure 3, Plates 2 to 8 inclusive. The normal freezing index is compared with the freezing index for 1944-1945 in Table 1.

(2) SUBSURFACE TEMPERATURES. Subsurface temperatures were measured by a potentiometer which indicated the temperature of copper-constantan thermocouples imbedded in the pavement, base, and subgrade at various depth intervals. Details of thermocouple installation, wiring, and switch box are shown on Plate 11. Photographs of installation and switch box and method of obtaining readings during heavy snow cover are shown on Plates 12 and 13 respectively. Thermocouples were installed in the bituminous and cement concrete pavement test areas at Dow Field, Presque Isle, Pierre, Sioux Falls, and Watertown. Turfed areas were included at the same airfields except at Pierre. At Watertown and Sioux Falls, temperature measurements were also made, using thermometer wells which consisted of glass bulb thermometers suspended in anti-freeze in Saran pipes. Only thermometer wells were installed at Fargo and Great Bend. The thermometer well consisted of lengths of one-inch diameter plastic pipe, with a cap on the lower end and a standard galvanized three-inch diameter pipe nipple capped with a standard coupling and plug at the top. A rubber bushing held the nipple to the plastic pipe and the top of the well was installed flush with the pavement. The installation consisted generally of six to eight separate wells installed at different depths below the pavement. The lower end of each well contained not less than three inches of anti-freeze in which was suspended a mercury thermometer. The thermometers were insulated and withdrawn for reading. Plate 14 includes the details of the thermometer wells used by the Missouri River Division. Plate 15 shows typical temperature gradients at Dow Field measured from the surface to a depth of six feet during the period from January to April. The freezing temperature of soils is believed to be between 28 degrees F. and 32 degrees F. depending upon the soil. In Figure 11 on Plates 2 to 8, inclusive, are shown plots of the depth penetrated by the 28-degree F. and 32-degree F. subsurface temperature during the period of December to April. Also shown in Figure 11, Plates 2 to 8, inclusive, is the depth of frost penetration measured in test pits during the freezing period.

d. TESTS FOR FROST ACTION.

(1) ICE LENSES. The presence of ice lenses was investigated by means of test pits excavated during the freezing period. Location and measurements of ice lenses referred to soil profile for each test area are shown in Figure 8 on Plates 2 to 8 inclusive. These data are also summarized in tabular form in Table 1. The ice lenses in the subgrade occurred in non-continuous horizontal layers ranging from 1-3/8 inches to hairline in thickness and were generally spaced irregularly less than 1/2 inch apart. The lenses were thicker and more closely spaced near the bottom of the frost penetration. No ice lenses were observed in the base materials at the airfields except in the base materials in Test Area C and subbase materials in Test Area B at Truax. Photographs of ice lens formation at Dow Field are shown on Plates 16 and 17. Ice lens formations at Truax, Fargo, and Pierre Airfields are shown on Plates 18, 19, and 20 respectively.

Ice lenses were found to be thicker and more closely spaced near the bottom of frost penetration in the test areas at Dow, Presque Isle, Houlton, and Truax. Small, thin, scattered ice lenses were observed during the freezing period in the test areas at Otis, Pierre, Watertown, Fargo, and Bismarck. No ice lenses were encountered at Casper, Garden City, Great Bend, Fairmont, and Pratt.

(2) PAVEMENT HEAVE. The pavement heave was measured by level surveys supplemented by wire line readings during the normal, freezing, and frost melting periods. The amount of heave for all airfields is shown on Table 1 and Figure 7, Plates 2 to 8 inclusive. The maximum pavement heave was 0.7 foot and occurred in Test Area A at Dow Field. An equal amount of heave occurred at Dow Field during the previous winter of 1943-1944. The maximum average heave was 0.5 foot which also occurred in Test Area A at Dow Field. The average pavement heave at all test areas except those at Dow, Presque Isle, Houlton, Truax, and Sioux Falls was practically negligible being less than 0.07 foot. The pavement heave was more or less uniform at all airfields except Dow, Presque Isle, Watertown and Sioux Falls. In Test Area B at Pierre, Test Area A at Bismarck, Test Area B at Watertown, and Test Area A at Sioux Falls, pavement heave measurements show that the pavement at the crown did not heave. Instead, the center area subsided a very small amount while the pavement at the edges heaved. This type of heaving is illustrated on Plate 21 by frost heave contours plotted for Test Area B, Watertown Airfield.

e. INVESTIGATION OF FROST PENETRATION. The investigation of frost penetration was made by (1) field observation and measurements in test pits; (2) subsurface temperature measurements; (3) laboratory studies in the cold room of the Soils Mechanics Laboratory at Harvard University; and (4) mathematical studies of temperature changes in soil. The depth of frost penetration and rate at which the frost penetrates and leaves the ground is shown in Figure 11, Plates 2 to 8 inclusive. The laboratory studies and some of the mathematical studies are included in the following paragraphs. A graphical method of predicting the depth of frost penetration in soil is presented on Plate 22. The method is based on an article by W. P. Berggren; "Prediction of Temperature Distribution in Frozen Soils," Transactions, American Geophysical Union 1943.

(1) FIELD MEASUREMENTS. The depth and rate of frost penetration were obtained by measurement in a series of test pits excavated at the start of freezing and extending to the end of the frost melting period. At several airfields test pits were excavated to obtain only the maximum depth of frost penetration. It will be noted in Figure 11, Plates 2 to 8 inclusive, that at most airfields there is a close agreement in depth of penetration of the 32-degree F. curve obtained from results of subsurface temperature readings and the frost penetration obtained by measurement in test pits. The maximum observed frost penetration is indicated by symbol F.P. in Figure 8 on Plates 2 to 8 inclusive.

(2) LABORATORY STUDIES. Two types of laboratory tests were made for the following purposes: (a) To determine the temperature changes in laboratory specimens of sand due to suddenly impressed surface temperatures, and (b) to determine the thermal conductivity, in the unfrozen state, of five representative materials commonly used for base construction such as sand, sand and gravel, crushed rock, slag, and cinders and one sample of asphaltic concrete pavement. The investigations were performed in the cold room of the Soils Mechanics Laboratory at Harvard University Graduate School of Engineering. General layout of the cold room and equipment is shown on Plate 23. The cold room could be regulated to air temperatures ranging from 30 degrees F. to 50 degrees F. while the temperature in the air space above the drawers in the freezing cabinet could be regulated to temperatures ranging from that of the cold room to minus 10 degrees F.

(a) Test For Temperature Changes. The tests for temperature changes were conducted on a cohesionless medium sand designated "Lowell Sand". Figure 5, Plate 24 shows grain size curve for the material tested. The test specimens were 3.36 inches in diameter and 6.5

inches high and were compacted in cardboard ice cream containers. The samples were compacted to various densities and water contents as shown in Table A, Plate 24. Temperature changes were measured by thermocouples imbedded along the axis of each sample tested. To prevent evaporation from the surface, the top of the samples, except the saturated samples, was sealed with paraffin two mm. thick. As many as four samples could be placed in a freezing cabinet drawer. The samples were packed in fine, cohesionless sand for insulation. Plate 25 shows portograph of samples in freezing cabinet drawers with thermocouple lead wires. At the start of the test the top and bottom of the samples were at cold room temperature of 40 degrees F. The top of the samples was subjected to suddenly impressed temperatures of 10 degrees F., 20 degrees F., and 30 degrees F. Temperature changes versus time were measured until temperature equilibrium was reached for each sample. The bottom of the samples remained exposed to a constant cold room temperature of about 40 degrees F. Plate 26 shows photograph of thermocouple equipment used to measure the temperatures within the samples.

The data obtained are summarized on Plate 24. Table A summarizes the principal test conditions for each test performed. Figure 1 is a typical set of time versus temperature curves for each of the thermocouples in a selected test. Figure 2 is a typical set of temperature gradients obtained after a suddenly impressed surface temperature of 9.7 degrees F. has been applied. Figure 3 presents representative data showing the penetration of the 32-degree F. temperature versus time into test specimens at different water contents and unit dry weights and with two different, suddenly impressed, surface temperatures. In four tests, conditions were such that equilibrium was reached with the 32-degree F. temperature approximately at the midpoint of the specimen and equilibrium temperature gradients for these four tests are shown in Figure 4, Plate 24. From the tests conducted it is possible to investigate the effect of the surface boundary upon temperature conditions in the test specimens and its application to the prediction of penetration of frost. The temperature gradients at equilibrium, Figure 4, Plate 24, were extrapolated to the top and bottom surfaces of the sample. The specimen temperatures at the top and bottom were then determined and are recorded in Table A, Plate 24. The difference between the temperature of the specimen at the top or bottom and the air temperature at the top or bottom respectively is termed the "boundary temperature difference." It is indicated that small increases in the equilibrium temperature gradient produce substantial increases in the "boundary temperature difference" for all water contents and, in general, the greater the water content, the greater the boundary temperature difference for a given temperature gradient. A study of Table A, Plate 24, indicates that the time for temperature equilibrium to be reached within a given test specimen is dependent upon the magnitude of the suddenly impressed temperature difference between the top and bottom of the specimen and the density and water content of the specimen. Specimens at very low water contents reached equilibrium temperature earlier because of the small latent heat of fusion and volumetric heat capacity. Saturated specimens reached equilibrium more slowly because of the greater latent heat of fusion and volumetric heat capacity. The same results are illustrated by Figure 3, Plate 24, in which the penetration of 32-degree F. temperature is a function of the magnitude of temperature difference between top and bottom of a specimen and its density and water content. From Figure 4, Plate 24, the ratio of the thermal conductivity in the frozen to unfrozen state can be determined. This ratio is equal to the ratio of the slopes of the equilibrium temperature gradients in the frozen zone to that in the unfrozen zone. These ratios indicate that for the materials tested and the density and water contents tested, the thermal conductivity in the frozen state is approximately 52 to 85 per cent of that in the unfrozen state.

(b) Tests For Thermal Conductivity. Five base materials such as sand, sand and gravel, crushed rock, slag, and cinders were tested at various densities and water content; also one sample of asphaltic concrete was tested. Gradation of base materials tested is as shown in Figure 3, Plate 27. Each test specimen was contained in a brass cylinder 5.36 inches in diameter, 10.67 inches in height, and 1/16 inch wall thickness. The top and bottom of the cylinder were sealed. A thermocouple was placed at the midpoint of the cylinder, as shown on Plate 23, "Sections of Sample Cylinders, Brass." The test consisted of subjecting a cylindrical test specimen, immersed in a water bath located outside the cold room, to a constant temperature of about 75 degrees F. The specimen was then suddenly immersed in a second bath, located in the cold room, to a constant temperature of about 40 degrees F. The resulting temperature changes were measured at the midpoint of the specimen. Plate 23 shows details of constant temperature bath. The data obtained from these tests are summarized on Plate 27. Figure 2 is a plot of the typical curves of the per cent temperature change at the midpoint of the test specimen versus time. Table A is a summary of test data and Figure 4 is a summary plot showing the relations of thermal conductivity to water content and density of the materials tested. Figure 1 presents curves which were developed to obtain the "time factor" for temperature change at center of a cylinder. Plate 27 shows an example, by use of these curves and data, for obtaining the thermal conductivity. From Figure 4, the insulating value of cinders and slag is evident.

A comprehensive investigation of the thermal conductivity of ten different soils was made by Harrison E. Patten, "Heat Transference in Soils," U. S. Department of Agriculture, Bulletin No. 59, September 1909. The thermal conductivity of eight soils used in his investigation are shown on Plate 28. Table A is a summary of test data, Figure 1, a summary plot of thermal conductivity versus water content for densities tested, and Figure 2, grain size gradation curves of materials tested. It will be noted that the coarse quartz tested by Patten is similar in grain size and distribution to that of the Lowell sand used in this investigation and that the thermal conductivity of these two soils are approximately the same at equal water contents.

(3) MATHEMATICAL STUDIES. A rigorous solution was developed by W. P. Berggren for computing the depth of frost penetration. The computations take into consideration density, water content, latent heat of fusion, specific heat, and the thermal properties of the soil in the frozen and unfrozen state. This solution was expanded in graphical form as shown on Plate 22. An example for computing the depth of frost penetration is also presented on this plate. This solution is not suitable for use at the present time because of an inadequate knowledge of the thermal conductivity of soils in the frozen state. However, it does show the relation of the factors to be considered in predicting the depth of frost penetration.

f. TESTS FOR FLEXIBLE PAVEMENT SUPPORTING CAPACITY. The supporting capacity of flexible pavements was investigated by means of in-place C.B.R. and plate bearing tests conducted during the normal period and the frost melting period and traffic tests conducted during and after the frost melting period. The field test procedures for the C.B.R. were performed as outlined in Chapter XX, Paragraph 20-18d "C.B.R. Tests on Soils in-Place", Engineering Manual (March 1943). The plate bearing tests were of two types: static load and repeating load. The static load tests were conducted in the manner described in Chapter XX, Paragraph 20-41, Engineering Manual (March 1943) except that the 30-inch diameter plate was placed directly on top of the bituminous concrete pavement. The repeating load test used the same type and arrangement of testing apparatus as required for the static load test, except that a 24-inch diameter plate was used on top of the bituminous pavement. The test was conducted in the following manner: A seating load of 3500 pounds was applied for five minutes and released. A load of 20,000 pounds was then rapidly applied in one increment. The load was maintained for ten minutes during which the deformation was measured at the end 1/4, 1, 2½, 6½, and 10 minutes. The load was rapidly released and deformation readings taken at the end of a 5-minute period. The foregoing procedure was then repeated until ten load repetitions had been made. A 19-inch diameter plate was used instead of a 24-inch diameter plate during the normal period at Dow Field for the 1943-1944 investigations. The test locations and pertinent comments on the results are presented in the following paragraphs:

(1) C.B.R. TESTS. In-place C.B.R. tests were conducted on top of the base material and on top of the subgrade at all flexible pavement test areas. The average results of tests are shown in Figure 10, Plates 2 to 8 inclusive. Estimated values where shown are based upon laboratory tests and field experience with similar soils.

(2) PLATE BEARING TESTS. Static and repeating load plate bearing tests were conducted at Dow, Presque Isle, Pierre, Watertown, and Truax Airfields. Plate bearing tests were conducted during the fall and during and after the frost melting period, except at Pierre and Watertown where tests were made only during the fall. Figure 12, Plates 2 to 8 inclusive, presents the average results of the static load tests. In Figure 12, each point shows the load required to produce 0.1 inch deflection on the date a static load test was made. The curve shows the trend of the changes in pavement supporting capacity for the period investigated. During the freezing period, the high pavement strength is estimated by dashed portions of the curve. A more detailed summary of the results of all plate bearing tests is presented in Tables 2 to 6 inclusive.

(3) TRAFFIC TESTS ON BITUMINOUS CONCRETE. Traffic tests were conducted on the flexible pavement during the 1945 frost melting period at Dow Field in Test Area B (B1 and B2) and Test Area C (C1 and C2), at Truax Field in Test Area B (B1 and B2), and at Pierre Airfield in Test Area B (T2-T6, T7 and T11). A summary of the traffic test results is shown in sheet 1 of 2, Table 7. The wheel loads used were selected to bracket or approximate the evaluation of the specific pavements for frost melting conditions. The traffic test wheel loads for Dow were 40,000 and 60,000 pounds; for Truax 30,000 and 60,000 pounds; and for Pierre 7,000, 14,500, and 25,000 pounds. The equipment to obtain the various loads ranged from large rubber tired construction equipment to trucks. Photographs of the equipment used to produce the wheel loads tested at Dow and Truax Fields are shown in Plates 29 and 30, respectively. The application of traffic was made on the basis of a specified number of daily coverages during and after the frost melting period to simulate continuous use of a pavement by aircraft. Based upon the best available informa-

tion it was assumed that 15 coverages per day was equivalent to runway use and 45 coverages per day was equivalent to taxiway use. In all cases it was not possible with the available equipment to apply exactly 15 and 45 coverages; therefore, individual tests varied in the number of daily coverages. Where the traffic equipment extended outside the test lane, these coverages are not considered as part of the test. The number of passes made by the equipment was kept to a minimum and the traffic pattern was designed to gradually attain by steps the maximum coverages within the test lane. Traffic was started at the beginning of the frost melting period and continued through the frost melting period or until imminent failure had occurred. Measurements of the vertical deformation in the traffic test areas and observations of the behavior of the pavement were made daily. At the end of the traffic tests detailed measurements were made of the pavement surface and trenches were excavated in traffic test areas to observe and measure and determine the relative positions and condition of the pavement, base material, and subgrade. A test lane was considered to be in a condition of imminent failure if about 20 per cent of the area was map cracked or the flexing of the pavement reached one inch. Plate 31 shows photograph of failure area in bituminous concrete pavement. It was the intent to reduce the damage of pavement to a minimum consistent with test results. Imminent failure or the point at which failure almost occurred was used as a basis for determining whether pavement was satisfactory or unsatisfactory rather than complete failure which would leave the pavement impassable. In Table 7 results of the traffic tests for each test area are tabulated. As an example, at Dow Field, Test Area B1, imminent failure did not occur for 40,000-lb. wheel load after 16 coverages per day. Therefore, pavement is considered satisfactory for runway use. At 46 coverages per day, the same wheel load produced imminent failure as shown by photograph, Plate 31. The pavement is not satisfactory for taxiway use.

During the spring of 1944 traffic tests were conducted at Dow Field on the flexible pavement of the same runway as the traffic tests performed in the spring of 1945. These test results are shown in Sheet 2 of Table 7. A wheel load of 20,000 pounds was used for Traffic Test Areas I and II and 10,000 pounds for Test Area III. The traffic tests were started and continued through the frost melting period. The application of traffic was different for each area. Coverages varied from about 4 to 50 per day. In these tests it was assumed that 4 coverages per day was equivalent to runway traffic and 50 coverages per day equivalent to taxiway operation. The equipment used to obtain the wheel loads consisted of a five yard truck and Gar Wood scraper towed by a five yard truck. At the end of the traffic tests, detailed measurements were made of the pavement cracking and deflection. Trenches were excavated in the traffic test areas, including failed areas, to observe, measure, and determine the relative deflections and conditions of the pavement, base, and subgrade.

g. TESTS FOR RIGID PAVEMENT SUPPORTING CAPACITY. The supporting capacity of rigid pavements was investigated by means of plate bearing tests conducted during the normal period and the frost melting period and traffic tests conducted during and after the frost melting period. The plate bearing tests were of two types: rupture tests and subgrade modulus tests. The rupture tests were made by loading a 24-inch diameter plate placed on the surface of the pavement at a corner of a slab made by the intersection of a longitudinal construction joint and transverse expansion joint. The edge of the plate was about three inches inside the slab edges. The following test procedure was followed: The plate was seated on a thin layer of sand. Two extensometers were placed in a line bisecting the right angle formed by the pavement joints. The load was applied in increments to give succesive loads of 20, 30, 35, 40, 45, 50, 55, and 60 thousand pounds. If the available load was not sufficient to cause failure, the load was released and reapplied by increments. This procedure was repeated until rupture occurred or for a total of five repetitions. The subgrade modulus tests were conducted on the surface of the base material, at the same location as the rupture tests, after the removal of part of the slab. The surface of the base was levelled by a thin layer of fine, dry sand to evenly seat the bearing plate. A load equivalent to five pounds per square inch, rapidly applied and released, was used to obtain additional seating of the plate before beginning the test. Deformations were measured by two extensometers bearing on opposite sides of the bearing plate. The extensometers were mounted on a beam independent of the influence of deflections caused by test loads. Load increments were applied at the rate of five pounds per square inch. Each increment was held constant until the increase in deformation for that increment of loading, during a five minute period, was less than three per cent of the total deformation for that increment. Loadings were applied until either a total deformation of 0.3 inches was obtained or the loading capacity of the equipment was reached. Only single cycle loadings were used to determine subgrade modulus. The load-deformation data obtained from the subgrade modulus tests were used to determine subgrade modulus by means of the formula $K = \frac{P}{0.05}$; where "K" is the subgrade modulus in lbs. per sq. in. per in. and "P" is equal to the pressure in pounds per square inch required to produce a vertical deformation of 0.05 inch in the test. A 19-inch diameter plate was used instead of a 24-inch diameter plate for the rupture tests at Dow Field during the normal period of the 1943-1944 investigations. The results of plate bearing tests, traffic tests and pertinent comments on the results are presented in the following paragraphs:

(1) PLATE BEARING TESTS. Rupture tests were conducted at Dow, Presque Isle, Truax, Watertown and Pierre Airfields. Subgrade modulus tests were conducted during the frost melting period at Dow, Presque Isle, Pierre, and Truax Airfields. It was intended that the tests be conducted during the fall and again during the frost melting period to compare the difference in bearing capacity between these periods. Only at Presque Isle were subgrade modulus tests conducted during both periods. At Dow, Watertown, and Pierre the tests were conducted during or after the frost melting period. At Truax Field subgrade modulus tests were conducted during the fall and rupture tests during frost melting. In the rupture tests, failure was reached before 0.2 inch deflection at Pierre and Watertown Airfields, and at Dow Field during the 1943-1944 investigations. Summary of results of plate bearing tests are presented in Tables 2 to 6 and average results are shown in Figure 12, Plates 2 to 8 inclusive.

(2) TRAFFIC TESTS ON CEMENT CONCRETE. Traffic tests were conducted on portland cement concrete pavement during the 1945 frost melting period at Truax Field in Test Area C (C1 and C2) and at Pierre Airfield in Test Area A (R2, R3, and R4). A summary of these traffic tests is presented in Sheet 1 of Table 7. The wheel loads used were consistent with the previous evaluation of the specific airfields. The traffic test wheel loads for Truax Field were 15,000 and 30,000 pounds and for Pierre Airfield 14,500 and 25,000 pounds. The wheel loads were obtained by loaded trucks and loaded A and B Tournapulls and scrapers. The equipment was the same as that used for the traffic tests conducted concurrently on bituminous concrete pavement. The application of traffic was made on the basis of 15 coverages per day which was considered equivalent to operation for runways and 45 coverages per day which was equivalent to operation for taxiways. With the equipment available, it was not always possible to apply exactly 15 and 45 coverages. Therefore, the nearest possible figure to these was used. The test lane was located with its center line over a construction joint and the traffic pattern was so designed to gradually attain by steps the maximum coverages in the test lane. Where the traffic equipment extended outside the test lane, these coverages are not considered as part of the test. The number of passes made by the equipment was kept to a minimum. Traffic tests were generally started just before the beginning of the frost melting

period and continued through the frost melting period or until imminent failure occurred. A test lane was considered to be in a condition of imminent failure when cracks appeared in about 20 per cent of the test lane area or when a vertical displacement was apparent. Plate 32 shows photograph of the cracks in a concrete slab considered failed after traffic test. It was attempted to keep pavement damage resulting from traffic tests at a minimum.

In Spring of 1944, traffic tests were conducted at Dow Field on a rigid pavement test area soon after the frost melting period. Wheel loads of 20,000 pounds were used for test area IV, 40,000 pounds for test area V, and 30,000 pounds for test area VI and VII. The number of coverages varied for each test area. The equipment used to obtain the wheel loads consisted of a Gar Wood scraper towed by a five yard truck and a Tournapull scraper. Sheet 2 of Table 7 presents a summary of these traffic tests.

h. INVESTIGATION OF TURFED AREAS. Investigations were conducted at two turfed areas ar Presque Isle, Dow and Watertown Airfields and at one turfed area at Pierre Airfield. Tests and observations were made for soil classification, availability of water for frost action, air and subsurface temperature, frost action, depth of frost penetration, and snow cover. At Dow and Presque Isle Airfields one of the two turfed areas was kept free of snow as far as practicable while the other turfed area was not plowed. It was the purpose of these tests to obtain a comparison of test results, particularly frost penetration, in turfed areas with and without snow cover and a comparison of turfed areas with paved areas. Results of tests in turfed areas are summarized in Table 1 and included on Plates 2 to 8 inclusive. The snowfall data for the various airfields were either obtained from the nearest United States Weather Bureau or from the Army Air Force Weather Officer. These data were augmented by measurements and observations at the specific airfields. At the turfed areas measurements of snow cover were made periodically.

i. TESTS FOR WATER INFILTRATION IN PAVEMENTS. Changes in moisture conditions were measured in the subgrade soil beneath expansion, contraction, and construction joints of the portland cement concrete pavements. The tests were made to determine the relative amount of water infiltration through the various joints during the fall and spring seasons. At Pratt, Great Bend, and Fairmont Airfields, the tests were made prior to the freezing period. At Sioux Falls and Watertown Airfields a comparison was obtained for moisture conditions during the fall and spring test periods. Water contents were obtained from auger hole samples.

Each auger hole was spaced at approximately 12-inch intervals with one hole directly over a joint and the remaining three holes on a line perpendicular to the joint. Soil moisture determinations were made at a depth of three inches below the bottom of the concrete pavement and thereafter at six-inch intervals to a depth of approximately five feet. No evidence of water infiltration was noted at the test areas.

7. ANALYSES.

In the following paragraphs, the results of the explorations, tests, measurements, and studies are analyzed and discussed with reference to the effect or relation each bears to the phenomenon of frost action and the results of frost action:

a. EFFECT OF WATER SOURCE ON FROST ACTION. For frost action to occur there must be a source of water. This water source may consist of a ground water table at the depth of freezing, a rise of water by capillarity from a relatively close ground water table to the freezing soil, or a flow of water from the soil voids of the adjoining unfrozen soil. There are a number of different methods by which the availability of water for frost action can be measured or indicated. These methods consist of measuring depth to ground water, measuring precipitation occuring prior to the freezing period, and measuring soil water content and degree of saturation before freezing. Results of these measurements and related data at all test areas are summarized in Sheet 1 and 2 of Table 8. From a study of these data the character and extent of frost actions are shown and the following analyses of results are presented:

(1) Extensive to slight frost action occurred in frost susceptible soils where the water table is less than 12 feet from the ground surface and where there is no stratum, such as a layer of clean sand, which will prevent the upward flow of water when freezing starts.

(2) Slight to no frost action occurred in frost susceptible soils where the water table is below 25 feet or where there is a stratum of clean sand above the water table which cuts off upward flow of water.

(3) The magnitude and extent of ice lenses formed ranged from a few exceedingly thin lenses to many thin to thick lenses, depending upon two related factors: the degree of saturation at start of freezing and the relationship between the natural water content at start of freezing and the Atterberg limits. The greater the degree of saturation, the greater the magnitude and extent of frost action. Frost action was negligible when the degree of saturation was less than 65 per cent. Soils with natural water contents below the plastic limit in the fall, prior to freezing, had negligible frost action. As the natural water content approached the liquid limit the degree of frost action increased.

(4) The degree of saturation beneath paved areas varied generally with the climatic conditions; the lower degree of saturation was found in the areas of low annual rainfall. The degree of saturation also varied generally with the depth to ground water; the higher the ground water table the greater the degree of saturation.

(5) At four test areas, frost heaving was maximum at the pavement edge and decreased toward the center with some test areas showing a slight settlement during the winter. This type of heaving appears to be caused by a flow of water from adjoining turfed area into the subgrade beneath the pavement. Greater heaving at edges than at center of pavements occurred only at test areas of bituminous concrete pavements without subsurface drains at pavement edges.

(6) At all concrete paved test areas, it appears that surface water infiltrating through joints into the base and subgrade prior to freezing augmented to a slight degree the available water for frost action. At three of these test areas the heaving of the cement concrete pavement was more uniform compared to adjacent bituminous paved areas and the settlement which occurred at three bituminous concrete paved test areas did not occur in the three cement concrete test areas.

b. EFFECT OF TEMPERATURE ON FROST ACTION. In general, the observations made do not indicate the effect of below freezing air temperature on frost action. For such a study, it will be necessary to carry out observations over a number of years at the same locations to investigate this effect. It is the general experience of highway engineers that the damaging effects of frost action at the same location vary from year to year depending upon the freezing index and availability of water.

c. EFFECT OF SOIL ON FROST ACTION. In all cases the base materials from each test area had slightly more than three per cent by weight finer than 0.02 mm. diameter with the exception of Test Areas A and B, Truax Field. However, only occasional ice crystals and in one instance a few ice lenses were found despite the slight frost susceptibility of the base material. These results may be considered a contradiction of the criteria; however, it may be explained on the basis that there was no readily available water supply except in the one instance where a few ice lenses were observed. In this case water is believed to have entered the base through joints in the pavement just prior to freezing and during the early stages of freezing when surface thawing occasionally occurred. Since the ice lense were observed in the base immediately beneath the pavement and not in depth this conclusion appears reasonable.

At Watertown and Fargo, organic soils were encountered within the depth of frost penetration. At both airfields, ice lenses were observed in the organic soil. From these observations it may be concluded, lacking further proof, that a slight organic content does not act to produce a non-frost susceptible soil.

The observations performed do not indicate which soils are more susceptible to frost action since other factors such as water availability and freezing index were different at the various locations tested and mask the effect of the soil type on frost action. However, other factors constant, the observations indicate that the finer grained soils are more susceptible to frost action than those with gravel and coarse sand sizes.

d. ANALYSIS OF FROST PENETRATION. The depth to which a pavement base and underlying subgrade will be frozen during a winter will depend principally upon (1) the magnitude and duration of below freezing air temperatures, (2) the coefficient of the thermal conductivities of the several materials in frozen state and to a lesser degree upon the other thermal properties and (3) the subsurface temperature conditions at start of freezing. All these factors were analyzed by W.P. Berggren whose solution is presented in a simplified form on Plate 22. It is realized that the prediction of frost penetration depends on the further study of thermal properties of soils in the frozen and unfrozen states and present theories for analyzing frost penetration are complicated by the changing water content while the soil freezes. However, it may be shown that the depth of frost penetration varies as the square root of the thermal conductivity of the frozen soil and as the square root of the reciprocal of the total heat required to freeze the soil.

A method of predicting the depth of frost penetration is shown on Plate 33. All observations of frost penetration beneath paved areas versus freezing index are plotted. The trend of the observations is a straight line when plotted on a log scale as shown. Figure 1 shows data for portland cement concrete pavements, Figure 2 is for bituminous concrete pavements, and Figure 3 contains the combined results. The same straight line is derived for each of these figures on the basis of the test data and is presented for design purposes in Appendix A, as Figure 3, Part XII, Chapter 4 of the Ad Interim Engineering Manual. This curve may be used to predict the depth of frost penetration beneath rigid and flexible pavements which are maintained snow free and have bases constructed of non-insulating materials such as sand, gravel, or crushed rock.

Based upon the tests for thermal conductivity conducted upon selected samples of base materials in unfrozen state it may be concluded that the thermal conductivity of slag and cinders is about one-half that of other base materials such as sand, sand and gravel, or crushed rock. Since the depth of frost penetration, all other conditions the same, varies with the square root of the coefficient of thermal conductivity in frozen state it may be concluded that the depth of frost penetration into cinders or slag would be about two thirds of that into sand, sand and gravel, or crushed rock. This conclusion is contingent upon cinder or slag having approximately the same ratio of thermal conductivity in the frozen state as in the unfrozen state to that of sand, sand and gravel or crushed rock.

The results of frost penetrations measured in the turfed areas with snow cover are summarized in the following table and compared with frost penetrations in adjacent paved areas.

LOCATION OF TURF TEST AREA	AVERAGE SNOW COVER DURING WINTER IN TURFED AREAS (Feet)	AVERAGE TOTAL FROST PENETRATION IN FEET		
		TURF	PAVEMENT	
			BIT.	P.C.C.
Dow Field	1.8	2.0	4.7	4.5
Presque Isle	2.5	3.0*	5.9	5.3
Watertown	0.75	3.5*	4.1	3.4
Pierre	0.75	0.5**	2.1**	3.5

These data indicated that snow cover and turf together provide an insulating blanket which retards frost penetration to a considerable magnitude.

A statistical study has been made of the normal freezing index with respect to geographical location in the United States. From this study a map, shown in Figure 2 of Appendix A, has been prepared on which are plotted contours of equal normal freezing indices for the United States. Using the freezing index obtained in Figure 2, the depth of frost penetration may be estimated from Plate 33 for any particular location in the United States. This value for frost penetration so determined is an average or normal value and not a maximum value.

* From Subsurface temperature readings at 32° F.

**Frost penetration 3 February 1945.

e. EFFECT OF FROST ACTION ON FLEXIBLE PAVEMENT SUPPORTING CAPACITY.

(1) TRUAX. At Truax Field no ice lens formation occurred in the crushed rock base and only a few lenses of hairline thickness were found in the sand clay gravel subbase. Numerous ice lenses were found in the subgrade at depths of 4.3 feet to about 4.7 feet. The heave in the traffic test area B1 and B2 ranged from 0.01 to 0.03 feet and was relatively uniform. Results of traffic tests are presented in Table 7. Traffic test areas B2 and B1, subjected to 30,000 and 60,000-lb. wheel loads respectively, were conducted using 45 and 15 coverages daily or as near these coverages as possible. The traffic tests were conducted through the frost melting period having been started on 11 March and continued through 3 April 1945. No failure or distress was obtained in traffic test area B2 with 30,000-lb. wheel load for 14 and 42 coverages daily for 10 days. The maximum vertical deflections were 0.5 inch, and no cracking occurred in pavement during the traffic tests. For the 60,000-lb. wheel load traffic test area B1, no cracking or failure occurred for 15 coverages, but failure occurred at 45 coverages for test duration of 19 days. Flexing of the pavement of 0.06 inch for the 15-coverage lane and about 0.24 inch for the 45-coverage lane was observed during the tests. Deformation of 0.6 to 0.8 inch and 1.0 to 1.5 inches occurred in the 15-coverage lane and 45-coverage lane respectively, and traffic was stopped because it was apparent that localized cracking would result if continued. The evaluation of the pavement is 30,000-lb. wheel load. This evaluation is controlled by the 2.5 inch thickness of bituminous concrete pavement. Disregarding the controlling 2.5 inch thickness of pavement, the evaluation is greater than 60,000-lb. wheel load. The 60,000-lb. wheel caused the greatest pavement damage at the turn around area. Flexing at the turnaround areas was about 0.4 inch and considerable map cracking and rutting occurred. The behavior of the pavement in this area is explained by an inferior subbase material and about four to five inches less crushed rock base than in traffic test areas B1 and B2. Based upon the traffic tests, C.B.R. values for the subgrade may be determined using the design curves, Engineering Manual, Part XII Chapter 2, February 1, 1946, Figure 2. These computations indicate the following C.B.R. values for the two traffic test areas.

TRAFFIC TEST AREA	WHEEL LOAD LBS.	DAILY COVERAGES	FAILURE	PAVEMENT AND BASE THICKNESS INCHES	C.B.R.
B1	60,000	15	No	53.5	>3
B1	60,000	45	Yes	53.5	<3
B2	30,000	15	No	53.5	>2
B2	30,000	45	No	53.5	>2

The C.B.R. values shown in the above tabulation represent the subgrade strength during the period of tests, and indicate an average C.B.R. value of three. In-place C.B.R. tests conducted during the frost melting period indicate an average value of three and tests conducted during the normal period indicate an average value of five. The traffic for test area B1 for 60,000-lb. wheel load for 45 coverages per day was stopped because of imminent failure. Therefore, this test may be considered to have failed the pavement. The traffic tests substantiate the C.B.R. value of three obtained during the frost melting period and this together with the reduction of the C.B.R. values from the normal period to the frost melting period from five to three indicate a reduction in pavement supporting capacity during the frost melting period.

The results of plate bearing tests also confirm a reduction in pavement supporting capacity during the frost melting period. Results of these tests shown in Table 7, and Plate 34, indicate that the ratio of the loads to produce a 0.1 inch deformation of the plate during the normal period to the frost melting period at an average thickness of frozen subgrade of 3.2 feet is 1.7. Similarly, in Table 7, the repeating plate bearing tests show that the same load in the normal period produced from 0.5 to 0.6 of the deflection obtained during the frost melting period.

(2) PIERRE. No ice lens formations were found in the sand and gravel base at Pierre Airfield; however, a few ice lenses were observed in the subgrade about 1.3 to 2.1 feet from the surface. The heave was non-uniform with a slight heave at the edges of paved shoulders and a slight subsidence in the center of the taxiway test area. The traffic test areas T1, T4, T5, T8, T9, T11 and T12 were located near the concentration of slight heave and the traffic test areas T2, T3, T6, T7, and T10 were located in areas of subsidence. Results of traffic tests are presented in Table 7. The traffic tests were conducted on the shoulder test areas and paved taxiway test areas using 7,000, 14,500, and 25,000-lb.

wheel loads for 14, 16, 32, 42, and 48 coverages daily. The paved shoulders, with 1.5 inches of bituminous concrete pavement, under wheel loads of 7,000, 14,500 and 25,000 pounds for 14, 16 and 48 coverages daily generally developed distressed areas shown by rutting and map cracking and can be considered failed under these loads. In the paved taxiway traffic test areas, with 5.5 inches of bituminous concrete pavement, failure occurred only at test area T2 under wheel load of 25,000 pounds and 42 daily coverages after seven days application of traffic. The evaluation for the normal period for the paved shoulders is 15,000-lb. wheel load based upon in-place C.B.R. tests. This evaluation is controlled by the 1.5 inch bituminous concrete pavement. The C.B.R. values for the subgrade may be determined from the results of the traffic tests using the design curves, Engineering Manual, Part XII Chapter 2, February 1, 1946 Figure 2. These computations indicate the following C.B.R. values for the traffic test areas in the paved shoulders where frost heaving occurred:

AREAS OF FROST ACTION

TEST AREA	WHEEL LOAD LBS.	DAILY COVERAGES	FAILURE	PAVEMENT AND BASE THICKNESS INCHES	C.B.R.
T1	14,500	15	Yes	13.5	<9
T4	25,000	45	Yes	13.5	<15
T5	14,500	45	Yes	13.5	<10
T8	25,000	15	Yes	13.5	<13
T9	7,000	45	Yes	13.5	<7
T11	7,000	15	Yes	13.5	<7
T12	25,000	(2 days traffic)	Yes	13.5	<15

A study of these C.B.R. values which represent the subgrade strength during the period of tests, indicates that the C.B.R. value was less than seven. In the following table are data for the traffic tests conducted where a slight settlement occurred during the winter and the pavement is 5.5 inches thick.

AREAS OF NO FROST ACTION

TEST AREA	WHEEL LOAD LBS.	DAILY COVERAGES	FAILURE	PAVEMENT AND BASE THICKNESS INCHES	C.B.R.
T2	25,000	45	Yes	13.5	<15
T3	14,500	15	No	13.5	>9
T6	25,000	15	No	13.5	>13
T7	14,500	45	No	13.5	>10
T10	7,000	45	No	13.5	>7

The C.B.R. values from these traffic tests were greater than seven and less than fifteen. A comparison of the results of the two sets of tests indicates a reduction in the pavement supporting capacity due to frost action. However, an indeterminate amount of the reduction in pavement supporting capacity may result from the difference in thickness of shoulder and central portion pavements even though the combined thickness of pavement and base was equal. The results of the C.B.R. tests conducted during the normal period and during the frost melting period indicated a reduction from 14 to 12. These tests were conducted in the area of pavement subsidence and no frost action. The small reduction in C.B.R. values can be attributed to soil and testing variations.

The plate bearing tests in the paved shoulder and central section indicate that during and after the frost melting period the paved shoulders which heaved slightly were much weaker than the central section which settled slightly during the winter. This conclusion is based upon both the static and repeating load tests. As pointed out previously, it cannot be stated how much of the indicated weakening is caused by frost action or difference in pavement thickness.

(3) DOW (1944-1945). At Dow Field ice crystals were found in the sand and gravel base in test areas B and C. Numerous ice lenses were located in the subgrade at depths ranging from three to five feet. The heave was fairly uniform averaging 0.25 foot. Traffic tests were conducted with 40,000 and 60,000-lb. wheel load for traffic test areas B1 and B2 and C1 and C2 respectively for 16 and 46 coverages daily. The traffic tests were started 1 April 1945, near the end of the frost melting period, and continued to 20 April 1945. Failure occurred in traffic test area B1 using a 40,000-lb. wheel load at 46 coverages daily and in traffic test area B2 using a 60,000-lb. wheel load at 16 coverages daily. Results of traffic tests are presented in Sheet 1, Table 7.

Photograph on Plate 31 shows failure in test area B1. No failure occurred in traffic test areas C1 and C2 for 40,000 and 60,000-lb. wheel loads respectively at either 16 or 46 coverages. Based upon these traffic tests, C.B.R. values for the subgrade can be determined from the design curves, Engineering Manual, Part XII, Chapter 2, February 1, 1946 Figure 2. The design curves indicate the following C.B.R. values for the four test areas:

TEST AREA	WHEEL LOAD LBS.	DAILY COVERAGES	FAILURE	PAVEMENT AND BASE THICKNESS INCHES	C.B.R.
B1	40,000	16	No	31	>4
B1	40,000	46	Yes	31	<5
B2	60,000	16	Yes	29	<6
C1	40,000	16	No	40.5	>3
C1	40,000	46	No	40.5	>3
C2	60,000	16	No	48	>3
C2	60,000	46	No	48	>3

A study of these C.B.R. values, representing the subgrade strength during the period of traffic test, indicates that an average C.B.R. of four was obtained. In-place C.B.R. tests conducted after traffic testing indicate an average value for the C.B.R. of three and tests conducted during the normal period indicate an average value of eight. Thus, both the traffic tests and the in-place C.B.R. tests are a measure of the reduction in pavement supporting capacity during the frost melting period. Further measurement of a reduction in pavement supporting capacity is obtained by the plate bearing tests performed upon the pavement surface. Results of these tests, shown in Table 7 and Plates 34, indicate that the ratio of loads to produce a 0.1-inch deformation of the plate in normal period to frost melting period at the average thickness of frozen subgrade of 0.9 foot is 1.6. Likewise, the repeating plate bearing tests show that the same load in the summer produced about 0.7 of the deflection obtained during the frost melting period. Moreover, these plate bearing tests indicate that the reduction in pavement supporting capacity occurs suddenly at the beginning of the frost melting period after which the subgrade gradually regains strength. From Figure 12, Plate 3, it is indicated that the return to normal supporting value requires at least three months on the basis of the loads required to produce a constant deflection of a 30-inch diameter test plate.

(4) DOW (1943-1944). No ice formations occurred in the base material during the winter of 1943-1944. Ice lenses were found throughout the subgrade which were thin and infrequent near the upper subgrade but closely spaced and averaging 0.25 inch in thickness at the depth of frost penetration. The pavement heave ranged from 0.00 to 0.40 foot in the traffic test areas. Results of traffic tests are shown in Sheet 2 of Table 7. Traffic tests, using wheel loads of 20,000 pounds on Test Areas I and II, and 10,000 pounds on Test Area III were conducted directly after the frost melting period, from 5 April to 5 May 1944. Test Area I, a circular track area, was found to be satisfactory for a 20,000-lb. wheel load at taxiway operation where the combined thickness of pavement and base was 21 or more inches overlying a glacial till subgrade of GC material. Another portion of the same area, with a combined thickness of pavement and base of 18 inches but overlying a silty clayey subgrade of CL material was found to be inadequate for any coverages of a 20,000-lb. wheel load during or directly after the frost melting period. Test Area II was satisfactory for a 20,000-lb. wheel load at taxiway operation. Test Area III, a circular track area, was considered unsatisfactory for a 10,000-lb. wheel load at taxiway operation where the combined thickness of pavement and base was 24 inches. This low supporting value is explained by a silty clay (CL) subgrade. Although relatively minor flexing and cracking occurred, it was believed that the pavement would not withstand one or more additional seasons of frost melting at the same test loads. Based upon these traffic tests, C.B.R. values for the subgrade can be determined by using the design curves, Engineering Manual, Part XII, Chapter 2, February 1, 1946, Figure 2. .These computations indicate the following C.B.R. values for the three test areas:

TEST AREA	WHEEL LOAD LBS.	DAILY COVERAGES	TOTAL COVERAGES	FAILURE	PAVEMENT AND BASE THICKNESS INCHES	C.B.R.
I*	20,000	4	72	Yes	18	<6
I**	20,000	50	523	No	21	>5
II*	20,000	44	386	No	33	>3
III*	10,000	50	965	Yes	24	<3

* Silty Clay Subgrade (CL)
**Glacial Till Subgrade (GC)

A study of the C.B.R. values for the silty clay subgrade, which represent the subgrade strength during the period of tests, indicates a C.B.R. range from less than three to less than six. In-place C.B.R. tests, conducted after the traffic testing, indicate an average C.B.R. value of five, and tests conducted in the normal period showed an average value of thirteen. Plate bearing tests (static and repeating load) were conducted during the normal and frost melting periods. As shown in Sheet 2 of Table 7, the ratio of loads required to produce a 0.1-inch deflection in normal to frost melting period is 1.5 for Test Area II and 1.9 for Test Areas I and III. The repeating load plate bearing tests show that the same load in the normal period produced 0.4 of the deflection obtained during the frost melting period. Thus the traffic tests, C.B.R. tests, and pavement bearing tests serve as a measure of the reduction in pavement supporting capacity during the frost melting period.

(5) PRESQUE ISLE. At Presque Isle Airfield, results of the plate bearing tests, both static load and repeating load, indicate a reduction of the pavement supporting capacity during the frost melting period as shown by results summarized on Table 2. Likewise, the results of in-place C.B.R. tests conducted during the normal and frost melting periods indicate a reduction of the pavement supporting capacity.

(6) WATERTOWN. At Watertown Airfield, frost action was confined to the pavement edges and none occurred at the center as evidenced by the results of pavement heave measurements. Plate bearing tests, both static and repeating load, were conducted during and immediately after the frost melting period in both the areas which heaved and those which did not heave. Tests conducted about one month after the end of frost melting period indicated in all but one case practically no change in pavement supporting capacity from that of the frost melting period. The exception was a set of repeating load tests located in an area which settled slightly during the winter and the results of these tests indicate a reduction in pavement supporting capacity. Comparing the results of static tests in shoulder areas which heaved with static tests in the center portion which settled slightly, a definite reduction in pavement supporting capacity is indicated. However, since the pavement thickness in paved shoulders is 1.5 inches compared with 5 inches in the center, this comparison may be discounted even though the total thickness of pavement and base was the same in the two areas. Although the C.B.R. tests indicate a reduction in C.B.R. during the frost melting period, this reduction is discounted for two reasons: (1) the subgrade soil at this site is exceedingly variable and even though the test locations were close together, slight differences in C.B.R. are probable due to

differences in soil and (2) no frost action occurred in areas tested for C.B.R. since these test locations are at points which settled slightly during the winter.

(7) CASPER. At Casper Airfield, a very small concentration of heave occurred at the shoulders and a slight subsidence occurred at the center of the taxiway pavement. C.B.R. tests conducted in the area of concentrated heave indicate no reduction in C.B.R. value of the subgrade from the normal to the frost melting period. Sufficient data are not available for comparison of test results between areas of subsidence and concentrated heave.

(8) FARGO. At Fargo Airfield, ice lens formations were numerous in the subgrade; however, none were observed in the subbase. The heave was uniform with an average of 0.07 foot. The results of C.B.R. tests conducted during the frost melting period has a value of six and during the normal period the C.B.R. value is seven. A slight decrease of pavement supporting capacity during the frost melting period is thus indicated.

(9) BISMARCK. At Bismarck Airfield, tests are insufficient to indicate whether or not there was any reduction in C.B.R. due to the slight amount of frost action which occurred as evidenced by the minor heave. Furthermore, the variations in subgrade soil at locations tested complicate the test results obtained. In general, it may be stated that any reduction in load supporting capacity during the frost melting period which would occur at this site would be minor.

(10) HOULTON. No ice lens formation occurred in the bituminous concrete pavement test area at Houlton Airfield. The heave was uniform and ranged from zero to 0.05 foot. Sufficient data are not available for a comparison of results of C.B.R. tests conducted during the frost melting period and normal period. On basis of estimated C.B.R. results based on laboratory compacted samples, a slight decrease in C.B.R. may be shown during the frost melting period.

(11) OTIS. At Otis Field, ice lens formation occurred in pockets of sandy silts resulting in non-uniform heave. The results of the C.B.R. tests indicate a reduction in C.B.R. during the frost melting period; however, because of the non-uniform subgrade at Otis with scattered pockets of sandy silt it is not possible to definitely attribute the reduction to frost action.

(12) SIOUX FALLS. At Sioux Falls Airfield, a few ice crystals formed in the base course and ice lenses in the subgrade.

Pavement heave was negligible being 0.05 foot average and was concentrated at the edge of pavement. The results of C.B.R. tests conducted on top of the base and subgrade during the frost melting period indicate approximately 0.5 the value obtained during the normal period, thus indicating a decrease of pavement supporting capacity during the frost melting period.

(13) GARDEN CITY. At Garden City Airfield, the frost action was negligible and no visible ice lenses were encountered. The pavement heave was a negligible amount of only 0.01 foot. The C.B.R. was obtained during the normal period on the base and subgrade and averaged 22 and 17, respectively. No comparison was made for conditions during the frost melting period, but it is indicated from the minor amount of frost action that the pavement supporting capacity has only a slight reduction during the frost melting period.

(14) SUMMARY. The traffic tests performed at Pierre, Truax, and Dow Airfields, the pavement bearing tests performed at Presque Isle, Dow, Pierre, Watertown and Truax Airfields and the C.B.R. tests performed at all the airfields indicate that a reduction in flexible pavement supporting capacity occurs during the frost melting period as a result of frost action in the subgrade. The best measure of the reduction is by a comparison of C.B.R. values during the frost melting period with those during the normal period as obtained from both traffic tests and in-place C.B.R. tests.

The traffic test data are inadequate to determine the magnitude of reduction of pavement supporting capacity with various degrees of frost action. However, the plate bearing tests on the pavement surface, as summarized on Plate 34, indicate that the reduction of pavement supporting capacity apparently is not influenced by the thickness of frozen subgrade. The in-place C.B.R. tests conducted during the frost melting period and normal periods indicate a reduction of the pavement supporting capacity during frost melting period.

For the design of flexible pavements in areas where frost action is encountered, design curves as shown in Appendix A, Figure 4, Part XII, Chapter 4, Ad Interim Engineering Manual have been drawn based upon the reduced strength as indicated by the traffic tests, plate bearing tests, and C.B.R. tests.

f. EFFECT OF FROST ACTION ON RIGID PAVEMENT SUPPORTING CAPACITY.

(1) TRUAX. At Truax Field, ice lens formations occurred

in the top four inches of the base and ice lenses adhered to the bottom of the pavement. No other ice lens formation occurred in the base; however, numerous ice lenses formed in the subgrade at depths of 3.0 to 4.7 feet. The pavement heave ranged from 0.08 foot to 0.12 foot in the traffic test areas. Results of traffic tests are shown in Table 7, sheet 1. Traffic tests using 15,000 and 30,000-lb. wheel loads at 45 and 18 coverages daily were conducted through the frost melting period from 7 to 20 March 1945 inclusive. No failure was obtained with the 15,000-lb. wheel load; however, progressive cracking developed for the 30,000-lb. wheel load and the traffic test area C2 was considered failed. Pumping of water at the joints occurred in both these tests except during the last three days of traffic application. In traffic test area C1, previously tested with 15,000-lb. wheel load, a 30,000-lb. wheel load traffic test was conducted from 21 March to 3 April 1945, after the frost melting period. No failure occurred and no pumping of water at the joints occurred. The evaluation of the pavement during the normal period is 35,000-lb. wheel load for runways, and 28,000-lb. wheel load for taxiways and apron. For purposes of analyses, it is assumed that average maximum daily plane traffic over taxiways and aprons is 15 and 45 coverages respectively.

The pavement was satisfactory for 15 and 45 coverages of a 15,000-lb. wheel load, failed under 45 daily coverages but did not fail under 15 daily coverages of the 30,000-lb. wheel load during the frost melting period. Directly after the frost melting period, the pavement did not fail under 15 and 45 daily coverages of 30,000-lb. wheel load. The failure of the pavement during the frost melting period under only 14 daily coverages of the 30,000-lb. wheel load compared to the normal period evaluation for aprons of a 28,000-lb. wheel load indicates a reduction in pavement supporting capacity during the frost melting period. A reduction is also indicated since a 30,000-lb. wheel load was satisfactory directly after the frost melting period, although it is recognized that traffic was applied for a relatively few number of total coverages. The reduction in pavement supporting capacity is due directly to the ice lens formation in the top four inches of the gravel base as the ice lens formation in the subgrade was at a depth which is considered too great to be effective under a 30,000-lb. wheel load. Pumping of water through the joints and cracks carried out fines from the base beneath the pavement and undoubtedly resulted in a weakening of the subgrade support at these points. It is believed that pumping would not have occurred if the base had consisted of a non-frost susceptible material.

The plate bearing tests (rupture) conducted during the frost melting period with total load of 60,000 pounds did not crack the pavement at a maximum deflection of 0.16 inch. No observations for deflections under moving or static wheel loads were obtained during the traffic test. Plate bearing tests (subgrade modulus) were conducted only during the normal period.

(2) PIERRE. At Pierre Airfield, there was no ice lens formation in the base and practically none in the subgrade. The heave, ranging from zero to 0.02 foot was uniform. Results of traffic tests are shown in Table 7, Sheet 1. Traffic tests using 14,500 and 25,000-lb. wheel loads were conducted from 14 to 29 March 1945 which was directly after the end of the frost melting period. For each test daily coverages of 15 and 45 were applied. Additional tests of 178 daily coverages were conducted using 14,500 and 25,000-lb. wheel loads in traffic test areas R2 and R3 from 30 March to 4 April 1945. Total coverages for the additional traffic tests were 1611 for traffic test area R2 and 1698 for R3. During the period 14 to 29 March, no failure was obtained with the 14,500-lb. wheel load at both 15 and 45 daily coverages and the 25,000-lb. wheel load for 15 coverages, but failure did occur almost at start of traffic for 45 coverages. The additional concentrated traffic by 14,500-lb. wheel load on traffic test areas R2 and R3 with increased daily coverages produced no failure but produced additional failure for the 25,000-lb. wheel load on traffic test area R3. The evaluation of the runway pavement during the normal period is a 30,000 lb. wheel load and for taxiway and aprons the evaluation is a 25,000-lb. wheel load. The failure is attributed primarily to pumping during traffic, resulting from the infiltration of surface water through the pavement joints, and not to frost action. This conclusion is substantiated by the rapid increase in pumping and cracking of the pavement following a rainfall.

The plate bearing tests (rupture) conducted after the frost melting period caused failure in the pavement at total loads ranging from 72,000 to 90,000 pounds at deflection of 0.18 inch and 0.24 inch respectively. The deflections produced by the 25,000-lb. wheel load in traffic test area R3 where failure occurred under moving load was 0.052 inch and for static load 0.003 inch.

(3) WATERTOWN. The plate bearing tests (rupture) at Watertown Airfield indicated corner failure of the pavement with maximum load of 100,000 pounds at deflections of 0.18 inch, 0.32 inch and 0.35 inch. These tests were conducted directly after the frost melting period and no tests were made during the normal period. -

(4) DOW AND PRESQUE ISLE. Pavement bearing tests (rupture) were made only during the frost melting periods at these

airfields. Failure of the pavements was not obtained at Presque Isle and Dow Airfields at maximum load of 60,000 pounds for deflections 0.16 and 0.19 inch respectively. The plate bearing test (subgrade modulus) was conducted at both airfields. At Presque Isle Airfield, the maximum ratio of normal to frost melting period load for 0.1 inch deflection for the subgrade modulus tests were 1.0 and 1.5 for two tests.

(5) DOW (1944 TRAFFIC TESTS). At Dow Field, no ice formations occurred in base material during the winter of 1943 and 1944. Ice lenses were found throughout the subgrade and ranged from thin and infrequent near the upper limits of subgrade material to closely spaced and averaging 0.25 inch in thickness at the depth of frost penetration. The pavement heave ranged from 0.30 to 0.70 foot in the traffic areas. Results of traffic tests are shown in sheet 2 of Table 7. Traffic tests, using wheel loads of 20,000 pounds on Test Area IV, 30,000 pounds on Test Areas VI, VII, and 40,000 pounds on Area V, were conducted during and directly after the frost melting period, from 25 April to 9 May 1944. Test Area IV withstood 25 daily coverages of a 20,000-lb. wheel load for 11 days and was not considered to have failed. Imminent failure occurred, due to excessive cracking after a few coverages of the 40,000-lb. wheel load on Test Area V. Traffic test area VI was considered to have failed at 13 daily coverages for 5 days with 30,000-lb. wheel load. A 30,000-lb. wheel load with 230 passes per day for 7 days caused only minor cracking on Test Area VII. Results of this test in Test Area VII cannot be used in determining the pavement bearing capacity since it was performed on the thickened edge of the slab. Since pavement failed at 30,000-lb. wheel load and was satisfactory for 20,000-lb. wheel load at which the pavement was just adequate was between 20,000 and 30,000-lb. wheel load. The evaluation of the pavement is 32,000-lb. wheel load for taxiway and 40,000-lb. wheel load for runway pavement during the normal period. A reduction in the bearing capacity of the pavement is indicated due to frost action.

Two plate bearing tests (rupture) were conducted during the frost melting period and resulted in cracking of the pavement by loads of 60,000 and 48,000 pounds at deflections of 0.28 and 0.20 inch respectively. Another pair of rupture tests were conducted adjacent to these tests during the normal period and cracking occurred at loads of 76,000 and 80,000 pounds with deflections of 0.21 and 0.18 inch respectively. Deflections of 0.1 inch were obtained during these tests by loads of 50,000 pounds during the normal period and 28,000 pounds during the frost melting period. The results of the plate bearing tests indicate a definite reduction in the pavement supporting capacity during or directly after the frost melting period.

(6) SUMMARY. At Truax and at Dow Airfields, the traffic tests indicate a definite reduction in pavement supporting capacity due to frost action. At Pierre Airfield the results of traffic tests indicate that failure of the pavement was due to pumping resulting from infiltration of surface water and not frost action. The application of the traffic test results obtained at Truax Field to the establishment of design criteria is limited to the principal conclusion that a non-frost susceptible base material should be provided beneath concrete pavements. Such a base at Truax Field would be of three benefits (1) eliminate the ice lenses which formed directly beneath the pavement, (2) provide a layer through which the water infiltrating through joints and cracks can be drained away, and (3) eliminate pumping under traffic. Likewise, the traffic tests at Pierre Airfield show clearly the necessity for a non-frost susceptible base course beneath concrete pavements to eliminate failures due to pumping.

For the design of rigid pavements in areas where frost action is encountered, design curves as shown in Appendix A, Figure 5, Part XII, Chapter 4, Ad Interim Engineering Manual, have been drawn based upon the reduced strength as indicated by the traffic tests, rupture tests, and subgrade modulus tests. On Plate 35 are plotted the results of the subgrade modulus tests obtained at Pierre, Presque Isle, and Dow Airfields during the frost melting period. Curve "A" represents the trend of the tests. The test results have been superimposed on the design curves shown on Figure 5 of Appendix A. The type of subgrade soils at all of these airfields falls into group 3. It will be noted from Plate 35 that there is not a close agreement with Curve A and curve designated "3." The three design curves were purposely drawn to indicate conservative values for the subgrade modulus during the frost melting period. It is considered that the data available to date are exceedingly limited and do not necessarily indicate the most severe conditions that may occur during the frost melting period.

8. DESIGN CRITERIA.

Criteria have been formulated for the design of flexible and rigid pavements in areas subject to frost action. Appendix A of this report contains these criteria which are included in the Ad Interim Engineering Manual, Part XII, Chapter 4. The method of design outlined in Chapter 4 is based upon the results of this investigation. However, since the subject is complex and not readily suited to the establishment of exact criteria, some of the statements are based upon previous experience with frost action by the consultants and personnel associated with this investigation. The design procedure will be checked by additional investigations and revisions will be made as required.

9. CONCLUSIONS.

Based upon the analyses of the data presented herein, Chapter 4, Part XII, Ad Interim Engineering Manual, "Frost Conditions," Airfield Pavement Design, is satisfactory for design of airfield pavements and evaluation of airfield pavements in areas subject to frost action.

10. RECOMMENDATIONS.

It is recommended that observations and tests for frost action be continued over a period of several years to investigate further the effect of frost action upon pavement supporting capacity, particularly with respect to rigid pavements.

II. BIBLIOGRAPHY.

* Aaron, H. "Frost Heave in Highways and Its Prevention". Public Roads, Vol. 15, No. 1, pp. 10–16+, March 1934.

Agafonoff, V. and Pavlovitch, St. "L'Analyse dite Thermique, Appliquee a L'etude du Sol." Academie des Sciences C.R., Vol. 197, pp. 166–168, July 10, 1933. (In French).

* Anderson, A.B.C., Fletcher, J.E., and Edlefsen, N.E. "Report of Committee on Physics of Soil-Moisture, 1941-42 (Soil-Moisture Conditions and Phenomena in Frozen Soils)". Transactions, American Geophysical Union, pp. 355–371, 1942.

Angstrom, A. and Petri, E. "New Ground Thermometer and Some Observations on the Ground Temperature in the Vicinity of Stockholm". Teknick Tidskrift. Vol. 58, pp. 237–241, June 9, 1928. (In Swedish)

* Atkinson, H.B. and Bay, C.E. "Some Factors Affecting Frost Penetration". Transactions, American Geophysical Union. pp. 935–951, 1940.

Baver, L.D. "Soil Temperature" Soil Physics, Chapter VIII, pp. 267–289, Wiley & Sons 1940.

* Belotelkin, K.T. "Soil-Freezing and Forest-Cover". Transactions, American Geophysical Union, pp. 173–175, 1941.

* Benkelman, A.C. "Studies of Frost Heaves in Michigan". Roads and Streets, Vol. 71, pp. 272-276, July 1931.

* Benkelman, A.C. and Olmstead, F.R. "A New Theory of Frost Heaving". Highway Research Board, Vol. II, pp. 152–177, 1932. (Discussion by A. Casagrande, W.I. Watkins, S. Taber).

* Berggren, W.P. "Prediction of Temperature Distribution in Frozen Soils". Transactions, American Geophysical Union. pp. 71–77, 1943.

* Beskow, G. "Prevention of Detrimental Frost Heave in Sweden". Highway Research Board, Proc. 18th Meeting, Part II, pp. 366–370, 1938.

* Copy on file at Frost Effects Laboratory.

* Beskow, G. "Soil Freezing and Frost Heaving". Sveriges Geologiska Undersokning, Stockholm, 1935 Series CV, No. 375, 242 pages. (Translated into English by J. Osterberg).

* Beskow, G. "Soil Freezing and Frost Heaving". Public Works, Vol. 67, pp. 41-42, February 1936. (Abstract).

Buoyoucos, G.J. "Movement of Soil Moisture from Small to the Large Capillaries of the Soil Upon Freezing". Journal of Agricultural Research, Vol. 24, pp. 427-431, 1923.

Bouyoucos, G.J. "Soil Temperatures." Mich. Agr. Coll. Exp. Station Bulletin No. 26.

* Bouyoucos, G.J. "Degree of Temperature to Which Soils Can Be Cooled Without Freezing". Journal of Agricultural Research, Vol. 20, No. 4, pp. 267-269, Nov. 15, 1920.

Bouyoucos, G.J. "Classification and Measurement of Different Forms of Water in the Soil by means of the Dilatometer Method". Mich Agric. College, Teach.-Bull, No. 36, pp. 48, 1917.

Bouyoucos, G.J. "Further Studies on the Freezing Point Lowering of Soils". Michigan Agricultural College, Bulletin 31, 1916.

Bouyoucos, G.J. "An Investigation of Soil Temperature and Some of the Most Important Factors Influencing It". Michigan Agricultural College, Bulletin 17, 1913.

Bridgman, P.W. "Effect of Pressure on the Freezing Point of Water". Smithsonian Phys. Tables, 200 Pages, 1921.

Buetow, W.C. "Causes and Control of Damaging Frost Action in Shoulders and Subgrade". 8th Annual Asphalt Pavement Conference. 1929

* Burton, V.R. "Application of Soil Science to Highway Engineering". Roads and Streets, Vol. 71, pp. 163-165, May 1931.

* Burton, V.R. and Benkelman, A.C. "Frost Action in Silt Soils Defined by Field and Cold Room Studies". Engineering News-Record, Vol. 106, pp. 266-270, Feb. 12, 1931.

Burton, V.R. and Benkelman, A.C. "Frost Action and Relocated Troubles with Paved Roads". Engineering News-Record, Vol. 105, pp. 980-981, Dec. 18, 1930.

• Casagrande, A. "Discussion of Frost Heaving". Proceedings Highway Research Board, Vol II, Part 1, pp. 168-172. 1932.

Casagrande, L. "Lessons from Frost Damage to Roads". Roads and Bridges, Vol. 80, pp. 100, Feb. 1942. (Abstract).

• Clark, K.A. "Some Examples of Frost Boils Occurring on Alberta Highways". The Canadian Engineer, Vol. 69, pp. 7-10, Sept. 10, 1935.

• Collins, A.R. "Destruction of Concrete by Frost". Journal of the Institution of Civil Engineers (London), No. 1, Nov. 1944. (Abstract in "H'way Research Abstracts", Jan. 1945).

Day, P.R. and Bodman, G.B. "Thermoelectric Method of Determining the Freezing Points of Soils". Proc. Soil Sci. Soc. Amer., pp. 65-71, 1937.

• Dockstader, E.A. "Effect of Freezing and Thawing of Soil Under Foundations of Cold Storage Warehouse". Proc. of the International Conference on Soil Mechanics and Foundation Engineering. Vol. III, pp 171-172, June 1936.

Duecker, A. "Experimental Study of Effect of Texture on Freezing of Non-Cohesive Soils; Freezing of Texture Fractions of Soils and their Mixture". Forschungsarbeiten aus dem Strassenwessen, Bulletin 17, 1939. (In German).

• Duecker, A. "Soils Colloids and Their Behavior When Subjected to Frost Action". (Ueber "Bodenkolloide" und ihr verhalten bel frost) (From Der Bauingenieur Vol. 23, pp. 235-237. August 5, 1942; translated by H.B. Edwards, Engineer Department Research Centers, Vicksburg, Miss., Dec. 1944, 11 pages, Tr. 141, 44-40).

Edlefson, N.E. and Anderson, A.B.C. "Thermodynamics of Soil Moisture". Hilgardia, (in press 1942).

• Elgar, W.H. "Soil Movements as Affecting Paved Surfaces". Public Works, Vol. 75, pp. 17-18+, December 1944, (Abstract from "The Surveyor")

• Emrey, D.J. "Subgrade Soils, Their Analysis and Drainage". The Canadian Engineer, Vol. 72, pp. 5-9, Mar. 23, 1937.

Endell, K., Loos, W., and Breth, H. "Report on original experimental studies of relation between freezing of soils and its physical properties; condition of soil colloids, water capacity, water perviousness and capillary phenomena". Forschungsarbeiten aus dem Strassenwessen, Bulletin 16, 1939, 655 pages. (In German).

* Eno, F.H. "The Influence of Climate on the Building, Maintenance and Use of Roads in the United States". Highway Research Board, Vol. 9, pp. 211-243, 1929.

Ewdokimow, I. and Rokotowsky. "Bouten in Ewiggefrerenen Boden in Siberien". Bauingenieur, Vol. 14, pp. 224-226, April 14, 1932. (In German).

* Fuller, H.U. "Studies of Frost Penetration". Journal of the New England Water Works Assoc., Vol. 54, No. 3, pp. 275-281, Sept. 1940.

* Fuller, H.U. "Frost Penetration as Affected by Weather and Snow Conditions". Journal of the New England Water Works Assoc., Vol. 50, pp. 299-301, Sept. 1936.

* Garneau, J.B. Discussion: "Soil Stabilization and Prevention of Frost Heaves". The Canadian Engineer, Vol. 77, pp. 52-54, Sept. 19, 1939.

Gilkey, H.J. "Freezing Ground Acts Like Hydraulic Jack". Engineering News-Record, Vol. 79, pp. 360-361, August 23, 1917.

Goodell, B.C. "Soil Boring Tool for Frost Depth Determination". Journal of Forestry, Vol. 37, No. 6, pp. 457-459, June 1939.

Harrington, E.L. "Soil Temperatures in Saskatchewan". Soil Science, Vol. 25, pp. 183, 1928.

* Hieronymus, G. "Earth Ambient Temperatures for Cable Loading Limits". Electrical World, pp. 92-93, December 9, 1944.

* Highland S.G. "Study of Year-Round Soil Temperatures". Journal American Water Works Association, Vol. 16, pp. 342-354, Sept. 1926.

* Ingersoll, L.R. and Koepp, O.A. "Thermal Diffusivity and Conductivity of Some Soil Materials". Physical Review, Vol. 24, pp. 92-93, July 1924.

Ivie, J.Q. and Richards, L.A. "Meter for Recording Slow Liquid Flow". Review of Scientific Instruments, Vol. 8, No. 86-89, March 1937.

* Jurgenson, L. "Field Test for Identification of Soils Capable of Frost Heaving". Proc. of the International Conference on Soil Mechanics and Foundation Engineering, Vol. II, pp. 320, June 1936.

* Keen, B.A. "Soil Temperature". Physical Properties of the Soil. Chapter IX, pp. 297-333, Longmans Green & Co., 1931.

* Keil, K. "Results of Frost Action on Experimental Road" (Abstract). Public Works, Vol. 70, pp. 49-50, Sept. 1939.

Keen, B.A. and Russell. "The Factors Determining Soil Temperatures". Journal of Agricultural Science, Vol. II, pp. 211-240, 1921.

Krischer, O. "Experiments on heat conductivity of soils; principally quartz and calcareous sands, lime and clay. Effect of dampness, texture, porosity, temp. etc. on thermal conductivity". Published by Munich & Berlin, R. Oldenbourg, 1934. (In German).

* Lewis, M.R. "Rate of Flow of Capillary Moisture". U.S. Dept. of Agriculture, Tech. Bull. No. 579, 29 pages, Oct. 1937.

* Mackintosh, A. "Progress Report on an Investigation of Frost Action in Soils". Proc. of the International Conference on Soil Mechanics and Foundation Engineering, Vol. II, pp. 260-262, June 1936.

Mail, G.A. "Soil Temperatures at Bozeman, Montana, during Sub-Zero Weather". Science, Vol. 83, pp. 574. June 12, 1936.

* McLeod, N.W. "Soil Science Applied to Subgrade and Base Course Design". The Canadian Engineer, Vol. 77, pp. 5-6, Aug. 1, 1939.

* Mersman, W.A. Berggren, W.P., Boelter, L.M.K. "The Conduction of Heat in Composite Infinite Solids". University of California Publications in Engineering - Vol. 5. No. 1, pp. 1-22, Dec 15, 1942.

* Meyer, E.V. "Cell Concrete". 25 Years of Civil Engineering, Christiani and Nielsen, 1904-1929, pp. 139-153.

Miller, H.H., and Smith, D.M. "Methods for Prevention of Road Failures Due to Frost". Roads and Streets, Vol. 77, pp. 219-221, June 1934.

Miller, H.H., and Smith D.M. "Prevention of Frost Heaving in Roads". Roads and Streets, Vol. 78, pp. 273-274, Aug. 1935.

* Morton, J.O. "The Application of Soil Mechanics to Highway Foundation Engineering". Proc. of the International Conference on Soil Mechanics and Foundation Engineering, Vol. I, pp. 243-247, June 1936.

* Morton, J.O., Tremper, B., Stokstad, O.L., Casagrande, L. "Prevention of Detrimental Frost Heave". Highway Research Board, Proc. 18th Meeting, Part II, pp. 356-365, 1938.

* Motl, C.L. "Curing Minnesota Frost Boils by Drains". Engineering News-Record, Vol. 106, pp. 270-272, Feb. 12, 1931.

* Mullis, I.B. "Illustrations of Frost and Ice Phenomena". Public Roads, Vol. II, No. 4, pp. 61-68+, June 1930.

* Norgaard, H. "Long-Distance Heating Systems Insulated with Cell Concrete". 25 Years of Civil Engineering, Christiani and Nielsen, 1904-1929, pp. 154-169.

* Osterberg, J.O. "A Survey of the Frost Heaving Problem". Civil Engineering, Vol. 10, No. 2, pp. 100-102, Feb. 1940.

* Paradis, A. "Foundations and Protection Against Frost Heaving". The Canadian Engineer, Vol. 67, pp. 21-24, Oct. 16, 1934.

* Patten, H.E. "Heat Transference in Soils". U.S. Department of Agriculture, Bulletin No. 59, Sept. 1909.

* Rucklie, R. "Frost Damage in Highway Subgrades". Strasse and Verkehr, Vol. 29, No. 19-22, 24-25, Sept. 17-Dec. 10, 1943. (Translation in English by Engineer Dept., Research Centers. Translation No.44-27.)

* Schaible, L. "The Repair of Frost Damage". Highway Research Abstracts, No. 118, Page 4, March 1945. (Abstract of Article in "Strasse" 1942 9(17/18), pp. 173-176).

* Shanklin, G.B. "The Effects of Moisture on the Thermal Conductivity of Soils". Journal American Institute of Electrical Engineers, Vol. 41, pp. 92-98, Feb. 1922.

* Shannon, W.L. "Frost Investigations at Dow Field, Bangor, Me.". Proc. Highway Research Board. Vol. 24, pp. 71-86, 1944.

* Shannon, W.L. "Prediction of Frost Penetration". Journal of the New England Water Works Association, Vol. LIX, No. 4.

* Slate, F.O. "Use of Calcium Chloride in Subgrade Soils for Frost Prevention". Proc. Highway Research Board, pp. 422-441, 1942.

* Smirnoff, A. "Soil Temperatures and Cable Rating". Electrical World, Vol. 82, pp. 438-439, Sept. 1, 1923.

Smith, A. "A Contribution to the Study of Interrelations between the Temperature of Soil and the Atmosphere and a New Type of Thermometer for such Study". Soil Science, Vol. 22, pp. 447, 1926.

Sourwine, J.A. "Art of Preparing an Earthen Foundation". U.S. Patent Office, Patent No. 2162185, 1939.

* Sourwine, J.A. "A Method of Analysis of Data on Frost Occurrence for Use in Highway Design". Public Roads, Vol. 11, No. 3, pp. 51-60, May 1930.

Stucky, A. and Bonnard, D. "Theory of Formation of Frozen Lenses in Soils; Application of Theory to Study of Soil Freezing in Subgrades of Several Swiss Highways". Bul. Technique de la Suisse Romande, Vol. 64, No. 7, pp. 85-92, March 26, 1938.

* Taber, S. "Freezing and Thawing of Soils as Factors in the Destruction of Road Pavements". Public Roads, Vol. 11, No. 6, pp. 113-132, August 1930.

* Taber, S. "The Mechanics of Frost Heaving". Journal of Geology, Vol. 38, pp. 303-317, 1930.

* Taber, S. "Frost Heaving". Journal of Geology, Vol. 37, pp. 428-461, 1929.

Taber, S. "Surface Heaving Caused by Segregation of Water Forming Ice Crystals". Engineering News-Record, Vol. 81, pp. 683-684, 1918.

* Taber, S. "Pressure Phenomena Accompanying the Growth of Crystals". National Academy of Science, Vol. 3, pp. 297-302, April 1917.

* Taber, S. "The Growth of Crystals Under External Pressure". American Journal of Science, Vol. 16, pp. 532-556,, 1916.

* Thompson, W.A. "Soil Temperature at Winnipeg, Manitoba". Scientific Agriculture, Vol. 15, pp. 299, 1934.

Tzitovitch, N.A. and Sumgin, M.I. "Principles of Mechanics of Frozen Grounds". Academy of Sciences of USSR, 1937, 432 pages. (In Russian).

Tzarevich, K.A. and Yablonsky, V.S. "Study of Heat Conductivity of Soils as Function of their Composition, Presence of Salts, and Moisture". Nephtyanoye Khazyaistvo, Vol. 2, pp. 190-195, Feb. 1931. (In Russian).

West, E.S. "Effect of Soil Mulch on Soil Temperature". Council of Science and Industrial Research, Vol. 5, No. 4, pp. 236-246, Nov. 1932.

* Williams, M.A. "What Causes the Spring Break-Up?" Better Roads, pp. 22-23, Nov. 1945.

* Winn, H.F. and Rutledge, P.C. "Frost Action in Highway Bases Subgrades". Purdue University Engineering Experiment Station. Ser. 73, 100 pages, 1940.

* Winn, H.F., Lang, F.C., Skelton, R.R., Bennett, E.F., Belcher, D.J. "Symposium of Frost Action". Proceedings of the Purdue Conference on Soil Mechanics and Its Applications, Sect. VII, pp. 444-482 July 1940.

* Wintermyer, A.M. "Percentage of Water Freezable in Soils". Public Roads, Vol. 5, pp. 5-8, Feb. 1925.

Special Comm. of H'way. Research Board. Progress Report of Committee on "Treatment of Subgrade Soils with Calcium Chloride to Prevent Detrimental Frost Action". Highway Research Abstracts, No. 118, pp. 9-10, March 1945.

Corps of Engineers, U.S. Army. "Investigation of Airfield Construction in Arctic and Subarctic Regions". (Confidential). Report 881, October 28, 1944.

U.S. Geological Survey, "Permafrost or Permanently Frozen Ground and Related Engineering Problems". Special Report Strategic Engineering Study, No. 62, 136 pages, March 1943.

* "Frost Penetration Studies at Portland, Maine". Engineering News-Record, Vol. 116, pp. 536, April 19, 1936.

* "Ice-Pressure Determinations in Clay Soils". Engineering News-Record, Vol. 115, pp. 127, July 25, 1935.

"Mitigating Frost Action on Road Surfaces". Engineering News-Record, Vol. 1, 104, pp. 1021-1023, June 19, 1930.

* "Heavy Frost Damage to Roads Follows Open Winter". Engineering News-Record, Vol. 100, pp. 668-669, April 26, 1928.

"Extent of Frost Penetration in Soils". Engineering and Contract Record, Vol. 50, pp. 11, Sept. 8, 1937.

* From Calcium Chloride Assoc. News. "Preventing Spring Breakup of Roads". Public Works, Vol. 75, pp. 18, Aug. 1944.

* Road Abstracts" from Bauingeneur. "Frost Heaving in Road Subgrades". Public Works, Vol. 74, pp. 44-45, Sept. 1943.

"Mechanics of Frost Heaving". Roads and Bridges, Vol. 81, pp. 84-85, May 1943.

"How Can Frost Boils be Prevented". Roads and Bridges, Vol. 80, pp. 26+ Nov. 1942.

"Tile Drains Solve Frost-Boil Problem". Roads and Streets, Vol. 71, pp. 257-258, July 1931.

"Problems of Porous Bodies and their Behavior as Building Materials". Journal of the Sec. of Chemical Industry (British), Vol. 53, pp. 397T-402T, December 28, 1934.

"Freezing of Foundation Soil under Cold Storage Buildings". Building Science Abstracts (British Pub.), Vol. 16, pp. 41, March 1943.

* "Frost Penetration in Ground in 100 Cities". Heating and Ventilating, Vol. 35, pp. 53-56, June 1938.

* Frost Investigation 1944-1945, "Comprehensive Report," Frost Effects Laboratory, Corps of Engineers, New England Division, Boston, Mass., February, 1947.

* "Report on Frost Investigation and Pavement Behavior Tests, Dow Field, Bangor, Maine". Corps of Engineers, U.S. Engineer Office, Boston, Mass., January 1946.

SITE	FREEZING INDEX			PRECIPITATION (3 MO. PRIOR TO FREEZING)			TEST AREA	SURFACE		PAVEMENT HEAVE (FEET)			MAX. DEPTH OF FROST (FEET)	UNDERLYING MATERIAL			WATER CO (PERCENT DRY	
	NORMAL DEGREE DAYS	1944-1945 DEGREE DAYS	1944-1945 PERCENT OF NORMAL	NORMAL (INCHES)	1944-1945 INCHES	1944-1945 PERCENT OF NORMAL		TYPE	THICKNESS (INCHES)	MIN.	MAX.	AVG.		CLASSIFICATION	THICKNESS (INCHES)	PERCENT FINER THAN 0.02MM	NORMAL PERIOD	FREEZIN PERIOD
PRESQUE ISLE	2061	2190	106	10	14	140	A	Com. Conc.	7, 10(A)	0.05	0.30	0.18	5.8	Base GW Subgrade GC	30-36 -	0-7 10-35	10 16	6 18 16
							B	Bit. Conc.	4	-0.10	0.55	0.10	5.9	Base GW Subgrade GC	24-30 -	0-5 10-35	8 16	6 15 14
							Turf	Topsoil	5	-	-	-	-	Subgrade GC	-	10-35	-	19 16
HOULTON	1780	1605	90	9	17	190	A	Bit. Conc.	1.5	0.05	0.20	0.20	4.1	Base Soil Cem. Subgrade GF Subgrade GC	6 - -	- 6-15 20-45	15 18 -	16 15 8 10(
							B	Bit. Conc.	4	-0.05	0.05	0.00	2.6 (boulder)	Base GW Subgrade GF	6 -	2-15 6-15	7 14	9 -
DOW	1275	1746 (1943-1944)	137	11	18.4 (1943)	164 (1943)	I & III	Bit. Conc.	4	0.00	0.40	0.18	4.0	Base GW Subgrade CL	17.5 -	3-7 40-97	6 20	10 30
							II	Bit. Conc.	3.5	0.02	0.20	0.10	4.2	Base GW Subgrade CL	36 -	3-7 40-97	4 19	- -
							IV - VII	Com. Conc.	7, 10(A)	0.30	0.70	0.45	4.1	Base GW Subgrade CL Subgrade GC	15 - -	3-7 40-97 15-35	- - -	9 28 -
	1275	1444	114	11	16	145	A	Com. Conc.	7, 10(A)	0.20	0.70	0.50	4.5	Base GW Subgrade CL Subgrade GC	15 - -	3-7 40-97 15-35	- - -	11 26 25(-
							B	Bit. Conc.	3.5	0.00	0.40	0.12	4.3	Base GW Subgrade CL	24-36 -	3-7 40-97	5 25	7 31 24
							C	Bit. Conc.	3.5	0.00	0.25	0.10	5.1	Base GW Subgrade CL	28-63 -	3-7 40-97	2 22	9 20 19(
							Turf	Topsoil	6	-	-	-	2.0	Subgrade CL	-	40-97	-	23 15(
OTIS	202	512	250	13	18	136	A	Bit. Conc.	5-7	0.00	0.16	0.02	2.2	Subgrade SP Subgrade ML Subgrade SP Subgrade GP	- - - -	5-18 20-40 0-3 0-5	3 - 12 -	- 21 1(1(
TRUAX	1227	1261	103	7	6	86	A	Bit. Conc.	2.5	0.08	0.14	0.12	4.0	Base CR Sub-base GP Subgrade CL Subgrade SP	8 15-17 - -	- 9-20 60-80 8-9	- 5 21 6	- 6 27 14
							B	Bit. Conc.	2.5	0.01	0.05	0.03	4.6	Base CR Sub-base GP Subgrade CL	20.5 21-31 -	- 9-20 60-80	- 6 25	- 8 27(
							C	Com. Conc.	6, 9(A)	0.02	0.14	0.11	4.6	Base GP Subgrade CL	36-60 -	9-20 50-80	12 20	13 30(
PIERRE	1294	962	74	2.4	2.85	119	A	Com. Conc.	7, 10(A)	0.00	0.03	0.00	3.5	Base GP Subgrade CL	7-14.5 -	6-13 27-59	9 15	9 14 20(
							B	Bit. Conc.	5.5	-0.02	0.03	-0.01	2.1(3Feb)	Base SP Subgrade CL	6-15.5 -	6-13 27-59	6 14	7 13 15(
							Turf	-	-	0.00	0.10	0.05	0.5(3Feb)	Subgrade CL	-	27-59	-	-
CASPER	530	745	140	4.4	2.5	57	A	Com. Conc.	7,9-10.5(A)	0.00	0.03	0.01	2.5	Subgrade SP-CL Subgrade SP Subgrade SP	- - -	5-30 5-18 1-7	11 7 5	10 9(9
							B	Bit. Conc.	5	-0.01	0.03	0.01	1.5(16Jan	Base GP Subgrade SP-CL Subgrade SP	7-13 - -	2-5 5-30 1-7	4 6 4	4 7 5

(A) Thickened edge.

FROST INVESTIGATION
1944-1945.
TABULATION OF DATA

WATER CONTENT (PERCENT DRY WEIGHT)			DENSITY (DRY WEIGHT - LBS/CU.FT.)			PERCENT SATURATION			ATTERBERG LIMITS		DEPTH OF WATER TABLE (FT)			ICE SEGREGATION			NATURA DRAINA CONDIT
															LENSES		
NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	LIQUID LIMIT	PLASTICITY INDEX	NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	CRYSTALS	THICKNESS (INCHES)	DESCRIPTION	
10	6	6	141	134	127	100	67	94	Non-plastic		4-6(S)	Below 6(S)	1-3(B)	Yes	-	No	
16	18 16(NF)	13	114	108 113(NF)	113	89	86 89(NF)	72	29	8				No	0-1/8	Numerous	
8	6	6	135	134	138	89	67	60	Non-plastic		Below 6(B)	Below 6(B)	3-5(S)	Yes	-	No	Poor:- High water table
16	15 14(NF)	17	114	114 114(NF)	113	89	88 84(NF)	94	29	8				No	0-1/8	Numerous	Impervious subgrade
-	19 16(NF)	-	-	105 110(NF)	-	-	94 79(NF)	-	29	8	Below 6(S)	-	5-6(S)	No observations made			
15	16	15	124	113	-	100	100	-	-	-	Below 6(S)		1.8-4.5(S)	No	-	No	
18	15	14	123	110	114	100	79	84	30-33	0-8				Yes	0-1/8	0.8'-2.1'	
-	8 10(NF)	14	-	134 116(NF)	[illegible]	-	90 45(NF)	93	26-30	16-17				Yes	0-1/8	3.5'-4.0'	Poor:- High water table
7	9	6	144	125	135	100	75	56	Non-plastic		Below 6.5(S)			No	-	No	deposits
14	-	8	125	-	130	100	-	80	42	4				No	-	No	
6	10	8	140	135	140	90	100	100	Non-plastic		2 to below 6 (D)			No	-	No	
20	30	18	108	81	114	93	71	94	29-36	11-17				No	0-1/4	Infrequent	
4	-	6	135	-	136	50	-	70	Non-plastic		2 to below 6 (D)			No	-	No	
19	-	21	107	-	105	89	-	91	29-36	11-17				No	0-1/4	Infrequent	
-	9	10	-	133	134	-	100	100	Non-plastic		2 to below 6 (D)			No	-	No	
-	28	25	-	98	95	-	81	87	29-36	11-17				No	0-1/4	Infrequent	
-	-	-	-	-	-	-	-	-	19-21	2-6				-	-	-	
-	11	5	-	119	136	-	73	96	Non-plastic		Below 6(S)	5-6(S)	1-3(B)	Yes	-	No	Poor:- Highly impervio
-	26 25(NF)	26	-	98 103(NF)	99	-	95 100(NF)	96	29-36	11-17				Yes	0-7/8	Numerous	
-	-	-	-	-	-	-	-	-	19-21	2-6				-	-	-	
5	7	8	141	131	134	71	70	69	Non-plastic		4-6(S)	Below 6(S)	2-3(P)(S)	Yes	-	No	
25	31 24(NF)	25	102	93 98(NF)	98	100	100 73(NF)	93	29-36	11-17				Yes	0-3/8	Numerous	
2	9	8	136	121	129	37	64	73	Non-plastic		4-5(S)	Below 6(B)	2-4(P)(S)	Yes	-	No	
22	20 19(NF)	20	109	102 111(NF)	111	100	80 95(NF)	100	29-36	11-17				Yes	0-1/4	Numerous	
-	23 15(NF)	-	-	99 112(NF)	-	-	100 75(NF)	-	29-36	11-17	Below 6(S)	1.5-6(S)	.7-4(S)	No	0-1 3/8	Numerous	
3	-	9	122	-	124	20	-	69	17	2	Below 15 (S)			No	0-1/32	1.2'-2.2'	
-	21	23	-	108	87	-	100	70	25	5				No	0-1/32	1.2'-2.2'	Good:- Low water table
12	1(NF)	0	126	119(NF)	103	100	7(NF)	8	Non-plastic					-	-	-	soil
-	1(NF)	-	-	126(NF)	-	-	8(NF)	-	Non-plastic					-	-	-	
-	-	-	-	-	-	-	-	-	-	-	6-6.7(B)	5.8-6(S)	2-4(P)(B)	Yes	-	No	
5	6	6	141	-	146	77	-	100	19-30(C)	2-9(C)				Yes	-	No	
21	27	23	107	-	105	97	-	99	43	20				No	0-1/16	1/8" apart	
6	14	-	115	-	-	35	-	-	Non-plastic					-	-	-	
-	-	-	-	-	-	-	-	-	-	-	6.5 - 7.5 (B)		6.5-6.5(S)	Yes	-	No	Poor:- Low level area,
6	8	8	136	122	130	78	56	80	19-30(C)	2-9(C)				No	0-1/32	Few	table and impervious s
23	27(NF)	26	103	95(NF)	96	100	100(NF)	94	44	20				No	0-1/16	Numerous	
12	13	12	125	112	125	98	70	92	19-30(C)	2-9(C)	5.5-6.5(S)	6.5-7.4(S)	5.4-6(B)	Yes	0-1/16	Numerous	
20	30(NF)	22	106	82(NF)	101	90	77(NF)	91	38	18				No	0-1/32	Numerous	
9	9	9	135	-	136	89	-	100	26-33	8-16	Below 25 (S)			No	-	No	
15	14 20(NF)	24	105	-	89	65	-	69	36-42	16-23				Not well defined			
6	7	8	140	-	134	90	-	78	23-29	[illegible]-13	Below 25 (S)			No	-	No	Good:- Elevation above
14	15 15(NF)	15	97	-	108	57	-	68	34-45	[illegible]-25				Yes	0-1/50	1.3'-2.1'	
-	-	12	-	-	100	-	-	55	35-42	15-24	Below 25 (S)			Not well defined			
11	10	11	114	-	121	65	-	79	15-29	2-11	Below 90 (S)			No	-	No	
7	9(NF)	10	120	-	114	50	-	59	17-20	3-5				-	-	-	
5	9	-	111	-	-	31	-	-	Non-plastic					-	-	-	
4	4	4	131	-	135	40	-	45	Non-plastic		Below 90 (S)			No	-	No	Good:-Very low water t
6	7	8	117	-	122	40	-	50	15-29	2-11				No	-	No	annual precipitation
4	5	4	109	-	113	21	-	23	Non-plastic					-	-	-	

(NF) Test on unfrozen soil.

(C) Atterberg limits on portion passing 200 mesh sieve.

(P) Ground water table in base.

(S) Ground water table in subgrade.

(D) No observation wells installed. Depth indicated from test pit observation.

B

PERCENT SATURATION			ATTERBERG LIMITS		DEPTH OF WATER TABLE (FT.)			ICE SEGREGATION			NATURAL DRAINAGE CONDITIONS	TRAFFIC HISTORY		
									LENSES					
NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	LIQUID LIMIT	PLASTICITY INDEX	NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	CRYSTALS	THICKNESS (INCHES)	DESCRIPTION		PERIOD	GROSS PLANE WEIGHT (THOUSAND LBS)	CYCLES PER DAY
100 89	67 86 89(NF)	94 72	Non-plastic 29	8	4-6(S)	Below 6(S)	1-3(B)	Yes No	- 0-1/2	No Numerous	Poor:- High water table, peat deposits and impervious subgrade	1943 1943 1944 1944 1944 1944	27-38 65 5 39 48 65	5 25 20 7 7 6
89 89	67 88 84(NF)	60 94	Non-plastic 29	8	Below 6(B)	Below 6(S)	2-3(B)	Yes No	- 0-1/2	No Numerous				
-	94 79(NF)	-	29	8	Below 6(S)	-	3-6(S)	No observations made						
100 100 -	100 79 80 45(NF)	- 84 95	- 30-33 26-30	- 0-2 16-17	Below 6(S)		1.0-4.5(S)	No Yes Yes	- 0-1/8 0-1/8	No 0.8'-2.1' 3.5'-4.0'	Poor:- High water table, peat and ledge deposits	1941-42 1941-42 1942-43	12 30-60 60	- - -
100 100	75 -	56 80	Non-plastic 22	4	Below 6.5(S)		-	No No	- -	No No				
90 93	100 71	100 94	Non-plastic 29-36	11-17	2 to below 6 (D)			No No	- 0-1/4	No Infrequent	Poor:- Highly impervious silty clay soil	5/42-10/42 1943 1944	All weights up to 60	14 10 17
50 89	- -	70 91	Non-plastic 29-36	11-17	2 to below 6 (D)			No No	- 0-1/4	No Infrequent				
- - -	100 81 -	100 87 -	Non-plastic 29-36 19-21	11-17 2-6	2 to below 6 (D)			No No -	- 0-1/4 -	No Infrequent -				
- - -	73 93 100(NF) -	96 96 -	Non-plastic 29-36 19-21	11-17 2-6	Below 6(S)	3-6(S)	1-3(B)	Yes Yes -	- 0-7/8 -	No Numerous -				
71 100	70 100 73(NF)	69 95	Non-plastic 29-36	11-17	4-6(S)	Below 6(S)	2-3(B)(S)	Yes Yes	- 0-3/8	No Numerous				
37 100	64 80 95(NF)	73 100	Non-plastic 29-36	11-17	4-5(S)	Below 6(S)	2-4(B)(S)	Yes Yes	- 0-1/4	No Numerous				
-	100 75(NF)	-	29-36	11-17	Below 6(S)	1.5-6(S)	.7-4(S)	No	0-1 3/8	Numerous				
20 - 100 -	- 100 7(NF) 8(NF)	69 70 [illegible] -	17 25 Non-plastic Non-plastic	2 5	Below 15 (S)			No No - -	0-1/32 0-1/32 - -	1.2'-2.2' 1.2'-2.2' - -	Good:- Low water table and sandy pervious soil	1942 To 1944 6-12 1944	8 30 60 10-15	75 45 5 200-500
- 77 97 35	- - - -	- 100 99 -	- 19-30(C) 43 Non-plastic	- 2-9(C) 20	6-6.7(B)	5.8-6(S)	2-4(B)(S)	Yes Yes No -	- - 0-1/16 -	No No 1/2" apart -	Poor:- Low level area, marsh, high water table and impervious subgrade	1942-44	All weights up to 60	10-100
- 78 100	- 56 100(NF)	- 80 94	- 19-30(C) 44	- 2-9(C) 20	6.5 - 7.5 (B)		5.5-6.5(S)	Yes No No	- 0-1/32 0-1/16	No Few Numerous				
92 90	70 77(NF)	92 91	19-30(C) 38	2-9(C) 18	5.5-6.5(B)	6.5-7.4(S)	5.4-6(B)	Yes No	0-1/16 0-1/32	Numerous Numerous				
89 65	- -	100 69	26-33 36-42	8-16 16-23	Below 25 (S)			No Not	- well	No defined	Good:- Elevation above surrounding area	12/42-9/43 9/43-9/44 9/44	29-60 10-15 5-10	5-200 50 2
90 57	- -	78 68	23-29 34-45	7-13 16-25	Below 25 (S)			No Yes	- 0-1/30	No 1.3'-2.1'				
-	-	55	35-42	15-24	Below 25 (S)			Not	well	defined				
65 50 31	- - -	79 59 -	15-29 17-20 Non-plastic	2-11 3-5	Below 90 (S)			No - -	- - -	No - -	Good:-Very low water table and little annual precipitation	11/42-10/44	50	95
40 40 21	- - -	45 50 23	Non-plastic 15-29 Non-plastic	2-11	Below 90 (S)			No No -	- - -	No No -				
			(C) Attorberg limits on portion passing 200 mesh sieve.		(B) Ground water table in base. (S) Ground water table in subgrade. (D) No observation wells installed. Depth indicated from test pit observation.							TABULATION OF DATA		

SHEET 1 OF 2 TABLE 1

SITE	FREEZING INDEX			PRECIPITATION (3 MO. PRIOR TO FREEZING)			TEST AREA	SURFACE		PAVEMENT HEAVE (FEET)			MAX. DEPTH OF FROST (FEET)	UNDERLYING MATERIAL			WATER C (PERCENT DR	
	NORMAL DEGREE DAYS	1944-1945		NORMAL (INCHES)	1944-1945			TYPE	THICKNESS (INCHES)	MIN.	MAX.	AVG.		CLASSIFICATION	THICKNESS (INCHES)	PERCENT FINER THAN 0.02MM	NORMAL PERIOD	FREEZI PERIO
		DEGREE DAYS	PERCENT OF NORMAL		INCHES	PERCENT OF NORMAL												
WATERTOWN	1742	1563	90	4.4	4.0	90	A	Com. Conc.	8,12(A)	0.00	0.13	0.05	4.0	Subgrade SP-CL	-	13 - 35	15	14
														Subgrade CL-CL	-	34 - 45	24	10(
														Subgrade GP	-	1 - 3	-	-
							B	Bit. Conc.	5	-0.03	0.11	-0.01	4.0	Base GP	8	4 - 15	5	5
														Subgrade SP-CL	-	13 - 35	14	13
														Subgrade CL-CL	-	35 - 45	22	6(
							Turf	Topsoil	8	-0.04	0.10	0.00	3.5	Subgrade SP-CL	-	13 - 35	6	16 8(
FARGO	2646	1820	69	3.7	3.5	93	A	Bit. Conc.	1.5	0.06	0.12	0.07	3.8	Base Soil Cem.	6.5	-	11	12
														Subgrade CL-SP	-	11 - 17	11	10
														Subgrade OH-CH	-	47 - 55	27	27
														Subgrade CH	-	76 - 90	31	35(
BISMARCK	2552	1745	68	2.6	3.0	115	A	Bit. Conc.	2-4.5	0.01	0.10	0.02	3.8	Base SC	6-6.5	5 - 9	5	5
														Subgrade CL-ML	-	27 - 37	17	18 10(
														Subgrade SP	-	3 - 12	-	-
SIOUX FALLS	1100	1150	105	5.5	4.1	75	A	Bit. Conc.	2	0.03	0.12	0.05	3.8	Base GC	9.5	7 - 11	7	7
														Sub-base CL	12	36 - 41	17	17
														Subgrade CL	-	41 - 69	24	22
														Subgrade CH	-	53 - 73	31	31(
							B	Com. Conc.	6,9(A)	0.07	0.10	0.08	-	Subgrade CH	-	60 - 77	32	-
FAIR-MONT	581	415	72	6.5	4.0	61	A	Com. Conc.	8,11(A)	0.01	0.05	0.03	1.25	Subgrade CL	-	56 - 79	28	32 27(
														Subgrade CH	-	61 - 76	23	26(
GREAT BEND	29	64	222	5.3	3.9	74	A	Com. Conc.	7,10.5(A)	0.00	0.02	0.01	1.12	Base SW	6	1 - 3	2	7
														Subgrade CL-SP	-	23 - 33	13	17(
														Subgrade SP-CL	-	30 - 34	15	-
														Subgrade CL	-	30 - 60	17	19(
GARDEN CITY	56	60	107	4.1	2.8	68	A	Bit. Conc.	1.5	-0.01	0.03	0.01	0.95	Base SC	10.5	7 - 8	5	-
														Subgrade CL	-	30 - 45	16	-
														Subgrade CH-CL	-	55	16	-
														Subgrade CH	-	55	19	-
PRATT	28	58	209	6.3	5.4	86	A	Com. Conc.	7,10.5(A)	0.00	0.06	0.01	Alternate freezing & thawing	Base SP-CL	0-12	24	17	21
														Subgrade CL	-	37 - 41	19	19
														Subgrade CH	-	56 - 66	21	23

(A) Thickened edge

(W7)

A

FROST INVESTIGATION
1944-1945
TABULATION OF DATA

WATER CONTENT (PERCENT DRY WEIGHT)			DENSITY (DRY WEIGHT - LBS/CU FT)			PERCENT SATURATION			ATTERBERG LIMITS		DEPTH OF WATER TABLE (FT)			ICE SEGREGATION			NATURA DRAINA CONDITI
															LENSES		
NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	LIQUID LIMIT	PLASTICITY INDEX	NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	CRYSTALS	THICKNESS (INCHES)	DESCRIPTION	
15 24 -	14 10(UF) -	14 28 -	112 87 -	- - -	119 85 -	78 67 -	- - -	94 78 -	38 - 38 32 - 50 Non-plastic	12 - 14 12 - 18	12(S)	12(B)	12(B)	Yes Yes -	Very thin - -	Few 2.7'-3.2' No -	
5 14 22	5 13 6(UF)	5 14 22	139 105 88	- - -	141 108 95	72 61 65	- - -	65 67 71	19 - 24 32 - 38 30 - 43	5 - 9 12 - 14 12 - 16	12(B)	12(S)	12(S)	No No -	- Very thin -	No Few 1.2'-1.7' -	Fair:- Ponding until re into lower gravel strat high capillarity neares
6	16 8(UF)	7	136	-	130	88	-	65	17 - 46	6 - 18	12(B)	12(B)	12(B)	Yes	Minor	1.1'-1.8'	
11 11 27 31	12 10 27 35(UF)	11 11 27 33	122 126 95 86	- - - -	120 131 96 89	72 98 100 98	- - - -	74 100 93 97	- 30 63 73 - 80	- 12 30 40 - 56	4.8-5.5(B)	5.5-7.2(B)	3-6(S)	No No No No	- - 1/16 1/16	No No Numerous Numerous	Poor:- Located in a flat is very slow
5 17 -	5 18 10(UF) -	5 21 -	130 87 -	- - -	132 88 -	50 49 -	- - -	50 64 -	18 - 19 24 - 33 Non-plastic	1 - 4 7 - 9	40, Perched 12(S)			No No -	- Thin -	No Top 0.5' -	Good:- Low water table, adjacent area
7 17 24 31 38	7 17 22 31(UF) -	7 18 26 30 -	132 112 95 84 -	- - - - -	136 118 95 95 -	78 93 82 82 -	- - - - -	80 97 98 100 -	25 38 - 46 38 - 46 50 - 53 62	5 - 7 17 - 21 17 - 21 26 31	9(B) -	8-9(B) -	6(B) -	Yes Yes No - No observations made	- - Thin -	No No Infrequent -	Poor:- Natural water rou airfield tend to maintai content in subgrade mate
28 25	32 27(UF) 26(UF)	- -	89 88	- -	- -	90 73	- -	- -	42 - 50 52 - 73	19 - 27 28 - 43	Below 90(B)			No -	- -	No -	Good:- Very low water ta
2 13 15 17	7 17(UF) - 19(UF)	- - - -	120 102 109 100	- - - -	- - - -	14 55 75 67	- - - -	- - - -	18 - 21 26 - 27 31 30 - 41	2 - 6 9 - 11 18 13 - 20	15(B)	12(B)	12(S)	No - - -	- - - -	No - - -	Good:- Except during per continued precipitation
5 16 16 19	- - - -	- - - -	128 107 97 95	- - - -	- - - -	44 76 60 68	- - - -	- - - -	21 26 - 40 47 55	7 10 - 21 25 32	Below 90(B)			No - - -	- - - -	No - - -	Good:- Low water table, above surrounding area
17 19 21	21 19 23	- - -	- 132 105	- - -	- - -	- 91 85	- - -	- - -	22 - 25 38 - 41 49 - 55	5 - 7 19 - 21 29 - 32	Below 90(B)			No - -	- - -	No - -	Good:- Low water table; terrain

(UF) Test on unfrozen soil

(B) Ground water table in base.

(S) Ground water table in subgrade.

B

PERCENT SATURATION			ATTERBERG LIMITS		DEPTH OF WATER TABLE (FT.)			ICE SEGREGATION			NATURAL DRAINAGE CONDITIONS	TRAFFIC HISTORY		
									LENSES					
NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	LIQUID LIMIT	PLASTICITY INDEX	NORMAL PERIOD	FREEZING PERIOD	FROST MELTING PERIOD	CRYSTALS	THICKNESS (INCHES)	DESCRIPTION		PERIOD	GROSS PLANE WEIGHT THOUSAND LBS	CYCLES PER DAY
78 67 - 72 61 65 88	- - - - - - -	94 78 - 63 67 71 63	32 - 38 32 - 50 Non-plastic 19 - 24 32 - 38 30 - 43 17 - 46	12 - 14 12 - 18 5 - 9 12 - 14 12 - 16 6 - 18	12(S) 12(B) 12(B)	12(B) 12(S) 12(B)	12(B) 12(S) 12(B)	Yes Yes - No No - Yes	Very thin - - - Very thin - Minor	Few 2.7'-3.2' No - No Few 1.2'-1.7' - 1.1'-1.8'	Fair:- Ponding until relieved by seepage into lower gravel stratum, materials of high capillarity nearest the surface	12/42-12/43 3/44-12/44	60 18-60	100 100
72 98 100 92	- - - -	74 100 93 97	- 30 65 73 - 80	- 12 30 40 - 56	4.8-5.5(B)	5.5-7.2(B)	3-6(S)	No No No No	- - 1/16 1/16	No No Numerous Numerous	Poor:- Located in a flat area where runoff is very slow	1941-6/45 1941-6/45	5-29 60	28 2
50 49 -	- - -	50 64 -	18 - 19 24 - 33 Non-plastic	1 - 4 7 - 9	40, Perched 12(B)			No No -	- Thin -	No Top 0.3' -	Good:- Low water table, site above adjacent area	9/43-6/45	5-60	20
72 93 82 82 -	- - - - -	80 97 92 100 -	23 38 - 46 38 - 46 50 - 53 62	5 - 7 17 - 21 17 - 21 26 31	9(B) -	8-9(B) -	6(B) -	Yes Yes No - No observations made	- - Thin -	No No Infrequent -	Poor:- Natural water courses surrounding airfield tend to maintain high moisture content in subgrade material.	6/42-6/45 5/42-6/45	10 20-30	4 45
90 73	- -	- -	42 - 50 52 - 73	19 - 27 28 - 43	Below 90(B)			No -	- -	No -	Good:- Very low water table	5/43-8/43 9/43-6/45	10 120	25 75
14 95 75 67	- - - -	- - - -	18 - 21 26 - 27 31 30 - 41	2 - 6 9 - 11 12 13 - 20	15(B)	12(S)	12(S)	No - - -	- - - -	No - - -	Good:- Except during periods of high or continued precipitation	3/43-8/43 8/43-7/44 7/44-6/45	10 30-60 120	20 130 130
44 76 60 68	- - - -	- - - -	21 26 - 40 47 55	7 10 - 21 25 32	Below 90(B)			No - - -	- - - -	No - - -	Good:- Low water table, elevation of site above surrounding area	1/43-12/44 1/43-12/44	4 20-60	1000 15
- 91 89	- - -	- - -	22 - 25 38 - 41 49 - 55	5 - 7 19 - 21 29 - 32	Below 90(B)			No - -	- - -	No - -	Good:- Low water table; gently rolling terrain	7/43-6/45	20-120	150
					(B) Ground water table in base. (S) Ground water table in subgrade.									

C

TABULATION OF DATA

SHEET 2 OF 2 TABLE 1

WAR DEPARTMENT

FROST INVESTIGATION
PRESQUE ISLE AIRFIELD, PRESQUE ISLE, ME.
SUMMARY OF PLATE BEARING TESTS

TEST AREA	TEST NO.	DATE	TYPE OF TEST	STATION	OFFSET (in Feet)	NEAREST EXPLORATION	MATERIAL UNDERLYING TEST PLATE Thickness in inches			DIAM. OF TEST PLATE (in inches)	TOTAL LOAD IN POUNDS		
							(A) PAVEMENT	BASE	SUBGRADE		* 0.05 inch Deflection	* 0.10 inch Deflection	* 0.20 Deflec
A	SMT 27	26 Oct. 1944	Subgrade Modulus	49+88	97 E of W edge	T182p	-	34 (C)	Compact Clayey Silt, Sand and Gravel (Till)	30	20,000	36,000*	60,0
"	SMT 35	12 April 1945	" "	49+53	73 E of W edge	T255p	-	24 (C)		30	12,000	24,000*	47,0
A	SMT 28	2 Nov. 1944	Subgrade Modulus	58+87	47 E of W edge	T183p	-	32 (C)		30	12,000	21,000*	37,0
"	SMT 33	12 April 1945	" "	58+53	52 E of W edge	T254p	-	34 (C)		30	11,000	21,000*	41,0
A	PBT 32	10 April 1945	Pavement Rupture	58+50	48 E of W edge	T254p	7.2 Com. Conc.	34 (C)		24	33,000	53,000	- (
"	PBT 34	12 April 1945	" "	49+50	74 E of W edge	T255p	7.2 Com. Conc.	24 (C)		24	28,000	49,000	- (
B	PBT 26	30 Oct. 1944	Pavement Bearing Test - (Static Load)	7+61	12.5 W of ℄	T262p	3.4	4 (B), 24 (C)		30	43,000*	- (G)	- (
"	PBT 36	14 April 1945		7+30	17.5 W of ℄	T277a	5.6	1.6 (B), 23 (C)			18,000*	34,000	- (
"	PBT 46	3 May 1945		7+30	27 W of ℄	T282a	4.8	2.5 (B), 24 (C)			26,000	45,000	- (
"	PBT 63	28 May 1945		7+30	22.5 W of ℄	T277a	5.6	1.6 (B), 23 (C)			26,000	43,000	- (
"	PBT 68	12 June 1945		7+25	22.5 W of ℄	"	5.6	1.6 (B), 23 (C)			29,000	51,000	- (
B	PBT 24	28 Oct. 1944		10+50	12.5 W of ℄	T251p	4.8	2.5 (B), 24 (C)			37,000	60,000*	- (
"	PBT 38	15 April 1945		10+40	17.5 W of ℄	T275a	4.0	3.2 (B), 24 (C)			19,000	35,000	60,0
"	PBT 48	4 May 1945		10+40	27 W of ℄	"	4.4	3.2 (B), 24 (C)			15,000	27,000*	50,0
"	PBT 62	28 May 1945		10+43	20 W of ℄	"	4.4	3.2 (B), 24 (C)			26,000	44,000	- (
"	PBT 67	12 June 1945		10+45	15 W of ℄	T281a	5.4	1.8 (B), 23 (C)			26,000	44,000	- (
B	PBT 22	27 Oct. 1944		14+40	12.5 E of ℄	T252p	4.1	1.8 (B), 25 (C)			41,000*	- (G)	- (
"	PBT 42	18 April 1945		14+34	17.5 E of ℄	T272a	4.1	3.1 (B), 24 (C)			21,000*	35,000	60,0
"	PBT 47	5 May 1945		14+34	27 E of ℄	"	4.1	3.1 (B), 24 (C)			19,000	33,000	57,0
"	PBT 58	25 May 1945		14+35	20 E of ℄	"	4.1	3.1 (B), 24 (C)			21,000	41,000	- (
"	PBT 74	15 June 1945		14+40	27 E of ℄	"	4.1	3.1 (B), 24 (C)			23,000	43,000	- (
B	PBT 21	26 Oct. 1944		18+35	12.5 E of ℄	T261p	3.2	1.6 (B), 25 (C)			34,000	56,000*	- (
"	PBT 41	17 April 1945		18+35	17.5 E of ℄	T253p	3.6	2.4 (B), 26 (C)			12,000	24,000	45,0
"	PBT 51	6 May 1945		18+40	27 E of ℄	T285a	5.1	1.4 (B), 24 (C)			11,000	21,000*	37,0
"	PBT 65	29 May 1945		18+37	22 E of ℄	T279a	5.4	1.8 (B), 24 (C)			13,000	31,000	54,0
"	PBT 72	14 June 1945		18+35	27 E of ℄	T285a	5.1	1.4 (B), 24 (C)			19,000	35,000	60,0
B	PBT 50	6 May 1945		18+85	30 W of ℄	T286a	5.0	1.7 (B), 24 (C)			7,500	12,000	18,5
"	PBT 60	26 May 1945		18+30	27 W of ℄	T266p	4.8	2.4 (B), 26 (C)			14,000	22,000	32,5
"	PBT 73	6 May 1945		18+88	32 W of ℄	"	4.8	2.4 (B), 26 (C)			14,000	23,500	34,5
"	PBT 54	8 May 1945		19+00	24 W of ℄	T264a	3.6	3.6 (B), 7 (C)			18,000	31,000	55,0
NW-SE Runway	PBT 1	25 May 1943		12+10	49 E of ℄	-	4.0	21 (C)			18,000	31,000*	51,0
"	PBT 13	13 Sept. 1943		12+15	46 E of ℄	-	4.0	21 (C)			14,000	45,000*	- (
NW-SE Runway	PBT 2	26 May 1943		1+87	55 E of ℄	-	3.5	16 (C)			7,500	13,000*	25,0
"	PBT 14	13 Sept. 1943		1+98	55 E of ℄	-	3.5	16 (C)			17,000	30,000*	50,0
E-W Runway	PBT 5	27 May 1943		14+31	50 E of ℄	T208a	3.6	18 (C)			10,500	18,000*	38,0
"	PBT 19	16 Sept. 1943		14+41	50 E of ℄	T257a	5.4	18 (C)			15,000	31,000*	68,0
E-W Runway	PBT 31	3 Nov. 1944		14+36	59 E of ℄	T268a	5.0	18 (C)			19,000	33,000*	57,0
"	PBT 40	16 April 1945		14+40	60 E of ℄	T274a	4.8	11 (C)			11,000	19,000*	36,0
"	PBT 52	7 May 1945		14+40	50 E of ℄	T276a	2.5	13 (C)			12,000	23,000	48,0
"	PBT 59	26 May 1945		14+40	55 E of ℄	T276a	2.5	13 (C)			12,000	29,000	60,0
E-W Runway	PBT 3	26 May 1943		32+97	54 E of ℄	T209a	3.6	36 (C)			12,000	18,000*	29,0
"	PBT 16	14 Sept. 1943		32+65	54 E of ℄	T259a	7.2	36 (C)			20,000	33,000*	51,0
E-W Runway	PBT 29	1 Nov. 1944		32+81.5	60.5 E of ℄	T267a	4.0	36 (C)			20,000	31,000*	47,0
"	PBT 39	16 April 1945		32+70	60 E of ℄	T270a	6.0	36 (C)			9,000	16,000*	28,0
"	PBT 55	8 May 1945		32+70	50 E of ℄	T284a	4.8	44 (C)			11,000	19,500	34,0
"	PBT 56	24 May 1945		32+70	55 E of ℄	"	4.8	44 (C)			10,000	24,000	38,0
"	PBT 71	13 June 1945		32+75	57 E of ℄	"	4.8	44 (C)			13,000	24,000	35,0
N-S Runway	PBT 4	27 May 1943		14+0	50 E of ℄	T211a	3.6	18 (C)			15,000	22,000*	38,0
"	PBT 15	14 Sept. 1943		14+05	50 E of ℄	T256a	7.2	18 (C)			20,000	34,000*	68,0
N-S Runway	PBT 30	2 Nov. 1944		14+07	55.5 E of ℄	T269a	2.5	18 (C)			27,000	45,000*	- (
"	PBT 43	18 April 1945		14+0	60 E of ℄	T280a	3.6	18 (C)			11,000	20,000*	36,0
"	PBT 53	7 May 1945		13+80	50 E of ℄	T283a	5.4	11 (C)			16,000	27,000	48,0
"	PBT 66	30 May 1945		13+95	55 E of ℄	T211a	3.6	11 (C)			18,000	30,000	52,0
"	PBT 70	13 June 1945		14+0	50 E of ℄	"	3.6	12 (C)			20,000	32,000	55,0
											DEFLECTION IN INCHES @ 20,000 LBS.		
											1st Load		10th Repet
B	PBT 23	28 Oct. 1944	Pavement Bearing (Repeating Load)	14+60	12 E of ℄	T252p	4.8	2.4 (B), 24 (C)		[illegible]	.040		.046
"	PBT 44	18 April 1945		14+50	17.5 E of ℄	"	4.8	2.4 (B), 24 (C)			.084		.112
"	PBT 49	5 May 1945		14+50	27 E of ℄	T287a	4.8	2.4 (B), 24 (C)			.066		.099
"	PBT 57	25 May 1945		14+55	20 E of ℄	"	4.8	2.4 (B), 24 (C)			.054		.061
"	PBT 75	16 June 1945		14+55	18 E of ℄	"	4.8	2.4 (B), 24 (C)			.058		.068
B	PBT 25	29 Oct. 1944		7+40	12 W of ℄	T250p	3.6	2.4 (B), 24 (C)			.038		.059
"	PBT 37	14 April 1945		7+60	17.5 W of ℄	T278a	3.6	3.6 (B), 23 (C)			.070		.085
"	PBT 45	3 May 1945		7+60	27 W of ℄	T262p	3.6	3.6 (B), 24 (C)			.072		.095
"	PBT 64	29 May 1945		7+53	22 W of ℄	T278a	3.6	3.6 (B), 23 (C)			.053		.091
"	PBT 69	12 June 1945		7+55	27.5 W of ℄	"	3.6	3.6 (B), 23 (C)			.060		.079

NOTES:

(A) Pavements are bi
(B) Bituminous penet
(C) Sand and Gravel.
(D) Depth of frost p
(E) Estimated depth
(F) Ratio at 0.05" de
(G) Deflection not r
* Values used to d

A

CORPS OF ENGINEERS, U.S. ARMY

FROST INVESTIGATION
PRESQUE ISLE AIRFIELD, PRESQUE ISLE, ME.

SUMMARY OF PLATE BEARING TESTS

MATERIAL UNDERLYING TEST PLATE Thickness in Inches			DIAM. OF TEST PLATE (in Inches)	TOTAL LOAD IN POUNDS			MAX. RATIO OF NORMAL TO FROST MELTING PERIOD LOAD FOR 0.1" DEFLECTION	AVG. THICKNESS OF PAVEMENT PLUS BASE (Feet)	MAX. DEPTH OF FROST PENETRATION (Feet)	THICKNESS OF FROZEN SUBGRADE (Feet)
(A) PAVEMENT	BASE	SUBGRADE		@ 0.05 Inch Deflection	@ 0.10 Inch Deflection	@ 0.20 Inch Deflection				
-	34 (C)	Compact Clayey Silt, Sand and Gravel (T111)	30	20,000	36,000*	60,000	1.5	3.0	5.8	2.8
-	24 (C)		30	12,000	24,000*	47,000				
-	30 (C)		30	12,000	21,000*	37,000	1.8	3.5	5.8	2.5
-	34 (C)		30	11,000	21,000*	41,000				
7.2 Com. Conc.	34 (C)		24	33,000	53,000	- (G)	-	3.0	5.8	2.8
.2 Com. Conc.	24 (C)		24	26,000	49,000	- (G)				
.4	4 (B), 24 (C)		30	43,000*	- (G)	- (G)	2.4 (F)	2.6	5.9	3.3
.6	1.6 (B), 23 (C)			18,000*	34,000	- (G)				
.8	2.5 (B), 24 (C)			26,000	42,000	- (G)				
.6	1.6 (B), 23 (C)			26,000	43,000	- (G)				
.6	1.6 (B), 23 (C)			29,000	51,000	- (G)				
.8	2.5 (B), 24 (C)			37,000	60,000*	- (G)	2.2	2.7	5.9	3.2
.0	3.2 (B), 24 (C)			19,000	35,000	60,000				
.4	3.2 (B), 24 (C)			15,000	27,000*	50,000				
.4	3.2 (B), 24 (C)			26,000	44,000	- (G)				
.4	1.8 (B), 23 (C)			26,000	44,000	- (G)				
.1	1.8 (B), 23 (C)			41,000*	- (G)	- (G)	2.0 (F)	2.6	5.9	3.3
.1	3.1 (B), 24 (C)			21,000*	35,000	60,000				
.1	3.1 (B), 24 (C)			39,000	33,000	57,000				
.1	3.1 (B), 24 (C)			21,000	41,000	- (G)				
.1	3.1 (B), 24 (C)			23,000	41,000	- (G)				
.2	1.6 (B), 23 (C)			34,000	56,000*	- (G)	2.7	2.5	5.9	3.4
.6	2.4 (B), 26 (C)			12,000	24,000	45,000				
.1	1.4 (B), 24 (C)			11,000	21,000*	37,000				
.4	1.8 (B), 24 (C)			13,000	31,000	54,000				
.1	1.4 (B), 24 (C)			18,000	35,000	60,000				
.8	1.7 (B), 24 (C)			7,500	12,000	18,500	-	2.2	5.9	3.7
.8	2.4 (B), 26 (C)			14,000	22,000	32,500				
.6	2.4 (B), 26 (C)			14,000	23,500	34,500				
.6	3.6 (B), 7 (C)			18,000	31,000	55,000				
.0	21 (C)			18,000	31,000*	51,000	1.5	2.1	4.5 (D)	2.4
.0	21 (C)			14,000	45,000*	- (G)				
.5	16 (C)			7,500	13,000*	25,000	2.3	1.7	4.5 (D)	2.8
.5	16 (C)			17,000	30,000*	50,000				
.6	18 (C)			18,500	18,000*	38,000	1.7	1.7	4.5 (D)	2.8
.4	18 (C)			15,000	31,000*	68,000				
.8	18 (C)			39,000	33,000*	57,000	1.7	1.5	5.5 (E)	4.0
.8	11 (C)			11,000	19,000*	36,000				
.5	13 (C)			18,000	23,000	48,000				
.5	13 (C)			12,000	29,000	60,000				
.6	36 (C)			12,000	18,000*	29,000	1.8	3.4	4.5 (D)	1.1
.8	36 (C)			20,000	33,000*	51,000				
.0	36 (C)			20,000	31,000*	47,000	1.9	3.5	5.5 (E)	2.0
.0	36 (C)			9,000	16,000*	28,000				
.8	44 (C)			11,000	19,500	34,000				
.8	44 (C)			10,000	24,000	38,000				
.8	44 (C)			13,000	24,000	35,000				
.6	18 (C)			15,000	22,000*	38,000	1.5	1.7	4.5 (D)	2.8
.8	18 (C)			20,000	34,000*	62,000				
.5	18 (C)			27,000	45,000*	- (G)	2.2	1.3	5.5 (E)	4.2
.6	18 (C)			11,000	20,000*	36,000				
.4	11 (C)			16,000	27,000	48,000				
.6	11 (C)			18,000	30,000	52,000				
.6	10 (C)			20,000	38,000	55,000				
				DEFLECTION IN INCHES @ 20,000 LBS.						
				1st Load		10th Repetition				
.8	2.4 (B), 24 (C)		24	.040		.046	-	2.6	5.9	3.3
.8	2.4 (B), 24 (C)			.084		.112				
.8	2.4 (B), 24 (C)			.066		.099				
.8	2.4 (B), 24 (C)			.054		.061				
.8	2.4 (B), 24 (C)			.058		.068				
.6	2.4 (B), 24 (C)			.058		.099	-	2.6	5.9	3.3
.6	3.6 (B), 23 (C)			.070		.085				
.6	3.6 (B), 24 (C)			.072		.095				
.6	3.6 (B), 23 (C)			.053		.091				
.6	3.6 (B), 23 (C)			.060		.079				

NOTES:

(A) Pavements are bituminous concrete unless otherwise shown.
(B) Bituminous penetrated crushed rock.
(C) Sand and Gravel.
(D) Depth of frost penetration measured winter 1943.
(E) Estimated depth of frost penetration.
(F) Ratio at 0.05" deflection.
(G) Deflection not reached with available max. load.
* Values used to determine maximum ratio.

B

PRESQUE ISLE
SUMMARY OF
PLATE BEARING TESTS

TABLE 2

WAR DEPARTMENT

FROST INVESTIGATION
DOW FIELD, BANGOR, M

SUMMARY OF PAVEMENT BEA

TEST AREA	TEST NO.	DATE	TYPE OF TEST	STATION	OFFSET (in Feet)	NEAREST EXPLORATION	MATERIAL UNDERLYING TEST PLATE Thickness in inches		
							PAVEMENT (A)	BASE (OP)	SUBGRADE
A	PBT 64	30 Mar. 1945	Rupture	-6/13	24 S	T732p	7.8 Cem. Conc.	13.8	Gravelly Clay
"	PBT 65	31 Mar. 1945	Rupture	-6/91	95 S	T735p	10.2 " "	13.8	Silty Clay
"	PBT 66	2 April 1945	Foundation Mod.	-6/13	24 S	T732p	— —	13.8	Gravelly Clay
"	PBT 67	3 April 1945	Foundation Mod.	-6/91	95 S	T735p	— —	13.8	Silty Clay
B	PBT 22	15 April 1944	Pavement Bearing Test - (Static Load)	10/23	22 S	T560p	4.3	42.5	Silty Clay
"	PBT 34	23 Aug. 1944		10/30	20 S	T574p	4.3	42.5	
"	PBT 61	20 April 1945		10/30	32 S	T728p	4.2	41.0	
"	PBT 71	15 April 1945		10/50	22 S	T874a	4.2	41.4	
"	PBT 83	4 June 1945		10/50	17 S	T877a	5.0	32.2	
B	PBT 48	28 Sept. 1944		14/86	52 N	T598ap	4.2	27.0	
"	PBT 58	26 Mar. 1945		14/85	45 N	T727p	4.2	27.0	
"	PBT 79	28 April 1945		14/75	50 N	"	4.2	27.0	
"	PBT 49	29 Sept. 1944		14/11	51 S	T633ap	3.6	24.1	
"	PBT 57	25 Mar. 1945		14/30	39 S	T726p	4.2	23.0	
B	PBT 50	30 Sept. 1944		12/40	21 N	T643p	3.6	30.0	
"	PBT 62	28 Mar. 1945		12/42	12 N	T730p	3.4	27.2	
"	PBT 77	25 April 1945		12/65	30 N	T872a	4.8	28.8	
"	PBT 81	2 June 1945		12/65	16 N	"	4.8	28.8	
"	PBT 86	5 June 1945		12/62	17 N	"	4.8	28.8	
B	PBT 63	29 Mar. 1945		10/25	125 N	T729p	1.8 Bit. Surf. Treat.	18.6	
"	PBT 80	29 April 1945		10/25	125 N	"	1.8 " " "	18.6	
C	PBT 45	25 Sept. 1944		7/36	24 N	T528p	4.2	40.0	
"	PBT 56	25 Mar. 1945		7/21	24 N	T721p	4.8	44.4	
"	PBT 46	26 Sept. 1944		8/85	24 N	T875a	4.6	37.4	
"	PBT 60	27 Mar. 1945		8/90	10 N	T712p	4.4	41.2	
"	PBT 76	24 April 1945		8/75	20 N	T875a	4.6	37.4	
"	PBT 84	4 June 1945		8/75	17 N	"	4.6	37.4	
C	PBT 59	27 Mar. 1945		4/92	63 S	T731p	3.6	44.0	
"	PBT 73	23 April 1945		4/75	63 S	T878a	5.0	43.0	
"	PBT 85	4 June 1945		4/75	58 S	T876a	4.2	43.8	
C	PBT 52	2 Oct. 1945		5/10	50 S	T594ap	4.2	44.0	
C	PBT 75	25 April 1945		6/05	10 S	T723a	3.6	37.0	
B	PBT 47	27 Sept. 1944	Pavement Bearing (Repeating load)	10/06	23 S	T560p	4.3	42.5	
"	PBT 70	6 April 1945		10/05	10 S	"	4.3	42.5	
"	PBT 72	21 April 1945		10/60	22 S	T877a	5.0	32.2	
"	PBT 87	5 June 1945		10/60	17 S	"	5.0	32.2	
B	PBT 51	1 Oct. 1945		12/58	22 N	T643p	4.8	26.4	
"	PBT 68	4 April 1945		12/65	14 N	T872a	4.8	28.8	
"	PBT 78	25 April 1945		12/75	20 N	T873a	4.2	25.8	
"	PBT 82	2 June 1945		12/75	16 N	"	4.2	25.8	
C	PBT 53	2 Oct. 1944		4/90	52 S	T876a	4.2	43.8	
"	PBT 69	4 April 1945		5/11	63 S	T739a	4.2	37.8	
"	PBT 74	23 April 1945		4/65	63 S	T878a	5.0	43.0	
"	PBT 88	5 June 1945		4/65	58 S	"	5.0	43.0	

CORPS OF ENGINEERS, U.S. ARMY

FROST INVESTIGATION
DOW FIELD, BANGOR, ME.

OF PAVEMENT BEARING TESTS

	UNDERLYING TEST PLATE ckness in inches BASE (GP)	SUBGRADE	DIAM. OF TEST PLATE (in inches)	TOTAL LOAD IN POUNDS * 0.05 inch Deflection	* 0.10 inch Deflection	* 0.20 inch Deflection	MAX. RATIO OF NORMAL TO FROST MELTING PERIOD LOAD FOR 0.1" DEFLECTION	AVG. THICKNESS OF PAVEMENT PLUS BASE (Feet)	AVG. DEPTH OF FROST PENETRATION (Feet)	THICKNESS OF FROZEN SUBGRADE (Feet)
	13.8	Gravelly Clay	24	22,000	36,000	57,000				
	13.8	Silty Clay	24	28,000	47,000	-				
	13.8	Gravelly Clay	30	3,500	13,000	31,000				
	13.8	Silty Clay	30	7,000	19,000	35,000				
	42.5	Silty Clay	30	14,000	27,000	49,000	1.75	3.8	4.0	0.2
	42.5			20,000	39,000	-				
	41.0			15,000	26,000*	45,000				
	41.4			18,000	34,000	59,000				
	32.2			26,000	45,000*	-				
	27.0			18,000	29,000	46,000	1.89	2.6	4.0	1.4
	27.0			11,000	18,000	32,000				
	27.0			10,000	18,000*	32,000				
	24.1			17,000	34,000*	-				
	23.0			10,000	19,000	36,000				
	30.0			16,000	33,000*	59,000	1.5	2.8	4.0	1.2
	27.2			9,000	15,000	30,000				
	28.8			13,000	23,000	40,000				
	28.8			16,000	29,000	-				
	28.8			9,000	22,000*	57,000				
t.	18.6			5,000	8,000	14,000				
	18.6			7,000	11,000	18,000				
	40.0			18,000	48,000*	-	1.92	3.8	4.8	1.0
	44.4			12,000	24,000	47,000				
	37.4			30,000	50,000	-				
	41.2			14,000	25,000*	43,000				
	37.4			17,000	33,000	58,000				
	37.4			26,000	46,000	-				
	44.0			15,000	29,000*	52,000	1.59	4.0	4.8	0.8
	43.0			22,000	38,000	-				
	43.8			27,000	46,000*	-				
	44.0			26,000	43,000	-		4.0	4.8	0.8
	37.0			12,000	24,000	45,000		4.0	4.8	0.8
				1st Load	DEFLECTION IN INCHES @ 20,000 LBS.	10th Repetition				
	42.5		24	.054		.065		3.9	4.0	0.1
	42.5			.068		.097				
	32.2			.078		.120				
	32.2			.059		.077				
	26.4			.063		.078		2.7	4.0	1.3
	28.8			.127		.157				
	25.8			.108		.155				
	25.8			.080		.116				
	43.8			.050		.053		3.9	4.8	0.9
	37.8			.045		.071				
	43.0			.085		.090				
	43.0			.062		.077				

* Values used to determine maximum ratio.

(A) Bituminous Concrete unless otherwise noted.

DOW FIELD
SUMMARY OF
PLATE BEARING TESTS

SHEET 1 OF 2, TABLE 3

FROST INVESTIGATION
DOW FIELD, BANGOR, M

SUMMARY OF PAVEMENT BEA

TEST AREA	TEST NO.	DATE	TYPE OF TEST	STATION	OFFSET (in feet)	NEAREST EXPLORATION	MATERIAL UNDERLYING TEST PLATE Thickness in inches		
							PAVEMENT (A)	BASE (GW)	SUBGRADE
IV-VII	PBT 27	22 Apr. 1944	Rupture	-6+16	44N	T587a	7.0 Cem. Conc.	13	CL
IV-VII	PBT 33	6 May. 1944	"	-6+14	44N	T587a	7.0 " "	13	CL
IV-VII	PBT 40	27 Aug. 1944	"	-6+15	31N	T588a	7.0 " "	13	CL
IV-VII	PBT 43	29 Aug. 1944	"	-6+13	31N	T588a	7.0 " "	13	CL
I&III	PBT 20	12 Apr. 1944	Pavement Bearing (Static Load)	-1+02	50N	T551p	4.5	17	CL
I&III	PBT 42	28 Aug. 1944		-0+62	47N	T551p	4.0	14	CL
I&III	PBT 21	13 Apr. 1944		0+08	50S	T542p	4.0	17	CL
I&III	PBT 39	26 Aug. 1944		-0+06	51S	T542p	4.0	17	CL
I&III	PBT 26	20 Apr. 1944		-1+52	33S	T554p	3.5	18	CL
I&III	PBT 35	22 Aug. 1944		-1+56	32S	T554p	3.5	16	CL
I&III	PBT 32	1 May 1944		-2+71	39S	T562p	4.0	22	CL
I&III	PBT 37	25 Aug. 1944		-2+77	41S	T562p	4.0	22	CL
II	PBT 22	15 Apr. 1944		10+23	22S	T560p	3.5	43	CL
II	PBT 34	23 Aug. 1944		10+30	20S	T560p	3.5	43	CL
II	PBT 22	17 Apr. 1944		10+26	48S	T559p	3.5	35	CL
II	PBT 54	3 Oct. 1944		10+33	47S	T559p	3.5	35	CL
II	PBT 24	17 Apr. 1944		10+36	59S	T558p	4.0	28	CL
II	PBT 44	25 Sep. 1944		10+35	58S	T558p	4.0	28	CL
I&III	PBT 25	18 Apr. 1944	Pavement Bearing (Repeating Load)	0+01	52S	T542p	4.0	17	CL
I&III	PBT 38	26 Aug. 1944		0+13	50S	T542p	4.0	17	CL
I&III	PBT 30	29 Apr. 1944		0+74	49N	T541p	3.5	14	CL
I&III	PBT 41	28 Aug. 1944		-0+15	31N	T522p	4.5	15	CL
I&III	PBT 31	30 Apr. 1944		-2+68	44S	T562p	4.0	22	CL
I&III	PBT 36	25 Aug. 1944		-2+60	39S	T562p	4.0	22	CL

FROST INVESTIGATION
DOW FIELD, BANGOR, ME.

OF PAVEMENT BEARING TESTS

AL UNDERLYING TEST PLATE hickness in inches BASE (GW)	SUBGRADE	DIAM. OF TEST PLATE (in inches)	TOTAL LOAD IN POUNDS @ 0.05 inch Deflection	@ 0.10 inch Deflection	@ 0.20 inch Deflection	MAX. RATIO OF NORMAL TO FROST MELTING PERIOD LOAD FOR 0.1" DEFLECTION	AVG. THICKNESS OF PAVEMENT PLUS BASE (Feet)	AVG. DEPTH OF FROST PENETRATION (Feet)	THICKNESS OF FROZEN SUBGRADE (Feet)
13	CL	24	15,000	27,000**	46,000	1.8	1.7	3.3	1.6
13	CL	24	16,000	29,000	50,000				
13	CL	19	20,000	50,000**	79,000				
13	CL	19	25,000	50,000	Failure				
17	CL	30	2,000	3,000	6,000	8.3	1.8	4.0	2.2
14	CL		13,000	25,000	45,000				
17	CL		8,000	15,000	25,000	2.0	1.8	4.0	2.2
17	CL		19,000	30,000	48,000				
18	CL		8,000	16,000	40,000	3.0	1.8	4.0	2.2
16	CL		25,000	48,000	-				
22	CL		14,000	27,000	48,000	0.6	2.2	4.0	1.8
22	CL		8,000	17,000	39,000				
43	CL		17,000	26,000	50,000	1.5	3.9	4.2	0.3
43	CL		20,000	39,000	-				
35	CL		15,000	36,000	65,000*	1.2	3.2	4.2	1.0
35	CL		22,500	44,000	60,000				
28	CL		12,000	23,000	42,000	1.7	2.7	4.2	1.5
28	CL		20,000	40,000	67,000*				
			DEFLECTION IN INCHES @ 20,000 LBS.						
			1st Load		10th Repetition				
17	CL	24	.218		.287		1.8	4.0	2.2
17	CL	19	.101		.130				
14	CL	24	.280		.372		1.5	4.0	2.5
15	CL	19	.098		.122				
22	CL	24	.089		.123		2.2	4.0	1.8
22	CL	19	.092		.094				

(A) Bituminous Concrete unless otherwise noted.

* Extrapolated

** Values used to determine maximum ratio.

B

DOW FIELD
SUMMARY OF
PLATE BEARING TESTS
SHEET 2 OF 2, TABLE 3

FROST INVESTIGAT
PIERRE AIRFIELD, PIERRE, SC
SUMMARY OF PLATE BE

TEST AREA	TEST NO.	DATE	TYPE OF TEST	STATION LOCATION	OFFSET (in Feet)	NEAREST EXPLORATION	MATERIAL UNDERLYING TEST PLATE Thickness in inches		
							PAVEMENT	BASE	SUBGRADE
A		14 Mar. 1945	Pavement Rupture	34+08 Apron	51' NE of SW Edge	TP-3D	7 PCC	9 GF	CL
A		24 Mar. 1945		33+96 "	76' " " " "	"	7 PCC	9 GF	CL
A		31 Mar. 1945		33+97 "	152' " " " "	"	7 PCC	9 GF	CL
A		15 Apr. 1945		33+96 "	167' " " " "	"	7 PCC	9 GF	CL
A		14 Mar. 1945		34+36 Apron	51' " " " "	TP-3D	7 PCC	9 GF	CL
A		24 Mar. 1945		34+26 "	76' " " " "	"	7 PCC	9 GF	CL
A		31 Mar. 1945		34+27 "	151' " " " "	"	7 PCC	9 GF	CL
A		15 Apr. 1945		34+26 "	176' " " " "	"	7 PCC	9 GF	CL
A		23 Apr. 1945	Subgrade Modulus On Base	37+34 Apron	26' " " " "	TP-3C	-	10 GF	13 CL;11 SF-CL;
A		24 Apr. 1945		34+95 "	39' " " " "	TP-4A	-	8 GF	6 CL; CH
A		25 Apr. 1945		38+04 "	110' " " " "	TP-3B	-	11 GF	CL
A		26 Apr. 1945		34+66 "	101' " " " "	TP-3D	-	12 GF	12 CH; CL
A		23 Apr. 1945	Subgrade Modulus On Subgrade	37+34 Apron	26' " " " "	TP-3C	-	-	13 CL;11 SF-CL;
A		24 Apr. 1945		34+95 "	39' " " " "	TP-4A	-	-	6 CL; CH
A		24 Apr. 1945		37+04 "	110' " " " "	TP-3B	-	-	CL
A		26 Apr. 1945		34+66 "	101' " " " "	TP-3D	-	-	12 CH; CL
B		13 Mar. 1945	Pavement Bearing (Static Load)	21+18	2' Rt. of ℄	TP-2A	6 BC	11 GF	CL
B		22 Mar. 1945		to	" " " "	"	" "	" "	"
B		29 Mar. 1945		21+38	" " " "	"	" "	" "	"
B		14 Apr. 1945		Taxiway #4	" " " "	"	" "	" "	"
B		13 Mar. 1945		28+61	1.5' Rt. of ℄	TP-2B	6 BC	7 GF	CL
B		22 Mar. 1945		to	" " " "	"	" "	" "	"
B		31 Mar. 1945		28+89	" " " "	"	" "	" "	"
B		14 Apr. 1945		Taxiway #4	" " " "	"	" "	" "	"
B		14 Mar. 1945		20+64	47' Rt. of ℄	TP-2A	1.5 BC	12 GF	CL
B		23 Mar. 1945		to	" " " "	"	" "	" "	"
B		31 Mar. 1945		20+79	" " " "	"	" "	" "	"
B		14 Apr. 1945		Taxiway #4	" " " "	"	" "	" "	"
B		14 Mar. 1945		21+11	46' Lt. of ℄	TP-2A	1.5 BC	12 GF	CL
B		23 Mar. 1945		to	" " " "	"	" "	" "	"
B		31 Mar. 1945		21+27	" " " "	"	" "	" "	"
B		14 Apr. 1945		Taxiway #4	" " " "	"	" "	" "	"
B		13 Mar. 1945	Pavement Bearing (Repeated Load)	25+04	15' Rt. of ℄	TP-3A	6 BC	8 GF	CL
B		22 Mar. 1945		25+15	2' " " "	"	" "	9 GF	"
B		30 Mar. 1945		24+96	1' " " "	"	" "	8 GF	"
B		12 Apr. 1945		24+99	1.5' " " "	"	" "	11 GF	"
B		12 Mar. 1945		25+30	45' Rt. of ℄	TP-3A	1.5 BC	12 GF	CL
B		23 Mar. 1945		29+73	45' " " "	TP-4B	" "	" "	"
B		30 Mar. 1945		29+67	46' " " "	"	" "	" "	"
B		12 Apr. 1945		29+06	44' " " "	"	" "	" "	"

PCC - Portland Cement Concrete
BC - Bituminous Concrete

GF)
CL)
CH) Casagrande's Soil Classifications
SF-CL)

A

ROST INVESTIGATION
RFIELD, PIERRE, SOUTH DAKOTA
F PLATE BEARING TESTS

RLYING TEST PLATE s in inches		DIAM. OF TEST PLATE (in inches)	TOTAL LOAD IN POUNDS			MAX. RATIO OF NORMAL TO FROST MELTING PERIOD LOAD FOR 0.1" DEFLECTION	AVG. THICKNESS OF PAVEMENT PLUS BASE (Feet)	MAX. DEPTH OF FROST PENETRATION (Feet)	THICKNESS OF FROZEN SUBGRADE (Feet)
SE	SUBGRADE		@ 0.05 inch Deflection	@ 0.10 inch Deflection	@ 0.20 inch Deflection				
9 GP	CL	30	30,000	52,000	70,000		1.3	3.5	3.7
9 GP	CL		30,000	46,000	56,000				
9 GP	CL		40,000	64,000	86,000				
9 GP	CL		33,000	55,000	Failure				
9 GP	CL		34,000	56,000	83,000		1.3	3.5	3.7
9 GP	CL		30,000	44,000	61,000				
9 GP	CL		40,000	60,000	Failure				
9 GP	CL		35,000	56,000	Failure				
0 GP	13 CL;11 SP-CL;CL	12	4,000	7,000	11,000		1.5	3.5	3.5
2 GP	6 CL; CH		5,000	9,000	15,000				
1 GP	CL		4,000	7,000	12,300				
2 GP	12 CH; CL		6,000	10,000	14,000				
-	13 CL;11 SP-CL;CL		3,000	5,000	8,000		1.5	3.5	3.5
-	6 CL; CH		5,000	9,000	15,000				
-	CL		5,000	8,000	11,000				
-	12 CH; CL		4,000	6,000	10,000				
GP	CL	12	22,000	34,000	63,000		1.4	2.1	0.7
"	"		25,000	40,000	63,000				
"	"		25,000	40,000	62,000				
"	"		30,000	49,000	73,000				
GP	CL		19,000	33,000	53,000		1.1	2.1	1.0
"	"		13,000	23,000	36,000				
"	"		17,000	27,000	46,000				
"	"		21,000	37,000	58,000				
GP	CL		7,000	13,000	22,000		1.1	2.1	1.0
"	"		8,000	15,000	27,000				
"	"		9,000	16,000	28,000				
"	"		12,000	21,000	35,000				
GP	CL		10,000	18,000	30,000		1.1	2.1	1.0
"	"		9,000	16,000	29,000				
"	"		12,000	20,000	34,000				
"	"		11,000	19,000	33,000				
			Deflection in inches @ 25,000 lb.						
			1st. Load		10th Repetition				
GP	CL	30	.120		.193		1.3	2.1	0.8
GP	"		.127		.198				
GP	"		.125		.175				
GP	"		.127		.175				
GP	CL		.330		.453		1.1	2.1	1.0
"	"		.207		.295				
"	"		.155		.247				
"	"		.155		.205				

nt Concrete
ncrete

Soil Classifications

B

PIERRE AIRFIELD
SUMMARY OF PLATE BEARING TESTS

TABLE 4

FROST INVESTIGAT

WATERTOWN AIRFIELD, WATERTO

SUMMARY OF PLATE BE

TEST AREA	TEST NO.	DATE	TYPE OF TEST	STATION LOCATION	OFFSET (in Feet)	NEAREST EXPLORATION	MATERIAL UNDERLYING TEST PLATE Thickness in inches PAVEMENT	 BASE	 SUBGRADE
A		19 Mar. 1945	Pavement Rupture	- 10+30			8 PCC	22 SF-CL	OL
A		2 Apr. 1945	" "	to			" "	" "	"
A		19 Apr. 1945	" "	- 10+70			" "	" "	"
A		20 Mar. 1945	Pavement Rupture	- 10+30			8 PCC	22 SF-CL	OL
A		2 Apr. 1945	" "	to			" "	" "	"
A		19 Apr. 1945	" "	- 10+70			" "	" "	"
B		21 Mar. 1945	Pavement Bearing (Static Load)	- 4+75	20' Rt. of ℄	TP-3A	5 BC	8 SF	OL-CL
B		4 Apr. 1945		to	" " " "	"	" "	" "	"
B		19 Apr. 1945		- 4+93	" " " "	"	" "	" "	"
B		21 Mar. 1945		- 12+00	20' Lt. of ℄	TP-3B	5 BC	8 SF	SF-CL
B		4 Apr. 1945		to	" " " "	"	" "	" "	"
B		20 Apr. 1945		- 12+45	" " " "	"	" "	" "	"
B		21 Mar. 1945		- 4+75	43' Lt. of ℄	TP-3A	1.5 BC	12 SF	OL-CL
B		4 Apr. 1945		to	" " " "	"	" "	" "	"
B		18 Apr. 1945		- 4+93	" " " "	"	" "	" "	"
B		21 Mar. 1945		- 12+00	43' Rt. of ℄	TP-3B	1.5 BC	12 SF	SF-CL
B		4 Apr. 1945		to	" " " "	"	" "	" "	"
B		20 Apr. 1945		- 12+57	" " " "	"	" "	" "	"
A		19 Mar. 1945	Pavement Bearing (Repeated Load)	- 10+71	59' Rt. of ℄	TP-1B	8 PCC	22 SF-CL	OL
A		19 Apr. 1945		- 10+69	39' Lt. of ℄	TP-2B	" "	" "	"
A		19 Apr. 1945		- 10+39	39' " " "	"	" "	" "	"
B		20 Mar. 1945		- 4+13	20' Lt. of ℄	TP-3A	5 BC	8 SF	OL-CL
B		3 Apr. 1945		- 4+62	20' " " "	"	" "	" "	"
B		20 Apr. 1945		- 4+72	20' " " "	"	" "	" "	"
B		20 Mar. 1945		- 10+40	43' Rt. of ℄	TP-2B	1.5 BC	12 SF	SF-CL
B		3 Apr. 1945		- 10+48	43' " " "	"	" "	" "	"
B		20 Apr. 1945		- 10+56	43' " " "	"	" "	" "	"

PCC - Portland Cement Concrete
BC - Bituminous Concrete

SF SF-CL OL OL-CL	Casagrande's Soil Classifications

ST INVESTIGATION
LD, WATERTOWN, SOUTH DAKOTA

PLATE BEARING TESTS

NG TEST PLATE r inches	SUBGRADE	DIAM. OF TEST PLATE (in inches)	TOTAL LOAD IN POUNDS @ 0.05 inch Deflection	@ 0.10 inch Deflection	@ 0.20 inch Deflection	MAX. RATIO OF NORMAL TO FROST MELTING PERIOD LOAD FOR 0.1" DEFLECTION	AVG. THICKNESS OF PAVEMENT PLUS BASE (Feet)	MAX DEPTH OF FROST PENETRATION (Feet)	THICKNESS OF FROZEN SUBGRADE (Feet)
CL	OL	12	46,000	80,000	-		2.5	3.4	0.9
	"		25,000	54,000	91,000				
	"		46,000	77,000	-				
CL	OL		34,000	70,000	Failure		2.5	3.4	0.9
	"		34,000	62,000	93,000				
	"		42,000	72,000	-				
	OL-CL	30	26,000	48,000	76,000		1.1	4.8	3.7
	"		37,000	55,000	80,000				
	"		35,000	57,000	83,000				
	SF-CL		24,000	44,000	77,000		1.1	4.8	3.7
	"		27,000	45,000	72,000				
	"		21,000	39,000	64,000				
	OL-CL		8,000	15,000	31,000		1.1	4.8	3.7
	"		8,000	15,000	28,000				
	"		11,000	21,000	40,000				
	SF-CL		8,000	16,000	30,000		1.1	4.8	3.7
	"		8,000	16,000	24,000				
	"		9,000	18,000	31,000				
			Deflection in inches @ 100,000 lb.						
			1st. Load		10th Repetition				
CL	OL	12	.140		.165		2.5	3.4	0.9
	"		.191		.214				
	"		.160		.202				
			Deflection in inches @ 25,000 lb.						
			1st. Load		10th Repetition				
	OL-CL		.166		.233		1.1	4.8	3.7
	"		.070		.088				
	"		.057		.097				
	SF-CL		.268		.345		1.1	4.8	3.7
	"		.255		.354				
	"		.240		.325				

Concrete
rete

oil Classifications

B

WATERTOWN AIRFIELD
SUMMARY OF PLATE BEARING TESTS

TABLE 5

FROST INVESTIGAT
TRUAX FIELD, MADISON, W
SUMMARY OF PLATE BE

TEST AREA	TEST NO.	DATE	TYPE OF TEST	STATION LOCATION	OFFSET (in Feet)	NEAREST EXPLORATION	MATERIAL UNDERLYING TEST PLATE Thickness in inches		
							PAVEMENT	BASE	SUBGRADE
A	PBE 1	19 Oct. 1944	Pavement Bearing (Static Load)	0+78 E-W.TAX	11' S of ℄	TP-4	2.5 BC	8 CR; 16 GP	22 CL; 38 SF; C
A	PBE 2	20 Oct. 1944		2+54 E-W. "	12' N of ℄	TP-2	2.5 BC	8 CR; 17 GP	20 CL; 40 SF; C
A	PBE 3	29 Mar. 1945		2+52 E-W. "	6' N of ℄	TP-2	2.5 BC	8 CR; 16 GP	20 CL; 41 SF; C
B	PBE 1	24 Nov. 1944		8+60 N-S.RWY	42' E of ℄	TP-3	2.5 BC	20 CR; 22 GP	CL
B	PBE 2	29 Nov. 1944		8+40 N-S. "	42' W of ℄	TP-4	2.5 BC	24 CR; 20 GP	CL
B	PBE 3	30 Nov. 1944		12+42 N-S. "	42' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBE 4	28 Nov. 1944		12+58 N-S. "	44' W of ℄	TP-7	2.5 BC	24 CR; 23 GP	CL
B	PBE 5	13 Mar. 1945		12+25 N-S. "	60' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBE 6	16 Mar. 1945		12+38 N-S. "	60' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBE 7	23 Mar. 1945		12+28 N-S. "	65' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBE 8	25 Mar. 1945		12+38 N-S. "	65' E of ℄	TP-10	2.5 BC	19 CR; 25 GP	CL
B	PBE 9	27 Mar. 1945		12+16 N-S. "	42' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBE 10	30 Mar. 1945		12+12 N-S. "	50' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBE 11	2 Apr. 1945		12+26 N-S. "	50' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
C	PBC 1	14 Mar. 1945	Pavement Rupture	2+0 Apron	22' NW of SE Edge	TP-1	7 PCC	42 GP	CL
C	PBC 2	15 Mar. 1945	" "	2+0 "	22' " " " "	TP-1	7 PCC	42 GP	CL
C	PBC 3	17 Mar. 1945	" "	2+20 "	12' " " " "	TP-1	7 PCC	42 GP	CL
C	PBC 4	22 Mar. 1945	" "	2+80 "	140' " " " "	TP-13	7 PCC	48 GP	CL
C	PBC 5	22 Mar. 1945	" "	3+00 "	140' " " " "	TP-13	7 PCC	48 GP	CL
C	PBE 1	2 Nov. 1944	Subgrade Modulus	1+05 "	23' " " " "	TP-1	-	39 GP	CL
C	PBE 2	6 Nov. 1944	" "	1+18 "	83' " " " "	TP-2	-	45 GP	CL
C	PBE 3	7 Nov. 1944	" "	3+85 "	118' " " " "	TP-3	-	51 GP	CL
C	PBE 4	15 Nov. 1944	" "	3+[illegible] "	33' " " " "	TP-4	-	31 GP	CL
A	PBR 1	20 Oct. 1944	Pavement Bearing (Repeated Load)	0+92 E-W.TAX	11' S of ℄	TP-4	2.5 BC	8 CR; 16 GP	22 CL; 36 SF; C
A	PBR 2	21 Oct. 1944		2+67 E-W. "	12' N of ℄	TP-2	2.5 BC	8 CR; 16 GP	20 CL; 40 SF; C
A	PBR 3	25 Mar. 1945		2+60 E-W. "	6' N of ℄	TP-2	2.5 BC	8 CR; 16 GP	20 CL; 40 SF; C
B	PBR 1	23 Nov. 1944		8+40 N-S.RWY	42' E of ℄	TP-3	2.5 BC	20 CR; 22 GP	CL
B	PBR 2	25 Nov. 1944		12+41 N-S. "	44' W of ℄	TP-7	2.5 BC	24 CR; 23 GP	CL
B	PBR 3	14 Mar. 1945		12+31 N-S. "	60' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBR 4	16 Mar. 1945		12+46 N-S. "	60' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBR 5	27 Mar. 1945		12+35 N-S. "	65' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBR 6	26 Mar. 1945		12+44 N-S. "	65' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBR 7	27 Mar. 1945		12+22 N-S. "	42' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBR 8	31 Mar. 1945		12+20 N-S. "	50' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL
B	PBR 9	3 Apr. 1945		12+35 N-S. "	50' E of ℄	TP-10	2.5 BC	19 CR; 23 GP	CL

PCC - Portland Cement Concrete
BC - Bituminous Concrete
CR - Crushed Rock

GP)
SP) Casagrande's Soil Classifications
CL)

A

OST INVESTIGATION
LD, MADISON, WISCONSIN
PLATE BEARING TESTS

YING TEST PLATE in inches		DIAM. OF TEST PLATE (in inches)	TOTAL LOAD IN POUNDS			MAX. RATIO OF NORMAL TO FROST MELTING PERIOD LOAD FOR 0.1" DEFLECTION	AVG. THICKNESS OF PAVEMENT PLUS BASE (Feet)	MAX. DEPTH OF FROST PENETRATION (Feet)	THICKNESS OF FROZEN SUBGRADE (Feet)
E	SUBGRADE		● 0.05 inch Deflection	● 0.10 inch Deflection	● 0.20 inch Deflection				
6 GF	22 CL; 38 SF; CL	30	23,000	-	-				
7 GF	20 CL; 40 SF; CL		22,000	32,000*	-		2.3	3.9	1.6
6 GF	20 CL; 41 SF; CL		13,000	20,000*	30,000	1.6			
2 GF	CL		27,000	-	-				
0 GF	CL		30,000	-	-		3.9	4.7	0.8
3 GF	CL		31,000*						
3 GF	CL		30,000	-	-				
3 GF	CL		20,000	28,000	-				
3 GF	CL		14,000*	23,000	40,000				
3 GF	CL		19,000	27,000	41,000	2.2' ● 0.05" Defl.			
5 GF	CL		18,000	29,000	47,000		3.7	4.7	1.0
3 GF	CL		21,000	34,000	54,000				
3 GF	CL		20,000	32,000	49,000				
3 GF	CL		13,000	23,000	39,000				
2 GF	CL	24	38,000	-	-				
2 GF	CL		36,000	-	-				
2 GF	CL		17,000	33,000	-		4.3	4.6	0.3
3 GF	CL		27,000	44,000	-				
3 GF	CL		37,000	58,000	-				
GF	CL	30	10,000	14,000	20,000				
5 GF	CL		9,000	14,000	21,000		4.0	4.6	0.6
1 GF	CL		8,000	11,000	17,000				
1 GF	CL		7,000	10,000	-				
			Deflection in inches ● 20,000 lb.						
			1st. Load.		10th Repetition				
GF	22 CL; 38 SF; CL	24	.053		.077				
GF	20 CL; 40 SF; CL		.051		.075		2.3	3.9	1.6
GF	20 CL; 40 SF; CL		.085		.143				
GF	CL		.036		.048				
GF	CL		.039		.049				
GF	CL		.054		.088				
GF	CL		.055		.093				
GF	CL		.061		.105				
GF	CL		.066		.094		3.7	4.7	1.0
GF	CL		.043		.062				
GF	CL		.063		.082				
GF	CL		.079		.129				

t Concrete
crete

Classifications

*Values used to determine maximum ratio.

B

TRUAX FIELD
SUMMARY OF PLATE BEARING TESTS

TABLE 6

FROST INVESTIGATIO
1944 - 1945
SUMMARY OF TRAFFIC T

	AIRFIELD	TEST AREA	TRAFFIC TEST LOCATION		PAVEMENT			BASE					SUBGRADE				EVALUATION (NORMAL PERIOD)	
			STATION	OFFSET TO ℄ OF TEST AREA	TYPE AND THICKNESS (INCHES)	1945 FROST HEAVE TYPE	1945 FROST HEAVE RANGE (FEET)	CASAGRANDE CLASS. AND THICKNESS (INCHES)	ICE FORMATIONS	K OR CBR (IN PLACE) NORMAL PERIOD	K OR CBR (IN PLACE) FROST MELT PERIOD	PAVE. & BASE THICK. (INCHES)	CASAGRANDE CLASS.	ICE FORMATIONS	K OR CBR (IN PLACE) NORMAL PERIOD	K OR CBR (IN PLACE) FROST MELT PERIOD	RUNWAY WHEEL LOAD (POUNDS)	TAXIWAY WHEEL LO (POUNDS
FLEXIBLE PAVEMENT	DOW FIELD	B 1	E-W Runway 11+40 to 12+90	40' S. of ℄	BC 3.5	Uniform	0.2 to 0.35	27.5 GW	Crystals Throughout	-	-	31	CL	Numerous Lenses	8	3	60,000 +	60,000 +
		C 1	E-W Runway 4+20 to 5+70	40' S. of ℄	BC 3.5	do	0.1 to 0.15	37.5 GW	do	-	-	41	CL	do	8	3	60,000 +	60,000 +
		B 2	E-W Runway 12+20 to 13+80	40' N. of ℄	BC 3.5	do	0.25 to 0.30	25.5 GW	do	-	-	29.	CL	do	8	3	60,000 +	60,000 +
		C 2	E-W Runway 4+50 to 5+70	40' N. of ℄	BC 3.5	do	0.05 to 0.15	44.5 GW	do	-	-	48.	CL	do	8	3	60,000 +	60,000 +
	TRUAX	B 1	N-S Runway 12+00 to 13+50	18' E. of ℄	BC 2.5	do	0.01 to 0.05	20.5 Cr. Rock 28.0 GF Sub-base	Few Crystals Few hairline lenses in sub-base	35	31	51	CL	do	5	3	30,000 (C)	30,000 (C
		B 2	N-S Runway 12+00 to 13+50	18' W. of ℄	BC 2.5	do	0.01 to 0.03	do	do	35	31	51.	CL	do	5	3	30,000 (C)	30,000 (C
	PIERRE B	T 1	Taxiway ℄ (22+0 to 23+50)	40' N. of ℄	BC 1.5	Concentrated	-0.01 to 0.02	12 GP	None	28	24	13.5	CL	Very few	14	12	15,000 (D)	15,000 (D
		T 4 SHOULDER	(22+0 to 23+50)	40' S. of ℄	BC 1.5	do	-0.01 to 0.02	do	do	do	do	do	do	do	do	do	do	do
		T 5	(26+75 to 28+25)	40' N. of ℄	BC 1.5	do	-0.01 to 0.03	do	do	do	do	do	do	do	do	do	do	do
		T 8	(26+75 to 28+25)	40' S. of ℄	BC 1.5	do	-0.01 to 0.02	do	do	do	do	do	do	do	do	do	do	do
		T 9	(30+50 to 32+00)	40' N. of ℄	BC 1.5	do	do	do	do	do	do	do	do	do	do	do	do	do
		T 11	30+50 to 32+00;	40' S. of ℄	BC 1.5	do	do	do	do	do	do	do	do	do	do	do	do	do
		T 12	-	-	BC 1.5	do	do	do	do	do	do	do	do	do	do	do	do	do
		T 2	Taxiway ℄ (22+00 to 23+50)	15' N. of ℄	BC 5.5	Subsidence in center of pavement	-0.02 to 0.0	8 GF	None	28	24	13.5	CL	Very few	14	12	36,000	28,000
		T 3	(22+00 to 23+50)	15' S. of ℄	BC 5.5		-0.01 to 0.0	do	do	do	do	do	do	do	do	do	do	do
		T 6	(26+75 to 28+25)	15' N. of ℄	BC 5.5		-0.01 to 0.0	do	do	do	do	do	do	do	do	do	do	do
		T 7	26+75 to 28+25)	15' S. of ℄	BC 5.5		-0.01 to -0.02	do	do	do	do	do	do	do	do	do	do	do
		T 10	(30+00 to 32+00)	15' S. of ℄	BC 5.5		-	do	do	do	do	do	do	do	do	do	do	do
RIGID PAVEMENT	TRUAX	C 1	Apron 3+00 to 4+50	55' NW of SE edge	PCC 6 (A)	Uniform	0.08 to 0.12	36 GF	Ice lenses adhered to bottom of slab	250	-	42	CL	Numerous lenses	-	-	35,000	28,000
		C 2	Apron 3+00 to 4+50	110' NW of SE edge	PCC 6 (A)	Uniform	0.08 to 0.12	48 GF	do	250	-	54	CL	Numerous lenses	-	-	35,000	28,000
	PIERRE A	R1	Apron (33+50 to 35+00)	25' NE of SW edge	PCC 7 (B)	Uniform	0.01 to 0.02	9 GP	None	-	140	16	CL	Very few	-	110	30,000	25,000
		R2	(36+50 to 38+00,	do	do	do	0.00 to 0.02	do	do	do	do	do	do	do	do	do	do	do
		R3	(33+50 to 35+00)	125' NE of SW edge	do	do	0.00 to 0.01	do	do	do	do	do	do	do	do	do	do	do
		R4	(36+50 to 38+00)	do	do	do	do	do	do	do	do	do	do	do	do	do	do	do
		R2	(36+50 to 38+00)	25' NE of SW edge	do	do	0.00 to 0.02	do	do	do	do	do	do	do	do	do	do	do
		R3	(33+50 to 35+00)	125' NE of SW edge	do	do	0.00 to 0.01	do	do	do	do	do	do	do	do	do	do	do

(A) FLEXURAL STRENGTH OF CEMENT CONCRETE 865 LBS./SQ.IN.

(B) FLEXURAL STRENGTH OF CEMENT CONCRETE 700 LBS./SQ.IN.

(C) EVALUATION CONTROLLED BY 2 THICKNESS OF PAVEMENT.

(D) EVALUATION CONTROLLED BY 1 THICKNESS OF PAVEMENT.

ST INVESTIGATION
1944 - 1945
F TRAFFIC TEST DATA

EVALUATION (NORMAL PERIOD)		FROST PENE-TRATION (FEET)	PLATE BEARING TESTS			TRAFFIC TESTS							
RUNWAY HEEL LOAD (POUNDS)	TAXIWAY WHEEL LOAD (POUNDS)		REPEATING LOAD RATIOS(E)		STATIC LOAD RATIOS(F)	TEST PERIOD 1945	IDLE PERIOD	APPROX. PERIOD OF FROST MELTING (1945		WHEEL LOAD (POUNDS)	NUMBER OF COVERAGES		REMARKS
			1st LOAD	10th LOAD				START	END		APPROX. DAILY	TOTAL	
60,000 ✓	60,000 ✓	4.3	0.77	0.66	1.5	2 to 20 April	10 & 18 April	15 March	2 April	40,000 40,000**	15 45	272 524	Flexing started at 16 coverages, map cracking started at 64 coverages, rutting developed after 400 coverages.
60,000 ✓	60,000 ✓	5.1	0.85	0.76	1.7	2 to 20 April	10 & 18 April	15 March	10 April	40,000 40,000	15 45	272 848	
60,000 ✓	60,000 ✓	4.3	0.65	0.62	1.9	1 April		15 March	2 April	60,000**	16	16	Flexing, rutting, and map cracking. Test stopped after 1 day. Vertical deformations formed 0.09 to 0.26 foot.
60,000 ✓	60,000 ✓	5.1	-	-	1.6	1 to 20 April	5,8 to 14, 18 and 19 April	15 March	10 April	60,000 60,000	15 45	186 594	
30,000 (C)	30,000 (C)	4.7	0.62	0.52	2.2 ● (0.05" Defl.)	12 March-3 April	16,21,25 March and 1 April	12 March	20 March	60,000 60,000**	15 45	237 710	Final vertical deformation 1.0" to 1.5".
30,000 (C)	30,000 (C)	4.7	0.62	0.52	-	11 to 20 March	-	12 March	20 March	30,000 30,000	15 45	140 420	
15,000 (D)	15,000 (D)	2.1 (3 Feb.)	No tests made during normal period.			13 to 29 March	-	5 March	15 March	14,500**	15	248	
do	do	do				13 March	-	do	do	25,000**	42	42	
do	do	do				do	-	do	do	14,500**	36	36	
do	do	do				13 to 25 March	-	do	do	25,000**	15	168	Shoulder pavement suffered severe distress under all loading conditions.
do	do	do				17 to 29 March	-	do	do	7,000**	45	624	
do	do	do				do	-	do	do	7,000**	15	208	
do	do	do				30 March - 1 April	-	do	do	25,000**	15	42	
36,000	2[illegible],000	2.1 (3 Feb.)				13 to 20 March	-	5 March	15 March	25,000**	45	200	
do	do	do				13 to 29 March	-	do	do	14,500	15	248	
do	do	do				do	-	do	do	25,000	15	224	Considerable flexing of pavement surface under rolling wheel loads.
do	do	do				do	-	do	do	14,500	45	720	
do	do	do				17 to 29 March	-	do	do	7,000	45	416	
35,000	28,000	4.7				7 to 20 March 21 March - 3 April	- 1 April	12 March 12 March	20 March 20 March	15,000 15,000 30,000 30,000	15 45 15 45	210 630 234 535	
35,000	28,000	4.7				7 to 20 March	-	12 March	20 March	30,000 30,000**	15 45	162 405	Water pumping at all joints after 45 coverages. Extensive cracking after 315 coverages. Traffic discontinued because of imminent pavement failure.
30,000	25,000	3.5				14 to 29 March	-	5 March	15 March	14,500	15	240	
do	do	do				do	-	do	do	14,500	45	720	
do	do	do				do	-	do	do	25,000**	45	513	Severe cracking after 2 days traffic.
do do	do do	do do				do 30 March - 4 April	- -	do do	do do	25,000 14,500	15 178	270 1611	
do	do	do				do	-	do	do	25,000**	178	1698	Failure due to pumping resulting from infiltration of surface water through pavement joints.

C) EVALUATION CONTROLLED BY 2.5" THICKNESS OF PAVEMENT.

D) EVALUATION CONTROLLED BY 1.5" THICKNESS OF PAVEMENT.

(E) RATIO OF DEFLECTION OF TEST PLATE DURING NORMAL PERIOD TO FROST MELTING PERIOD AFTER APPLICATION OF 20,000 POUND LOAD.

(F) RATIO OF LOAD DURING NORMAL PERIOD TO FROST MELTING PERIOD THAT PRODUCED 0.1" DEFLECTION OF TEST PLATE.

**WHEEL LOAD PRODUCED IMMINENT PAVEMENT FAILURE.

SHEET 1 OF 2, TABLE 7

FROST INVESTIGAT
1944 - 1945

SUMMARY OF TRAFFIC

DOW FIELD 1944

AIRFIELD	TEST AREA	TRAFFIC TEST LOCATION		PAVEMENT			BASE					SUBGRADE				EVALUATION (NORMAL PERIO	
		STATION	OFFSET TO ℄ OF TEST AREA	TYPE AND THICKNESS (INCHES)	1945 FROST HEAVE TYPE	1945 FROST HEAVE RANGE (FEET)	CASAGRANDE CLASS AND THICKNESS (INCHES)	ICE FORMATIONS	K OR CBR (IN PLACE) NORMAL PERIOD	K OR CBR (IN PLACE) FROST MELT PERIOD	PAVE. & BASE THICK (INCHES)	CASA-GRANDE CLASS	ICE FOR-MATIONS	K OR CBR (IN PLACE) NORMAL PERIOD	K OR CBR (IN PLACE) FROST MELT PERIOD	RUNWAY WHEEL LOAD (POUNDS)	TAXIW WHEEL (POUN
FLEXIBLE PAVEMENT DOW	I	E-W Runway 0/00 to -2/00	Circular track area	BC 4.0	Uniform	0.00 - 0.40	14.0 GW	None	-	-	18	CL	Few thin lenses	15	5	60,000 /	60,00
				BC 4.0	Uniform	0.00 - 0.40	17.0 GW	None	-	-	21	SC	Few thin lenses	-	60	60,000 /	60,00
	II	E-W Runway 9/50 to 11/00	50' S of ℄	BC 3.5	Uniform	0.00 - 0.40	29.5 GW	None	-	-	33	CL	Few thin lenses	-	4.5	60,000 /	60,00
	III	E-W Runway -2/85 to -3/05	Circular track area	BC 5.8	Uniform	0.02 - 0.20	20.0 GW	None	-	-	25.8	CL	Few thin lenses	15	5	60,000 /	60,00
RIGID PAVEMENT DOW	IV	E-W Runway -5/80 to -6/60	30' S of ℄	PCC 7.0	Differ-ential	0.30 - 0.70	15.0 GW	None	315	-	22	GC	Numerous	-	-	40,000	32,00
	V	E-W Runway -5/80 to -6/60	40' S of ℄	PCC7.0	Differ-ential	0.30 - 0.70	16.0 GW	None	315	-	25	CL	Numerous	-	-	40,000	32,00
	VI	E-W Runway -5/80 to -6/60	15' S of ℄	PCC 7.0	Differ-ential	0.30 - 0.70	13.0 GW	None	315	-	20	GC	Numerous	-	-	40,000	32,00
	VII	E-W Runway -5/80 to -6/60	57' S of ℄	PCC 7.0	Differ-ential	0.30 - 0.70	10.0-13.0 GW	None	315	-	17-20	CL	Numerous	-	-	40,000	32,00

A

ROST INVESTIGATION
1944 - 1945
OF TRAFFIC TEST DATA
DOW FIELD 1944

EVALUATION (NORMAL PERIOD)		FROST PENETRATION (FEET)	PLATE BEARING TESTS			TRAFFIC TESTS							
RUNWAY WHEEL LOAD (POUNDS)	TAXIWAY WHEEL LOAD (POUNDS)		REPEATING LOAD RATIOS (A)		STATIC LOAD RATIOS (B)	TEST PERIOD 1944	IDLE PERIOD	APPROX. PERIOD OF FROST MELTING (1945)		WHEEL LOAD (POUNDS)	NUMBER OF COVERAGES		REMARKS
			1st LOAD	10th LOAD				START	END		APPROX DAILY	TOTAL	
60,000 ✓	60,000 ✓	4.0	0.40	0.39	1.9	5 to 22 April	-	22 March	21 April	20,000**	4	72	
60,000 ✓	60,000 ✓	4.0	-	-	-	5 to 22 April	-	22 March	21 April	20,000	50	583	
60,000 ✓	60,000 ✓	4.0	-	-	1.5	6 to 14 April	-	22 March	21 April	20,000	44	396	
60,000 ✓	60,000 ✓	4.2	0.40	0.39	1.9	11 April to 5 May	16 April 18 April 25 April 26 April 30 April	22 March	21 April	10,000**	50	965	Flexing on 3 portions of test area after a few cycles.
40,000	32,000	4.1	-	-	-	25 April to 5 May	-	22 March	18 April	20,000	25	225	
40,000	32,000	4.1	-	-	-	27 April	-	22 March	18 April	40,000**	15	15	Tests discontinued after one day due to excessive cracking. Cracking started at two coverages.
40,000	32,000	4.1	-	-	-	30 April to 4 May	-	22 March	18 April	50,000**	15	76	Cracking developed after one coverage. Tests stopped due to excessive breaks
40,000	32,000	4.1	-	-	-	3 to 9 May	-	22 March	16 April	30,000	60-400 passes	1610 passes	Equipment tracked forward and reverse for 40 foot length of pavement was considered two passes.

(A) RATIO OF DEFLECTION OF TEST PLATE DURING NORMAL PERIOD TO FROST MELTING PERIOD AFTER APPLICATION OF 20,000 LB. LOAD.

(B) RATIO OF LOAD DURING NORMAL PERIOD TO FROST MELTING PERIOD THAT PRODUCED 0.1" DEFLECTION OF TEST PLATE.

**WHEEL LOAD PRODUCED IMMINENT FAILURE.

B

SHEET 2 OF 2, TABLE 7

DATA SHOWING INFLUENC
OF
WATER ON FROST ACTIO
1944 - 1945

AIRFIELD	TEST AREA	ICE LENSES OBSERVED		PAVEMENT HEAVE (FEET)		DEPTH TO GROUND WATER IN WINTER (FEET)	WATER CONTENT OF FROST SUSCEPTIBLE SUBGRADE	
		IN BASE	IN SUBGRADE	AVERAGE	RANGE		FALL	WINTER
PRESQUE ISLE	A	No lenses few crystals	Numerous-ranged from 1/8" to hairline	0.18	.05-.30	Below 6	16.1 GC	17.9 GC
	B	No lenses few crystals	Numerous-ranged from 1/8" to hairline	0.10	0.10-0.55	Below 6	15.7 GC	14.8 GC
HOULTON	A	None	Numerous lenses and crystals from 0.8' to 2.1' and 3.5' to 4.0'-ranged from 1/8" to hairline	0.20	0.05-0.20	Below 6	17.6 GF	14.7 GF, 8.3 GC
	B	None	None	0.00	-0.05 to +0.05	Below 6.5	13.7 GF	-
DCW	A	No lenses-ice crystals throughout	Numerous lenses ranging from 7/8" to hairline	0.50	0.20 to 0.70	5-6	-	25.7 CL
	B	No lenses-crystals throughout	Numerous lenses ranging from 3/8" to 1/8"	0.12	0.00 to 0.40	Below 6	25.1 CL	31.1 CL
	C	No lenses-crystals throughout	Numerous-ranged from 1/4" to hairline	0.10	0.00 to 0.25	Below 6	22.0 CL	19.3 CL
OTIS	A	None	Lenses 1/32" to hairline 12" above F.P.	0.02	0.00 to 0.16	Below 15	3.3 SF 11.9 SP	- 1.2 SP
TRUAX	A	No lenses-few crystals	Lenses 1/16" to hairline	0.12	0.08 to 0.14	5.8 -6.0	21.1 CL	27 CL
	B	No lenses-few crystals	Few hairline lenses	0.03	0.01 to 0.05	6.5 -7.5	23.5 CL	27 CL
	C	Lenses 1/16" to hairline	Fine lenses	0.11	0.02 to 0.14	6.5 -7.5	20 CL	30 CL
PIERRE	A	None	Minor-Not well defined	0.00	0.00 to 0.03	Below 25	15.1 CL	14.3 CL
	B	None	Small lenses and few crystals	-0.01	-0.02 to +0.03	Not Encountered	14.1 CL	13.3 CL
CASPER	A	None	None-16 January	0.01	0.00 to 0.03	Below 90	11.4 SF-CL 6-8 SF	9.6 SF-CL 8.5 SF
	B	None	None-16 January	0.01	-0.01 to +0.03	Below 90	6.2 SF-CL 3.5 SP	7.3 SF-CL 5.0 SP
WATERTOWN	A	None	Few thin lenses at bottom of pavement	0.05	0.00 to 0.13	12	14.6 SF-CL 23 OL-CL	13.6 SF-CL 10.1 CL-CL
	B	None	Very thin lenses to 1.7' depth	-0.01	-0.03 to 0.11	12	14.1 SF-CL 22.1 OL-CL	13.4 SF-CL 6.4 OL-CL
FARGO	A	None	Numerous from 2.4'-3.1'	0.07	0.06 to 0.12	5.5-7.2	10.6 CL-SF 26.7 OH-CH	10.4 CL-SF 7.4 OH-CH
BISMARCK	A	None	Numerous in upper .3 of subgrade. Hairline thickness.	0.06	0.01 to 0.10	Perched water table 12	16.8 CL-ML	18.1 CL-ML

SHOWING INFLUENCE
OF
R ON FROST ACTION
1944 - 1945

WATER CONTENT OF FROST SUSCEPTIBLE SUBGRADE		ATTERBERG LIMITS		PERCENT SATURATION OF FROST SUSCEPTIBLE SOIL PRIOR TO FREEZING	PRECIPITATION DURING 3 MONTHS PRIOR TO START OF FREEZING (INCHES)		SOURCE OF WATER FOR FROST ACTION
FALL	WINTER	LIQUID LIMIT	PLASTIC LIMIT	SUBGRADE	NORMAL	1944	
16.1 GC	17.9 GC	29 GC	21 GC	89	10	14	From water table
15.7 GC	14.8 GC	29 GC	21 GC	89	10	14	From water table
17.6 GF	14.7 GF, 8.3 GC	30-33 GF 36-30 GC	26 GF 10-13 GC	100	9	17	From water table
13.7 GF	-	22 GF	18 GF	100	9	17	From water table
-	25.7 CL	29-36 CL 19-21 GC	17 CL 17 GC	-	11	16	From water table
25.1 CL	31.1 CL	29-36 CL	17 CL	100	11	16	From water table
22.0 CL	19.3 CL	29-36 CL	17 CL	100	11	16	From water table
3.3 SF 11.9 SP	- 1.2 SP	17 SF -	15 SF Non Plastic	20 100	13	18	From soil underlying freezing soil
21.1 CL	27 CL	43 CL	23 CL	97	7	6	From water table
23.5 CL	27 CL	19-30 GF 44 CL	17-21 GF 24 CL	100	7	6	From water table
20 CL	30 CL	19-30 GF 38 CL	17-21 GF 20 CL	90	7	6	From water table
15.1 CL	14.3 CL	36-42 CL	20 CL	65	2.4	2.85	Infiltration through cracks in pavement and through pavement edges
14.1 CL	13.3 CL	34-45 CL	18-20 CL	57	2.4	2.85	Same as above
11.4 SF-CL 6-8 SF	9.6 SF-CL 8.5 SF	15-29 SF-CL 17-20 SF	13-16 SF-CL 14-15 SF	50	4.4	2.5	-
6.2 SF-CL 3.5 SP	7.3 SF-CL 5.0 SP	15-29 SF-CL	13-18 SF-CL	40	4.4	2.5	
14.6 SF-CL 23 OL-CL	13.6 SF-CL 10.1 CL-CL	32-38 SF-CL 32-50 OL-CL	20-24 SF-OL 20-32 OL-CL	78 67	4.4	4.0	Infiltration from pavement edges and from water table
14.1 SF-CL 22.1 OL-CL	13.4 SF-CL 6.4 OL-CL	32-38 SF-CL 30-43 CL-CL	20-24 SF-CL 18-27 OL-CL	61 65	4.4	4.0	
10.6 CL-SF 26.7 OH-CH	10.4 CL-SF 7.4 OH-CH	30 CL-SF 63 OH-CH 73-80 CH	18 CL-SF 33 CH-CH 30 CH	92 100 92	3.7	3.5	From water table
16.8 CL-ML	18.1 CL-ML	18-19 SC 24-32 CL-ML	16 SC 17-22 CL-ML	49	2.6	3.0	Perched water table

DATA SHOWING INFLUEN
OF
WATER ON FROST ACTIO
1944 - 1945

AIRFIELD	TEST AREA	ICE LENSES OBSERVED		PAVEMENT HEAVE (FEET)		DEPTH TO GROUND WATER IN WINTER (FEET)	WATER CONTENT OF FROST SUSCEPTIBLE SUBGRADE	
		IN BASE	IN SUBGRADE	AVERAGE	RANGE		FALL	WINTER
DOW FIELD (1943-44)	I III	None	Few thin lenses near top-closely spaced averaging ¼" at frost line.	.18	.00-.40	2-6	- 29 CL	- 31 CL
	II	None	Few thin lenses near top-closely spaced averaging ¼" at frost line.	.10 -	.02-.20	2-6	- 19 CL	-
	IV-VII	None	Few thin lenses near top-closely spaced averaging ¼" at frost line.	.45	.30-.70	2-6	-	- 28 CL
SIOUX FALLS	A	Small widely dispersed ~~lenses and~~ crystals	Few small widely dispersed lenses	.05	.03-.12	8-9	24 CL 31 CH	22 CL 31 CH
	B	No observations	No observations	.08	.07-.10	-	32 CH	-
FAIRMONT	A	None	None	.03	.01-.05	Below 90	28 CL 23 CH	32 CL 27 CL (NF) 26 CH (NF)
GREAT BEND	A	None	None	.01	.00-.02	12	- 15 SF-CL 13 CL-SF - 17 CL	- - 17 CL-SF (NF - 19 CL (NF)
GARDEN CITY	A	None	None	.01	.01-.03	Below 90	16 CL 19 CH 16 CH-CL	- - -
PRATT	A	None	None	.01	.00-.02	Below 90	19 CL 21 CH	19 CL 23 CH

A

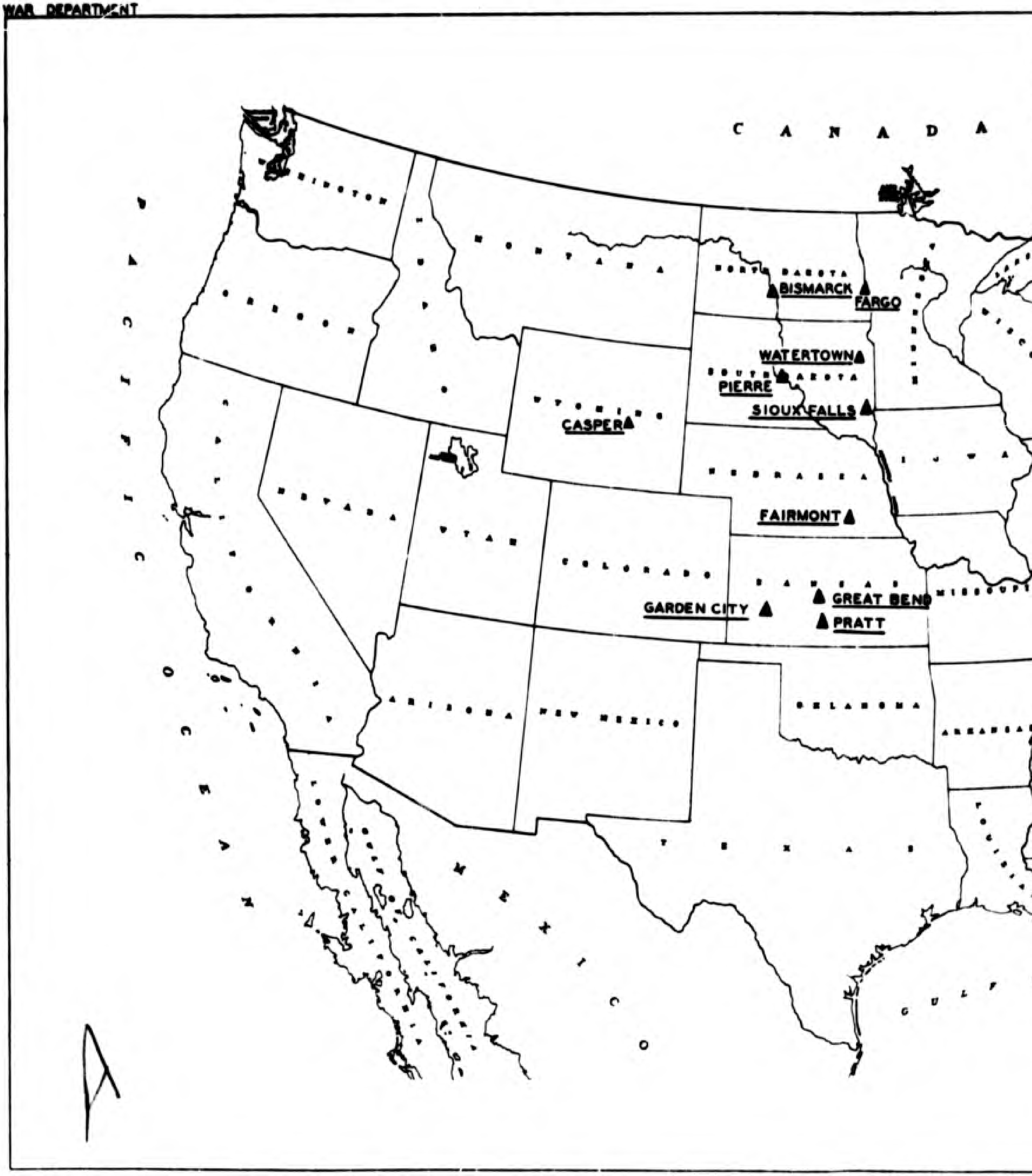
IOWING INFLUENCE
OF
ON FROST ACTION
944 - 1945

WATER CONTENT OF FROST SUSCEPTIBLE SUBGRADE		ATTERBERG LIMITS		PERCENT SATURATION OF FROST SUSCEPTIBLE SOIL PRIOR TO FREEZING	PRECIPITATION DURING 3 MONTHS PRIOR TO START OF FREEZING (INCHES)		SOURCE OF WATER FOR FROST ACTION
FALL	WINTER	LIQUID LIMIT	PLASTIC LIMIT	SUBGRADE	NORMAL	1944	
- 29 CL	- 31 CL	GW Non-Plastic 29-36 CL	18-19 CL	- 93	11.2	18.4	Water Table
- 19 CL	-	GW Non-Plastic 29-36 CL	18-19 CL	- 89	11.2	18.4	Water Table
-	- 28 CL	GW Non-Plastic 29-36 CL	18-19 CL	-	11.2	18.4	Water Table
24 CL 31 CH	22 CL 31 CH	23 GC 38-46 CL 50-53 CH	17 GC 21-25 CL 26 CH	-- 82 82	5.5	4.1	Water Table and Infiltration
32 CH	-	62 CH	31 CH	-	5.5	4.1	Water Table and Infiltration
28 CL 23 CH	32 CL 27 CL (NP) 26 CH (NP)	42-50 CL 52-73 CH	23 CL 24-30 CH	90 73	6.5	4.0	Infiltration
- 15 SP-CL 13 CL-SP - 17 CL	- - 17 CL-SP (NP) - 19 CL (NP)	18-21 SW 31 SP-CL 26-27 CL-SP 20-22 SP 30-41 CL	15-16 SW 19 SP-CL 16-17 CL-SP 14-19 SP 17-21 CL	- 76 55 - 67	5.3	3.9	Water Table and Infiltration
16 CL 19 CH 16 CH-CL	- - -	29-36 CL 55 CH 47 CH-CL 21 SC 26-27 SP-CL	18 CL 23 CH 28 CH-CL 14 SC 16 SP-CL	76 68 60	4.1	2.8	Infiltration
19 CL 21 CH	19 CL 23 CH	37-41 CL 49-55 CH 22-25 SP-CL	18-20 CL 20-23 CH 17-18 SP-CL	91 89	6.3	5.4	Infiltration

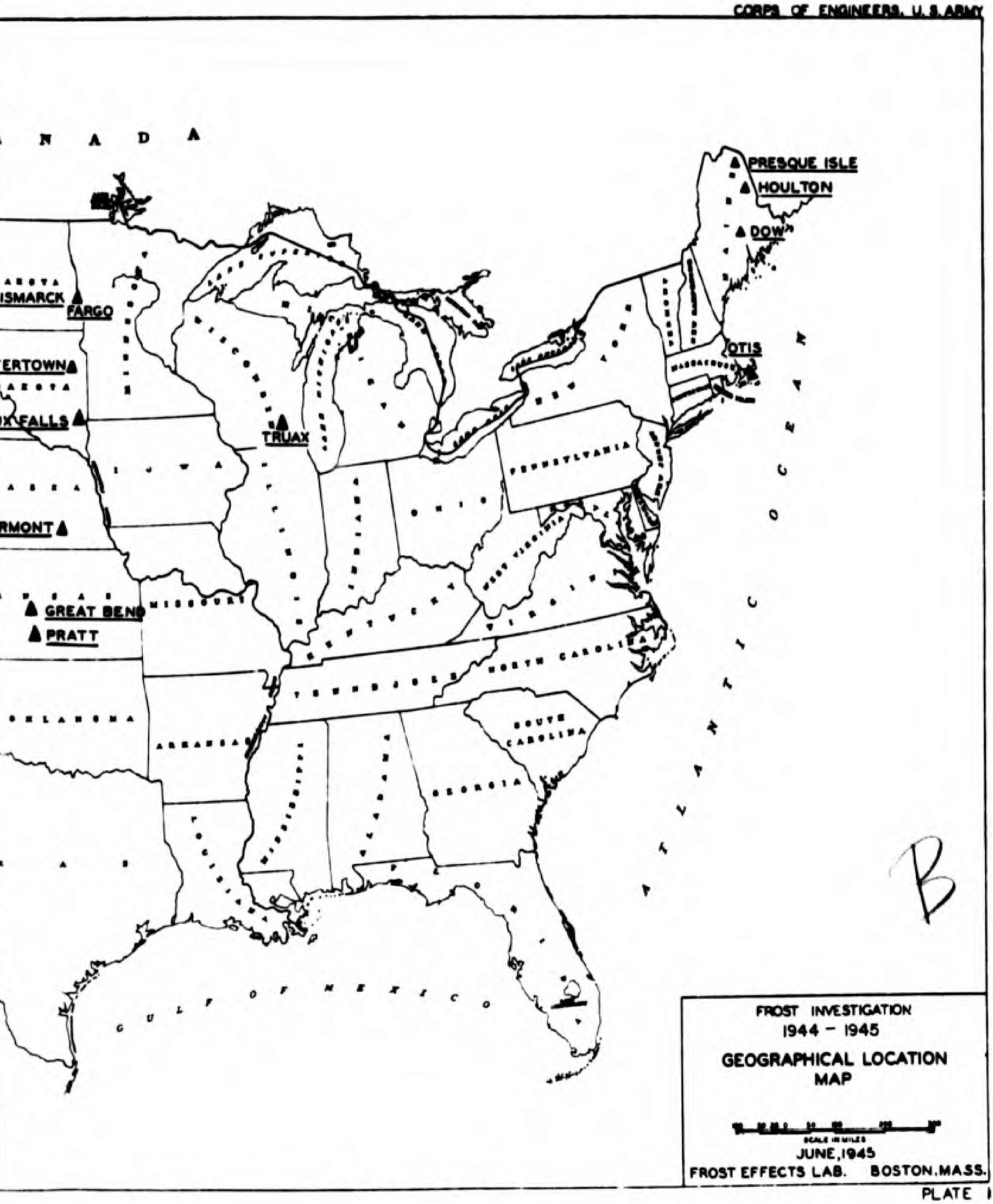
B

SHEET 2 OF 2, TABLE 8

WAR DEPARTMENT



CORPS OF ENGINEERS, U.S. ARMY



B

FROST INVESTIGATION
1944 – 1945

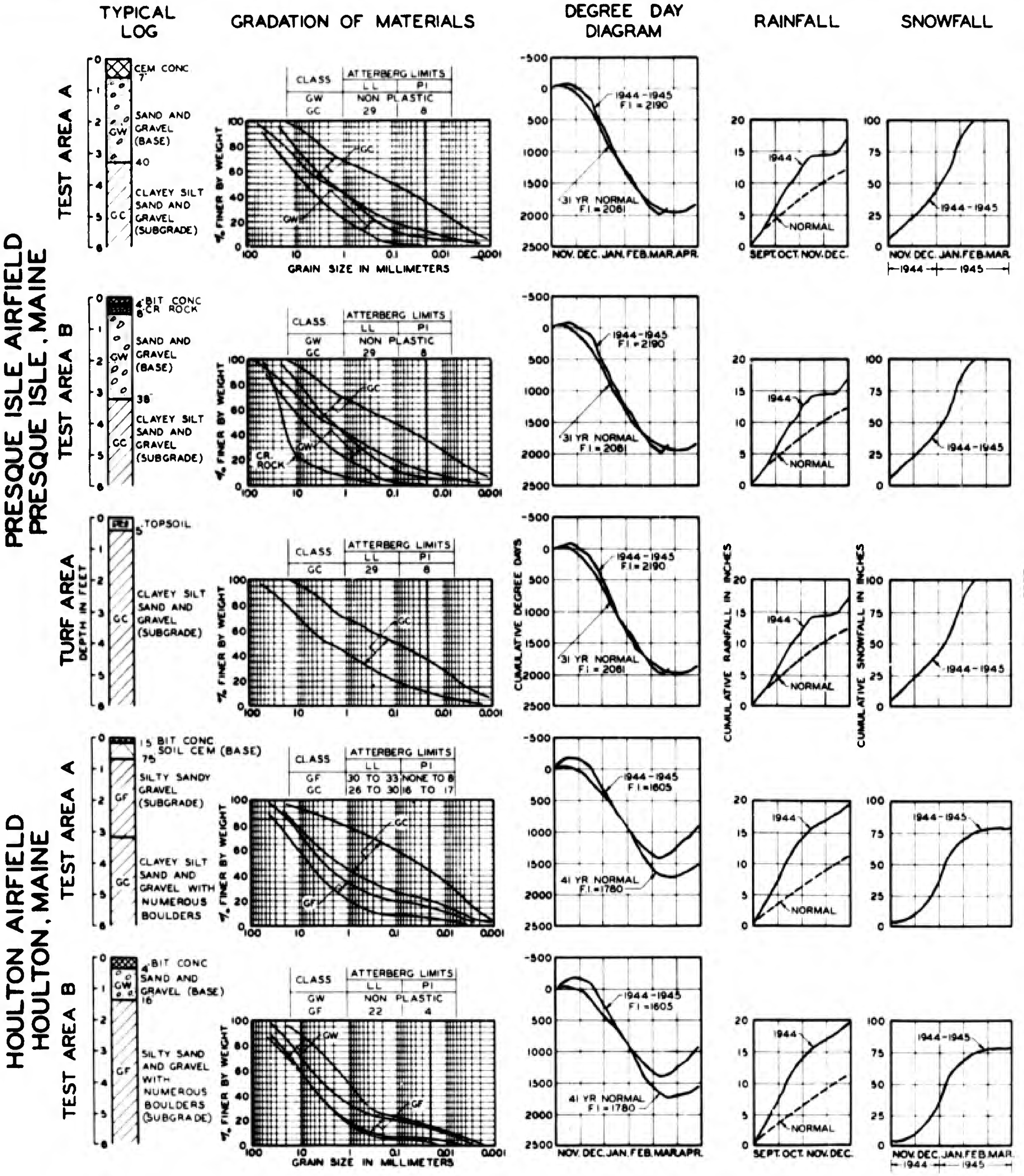
GEOGRAPHICAL LOCATION
MAP

SCALE IN MILES

JUNE, 1945

FROST EFFECTS LAB. BOSTON, MASS.

PLATE 1



Presque Isle, Test Area A:

CLASS	ATTERBERG LIMITS	
	LL	PI
GW	NON PLASTIC	
GC	29	8

Presque Isle, Test Area B:

CLASS	ATTERBERG LIMITS	
	LL	PI
GW	NON PLASTIC	
GC	29	8

Presque Isle, Turf Area:

CLASS	ATTERBERG LIMITS	
	LL	PI
GC	29	8

Houlton, Test Area A:

CLASS	ATTERBERG LIMITS	
	LL	PI
GF	30 TO 33	NONE TO 8
GC	26 TO 30	16 TO 17

Houlton, Test Area B:

CLASS	ATTERBERG LIMITS	
	LL	PI
GW	NON PLASTIC	
GF	22	4

FIG.1 FIG.2 FIG.3 FIG.4 FIG.5

CORPS OF E

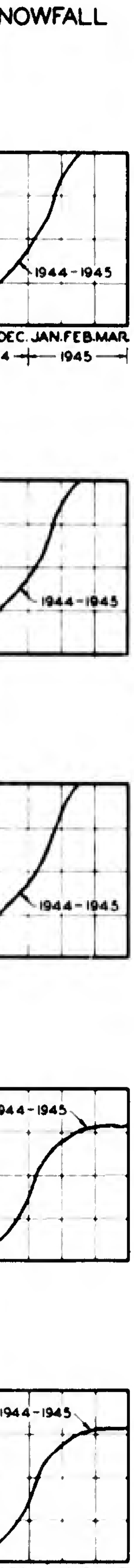


FIG.5

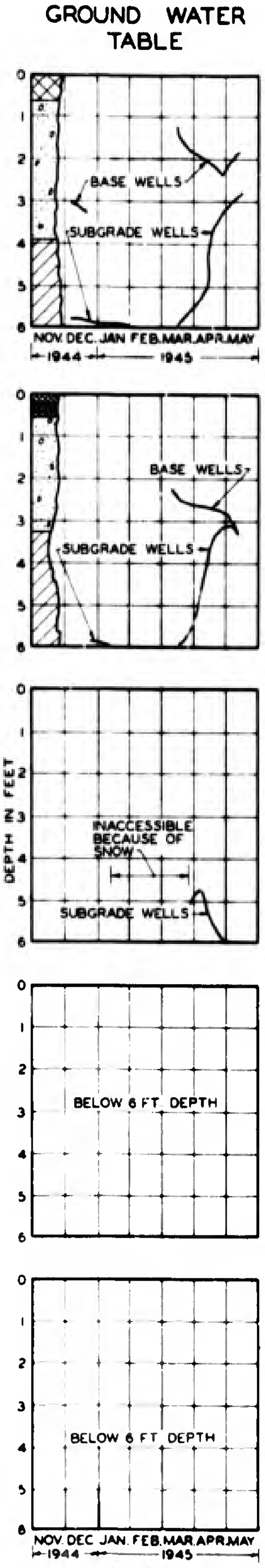


FIG.6

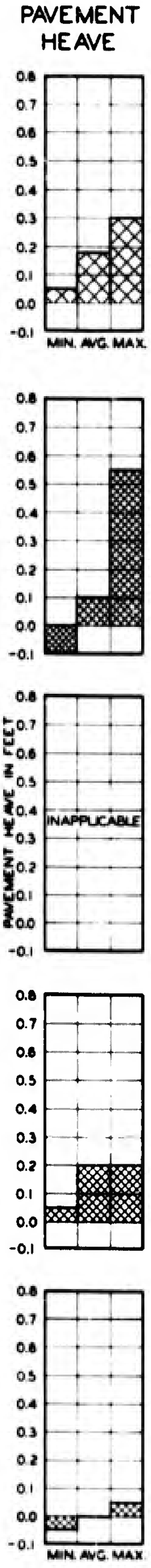


FIG.7

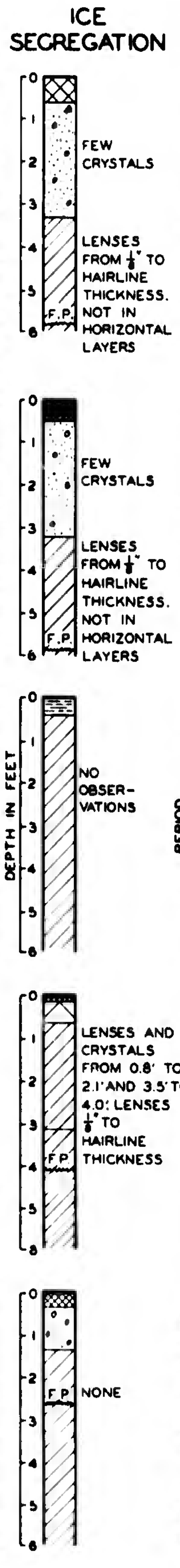


FIG.8

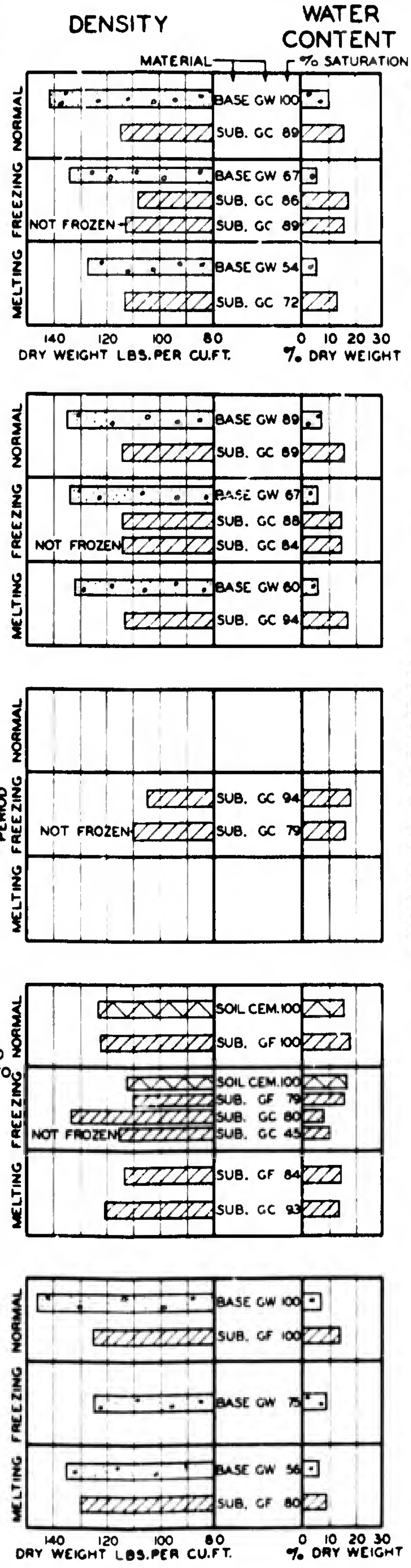


FIG.9

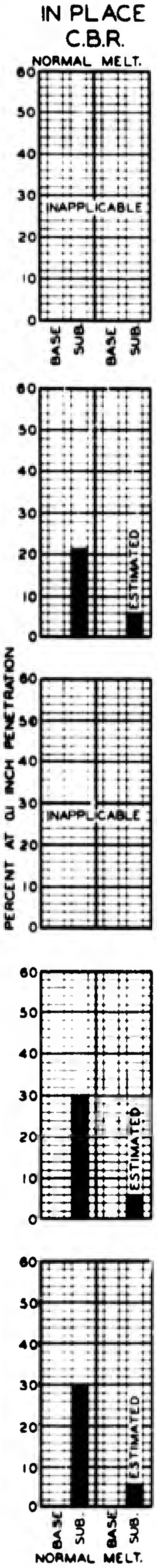


FIG.10

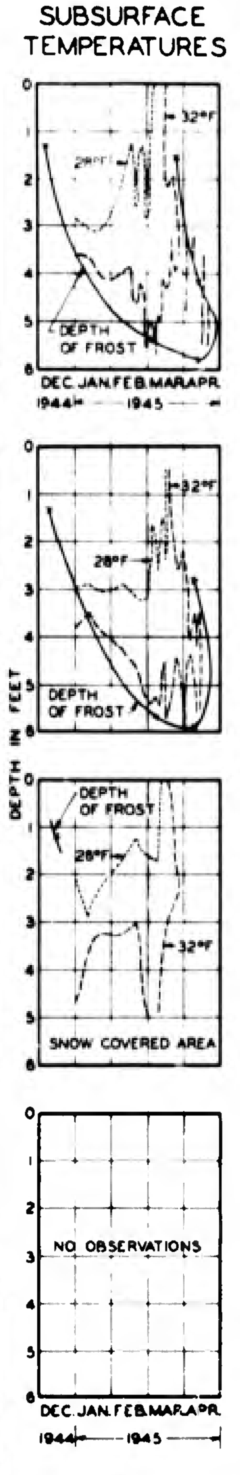


FIG.11

FROST IN
194
SUMMARY
BOSTON
PRESQUE
HOULTO

FROST EFFECTS LABORAT

CORPS OF ENGINEERS, U. S. ARMY

AVEMENT HEAVE

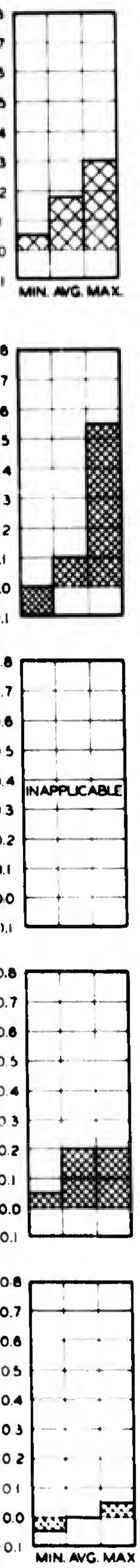


FIG.7

ICE SEGREGATION

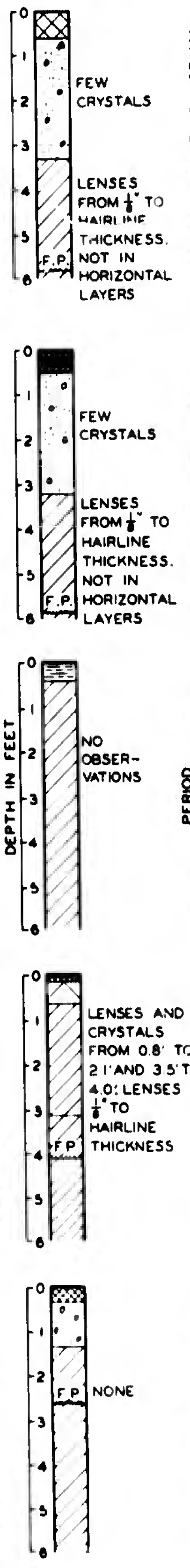


FIG.8

DENSITY

WATER CONTENT

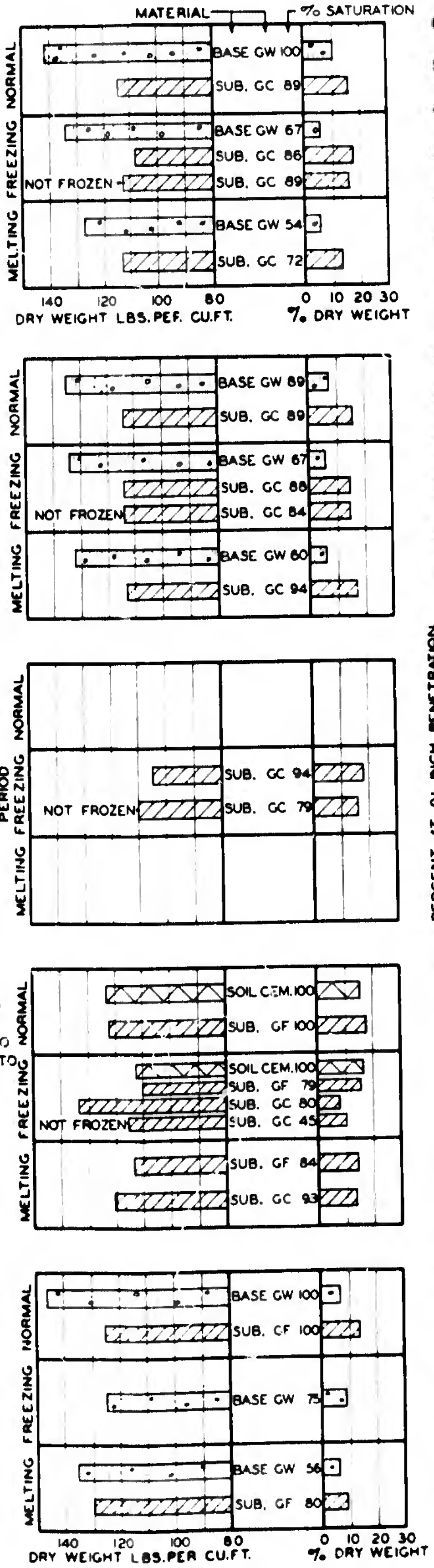


FIG.9

IN PLACE C.B.R.

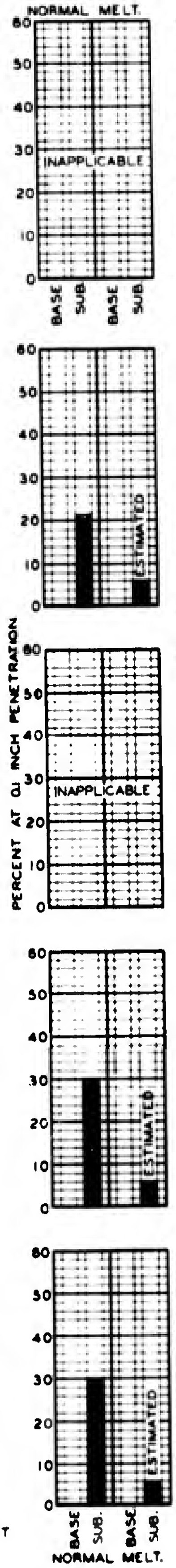


FIG.10

SUBSURFACE TEMPERATURES

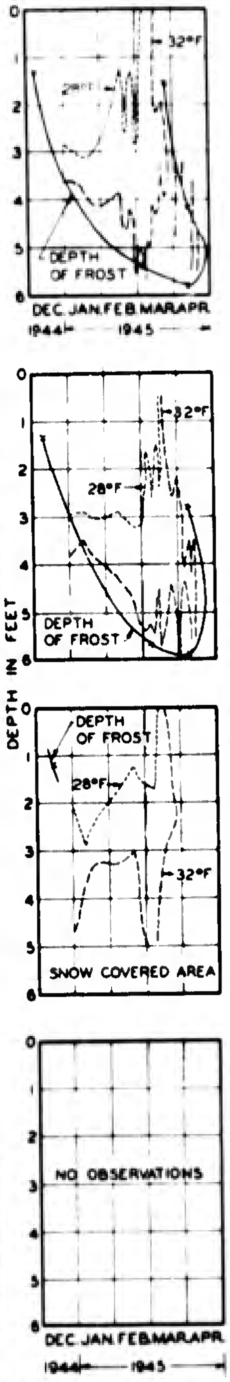


FIG.11

PLATE BEARING TESTS

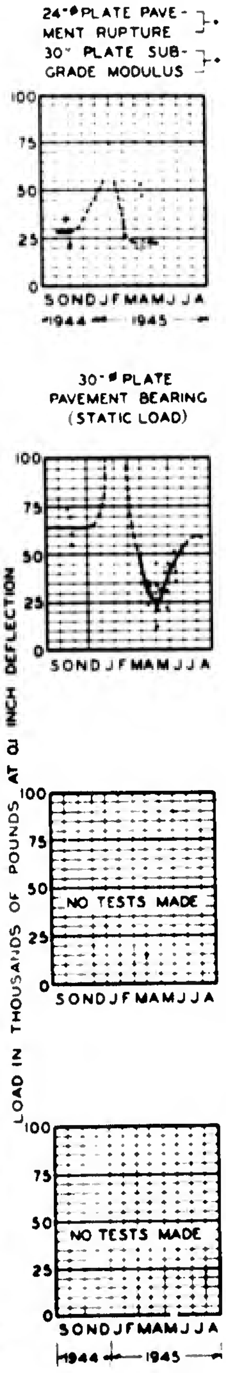


FIG.12

FROST INVESTIGATION

1944 - 1945

SUMMARY OF DATA

BOSTON DISTRICT

PRESQUE ISLE AIRFIELD
HOULTON AIRFIELD

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE, 1945

PLATE 2

WAR DEPARTMENT

DOW FIELD – BANGOR, MAINE

TEST AREA A

TEST AREA B

TEST AREA C

TURF AREA

OTIS FIELD SANDWICH MASS.

TEST AREA A

TYPICAL LOG

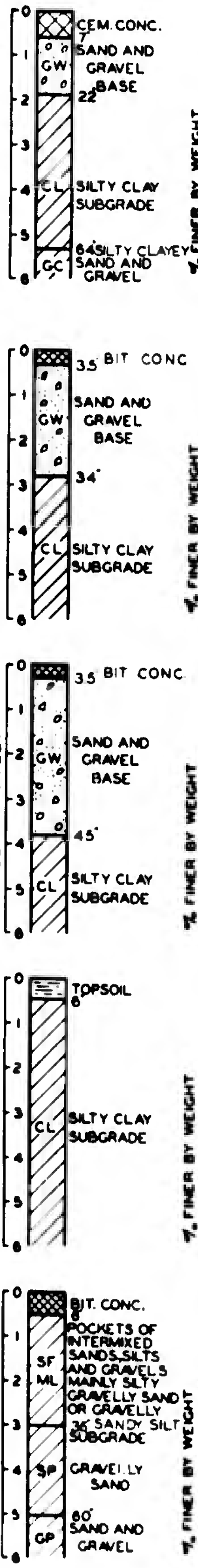
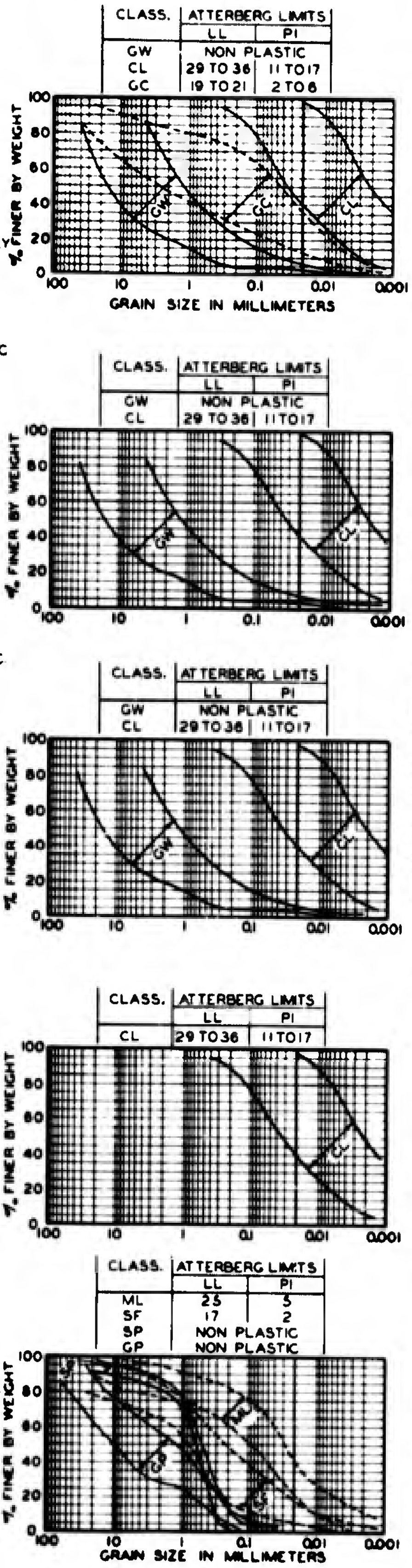


FIG.1

GRADATION OF MATERIALS



CLASS.	ATTERBERG LIMITS LL	ATTERBERG LIMITS PI
GW	NON PLASTIC	
CL	29 TO 36	11 TO 17
GC	19 TO 21	2 TO 8

CLASS.	ATTERBERG LIMITS LL	ATTERBERG LIMITS PI
GW	NON PLASTIC	
CL	29 TO 36	11 TO 17

CLASS.	ATTERBERG LIMITS LL	ATTERBERG LIMITS PI
GW	NON PLASTIC	
CL	29 TO 36	11 TO 17

CLASS.	ATTERBERG LIMITS LL	ATTERBERG LIMITS PI
CL	29 TO 36	11 TO 17

CLASS.	ATTERBERG LIMITS LL	ATTERBERG LIMITS PI
ML	25	5
SF	17	2
SP	NON PLASTIC	
GP	NON PLASTIC	

FIG.2

DEGREE DAY DIAGRAM

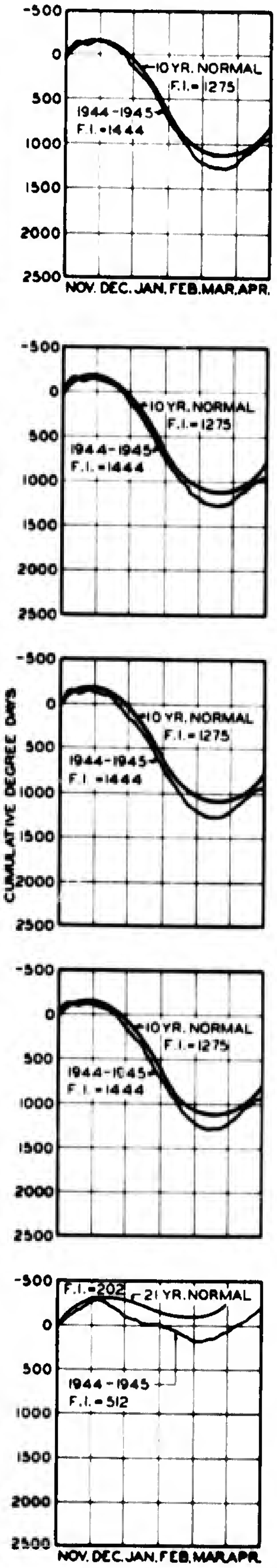


FIG.3

RAINFALL

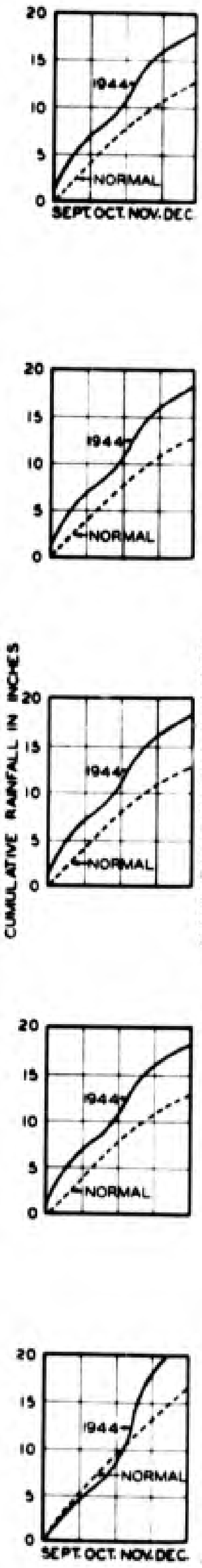


FIG.4

SNOWFALL

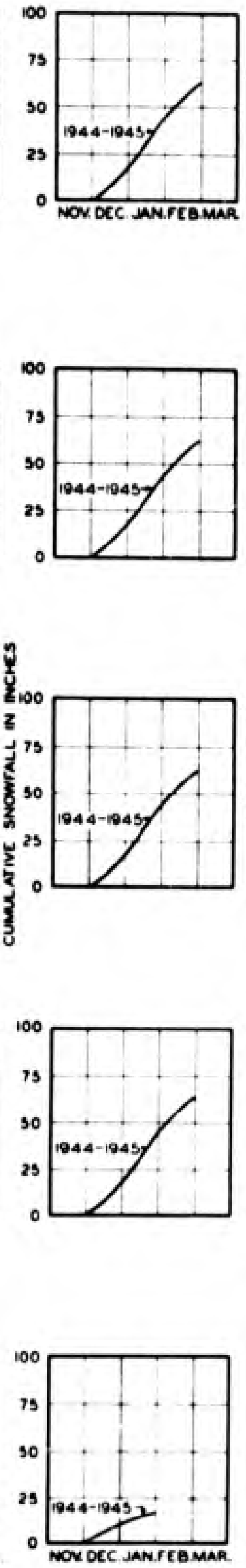


FIG.5

CORPS O

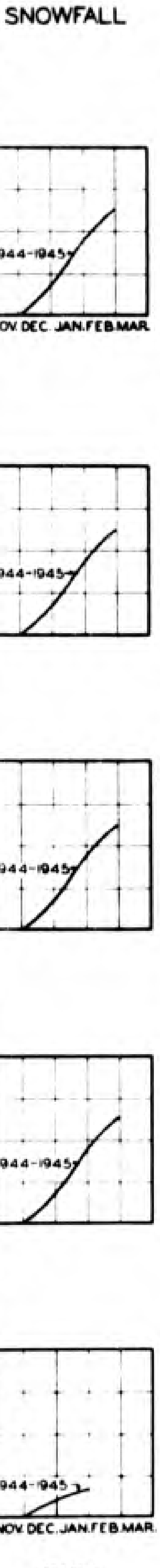


FIG.5

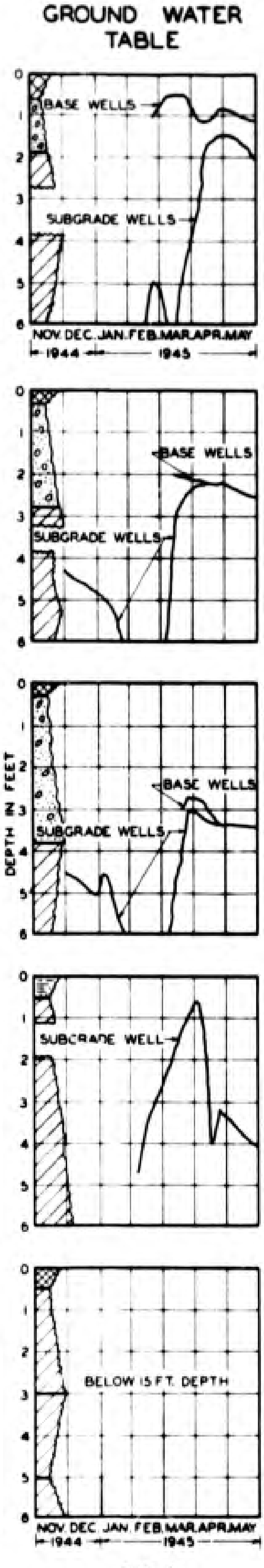


FIG.6

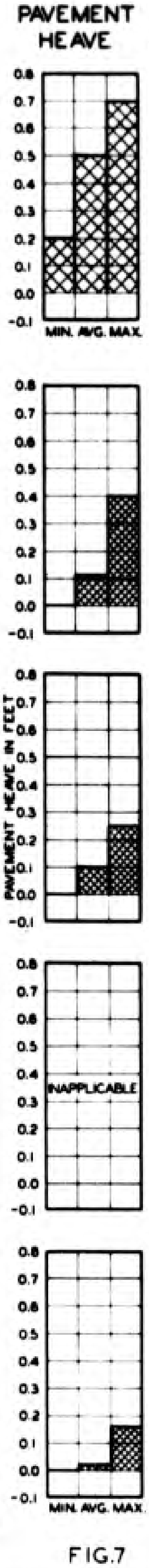


FIG.7

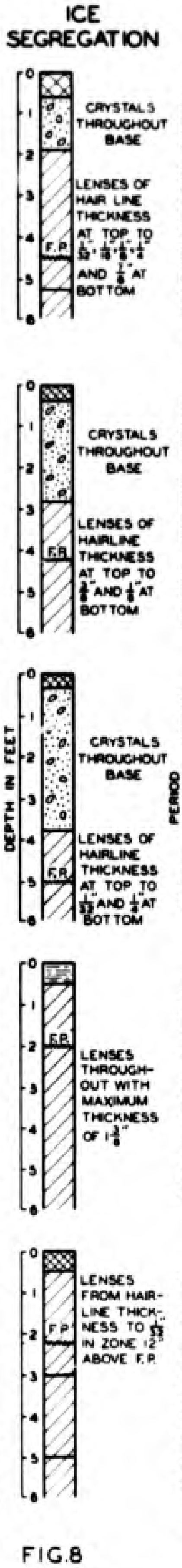


FIG.8

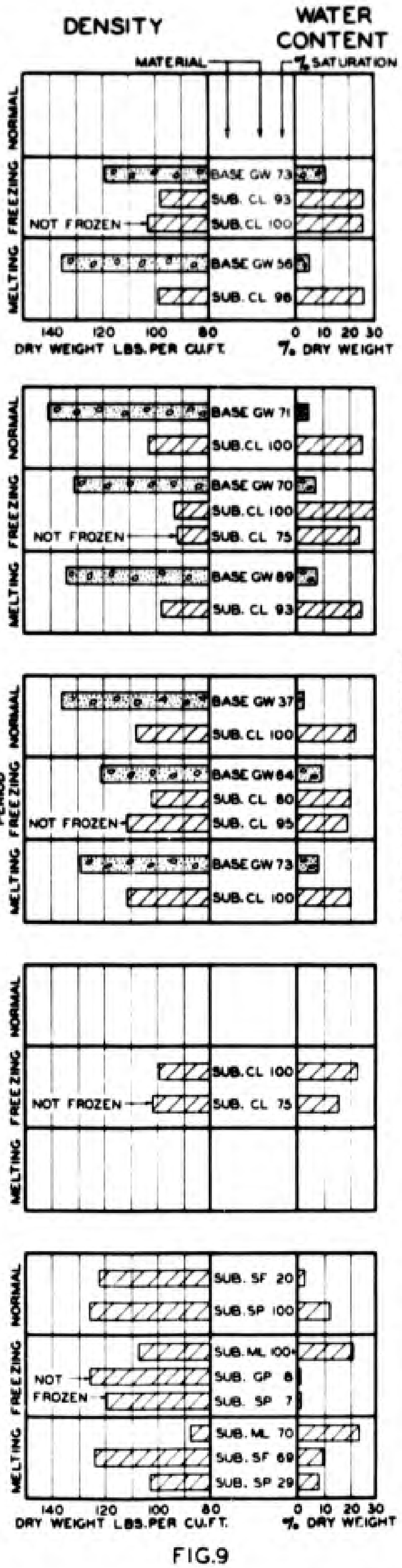


FIG.9

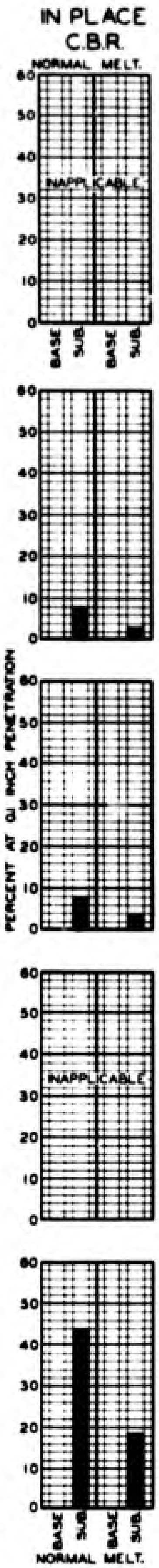


FIG.10

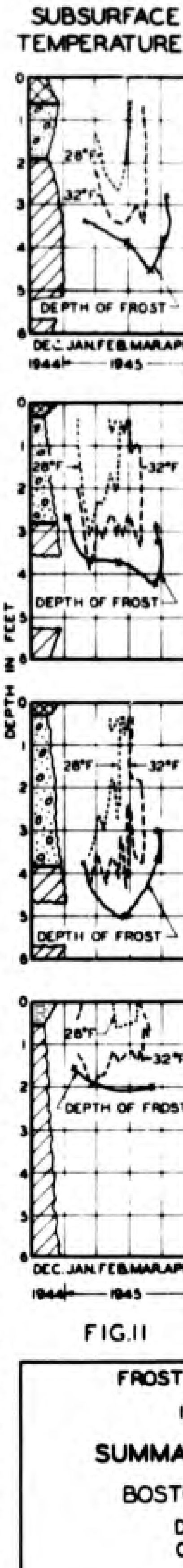


FIG.11

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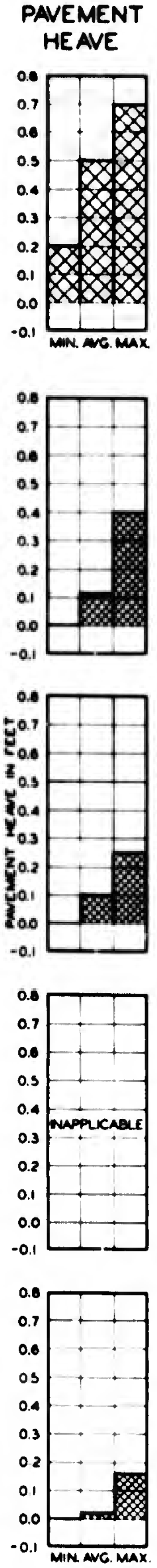


FIG.7

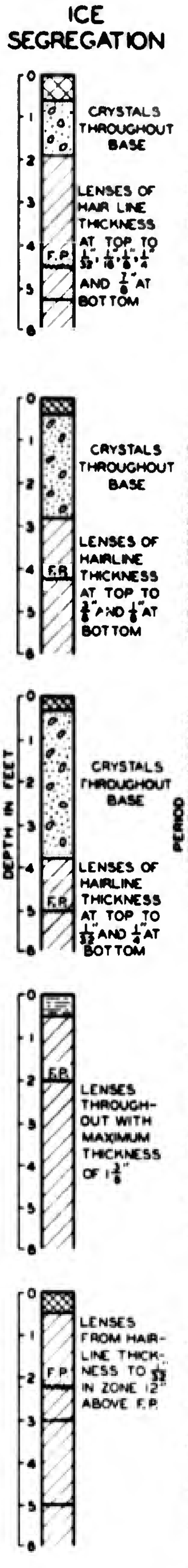


FIG.8

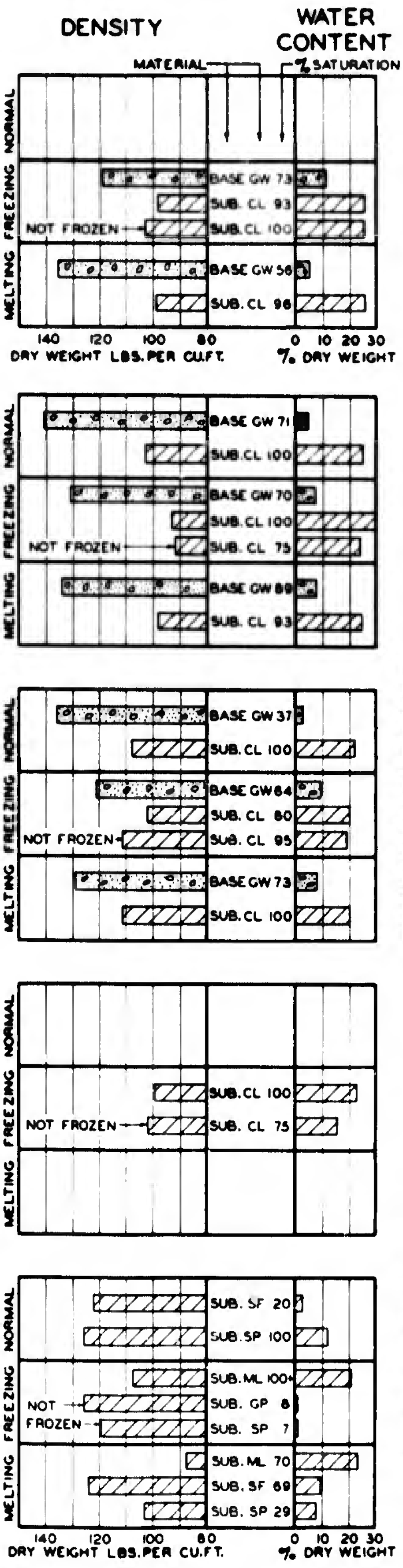


FIG.9

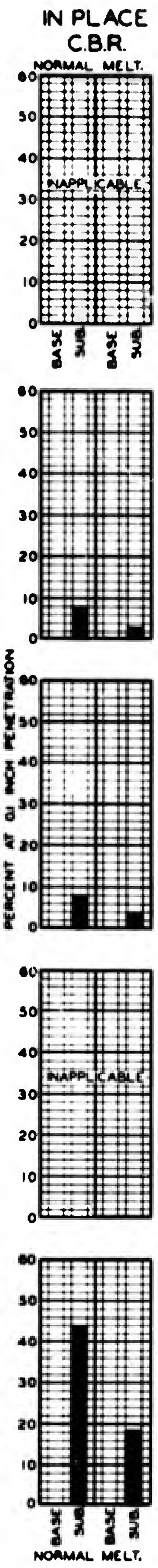


FIG.10

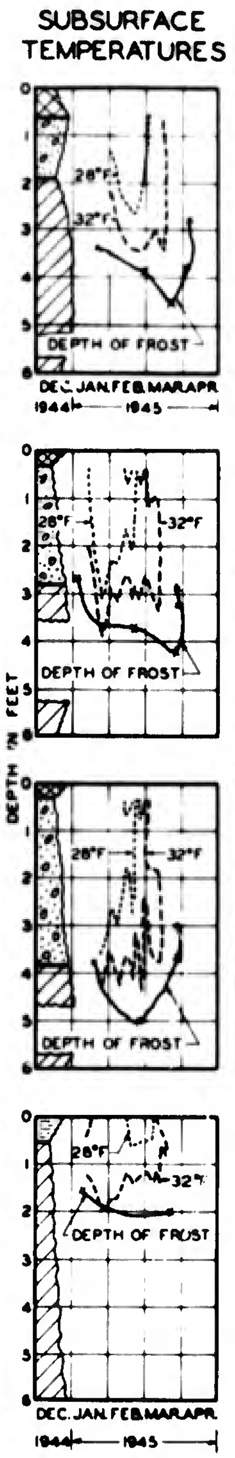


FIG.11

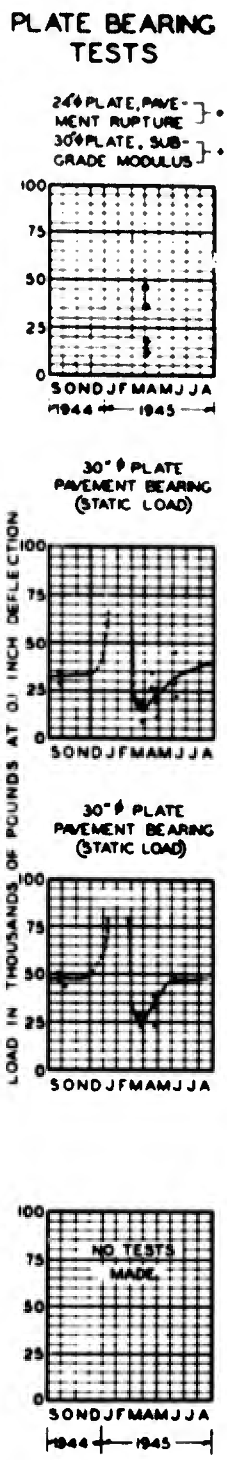


FIG.12

FROST INVESTIGATION
1944-1945

SUMMARY OF DATA

BOSTON DISTRICT
DOW FIELD
OTIS FIELD

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1945

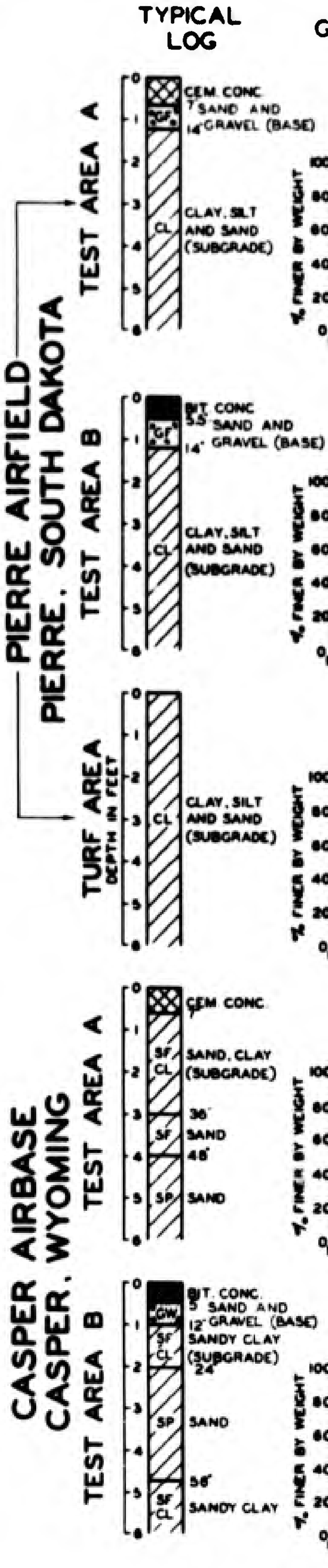
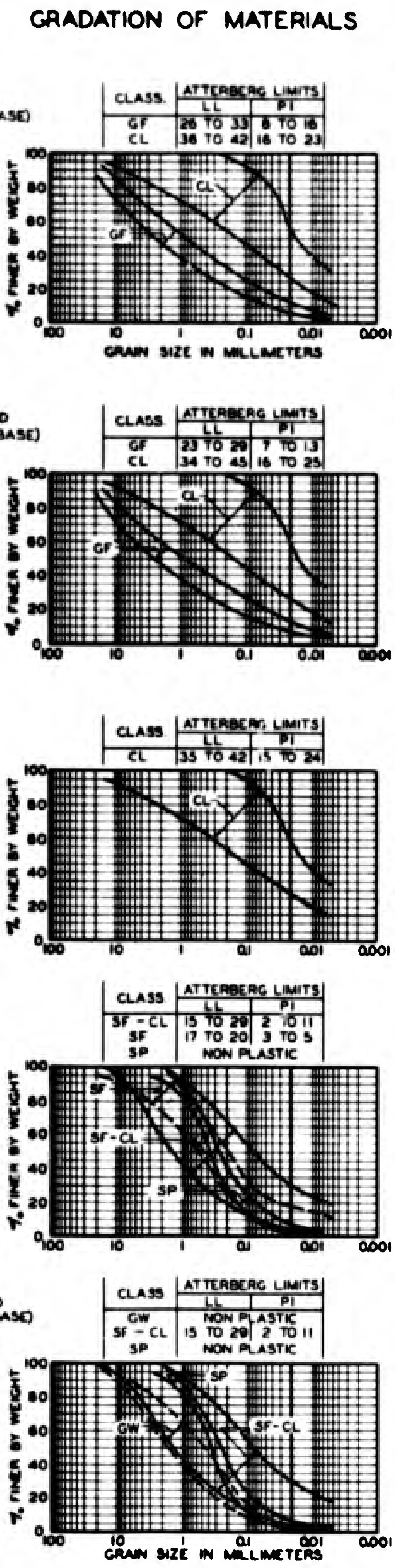


FIG.1



CLASS.	ATTERBERG LIMITS LL	ATTERBERG LIMITS PI
GF	26 TO 33	8 TO 18
CL	36 TO 42	16 TO 23

CLASS.	ATTERBERG LIMITS LL	ATTERBERG LIMITS PI
GF	23 TO 29	7 TO 13
CL	34 TO 45	16 TO 25

CLASS	ATTERBERG LIMITS LL	ATTERBERG LIMITS PI
CL	35 TO 42	15 TO 24

CLASS	ATTERBERG LIMITS LL	ATTERBERG LIMITS PI
SF - CL	15 TO 29	2 TO 11
SF	17 TO 20	3 TO 5
SP	NON PLASTIC	

CLASS	ATTERBERG LIMITS LL	ATTERBERG LIMITS PI
GW	NON PLASTIC	
SF - CL	15 TO 29	2 TO 11
SP	NON PLASTIC	

FIG.2

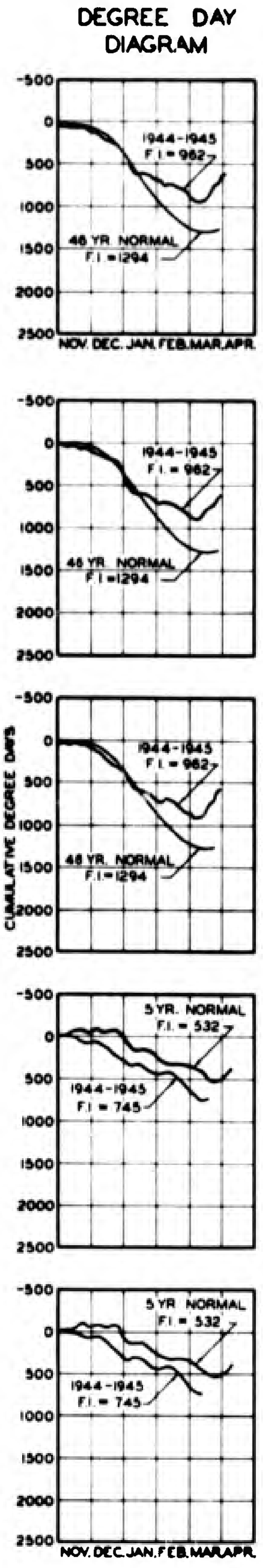


FIG.3

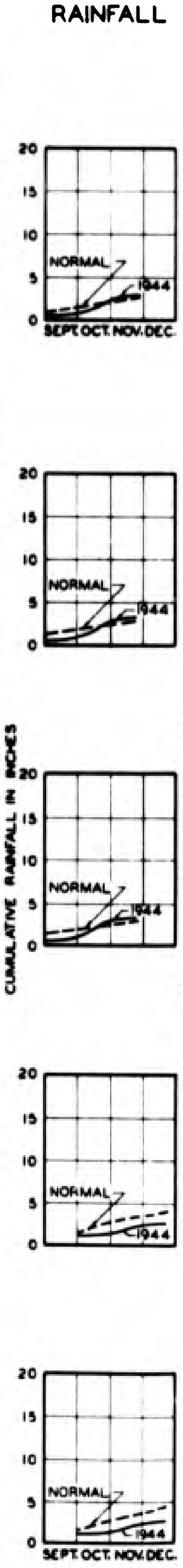


FIG.4

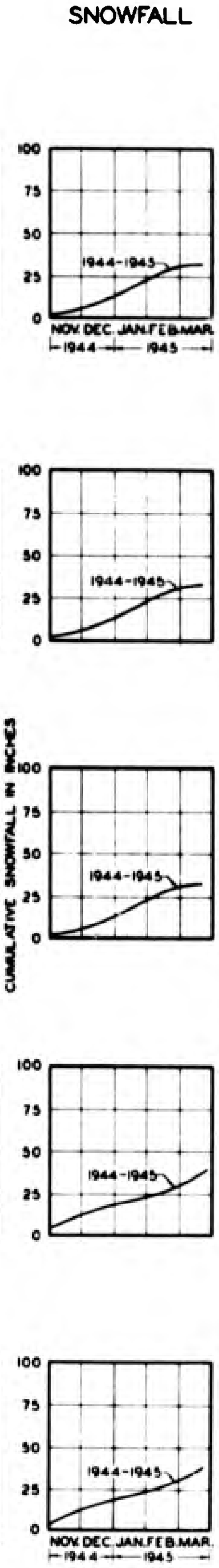


FIG.5

SNOWFALL

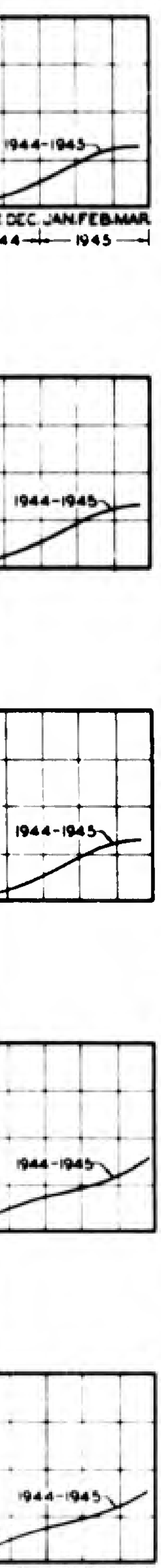


FIG.5

GROUND WATER TABLE

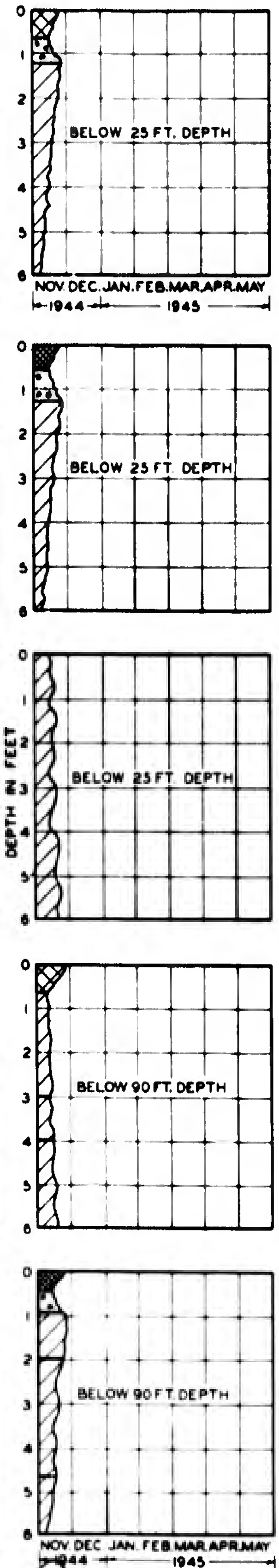


FIG.6

PAVEMENT HEAVE

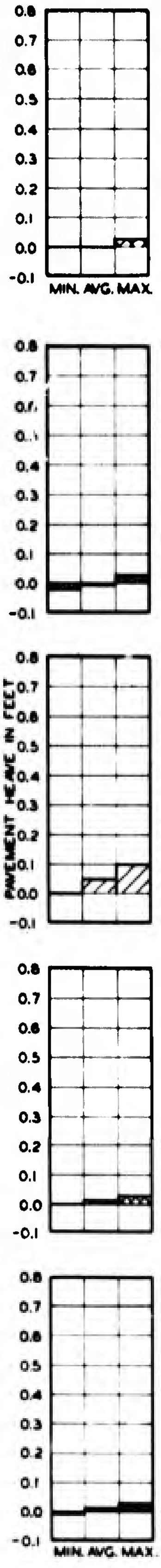


FIG.7

ICE SEGREGATION

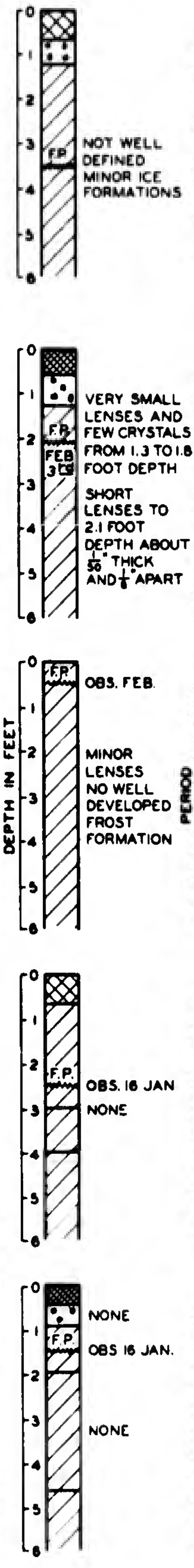


FIG.8

DENSITY

WATER CONTENT

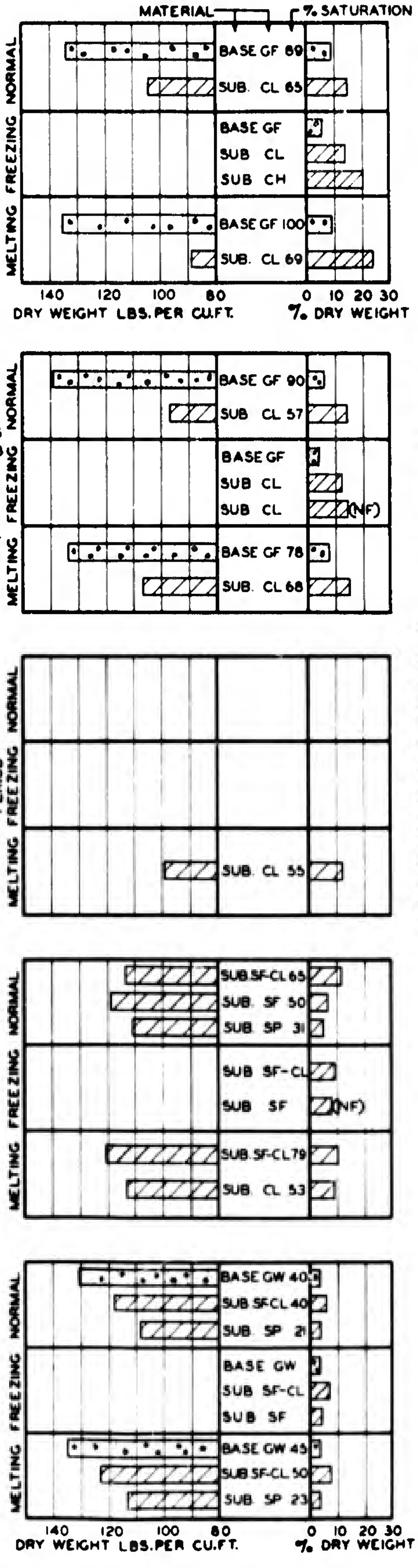


FIG.9
(NF) INDICATES NONFROZEN SOIL

IN PLACE C.B.R.

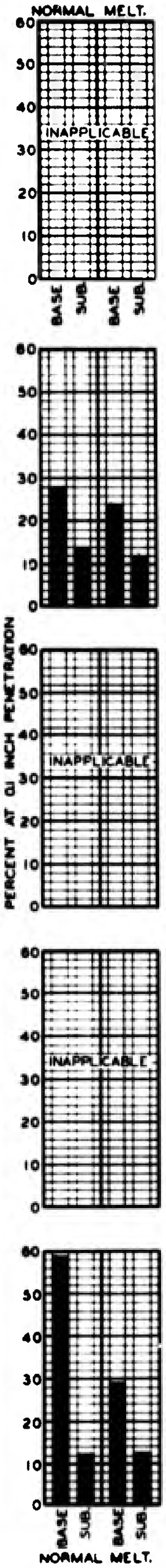


FIG.10

SUBSURFACE TEMPERATURES

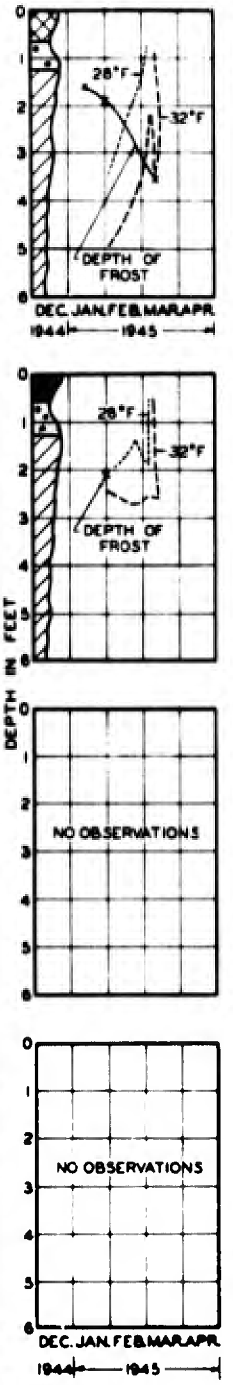


FIG.11

FROST I
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CORPS OF ENGINEERS, U. S. ARMY

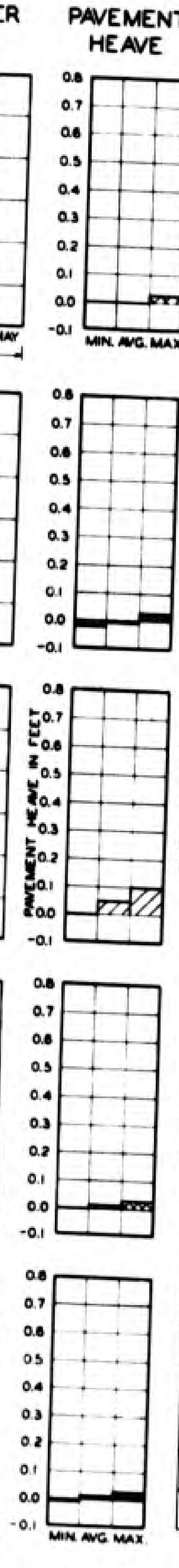


FIG.7

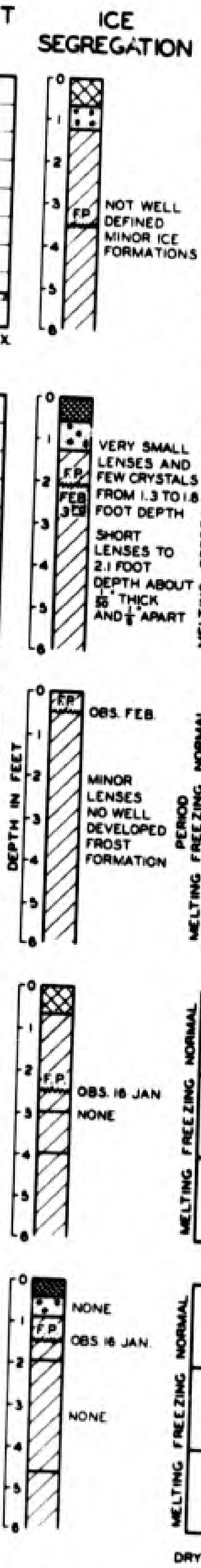


FIG.8

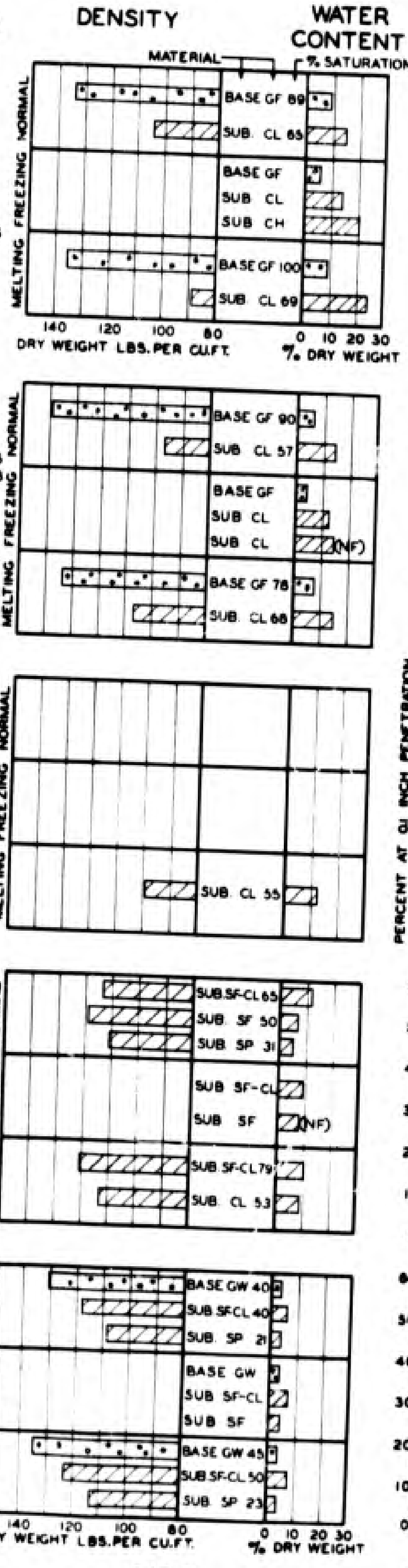


FIG.9
(NF) INDICATES NONFROZEN SOIL

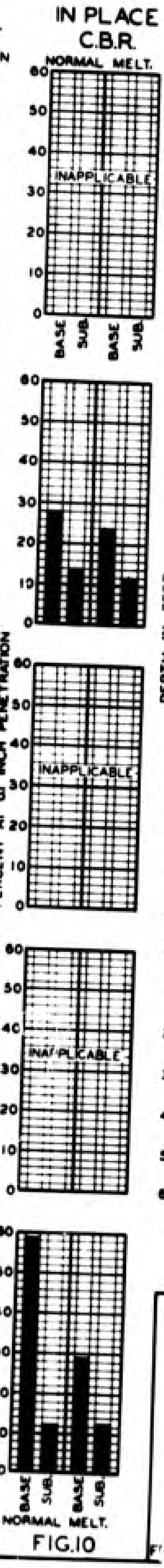


FIG.10

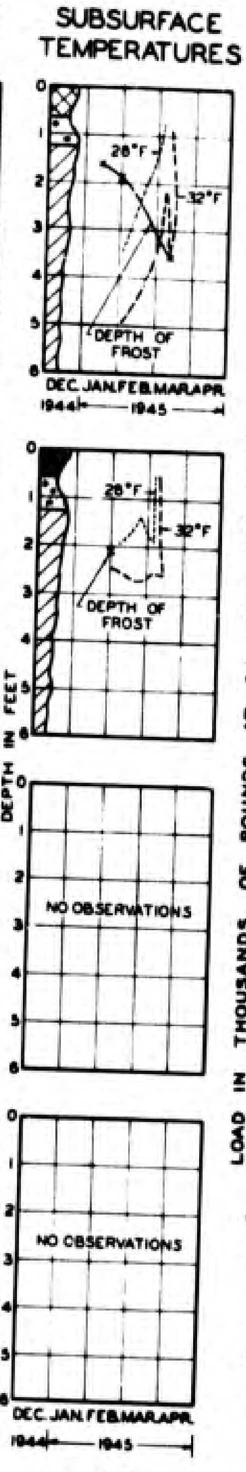


FIG.11

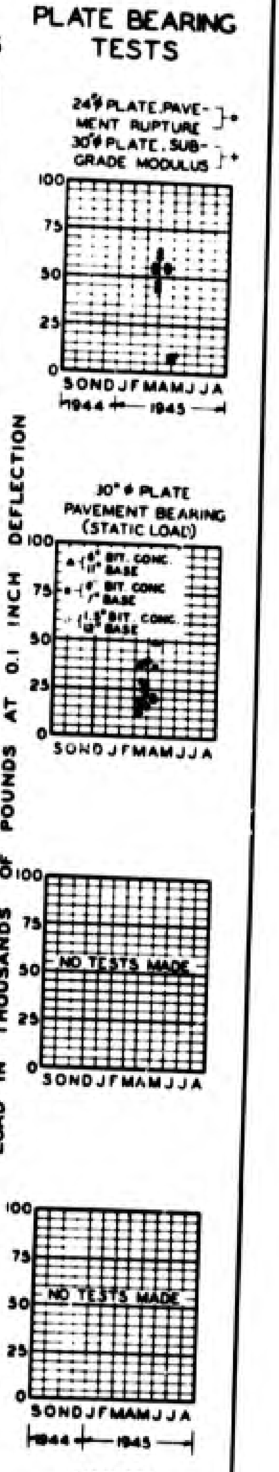


FIG.12

FROST INVESTIGATION
1944-1945

SUMMARY OF DATA

MISSOURI RIVER DIVISION
PIERRE AIRFIELD
CASPER AIRBASE

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1945

PLATE 4

WATERTOWN AIRFIELD
WATERTOWN, S. D.

TEST AREA A

TEST AREA B

TURF AREA

FARGO AIRFIELD
FARGO, N.D.
TEST AREA A

BISMARCK AIRFIELD
BISMARCK, N.D.
TEST AREA A

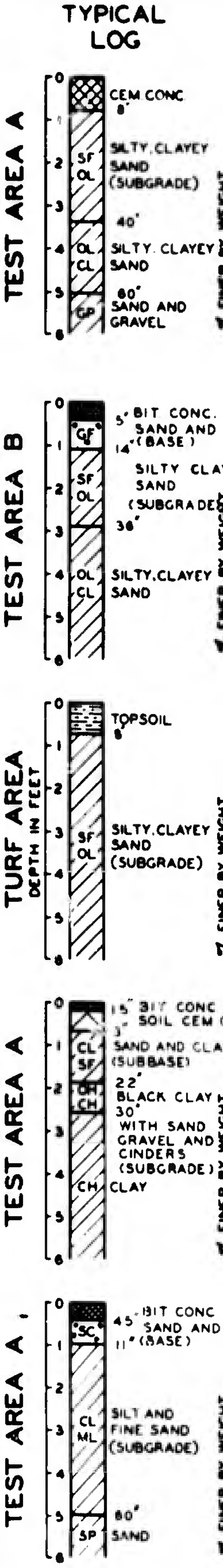
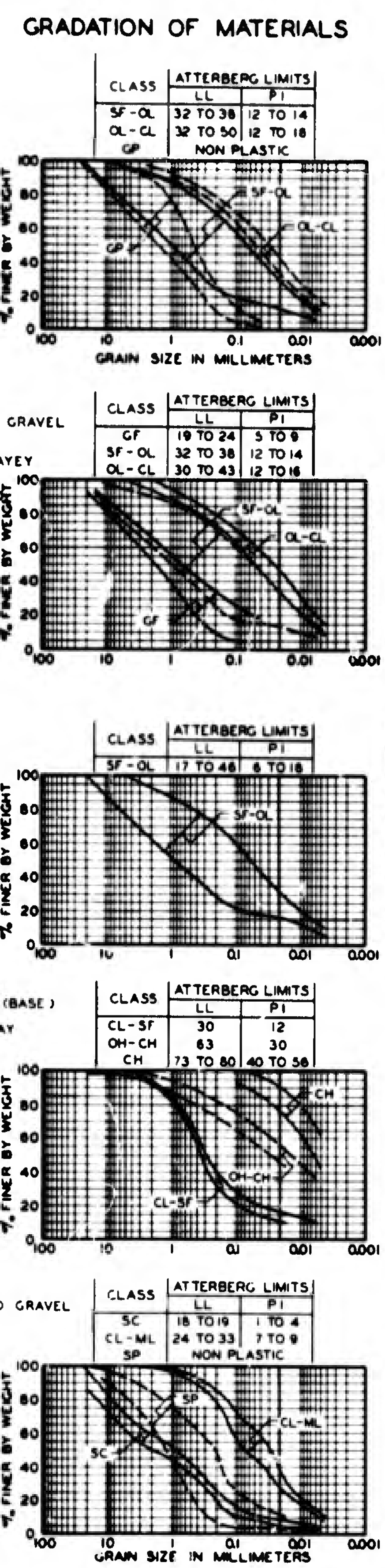


FIG.1



CLASS	ATTERBERG LIMITS	
	LL	PI
SF - OL	32 TO 38	12 TO 14
OL - CL	32 TO 50	12 TO 18
GP	NON PLASTIC	

CLASS	ATTERBERG LIMITS	
	LL	PI
GF	19 TO 24	5 TO 9
SF - OL	32 TO 38	12 TO 14
OL - CL	30 TO 43	12 TO 16

CLASS	ATTERBERG LIMITS	
	LL	PI
SF - OL	17 TO 46	6 TO 18

CLASS	ATTERBERG LIMITS	
	LL	PI
CL - SF	30	12
OH - CH	63	30
CH	73 TO 80	40 TO 56

CLASS	ATTERBERG LIMITS	
	LL	PI
SC	18 TO 19	1 TO 4
CL - ML	24 TO 33	7 TO 9
SP	NON PLASTIC	

FIG.2

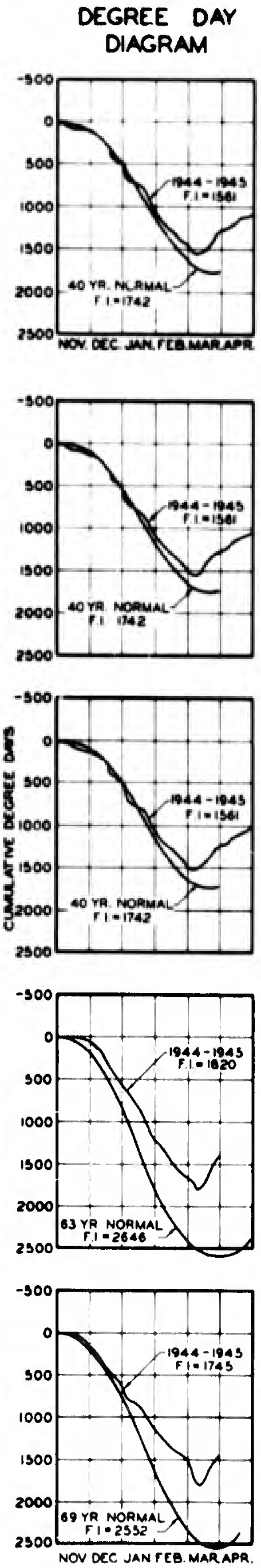


FIG.3

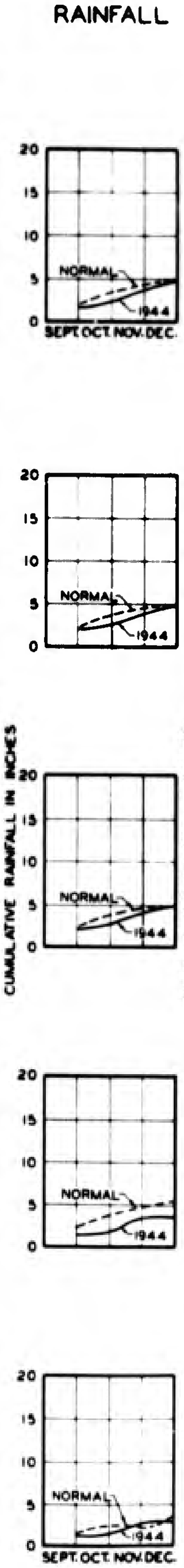


FIG.4

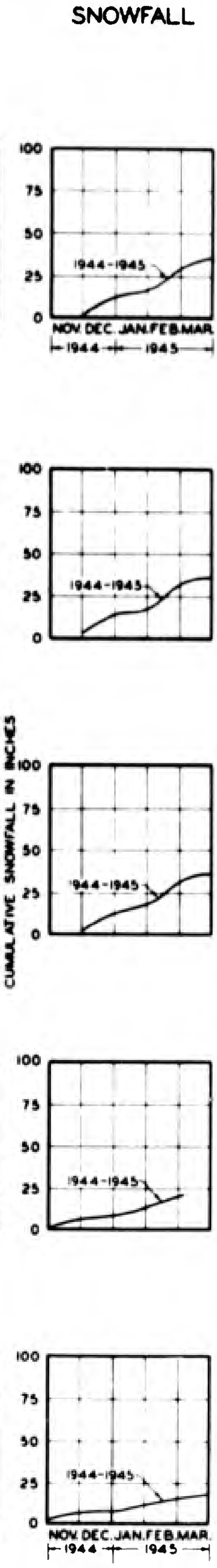


FIG.5

SNOWFALL

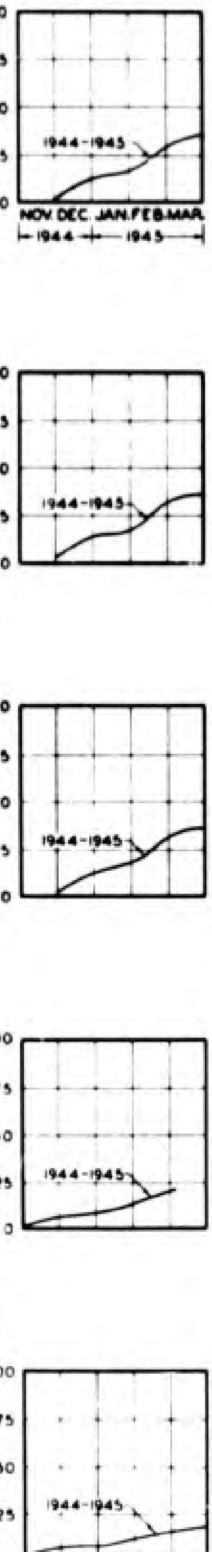


FIG.5

GROUND WATER TABLE

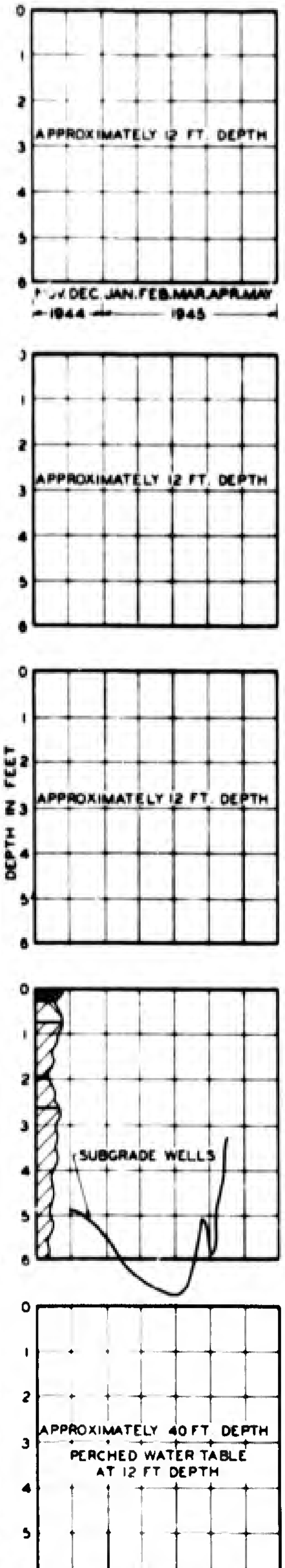


FIG.6

PAVEMENT HEAVE

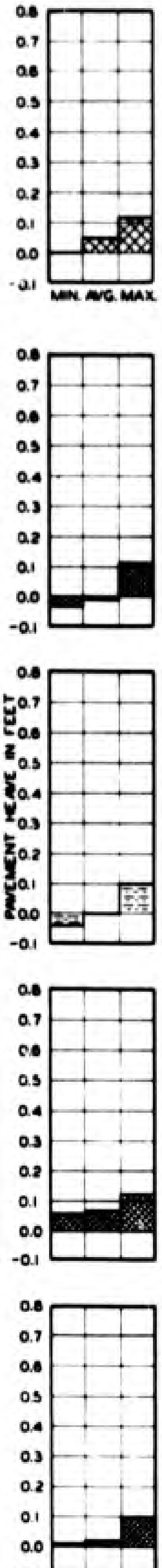


FIG.7

ICE SEGREGATION

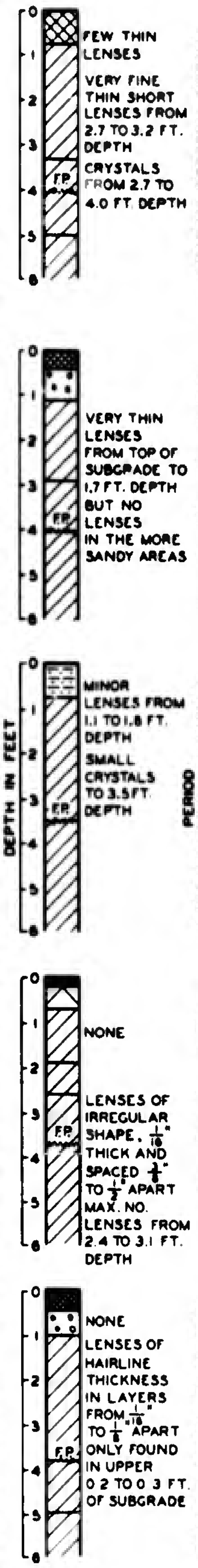


FIG.8

DENSITY

WATER CONTENT

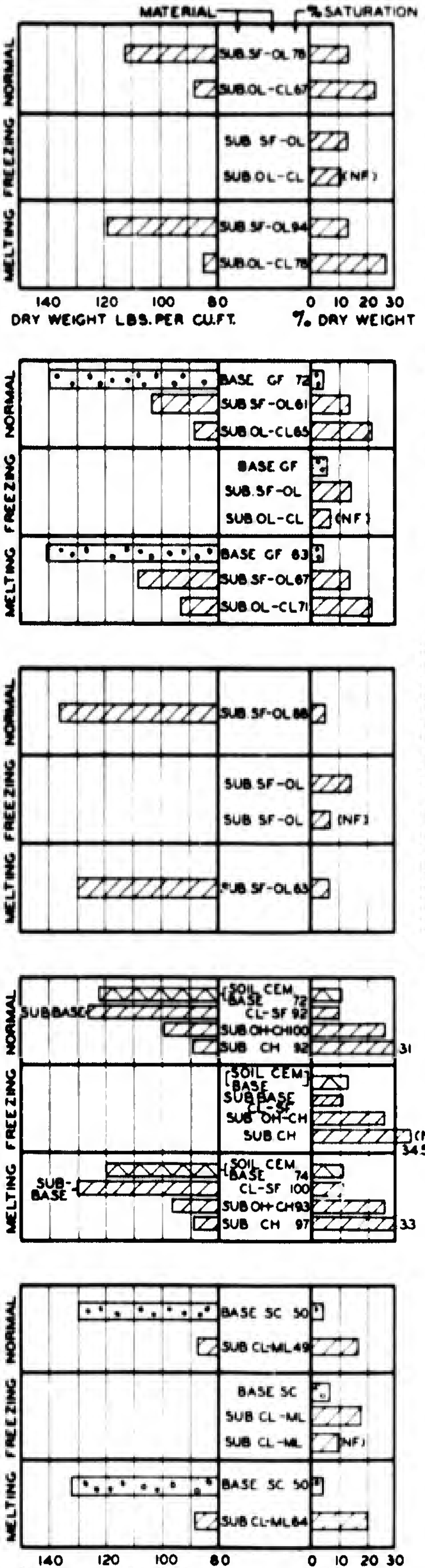


FIG.9
(NF) INDICATES NONFROZEN MATERIAL

IN PLACE C.B.R.

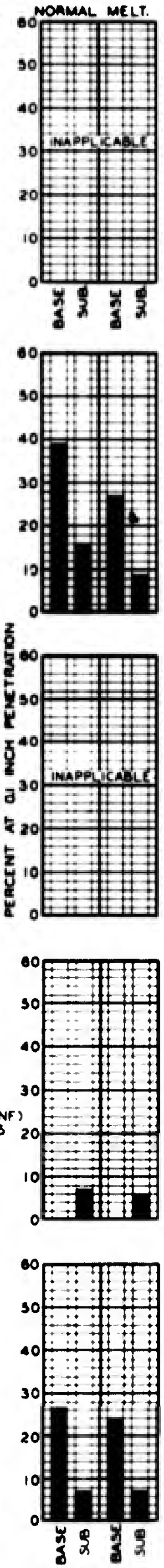


FIG.10

SUBSURFACE TEMPERATUR

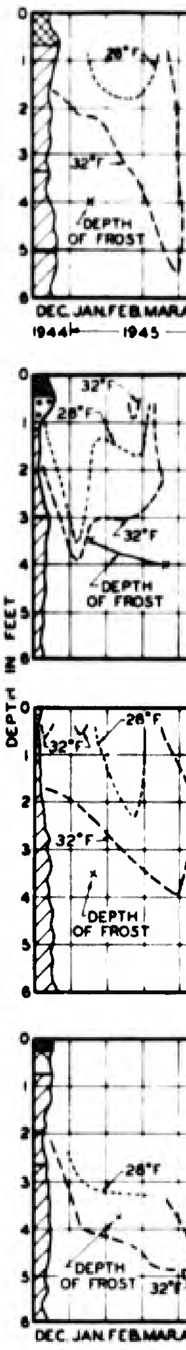


FIG.11

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CORPS OF ENGINEERS, U. S. ARMY

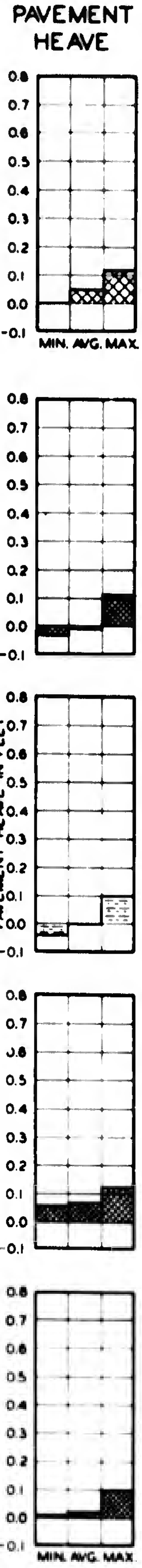


FIG.7

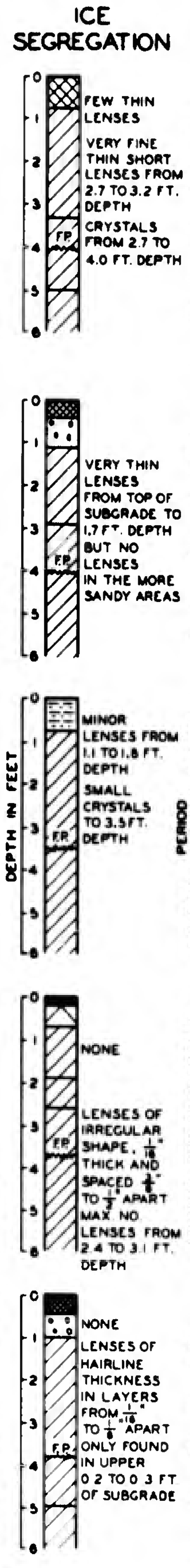


FIG.8

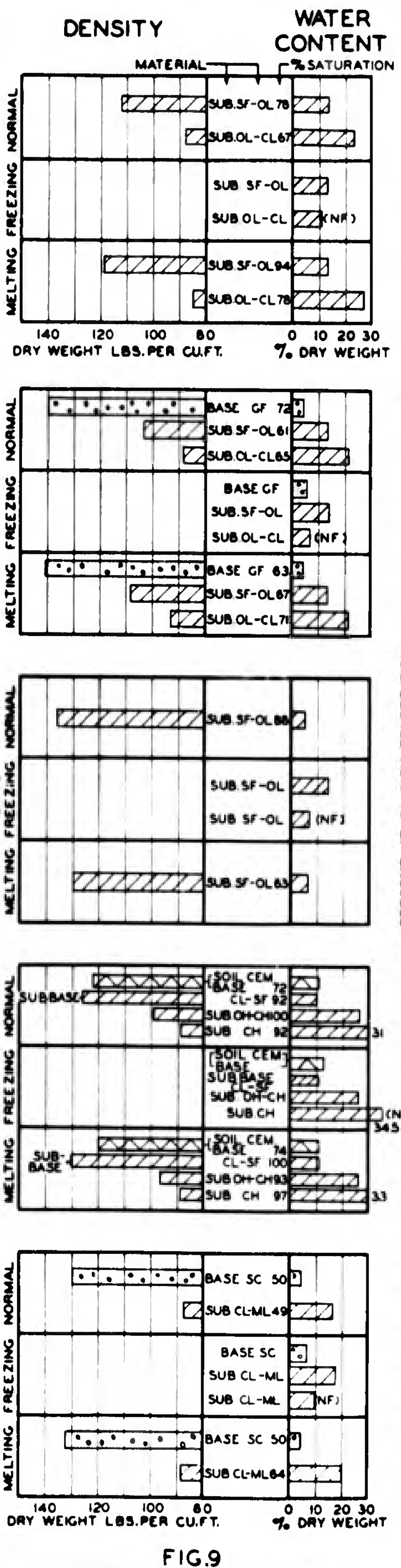


FIG.9

(NF) INDICATES NONFROZEN MATERIAL

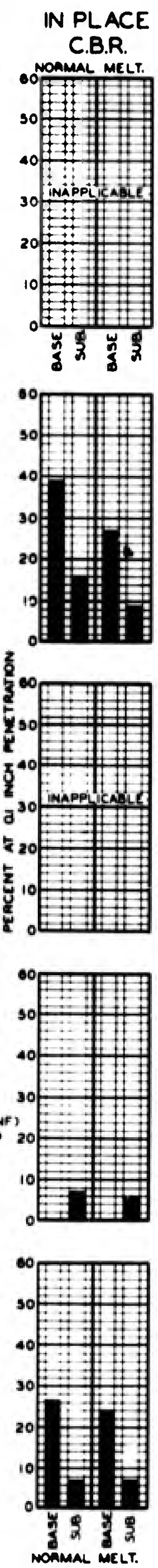


FIG.10

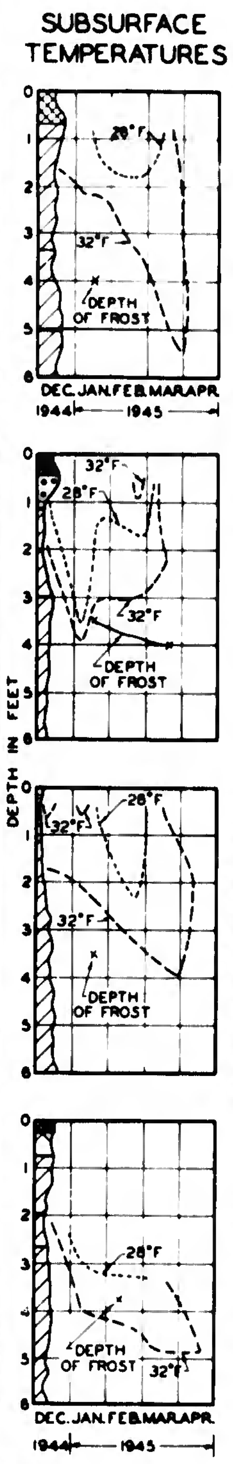


FIG.11

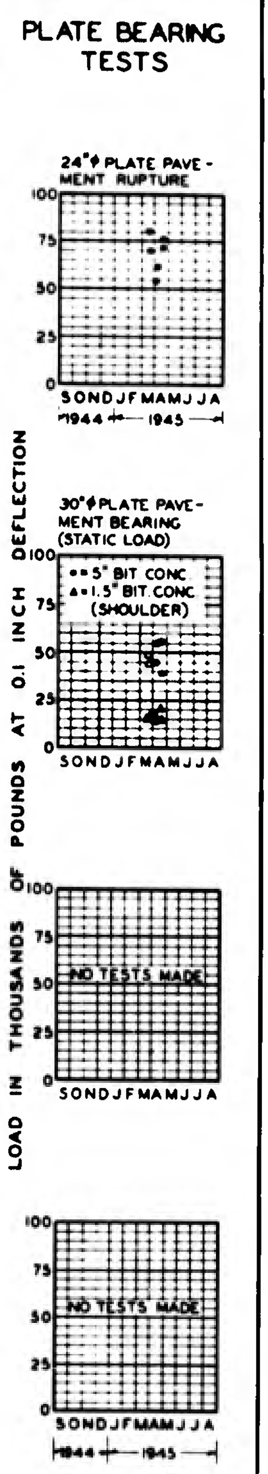


FIG.12

FROST INVESTIGATION

1944-1945

SUMMARY OF DATA

MISSOURI RIVER DIVISION

WATERTOWN AIRFIELD
FARGO MUNICIPAL AIRFIELD
BISMARCK MUNICIPAL AIRFIELD

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE, 1945

PLATE 5

WAR DEPARTMENT

TRUAX FIELD
MADISON, WISCONSIN

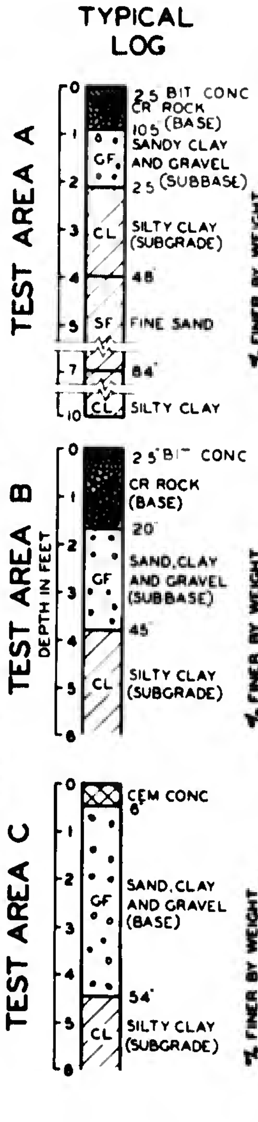
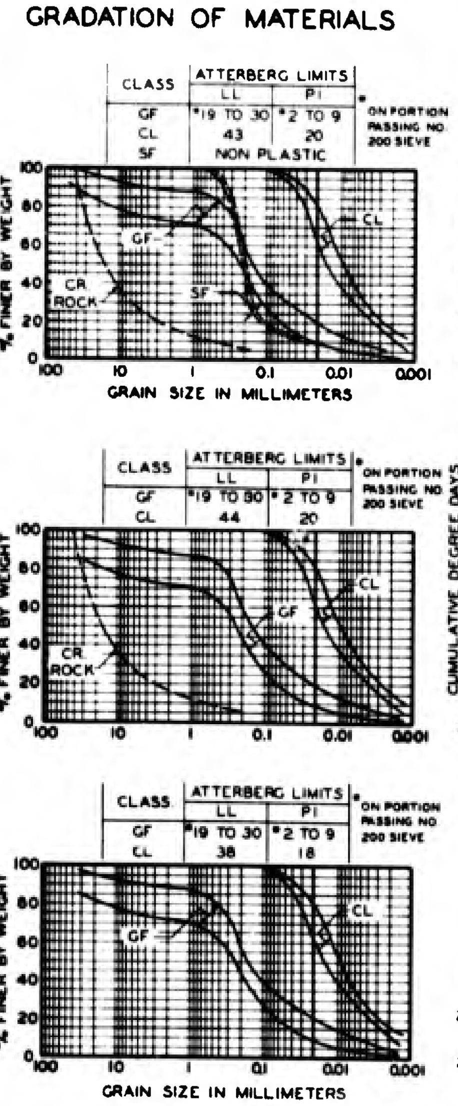


FIG.1



Test Area A:

CLASS	ATTERBERG LIMITS	
	LL	PI
GF	*19 TO 30	*2 TO 9
CL	43	20
SF	NON PLASTIC	

Test Area B:

CLASS	ATTERBERG LIMITS	
	LL	PI
GF	*19 TO 30	*2 TO 9
CL	44	20

Test Area C:

CLASS	ATTERBERG LIMITS	
	LL	PI
GF	*19 TO 30	*2 TO 9
CL	38	18

* ON PORTION PASSING NO 200 SIEVE

FIG.2

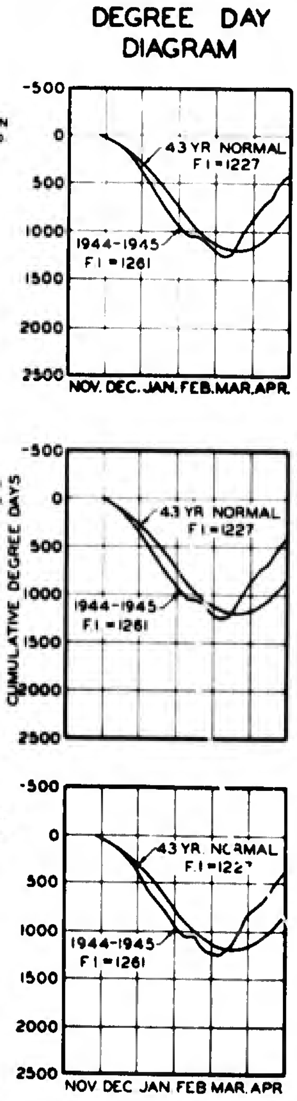


FIG.3

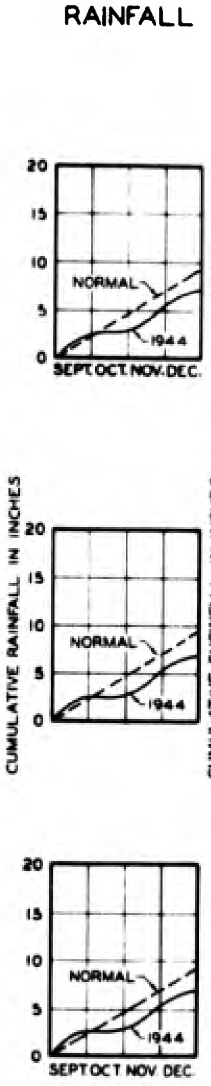


FIG.4

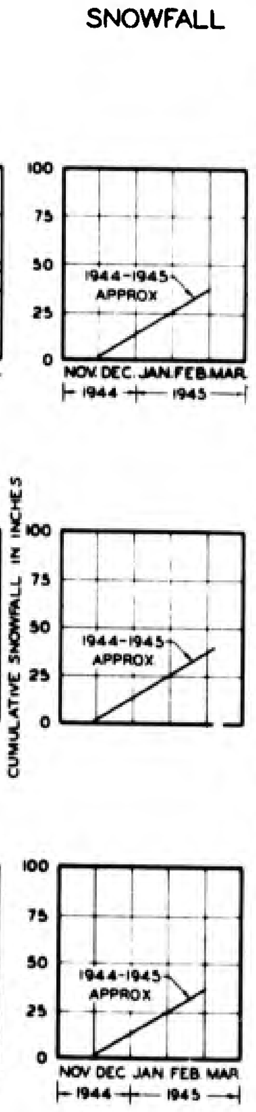


FIG.5

A

CORPS OF ENGINEE

LL

GROUND WATER TABLE

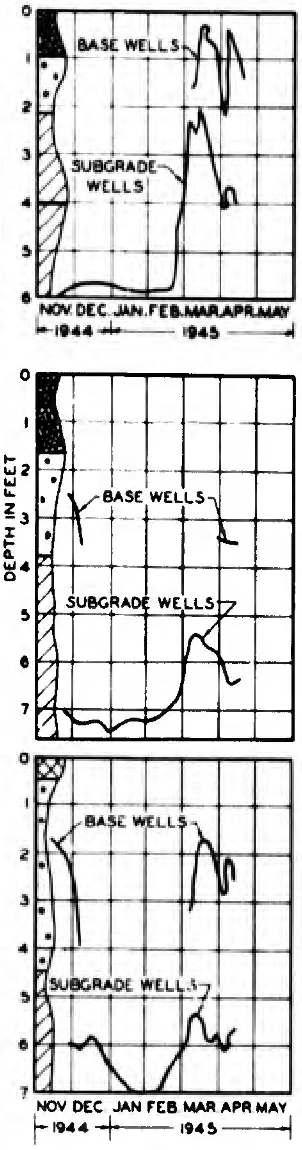


FIG.6

PAVEMENT HEAVE

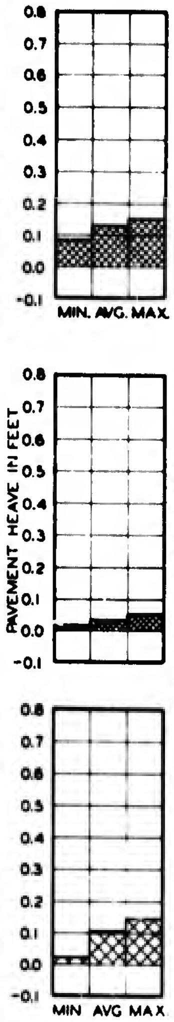


FIG.7

ICE SEGREGATION

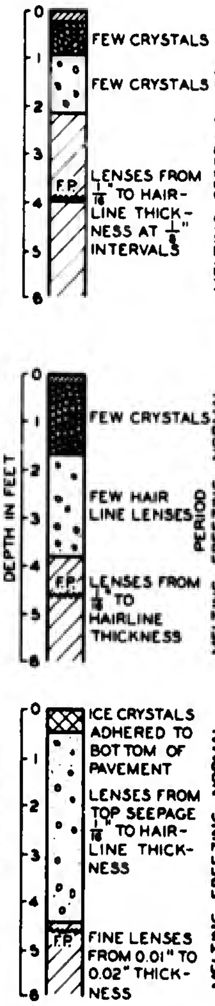


FIG.8

DENSITY

WATER CONTENT

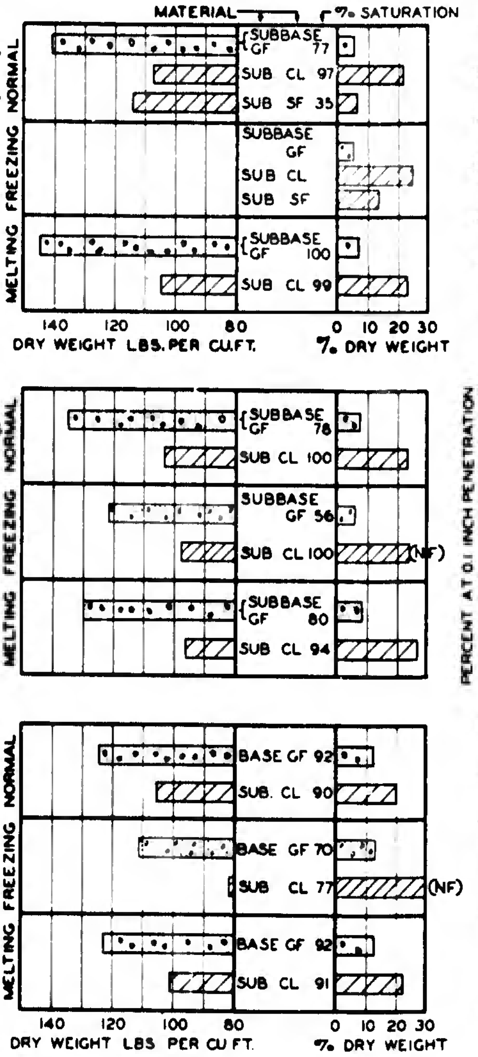


FIG.9

(NF) INDICATES NONFROZEN MATERIAL

IN PLACE C.B.R.

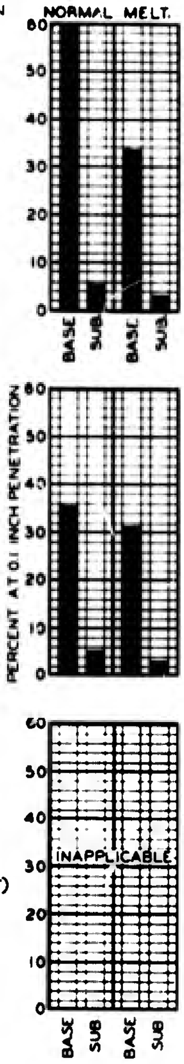


FIG.10

SUBSURFACE TEMPERATURES

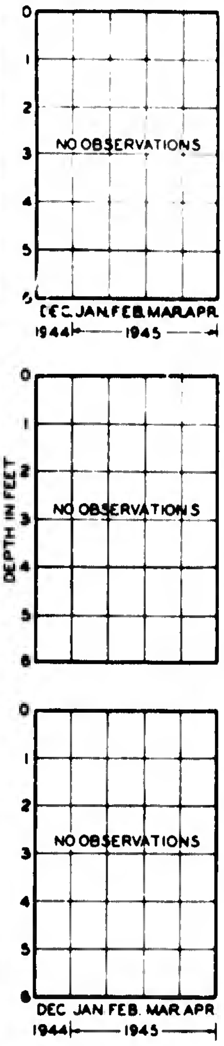
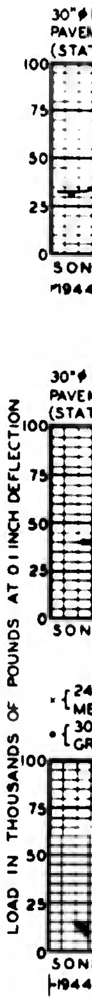


FIG.11

PLATE
T



B

FROST INVESTIGA
1944-1945
SUMMARY OF
GREAT LAKES DIV
TRUAX FIELD

FROST EFFECTS LABORATORY BOSTO

CORPS OF ENGINEERS, U. S. ARMY

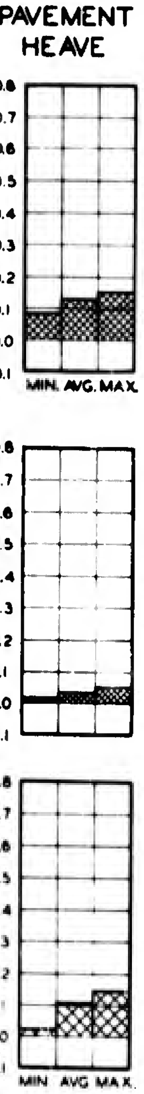


FIG.7

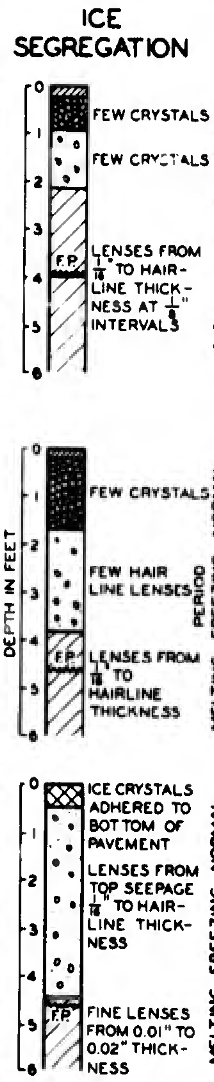


FIG.8

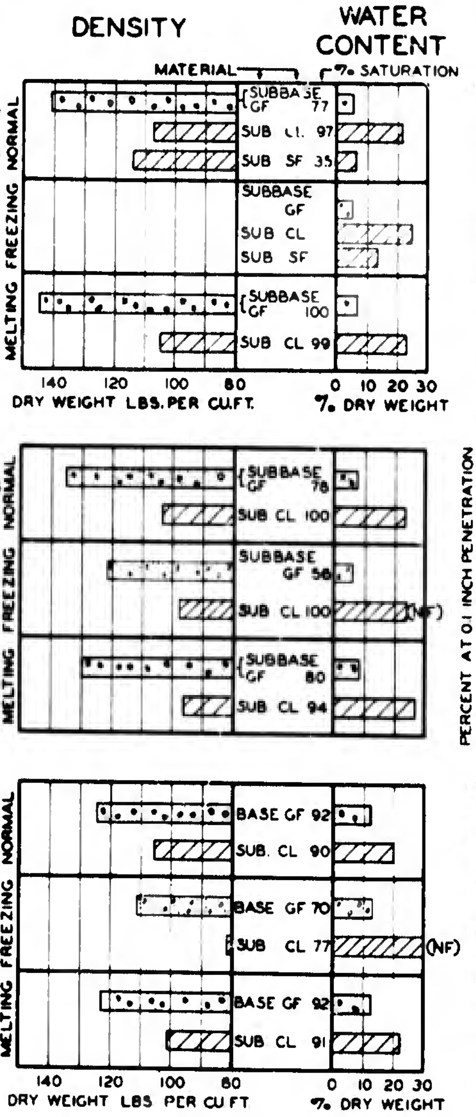


FIG.9
(NF) INDICATES NONFROZEN MATERIAL

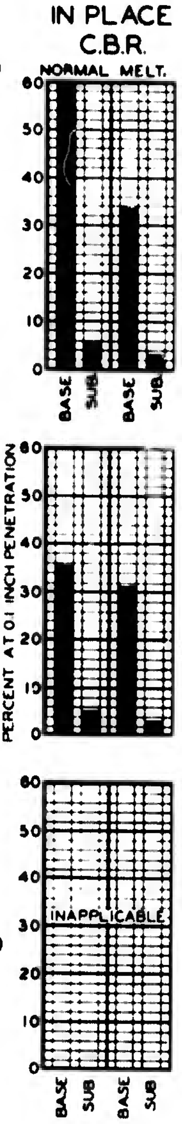


FIG.10

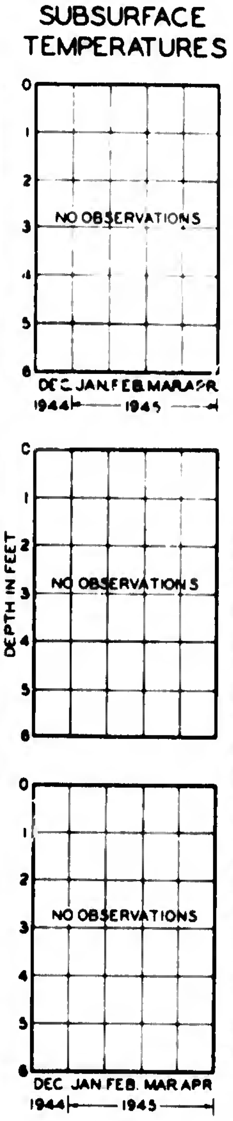


FIG.11

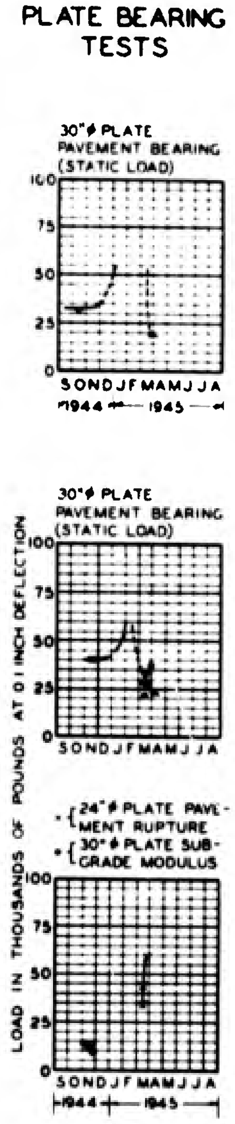


FIG.12

C

FROST INVESTIGATION

1944-1945

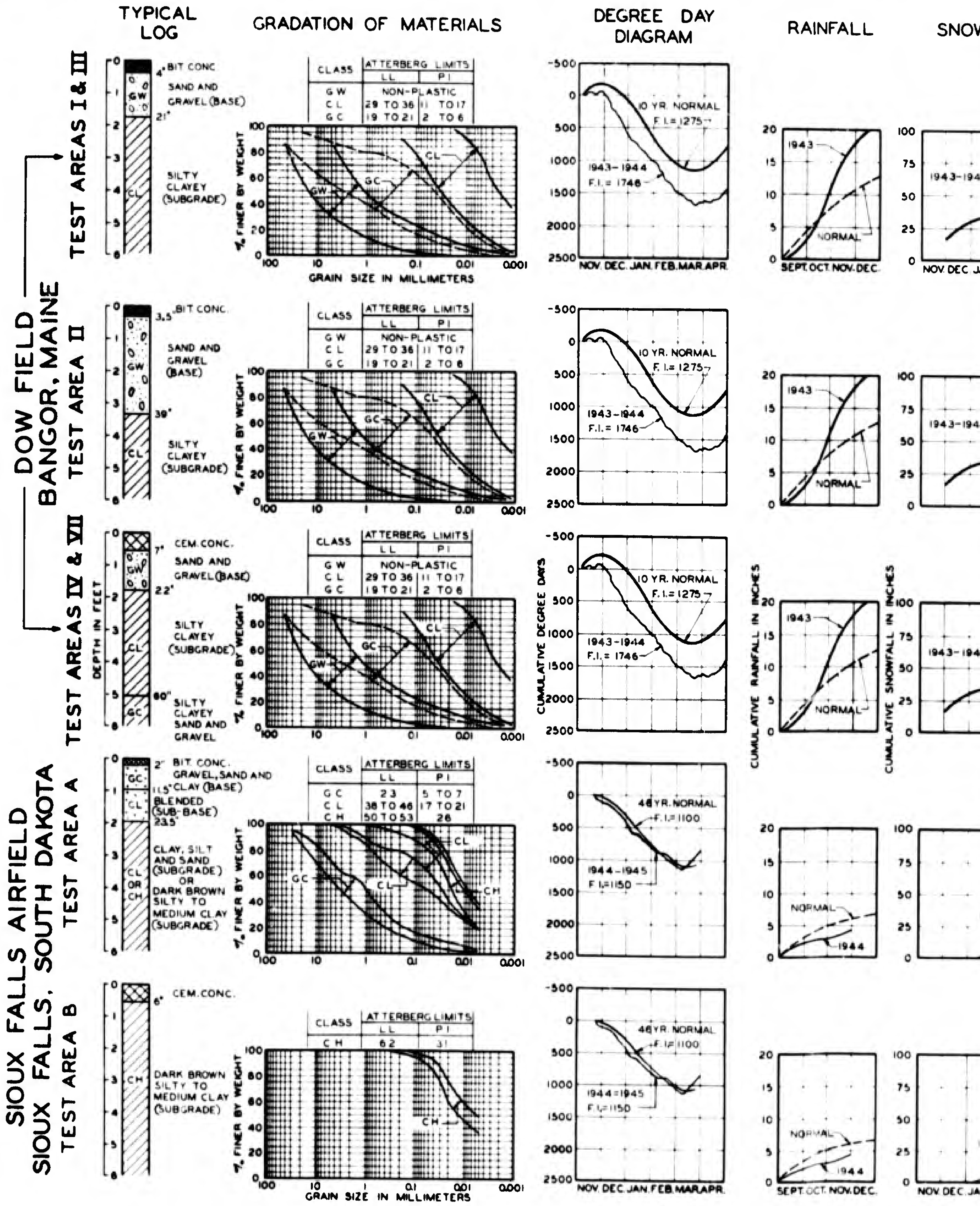
SUMMARY OF DATA

GREAT LAKES DIVISION

TRUAX FIELD

FROST EFFECTS LABORATORY BOSTON, MASS JUNE 1945

PLATE 6



CLASS	ATTERBERG LIMITS	
	LL	PI
GW	NON-PLASTIC	
CL	29 TO 36	11 TO 17
GC	19 TO 21	2 TO 6

CLASS	ATTERBERG LIMITS	
	LL	PI
GC	23	5 TO 7
CL	38 TO 46	17 TO 21
CH	50 TO 53	26

CLASS	ATTERBERG LIMITS	
	LL	PI
CH	62	31

FIG. 1 FIG. 2 FIG. 3 FIG. 4 FIG


ALL

4

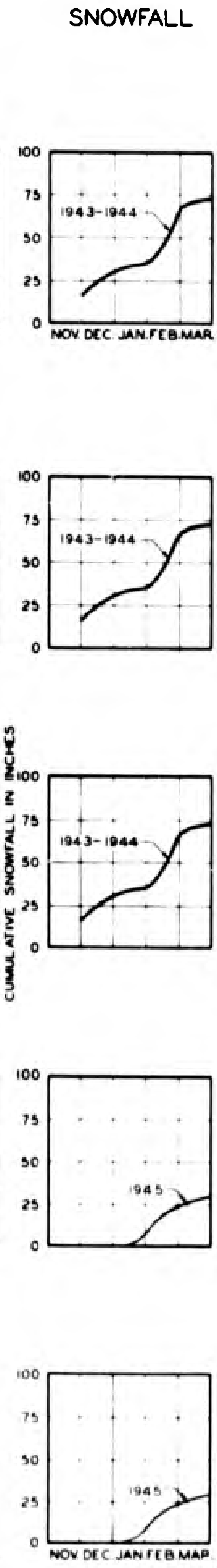

SNOWFALL

FIG.5

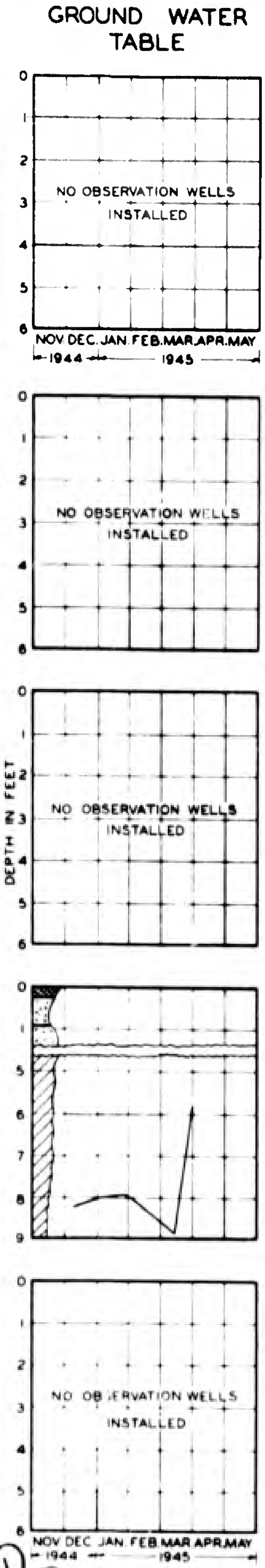

GROUND WATER TABLE

FIG.6

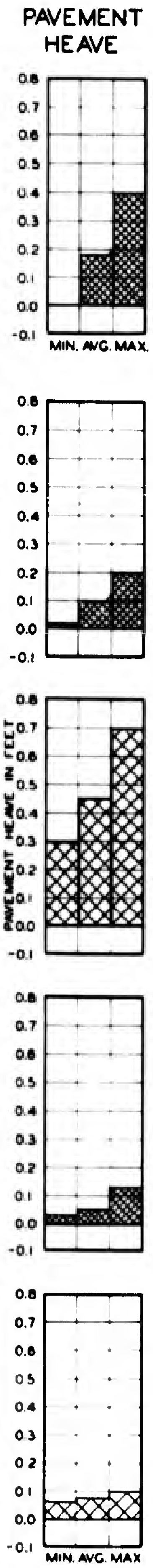

PAVEMENT HEAVE

FIG.7

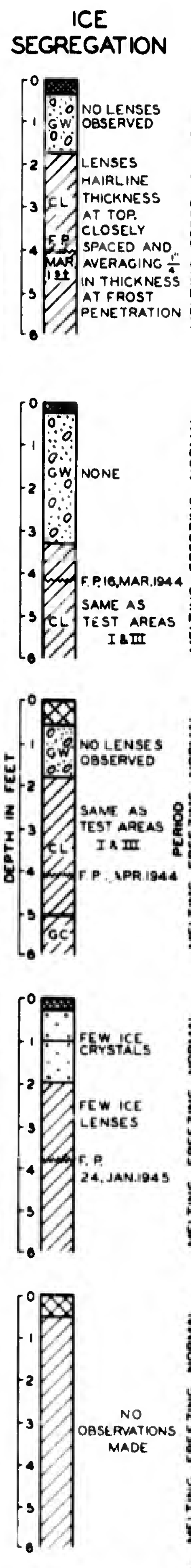
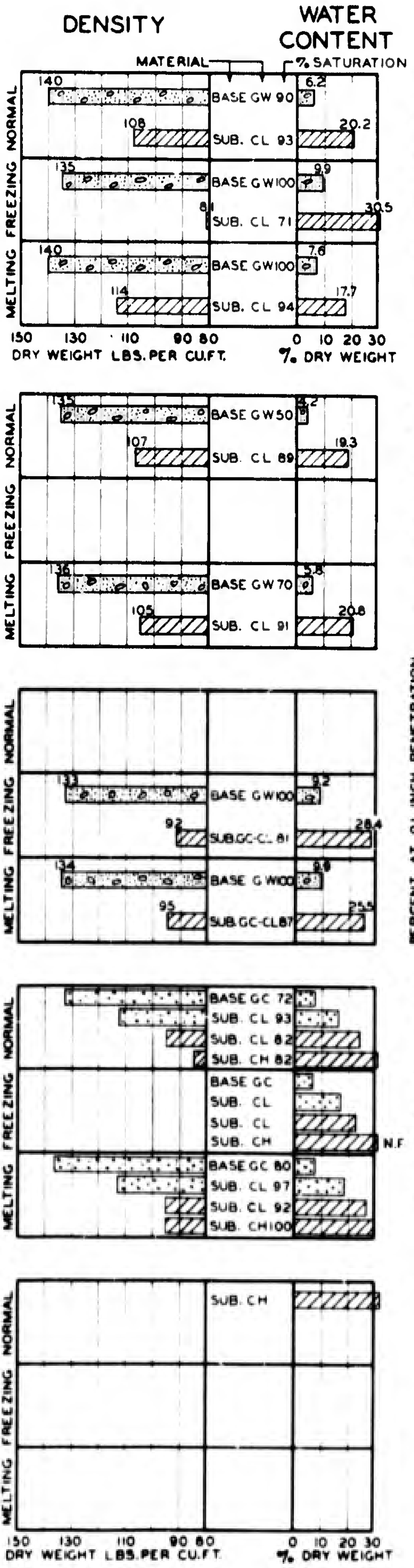

ICE SEGREGATION

FIG.8


DENSITY

WATER CONTENT

FIG.9

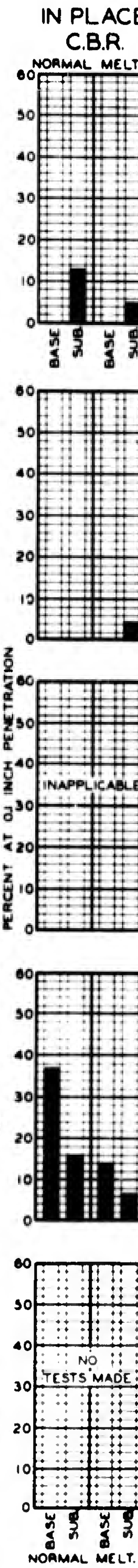

IN PLACE C.B.R.

FIG.10

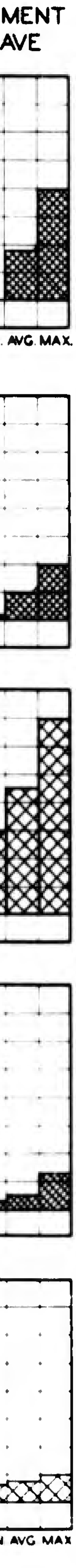


FIG.7

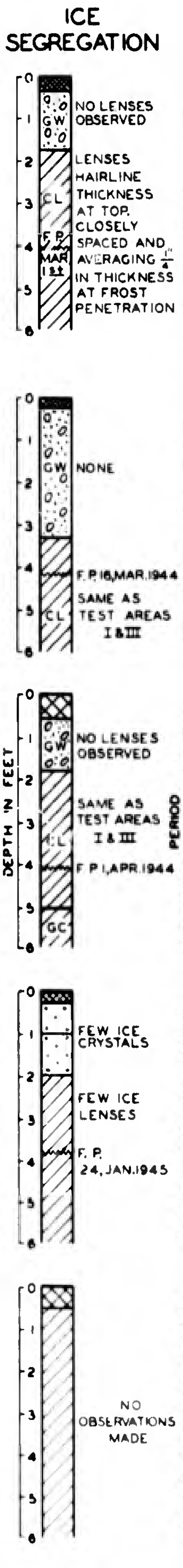


FIG.8

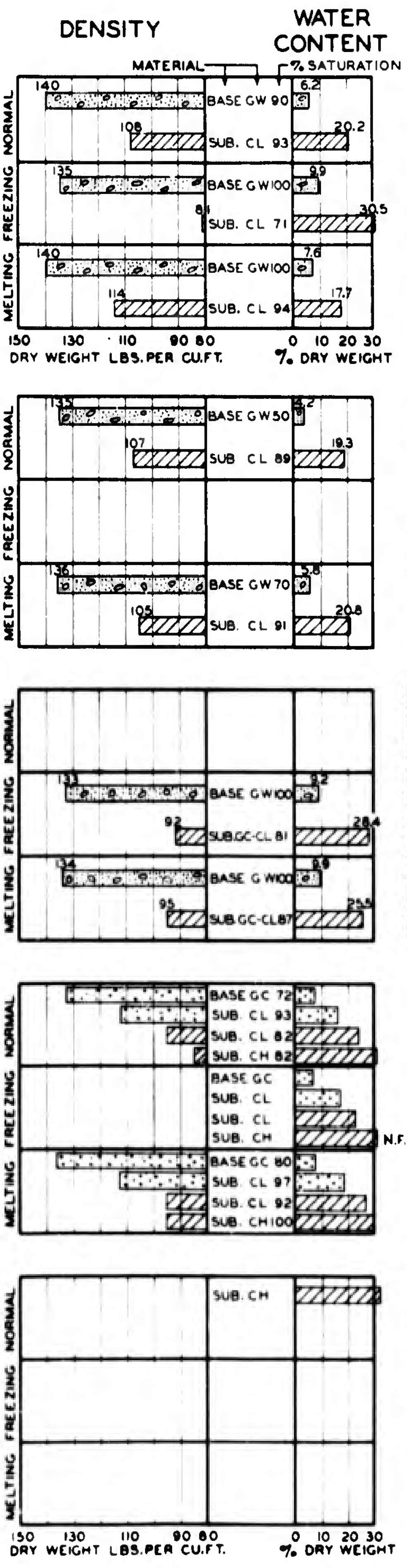


FIG.9

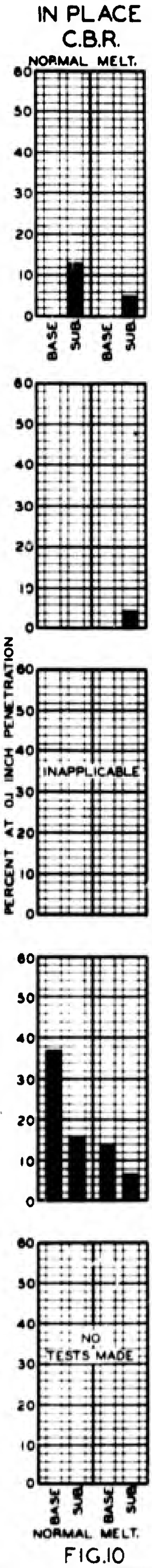


FIG.10

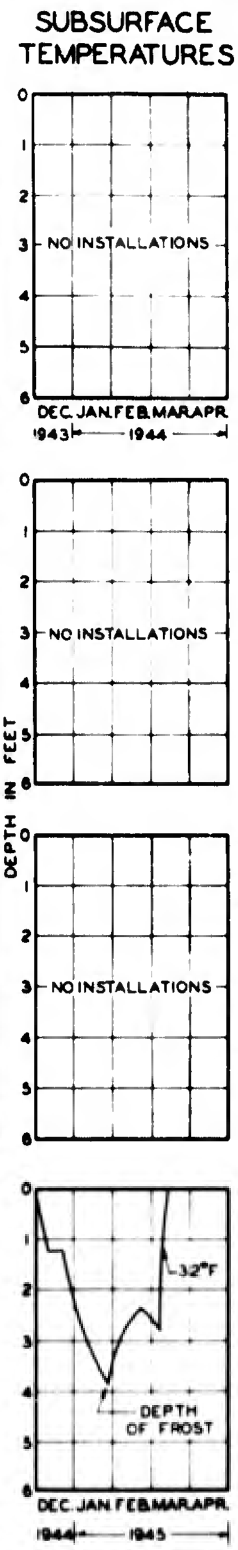


FIG.11

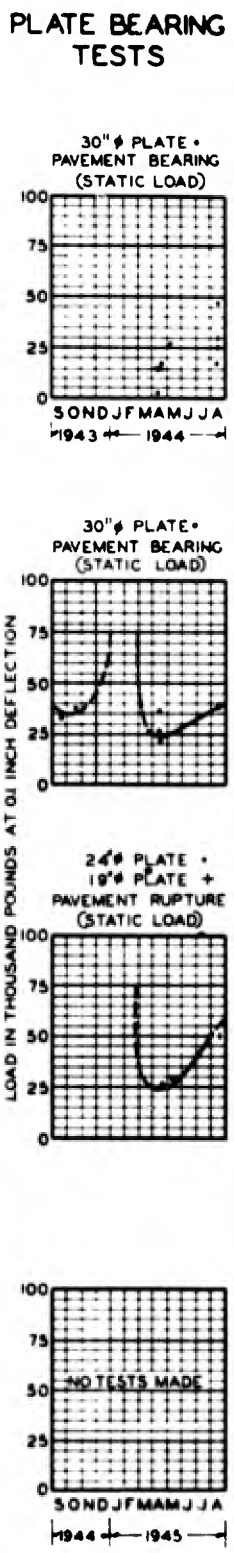


FIG.12

FROST INVESTIGATION
1944-1945

SUMMARY OF DATA

BOSTON DISTRICT
DOW FIELD

MISSOURI RIVER DIVISION
SIOUX FALLS

FROST EFFECTS LABORATORY, BOSTON, MASS.

FAIRMONT AIRFIELD
FAIRMONT, NEBRASKA
TEST AREA A

GREAT BEND AIRFIELD
GREAT BEND, KANSAS
TEST AREA A

GARDEN CITY AIRFIELD
GARDEN CITY, KANSAS
TEST AREA A

PRATT AIRFIELD
PRATT, KANSAS
TEST AREA A

TYPICAL LOG

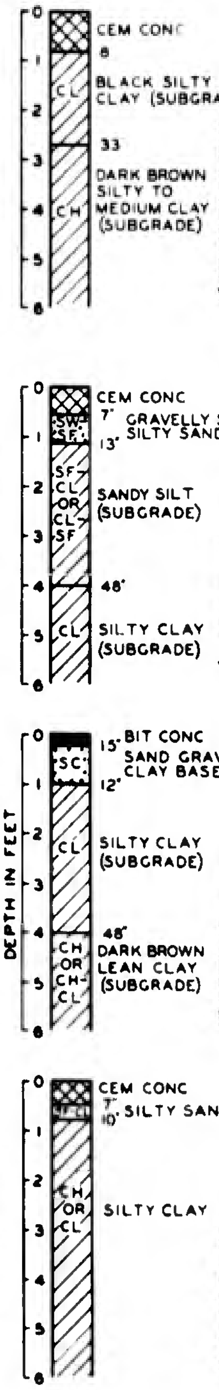
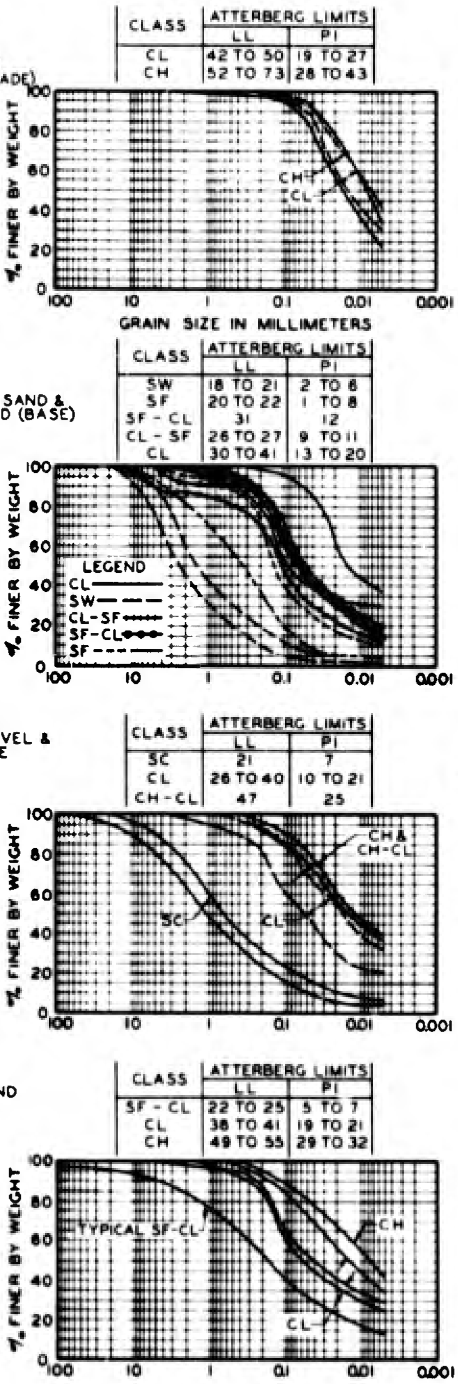


FIG.1

GRADATION OF MATERIALS



CLASS	ATTERBERG LIMITS	
	LL	PI
CL	42 TO 50	19 TO 27
CH	52 TO 73	28 TO 43

CLASS	ATTERBERG LIMITS	
	LL	PI
SW	18 TO 21	2 TO 6
SF	20 TO 22	1 TO 8
SF - CL	31	12
CL - SF	26 TO 27	9 TO 11
CL	30 TO 41	13 TO 20

CLASS	ATTERBERG LIMITS	
	LL	PI
SC	21	7
CL	26 TO 40	10 TO 21
CH - CL	47	25

CLASS	ATTERBERG LIMITS	
	LL	PI
SF - CL	22 TO 25	5 TO 7
CL	38 TO 41	19 TO 21
CH	49 TO 55	29 TO 32

FIG.2

DEGREE DAY DIAGRAM

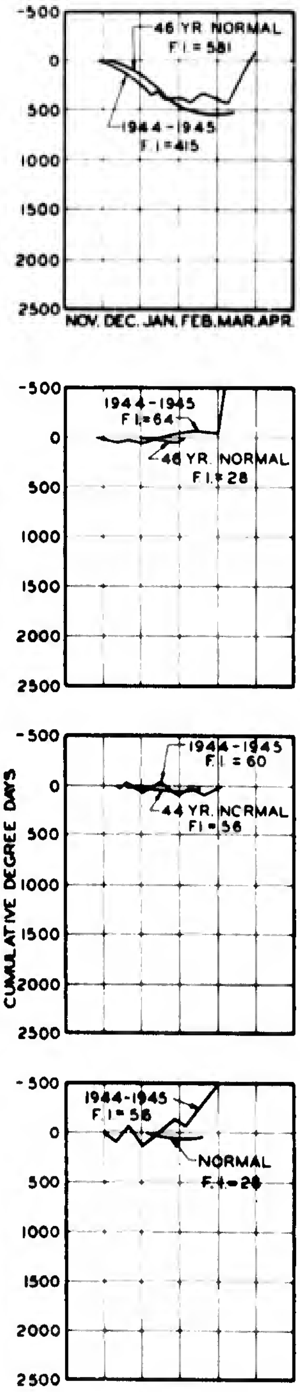


FIG.3

RAINFALL

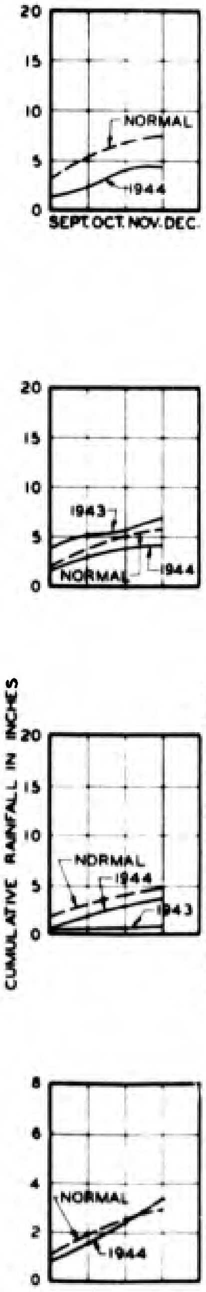


FIG.4

SNOWFALL

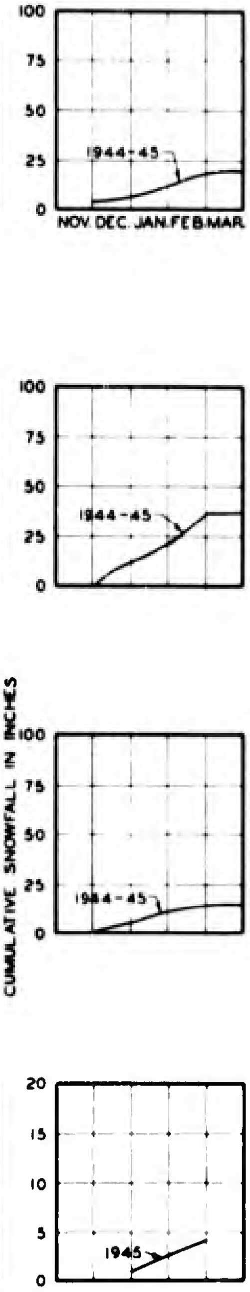


FIG.5

CO

SNOWFALL

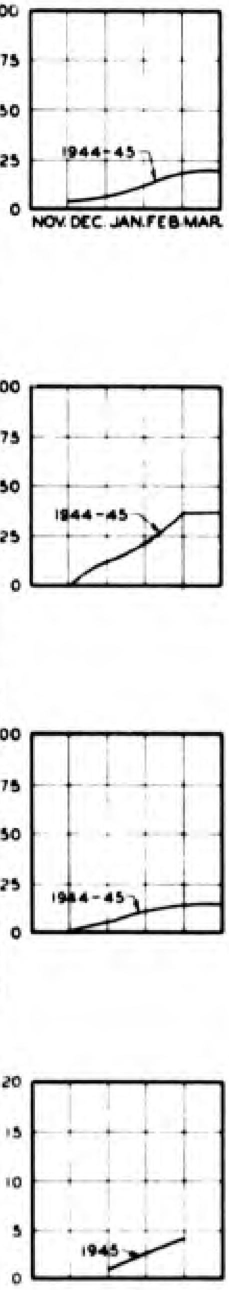


FIG.5

GROUND WATER TABLE

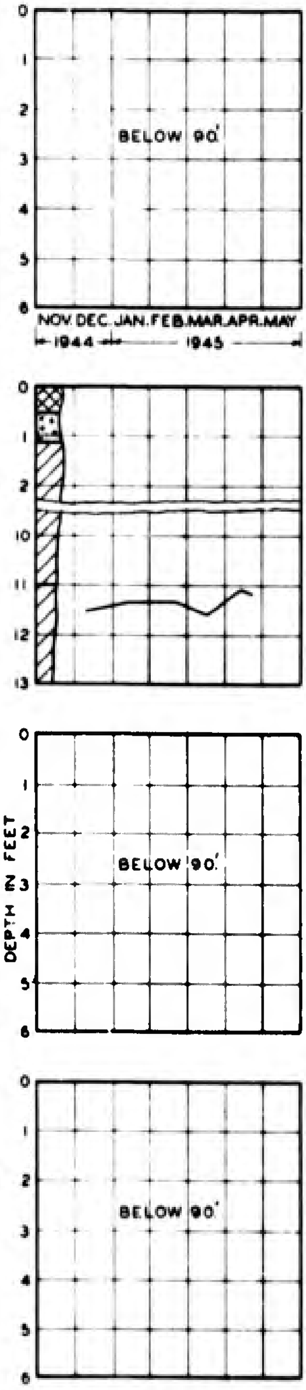
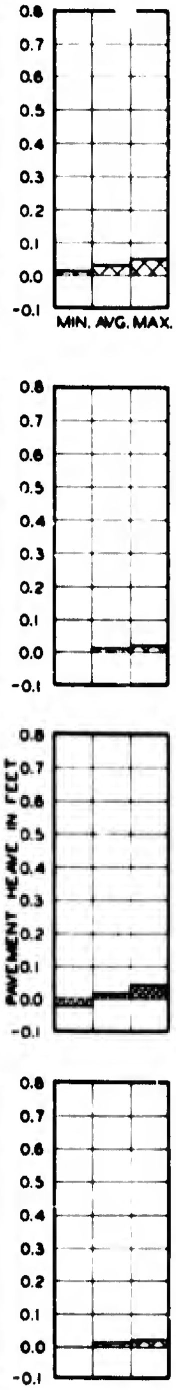


FIG.9

PAVEMENT HEAVE



ICE SEGREGATION

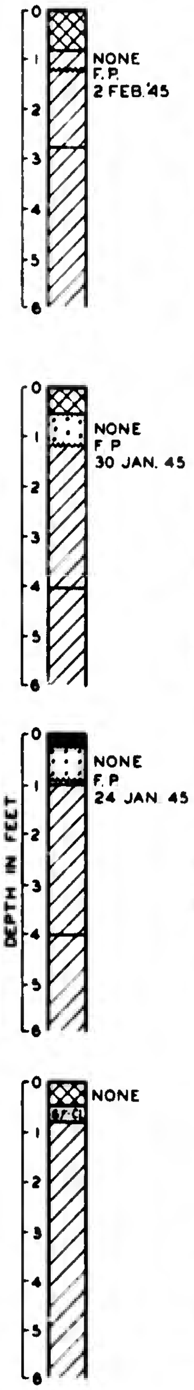


FIG.8

DENSITY

WATER CONTENT

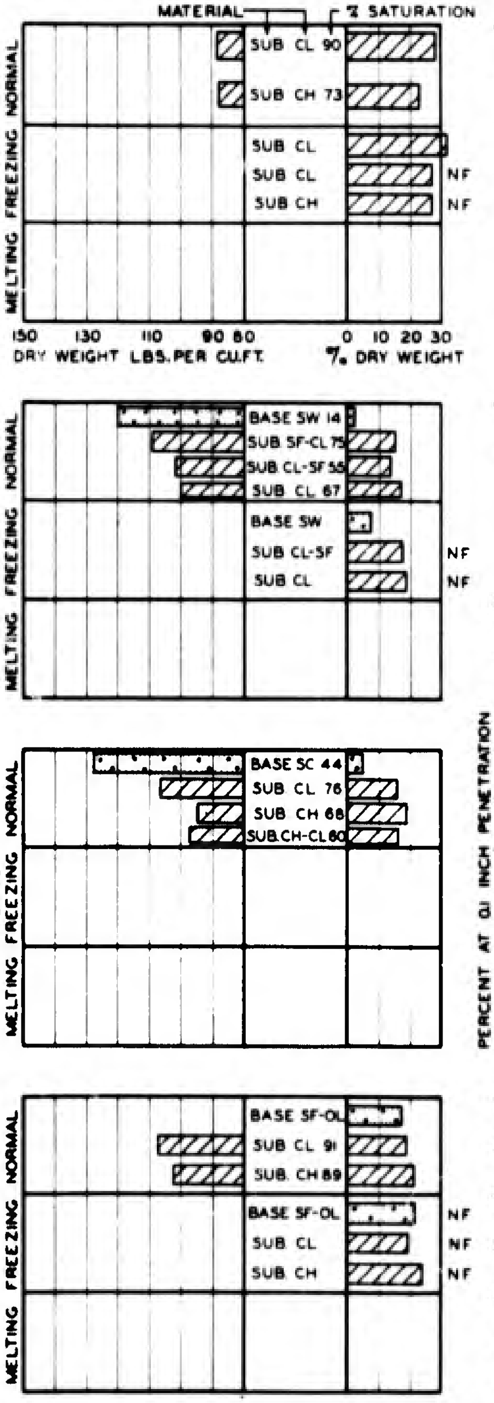


FIG.9
NF INDICATES NONFROZEN MATERIAL

IN PLACE C.B.R.

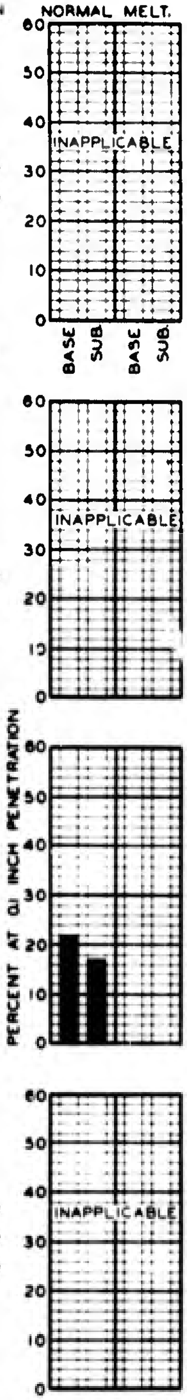
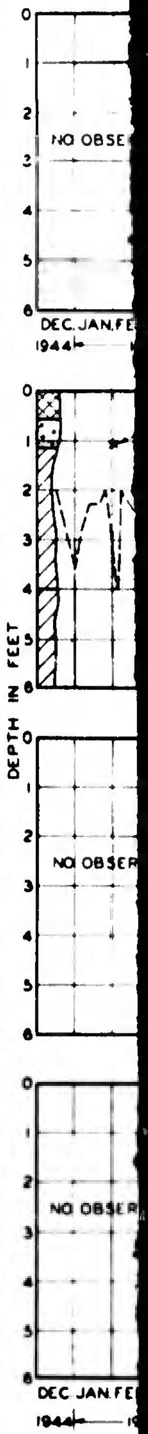


FIG10

SUBSU TEMPER



FIC

SU

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C
G

FROST EFFE

B

I

CORPS OF ENGINEERS, U. S. ARMY

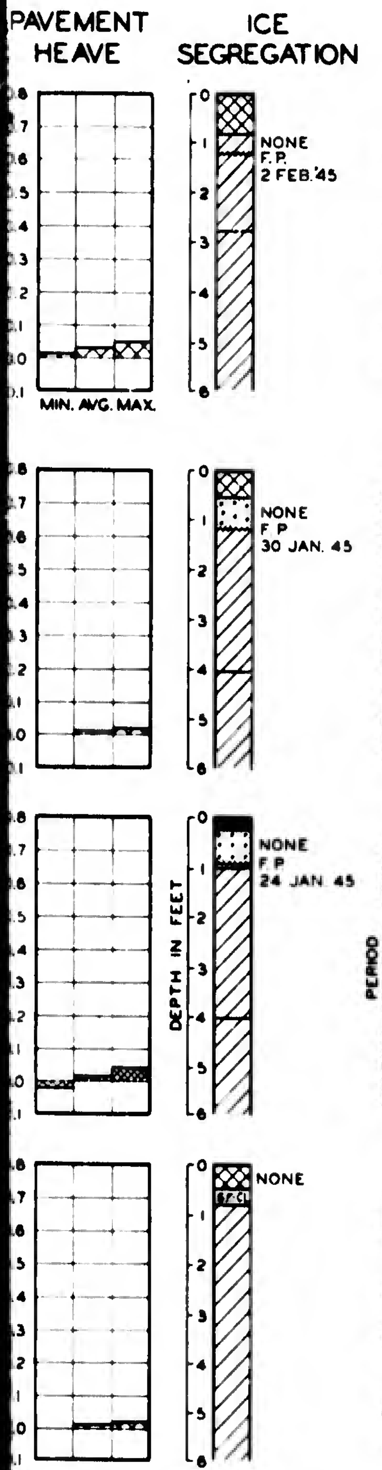


FIG.8

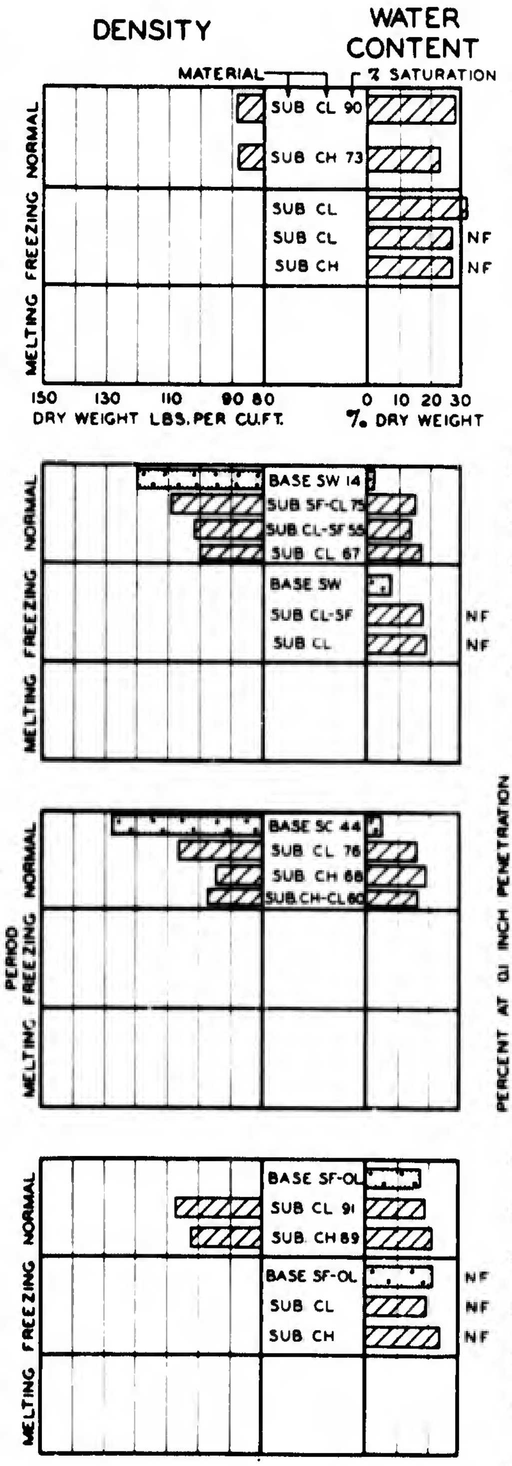


FIG.9
NF INDICATES NONFROZEN MATERIAL

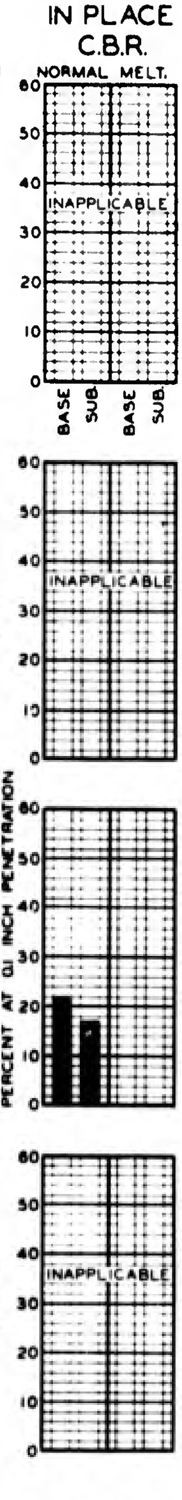


FIG.10

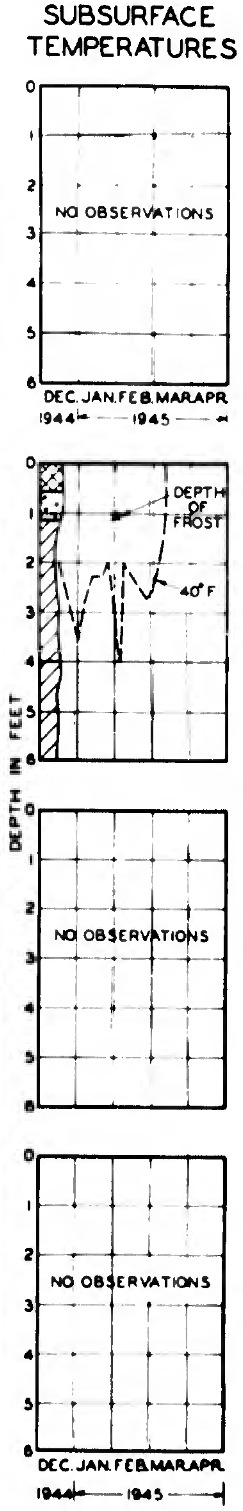


FIG.11

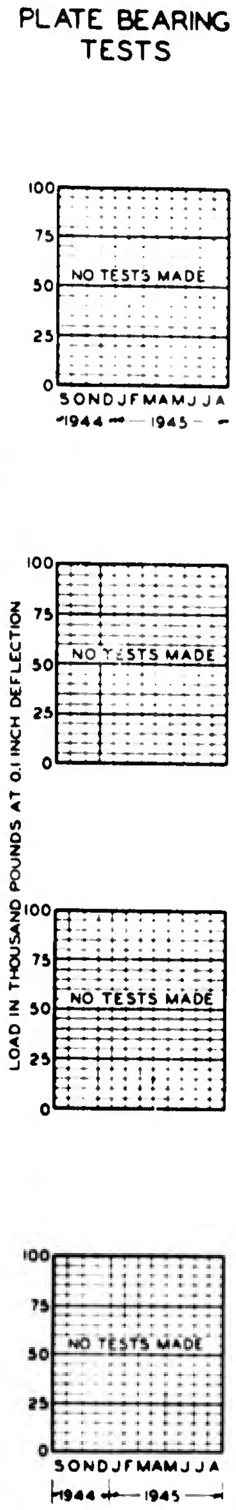


FIG.12

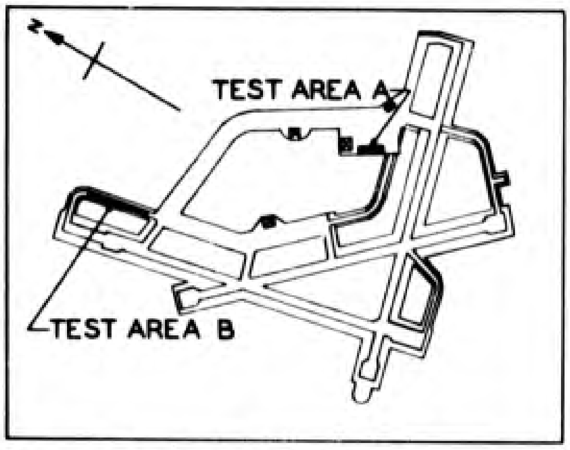
FROST INVESTIGATION
1944-1945

SUMMARY OF DATA

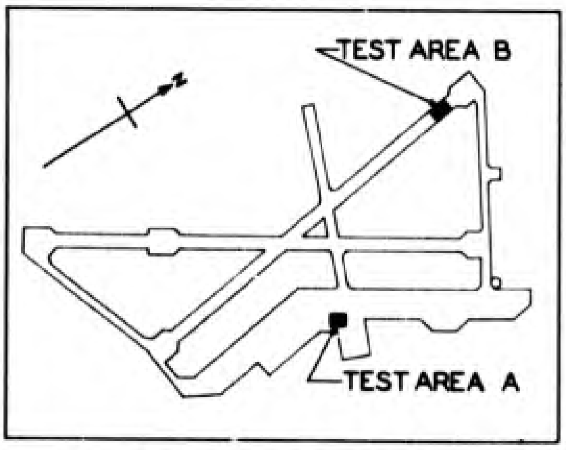
MISSOURI RIVER DIVISION
FAIRMONT AIRFIELD
GREAT BEND AIRFIELD
GARDEN CITY AIRFIELD
PRATT AIRFIELD

FROST EFFECTS LABORATORY, BOSTON, MASS.

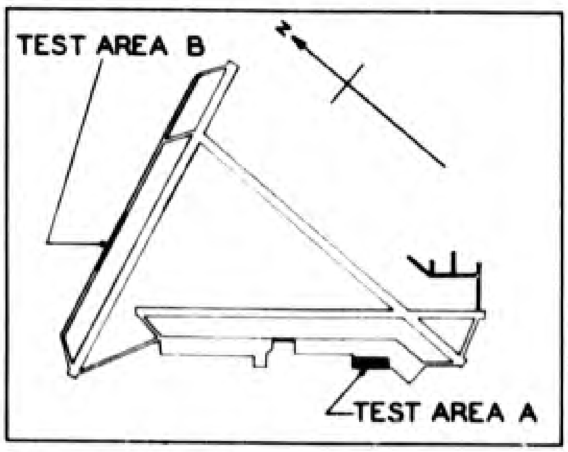
WAR DEPARTMENT



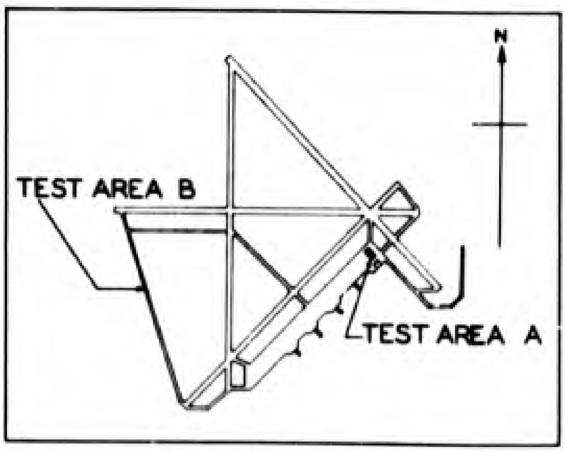
PRESQUE ISLE AIRFIELD



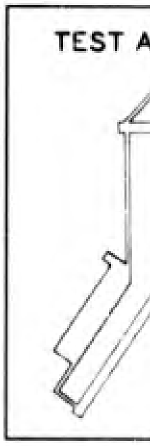
HOULTON AIRFIELD



PIERRE AIRFIELD

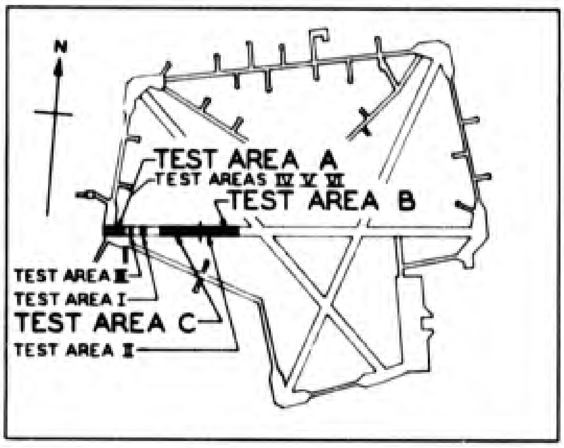


CASPER AIRBASE

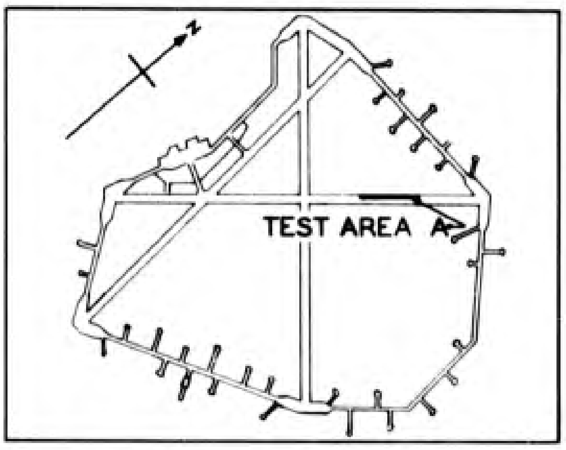


WA

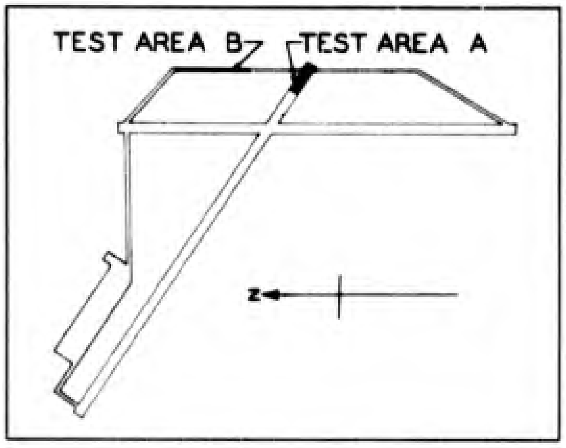
A



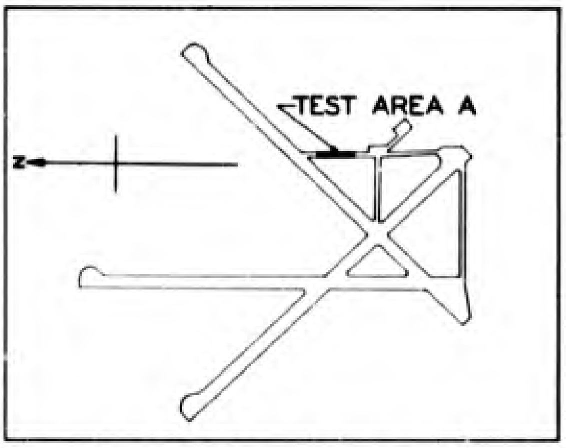
DOW FIELD



OTIS FIELD



WATERTOWN AIRFIELD



FARGO MUNICIPAL AIRFIELD

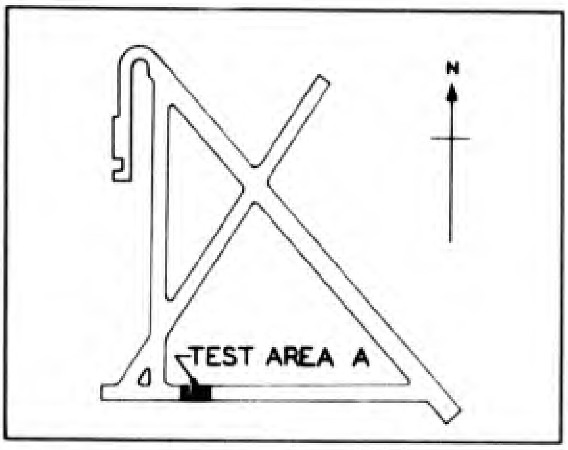
B

FROST INVESTIGATION
1944 – 1945

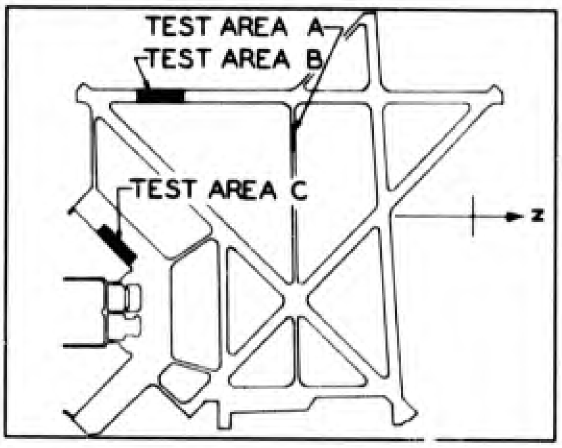
LOCATIONS OF TEST AREAS

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE, 1945

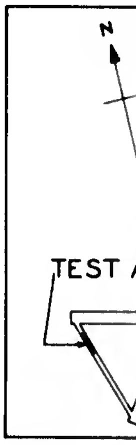
WAR DEPARTMENT



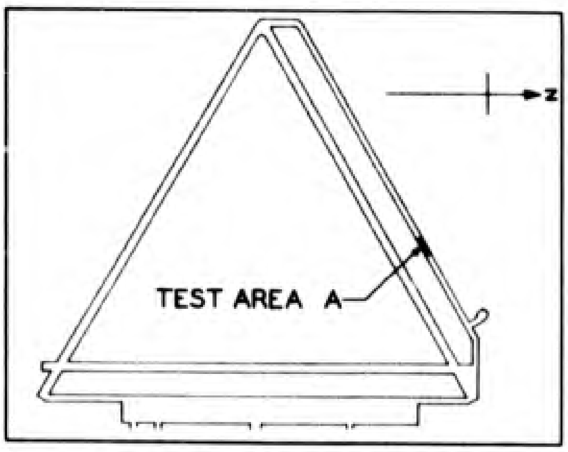
BISMARCK MUNICIPAL AIRFIELD



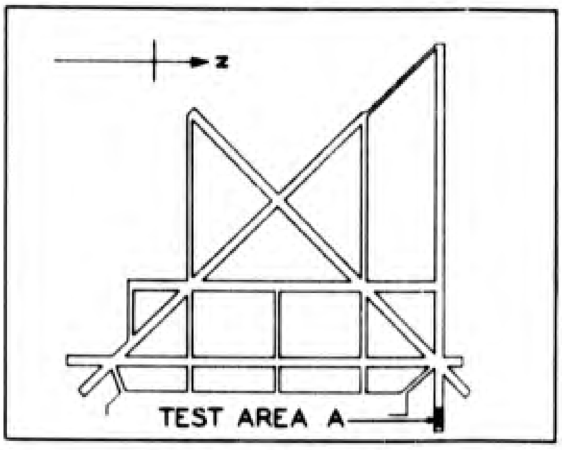
TRUAX FIELD



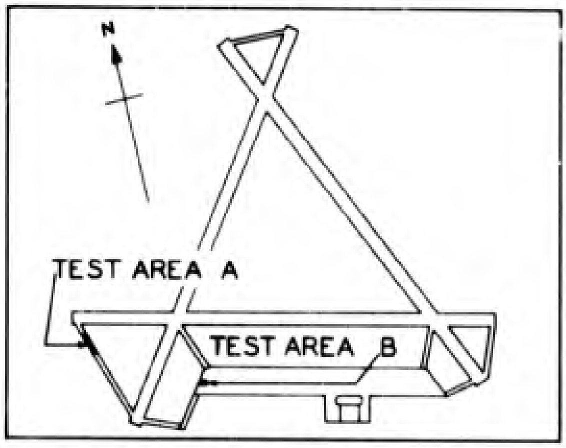
SI



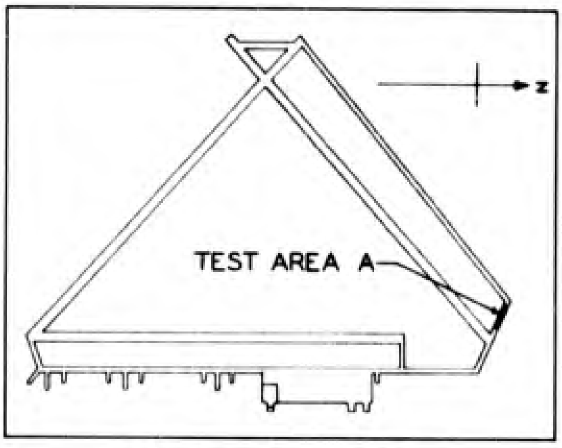
GREAT BEND AIRFIELD



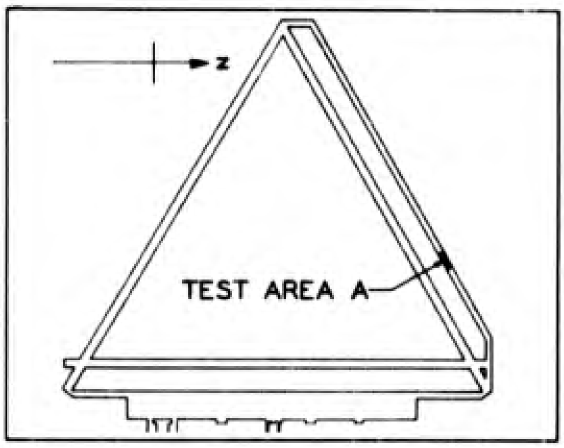
GARDEN CITY AIRFIELD



SIOUX FALLS AIRFIELD



FAIRMONT AIRFIELD



PRATT AIRFIELD

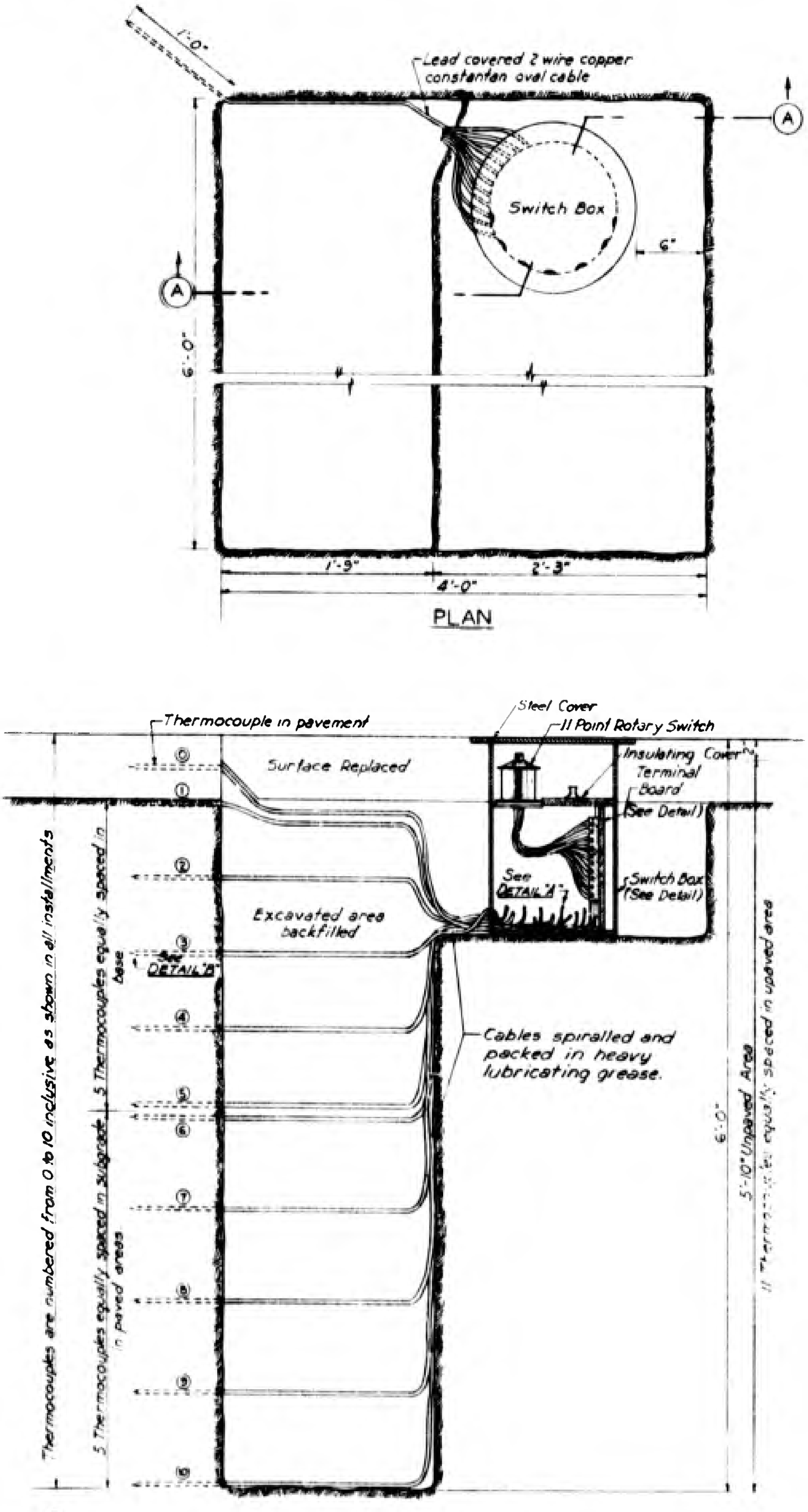
B

FROST INVESTIGATION
1944 – 1945

LOCATIONS OF TEST AREAS

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1945

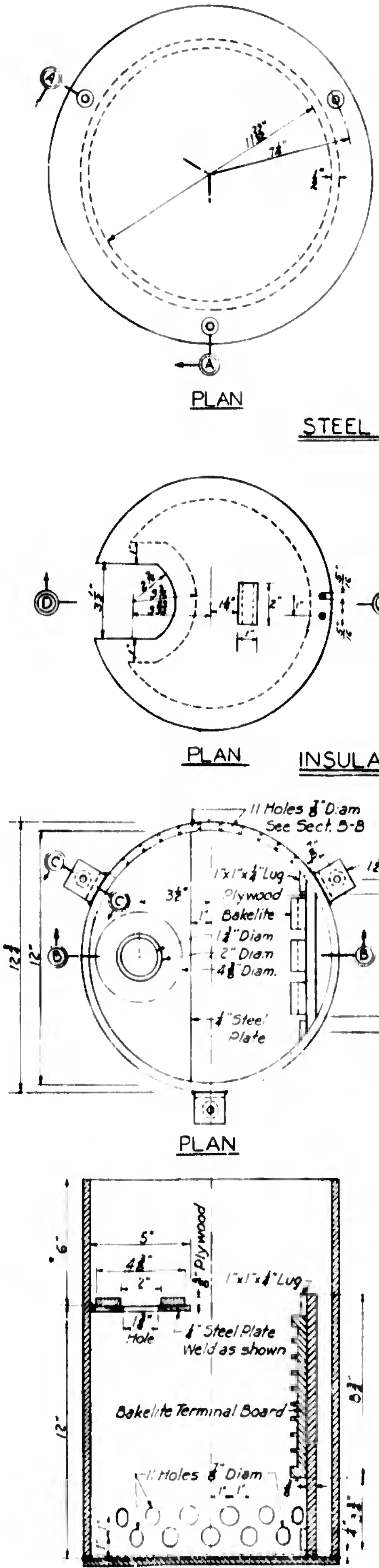
WAR DEPARTMENT



SECTION A-A

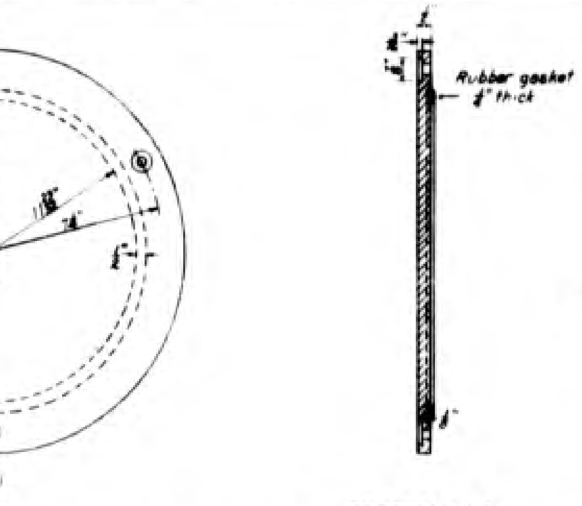
INSTALLATION OF THERMOCOUPLE EQUIPMENT

Scale 1½"=1'-0"



SWITCH BOX DETAILS

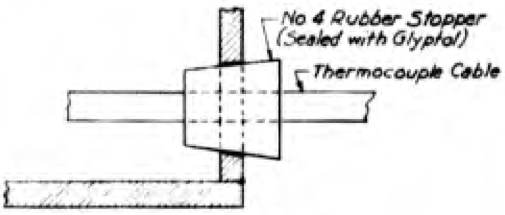
Quarter Scale



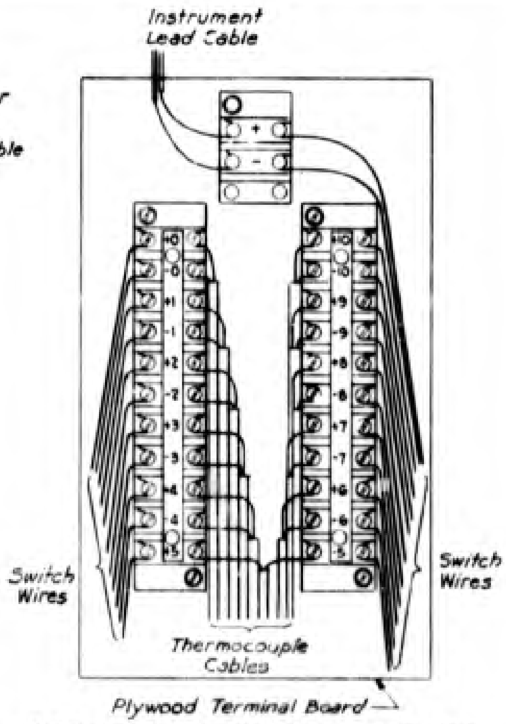
AN

SECTION A-A

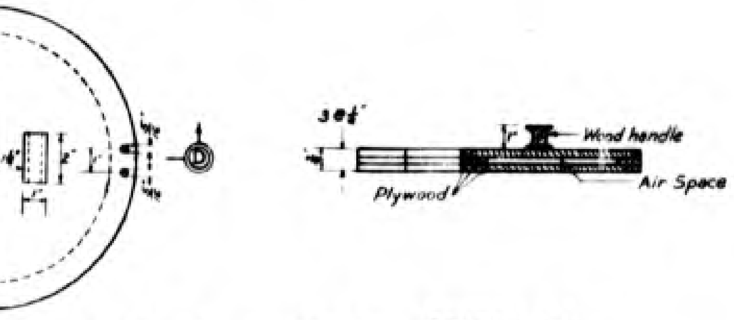
STEEL COVER



DETAIL A
Not to Scale



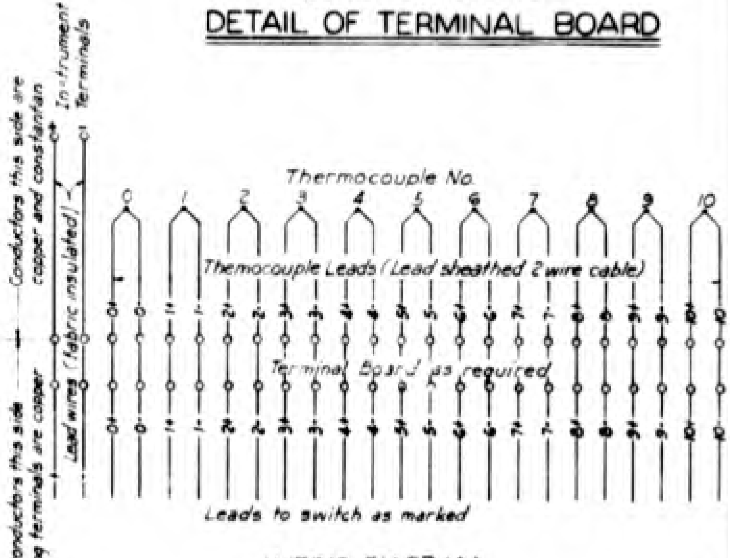
DETAIL OF TERMINAL BOARD



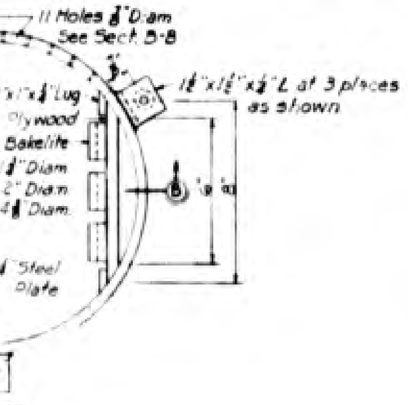
AN

INSULATING COVER

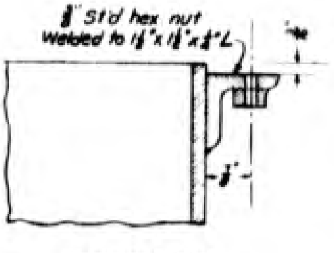
SECTION D-D



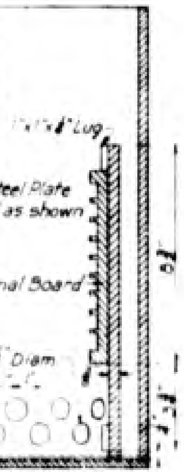
WIRING DIAGRAM



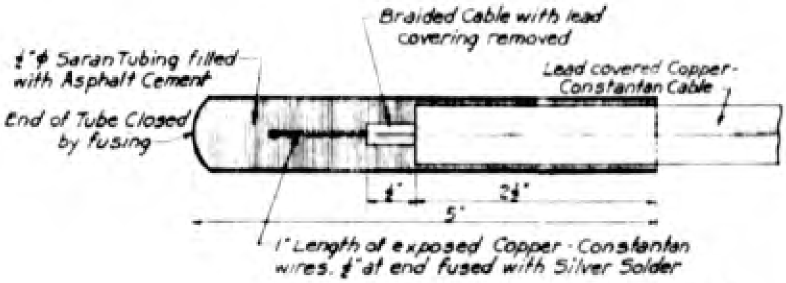
AN



SECTION C-C
Half Scale



ON B-B
BOX DETAILS
Scale



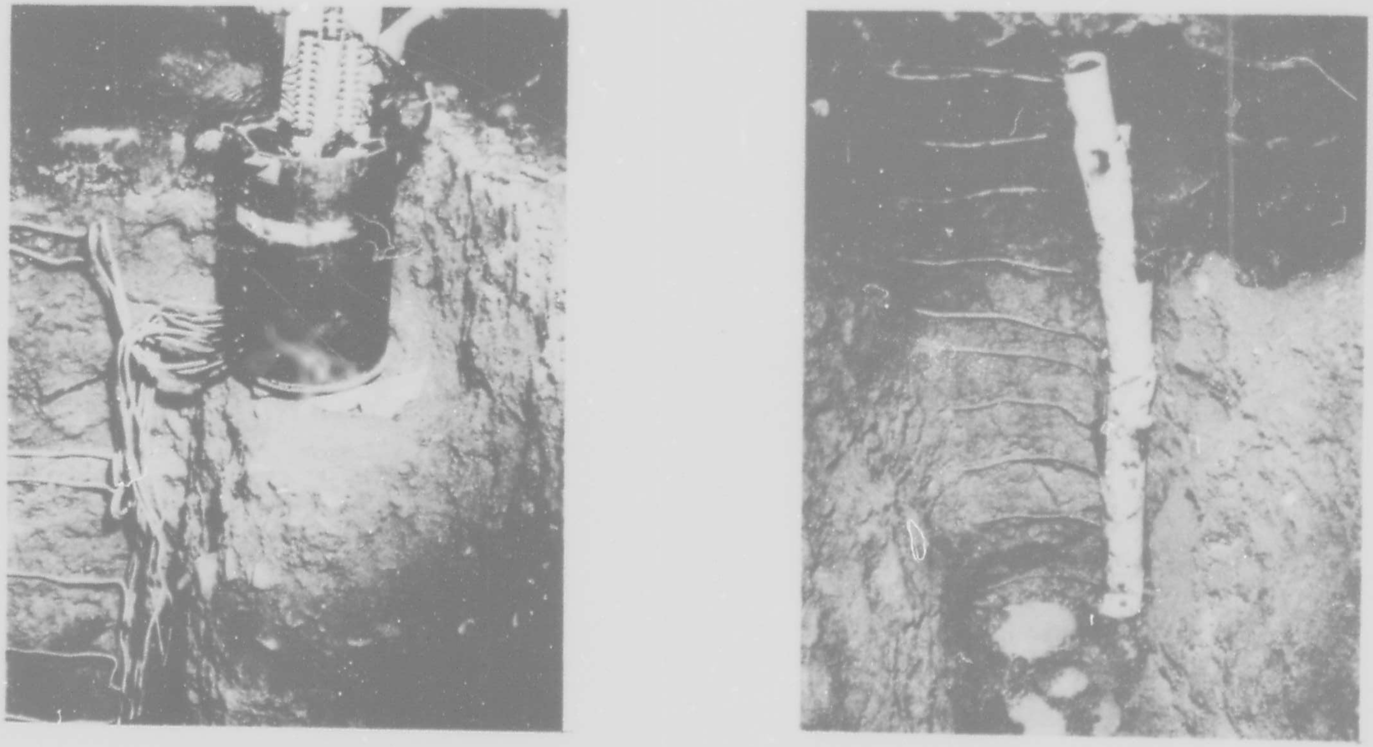
THERMOCOUPLE CONSTRUCTION
DETAIL B
Full Scale

B

FROST INVESTIGATION

THERMOCOUPLE INSTALLATION
AND SWITCH BOX DETAILS

SCALE AS SHOWN
FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE, 1945

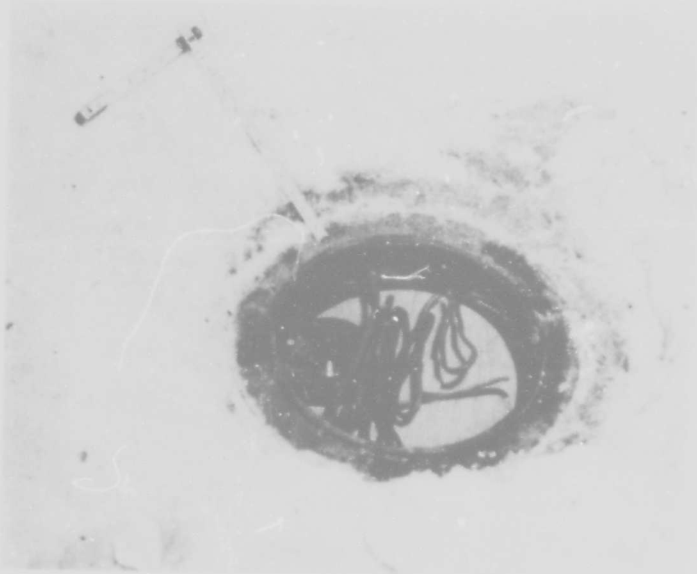


THERMOCOUPLE EQUIPMENT DURING INSTALLATION

Switch box with thermocouple cables, terminal board and wire connections.

Thermocouple equipment installed and test pit ready for backfilling.
Test Pit T239 Test Area A

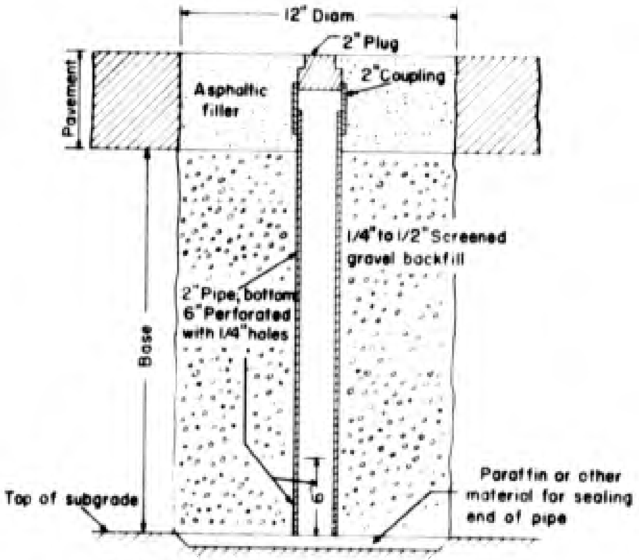
PRESQUE ISLE AIRFIELD



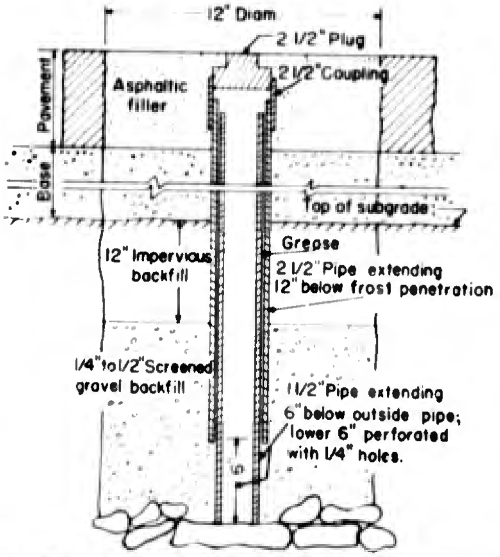
Thermocouple switch box installed. Steel cover removed to set rotary switch to obtain readings. Lead cable is to be connected to temperature indicator. Note plywood insulation cover.

Obtaining subsurface temperatures. Temperature indicator located in car.

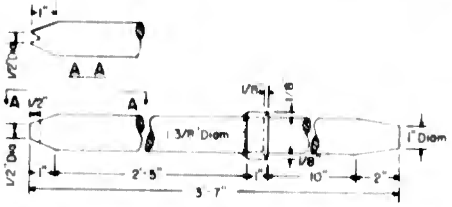
THERMOCOUPLE EQUIPMENT AFTER INSTALLATION



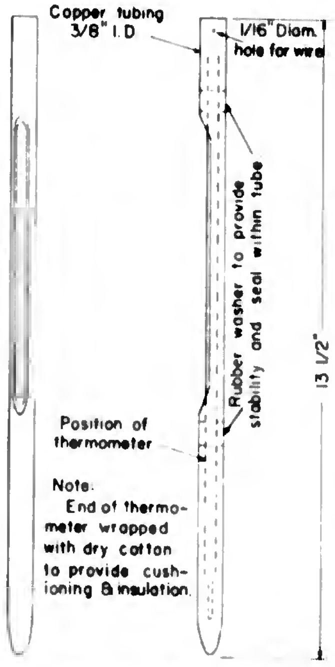
BASE OBSERVATION WELL



SUBGRADE OBSERVATION WELL AND BENCH MARK

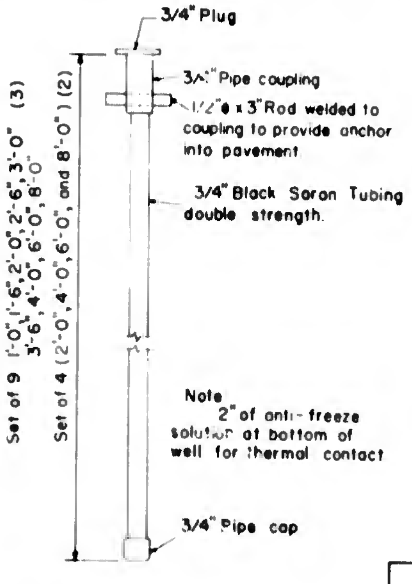


BENCH MARK EXTENSION ROD

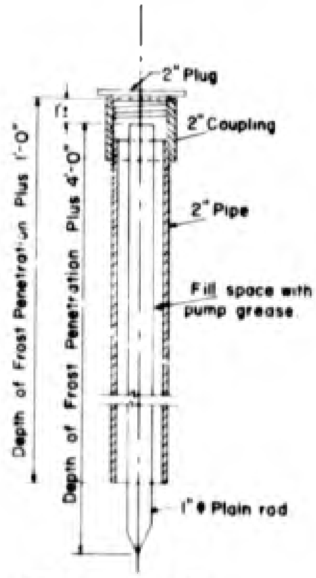


FRONT VIEW SIDE VIEW

THERMOMETER HOLDER



THERMOMETER WELL



BENCH MARK

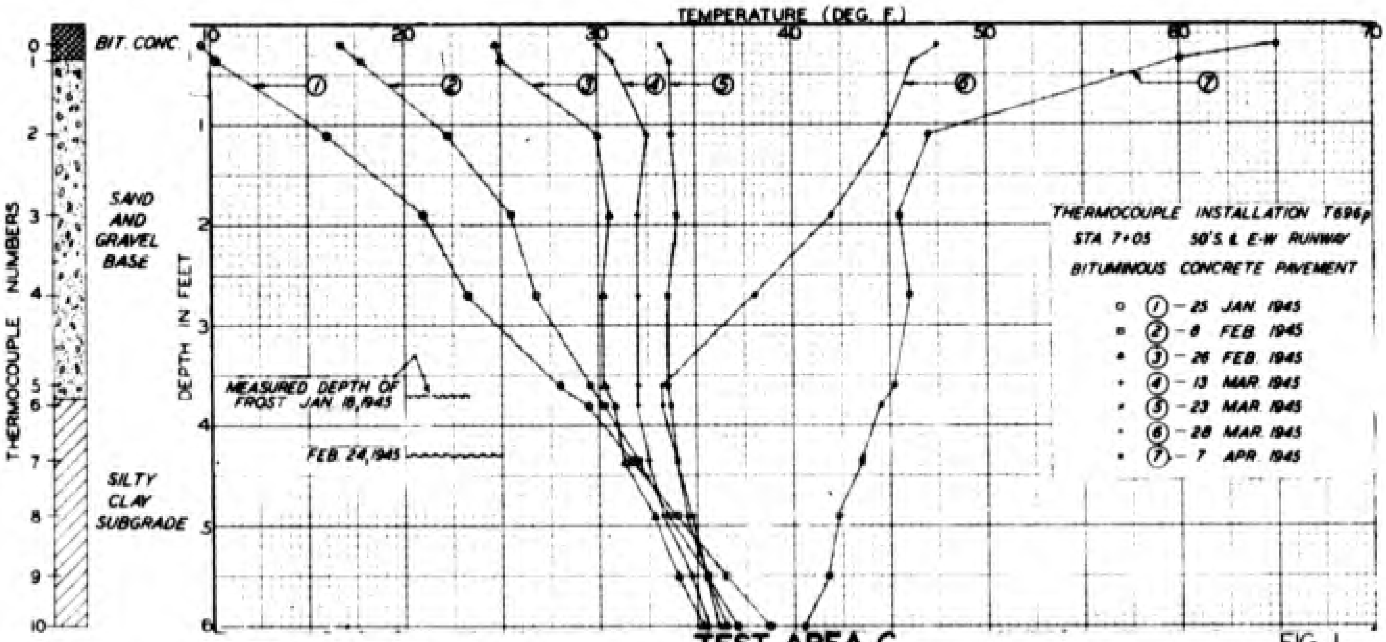
(USED BY MISSOURI RIVER DIVISION)

FROST INVESTIGATION
1944-1945

WELLS AND BENCH MARK INSTALLATIONS

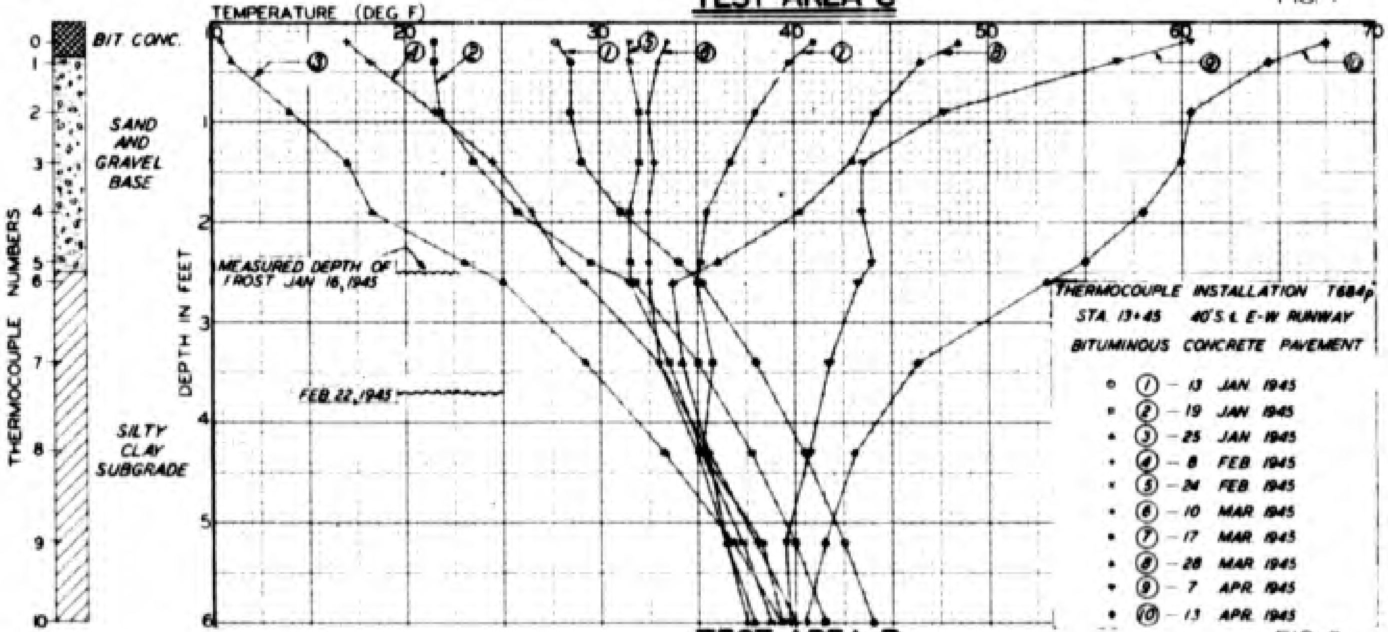
FROST EFFECTS LABORATORY BOSTON, MASS JUNE, 1945

PLATE 14



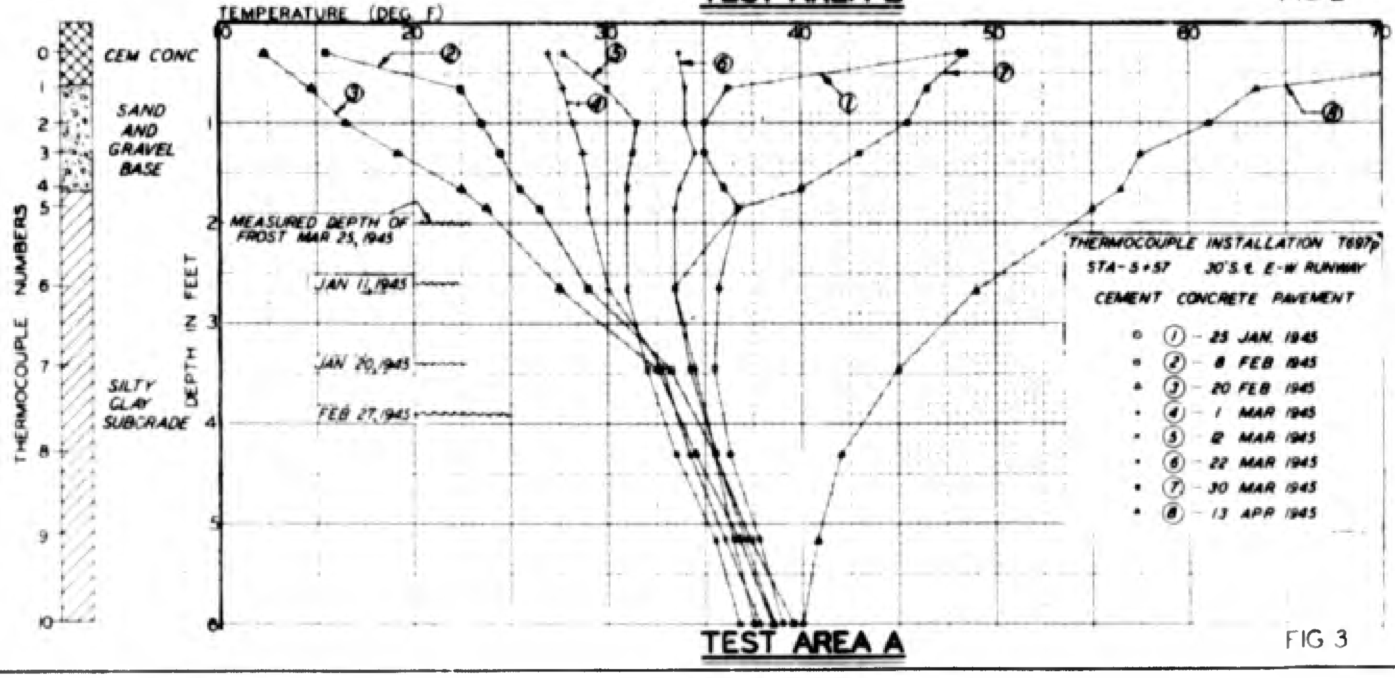
TEST AREA C

FIG. 1



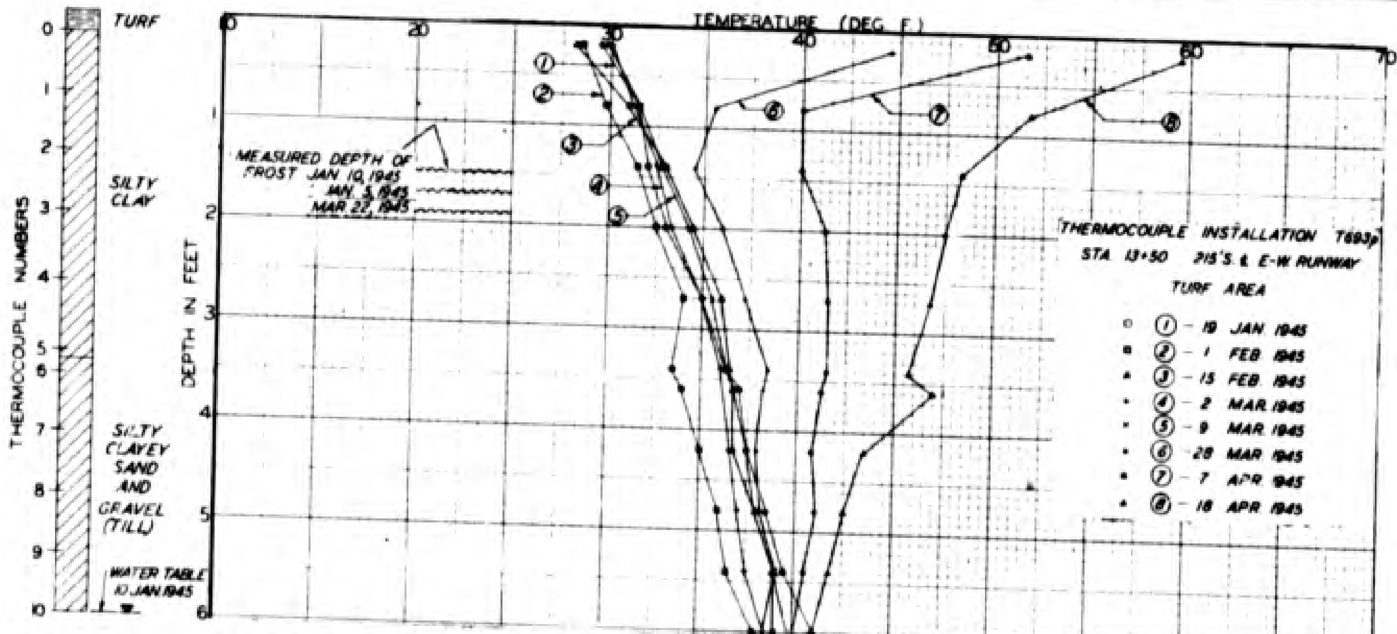
TEST AREA B

FIG. 2



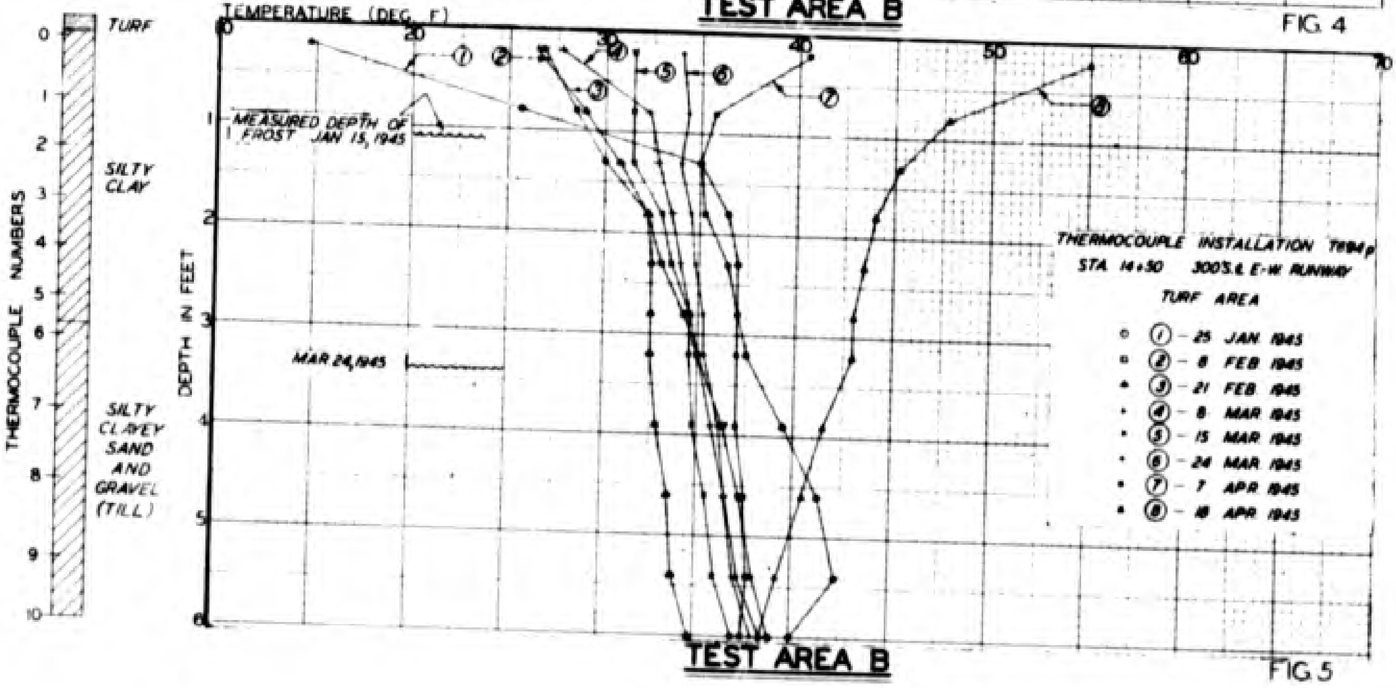
TEST AREA A

FIG. 3



TEST AREA B

FIG. 4



TEST AREA B

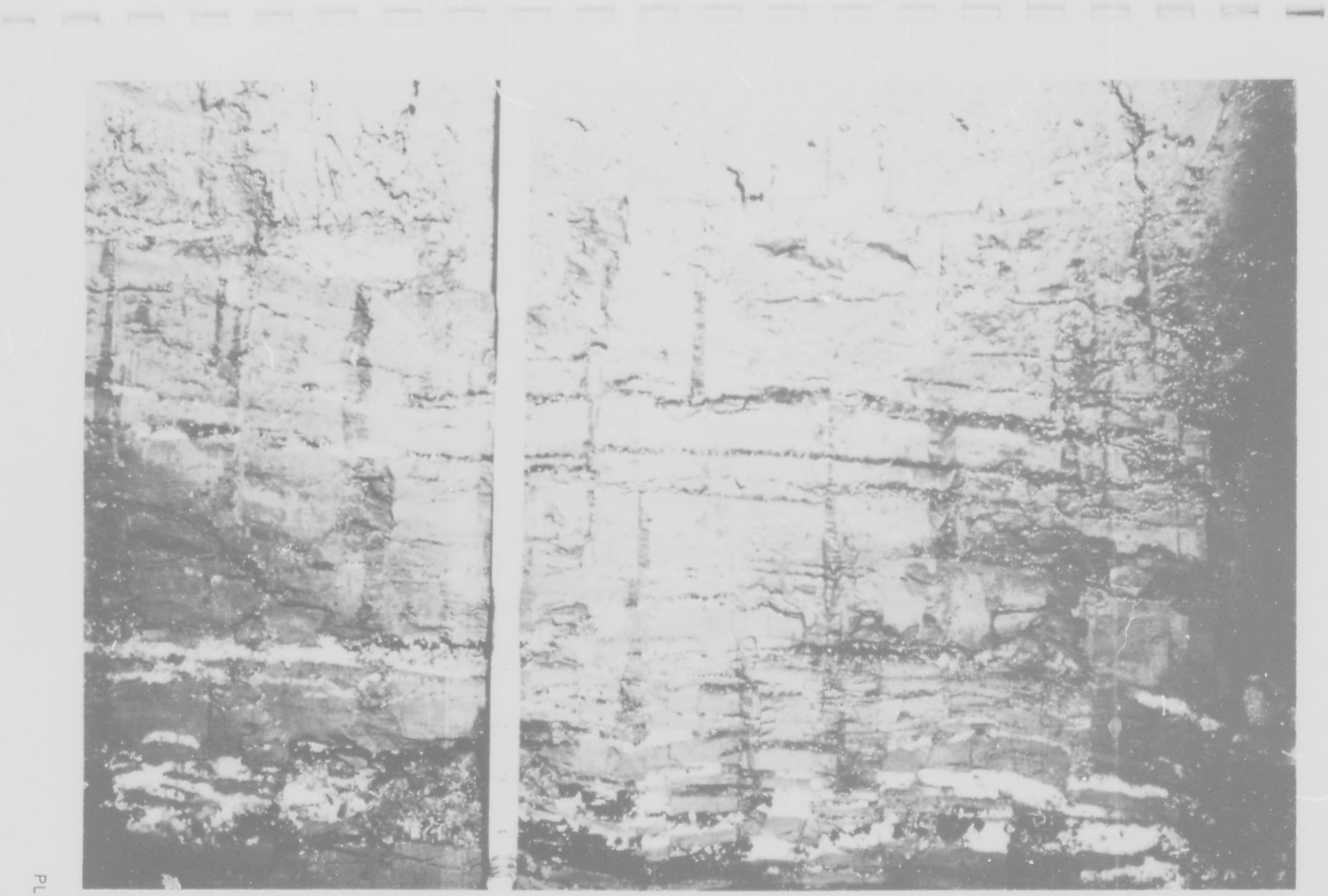
FIG. 5

B

FROST INVESTIGATION
DOW FIELD, BANGOR, MAINE

TYPICAL SUBSURFACE TEMPERATURES

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE, 1945



DOW FIELD, BANGOR, MAINE

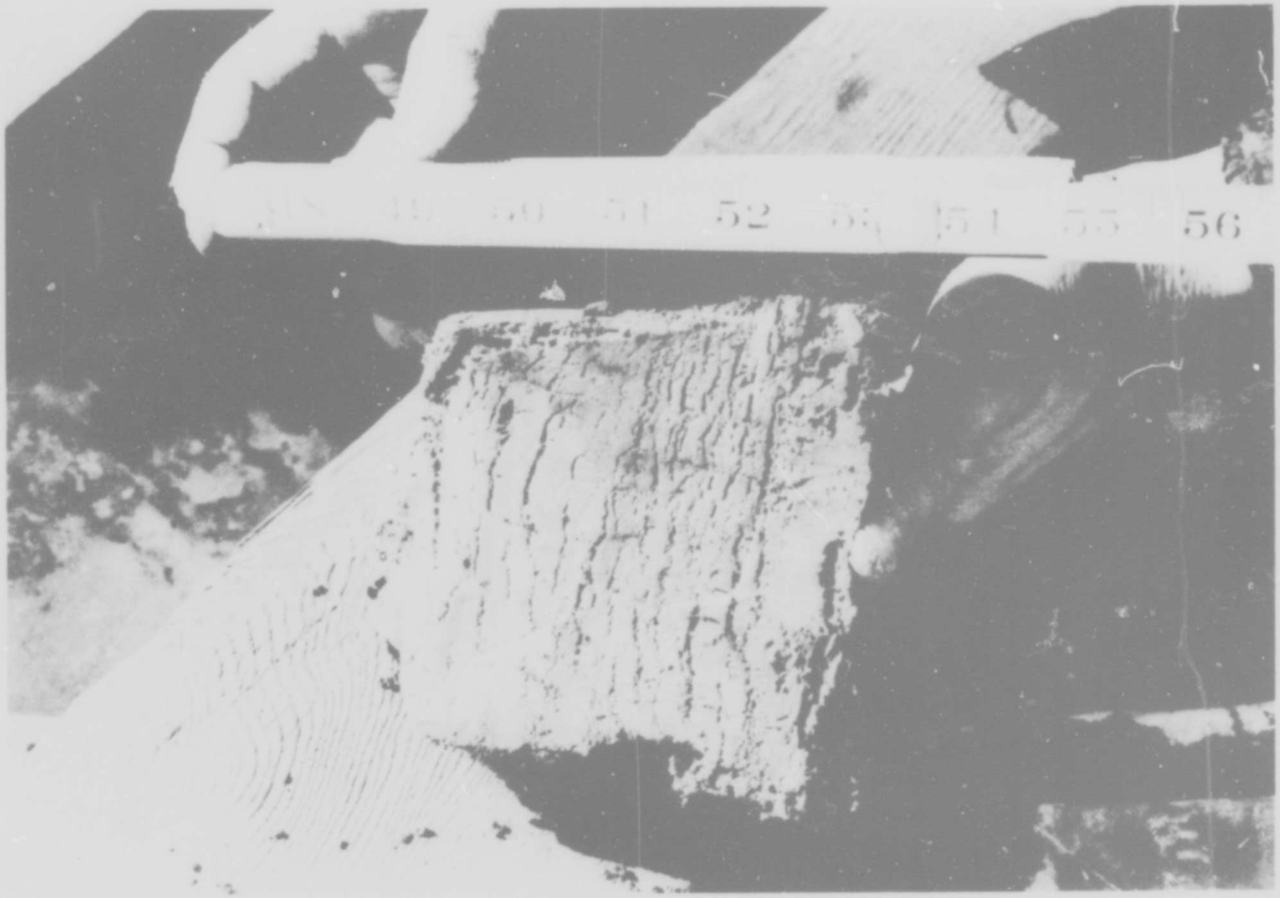
Example of Ice Lens Formation in a silty clay sub-grade

PLATE 16

DOW FIELD, BANGOR, MAINE

Close-up of sub-grade samples with ice lenses Test Pit T701p, Turf Area, Frost Penetration 2.0'; Freezing Index 1440, 22 March 1945. Note thickness of ice lenses and void in ice lenses.

PLATE 17

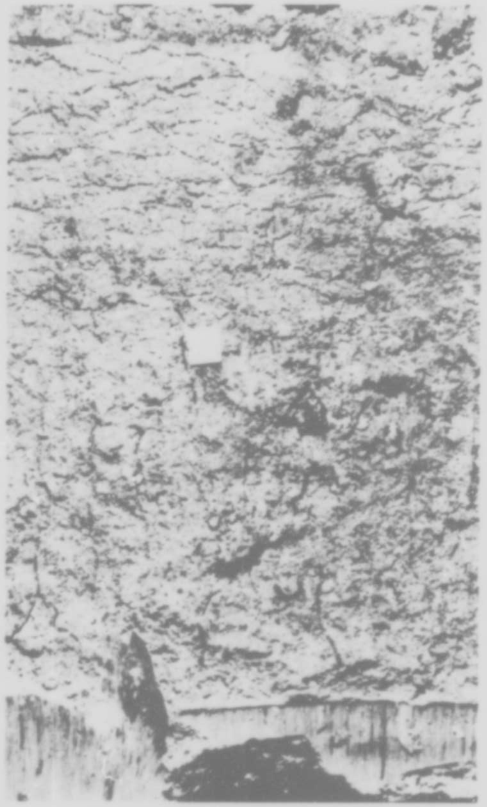


TRUAX FIELD, MADISON, WISCONSIN, TEST AREA C
Ice Lens formation, in frozen clay sub-grade sample, depth 49" - 53" (bottom of frost at 52½"),
Station 3-78. 34 ft. north of south edge, C-TP6   24 February 1945

FARGO AIRFIELD, FARGO, NORTH DAKOTA

Test Area A, Test Pit 2B, 2.3 feet below surface showing ice lenses and crystals

Test Area A, Test Pit 2B, 1.9 feet below surface. Ice lenses have been melted to show formation

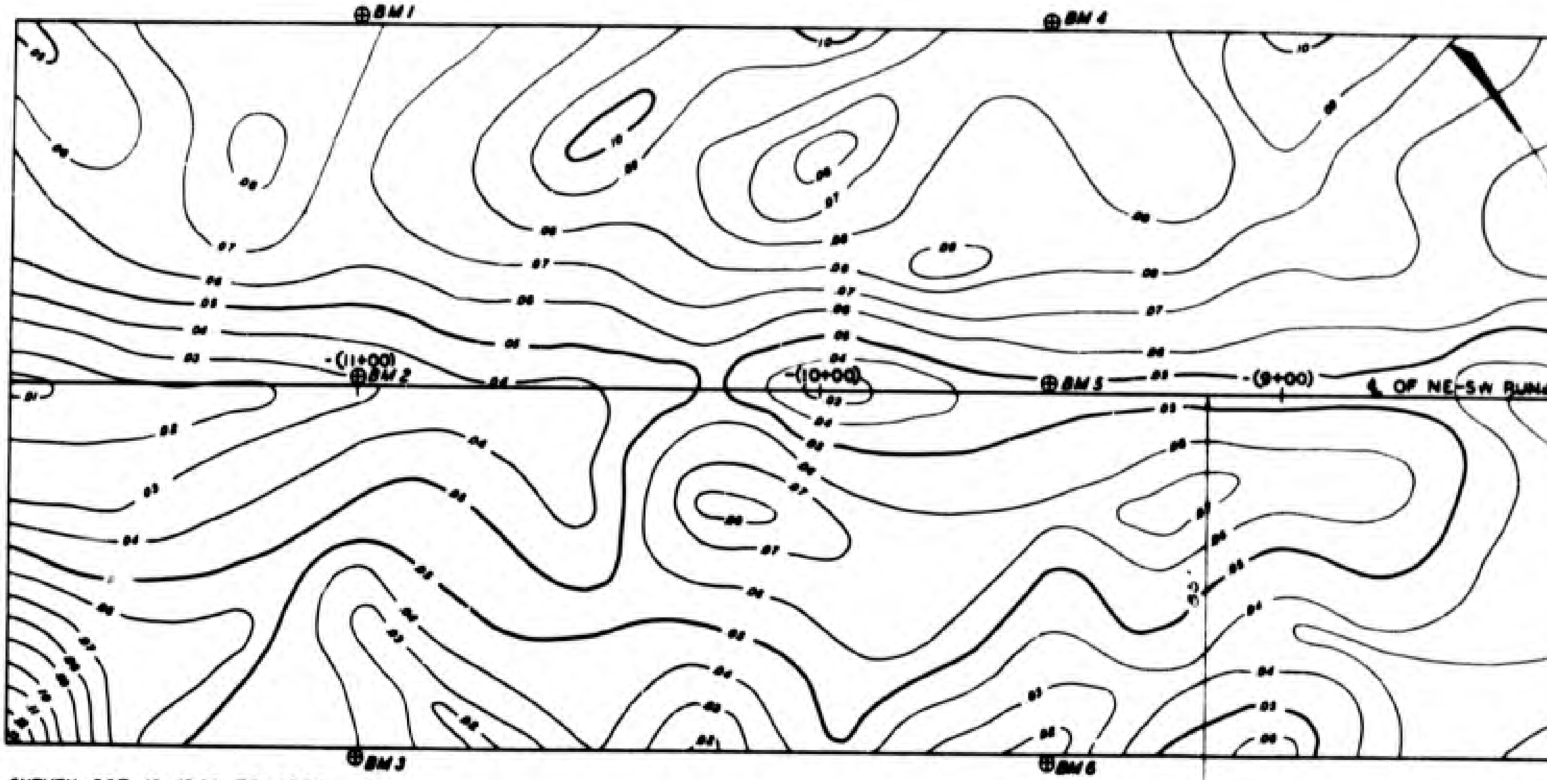


PIERRE AIRFIELD, PIERRE, SOUTH DAKOTA

Test Area B, Test Pit 2C, 1.9 to 2.2 feet below surface, showing ice lenses

Test Area B, Test Pit 2C, 1.9 to 2.2 feet below surface, ice lenses have been melted

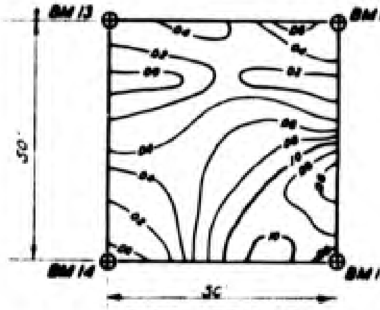
WAR DEPARTMENT



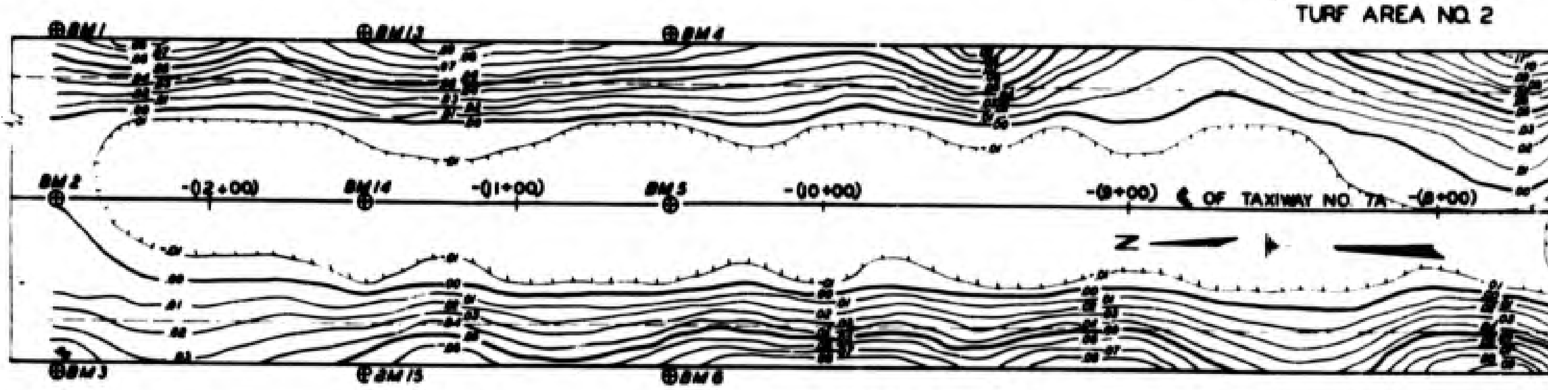
SURVEY OCT. 10, 1944 TO APRIL 2, 1945
FOR TEST AREAS A, B AND TURFS

TEST AREA A

20 0 20 40 60 80
SCALE IN FEET



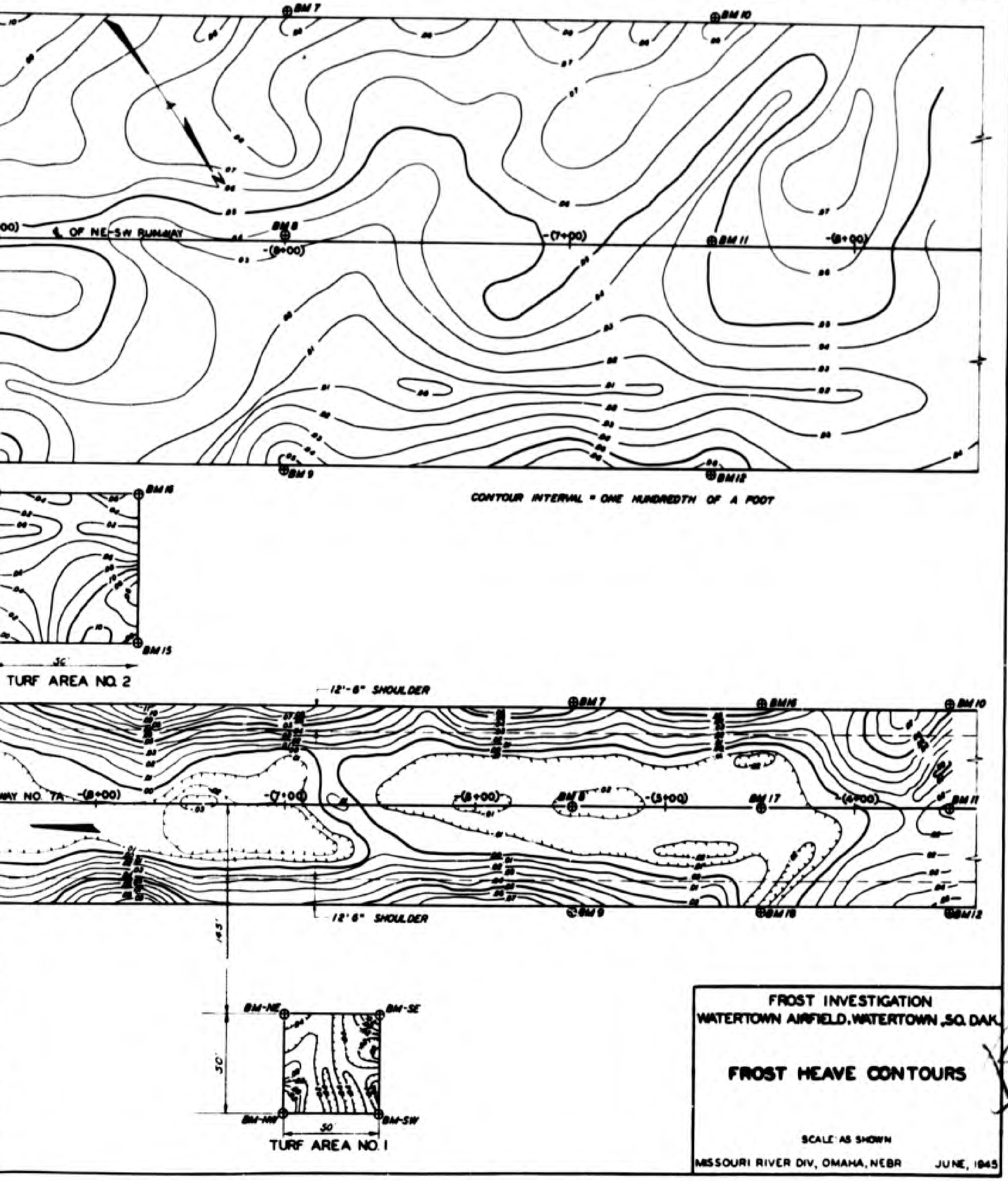
TURF AREA NO. 2



TEST AREA B

30 0 30 60 90 120
SCALE IN FEET

CORPS OF ENGINEERS, U. S. ARMY



FROST INVESTIGATION
WATERTOWN AIRFIELD, WATERTOWN, SO. DAK.

FROST HEAVE CONTOURS

SCALE AS SHOWN

MISSOURI RIVER DIV, OMAHA, NEBR JUNE, 1945

PLATE 21

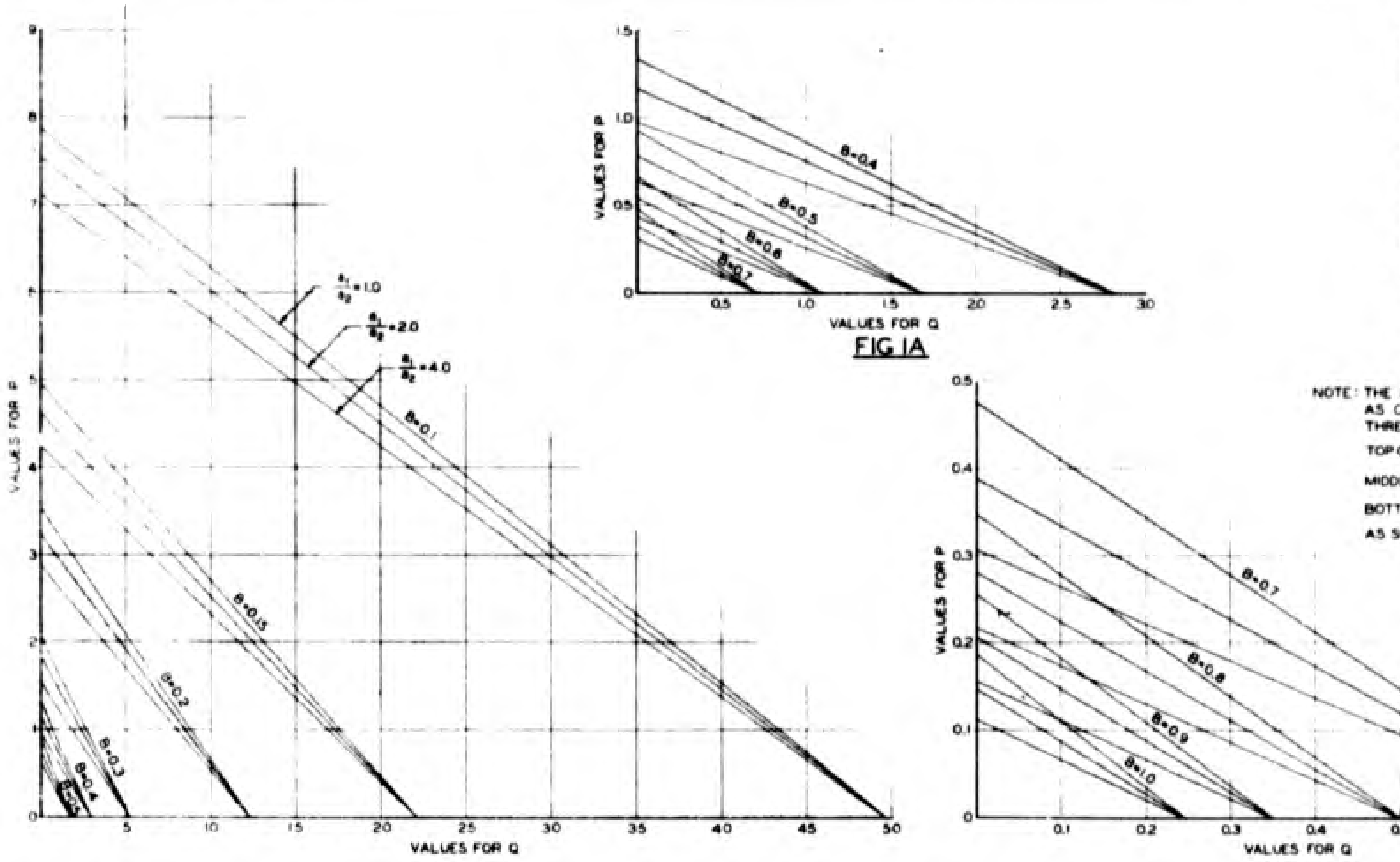


FIG I

FIG IA

NOTE: THE
AS C
THRE
TOP
MIDD
BOTT
AS S

FIG IB

B FOR VARIOUS VALUES OF Q, P AND $\frac{a_1}{a_2}$

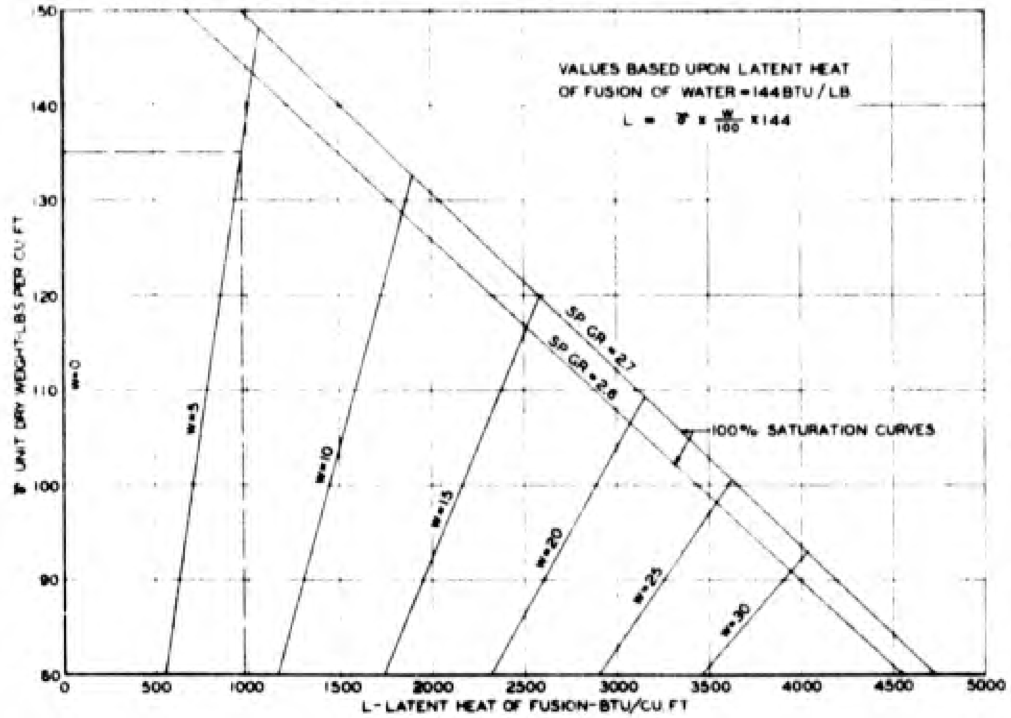


FIG.3

LATENT HEAT OF FUSION VS UNIT DRY WEIGHT

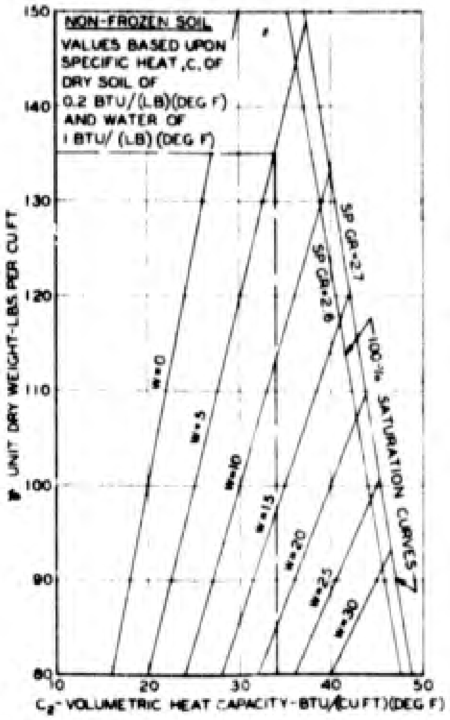


FIG.4

HEAT CAPACITY VS UNIT

30

NOTE: THE B VALUES ARE PRESENTED AS CURVES IN GROUPS OF THREE, WHERE

TOP CURVE IS FOR $\frac{a_1}{a_2} = 1.0$

MIDDLE CURVE IS FOR $\frac{a_1}{a_2} = 2.0$

BOTTOM CURVE IS FOR $\frac{a_1}{a_2} = 4.0$

AS SHOWN IN FIGURE 1

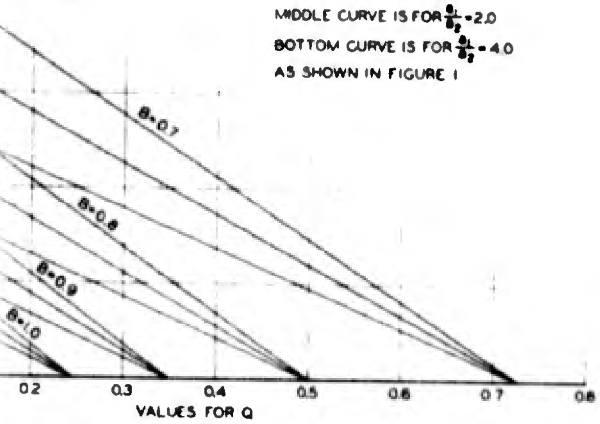


FIG 1B

L
2

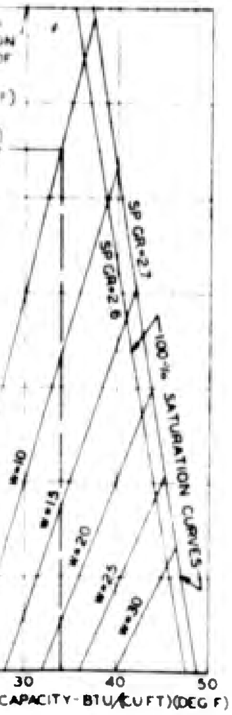


FIG 4

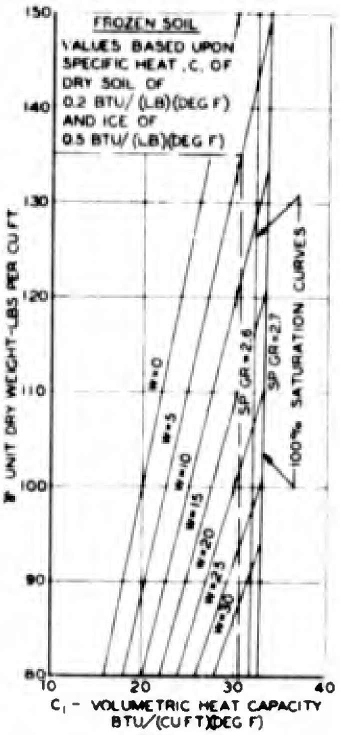
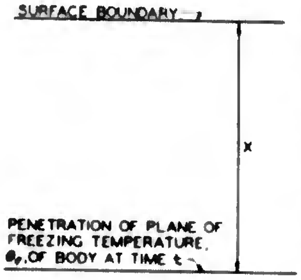


FIG. 4A

CAPACITY VS UNIT DRY WEIGHT



TEMPERATURE AT SURFACE BOUNDARY EQUAL $\theta_0 > 32°F$ UNTIL TIME t_0 WHEN SURFACE TEMPERATURE $\theta_s < 32°F$ SUDDENLY APPLIED

ISOTROPIC, HOMOGENEOUS BODY OF INFINITE EXTENT WITH SURFACE BOUNDARY PLANE AT TEMPERATURE θ_0 AT TIME t_0 AND OF FOLLOWING PROPERTIES:

γ = UNIT DRY WEIGHT, LBS/CU.FT.
w = WATER CONTENT PERCENT DRY WEIGHT
C_1 = VOLUMETRIC HEAT CAPACITY (FROZEN) = $\gamma(c + \frac{0.5w}{100})$ = BTU/(CU FT)(DEG F)
C_2 = VOLUMETRIC HEAT CAPACITY (NON-FROZEN) = $\gamma(c + \frac{w}{100})$ = BTU/(CU FT)(DEG F)
WHERE c IS THE SPECIFIC HEAT OF DRY SOIL (ASSUMED TO BE 0.2 BTU/(LB)(DEG F))
k_1 = THERMAL CONDUCTIVITY (FROZEN) BTU/(FT)(HR)(DEG F)
k_2 = THERMAL CONDUCTIVITY (NON-FROZEN) BTU/(FT)(HR)(DEG F)
L = LATENT HEAT OF FUSION BTU/CU FT
a = DIFFUSIVITY FT²/HR WHERE

$$a_1 = \frac{k_1}{C_1} \quad \text{AND} \quad a_2 = \frac{k_2}{C_2}$$

IT IS ASSUMED THAT THE WATER CONTENT OF THE BODY AT EVERY POINT IS CONSTANT DURING THE TEMPERATURE CHANGES

FIG. 2 - CONDITIONS

$X = 2B\sqrt{a_1 t}$ * WHERE
X = PENETRATION IN FEET OF PLANE OF EQUAL TEMPERATURE BELOW SURFACE BOUNDARY
t = THE TIME IN HOURS THAT TEMPERATURE θ_s HAS BEEN APPLIED TO THE SURFACE
B = A CONSTANT FOR A PARTICULAR SET OF CONDITIONS AND IS DEFINED BY THE EQUATION

$$\frac{e^{-B^2}}{G(B)} - \left\{\sqrt{\frac{k_2 C_2}{k_1 C_1}}\left(\frac{\theta_0-\theta_f}{\theta_f-\theta_s}\right)\right\}\frac{e^{-B^2\frac{a_1}{a_2}}}{1-G\left(B\sqrt{\frac{a_1}{a_2}}\right)} = \left\{\frac{L}{C_1(\theta_f-\theta_s)}\right\}B\sqrt{\pi}$$

IN WHICH
e = BASE OF NATURAL LOGARITHMS
G = PROBABILITY INTEGRAL, KNOWN AS GAUSS "ERROR-FUNCTION"

$$\sqrt{\frac{k_2 C_2}{k_1 C_1}}\left(\frac{\theta_0-\theta_f}{\theta_f-\theta_s}\right) = P$$

AND

$$\frac{L}{C_1(\theta_f-\theta_s)} = Q$$

VALUES FOR B FOR VARIOUS VALUES OF P AND Q HAVE BEEN COMPUTED AND ARE PLOTTED IN FIGURES 1, 1A AND 1B

FIGURES 3, 4 AND 4A GIVE VALUES FOR THE LATENT HEAT OF FUSION AND THE VOLUMETRIC HEAT CAPACITY OF SOILS FOR VARIOUS UNIT DRY WEIGHTS AND WATER CONTENTS

FIG. 2A - EQUATION

EQUATION FOR PENETRATION "X" OF PLANE OF EQUAL TEMPERATURE

IT IS ASSUMED THAT THE SOIL UNDER CONSIDERATION IS ISOTROPIC AND HOMOGENEOUS AND HAS THE FOLLOWING PROPERTIES AT THE CONDITIONS NOTED

γ = 135 LBS/CU FT
w = 5 PERCENT
θ_0 = 40 DEGREES F
θ_f = 32 DEGREES F
k_1 = 2.3 BTU/(FT)(HR)(DEG F)
k_2 = 1.3 BTU/(FT)(HR)(DEG F)

FROM FIGURES 4 AND 4A VALUES ARE OBTAINED FOR
C_1 = 30.5 BTU/(CU FT)(DEG F) AND
C_2 = 34 BTU/(CU FT)(DEG F)

THUS $\frac{a_1}{a_2} = \frac{k_1 C_2}{k_2 C_1} = \frac{(2.3)(34)}{(1.3)(30.5)} = 1.97$

L IS OBTAINED FROM FIGURE 3: L = 970 BTU/CU FT

IT IS THEN FURTHER ASSUMED THAT THE SURFACE TEMPERATURE θ_0 IS SUDDENLY REDUCED TO θ_s, 19 DEGREES FAHRENHEIT, AND MAINTAINED FOR 100 DAYS THUS

θ_s = 19 DEGREES F
t = 100 DAYS × 24 HRS/DAY = 2400 HRS

$$Q = \frac{L}{C_1(\theta_f-\theta_s)} = \frac{970}{(30.5)(32-19)} = 2.44$$

$$P = \sqrt{\frac{k_2 C_2}{k_1 C_1}}\left(\frac{\theta_0-\theta_f}{\theta_f-\theta_s}\right) = \sqrt{\frac{(1.3)(34)}{(2.3)(30.5)}}\left(\frac{40-32}{32-19}\right)$$

$$= \sqrt{0.63}\left(\frac{8}{13}\right) = 0.488$$

WITH P = 0.488 AND Q = 2.44 B IS OBTAINED BY INTERPOLATION IN FIGURE 1 USING THE MIDDLE CURVES OF THE GROUPS OF THREE SINCE $\frac{a_1}{a_2}$ EQUALS APPROXIMATELY 2.0
B = 0.37

FROM EQUATION $a_1 = \frac{k_1}{C_1}$, $a_1 = \frac{2.3}{30.5} = 0.0754$

SUBSTITUTING IN EQUATION
$X = 2B\sqrt{a_1 t}$
$X = 2(0.37)\sqrt{(0.0754)(2400)} = (0.74)(13.46)$
X = 9.96 FT.

EXAMPLE FOR USE OF EQUATION

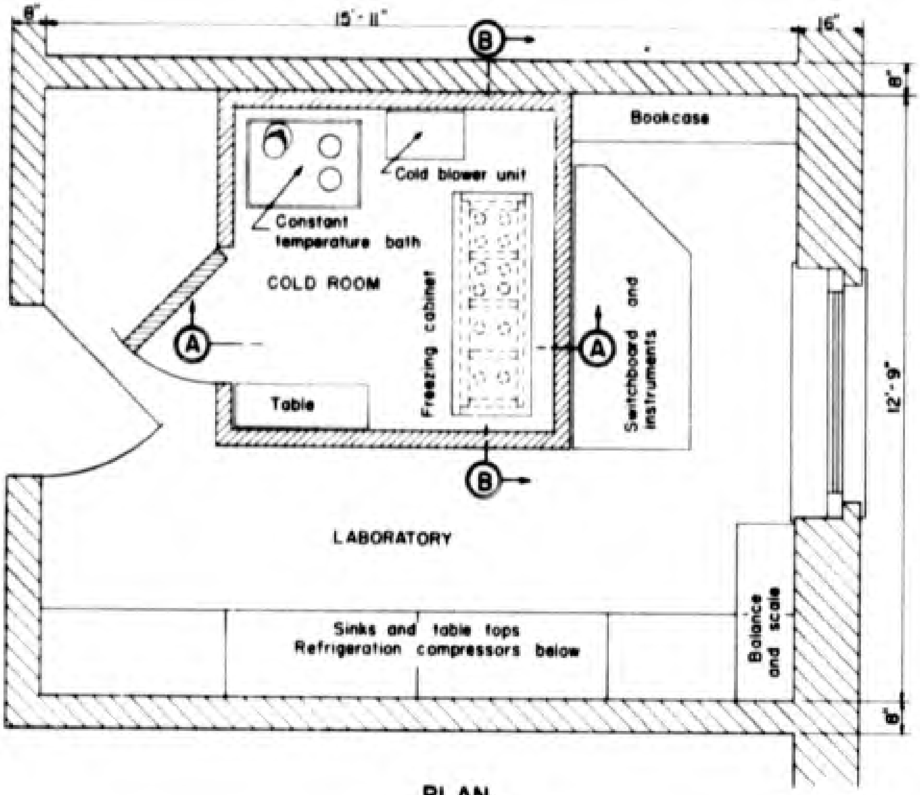
B

** REFERENCE*
BERGGREN, W. P. "PREDICTION OF TEMPERATURE DISTRIBUTION IN FROZEN SOILS" TRANSACTIONS AMERICAN GEOPHYSICAL UNION, 1943

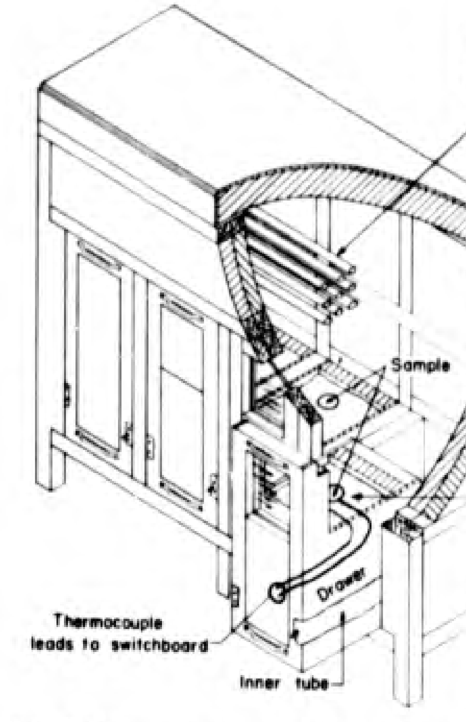
FROST INVESTIGATION

PREDICTION OF FROST PENETRATION

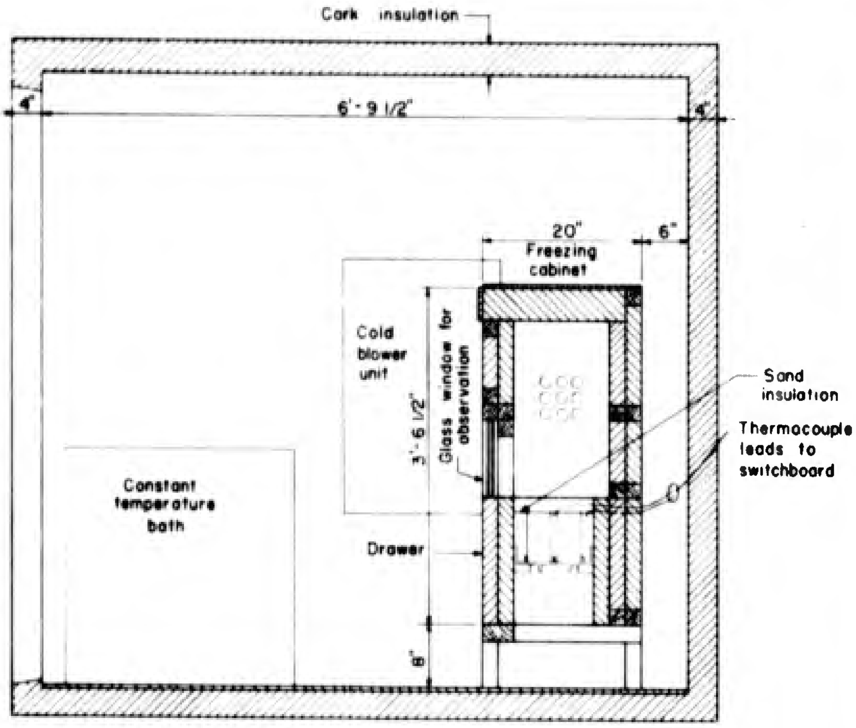
FROST EFFECTS LABORATORY BOSTON MASS JUNE 1945



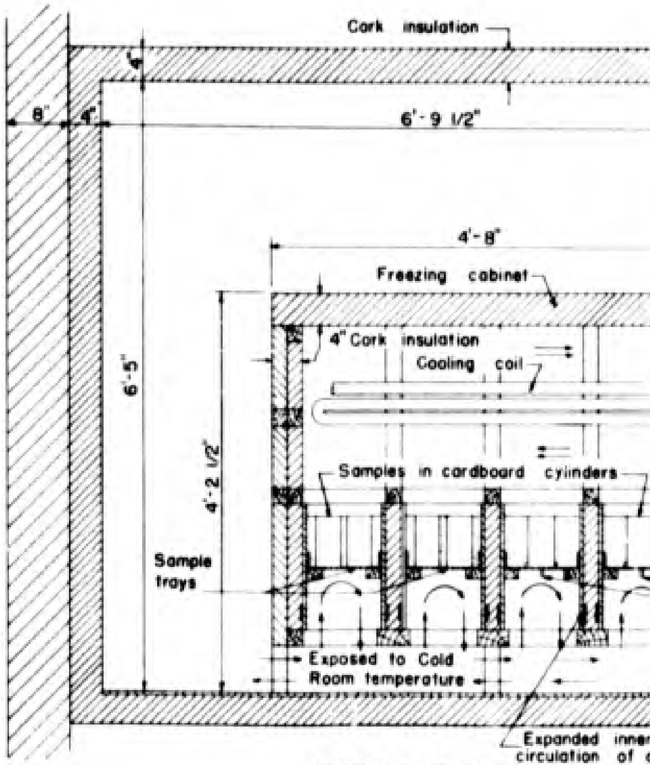
PLAN



ISOMETRIC VIEW OF FREEZING CA

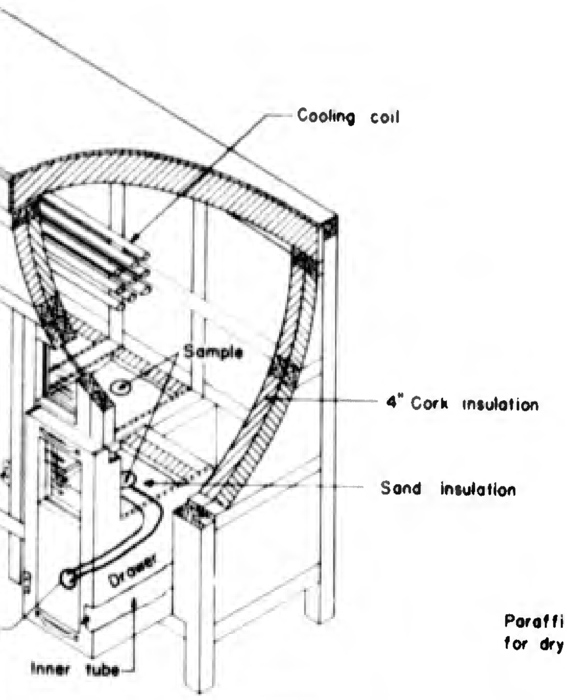


SECTION A-A

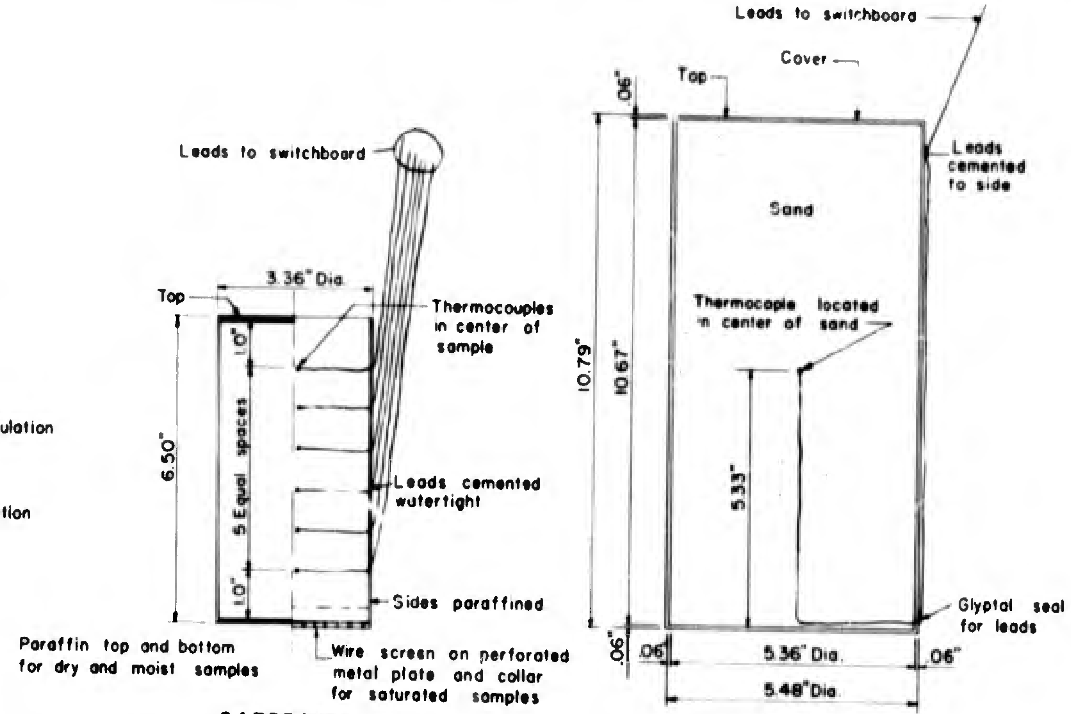


SECTION B-B

A



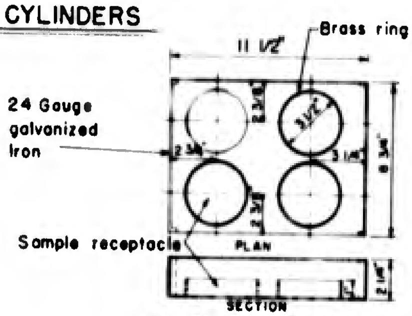
W OF FREEZING CABINET



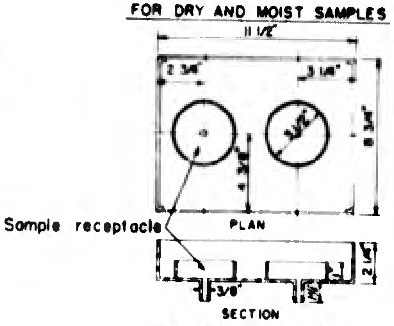
CARDBOARD
(FOR FROST PENETRATION TESTS)

BRASS
(FOR THERMAL CONDUCTIVITY TESTS)

SECTIONS OF SAMPLE CYLINDERS

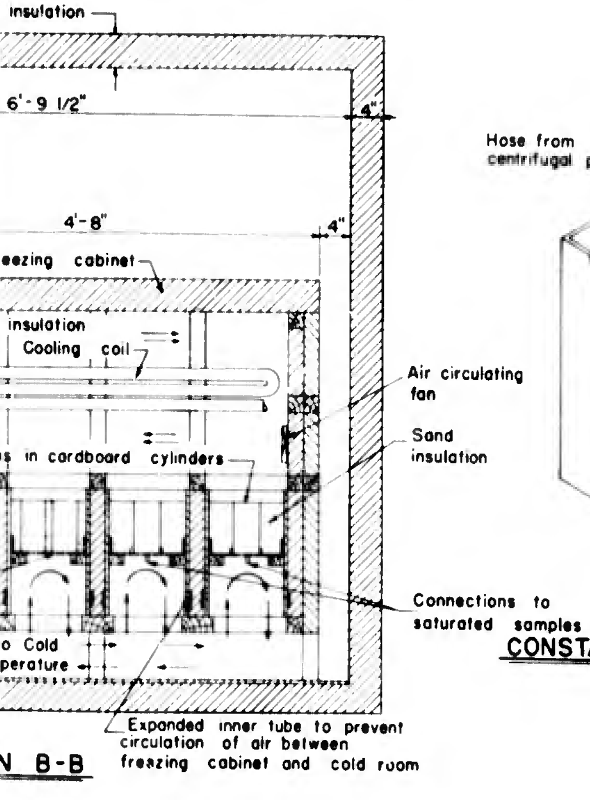


FOR DRY AND MOIST SAMPLES

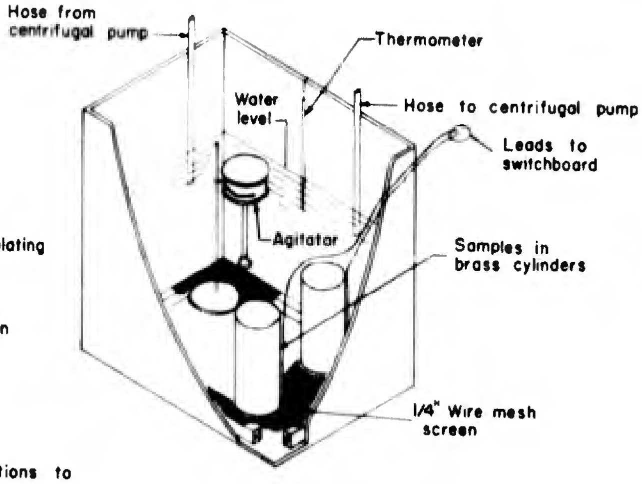


FOR SATURATED SAMPLES

DETAILS OF SAMPLE TRAYS



N B-B



CONSTANT TEMPERATURE BATH

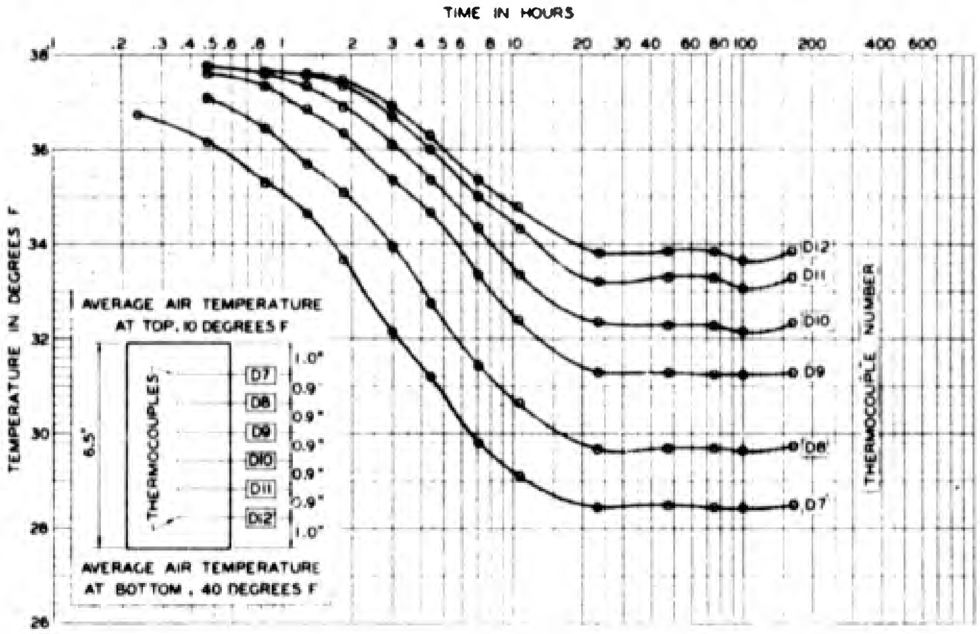
FROST INVESTIGATION

1944-1945

B

DETAILS OF COLD ROOM AND TEST APPARATUS

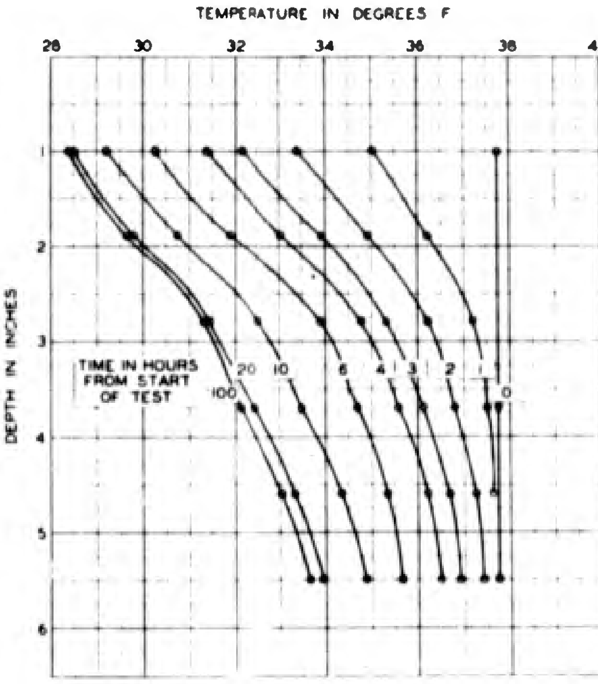
FROST EFFECTS LABORATORY BOSTON, MASS. JUNE, 1945



SAMPLE 2C-8

TYPICAL SET OF TIME TEMPERATURE CURVES

FIG. 1



SAMPLE 2C-8

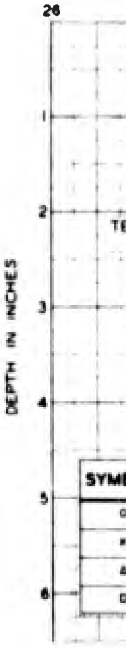
TYPICAL SET OF TEMPERATURE GRADIE

FIG. 2

SAMPLE NO.	UNIT DRY WEIGHT	WATER CONTENT	RUN A									RUN B								
			AVERAGE AIR TEMPERATURE		TIME FOR EQUILIBRIUM CONDITIONS TO BE REACHED	EXTRAPOLATED SAMPLE TEMPERATURE		EQUILIBRIUM TEMPERATURE GRADIENT IN SPECIMEN	[illegible]		AVERAGE AIR TEMPERATURE		TIME FOR EQUILIBRIUM CONDITIONS TO BE REACHED	EXTRAPOLATED SAMPLE TEMPERATURE		EQUILIBRIUM TEMPERATURE GRADIENT IN SPECIMEN	[illegible]	
			TOP OF SPECIMEN a	BOTTOM OF SPECIMEN b	HOURS	TOP c	BOTTOM d	°F/FT.	c - a	b - d	TOP OF SPECIMEN a	BOTTOM OF SPECIMEN b	HOURS	TOP c	BOTTOM d	°F/FT.	c - a	b d
1	98.3	0.2	30.0	38.3	20	32.1	35.2	5.7	2.1	3.1	20.3	38.3	30	26.3	33.3	12.9	6.0	5.0
2	99.3	0.2	30.0	38.3	25	31.5	35.4	7.2	1.5	2.9	20.3	38.3	40	25.6	33.3	14.2	5.3	5.0
3	104.7	0.2	30.0	38.3	30	30.9	35.3	8.1	0.9	3.0	20.3	38.3	50	24.0	33.5	17.5	3.7	4.8
4	106.0	0.2	30.0	38.3	30	31.6	35.2	6.7	1.6	3.1	20.3	38.3	50	25.1	33.9	16.5	4.8	4.4
5	81.8	2.8	30.0	38.3	30	32.3	35.6	6.1	2.3	2.7	20.3	38.3	60	26.1	34.7	15.9	5.8	3.6
6	86.2	2.8	30.0	38.3	30	31.0	36.3	9.8	1.0	2.0	20.3	38.3	30	24.2	34.3	18.6	3.9	4.0
7	102.6	2.8	30.0	38.3	40	31.1	35.4	7.9	1.1	2.9	20.3	38.3	50	22.5	34.2	21.6	2.2	4.1
8	103.6	2.7	30.0	38.3	30	31.5	36.8	9.8	1.5	1.5	20.3	38.3	30	24.7	35.7	16.6	4.4	4.6
9	101.0	23.8	30.0	38.3	50	31.3	35.0	6.8	1.3	3.3	20.3	38.3	100	25.5	33.5	14.8	5.2	4.8
10	101.0	23.8	30.0	38.3	100	31.1	34.8	6.8	1.1	3.5	20.3	38.3	100	25.0	32.3	13.5	4.7	6.0
11	106.0	21.0	30.0	38.3	150	30.8	33.8	5.5	0.8	4.5	20.3	38.3	70	23.1	30.1	12.9	2.8	8.2
12	106.8	20.7	30.0	38.3	50	31.1	34.4	6.1	1.1	3.9	20.3	38.3	80	23.9	30.9	12.9	3.6	7.4
			RUN C									RUN D								
1	98.3	0.2	9.7	38.3	20	19.6	31.0	21.1	9.9	7.3	25.0	37.0	20	27.9	33.3	10.0	2.9	3.7
2	99.3	0.2	9.7	38.3	20	18.7	30.8	22.3	9.0	7.5	25.0	37.0	30	27.5	33.8	11.6	2.5	3.2
3	104.7	0.2	9.7	38.3	25	16.5	31.4	27.5	6.8	6.9	25.0	37.0	30	26.8	34.3	13.8	1.8	2.7
4	106.0	0.2	9.7	38.3	25	18.1	31.2	24.2	8.4	7.1	25.0	37.0	30	27.5	34.4	12.7	2.5	2.6
5	81.9	2.8	9.7	38.3	25	18.6	32.9	26.4	8.9	5.4	25.0	37.0	30	29.4	35.8	11.5	4.4	1.2
6	86.2	2.8	9.7	38.3	25	17.0	32.4	28.4	7.3	5.9	25.0	37.0	30	26.0	34.0	14.8	1.0	3.0
7	102.6	2.8	9.7	38.3	30	15.3	32.1	31.0	5.6	6.2	25.0	37.0	30	27.4	34.5	13.1	2.4	2.5
8	103.6	2.7	9.7	38.3	30	17.7	32.3	27.0	8.0	6.0	25.0	37.0	30	27.3	34.3	12.9	2.3	2.7
9	101.0	23.8	9.7	38.3	100	14.3	26.0	21.6	4.6	12.3	25.0	37.0	100	28.8	33.4	8.5	3.8	3.6
10	101.0	23.8	9.7	38.3	100	16.1	26.7	19.6	6.4	11.6	25.0	37.0	100	28.5	33.0	8.3	3.5	4.0
11	106.0	21.0	9.7	38.3	50	18.3	26.4	15.0	8.6	11.9	25.0	37.0	100	27.1	31.8	8.7	2.1	5.2
12	106.8	20.7	9.7	38.3	50	19.3	27.2	14.6	9.6	11.1	25.0	37.0	100	26.2	31.4	9.6	1.2	5.6

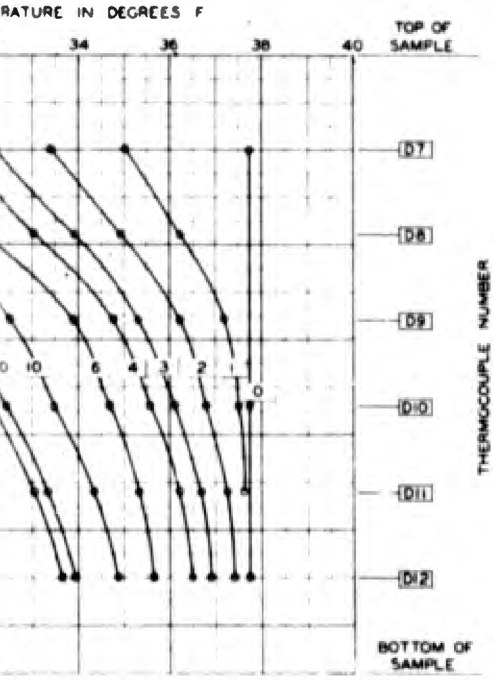
SUMMARY OF TEST CONDITIONS

TABLE A



E

CORPS OF ENGINEERS, U.S. ARMY



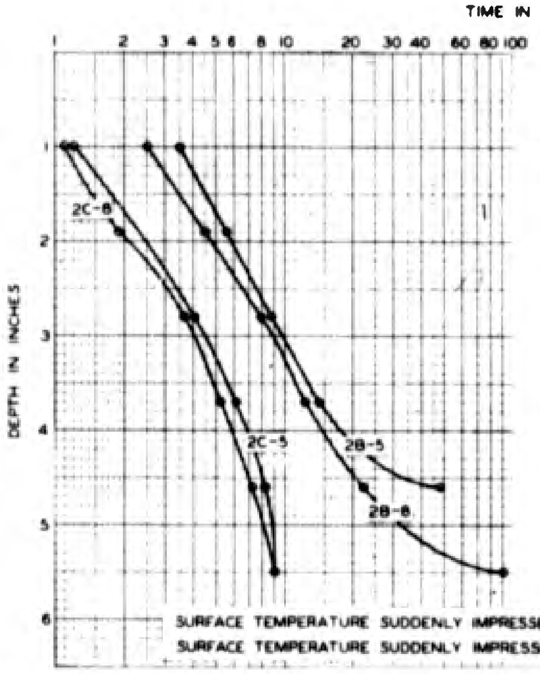
SAMPLE 2C-8

TEMPERATURE GRADIENTS

FIG. 2

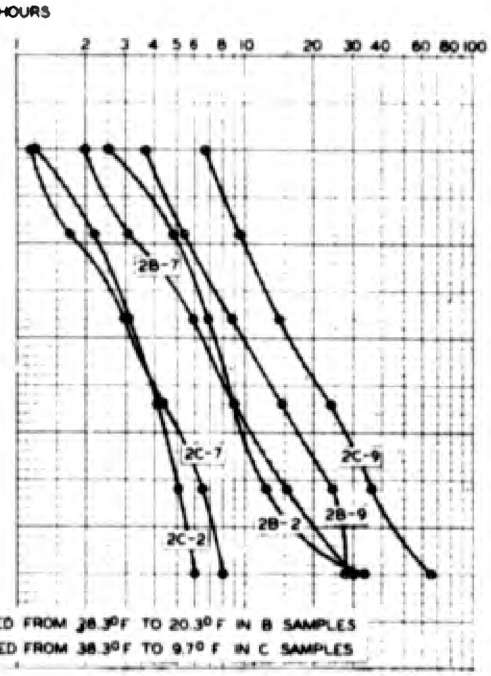
LIBRIUM ERATURE DIENT PECIMEN F/FT.	c-a	b-d
2.9	6.0	5.0
4.2	5.5	5.0
7.5	3.7	4.8
6.3	4.8	4.4
5.9	5.8	3.6
8.6	3.9	4.0
1.6	2.2	4.1
6.6	4.4	4.6
4.8	5.2	4.8
3.5	4.7	6.0
2.9	2.8	8.2
2.9	3.6	7.4
0.0	2.9	3.7
1.6	2.5	3.2
3.8	1.4	2.7
2.7	2.5	2.6
1.9	4.4	1.2
4.8	1.0	3.0
3.1	2.4	2.5
2.9	2.3	2.7
8.5	3.8	3.6
8.3	3.5	4.0
8.7	2.1	5.2
0.6	1.2	5.6

TIME IN HOURS



SAMPLE NO.	w	r
2B-5,2C-5	2.8	81.8
2B-8,2C-8	2.7	103.8

FIG. 3a



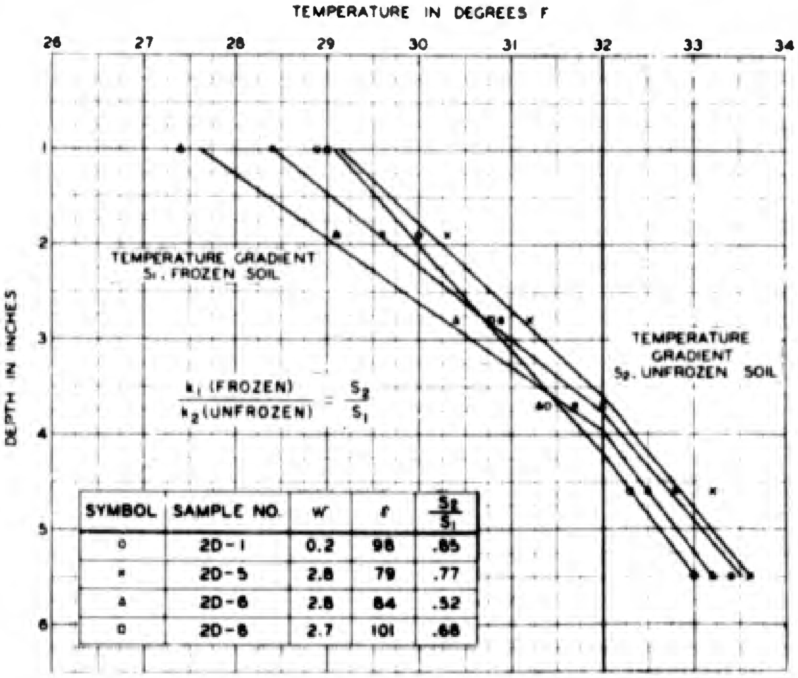
SURFACE TEMPERATURE SUDDENLY IMPRESSED FROM 38.3°F TO 20.3°F IN B SAMPLES
SURFACE TEMPERATURE SUDDENLY IMPRESSED FROM 38.3°F TO 9.7°F IN C SAMPLES

SAMPLE NO.	w	r
2B-2,2C-2	0.2	99.3
2B-7,2C-7	2.8	102.8
2B-9,2C-9	23.8	101.0

FIG. 3b

PENETRATION OF 32 DEGREES F TEMPERATURE VS TIME

FIG. 3



$$\frac{k_1\ (\text{FROZEN})}{k_2\ (\text{UNFROZEN})} = \frac{S_2}{S_1}$$

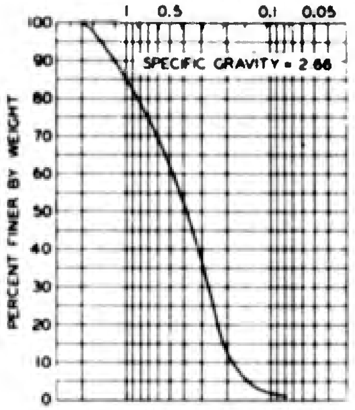
SYMBOL	SAMPLE NO.	w	r	$\frac{S_2}{S_1}$
○	2D-1	0.2	98	.85
×	2D-5	2.8	79	.77
▲	2D-6	2.8	84	.52
●	2D-8	2.7	101	.68

SAMPLES 2D-1, 2D-5, 2D-6, 2D-8

EQUILIBRIUM TEMPERATURE GRADIENTS

FIG. 4

GRAIN SIZE IN MILLIMETERS



GRAIN SIZE GRADATION CURVE

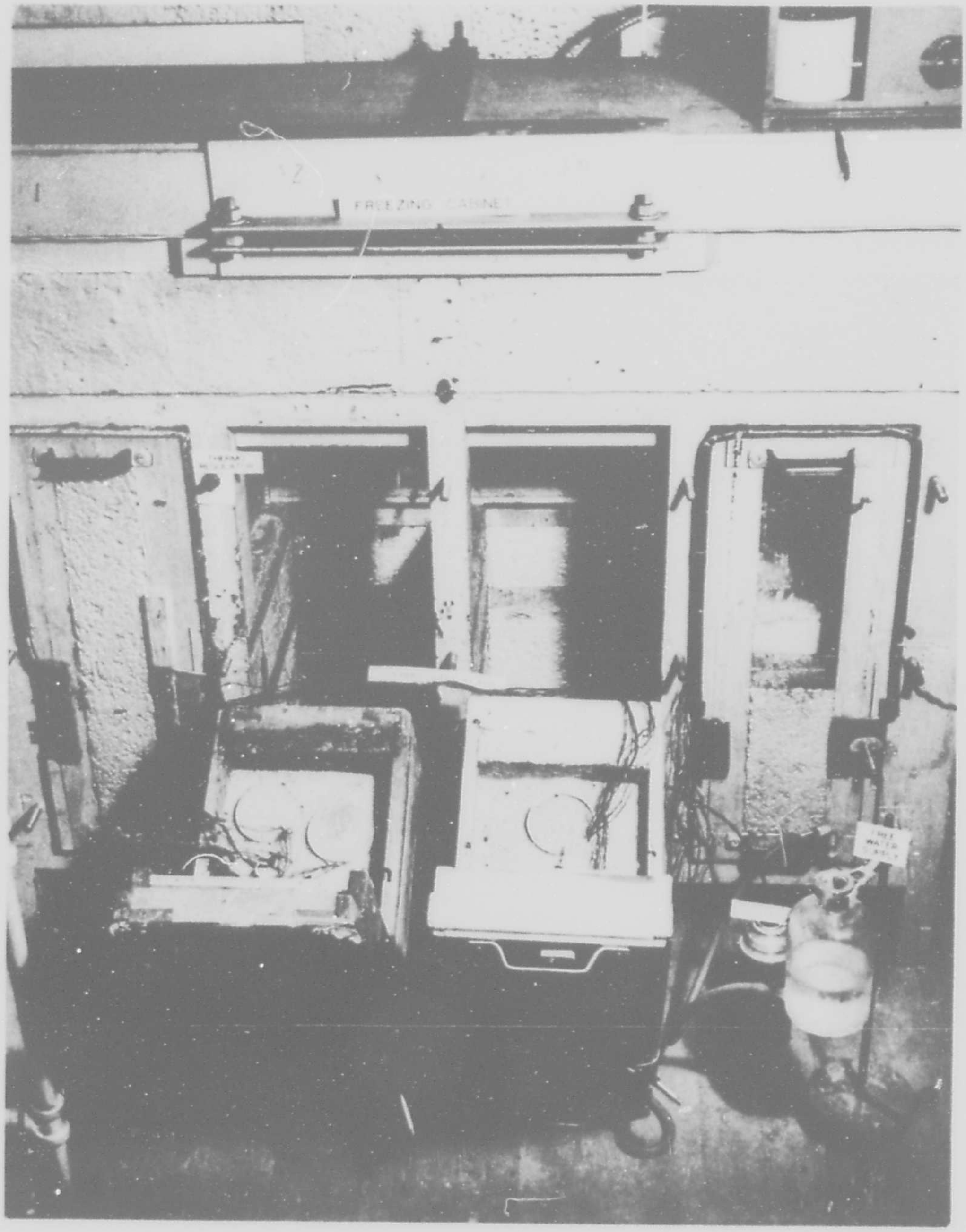
FIG. 5

FROST INVESTIGATION

SERIES 2 TESTS
INVESTIGATION OF TEMPERATURE CONDITIONS IN LABORATORY SPECIMENS

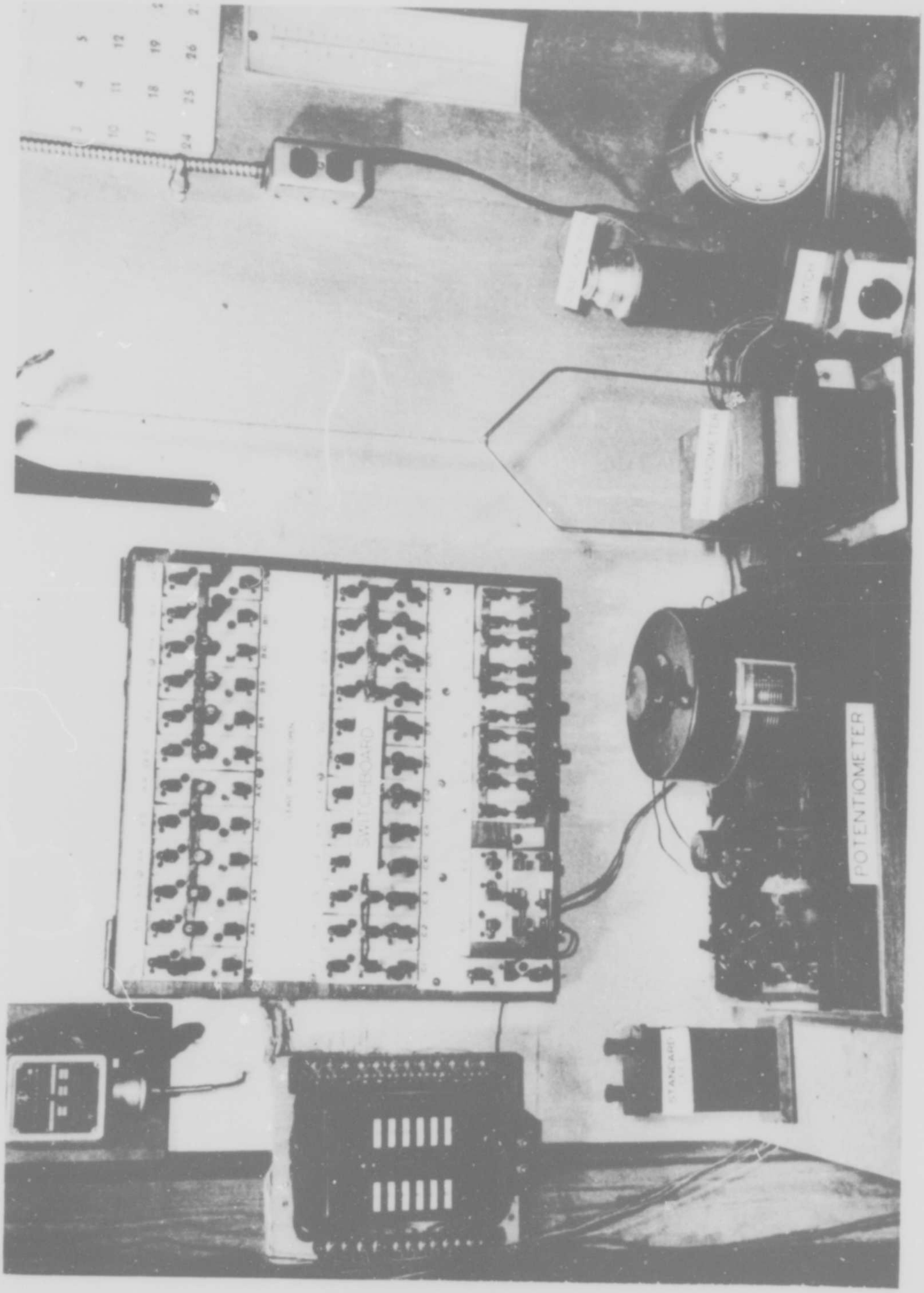
FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE, 1945

REVISED FEBRUARY, 1947



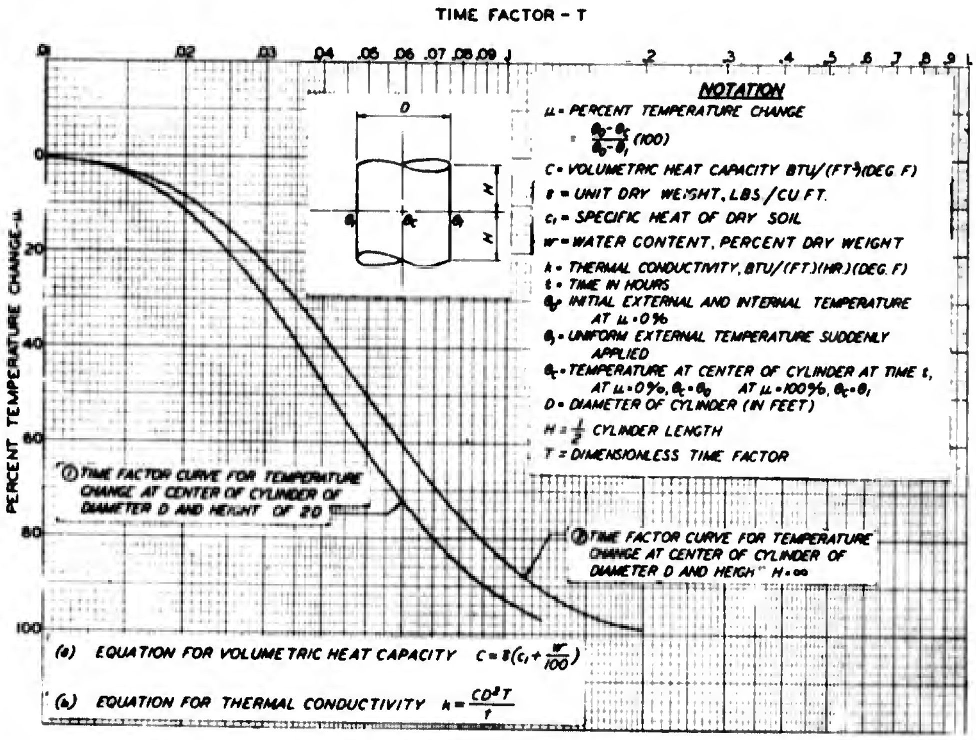
View of freezing cabinet

PLATE 25



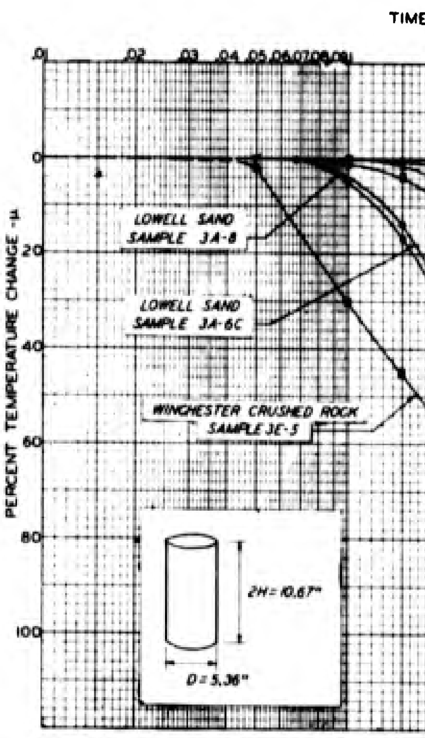
Temperature indicating apparatus

PLATE 26



TIME FACTOR CURVES FOR TEMPERATURE CHANGE AT CENTER OF A CYLINDER

FIG.1

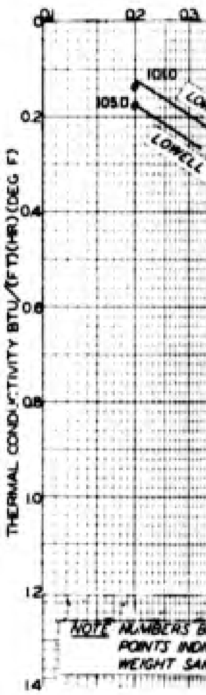


TYPICAL
THERMAL CONDUCT

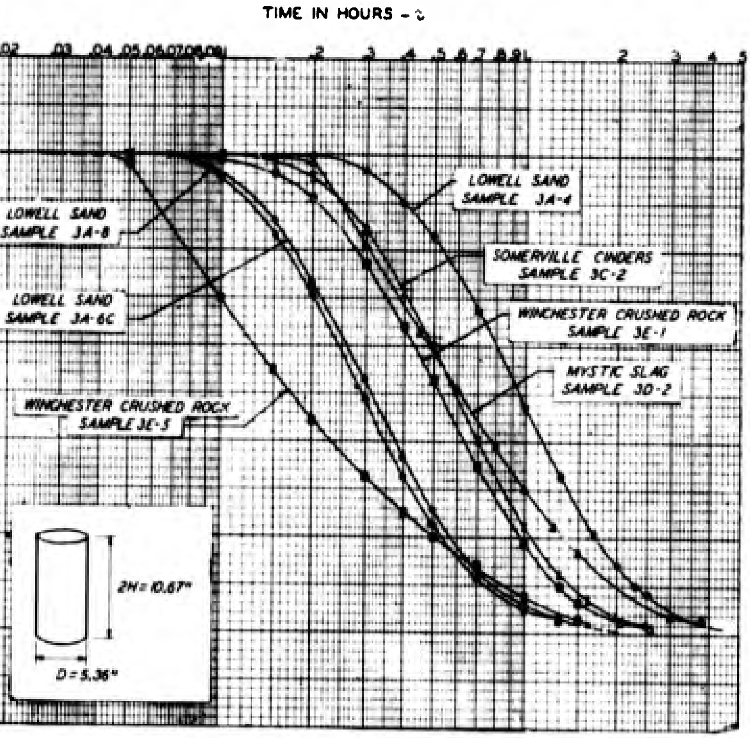
Series No.	Laboratory Sample No.	Material	Unit Dry Weight Lbs/cu. ft. γ	Water Content Percent Dry Weight w	Specific Gravity G	Specific Heat(1) Dry Soil Btu/(lb)(deg F) c1	Volumetric Heat Capacity Total Sample Btu/(ft³)(deg F) C	Thermal Conductivity Btu/(ft)(hr)(deg F) k	REMARKS
3A	3A-4 3A-4a 3A-5(3) 3A-6a 3A-7 3A-8 3A-9 3A-10(3) 3A-11(3) 3A-12 3A-13 3A-15 3A-16 3A-17	Lowell Sand (well-graded medium to coarse sand) (2)	105.0 105.0 101.0 106.5 101.0 103.0 83.5 84.5 91.1 109.0 103.0 89.3 105.0 90.8	0.2 0.2 0.2 16.4 20.9 4.5 4.9 2.3 1.9 2.2 2.0 2.1 5.1 2.1	2.66 2.66 2.66 2.66 2.66 2.66 2.66 2.66 2.66 2.66 2.66 2.66 2.66 2.66	0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20	21.2 21.2 20.4 38.8 41.3 25.3 20.8 18.8 19.9 24.3 22.7 19.7 26.4 20.1	0.188 0.180 0.160 1.025 1.000 0.718 0.460 0.335 0.352 0.582 0.476 0.463 0.777 0.457	(1) Assumed (2) Minimum dry density 92.9 lbs/cu. ft. Maximum dry density 110.9 lbs/cu. ft. (3) Sample not properly sealed; some water leaked into sample during test. (4) Test results are not consistent with results of other tests. (5) Average-- w = 14.2% top of sample w = 27.3% bottom of sample (6) Non-uniform water content (7) Percent Bitumen 4.5%. Specific Heat of Bitumen = 0.22 Btu/lb/Deg. F (8) Diameter of cylinder = 4.70" Length = 11.94" (9) Diameter of cylinder = 4.72" Length = 11.92"
3B	3B-1 3B-2 3B-3	Bangor Sand and Gravel	127.0 131.5 127.0	3.4 1.1 9.3	2.70 2.70 2.70	0.20 0.20 0.20	29.8 27.7 36.3	0.890 0.673 1.125	
3C	3C-1 3C-2 3C-3 3C-4	Somerville Cinders (1-inch maximum)	60.9 60.0 60.8 61.7	20.7(5) 36.6 21.2(6) 11.3	2.27 2.27 2.27 2.27	0.18 0.18 0.18 0.18	23.6 32.8 23.9 18.1	0.353 0.462 0.354 0.297	
3D	3D-1 3D-2(4)	Mystic Slag (1½-inch maximum)	79.1 81.2	9.1 33.5	2.45 2.45	0.17 0.17	17.5 40.9	0.188 0.553	
3E	3E-1 3E-2 3E-3 3E-4 3E-5(4) 3E-6a(4) 3E-7 3E-8	Winchester Crushed Trap Rock (3/4-inch maximum)	99.2 100.0 98.5 98.5 99.3 100.0 102.0 102.0	1.9 2.1 4.4 27.2 28.4 27.7 2.5 26.7	2.91 2.91 2.91 2.91 2.91 2.91 2.91 2.91	0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20	21.7 22.1 23.6 46.5 48.0 47.7 23.0 47.7	0.350 0.371 0.403 0.840 2.320 1.850 0.371 1.479	
3F	3F-1(8) 3F-2(9)	Asphaltic Bituminous Concrete	150.0(7) 150.0(7)	0.0 0.0	2.60 2.60	0.20 0.20	30.3 30.3	0.690 0.686	
3G	3G-1(3)	Blended Bituminous Concrete Aggregate	133.5	0.0	2.81	0.20	26.7	0.313	

SUMMARY OF TEST DATA

TABLE A

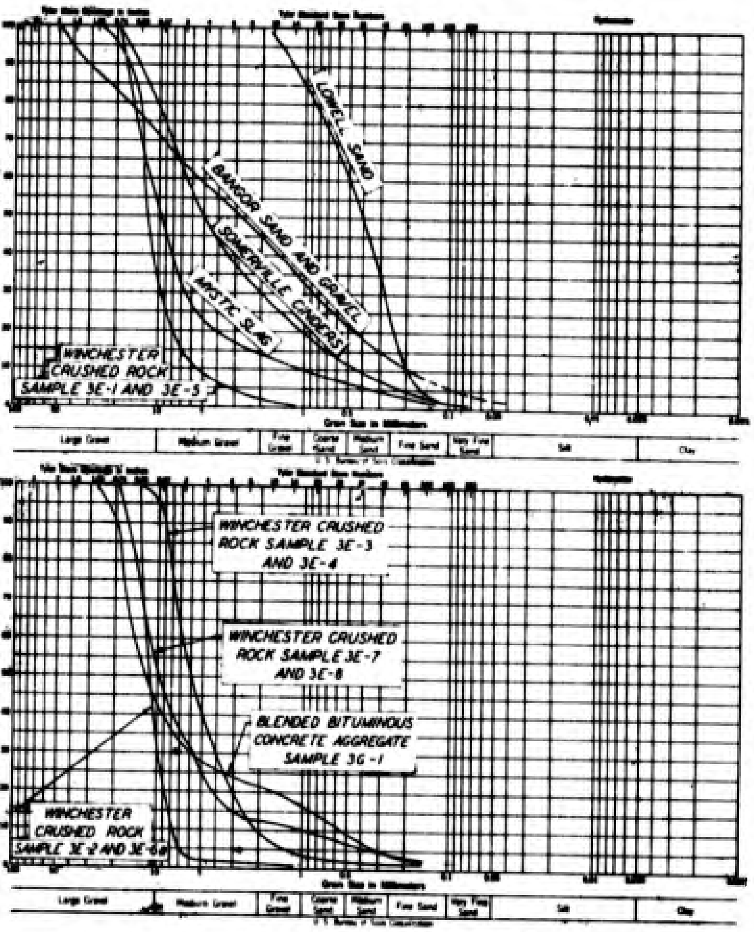


THERM



TYPICAL TIME CURVES
THERMAL CONDUCTIVITY DETERMINATIONS

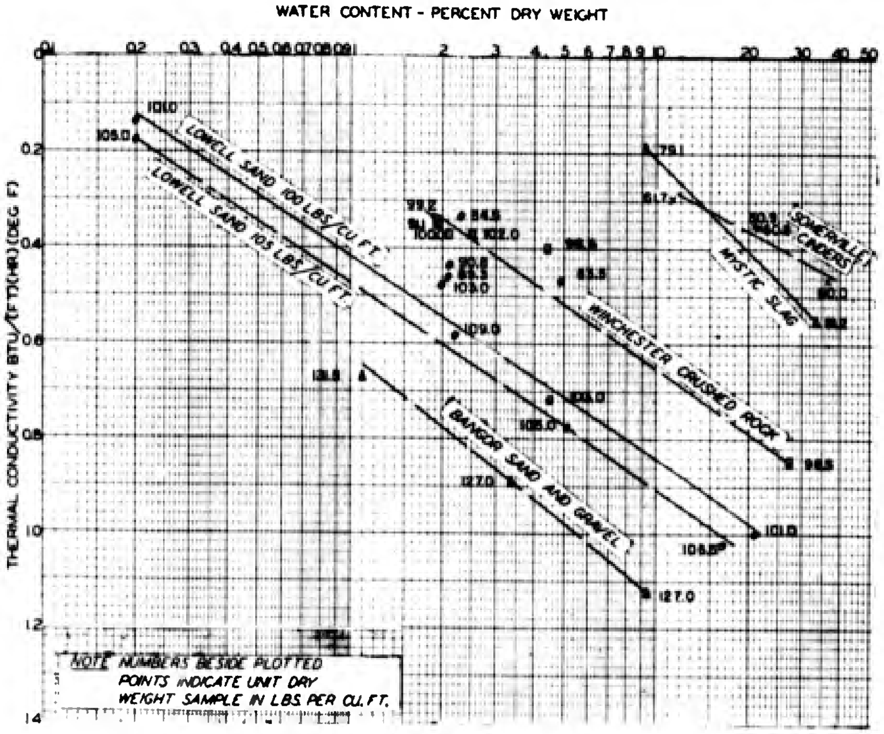
FIG.2



GRADATION OF BASE MATERIALS

FIG.3

y density
/cu. ft.
y density
/cu. ft.
properly
me water
e sample
t.
ts are
tent
ts of
e.
top of
bottom
le
n water
tumen
cific
tumen s
b/Deg. F
f cy-
.70"
1.14"
f cy-
.72"
1.00"



THERMAL CONDUCTIVITY VS WATER CONTENT OF VARIOUS BASE MATERIALS

FIG. 4

EXAMPLE FOR DETERMINATION OF k

EQUATION $k = \frac{C D^2 T}{t}$

TEST DATA FROM TABLE A, SAMPLE 3A-8 ARE USED

$c_1 = 0.20$

$\gamma = 103$ LBS/CU. FT.

$w = 4.5\%$

$C = \gamma\left(c_1 + \frac{w}{100}\right) = 103\left(0.20 + \frac{4.5}{100}\right) = 25.3$ BTU/(FT.^{3})(DEG. F)

FROM FIG. 2

$D^2 = (5.36")^2 = (0.446')^2 = 0.1995$ FT.^{2}

FOR $\mu = 50\%$, $t = 0.295$ HOURS

(50% TEMPERATURE CHANGE IS ARBITRARILY TAKEN. ANY VALUE OF μ ON THE STRAIGHT PORTION OF THE CURVE MAY BE USED.)

FROM FIG. 1 CURVE ①

FOR $\mu = 50\%$, $T = 0.042$

SUBSTITUTING IN EQUATION

$$k = \frac{C D^2 T}{t} = \frac{(25.3)(0.1995)(0.042)}{(0.295)}$$

$k = 0.718$ BTU/(FT)(HR)(DEG. F)

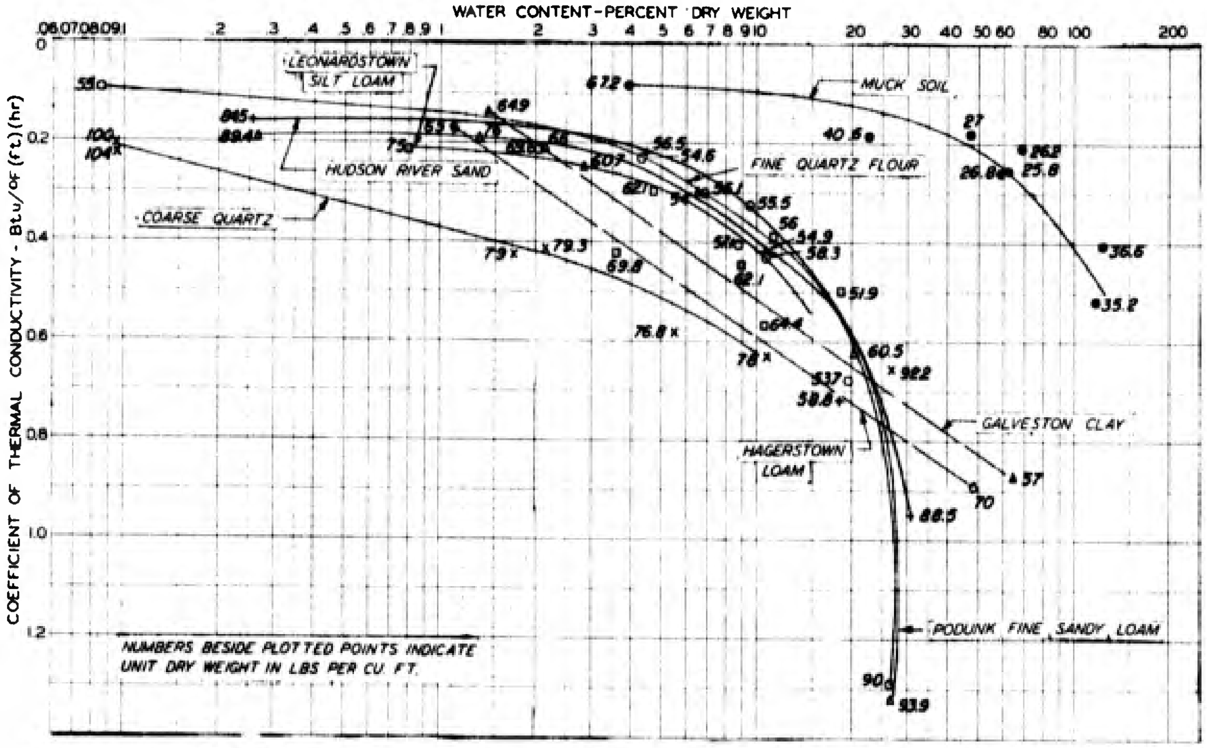
B

FROST INVESTIGATION

THERMAL CONDUCTIVITY DETERMINATIONS
COHESIONLESS BASE MATERIALS

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1945

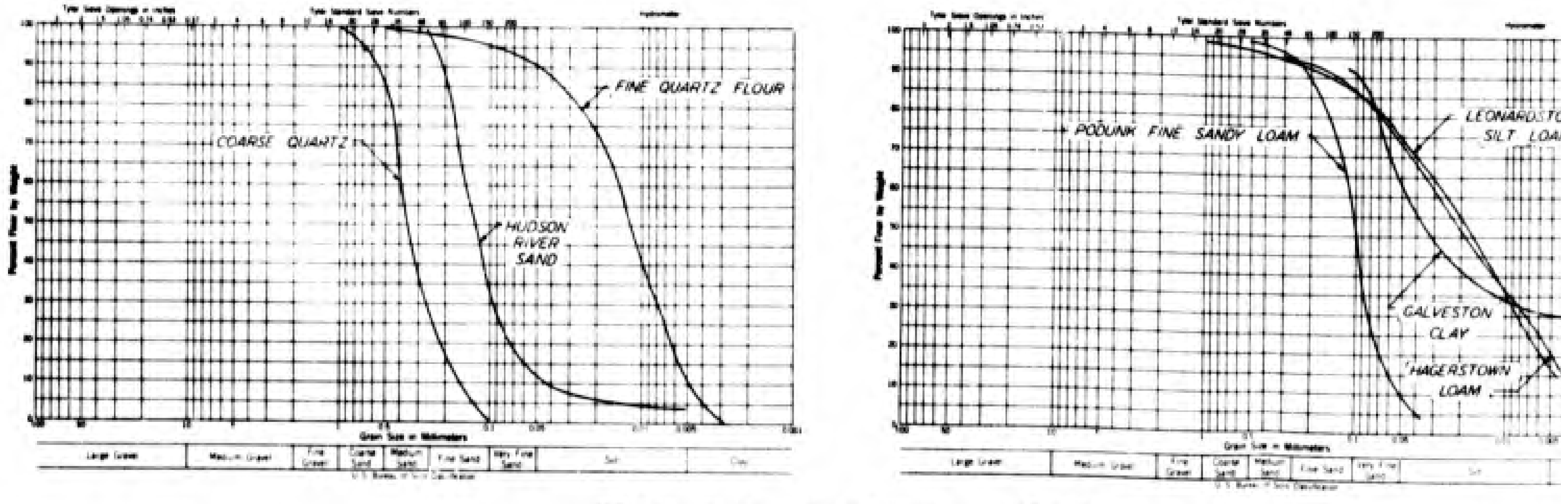
REVISED FEBRUARY, 1947



THERMAL CONDUCTIVITY VS WATER CONTENT

FIG. 1

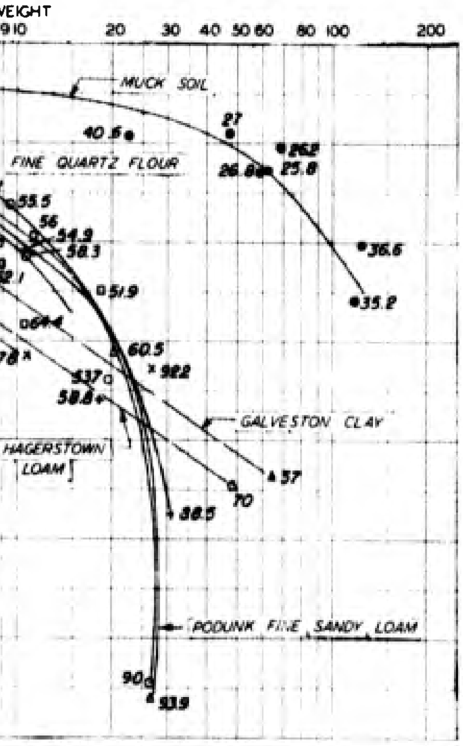
Mate
COARSE Q
FINE QUA FLOUR
HUDSON R SAND
PODUNK F SANDY L
LEONARDS SILT LOAM
HAGERSTO LOAM
GALVESTO CLAY
MUCK SOI



GRAIN SIZE GRADATION CURVES

FIG. 2

REVISED JUL

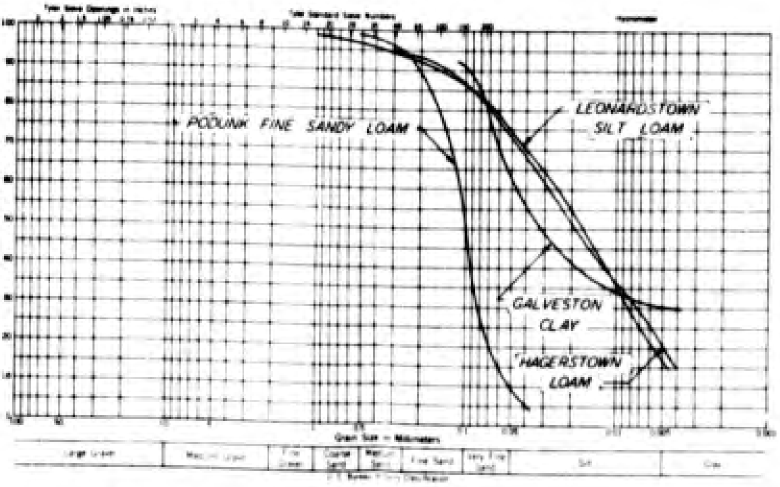


WATER CONTENT

Material	Unit Dry Weight	Water Content	Specific Heat	Volumetric Heat Capacity	Thermal Conductivity
	lbs/c.f.	% Dry Wt.		Btu/(°F)(cf)	Btu/°F (ft)(hr)
COARSE QUARTZ	104	0.095	0.1900	[illegible]	0.221
	100	0.095	0.1900	[illegible]	0.206
	79	1.710	0.1900	16.3	0.423
	79.3	2.160	0.1900	[illegible]	0.415
	76.8	5.520	0.1900	[illegible]	0.581
	78.0	10.910	0.1900	23.3	0.630
	92.2	26.700	0.1900	42.1	0.653
FINE QUARTZ FLOUR	55	0.0833	0.1900	[illegible]	0.0981
	54.6	4.280	0.1900	[illegible]	0.232
	56.1	6.930	0.1900	14.5	0.300
	57.1	8.720	0.1900	[illegible]	0.403
	55.5	9.530	0.1900	[illegible]	0.323
	58.3	10.920	0.1900	17.4	0.427
	53.7	19.670	0.1900	[illegible]	0.680
	90.0	26.650	0.1900	[illegible]	1.290
HUDSON RIVER SAND	84.5	0.257	0.1900	[illegible]	0.1575
	56.5	4.500	0.1900	13.3	[illegible]
	58.8	18.120	0.1900	[illegible]	[illegible]
	68.5	30.760	0.1900	[illegible]	[illegible]
PODUNK FINE SANDY LOAM	89.4	0.268	0.1900	[illegible]	0.191
	76.0	1.330	0.1900	15.5	0.191
	[illegible]	2.140	0.1900	[illegible]	0.209
	[illegible]	2.650	0.1900	13.2	0.244
	54.0	6.601	0.1900	[illegible]	0.302
	54.9	10.090	0.1900	16.0	0.418
	60.5	20.250	0.1900	23.7	0.623
	93.9	26.930	0.1900	[illegible]	1.32
LEONARDSTOWN SILT LOAM	75.0	0.806	0.1900	14.8	0.214
	69.6	2.127	0.1900	14.7	0.210
	69.8	3.580	0.1900	15.7	0.422
	62.1	4.690	0.1900	[illegible]	0.299
	62.1	8.980	0.1900	17.3	0.443
	64.4	10.650	0.1900	[illegible]	0.562
	56.0	11.570	0.1900	17.1	0.398
	51.9	18.350	0.1900	[illegible]	0.500
HAGERSTOWN LOAM	65.0	1.12	0.1914	[illegible]	0.1686
	70.0	48.06	0.1914	[illegible]	0.993
GALVESTON CLAY	64.9	1.41	0.2097	[illegible]	0.139
	57.0	67.55	0.2097	[illegible]	0.868
MUCK SOIL	67.2	3.93	0.1900	[illegible]	0.0842
	40.6	22.95	0.1900	[illegible]	0.184
	27.0	47.06	0.1900	[illegible]	0.190
	26.8	58.98	0.1900	[illegible]	0.260
	25.8	62.93	0.1900	21.1	0.257
	26.2	69.42	0.1900	[illegible]	0.208
	35.2	119.20	0.1900	[illegible]	0.519
	36.6	123.00	0.1900	[illegible]	0.402

DATA SUMMARY TABULATION

TABLE A



E GRADATION CURVES

FIG. 2

NOTE

(1) H. E. PATTEN "HEAT TRANSFERENCE IN SOILS" U.S. DEPARTMENT OF AGRICULTURE BULLETIN NO. 59 SEPTEMBER 1909.

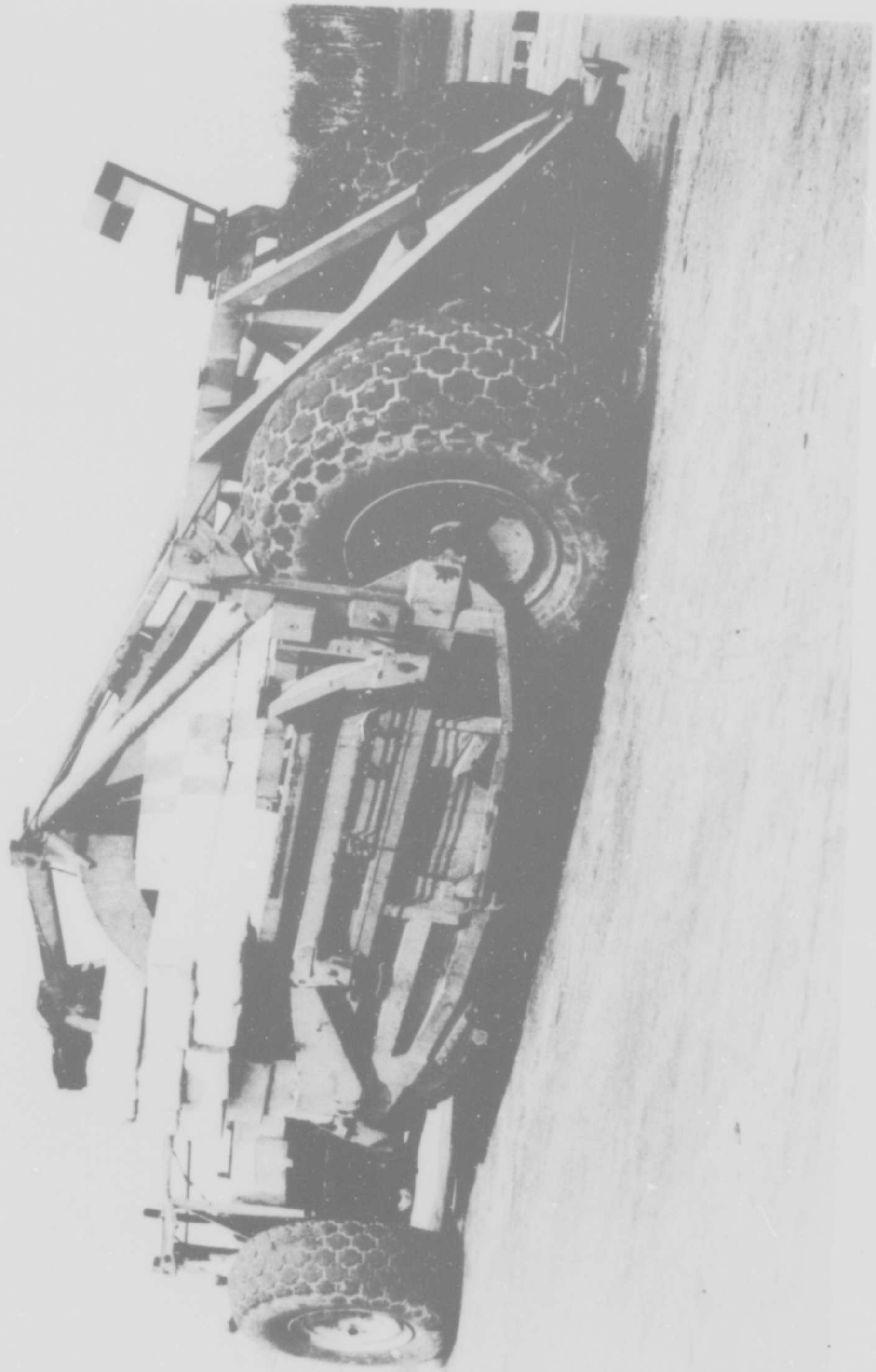
REVISED JULY, 1947

FROST INVESTIGATION

SUMMARY OF THERMAL CONDUCTIVITY TESTS BY H. E. PATTEN (1)

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1945

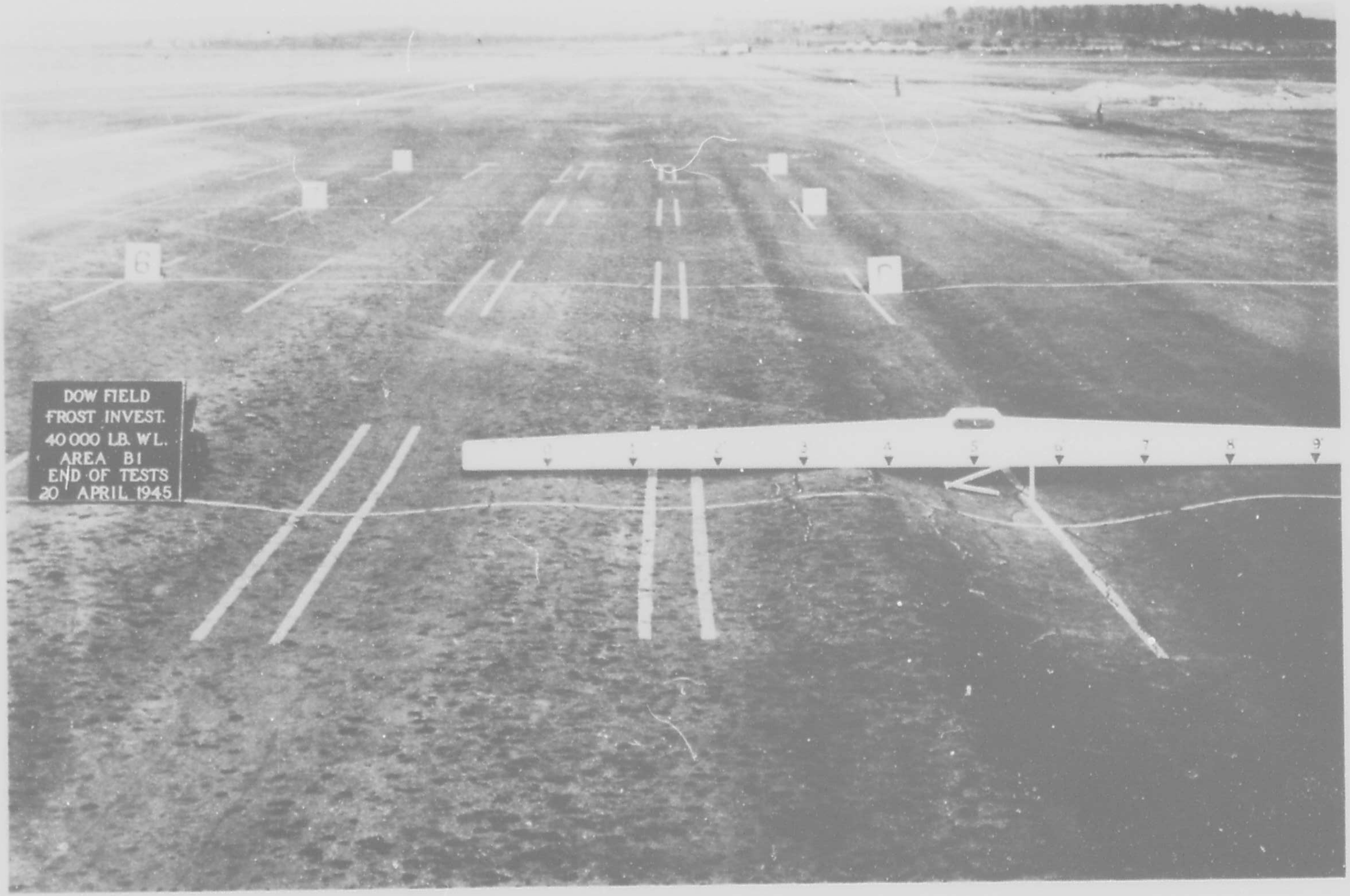
B



DOW FIELD, BANGOR, MAINE
Traffic Test Equipment for 60,000 pound wheel load.

TRUAX FIELD, MADISON, WISCONSIN

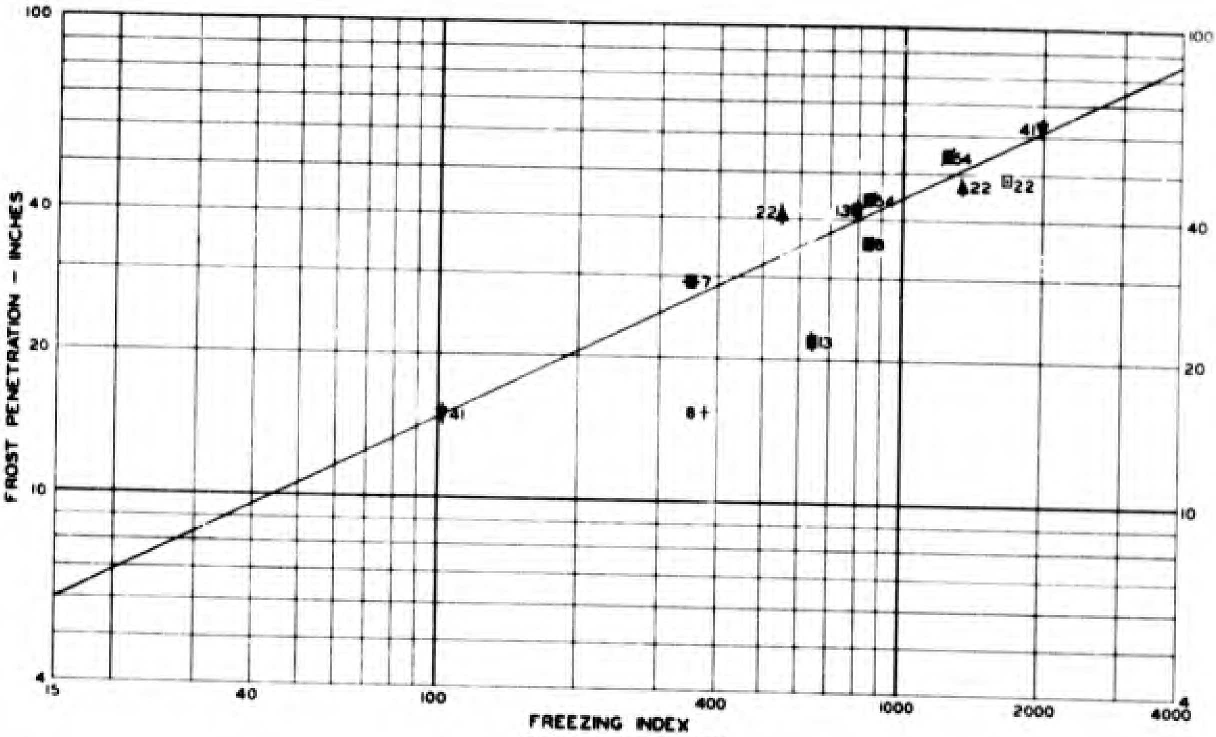
Sixty thousand pound wheel load equipment, Model A-6 Tournapull with Log Trailer



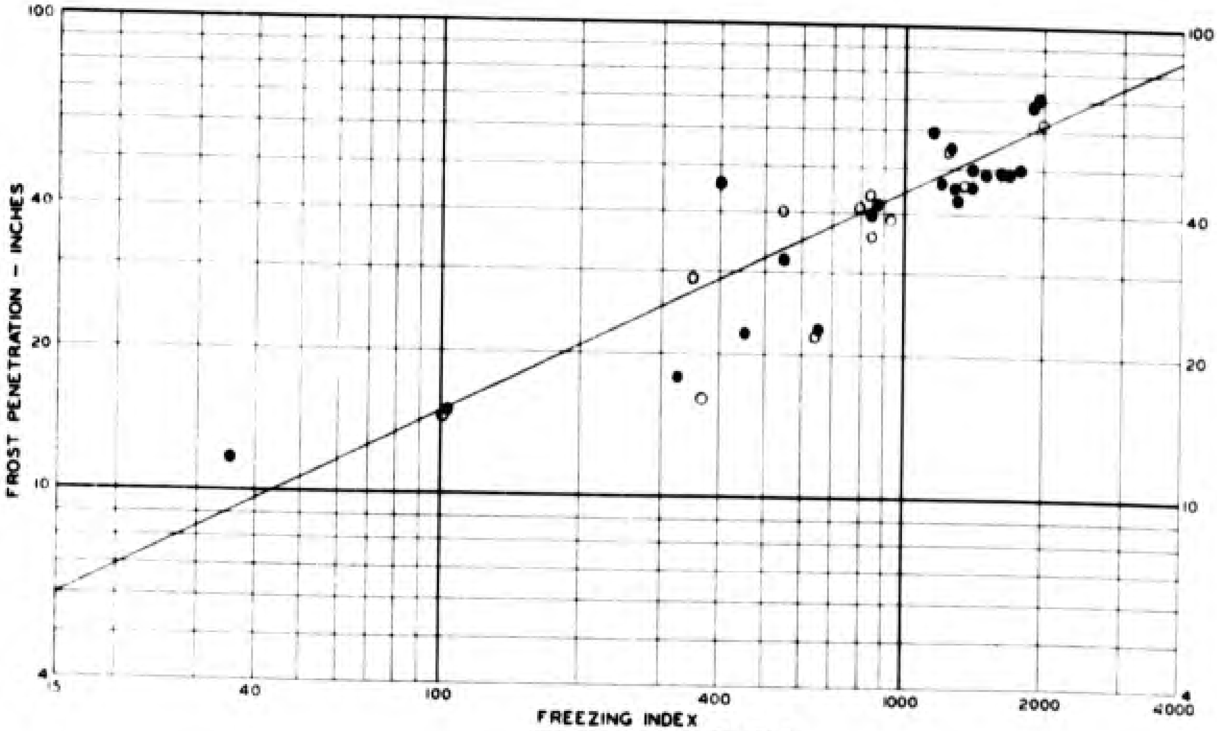
DOW FIELD, BANGOR, MAINE

Close-up of Traffic Test Area B1 map cracking in lane 3, Section Line 5-5 at completion of tests, 524 Coverages in 17 days, 20 April 1945

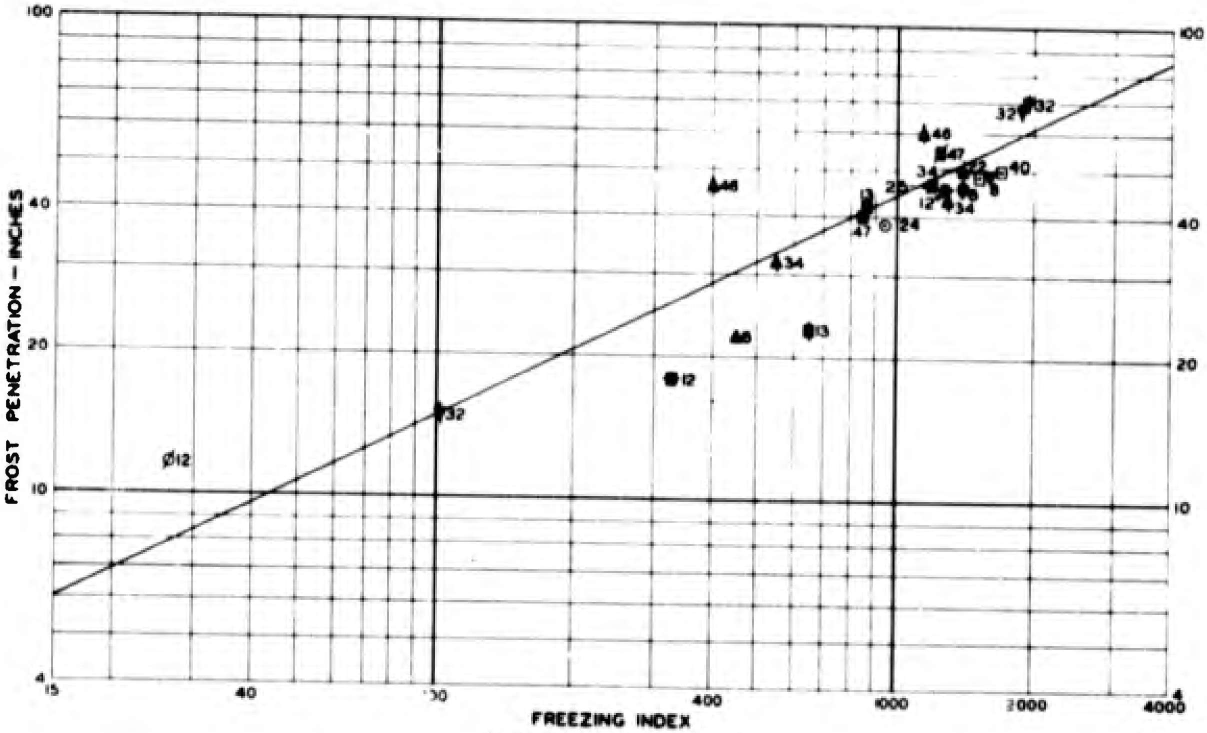
PIERRE AIRFIELD, TEST AREA 4, TRAFFIC TEST AREA R-3
[illegible] Cracks after [illegible] days traffic at 24 coverages per day plus 5 days traffic at 176 coverages per day, 35,000 pound wheel load



RIGID PAVEMENT
FIG. 1



RIGID AND FLEXIBLE
FIG. 3



FLEXIBLE PAVEMENT
FIG. 2

LEGEND

- ▼ PRESQUE ISLE
- ▼ HOULTON
- ▲ DOW FIELD
- ▲ OTIS
- ■ TRUAX
- ⬢ PIERRE
- ✚ CASPER
- ■ WATERTOWN
- ◆ FARGO
- ◆ BISMARCK
- ⊡ DOW (1943-1944)
- + FAIRMONT
- ⊙ SIOUX FALLS
- ∅ GARDEN CITY

- ○ CEMENT CONC.
- ● BITUMINOUS CONC.

NOTES:

FREEZING INDEX OBTAINED FROM DEGREE-DAY DIAGRAM ON DATE FROST PENETRATION WAS MEASURED

FOR THIS STUDY THE FREEZING INDEX IS NOT NECESSARILY THE MAXIMUM VALUE OF NEGATIVE AND POSITIVE VALUES ON THE DEGREE-DAY DIAGRAM

STRAIGHT LINE EQUALS THE DESIGN CURVE SHOWING COMBINED THICKNESS OF PAVEMENT AND BASE REQUIRED TO PREVENT FREEZING OF SUBGRADE RECOMENDED IN REVISIONS TO ENGINEERING MANUAL

COMBINED THICKNESS OF PAVEMENT AND BASE IN FIGS 1&2 INDICATED BY NUMBERS ADJACENT TO PLOTTED VALUES

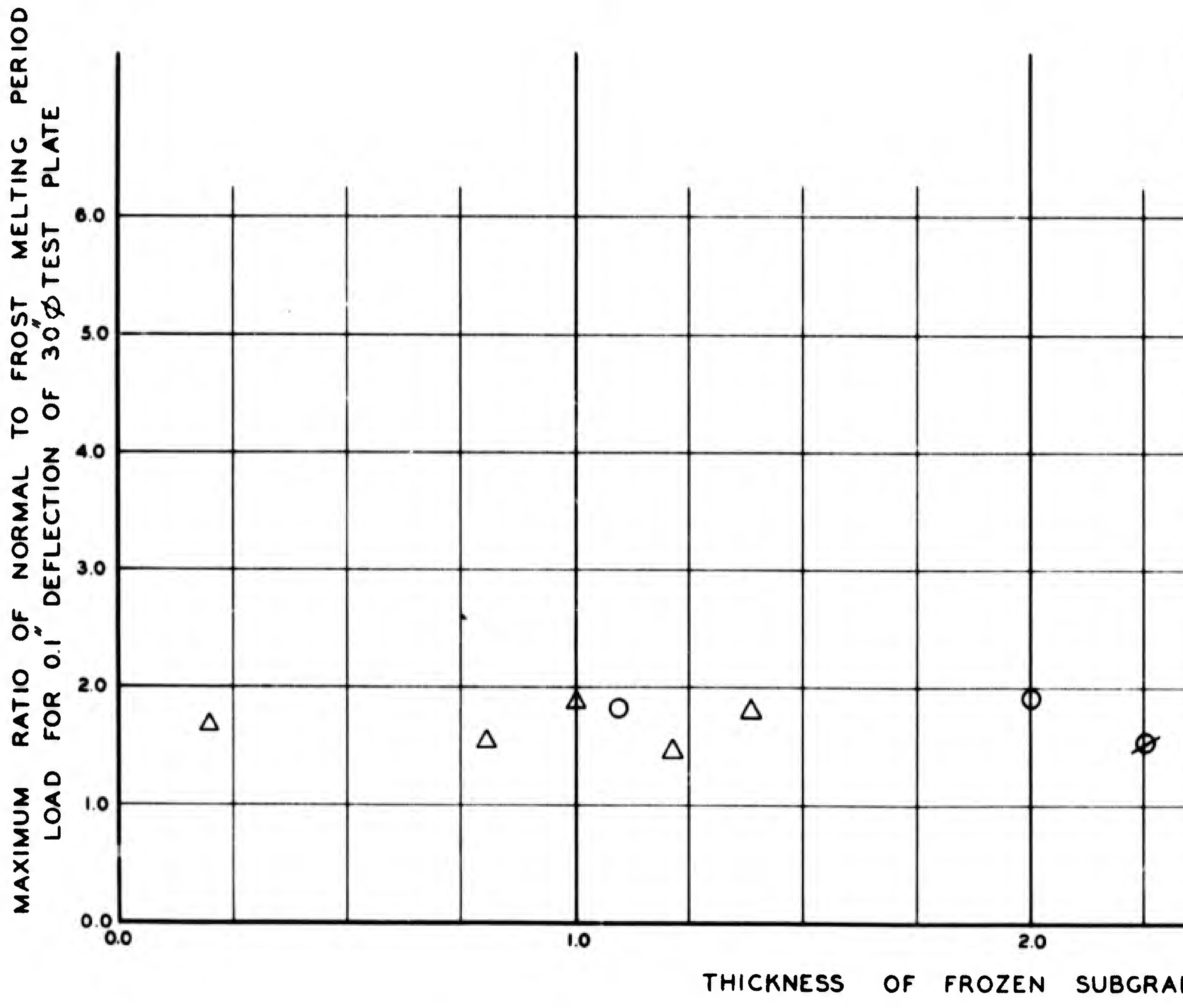
B

FROST INVESTIGATION
1944-1945

CORRELATION BETWEEN FROST PENETRATION AND FREEZING INDEX

FROST EFFECTS LABORATORY BOSTON, MASS. JUNE 1945

WAR DEPARTMENT

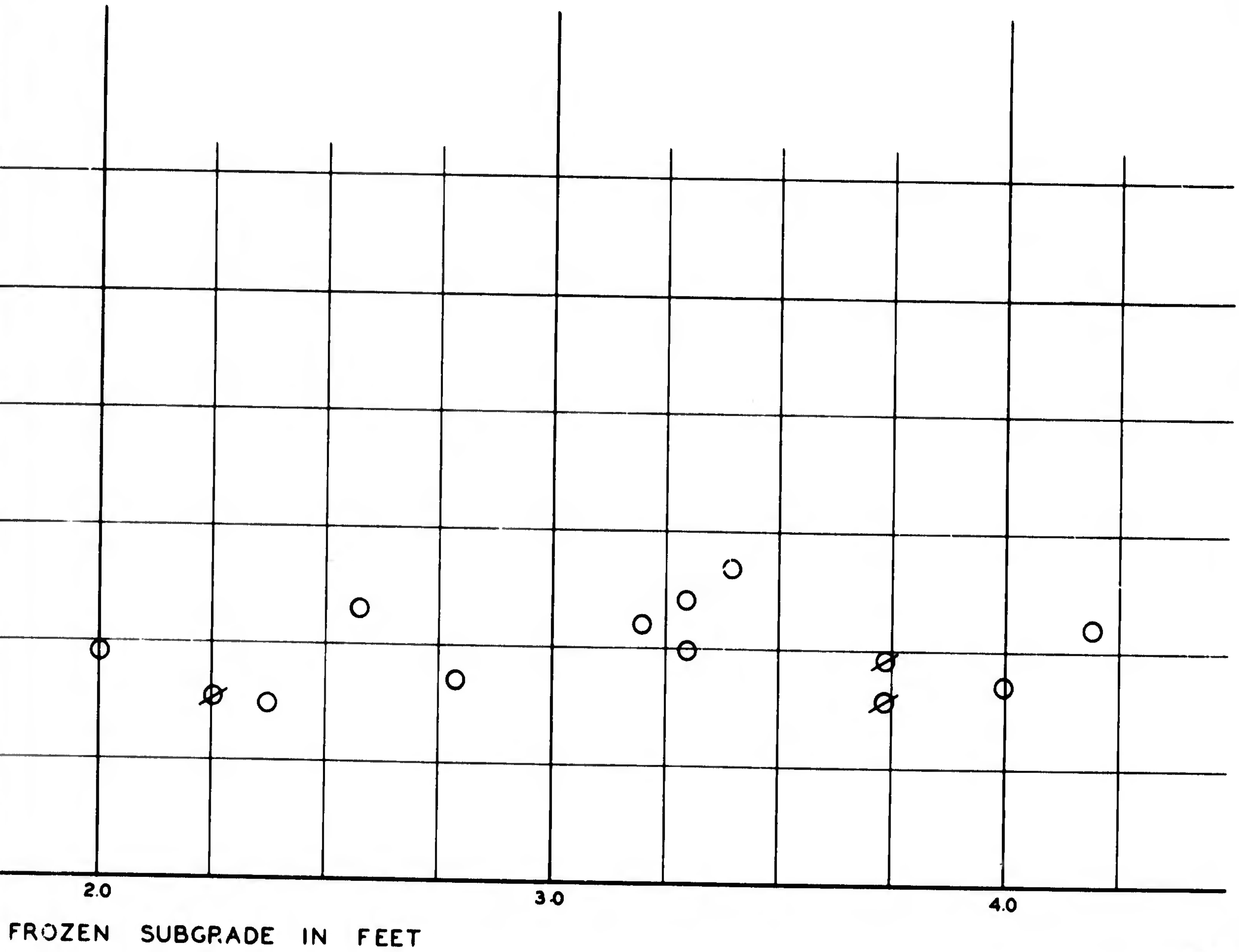


	SITE	CLASS OF SUB-GRADE SOILS	FREEZING INDEX 1944 - 1945	WATER TABLE
				FALL 1944
○	PRESQUE ISLE	CL	2190	6.0
Ø	TRUAX	SF AND CL	1260	6.0-7.0
△	DOW FIELD	CL	1244	4.5

NOTES:—

TESTS MADE ON TOP OF BITUMINOUS CONCRETE PAVEMENT.

THICKNESS OF FROZEN SUBGRADE EQUALS TOTAL FROST PENETRATION IN FEET LESS COMBINED THICKNESS OF PAVEMENT AND BASE IN FEET.



ING X 945	WATER TABLE DEPTH (FT.)	
	FALL 1944	SPRING 1945
0	6.0	3.0
0	6.0-7.0	0.5-6.0
4	4.5	2.0-3.5

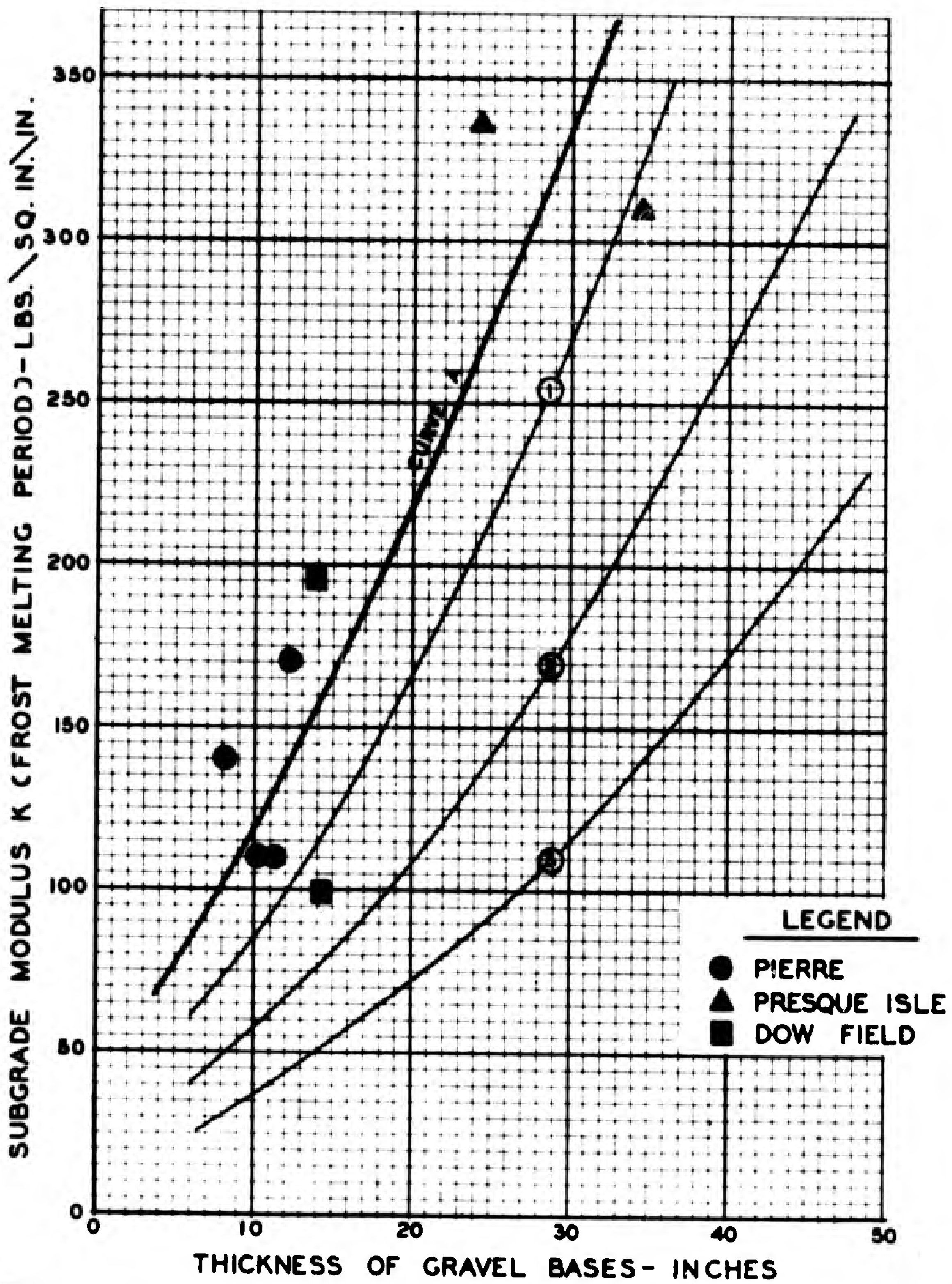
RATION IN FEET

B

FROST INVESTIGATION
1944 - 1945

RATIO OF PLATE BEARING TESTS NORMAL TO FROST MELTING PERIOD RELATED TO THICKNESS OF FROZEN SUBGRADE

FROST EFFECTS LABORATORY
BOSTON, MASS. JUNE 1945



NOTE:

CURVES ① ② ③ ARE DESIGN CURVES OF "RECOMMENDED REVISIONS TO ENGINEERING MANUAL."

ALL SUBGRADE SOILS ARE FROST SUSCEPTIBLE AND FALL IN GROUP ③

SUBGRADE MODULUS DETERMINED DURING FROST MELTING PERIOD.

FROST INVESTIGATION
1944 - 1945
SUMMARY OF FOUNDATION
MODULUS TESTS COMPARED
WITH
PROPOSED DESIGN CURVES

FROST EFFECTS LABORATORY,
BOSTON, MASS.
JUNE 1945

PLATE 35

APPENDIX A

Chapter 4

FROST CONDITIONS

Part XII

AIRFIELD PAVEMENT DESIGN

Chapter 4

FROST CONDITIONS

4–01 GENERAL. The strength of some soils is greatly reduced as a result of frost action. The detrimental effect of frost action, which is due to the accumulation of water in the form of ice lenses in the soil or base materials under natural freezing conditions, occurs during the thawing periods when the moisture of the ice lenses is released, thereby softening the soil. Frost action also causes detrimental heave of pavements in many types of soil. Frost heave is the raising of the pavement surface due to the growth of ice lenses, the total thickness of which is approximately equal to the heave of the pavement.

It is the policy of the Department to design pavements over frost susceptible subgrades so that there will be no interruption of plane traffic at any time due to reduction in load-supporting capacity of the pavement by softening of the subgrade.

a. Conditions Affecting Frost Action. The degree to which soils will lose their strength and the amount of frost heave depend on the type of soil, temperature conditions during the freezing and thawing periods, the permeability of the soil, the level of ground water, and the drainage conditions. Any soil which contains 3 percent or more by weight of grains smaller than 0.02 mm. in diameter should be considered susceptible to objectionable frost action.

A reliable indication of the effects of climate is the freezing index. The freezing index is a measure of the combined duration and magnitude of below freezing air temperature occurring during any given winter; the normal freezing index is computed for normal air temperatures based upon a long period of record, usually 10 or more years. (See figure 1 for method of determining freezing index.) The depth of pavement and base required to prevent freezing of the subgrade for corresponding freezing indices is shown on figure 2.

Observations have shown that frost-susceptible soils may lose strength even though a high water table is not present. This occurs when the natural moisture content is sufficiently high to allow migration of moisture from the underlying soil into the frost zone. The limiting conditions of moisture content are not well defined, but there is evidence that soils near optimum moisture content will allow migration of moisture.

b. Heaving. Heaving of pavement will occur when sufficient thickness of pavement and base is not provided to prevent freezing of the subgrade. The heaving will be uniform where conditions of subgrade and ground water are uniform. The heaving will be irregular where subgrade and ground water conditions are nonuniform. Conditions conducive to uniform heaving would occur at an airfield constructed upon a level plain with approximately uniform stripping, fill depth and ground water depth. Conditions conducive to irregular heaving occur at locations where subgrades vary from clean sands to silty soils with ground water close to surface.

Where conditions are conducive to irregular heaving, freezing of the subgrade should be prevented; this is especially true for soils of the ML and SF groups for which experience indicates that excessive differential heaving results if full thickness is not employed.

c. Insulating Materials. Where an insulating material, such as cinders or slag, is used in the base course, the combined thickness of pavement and base as determined from figure 2 may be decreased depending upon the thickness of the insulator. In the case of slag or cinders four inches may be substituted for every 6 inches of sand, gravel, or crushed rock. This reduction is not applicable when the design is based on a reduction in strength of the subgrade.

d. Base Composition Requirements. All materials for base course construction over subgrades susceptible to frost action should be nonfrost susceptible. Where the combined thickness of pavement and base is less than the value determined from figure 2 (not less than 6″), the bottom 4 inches of the base shall consist of any nonfrost susceptible gravel, sand, or crushed stone with at least 50 percent by weight of the grains passing a No. 40 mesh sieve. The purpose of this material is to form a filter which will prevent mixing of the subgrade with the base during and immediately following the frost melting period. In areas where suitable nonfrost susceptible base materials are not available locally, it may be possible to treat frost-susceptible base materials by admixtures to make them nonfrost susceptible. Only such admixtures are permissible for which reliable evidence of permanency of protection is available. Materials so treated may be used for the base except for the top 6 inches directly beneath pavement.

4–02 PROTECTION OF SUBGRADE FOR FLEXIBLE PAVEMENTS. The most generally accepted method of insuring no loss in strength of the subgrade due to frost action is to provide a thickness of pavement and base, not susceptible to frost action, which will prevent freezing of the subgrade. The combined thickness of pavement and base required to prevent frost action in the subgrade should be determined from figure 2 using the normal freezing index for the particular location. The normal freezing index may be determined from figure 3, which was plotted from Weather Bureau data. Where the normal freezing index on figure 3 is less than 100, the freezing index should be computed for the coldest year of record for the past 15 years and design based upon this value or 100, whichever is the smaller. In mountainous areas, the normal freezing index should be computed for the particular location. In southern areas below the zero contour line on figure 3, where detrimental frost occurs infrequently, the base course material should be composed of nonfrost susceptible material.

a. Reduction in Subgrade Value. Except where subgrade soils are subject to differential heaving, less depth of pavement and base than that required to prevent freezing of the subgrade is permissible, in which case the design is to be based on a reduction in strength of the subgrade due to frost action. Figure 4 should be used to determine the pavement and base thickness required for various wheel loads where frost action is permitted in the subgrade. These curves reflect the reduction in strength of soil during the frost melting period as a result of frost action. The reduction of strength of subgrades as a result of frost action is believed to be greater in cuts than in fills. If field data and experience definitely indicate that the reduction of strength in fill areas is less because of the height of fill and depth of water table below the fill, a reduction in combined thickness of base and pavement for the fill area may be taken. In no case should the minimum thickness be less than 9 inches, nor less than the thickness determined by the California Method, paragraphs 2–06 through 2–09 of this Part.

The above-described methods for determining the thickness of pavement and base furnish two values for a particular condition. The smaller of these two values should be compared with the combined thickness as determined by the California Method, and the greater value of this comparison should govern the design.

b. Example for Design. Assume the design to be a runway with a bituminous concrete surface and a 60,000-pound wheel load for the following conditions:

Normal Freezing Index	1500.
Subgrade	Cut Section; 50% by weight of grain sizes passing No. 200 sieve.
Subgrade CBR	8 (Undisturbed Soaked).
Base	Sand and Gravel; 80 CBR.

From figure 2, the combined pavement and base thickness required to prevent freezing of the subgrade is 54 inches. When allowing a reduction in strength of subgrade due to frost action, a total thickness of 46 inches is indicated from figure 4. By the California Method, a total thickness of only 24 inches is required. Since the value of 46 inches from figure 4 is smaller than the value of 54 inches from figure 2, and greater than the value resulting from the California Method, a combined thickness of 46 inches would be used in design.

If cinders or slag are used, the thickness of 54 from figure 2 may be reduced to 36 inches in accordance with sub-paragraph 4–01 *c* and a combined thickness of 36 inches would be used in design.

4–03 PROTECTION OF SUBGRADE FOR CONCRETE PAVEMENTS. The effects of and the design for frost action in subgrades beneath rigid pavements are similar to those discussed in paragraphs 4–01 and 4–02. To insure no loss in subgrade strength due to frost action, a thickness of base and pavement sufficient to prevent freezing of the subgrade should be employed. However, the combined thickness of pavement and non-frost susceptible base may be reduced to not less than one-half the value determined from figure 2 if the design is based upon a modulus of soil reaction which considers the reduced strength of the subgrade effected by frost action. In no case should a base thickness of less than 6 inches be used in frost areas where frost susceptible soils are involved.

a. *Subgrade Modulus for Design.* The subgrade modulus to be used for the design of the slab thickness at a particular location depends upon the combined thickness of pavement and base. Two foundation moduli should be determined, as stated below, and slab thickness design prepared for each. The final selection of the slab thickness and combined thickness of pavement and base will depend upon the economy of construction. Where a combined thickness of pavement and base equal to or greater than the value determined from figure 2 is selected, the design should be determined in accordance with chapter 3. When the combined thickness of pavement and base is less than the value from figure 2, but at least one-half this value, the design should be based upon the method stated in chapter 3 but using the subgrade modulus determined from figure 5. The subgrade modulus determined from figure 5, which considers a reduced strength of the subgrade, should never govern when that value is greater than the tested "k" value, in instances of this nature, the one-half depth of base and pavement thickness may be used with the "k" value obtained from figure 5 or the tested "k" value, whichever is smaller.

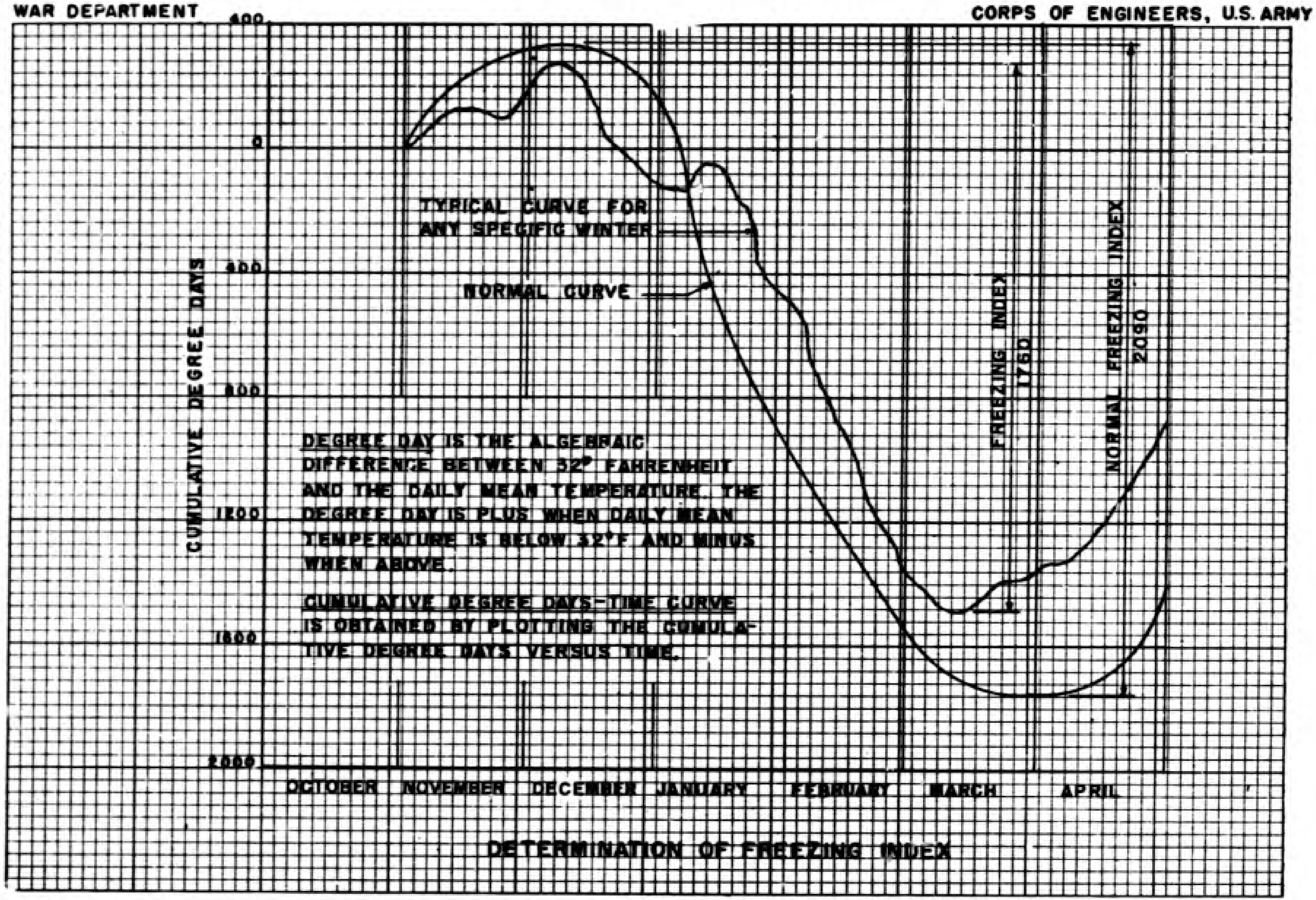
b. *Example of Design.* Design a concrete runway pavement for a 60,000-pound wheel load for the following conditions:

Normal Freezing Index	1500.
Topography	Level.
Subgrade	Lean clay; 40 percent by weight of grain sizes passing No. 200 sieve.
Groundwater	Uniform—3 ft. below surface of subgrade.
Subgrade Modulus	100 lbs./sq. in./in.
Concrete, Flexural Stress	650 lbs./sq. in.

From figure 2, the minimum thickness of pavement and base required to protect the subgrade from frost action is 54 inches. For the subgrade modulus, flexural strength of concrete, and wheel load of 60,000 pounds, the required thickness of pavement in accordance with chapter 3 and figure 1, chapter 3, is 14 inches with a resultant thickness of base course of 40 inches.

For a combined thickness of pavement and base of one-half the value determined from figure 2 (54 inches), which is 27 inches, the subgrade modulus as determined from figure 5 is 45 lbs./sq. in./in., assuming tentatively a pavement thickness of 15 inches which results in a base thickness of 12 inches. Using this subgrade value and the design curves of chapter 3, a concrete thickness of 15 inches is required.

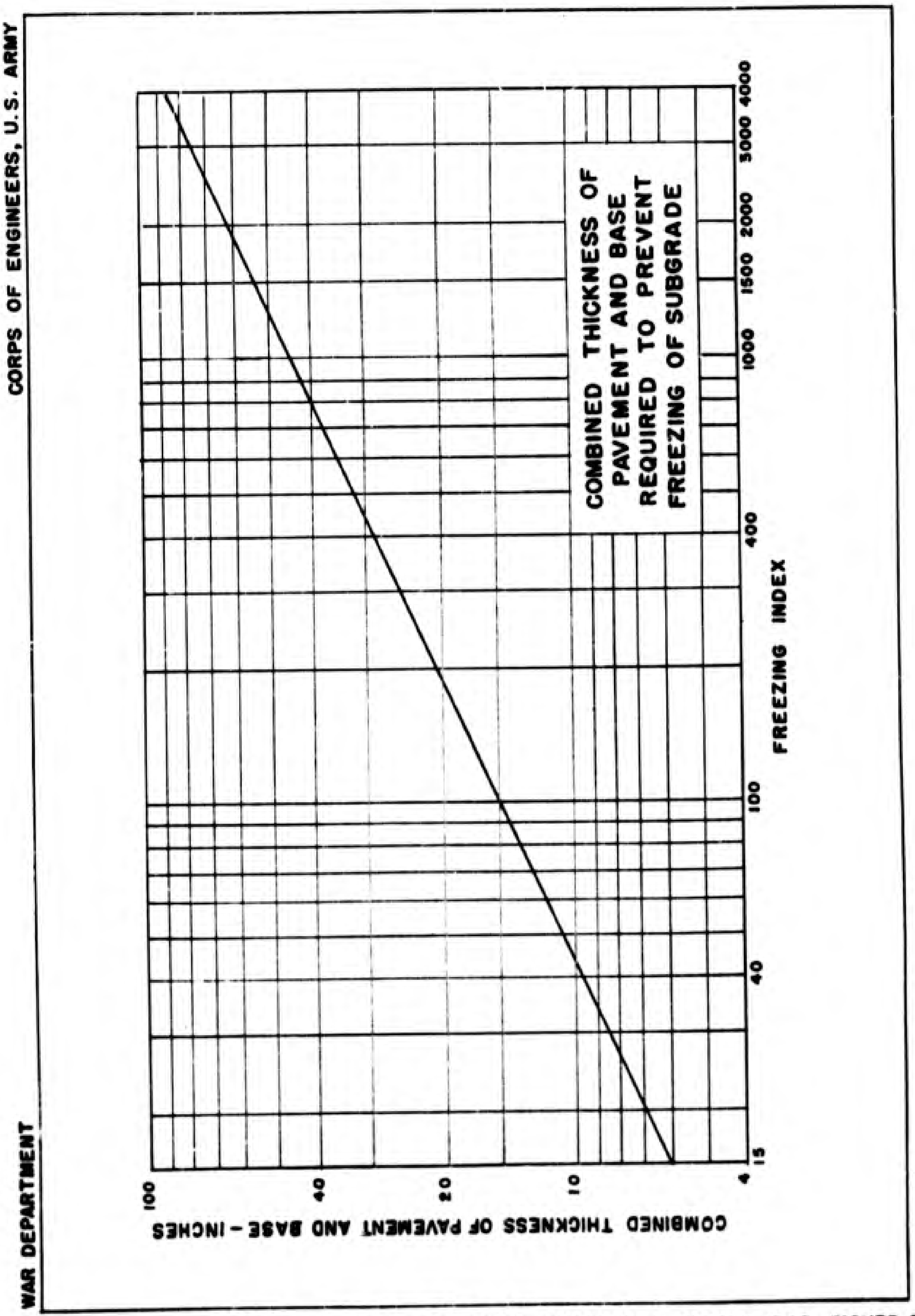
The thickness of base determined from figure 2 may be reduced if cinders or slag, which have insulating qualities, are used as a base material. This reduction in base thickness has been explained in paragraphs 4–01 *c* and 4–02 *b*.



DEGREE DAY IS THE ALGEBRAIC DIFFERENCE BETWEEN 32° FAHRENHEIT AND THE DAILY MEAN TEMPERATURE. THE DEGREE DAY IS PLUS WHEN DAILY MEAN TEMPERATURE IS BELOW 32°F AND MINUS WHEN ABOVE.

CUMULATIVE DEGREE DAYS-TIME CURVE IS OBTAINED BY PLOTTING THE CUMULATIVE DEGREE DAYS VERSUS TIME.

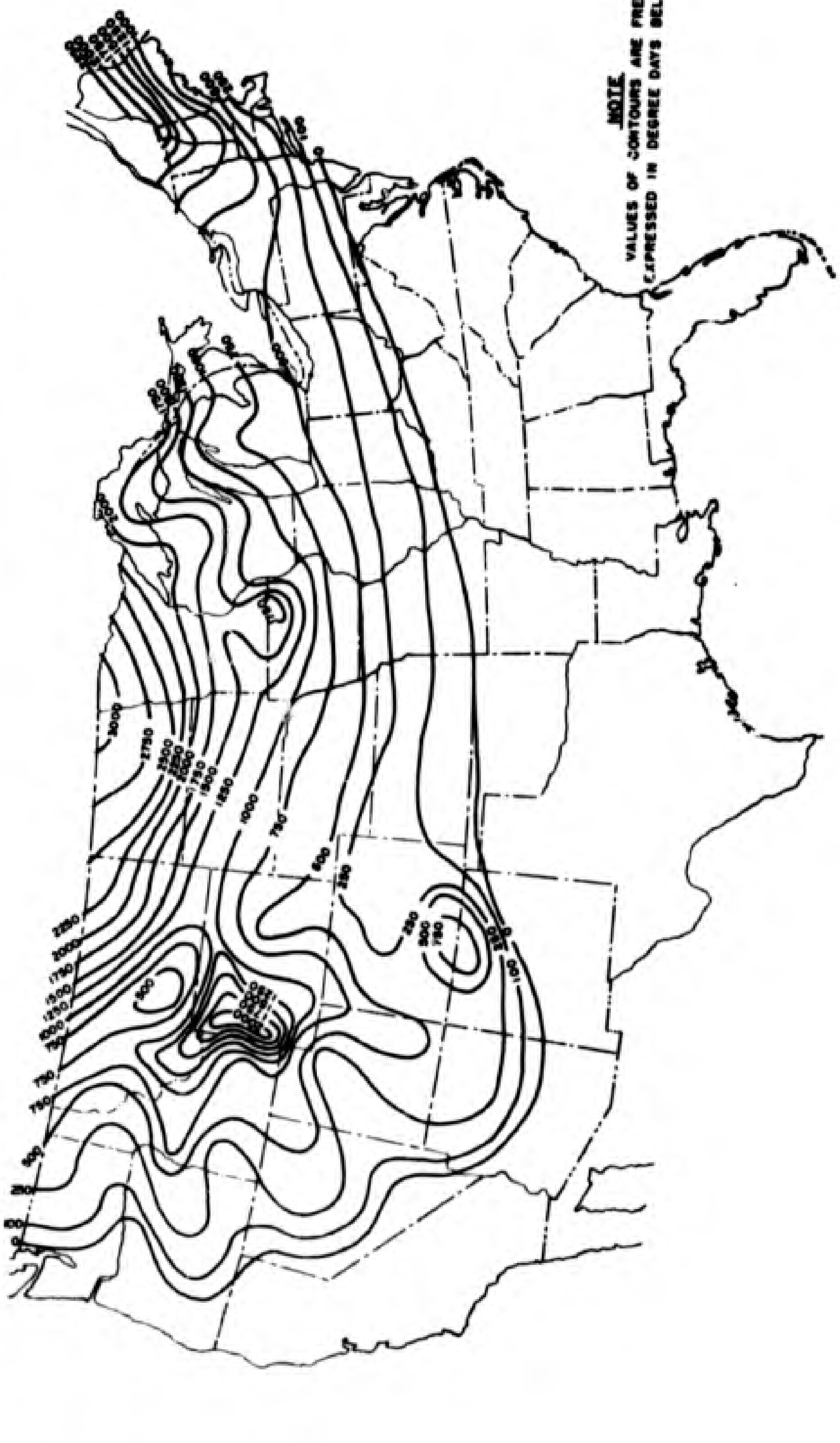
DETERMINATION OF FREEZING INDEX



ENGINEERING MANUAL - PART XII - CHAPTER 4 - MARCH 1946 FIGURE 2

WAR DEPARTMENT

CORPS OF ENGINEERS U.S. ARMY



NOTE

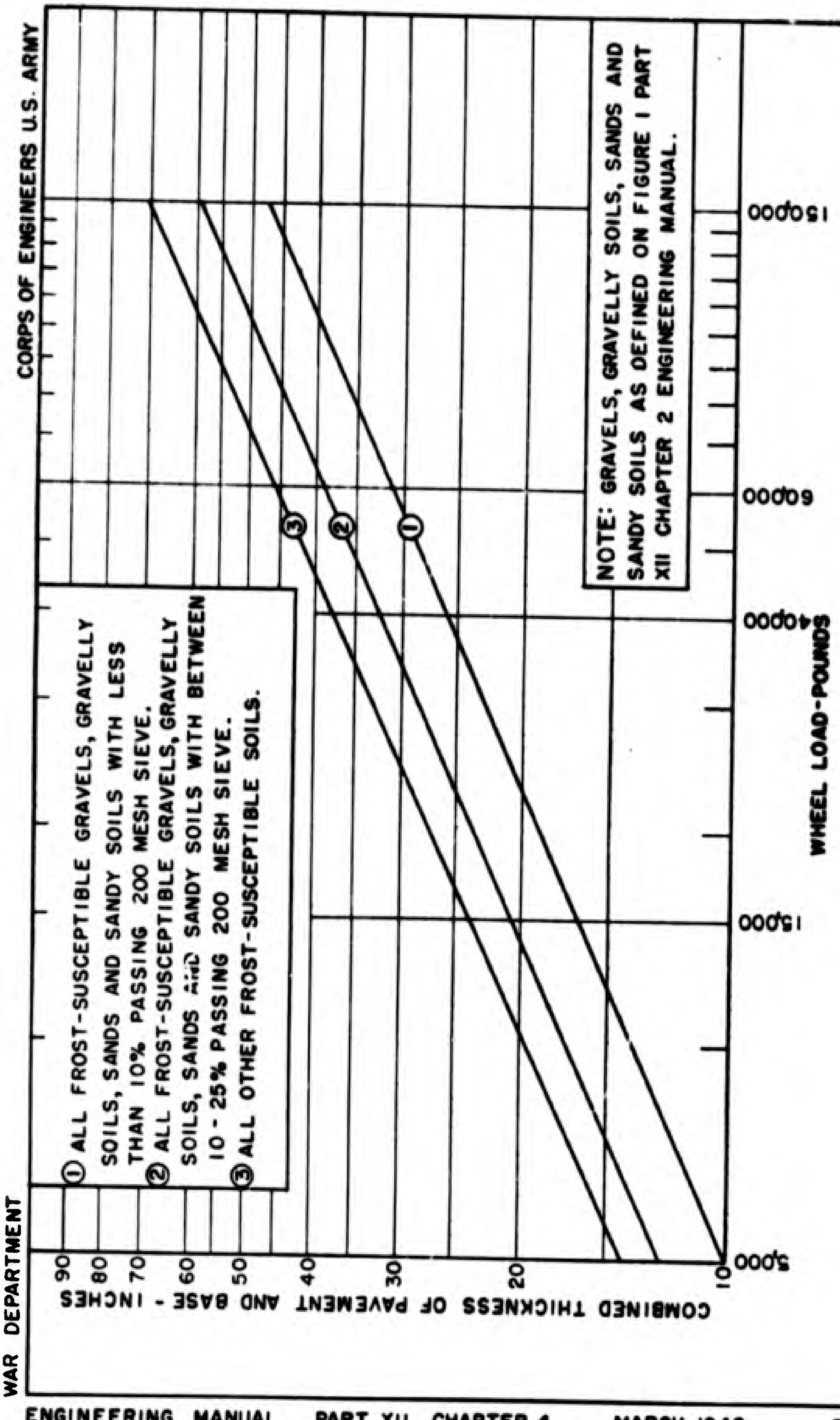
VALUES OF CONTOURS ARE FREEZING INDEX EXPRESSED IN DEGREE DAYS BELOW 32° F.

FREEZING INDEX DATA INFLUENCING FROST ACTION

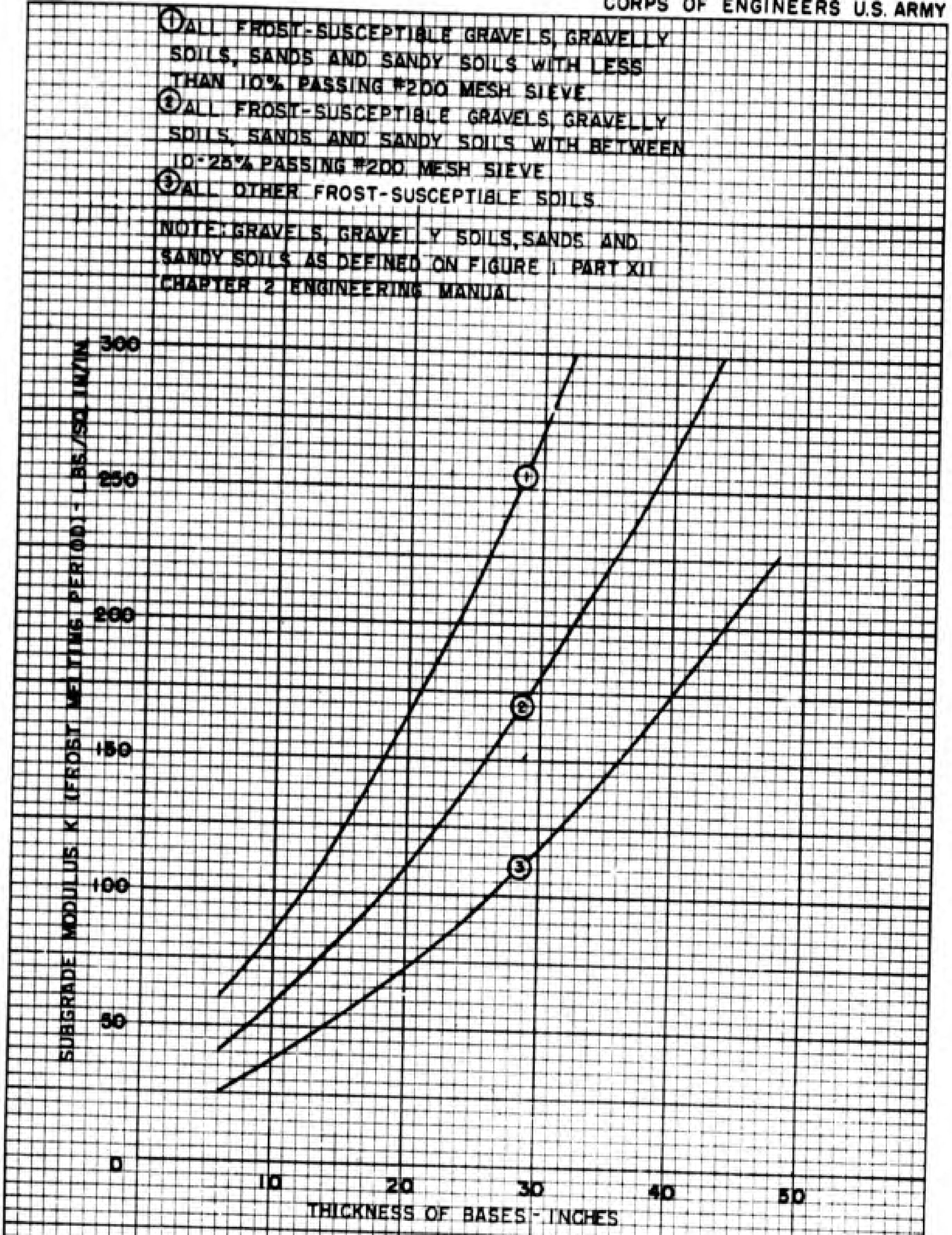
ENGINEERING MANUAL PART XII CHAPTER 4 MARCH 1946 FIGURE 3

WAR DEPARTMENT

CORPS OF ENGINEERS U.S. ARMY



FLEXIBLE PAVEMENT
DESIGN CURVES FOR FROST
ACTION IN SUBGRADE SOIL



① ALL FROST-SUSCEPTIBLE GRAVELS, GRAVELLY SOILS, SANDS AND SANDY SOILS WITH LESS THAN 10% PASSING #200 MESH SIEVE.

② ALL FROST-SUSCEPTIBLE GRAVELS, GRAVELLY SOILS, SANDS AND SANDY SOILS WITH BETWEEN 10-25% PASSING #200 MESH SIEVE.

③ ALL OTHER FROST-SUSCEPTIBLE SOILS.

NOTE: GRAVELS, GRAVELLY SOILS, SANDS AND SANDY SOILS AS DEFINED ON FIGURE 1 PART XII CHAPTER 2 ENGINEERING MANUAL.

RIGID PAVEMENT
SUBGRADE MODULUS CURVES FOR
FROST ACTION IN SUBGRADE SOIL