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FROST INVESTIGATION
1944-1945

COMPREHENSIVE REPORT

NEW ENGLAND DIVISION
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COMPREHENSIVE REPORT

1. Synopsis. 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 1944-1945 Frost Investigation included studies at 10 airfields in the northern part of the United States, with varying subsurface conditions, three traffic tests on rigid and flexible pavements, theoretical studies, cold room experiment, and laboratory and field tests. 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. Based upon the studies performed recommended revisions to the Engineering Manual for design of foundations for flexible and rigid pavements over subgrades susceptible to frost action were prepared and forwarded to the Chief of Engineers. The recommended criteria for design are 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 Boston District was assigned the responsibility for organizing the program, 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 at the Boston District 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.

b. Purpose. - The purpose of the frost investigation is to provide test data and analyses producing the following:

(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 airfield 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 reported in detail as appendices to this report and to present the recommended design and evaluation criteria resulting from a study of the accumulated data.

c. Scope. - This report with the appendices presents in detail the summary of the studies, the observations and tests made, and the conclusions based upon the data including the recommendations for revisions to the Engineering Manual. The work presented herein includes only the data obtained in 1944 and 1945. The program 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 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 with 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 was studied at 10 airfields located in northern United States. Flexible pavements received greater attention than rigid pavements and turf study was auxiliary. A total of 23 test areas were investigated at these airfields. Thirteen test areas had flexible pavements and six test areas had rigid pavements. Four turf areas were investigated adjacent to paved test areas. The individual test areas were selected to encompass the full range of the following variables influencing frost action:

(1) Air temperature ranging from moderate to severe.

(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 non-plastic 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.

Five 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 moisture variations in the base and subgrade materials.

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

The airfields selected to obtain the data described above were as follows:

(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 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 obtained from the five preceding 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 and mercury thermometers (except at Truax Field).

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

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

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

d. Arrangement of Report. - This report presents a summary and analysis of the data which were obtained from the field and laboratory investigations. Detailed reports of the investigations are recorded in the following appendices which are the basis for the results contained herein.

Appendix No.	Title
1	Report on Dow Field, Bangor, Maine, June 1945.
2	Report on Presque Isle Airfield, Presque Isle, Maine, June 1945.
3 & 4	Reports on Otis Field, Sandwich, Massachusetts, and Houlton Airfield, Houlton, Maine, June 1945.
5	Report on Truax Field, Madison, Wisconsin, June 1945.
6	Report on Pierre Airfield, Pierre, South Dakota, June 1945.
7	Report on Watertown Airfield, Watertown, South Dakota, June 1945.
8, 9 & 10	Reports on Casper Airbase, Casper, Wyoming; Fargo Municipal Airfield, Fargo, North Dakota: and Bismarck Municipal Airfield, Bismarck, North Dakota, June 1945.
11 & 12	Reports on Subsurface Temperature Investigations at Pierre Airfield, Pierre, South Dakota; Watertown Airfield, Watertown, South Dakota; Presque Isle Airfield, Presque Isle, Maine; Dow Field, Bangor, Maine, June 1945.
13	Report on Cold Room Laboratory Freezing Tests, June 1945.
14	Reports on Laboratory and Field Test Procedures for Missouri River Division, Part 1; Great Lakes

Appendix No.	Title
	Division, Part 2; Boston District, Part 3, June 1945.
15	Bibliography, June 1945.

e. Photographic Records. - The appendices contain the more important and typical photographs obtained during various phases of the work. A complete record of all photographs has been submitted to the Chief of Engineers and a copy is on file at the Frost Effects Laboratory. Several reels of motion pictures were made of the traffic tests at Dow, Truax, and Pierre Airfields. These pictures also show the various phases of field testing. The motion pictures are on file at the Frost Effects Laboratory and at the office of Chief of Engineers.

f. 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:

(1) Soil. - Frost action within a soil is a function ot its void size which may be conveniently expressed as a function of grain size. In this investigation any soil which contains three percent or more by weight of grains smaller than 0.02 m.m. is considered frost susceptible and a soil in which frost action is possible.

(2) Water. - Frost action depends upon the availability of water either by virtue of an adjacent ground water table or a capillary supply or as water within the soil voids.

(3) 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 super-cooled water has a high molecular attraction to ice crystals. Thus the super-cooled 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. The thawing occurs largely from the surface down under a rapid thaw 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.

g. 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 airfiel 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 traffic 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 distinguished 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 considered 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 or 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, in general, 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 surface 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 percent 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.

(28) Normal Freezing Index. - Normal freezing index 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.

h. Acknowledgement. - These studies are based upon fundamental relations developed and presented by previous investigators, particularly S. Taber, A. Casagrande, P. 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. Rutledge of Northwestern University acted in the capacity of consultants.

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

3. General Conditions.

a. Locations. - The ten 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 geographical location map shown on Plate 1 summarizes the locations, elevations, and general physiography:

	LOCATION				
AIRFIELD	NORTH LAT.	WEST LONG.	U.S.E.D. DIV.	ELEV. ABOVE MSL	PHYSIOGRAPHY
Presque Isle Airfield, Maine	47	68	New England Div.	500	Glaciated region of rolling hills
Houlton Airfield Maine	46	68	New England Div.	470	Narrow valley flanked by high hills
Dow Field Maine	45	69	New England Div.	170	Glaciated region of rolling hills
Otis Field Massachusetts	42	70	New England Div.	120	Flat outwash plain
Truax Field Wisconsin	43	89	Great Lakes Div.	860	Low level marsh
Pierre Airfield South Dakota	44	100	Missouri River Division	1720	Ravines to predominating flat plateau
Casper Airfield Wyoming	43	107	Missouri River Division	5320	Gullies to rolling hills mountains to South
Watertown Airfield, South Dakota	45	97	Missouri River Division	1730	Flat to Rolling
Fargo Municipal Airfield, North Dakota	47	97	Missouri River Division	900	Bed of ancient lake - very flat
Bismarck Municipal Airfield	47	101	Missouri River Division	1650	Ascending and descending benches

b. Weather. - Of the ten airfields investigated Fargo has the greatest normal freezing index. The ten airfields are tabulated to show the normal freezing index and the approximate dates of the freezing period:

AIRFIELD	NORMAL FREEZING INDEX	NORMAL FREEZING PERIOD
Fargo	2646	1 Nov. - 1 Apr.
Bismarck	2552	1 Nov. - 1 Apr.
Presque Isle	2061	10 Nov. - 1 Apr.
Houlton	1780	15 Nov. - 1 Apr.
Watertown	1742	1 Nov. - 20 Mar.
Pierre	1294	15 Nov. - 15 Mar.
Dow	1275	25 Nov. - 25 Mar.
Truax	1227	1 Dec. - 10 Mar.
Casper	532	20 Nov. - 20 Mar.
Otis	202	15 Dec. - 1 Mar.

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 is greatest at Otis Field where a total of 13 inches is measured for three months prior to the start of freezing. The other airfields have less precipitation during a similar period in the following order:

AIRFIELD	TOTAL PRECIPITATION DURING 3 MONTHS PERIOD PRECEDING FREEZING (INCHES)
Dow	11
Presque Isle	10
Houlton	9
Truax	7
Watertown	4.4
Casper	4.4
Fargo	3.7
Bismarck	2.6
Pierre	2.4

Snowfall is greatest in the New England region where Presque Isle has a cumulative total above 100 inches. Snowfall becomes less toward Houlton (75 Inches), Dow (60 Inches), and Otis (18 Inches). Snowfall at the midwestern airfields ranges from 20 to 35 inches cumulative total for the 1944-1945 winter.

c. Traffic History. - A brief traffic history is tabulated for each airfield as part of Table 1. The data was obtained from Pavement Evaluation Reports of 1944 and in some cases from the appendices to this report.

d. Type and Condition of Pavements. - The thickness and type of each airfield pavement is shown in Table 1. The condition of the surfaces of the pavements prior to investigations is briefly summarized below. Crack surveys made during the normal period and after the frost melting periods were made at Presque Isle and Dow Airfields. The surveys are presented in the respective appendices.

Airfield	Thickness and Type of Pavement (Inches)	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% of area cracked due to previous tests and frost action.
Test Areas 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	3 B.C.	Good - Minor cracking and minor depressions
Otis		
Test Area A	5 to 7 B.C.	Good - Minor cracking and minor depressions.

Airfield	Thickness and Type of Pavement (Inches)	Condition
Truax		
Test Areas 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, minor cracks, and ponding.
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.

e. Bases. - The description, classification and grain size curves for bases in each test area are shown in Figure 2 on Plates 2 to 6 inclusive.

The predominant type of base course consists of sand and gravel of GW classification ranging from six to 48 inches in thickness. These base courses are slightly frost susceptible since most samples from each test area contain more than three percent finer than the 0.02 mm. size. Several airfields have base courses which are exceptions to the predominant type. At Truax a crushed rock base is underlain by a frost susceptible sub-base. At Presque Isle, Test Area B, two inches of crushed rock is underlain by a sand and gravel base. At Houlton, Test Area A., and Fargo Airfields a soil cement base course, six inches thick, underlies a bituminous concrete wearing course. Otis, Casper, and Watertown Airfields each have pavements constructed directly on frost susceptible subgrades.

f. Subgrade. - The wide range of subgrade soils encountered is indicated by the description, classification, and grain size curves shown in Figure 2 on Plates 2 to 6 inclusive. The predominant type of subgrade consists of silty clayey sands and gravels of CL and GC classification respectively. All the soils are frost susceptible since the percentage finer by weight of the 0.02 mm. grain size ranges from three to 91 percent.

g. Ground Water. - Of the ten airfields investigated, five airfields, Dow, Truax, Presque Isle, Fargo, and Houlton Airfields have a ground water table from four to about eight feet below pavement surface. Two airfields, Watertown and Bismarck, have a water table at about 12 feet and three airfields, Otis, Pierre, and Casper, have ground water tables at a considerable depth below the surface.

h. 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 and pavement edge.	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.
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 turf area.	Open joint pipe at bit. conc. pvt. edges and skip pipe at 175 feet from ℄ runway at bit. surface 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.

Airfield	Test Area	Surface Drainage	Subsurface Drainage
Otis	A	Surface runoff collected by longitudinal turf ditches located 150 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 turf area collected by catch basins in turf 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 shallow swale at edge of pavement.	None
Casper	A	Surface runoff collected by catch basins located in shallow gutters 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.

Airfield	Test Area	Surface Drainage	Subsurface Drainage
Bismarck	A	Surface runoff collected by shallow swale at edge of shoulders.	None
Pierre	A	Surface runoff collected by shallow swale at edge of shoulders.	None
	B	Surface runoff collected by shallow swale at edge of shoulders.	None

4. Results.

a. Tests for Soil Classification. - Laboratory tests, including sieve analysis, hydrometer analysis, Atterberg limits, and specific gravity were conducted on representative base, sub-base, and subgrade materials at all airfields. The soils were classified in accordance with Casagrande classification as outlined in the Engineering Manual, Chapter XX. Grain size curves and classification data for typical materials and typical logs for each test area are shown on Plates 2 to 6 inclusive. A summary tabulation of the results of tests, including Atterberg limits, Casagrande soil classification, and 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 to April and snowfall record are shown in Figures 4 and 5 on Plates 2 to 6 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 at periodic intervals by means of observation wells in the base and subgrade. These measurements were augmented by excavation of test pits at periodic intervals. The readings in the wells were obtained during the normal period and the frost melting period. Depth of ground water from the surface of the pavements is plotted against time and log profile of subgrade and base in Figure 6 on Plates 2 to 6 inclusive. Tabulation of the depth of the water table from the surface of the pavement for the various periods 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, during the freezing period, during the frost melting period, and during the 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 density and water

contents for the subgrade and base materials during these periods is shown graphically for all test areas in Figure 9 on Plates 2 to 6 inclusive. Results are also summarized in Table 1.

(4) Degree of Saturation. - The degree of saturation of the base and subgrade materials during the normal freezing and frost melting periods was 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 on Plates 2 to 6 inclusive. The average degree of saturation of the base and subgrade materials for the various testing periods is summarized in Table 1.

c. Tests for Temperature. - Measurements were made, or obtained from other sources, of the air temperatures at all airfields investigated. At 15 test areas measurements of subsurface temperature were made. The following paragraphs contain pertinent comments on these observations:

(1) Air Temperatures. - The air temperatures 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. Shown in Figure 3 on Plates 2 to 6 inclusive, are air temperature data in the form of degree day curves from 1 November 1944 to 1 May 1945 and normal curve for same period at each airfield. The normal freezing index, [illegible] ezing index for 1944-1945,

and the percentage above or below normal are included in Table 1.

(2) Subsurface Temperatures. - Subsurface temperatures were measured by means of copper-constantan thermocouples, imbedded beneath the surfaces of pavement or turf at various depths to about six to eight feet, using a potentiometer which indicated the temperature directly. Complete description of installation and measurements of thermocouples is presented in Appendices 11 and 12. Thermocouples were installed in the bituminous concrete pavement and turf test areas at Dow Field, Presque Isle, and Watertown. At Pierre thermocouples were installed in the bituminous concrete test areas and in a special test box. At Watertown temperature measurements were also made using thermometer wells containing glass bulb thermometers suspended in antifreeze in saran pipes. Only thermometer wells were installed at Fargo. The variations in temperature from the surface to a depth of six feet between the months of January and April is shown for a typical installation on Plate 6 of Appendix 12. The freezing temperature of soils is believed to be between 28°F and 32°F depending upon the soil. In Figure 11 on Plates 2 to 6 inclusive are shown plots of the 28°F and 32°F subsurface temperature with respect to depth and time from December to April. Also plotted on these charts are the depth of frost penetration

obtained by excavation of test pits, plotted against the same depth and time.

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 9 on Plates 2 to 6 inclusive. These data are summarized in Table 1. The ice lenses observed in the subgrade occurred in non-continuous horizontal layers ranging from 1-3/8 inch to hairline thickness and were generally spaced irregularly, less than 1/2 inch apart, with the lenses becoming 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 at Truax in the base materials in Test Area C and sub-base materials in Test Area B. Photograph of typical ice lens formations at Dow Field is shown on Plate 7. Ice lenses were consistently observed in excavations, during the freezing period, in subgrade soils in order of increasing thickness and extent at all test areas at Dow, Presque Isle, Houlton, and Truax. Small, thin, scattered ice lenses were observed during the freezing period at all test areas at Otis, Pierre, Watertown, Fargo, and Bismarck. No ice lenses were found at Casper.

(2) Pavement Heave. - The pavement heave was measured by means of level surveys supplemented by wire line readings during the normal, freezing, and frost melting periods. The amount of heave is shown in Table 1 and in Figure 7 on Plates 2 to 6 inclusive. The greatest pavement heave occurred in Test Area A at Dow Field, with an average heave for the whole test area of 0.5 foot and a maximum heave of 0.7 foot. The average pavement heave at all test areas except those at Dow, Presque Isle, Houlton, and Truax was practically negligible being less than 0.07 foot. The pavement heave was relatively uniform for all airfields except Dow, Presque Isle, and Watertown. In test Area B at Pierre, in Test Area A at Bismarck, and Test Area B at Watertown, pavement heave observations indicate that the pavement at the crown did not heave, but rather subsided a very small amount while the pavement at the edges heaved. This type of heaving is best illustrated by contours on Plate 4, Appendix 7.

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 by solid line in Figure 11 on Plates 2 to 6 inclusive. The laboratory studies and part of the mathematical studies are reported in Appendix 13.

A graphical method of predicting the depth of frost penetration in soil is presented on Plate 8 of this report. The method is based on an article by W. P. Berggren "Prediction of Temperature Distribution in Frozen Soils", Transactions American Geophysical Union 1943. Pertinent comments on the field measurements, laboratory and mathematical studies are presented in the following paragraphs:

(1) Field Measurements. - The depth of frost penetration and the rate that frost enters the ground were obtained by measurements in a series of test pits excavated at the start of freezing and periodically to the end of the frost melting period. At some of the airfields test pits were excavated to obtain only the maximum depth of frost penetration. It will be noted in Figure 11 on Plates 2 to 6 inclusive that at most airfields there is a relatively close agreement between the 32°F curve obtained from results of subsurface temperature readings and the frost penetration obtained by observation in test pits.

(2) Laboratory Studies. - Tests were made to determine the temperature changes in laboratory specimens of sand due to suddenly impressed surface temperatures and to determine the thermal conductivity, in the unfrozen state, of five representative materials commonly used for base construction, sand, sand and gravel, crushed rock, slag, and cinders, and one sample of asphaltic concrete pavement. The results of the tests to determine the temperature changes within test specimens are reported in Appendix 13.

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." The "boundary temperature difference" was used principally to investigate its effect on the equilibrium temperature gradient within a specimen. The results of these tests are shown on Plates 6 to 8, Appendix 13. From four of these same tests, it was also possible to evaluate the ratio of the coefficient of thermal conductivity of the frozen to the unfrozen state. For the material tested, a uniformly graded, cohesionless, siliceous, medium sand, this ratio varied from 0.52 to 0.85, for the water contents and densities tested.

The results of tests to determine the coefficient of thermal conductivity are summarized on Plate 11 and tests by another investigator, on Plate 12, both of Appendix 13. These tests indicate that the coefficient of thermal conductivity varies with the water content and density of a given soil and that different soils may have widely different coefficients of heat conductivity.

Tests upon cinders and slag indicate that these materials are good insulators in comparison to the other materials tested.

(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 and is presented on Plate 8. An example for use in computing the depth of frost penetration is also presented on Plate 8. This solution cannot be used at the present time due to inadequate knowledge of coefficient of thermal conductivity of soils in the frozen state.

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. and plate bearing tests are described in Appendix 14. Detailed results of all tests and traffic tests conducted are presented in the appendix for the specific airfield. The tests performed 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 on Plates 2 to 6 inclusive. Estimated values where shown are based upon laboratory tests and field experiences with similar soils.

(2) Plate Bearing Tests. - Static and repeating load plate bearing tests were conducted on the surface of bituminous

concrete pavements in accordance with procedure described in Appendix 14. A summary of these tests is presented in Tables 2 to 6 inclusive. Both types of bearing tests were performed at Dow, Presque Isle, and Truax Airfields during the fall and frost melting period. The static load test results are plotted in Figure 12 on Plates 2 to 6 inclusive to show the variation in the load required to deflect the test plate 0.1 inch from fall to spring.

(3) Traffic Tests. - Traffic tests were conducted on the flexible pavement during the frost melting period at Dow in Test Area B (B1 and B2) and C (C1 and C2), at Truax in Test Areas B (B1 and B2), and at Pierre Airfield in Test Area B (T1 to T12). A summary of the traffic test data is presented in Table 7. The wheel loads used were determined to bracket or approximate the evaluation of the specific pavements for frost melting conditions. The wheel loads at Dow were 40,000 and 60,000 pounds, at Truax 30,000 and 60,000 pounds, and at Pierre 7,000, 14,500 and 25,000 pounds. 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 information it was assumed that 15 coverages per day were equivalent to operation of runways and 45 coverages per day equivalent to operation of taxiways. In all cases it was not possible with the

available equipment to apply exactly 15 and 45 coverages, hence individual tests vary in daily coverage. The traffic pattern was so designed to gradually attain by steps the maximum coverages in the traffic 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 for the vertical deformation in the traffic test areas and observations for the behavior of the pavement were made daily during the traffic tests. At the end of the traffic tests detailed measurements were made of the pavement surface and trenches were excavated in traffic test areas where failure and no failure had occurred, 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 percent of the area was map cracked or the flexing of the pavement reached one inch. 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 is about to occur was used as a basis to determine whether pavement was satisfactory or unsatisfactory rather than complete failure which would leave the pavement impassible. The equipment to obtain the various loads ranged from large rubber tired construction equipment to trucks. In Table 7 are listed results of the traffic tests with additional related data for each test area. Wheel loads considered unsatisfactory are identified by a double asterisk in Table 7. As an example: Dow Field Test Area (B-1) imminent failure did not occur for 40,000 pounds wheel load for 15 coverages per day; therefore, pavement was considered satisfactory for the conditions tested. At 45 coverages per day and same wheel load, imminent failure occurred and the pavement is not satisfactory for the conditions tested.

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 field test procedures for plate bearing tests are reported in Appendix 14. Detailed results of all tests and traffic tests conducted are presented in the appendix for the specific airfield. The results of plate bearing tests and traffic tests with pertinent comments thereon are presented in the following paragraphs:

(1) Plate Bearing Tests. - Two types of pavement bearing tests were made, rupture tests on the pavement surface and subgrade modulus tests. Summary of results of plate bearing tests are presented in Tables 2 to 6 inclusive and average results are shown in Figure 12 on Plates 2 to 6 inclusive. The rupture tests were made directly on the surface of the pavement using a 24-inch plate

placed at a corner of a slab made by the intersection of a longitudinal construction joint and a transverse expansion joint. In the rupture tests, if failure did not occur under increment loading, an attempt was made to cause failure by a number of repetitions of maximum load. At the same locations, but outside the influence of the rupture tests, subgrade modulus tests were conducted on the surface of the base material after the removal of part of the slab. Rupture tests and subgrade modulus tests were conducted at Dow, Presque Isle, Truax, Watertown, and Pierre Airfields. It was intended that the tests be conducted during the fall and again during the frost melting period in order that the difference in bearing capacity between these periods could be obtained. However, only at Presque Isle were these tests conducted during both periods. At Dow, Watertown, and Pierre the tests were conducted during the fall and rupture tests during and after frost melting. For the rupture tests, failure was reached only at Pierre and Watertown Airfields. The results of the subgrade modulus tests show a decrease in bearing capacity during the frost melting period at Presque Isle.

(2) Traffic Tests. - Traffic tests were conducted on portland cement concrete pavement during the frost melting period at Truax in Test Area C (C1 and C2) and at Pierre in Test Area A (R1 to R4). A summary of the traffic test

data is presented in Table 7. The wheel loads used were consistent with the previous evaluation of the specific airfields. The wheel loads for Truax were 15,000 and 30,000 pounds and for Pierre 14,500 and 25,000 pounds. The application of traffic was made on the basis of 15 coverages per day which was determined from a consideration of runway usage and 45 coverages per day equivalent to operation of taxiways. With the equipment available it was not possible to obtain the exact 15 and 45 coverages. Therefore, the nearest possible figure to these were used in the analysis of the results. The test lane was located with its center line over a construction joint. The traffic pattern was so designed to gradually attain by steps the maximum coverages in the traffic lane. Traffic tests were started generally 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 if cracks had occurred in about 20 percent of the test lane or when the permanent deformation exceeded one inch. It was the intent to reduce the damage from traffic tests to a minimum consistent with test results. The equipment was the same as used for the traffic tests for bituminous concrete pavement which were conducted concurrently. In Table 7 are listed the results of the traffic tests.

h. Tests for Insulation Qualities of Turf and Snow Cover. - Investigations were conducted at two turfed areas at Presque Isle, Dow, and Watertown Airfields and at one turfed area at Pierre Airfield. The tests conducted and observations made were 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 and the other turfed area was not plowed. The purpose of these tests was to obtain a comparison of frost action, particularly frost penetration, between 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 6 inclusive. Detailed results of effect of snow cover are presented in Appendices 11 and 12 and detailed results of all tests in turfed areas are contained in the respective appendices for Dow, Presque Isle, Watertown, and Pierre Airfields. The snowfall data for the various airfields were either obtained from the nearest U. S. Weather Bureau or from the A.A.F. Weather Officer. These data were augmented by measurements and observations at the specific airfields. The paved test areas were plowed and snow removed as close to the pavement as practicable immediately after each snow fall. It was not possible to remove the snow to the bare pavement with the result that during the winter months, and depending upon weather conditions, a layer of packed snow or ice from one-half to two inches in thickness covered the test areas. At the turfed areas measurements of snow cover were made periodically.

5. Analyses.

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 flow of water from a relatively close ground water table to the freezing soil, or a flow of water from adjoining 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 occurring prior to freezing period, and measuring soil water content and the degree of saturation before freezing. Results of these measurements at all test areas are summarized on Table 8. In addition, there have been added to this table data which show the character and extent of frost action. From a study of these data, the following conclusions are presented:

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

(2) At locations 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, slight to no frost action occurred in frost susceptible soils.

(3) The magnitude and extent of ice lens formations which varied from an exceedingly few thin lenses to many thin to thick lenses, was dependent upon two related factors: (1) the degree of saturation at start of freezing and (2) the relationship between the natural water content at start of freezing and the Atterberg limits. The magnitude and extent of frost action was greater for subgrades

well saturated or near the liquid limit. Frost action was negligible when the subgrade saturation was below approximately 65 percent or near the plastic limit.

(4) The degree of saturation beneath paved areas varied generally with the climatic conditions, the lesser degree of saturation occurring 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 three test areas, frost heaving was greater at the pavement edge than at the center. This condition is believed to be the result of water seepage from adjoining turfed areas into the subgrade beneath the pavement. Some test areas developed a slight settlement during the winter. Greater heaving at edges than at center of pavements occurred only at test areas with bituminous concrete pavements without subsurface drains at pavement edges.

(6) At all concrete paved test areas, it is believed 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 concrete paved test areas was more uniform compared to adjacent bituminous paved areas and the settlement which occurred at three bituminous paved test areas did not occur in

the three 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 percent 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 lenses 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 prevent frost action in a frost susceptible soil.

At Otis Field, a non-uniform soil profile with pockets of frost susceptible soil caused differential heaving of the pavement.

The observations performed do not indicate which soils are more susceptible to frost action than others 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 the magnitude and duration of below freezing air temperatures, the coefficient of the thermal conductivity of the several materials in a frozen state and to a lesser degree upon the other thermal properties, and the subsurface temperature conditions at start of freezing. All these factors are analyzed by W. P. Berggren whose solution is presented in a simplified form on Plate 8. This solution cannot be used to predict frost penetration as yet, since reliable data are not available on the thermal properties of various soils in both the frozen and unfrozen state. This analysis does permit the making of computations which show that the depth of frost penetration vs. freezing index varies approximately as a straight line function when plotted on log log plot as shown on Plate 9. On Plate 9 there are plotted all observations of frost penetration in frost susceptible and non-frost susceptible soils beneath paved areas. Figure 1 shows data for portland cement concrete pavements, Figure 2 for bituminous concrete pavements, and Figure 3 contains all results. The straight line shown on each of these figures is the same and was determined based upon a study of these test data. Figure 3 may be used to predict the depth of frost penetration beneath all types of paved areas which are maintained snow free and which 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 Turf 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

* From Subsurface temperature readings at 32°F.
** Frost penetration 3 February 1945.

These data indicate 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, Plate 13, has been prepared on which are plotted contours of equal normal freezing indices for the United States. Using this plate, the depth of frost penetration may be estimated from Plate 9 for any particular location in the United States. This approximate value for frost penetration so determined is an average value and not a maximum value.

e. Effect of Frost Action on Rigid Pavement Supporting Capacity.

(1) Truax. - At Truax, 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 feet to 0.12 feet in the traffic test areas. Results of traffic tests are shown in Table 7. Traffic tests with 15,000 and 30,000 lbs. wheel loads, traffic test areas C-1 and C-2 respectively, were conducted, through the frost melting period, from 7 to 20 March 1945 inclusive using 45 and 15 coverages daily. No failure was obtained with the 15,000 lbs. wheel load, however, progressive cracking developed for the 30,000 lbs. wheel load and the traffic test area C-2 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 C-1, previously tested with 15,000 lbs. wheel load, a 30,000 lbs. 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 lbs. wheel load for runways and 28,000 lbs. wheel load for taxiways and apron. For purposes of analyses, it is assumed that average maximum daily plane traffic over runways and aprons is 15 and 45 coverages respectively.

The pavement withstood 15 and 45 coverages of 15,000 lbs. wheel load, failed under 45 daily coverages but did not fail under 15 daily coverages of the 30,000 lbs. 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 lbs. wheel load. The failure of the pavement during the frost melting period under 45 daily coverages of 30,000 lbs. wheel load compared to the normal period evaluation for aprons of 28,000 lbs. wheel load indicates a reduction in pavement supporting capacity during the frost melting period. A reduction is also indicated since a 30,000 lbs. wheel load was satisfactory directly after the frost melting period. 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 lbs. 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 lbs. did not crack the pavement at a maximum deflection of 0.16 inches. 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 there was no ice lens formation in the base and practically none in the subgrade. The relatively uniform heave ranged from 0.0 to 0.03 feet. Results of traffic tests are shown in Table 7. Traffic tests with 14,500 and 25,000 lbs. wheel loads in traffic test areas R1 and R2, and R3 and R4 respectively were conducted from 14 to 29 March 1945 which was about the end of the frost melting period. For each wheel load, daily coverages of 15 and 45 were applied. During the period 14 to 29 March, no failure was obtained with the

14,500 lbs. wheel load at both 15 and 45 daily coverages. The 25,000 lbs. wheel load at 15 coverages was also satisfactory, but failure occurred for 45 coverages almost at start of traffic. Additional tests of 178 daily coverages were conducted using 14,500 and 25,000 lb. wheel loads in traffic test areas R2 and R3 respectively 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. The concentrated traffic of 14,500 lbs. wheel load on traffic test area R2 with increased daily coverages produced no failure. However, the 25,000 lbs. wheel load on traffic test area R3 produced failure. The evaluation of the pavement during normal period for runways is 30,000 lbs. wheel load and for taxiway and aprons the evaluation is 25,000 lbs. wheel load. The failure is attributed primarily to pumping during traffic and not frost action. Pumping results from the infiltration of surface water through the pavement joints. 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 lbs. to 90,000 lbs. at deflections of 0.18 inches and 0.24 inches respectively. The deflections produced by the 25,000 lbs. wheel load in traffic test area R3 where failure occurred under moving load was 0.052 inches and for static load 0.003 inches. The results of plate bearing tests (subgrade modulus) conducted after the frost melting period are plotted on Plate 11.

(3) Watertown. - The plate bearing tests (rupture) at Watertown indicated corner failure of the pavement with maximum load of 100,000 lbs. at deflections of 0.18 inches, 0.32 inches, and 0.35 inches. 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 were not obtained at Presque Isle and Dow at maximum load of 60,000 lbs. for deflections 0.16 and 0.19 inches respectively. Plate bearing tests (subgrade modulus) were conducted at both airfields. Results are plotted on Plate 11. At Presque Isle 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) Summary. - At Truax, the traffic tests indicate a definite reduction in pavement supporting capacity due to frost action. At Pierre 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.

On Plate 11 are plotted the results of the subgrade modulus tests conducted at Pierre, Presque Isle, and Dow during the frost melting period and curve "A" represents the trend of these tests. The type of subgrade soils at all of these airfields fall into group 3 on Plate 11. It will be noted that there is not a close agreement with Curve A and curve designated "3". The three curves designated "1", "2", and "3" on Plate 11 were purposely drawn for design purposes to indicate conservative values for 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. Data obtained from plate bearing tests on flexible pavements as plotted on Plate 10, indicate the extent to which frost action will affect the load required to produce a 0.1 inch deflection of the plate. Accordingly the three curves as shown on Plate 11 and repeated on Plate 16, are considered reasonable for design purposes until additional data become available. It is not feasible to check these curves using the traffic tests.

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 would benefit by (a) eliminating the ice lenses which formed directly beneath the pavement, (b) providing a layer through which the water infiltrating through joints and cracks can be drained away, and (c) eliminating the pumping under traffic.

Likewise the traffic tests at Pierre show clearly the necessity for a non-frost susceptible base course beneath concrete pavements to eliminate failures due to pumping.

f. Effect of Frost Action on Flexible Pavement Supporting Capacity.

(1) Truax. - At Truax 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 sub-base. 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 B-1 and B-2 ranged from 0.01 to 0.03 foot and was relatively uniform with no concentration. Results of traffic tests are presented in Table 7. Traffic tests with 30,000 and 60,000 lbs. wheel loads in traffic test areas B-2 and B-1 respectively, were conducted using 45 and 15 coverages daily or as near these daily coverages as possible. The traffic tests were conducted through the frost melting period having been started on 12 March and continued through 3 April 1945. No failure or distress was obtained in traffic test area B-2 with 30,000

lbs. wheel load for 14 and 42 coverages daily for 10 days. The maximum vertical deflections were 0.5 inches and no cracking occurred in pavement during the traffic tests. For the 60,000 lbs. wheel load, traffic test area B-1, no cracking or failure occurred for 15 coverages for test duration of 19 days. Flexing of the pavement of 0.005 foot for 15 coverages and about 0.02 foot for the 45 coverage lane was observed during the tests. Deformation of 1.0 to 1.5 inch occurred in the 45 coverage lane and traffic was stopped as it was believed localized cracking would result if traffic was continued. The evaluation of the pavementis 30,000 lbs. wheel load for runways or taxiways. This evaluation is controlled by the 2-1/2 inch thickness of bituminous concrete pavement, however, disregarding the controlling 2-1/2 inch thickness of pavement, the evaluation is greater than 60,000 lbs. wheel load. The greatest damage to the pavement occurred at the turn around areas for the 60,000 lbs. wheel load. Flexing at the turnaround areas was about 0.03 foot and considerable map cracking and rutting occurred. The explanation for the behavior of the pavement in this area is an inferior sub-base material and about four to five inches less crushed rock base than in traffic test areas B-1 and B-2. Based upon the traffic tests, C.B.R. values for the subgrade may be determined using the Engineering Manual design curves. These computations indicate the following C.B.R. values for the two traffic test areas.

Test Area	Wheel Load Lbs.	Daily Coverages	Failure	Pavement and Base Thickness Inches	C.B.R.
B-1	60,000	15	No	51	>3
B-1	60,000	45	Yes	51	<3
B-2	30,000	15	No	51	>2
B-2	30,000	45	No	51	>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 B-1 for 60,000 lbs. wheel load for 45 coverages per day was stopped since a continuance of traffic would have caused failure in a few more daily coverages. 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 in turn with the reduction of the C.B.R. values from the normal period to the frost melting period from five to three indicates a reduction in pavement supporting capacity during the frost melting period. The results of plate bearing tests further confirm a reduction in pavement supporting capacity during the frost melting period. Results of these tests plotted on Plate 10 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 0.8 foot at Truax is 1.2. Similarly 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. The repeating plate bearing tests also indicate that the reduction in pavement supporting capacity extends over a period of about three months after the sudden decrease during the frost melting period.

(2) Pierre. - No ice lens formations were found in the sand and gravel base at Pierre, 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 lbs. wheel loads for 14,

16, 32, 42, and 48 coverages daily. The paved shoulders, with 1-1/2 inches of bituminous concrete pavement, under wheel loads of 7,000, 14,000, and 25,000 lbs. for 14, 16, and 48 coverages daily generally developed distressed areas due to rutting and map cracking and can be considered failed under these loads. In the paved taxiway traffic test areas, with 5-1/2 inches of bituminous concrete pavement, failure occurred only at test area T2 under wheel load of 25,000 lbs. and 42 daily coverages after 5 days application of traffic. The evaluation for the normal period for the paved shoulders is 15,000 lbs. wheel load for runway and taxiway, based upon in-place C.B.R. tests. This evaluation is controlled by the 1-1/2 inch thickness of bituminous concrete pavement. The C.B.R. values for the subgrade may be determined from the results of the traffic tests using the Engineering Manual design curves. These computations indicate the following C.B.R. values for the traffic test areas in the paved shoulders.

Test Area	Wheel Load Lbs.	Daily Coverages	Failure	Pavement and Base Thickness Inches	C.B.R.
T-1	14,500	15	Yes	13.5	< 9
T-4	25,000	45	Yes	13.5	<15
T-5	14,500	45	Yes	13.5	<10
T-8	25,000	15	Yes	13.5	<13
T-9	7,000	45	Yes	13.5	< 7
T-11	7,000	15	Yes	13.5	< 7
T-12	25,000	(2 days traffic)	Yes	13.5	<15

The traffic test areas listed above are located in the paved shoulders, with 1-1/2 inches bituminous concrete pavement, where the frost heaving occurred. 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 listed the same data as tabulated above for the traffic tests conducted where a slight settlement occurred during the winter.

Test Area	Wheel Load Lbs.	Daily Coverages	Failure	Pavement and Base Thickness Inches	C.B.R.
T-2	25,000	45	Yes	13.5	<15
T-3	14,500	15	No	13.5	>9
T-6	25,000	15	No	13.5	>13
T-7	14,500	45	No	13.5	>10
T-10	7,000	45	No	13.5	>7

The C.B.R. values from these traffic tests were greater than seven and less than 15. 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 pavement and base thicknesses were equal. The results of the C.B.R. tests conducted during the normal period and during the frost melting period showed a decrease from 14 to 12. These tests were conducted in the area of subsidence and no frost action. The small variation 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 and how much by a difference in pavement thickness.

(3) Dow Field. - At Dow Field at both test areas B and C ice crystals were found in the sand and gravel base. Numerous ice lenses were located in the subgrade at depths ranging from three feet to five feet. The heave was fairly uniform averaging 0.25 foot. Results of traffic tests are presented in Table 7. Traffic tests were conducted with 40,000 and 60,000 lbs. wheel load for traffic test areas B-1 and C-1, and B-2 and C-2, respectively, for 16 and 46 coverages daily. The traffic tests were started 2 April 1945, the approximate end of the frost melting, and continued to 20 April 1945. Failure occurred in traffic test area B-1 using a 40,000 lbs. wheel load at 46 coverages daily and in traffic test area B-2 using a 60,000 lbs.

wheel load at 16 coverages daily. No failure occurred in traffic test areas C-1 and C-2 for 40,000 and 60,000 lbs. wheel loads respectively at 16 and 46 coverages respectively. Based upon these traffic tests, C.B.R. values for the subgrade may be computed using the Engineering Manual design curves. These computations 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.
B-1	40,000	16	No	31	>4
B-1	40,000	46	Yes	31	<5
B-2	60,000	16	Yes	29	<6
C-1	40,000	16	No	40.5	>3
C-1	40,000	46	No	40.5	>3
C-2	60,000	16	No	48	>3
C-2	60,000	46	No	48	>3

A study of these C.B.R. values, which represent the subgrade strength during the period of test, indicates that a C.B.R. of about four was obtained. In-place C.B.R. tests conducted on top of the subgrade 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 indicate a reduction in pavement supporting capacity during the frost melting period. Further confirmation of a reduction in pavement supporting capacity is evidenced by the plate bearing tests performed upon the pavement surface. Results of these tests, as plotted on Plate 10, 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 0.8 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. Further, these plate bearing tests indicate that the reduction in pavement supporting capacity occurs suddenly during the frost melting period, then the subgrade gradually regains strength. The results do not show how long a period is required for the subgrade to regain its full strength, however, the indications are that at Dow a period of at least three months is required.

(4) Presque Isle. - At Presque Isle, where the frost action was severe, results of the plate bearing tests, both static load and repeating load, indicate a definite reduction of the pavement supporting capacity during the frost melting period as shown by results summarized on Table 2. Similarly 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.

(5) Watertown. - At Watertown, frost action as evidenced by

pavement heave was confined to the pavement edges with none occurring at the center. Plate bearing tests, both static and repeated load, were conducted during and immediately after the frost melting period in both heaved and non-heaved areas. 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 during the frost melting period 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 five 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 as summarized in Table 7 indicate a slight reduction in C.B.R. during the frost melting period, this reduction is discounted for two reasons: (a) 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 (b) no frost action occurred in areas tested for C.B.R. since these test locations are at points which settled slightly during the winter.

(6) Casper. - At Casper a very small concentration of heave occurred at the shoulders and a subsidence 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 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.

(7) Fargo. - At Fargo ice lens formations were numerous in the subgrade however, none were observed in the base. The heave was uniform averaging about 0.07 foot. The results of C.B.R. tests conducted during the frost melting period and normal period indicate a small decrease from the normal period from about seven to six. Thus indicating a slight decrease of pavement supporting capacity during the frost melting period.

(8) Bismarck. - At Bismarck, 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 which

would occur at this site would be minor.

(9) Houlton. - No ice lens formation occurred in the bituminous concrete pavement test area at Houlton. 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 tests, a slight decrease in C.B.R. may be shown during the frost melting period.

(10) 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 evidenced to frost action.

(11) Summary. - The analysis of the test data obtained during this investigation indicate the following results in connection with the establishment of criteria for the design of airfield pavements where the subgrade is subject to frost action:

(a) The results of in-place C.B.R. tests, plate bearing tests conducted on top of the bituminous concrete pavement surface, and traffic tests indicate a definite reduction in the pavement bearing capacity during the frost melting period.

(b) The in-place C.B.R. tests and plate bearing tests are more adaptable to determine the reduction in pavement bearing capacity than the traffic tests, and it is believed that satisfactory qualitative results of pavement bearing reduction during the frost melting period may be obtained by the plate bearing tests.

(c) Sufficient results were not obtained to determine the duration of the period during which the reduction in pavement bearing capacity occurs.

(d) The plate bearing tests indicate that the depth of frost penetration in the subgrade has no direct bearing on the magnitude of the reduction in pavement bearing capacity during the frost melting period.

6. Conclusion. - Based upon the analysis of the test results and test data presented herein, a method of design of flexible and rigid pavements where conditions are conducive to frost action both in theaters of operations and in the United States is presented. The method of design as contained in "Recommended Revision to Engineering Manual, Chapter XX, Part II, Paragraph 20-23 and Part IV, Paragraph 20-46 dated September 1945, Revised 15 November 1945" is shown in its entirety in the following paragraphs. This design criteria has been reviewed, edited and published in final form by the Chief of Engineers as "Airfield Pavement Design, Frost Conditions, Ad Interim Engineering Manual For War Department Construction Part XII, Chapter 4" dated July 1946.

RECOMMENDED REVISION TO ENGINEERING MANUAL, CHAPTER XX, PART II, PARAGRAPH 20-23 AND PART IV, PARAGRAPH 20-46

REVISED 15 NOVEMBER 1945

20-23 DESIGN OF FOUNDATION FOR FLEXIBLE PAVEMENT OVER SUBGRADE SUSCEPTIBLE TO FROST ACTION.

a. General. - The strength of some soils is greatly reduced as a result of frost action. The detrimental effect of frost action occurs during the thawing periods when the moisture in the subgrade, accumulated in the form of ice segregation, is released, thereby softening the soil. The frost action in some soils also causes detrimental heave of pavement or treated surface. The degree to which soils will lose their strength and heave will depend upon the type of soil, air temperature during freezing and thawing, the permeability of the soil and the ground water and drainage conditions.

b. Department Policy. - Where subgrades are susceptible to frost action, it is the policy of the Department to design foundations for flexible pavements 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. It is also the policy of the Department to permit a greater degree of roughness due to frost heave over a short period of time for airfield pavements than is permissible in modern primary highways. Where frost action is possible in the subgrade, the design should be based on capacity operation.

c. Definitions.

(1) Frost Action is the accumulation of water in the form of ice lenses in the soil or base materials under natural freezing conditions.

(2) 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 the ice lenses.

(3) Freezing Index is a measure of the combined duration and magnitude of below freezing air temperatures occurring during any given winter. See Plate 12 for method for determining freezing index.

(4) Normal Freezing Index is the freezing index computed for normal air temperatures based upon a long period of record, usually 10 or more years.

(5) Frost Susceptible Soil is a soil in which frost action is possible. Any soil which contains three percent or more by weight of grains smaller than 0.02 mm. in diameter shall be considered a frost susceptible soil.

(6) Non-Frost Susceptible Base Materials are crushed rock, sand, sand and gravel, gravel, slag, cinders, or any other cohesionless material in which frost action is not possible. Any material which contains three percent or more by weight of grains smaller than 0.02 mm. diameter shall be considered susceptible to frost action.

(7) Ground Water Table is the free water surface nearest to the ground surface.

(8) Foundation Modulus refers to the modulus of soil reaction (k) in Paragraph 20-41.

d. Frost Action Criteria. - Frost action shall be considered in the design if conditions at the site meet all of the following:

(1) Normal freezing index is greater than zero.

(2) Subgrade soil is frost susceptible.

(3) The site is located within the unshaded area of Plate 13 or in the shaded area, if the ground water table in the spring is at a depth less than 20 feet.

e. Base Thickness Requirements for Stability.

(1) 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. Less depth of pavement and base than required to prevent freezing of the subgrade is permissible where the design is based upon a reduction in strength of the subgrade as a result of frost action. The reduction of strength of subgrades as a result of frost action is greater in cuts than in fills. The combined pavement and base thickness as determined by the California Method, Paragraphs 20-17 through 20-22 will control if it is greater than the combined thickness based upon consideration of frost action.

(2) The combined thickness of pavement and base required to prevent frost action in the subgrade in cut sections shall be determined using Plate 14 and the normal freezing index for the particular location. To determine the normal freezing index, Plate 13 upon which normal freezing indices for the United States based upon Weather Bureau data are plotted may be used. Where the normal freezing

index on Figure 2 is less than 100, the freezing index shall be computed for the coldest year of record for the past 15 years and design based upon this value or 100, whichever is the larger. In mountainous areas, the normal freezing index shall be computed for the particular location.

(3) North of the dash line indicated on Plate 13, a minimum thickness of pavement and non-frost susceptible base of nine inches shall be provided.

(4) Where the subgrade soil is an inorganic silt (ML), experience indicates that the combined thickness of pavement and base to prevent excessive differential heave should be not less than the value determined from Plate 14.

(5) 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 Plate 14 may be decreased depending upon the thickness and thermal properties of the insulator. Four inches of slag or cinders may be substituted for every six inches of sand, gravel or crushed rock.

(6) Plate 15 shall be used to determine the pavement and base thickness required in cut sections 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.

(7) In fill sections, where the depth of fill is greater than five feet and is composed of frost susceptible soil and the ground water is at a depth of at least three feet below bottom of fill, experience indicates that combined pavement and base thickness determined from Plate 15 may be reduced. For design, a 25 percent reduction may be used except that the minimum thickness shall be not less than nine inches.

(8) At locations within the shaded area on Plate 13 and provided the ground water table in the spring in this area is greater than 20 feet below ground surface, the design may be based on the California method.

(9) A 50-foot longitudinal transition should be provided for any changes in base thickness and the reduction should occur in the fill section where the fill is greater than five feet over the full cross section.

(10) Based upon the above methods for determination of pavement and base thickness (using Plate 14 and Plate 15), two values for this combined thickness are determined for a particular condition. The smaller of these values shall be compared with the combined pavement and base thickness determined using the California Method and whichever of the latter two values is the greater shall govern for design.

f. Base Composition Requirements.

(1) All base materials for designs of flexible pavement foundations over subgrades susceptible to frost action

shall be non-frost susceptible.

(2) Where the combined thickness of pavement and base is less than the value determined from Plate 14, the bottom four inches of the base shall consist of any non-frost susceptible gravel, sand or crushed stone with at least 50 percent by weight of the grains passing a No. 40 mesh sieve. This material will in general act as a filter and will prevent mixing of the subgrade with the base during and immediately following the frost melting period.

(3) In areas where suitable non-frost susceptible base materials are not available locally, it may be possible to treat frost susceptible base materials to make them non-frost susceptible by satisfactory admixtures. A satisfactory admixture is one for which reliable evidence of permanency of protection is available. Materials so treated may be used for the base except for the top six inches directly beneath pavement.

g. Compaction. - Compaction of the subgrade will be as outlined in Paragraph 20-14.

h. Example for Design:

(1) Conditions

Normal Freezing Index	1500
Subgrade	Cut section of lean clay with 50 percent by weight of grains passing No. 200 mesh sieve
Subgrade CBR	8 (undisturbed soaked)
Base	Non-frost susceptible sand and gravel

Base CBR	80
Design Wheel Load	60,000 lbs.
Pavement	Runway with bituminous concrete surface.

(2) Using Plate 14, the combined pavement and base thickness required to prevent subgrade freezing is 54 inches.

(3) From Plate 15, the combined pavement and base thickness required for design considering reduction in strength of subgrade due to frost action is 45 inches.

(4) Using the California Method, a combined thickness of pavement and base of 24 inches is required.

(5) The value from Plate 15, 45 inches, is smaller than value from Plate 14, 54 inches, and greater than the value using the California Method, hence, a combined thickness of pavement and base of 45 inches would be satisfactory for design.

(6) If 20 inches of cinders or slag, which is the insulating equivalent of 30 inches of sand, gravel, or crushed stone, (paragraph 20-23 e (5)), are used as part of the base, the combined thickness of pavement and base of 54 inches as obtained from Plate 14 may be reduced to 44 inches. If the entire base is constructed of cinders or slag, the required combined thickness of pavement and base would be 36 inches instead of 54 inches.

(7) The most economical design should be selected.

20-46 DESIGN OF FOUNDATION FOR RIGID PAVEMENT OVER SUBGRADES SUSCEPTIBLE TO FROST ACTION.

a. Introduction. - The effects of frost action in subgrades beneath rigid pavements are similar to those discussed in Paragraph 20-23-a. The Department policy for the design of foundations for rigid pavements shall be as stated in Paragraph 20-23-b.

b. Definitions. - For definitions of terms, see Paragraph 20-23-c.

c. Frost Action Criteria. - For frost action criteria, see Paragraph 20-23-d.

d. Base Thickness Requirements for Stability.

(1) The most generally accepted method in 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. Less depth of pavement and base than required to prevent freezing of the subgrade is permissible where the design is based upon a reduction in strength of the subgrade as a result of frost action. The reduction of strength of subgrades as a result of frost action is greater in cuts than in fills.

(2) The combined thickness of pavement and base in cut sections required to prevent frost action in subgrade shall be determined using Plate 14 and the normal freezing index for the particular location. On Plate 13 are plotted normal freezing indices for the United States based upon Weather Bureau data. Where the normal freezing index on Plate 13 is less than 100, the freezing index shall be

computed for the coldest year of record for the past 15 years and design based upon this value or 100, whichever is the larger. In mountainous areas the normal freezing index shall be computed for the particular location.

(3) North of the dash line indicated on Plate 13, a minimum thickness of non-frost susceptible base of six inches shall be provided to prevent pumping action.

(4) Where the subgrade soil is an inorganic silt (ML), experience indicates that the combined thickness of pavement and base should be not less than the value determined from Plate 14 to prevent excessive differential heave.

(5) 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 Plate 14 may be decreased depending upon the thickness and thermal properties of the insulator. Four inches of slag or cinders may be substituted for every six inches of sand, gravel, or crushed rock.

(6) The combined thickness of pavement and non-frost susceptible base may be reduced to not less than one-half the value determined from Plate 14 (except that a six inch minimum base thickness is required) if the design is based upon a foundation modulus which considers the reduced strength of the subgrade affected by frost action.

e. Foundation Modulus For Design.

(1) The foundation modulus to be used for the design of the

slab thickness at a particular location will depend upon the combined pavement and base thickness. Two foundation moduli shall be determined, as stated in the following paragraphs, 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.

(2) Where a combined thickness of pavement and base equal to or greater than the value determined from Plate 14 is selected, the design shall be based upon the method stated in Paragraph 20-50 using the foundation modulus determined as stated in Paragraphs 20-41 through 20-45.

(3) When the combined thickness of pavement and base is less than the value from Plate 14, but at least one half this value, the design shall be based upon the method stated in Paragraph 20-50 but using the foundation modulus determined from Plate 16.

f. Frost Heaving. - Where a combined thickness of pavement and non-frost susceptible base less than the maximum value determined from Plate 14 is used, heaving of the pavement will occur. The heaving will be uniform where conditions of pavement and base, subgrade, and ground water are uniform. The heaving will be irregular where subgrade and ground water conditions are non-uniform. An example of uniform subgrade and ground water is the case of an airfield constructed upon a level plain with approximately uniform stripping, fill depth, and ground water depth. An example of non-uniform conditions resulting in irregular heaving is an airfield constructed upon rolling terrain with ground water close to original ground surface throughout. Under such conditions pavement over cut sections would heave more than pavements in fill sections.

g. Design for Cut and Fill Sections.

(1) In cut sections the criteria stated herein shall apply regardless of the depth of cut.

(2) In fill sections, where the depth of fill is greater than five feet and is composed of frost susceptible soil and the ground water is at a depth of at least three feet below bottom of fill, experience indicates that the combined pavement and base thickness determined from Plate 16 may be reduced. For design a reduction of 25 percent may be used except that the minimum thickness of base shall be not less than six inches. Fills less than five feet in height shall be treated as cut section.

(3) A 50 foot longitudinal transition should be provided for any changes in base thickness and the reduction should occur in the fill section where the fill is greater than five feet over the full cross section.

(4) At locations within the shaded area on Plate 13 and provided the ground water table in the spring is greater than 20 feet below ground surface, the frost action criteria need not be considered.

h. Base Composition Requirements.

(1) All base materials for designs of rigid pavements and bases over subgrades susceptible to frost action shall be non-frost susceptible.

(2) Where the combined thickness of pavement and base is less than the value determined from Plate 14, the bottom four inches of the base shall consist of any non-frost susceptible gravel, sand, or crushed stone with at least 50 percent by weight passing a No. 40 mesh sieve. This material will, in general, act as a filter and will prevent mixing of the subgrade with the base during and immediately following the frost melting period. Where the minimum base thickness is six inches, the entire base shall be the same base materials as above.

(3) In areas where suitable non-frost susceptible base materials are not available locally, it may be possible to treat frost susceptible base materials to make them non-frost susceptible by satisfactory admixtures. A satisfactory admixture is one for which reliable evidence of permanency of protection is available. Materials so treated may be used except in the top six inches directly beneath the pavement.

i. Compaction. - Compaction of the subgrade will be as outlined in Paragraph 20-14.

j. Example for Design.

(1) Conditions

Design Wheel Load	60,000 lbs.
Pavement	Portland Cement Concrete runway
Topography	Level
Subgrade	Cut section of lean clay with 50 percent by weight of grains passing a No. 200 mesh sieve.

Groundwater	Uniform at 3 feet depth
Normal Freezing Index	1,500
Foundation Modulus for 46 inch Gravel Base on Subgrade	400 lbs./sq. in/in.
Concrete working stress	450 lbs./sq. in.

(2) From Plate 14, the minimum thickness of pavement and base required to protect the subgrade from frost action is 54 inches. For this thickness, the foundation modulus is 400 lbs./sq.in/in., assuming that the pavement thickness is eight inches. Using the design curves, Part V, Exhibit 1, Sheet 2, a concrete thickness of seven inches is required.

(3) For a combined thickness of pavement and base of one-half the value determined from Plate 14, (54 inches) is 27 inches, the foundation modulus as determined from Figure 5 is 60 lbs./sq.in/in., assuming a pavement thickness of ten inches. Using this value and the design curves, Part V, Exhibit 1, Sheet 2, a concrete thickness of ten inches is required.

(4) If 20 inches of cinders or slag, which is the insulating equivalent of 30 inches of sand, gravel or crushed stone (paragraph 20-46 <u>d</u>. (5)), are used as part of the base construction, the combined thickness of pavement and base of 54 inches as obtained from Plate 14 may be reduced to 44 inches. If the entire base is constructed of cinders or slag, the required combined thickness of pavement and base would be 36 inches instead of 54 inches.

(5) The most economical design should be selected.

7. Recommendations. - From the data and analyses presented herein the following recommendations are submitted:

a. 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.

b. That the continued investigations be directed to substantiating or revising the criteria of design of airfield pavements where the subgrade is subject to frost action.

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

FROST INVESTIGATION
1944 — 1945
SUMMARY OF DATA.

TEST AREA	PRESQUE ISLE A	PRESQUE ISLE B	PRESQUE ISLE TURF AREA	HOULTON A	HOULTON B	DOW FIELD A	DOW FIELD B	DOW FIELD C	DOW FIELD TURF AREA
TYPE OF SURFACE 1. THICKNESS (CENTER) 2. " (EDGES)	CEMENT CONC. 7" 10"	BIT. CONC. 4"	TURF	BIT. CONC. 1.5"	BIT. CONC. 4"	CEMENT CONC. 7" 10"	BIT. CONC. 3.5"	BIT. CONC. 3.5"	TURF
BASE MATERIAL 1. SOIL CLASSIFICATION 2. THICKNESS (INCHES) 3. PERCENT FINER .02mm	GW 30 - 36 0 - 7	GW 24 - 30 0 - 5	TOPSOIL - -	SOIL CEM. 6 -	GW 6 2 - 15	GW 15 3 - 7	GW 24 - 36 3 - 7	GW 28 - 63 3 - 7	TOPSOIL 6 -
SUBGRADE MATERIAL 1. SOIL CLASSIFICATION 2. PERCENT FINER .02mm	GC 10 - 35	GC 10 - 35	GC 10 - 35	GP GC 6-15 20-45	GP 6 - 15	CL GC 40-97 13-35	CL 40 - 97	CL 40 - 97	CL 40 - 97
TRAFFIC HISTORY	PERIOD 1943 1943 1944 1944 1944 1944	PLANE WEIGHT 27,000-38,000 65,000 5,000 29,000 48,000 65,000	CYCLES PER DAY 5 25 20 7 7 6	PERIOD 1941-1942 " " 1942-1943 PLANE WEIGHT 12,000 30,000-60,000 60,000	CYCLES PER DAY - - -	PERIOD May 1942-Oct.1942 Jan.1943-Dec.1943 June 1943	PLANE WEIGHT All weights up to max. gross weight of 60,000 pounds.		CYCLES PER DAY 14 10 17
NATURAL DRAINAGE CONDITIONS	Poor: - High water table, peat deposits and impervious subgrade.			Poor: - High water table, peat and ledge deposits.		Poor: - Highly impervious silty clay soil.			
PRECIPITATION. 3 MOS. PRIOR TO FREEZING. (NORMAL) (1944-45) '44,'45 RELATION TO NORMAL	10 Inches 14 " 40% above			9 Inches 17 " 90% above		11 Inches 16 " 45% above			
FREEZING INDEX (NORMAL) (1944-45) '44,'45 RELATION TO NORMAL	2061 2190 6% above			1780 1605 10% below		1275 1444 14% above			
DEPTH OF WATER TABLE, FT. 1. NORMAL PERIOD 2. FREEZING PERIOD 3. FROST MELTING PERIOD	4 - 6 (S) Below 6 (S) 1 - 3 (B)	Below 6 (S) Below 6 (S) 2 - 3 (B)	Below 6 (S) - 5 - 6 (S)	Below 6 (S) Below 6 (S) 1.8 - 4.5 (S)	Below 6.5 (S) Below 6.5 (S) Below 6.5 (S)	Below 6 (S) 5 - 6 (S) 1 - 3 (B)	4 - 6 (S) Below 6 (S) 2 - 3 (B)(S)	4 - 5 (S) Below 6 (S) 2.5 - 4.5 (B)(S)	Below 6 (S) 1.5 - 6 (S) 0.7 - 4 (S)
WATER CONTENT (BASE) 1. NORMAL PERIOD 2. FREEZING PERIOD 3. FROST MELTING PERIOD	10.3 GW 6.3 GW 5.8 GW	7.8 GW 6.5 GW 6.4 GW	- - -	15.0 Soil Cem. 16.3 Soil Cem. 14.7 Soil Cem.	7.1 GW 8.7 GW 5.7 GW	- 11.1 GW 5.1 GW	5.0 GW 6.9 GW 7.9 GW	2.7 GW 9.2 GW 8.5 GW	- - -
WATER CONTENT (SUBGR.) 1. NORMAL PERIOD	16.1 GC	15.7 GC	-	17.6 GP	13.7 GP	-	25.1 CL	22.0 CL	-
2. FREEZING PERIOD	17.9 16.2 (N.F.)	14.8 14.2 (N.F.)	18.6 15.9 (N.F.)	14.7 GP; 8.3 GC; 10.1 GC (N.F.)	-	25.7 25.4 (N.F.)	31.1 CL; 24.2 CL (N.F.)	19.3 CL	23.4 CL; 15.2 CL (N.F.)
3. FROST MELTING PERIOD	13.2 GC	17.1	-	14.3 GP; 13.7 GC	8.0 GP	25.8 CL	25.3 CL	20.2 CL	-
DENSITY (BASE) 1. NORMAL PERIOD 2. FREEZING PERIOD 3. FROST MELTING PERIOD	140.9 GW 133.9 GW 126.8 GW	134.8 GW 134.0 GW 131.8 GW	- - -	124.0 Soil Cem. 113.3 Soil Cem. -	146.0 GW 124.9 GW 135.5 GW	- 118.9 GW 135.8 GW	141.0 GW 131.3 GW 133.8 GW	136.3 GW 120.8 GW 129.3 GW	- - -
DENSITY (SUBGRADE) 1. NORMAL PERIOD	114.1 GC	114.5 GC	-	123.3 GP	125.5 GP	-	102.4 CL	108.7 CL	-
2. FREEZING PERIOD	108.1 112.9 (N.F.)	114.1 113.9 (N.F.)	105.2 110.1 (N.F.)	110.2 GP; 133.8 GC; 115.6 GC(N.F.)	-	97.9 102.8 (N.F.)	92.8 CL; 91.6 CL (N.F.)	108.8 CL	99.0 CL; 111.8 CL (N.F.)
3. FROST MELTING PERIOD	113.2 GC	112.6 GC	-	113.6 GP; 120.9 GC	130.4 GP	98.7 CL	98.3 CL	110.8 CL	-
AVERAGE PERCENT SATURATION BASE 1. NORMAL 2. FREEZING 3. MELTING	100 GW 67 GW 54 GW	89 GW 67 GW 60 GW	- - -	100 Soil Cem. 100 Soil Cem. -	100 GW 75 GW 56 GW	- 73 GW 56 GW	71 GW 70 GW 89 GW	37 GW 64 GW 73 GW	- - -
AVERAGE PERCENT SATURATION SUBGRADE 1. NORMAL	89 GC	89 GC	-	100 GP	100 GP	-	100 CL	100 CL	-
2. FREEZING	86 GC; 89 GC (N.F.)	88 GC; 84 GC (N.F.)	94 GC; 79 GC (N.F.)	79 GP; 80 GC; 45 GC (N.F.)	-	96 CL; 100 CL (N.F.)	100 CL; 75 CL (N.F.)	80 CL; 95 CL (N.F.)	100 CL; 75 CL (N.F.)
3. MELTING	72 GC	94 GC	-	84 GP; 93 GC	80 GP	-	93 CL	100 CL	-
MAX. DEPTH OF FROST PENETRATION: FEET	5.8	5.9	-	4.1	2.6 to boulders	4.5	4.3	5.1	2.0
ICE SEGREGATION	Ice lenses ranged from 1/8" to hair line. A few crystals formed in sand and gravel base. Ice segregation found to depth of frost penetration.	Ice lenses 1/8" to hairline. A few crystals in sand and gravel base. Ice segregation found to bottom of frost penetration.	No Observations	Lenses and crystals from 0.8'-2.1' and 3.5'-4.0'; Lenses were 1/8" to hairline in thickness.	None	Ice lenses throughout frozen base and subgrade. Lenses in subgrade ranged from 7/8" to hairline in thickness.	Ice crystals found in frozen base in subgrade. Ice lenses found in subgrade ranged from 3/8" to hairline thickness.	Ice crystals throughout frozen base and subgrade. Ice lenses in subgrade ranging from 1/4" to hairline in thickness.	Ice segregations throughout frozen zone with a maximum thickness of 1-3/8".
PAVEMENT-HEAVE (FEET) MINIMUM MAXIMUM AVERAGE	0.05 0.30 0.18	-0.10 0.55 0.10	- - -	0.05 0.20 0.20	-0.05 0.05 0.00	0.20 0.70 0.50	0.00 0.40 0.12	0.00 0.25 0.10	- - -
ATTERBERG LIMITS LIQUID LIMIT	GW, Non Plastic; GC, 29	GW, Non Plastic; GC, 29	GC, 29	GP, 30-33; GC, 26-30	GW, Non Plastic; GP, 22	GW, Non Plastic; CL, 29-36; GC 19-21	GW, Non Plastic; CL, 29-36	GW, Non Plastic; CL, 29-36.	CL, 29-36
ATTERBERG LIMITS PLASTICITY INDEX	GW, Non Plastic; GC, 8	GW, Non Plastic; GC, 8	GC, 8	GP, None to 8; GC, 16-17	GW, Non Plastic; GP, 4	GW, Non Plastic; CL, 11-17; GC, 2-6	GW, Non Plastic; CL, 11-17	GW, Non Plastic; CL, 11-17	CL, 11-17

TEST AREA	OTIS	TRUAX A	TRUAX B	TRUAX C	PIERRE A	PIERRE B	PIERRE TURF AREA
TYPE OF SURFACE 1. THICKNESS (CENTER) 2. " (EDGES)	BIT. CONC. 5" to 7"	BIT. CONC. 2.5"	BIT. CONC. 2.5"	CEM. CONC. 6" 9"	CEM. CONC. 7" 10"	BIT. CONC. 5.5"	TURF
BASE MATERIAL 1. SOIL CLASSIFICATION 2. THICKNESS (INCHES) 3. PERCENT FINER .02mm	-- -- --	C.R. GF 8 15-17 9-20	C.R. GF 20.5 21-31 - 9-20	GF 36 - 60 9 - 20	GF 7 - 14.5 6 - 13	GF 6 - 15.5 6 - 13	- - -
SUBGRADE MATERIAL 1. SOIL CLASSIFICATION 2. PERCENT FINER .02mm	SP ML SP GP 5-18 20-40 0-3 0-5	CL SF 60-80 8-9	CL 60 - 80	CL 60 - 80	CL 27 - 59	CL 27 - 59	CL 27 - 59
TRAFFIC HISTORY	PERIOD 1942 to 1944 May '44 to Dec. '44 PLANE WEIGHT 30,000 8,000 60,000 12,000 to 15,000 CYCLES PER DAY 45 75 5 200 to 250	PERIOD 1942-1944	PLANE WEIGHT All weights up to maximum gross weight of 60,000#	CYCLES PER DAY 10 - 100	PERIOD Dec.1942-Sep.'43 Sep.1943-Sep.'44 Sep.1944	PLANE WEIGHT 29,000-60,000 10,000-15,000 5,000-10,000	CYCLES PER DAY 5 - 200 50 2
NATURAL DRAINAGE CONDITIONS	Good: - Low water table and sandy pervious soil.	Poor: - low level area, marsh, high water table and impervious subgrade.			Good: - Topography and elevation above surrounding area.		
PRECIPITATION. 3 MOS. PRIOR TO FREEZING. (NORMAL) (1944-45) '44,'45 RELATION TO NORMAL	13 Inches 18 " 38% above	7 Inches 6 Inches 14% Below			2.4 Inches 2.85 " 19% Above		
FREEZING INDEX (NORMAL) (1944-45) '44,'45 RELATION TO NORMAL	202 512 150% above	1227 1261 2.7% Above			1284 962 26% Below		
DEPTH OF WATER TABLE, FT. 1. NORMAL PERIOD 2. FREEZING PERIOD 3. FROST MELTING PERIOD	Below 15 (S) Below 15 (S) Below 15 (S)	5.9-6.7 (S) 5.8-6.0 (S) 2.0-4.0 (B)(S)	6.5-7.5 (S) 6.5-7.5 (S) 5.5-6.5 (S)	5.5-6.5 (S) 6.5-7.4 (S) 5.4-6.2 (B)(S)	Below 25 (S) " " " " " "	Below 25 (S) " " " " " "	Below 25 (S) " " " " " "
WATER CONTENT (BASE) 1. NORMAL PERIOD 2. FREEZING PERIOD 3. FROST MELTING PERIOD	- - -	5.3 GF 6.5 GF 6.4 GF	6.3 GF 7.7 GF 8.1 GF	11.8 GF 12.7 GF 12.1 GF	8.7 GF 8.6 GF 8.7 GF	6.4 GF 6.6 GF 7.5	- - -
WATER CONTENT (SUBGR.) 1. NORMAL PERIOD	3.3 SF; 11.9 SP	21.1 CL; 6.1 SF	23.5 CL	20.0 CL	15.1 CL	14.1 CL	-
2. FREEZING PERIOD	0.8 GP; 1.2 SP (N.F.)	27 CL; 14 SF	27 CL	30 CL	14.3 CL 20.3 CH(NF)	13.3 CL 15.2 CL (NF)	-
3. FROST MELTING PERIOD	23.5 ML; 9.5 SF; 7.8 SP	22.6 CL	26.5 CL	22.5 CL	24.5 CL	15.0 CL	11.5 CL
DENSITY (BASE) 1. NORMAL PERIOD 2. FREEZING PERIOD 3. FROST MELTING PERIOD	- - -	141.4 GF - 145.6 GF	136.0 GF 122.0 GF 130.4 GF	125.3 GF 112.0 GF 123.3 GF	134.5 GF - 135.8 GF	140.0 GF - 133.9	- - -
DENSITY (SUBGRADE) 1. NORMAL PERIOD	122.8 SF; 126.0 SP	107.5 CL; 114.6 SF	103.5 CL	106.3 CL	105.4 CL	97.3 CL	-
2. FREEZING PERIOD	125.7 GP; 119.2 SP(N.F.)	-	99.0 CL	82.0 OL	-	-	-
3. FROST MELTING PERIOD	87.4 ML; 123.6 SF; 102.6 SP	105.1 CL	96.4 CL	100.8 CL	88.8 CL	107.8 CL	99.6 CL
AVERAGE PERCENT SATURATION BASE 1. NORMAL 2. FREEZING 3. MELTING	- - -	77 GF - 100 GF	78 GF - 80 GF	92 GF - 92 GF	89 GF - 100 GF	90 GF - 78 GF	- - -
AVERAGE PERCENT SATURATION SUBGRADE 1. NORMAL	20 SF; 100 SP	97 CL; 35 SF	100 CL	90 CL	65 CL	57 CL	-
2. FREEZING	100/ ML; 8 GP; 7 SP	-	-	-	-	-	-
3. MELTING	70 ML; 69 SF; 29 SP	99 CL	94 CL	91 CL	69 CL	68 CL	55 CL
MAX. DEPTH OF FROST PENETRATION: FEET	2.2	4.0	4.6	4.6	3.5	2.1 Feb. 3	0.5 Feb. 3
ICE SEGREGATION	Lenses from 1/32" to hairline thickness in zone 12" above the maximum frost penetration.	Few Crystals found in base and sub-base. Lenses 1/16" to hairline thickness found in frozen clay subgrade.	Few Crystals in base and few hairline lenses in sub-base. Numerous lenses in frozen subgrade of 1/16" to hairline in thickness.	Crystals adhered to bottom of pavement. Numerous 1/16" to hairline thickness from top seepage.	Not well defined minor ice formations.	Few crystals from 1.3 to 1.8' depth. Few short lenses from 1.3 to 2.1' depth.	Minor lenses, no well developed frost formations.
PAVEMENT-HEAVE (FEET) MINIMUM MAXIMUM AVERAGE	0.00 0.16 0.02	0.08 0.14 0.12	0.01 0.05 0.05	0.02 0.14 0.11	0.00 0.05 0.00	- 0.02 0.05 - 0.01	0.0 0.10 0.05
ATTERBERG LIMITS LIQUID LIMIT	ML, 25; SF, 17; SP and GP, Non Plastic	GF, *19-30; CL, 43; SF, Non Plastic	GF, *19-30; CL, 44.	GF, *19-30; CL, 38.	GF, 26-33; CL, 36-42.	GF, 23-29; CL, 34-45.	CL, 35-42
ATTERBERG LIMITS PLASTICITY INDEX	ML, 5; SF, 2; SP and GP, Non Plastic	GF, *2-9; CL, 20; SF, Non Plastic	GF, *2-9; CL, 20	GF, *2-9; CL, 18	GF, 8-16; CL, 16-23	GF, 7-13; CL, 16-25	CL, 15-24

TEST AREA	CASPER A	CASPER B	WATERTOWN A	WATERTOWN B	WATERTOWN TURF AREA	FARGO A	BISMARCK A
TYPE OF SURFACE 1. THICKNESS (CENTER) 2. " (EDGES)	CEM. CONC. 7" 9"-10.5"	BIT. CONC. 5"	CEM. CONC. 8" 12"	BIT. CONC. 5"	TURF	BIT. CONC. 1.5"	BIT. CONC. 2"-4.5"
BASE MATERIAL 1. SOIL CLASSIFICATION 2. THICKNESS (INCHES) 3. PERCENT FINER .02mm	- - -	GW 7 - 13 2 - 5	- - -	GP 8 4 - 15	- - -	SOIL CEMENT 6.5 -	SC 6 - 6.5 5 - 9
SUBGRADE MATERIAL 1. SOIL CLASSIFICATION 2. PERCENT FINER .02mm	SF-CL SP SP 5-30 5-18 1-7	SF-CL SP 5-30 1 - 7	SF-CL OL-CL GP 13-35 35-45 1-3	SF-CL OL-CL 13-35 35-45	SF-CL 13-35	CL-SF OH-CH CH 11-17 47-55 76-90	CL-ML SP 27-37 3-12
TRAFFIC HISTORY	PERIOD Nov.1942-Oct.1944	PLANE WEIGHT 50,000 CYCLES PER DAY 95	PERIOD Dec.1942-Dec.1943 Mar.1944-Dec.1944	PLANE WEIGHT 60,000 18,000-60,000	CYCLES PER DAY 100 100	PERIOD 1941-June 45 1941-June 45 PLANE WEIGHT 5,000-29,000 60,000 CYCLES PER DAY 50 2	PERIOD Sept.43-June 45 PLANE WEIGHT 5,000-60,000 CYCLES PER DAY 20
NATURAL DRAINAGE CONDITIONS	Good: - Very low water table and little annual precipitation.		Fair: - Ponding until relieved by seepage into lower gravel stratum materials of high capillarity nearest the surface.			Poor: - Location in a flat area where runoff is very slow.	Good: - Low water table, elevation of site and surrounding topography.
PRECIPITATION. 3 MOS. PRIOR TO FREEZING. (NORMAL) (1944-45) '44,'45 RELATION TO NORMAL	4.4 Inches 2.5 Inches 43% Below		4.4 Inches 4.0 " 10% Below			3.7 Inches 3.5 " 7% Below	2.6 Inches 3.0 " 19% Below
FREEZING INDEX (NORMAL) (1944-45) '44,'45 RELATION TO NORMAL	532 745 40% Above		1742 1561 10.4% Below			2646 1820 31% Below	2592 1745 33% Below
DEPTH OF WATER TABLE, FT. 1. NORMAL PERIOD 2. FREEZING PERIOD 3. FROST MELTING PERIOD	Below 90 (S) " " " " " "	Below 90 (S) " " " " " "	12 (S) " " " "	12 (S) " " " "	12 (S) " " " "	4.8-5.5 (S) 5.5-7.2 (S) 3.0-6.0 (S)	40', Perched 12' (S) " " " " " " " "
WATER CONTENT (BASE) 1. NORMAL PERIOD 2. FREEZING PERIOD 3. FROST MELTING PERIOD	- - -	3.8 GW 4.1 GW 3.7 GW	- - -	4.9 GP 5.4 GF 5.3 GP	- - -	11.1 Soil Cem. 12.1 C.L. 11.2 Soil Cem.	4.7 SC 4.7 SC 5.9 SC
WATER CONTENT (SUBGR.) 1. NORMAL PERIOD	11.4 SF-CL; 6.8 SF; 5.3 SP	6.2 SF-CL; 3.5 SP	14.6 SF-CL; 23.8 OL-CL	14.1 SF-CL; 22.1 OL-CL	6.4 SF-CL	10.6 CL-SF; 26.7 OH-CH; 31.1 CH	16.8 CL-ML
2. FREEZING PERIOD	9.6 SF-CL 8.5 SF-SP	7.3 SF-CL 5.0 SF	13.6 SF-OL 10.1 OL-CL	13.4 SF-OL 6.4 OL-CL	15.5 SF-OL 7.2 SF-OL	10.4 CL-SF; 27.4 OH-CH 34.5 CH	18.1 CL-ML 9.7 CL-ML (NF)
3. FROST MELTING PERIOD	10.9 SF-CL; 9.5 SF	7.6 SF-CL; 3.9 SP	14.0 SF-CL; 28.3 OL-CL	14.3 SF-CL; 21.5 OL-CL	6.8 SF-OL	11.2 CL-SF; 27.0 OH-CH; 33.1 CH	20.8 CL-ML
DENSITY (BASE) 1. NORMAL PERIOD 2. FREEZING PERIOD 3. FROST MELTING PERIOD	- - -	131.0 GW - 134.5 GW	- - -	139.0 GP - 140.5 GP	- - -	122.0 Soil Cem. - 120.0 Soil Cem.	129.5 SC - 132.0 SC
DENSITY (SUBGRADE) 1. NORMAL PERIOD	113.8 SF-CL; 120.9 SF; 110.8 SP	117.3 SF-CL; 108.6 SP	111.5 SF-CL; 86.8 OL-CL	103.0 SF-CL; 88.0 OL-CL	136.0 SF-CL	125.5 CL-SF; 99.0 OH-CH; 88.7 CH	86.9 CL-ML
2. FREEZING PERIOD	-	-	-	-	-	-	-
3. FROST MELTING PERIOD	120.5 SF-CL; 113.5 SP	122.0 SF-CL; 113.3 SP	119.0 SF-CL; 85.0 OL-CL	108.0 SF-CL; 93.0 OL-CL	130.0 SF-CL	130.5 CL-SF; 96.0 OH-CH; 88.8 CH	88.0 CL-ML
AVERAGE PERCENT SATURATION BASE 1. NORMAL 2. FREEZING 3. MELTING	- - -	40 GW - 45 GW	- - -	72 GP - 63 GP	- - -	72 Soil Cem. - 74 Soil Cem.	50 SC - 50 SC
AVERAGE PERCENT SATURATION SUBGRADE 1. NORMAL	65 SF-CL; 50 SF; 31 SP	49 SF-CL; 81 SP	78 SF-CL; 67 OL-CL	61 SF-CL; 65 OL-CL	88 SF-CL	92 CL-SF; 100 OH-CH; 92 CH	49 CL-ML
2. FREEZING	-	-	-	-	-	-	-
3. MELTING	79 SF-CL; 53 SF	50 SF-CL; 85 SP	94 SF-CL; 78 OL-CL	67 SF-CL; 72 OL-CL	68 SF-CL	100 CL-SF; 93 OH-CH; 97 CH	64 CL-ML
MAX. DEPTH OF FROST PENETRATION: FEET	2.5	1.5 Jan. 16	4.0	4.0	3.5	3.8	3.8
ICE SEGREGATION	NONE	NONE	Crystals from 2.7 to 4.0' depth. Few very thin lenses at bottom of pavement and from 2.7 to 3.8' depth.	Very thin lenses from top of subgrade to 1.7' depth but no lenses in the more sandy areas.	Small crystals to 3.5' depth. Minor lenses from 1.1 to 1.9' depth.	Lenses of irregular shape, 1/16" thick and spaced 3/8" to 1/2" apart with maximum number, between 2.4 to 3.1' depth.	Thin lenses and crystals were found only in upper 0.3' of subgrade.
PAVEMENT-HEAVE (FEET) MINIMUM MAXIMUM AVERAGE	0.0 0.05 0.01	- 0.01 0.05 0.01	0.00 0.13 0.05	- 0.05 0.11 - 0.01	- 0.04 0.10 0.02	0.06 0.12 0.07	0.01 0.10 0.02
ATTERBERG LIMITS LIQUID LIMIT	SF-CL, 15-29; SF, 17-29; SP, Non Plastic	GW & SP, Non Plastic, SF-CL, 15-29	SF-CL, 30-39; OL-CL, 38-52.	GP, 19-26; SF-CL, 32-38; OL-CL, 30-45.	SF-CL, 17-26	CL-SF, 30; OH-CH, 63; CH, 73-88.	SC, 18-19; CL-ML, 24-33; SP, Non Plastic.
ATTERBERG LIMITS PLASTICITY INDEX	SF-CL, 2-11; SF, 3-5; SP, Non Plastic	GW & SP, Non Plastic; SF-CL, 2-11	SF-CL, 10-14; OL-CL, 12-18.	GP, 5-9; SF-CL, 12-18; OL-CL, 10-26.	SF-CL, 6-18	CL-SF, 12; OH-CH, 30; CH, 40-56.	SC, 1-4; CL-ML, 7-9; SP, Non Plastic.

*Atterberg limits on portion passing 200 mesh sieve

LEGEND
(N.F.)-Test on soil not frozen. (S)-Water-Table in Subgrade. (B)-Water-Table in Base

TABLE I

WAR DEPARTMENT
CORPS OF ENGINEERS, U.S. ARMY

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			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				
A	SMT 27	26 Oct. 1944	Subgrade Modulus	49+88	97 E of W edge	T182p	-	34 (C)	Compact Clayey Silt, Sand and Gravel (Fill)	30	20,000	36,000*	60,000	1.5	3.0	5.8	2.8
"	SMT 35	12 April 1945	" "	49+53	73 E of W edge	T255p	-	24 (C)		30	12,000	24,000*	47,000				
A	SMT 28	2 Nov. 1944	Subgrade Modulus	52+87	47 E of W edge	T183p	-	32 (C)		30	12,000	21,000*	37,000	1.0	3.3	5.8	2.5
"	SMT 33	12 April 1945	" "	52+53	52 E of W edge	T254p	-	34 (C)		30	11,000	21,000*	41,000				
A	PBT 32	10 April 1945	Pavement Rupture	52+50	48 E of W edge	T254p	7.2 Com. Conc.	34 (C)		24	33,000	53,000	- (G)	-	3.0	5.8	2.8
"	PBT 34	12 April 1945	" "	49+50	74 E of W edge	T255p	7.2 Com. Conc.	24 (C)		24	28,000	49,000	- (G)				
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)	- (G)	2.4 (F)	2.6	5.9	3.3
"	PBT 36	14 April 1945		7+30	17.5 W of ℄	T277a	5.6	1.6 (B), 23 (C)			18,000*	34,000	- (G)				
"	PBT 46	3 May 1945		7+30	27 W of ℄	T282a	4.8	2.5 (B), 24 (C)			26,000	45,000	- (G)				
"	PBT 63	28 May 1945		7+30	22.5 W of ℄	T277a	5.6	1.6 (B), 23 (C)			26,000	43,000	- (G)				
"	PBT 68	12 June 1945		7+25	22.5 W of ℄	"	5.6	1.6 (B), 23 (C)			29,000	51,000	- (G)				
B	PBT 24	28 Oct. 1944		10+50	12.5 W of ℄	T251p	4.8	2.5 (B), 24 (C)			37,000	60,000*	- (G)	2.2	2.7	5.9	3.2
"	PBT 38	15 April 1945		10+40	17.5 W of ℄	T275a	4.0	3.2 (B), 24 (C)			19,000	35,000	60,000				
"	PBT 48	4 May 1945		10+40	27 W of ℄	"	4.4	3.2 (B), 24 (C)			15,000	27,000*	50,000				
"	PBT 62	28 May 1945		10+43	20 W of ℄	"	4.4	3.2 (B), 24 (C)			26,000	44,000	- (G)				
"	PBT 67	12 June 1945		10+45	15 W of ℄	T281a	5.4	1.8 (B), 23 (C)			26,000	44,000	- (G)				
B	PBT 22	27 Oct. 1944		14+40	12.5 E of ℄	T252p	4.1	1.8 (B), 25 (C)			41,000*	- (G)	- (G)	2.0 (F)	2.6	5.9	3.3
"	PBT 42	18 April 1945		14+34	17.5 E of ℄	T272a	4.1	3.1 (B), 24 (C)			21,000*	35,000	60,000				
"	PBT 47	5 May 1945		14+34	27 E of ℄	"	4.1	3.1 (B), 24 (C)			19,000	33,000	57,000				
"	PBT 58	25 May 1945		14+35	20 E of ℄	"	4.1	3.1 (B), 24 (C)			21,000	41,000	- (G)				
"	PBT 74	15 June 1945		14+40	27 E of ℄	"	4.1	3.1 (B), 24 (C)			23,000	41,000	- (G)				
B	PBT 21	26 Oct. 1944		18+35	12.5 E of ℄	T261p	3.2	1.6 (B), 25 (C)			34,000	56,000*	- (G)	2.7	2.5	5.9	3.4
"	PBT 41	17 April 1945		18+35	17.5 E of ℄	T253p	3.6	2.4 (B), 26 (C)			12,000	24,000	45,000				
"	PBT 51	6 May 1945		18+40	27 E of ℄	T285a	5.1	1.4 (B), 24 (C)			11,000	21,000*	37,000				
"	PBT 65	29 May 1945		18+37	22 E of ℄	T279a	5.4	1.8 (B), 24 (C)			13,000	31,000	54,000				
"	PBT 72	14 June 1945		18+35	27 E of ℄	T285a	5.1	1.4 (B), 24 (C)			18,000	35,000	60,000				
B	PBT 50	6 May 1945		18+25	30 W of ℄	T286a	5.0	1.7 (B), 24 (C)			7,500	12,000	18,500	-	2.2	5.9	3.7
"	PBT 60	26 May 1945		18+30	27 W of ℄	T266p	4.8	2.4 (B), 26 (C)			14,000	22,000	32,500				
"	PBT 73	6 May 1945		18+28	32 W of ℄	"	4.8	2.4 (B), 26 (C)			14,000	23,500	34,500				
"	PBT 54	8 May 1945		19+00	24 W of ℄	T264a	3.6	3.6 (B), 7 (C)			18,000	31,000	55,000				
NW-SE Runway	PBT 1	25 May 1943		12+10	49 E of ℄	-	4.0	21 (C)			18,000	31,000*	51,000	1.5	2.1	4.5 (D)	2.4
"	PBT 13	13 Sept. 1943		12+15	49 E of ℄	-	4.0	21 (C)			14,000	45,000*	- (G)				
NW-SE Runway	PBT 2	26 May 1943		1+87	55 E of ℄	-	3.5	16 (C)			7,500	13,000*	25,000	2.3	1.7	4.5 (D)	2.8
"	PBT 14	13 Sept. 1943		1+92	55 E of ℄	-	3.5	16 (C)			17,000	30,000*	50,000				
E-W Runway	PBT 5	27 May 1943		14+31	50 N of ℄	T208a	3.6	18 (C)			10,500	18,000*	32,000	1.7	1.7	4.5 (D)	2.8
"	PBT 19	16 Sept. 1943		14+41	50 N of ℄	T257a	5.4	18 (C)			15,000	31,000*	68,000				
E-W Runway	PBT 31	3 Nov. 1944		14+36	59 N of ℄	T268a	5.0	18 (C)			19,000	33,000*	57,000	1.7	1.5	5.5 (E)	4.0
"	PBT 40	16 April 1945		14+40	60 N of ℄	T274a	4.8	11 (C)			11,000	19,000*	36,000				
"	PBT 52	7 May 1945		14+40	50 N of ℄	T276a	2.5	13 (C)			12,000	23,000	48,000				
"	PBT 59	26 May 1945		14+40	55 N of ℄	T276a	2.5	13 (C)			12,000	29,000	60,000				
E-W Runway	PBT 3	26 May 1943		32+97	54 S of ℄	T209a	3.6	36 (C)			12,000	18,000*	29,000	1.8	3.4	4.5 (D)	1.1
"	PBT 16	14 Sept. 1943		32+65	54 S of ℄	T259a	7.2	36 (C)			20,000	33,000*	51,000				
E-W Runway	PBT 29	1 Nov. 1944		32+81.5	60.5 S of ℄	T267a	4.0	36 (C)			20,000	31,000*	47,000	1.9	3.5	5.5 (E)	2.0
"	PBT 39	16 April 1945		32+70	60 S of ℄	T270a	6.0	36 (C)			9,000	16,000*	28,000				
"	PBT 55	8 May 1945		32+70	50 S of ℄	T284a	4.8	44 (C)			11,000	19,500	34,000				
"	PBT 56	24 May 1945		32+70	55 S of ℄	"	4.8	44 (C)			10,000	24,000	38,000				
"	PBT 71	13 June 1945		32+75	57 S of ℄	"	4.8	44 (C)			13,000	24,000	35,000				
N-S Runway	PBT 4	27 May 1943		14+0	50 E of ℄	T211a	3.6	18 (C)			15,000	22,000*	38,000	1.5	1.7	4.5 (D)	2.8
"	PBT 15	14 Sept. 1943		14+05	50 E of ℄	T256a	7.2	18 (C)			20,000	34,000*	62,000				
N-S Runway	PBT 30	2 Nov. 1944		14+07	55.5 E of ℄	T269a	2.5	18 (C)			27,000	45,000*	- (G)	2.2	1.3	5.5 (E)	4.2
"	PBT 43	18 April 1945		14+0	60 E of ℄	T280a	3.6	18 (C)			11,000	20,000*	36,000				
"	PBT 53	7 May 1945		13+80	50 E of ℄	T283a	5.4	11 (C)			16,000	27,000	48,000				
"	PBT 66	30 May 1945		13+95	55 E of ℄	T211a	3.6	11 (C)			18,000	30,000	52,000				
"	PBT 70	13 June 1945		14+0	50 E of ℄	"	3.6	12 (C)			20,000	32,000	55,000				
											DEFLECTION IN INCHES @ 20,000 LBS.						
											1st Load		10th Repetition				
B	PBT 23	28 Oct. 1944	Pavement Bearing (Repeating Load)	14+60	12 E of ℄	T252p	4.8	2.4 (B), 24 (C)		24	.040		.046	-	2.6	5.9	3.3
"	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)			.052		.068				
B	PBT 25	29 Oct. 1944		7+40	12 W of ℄	T250p	3.6	2.4 (B), 24 (C)			.038		.039	-	2.6	5.9	3.3
"	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 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.

PRESQUE ISLE
SUMMARY OF
PLATE BEARING TESTS

TABLE 2

FROST INVESTIGATION
DOW FIELD, BANGOR, ME.

SUMMARY OF PAVEMENT BEARING TESTS

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	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)
A	PBT 64	30 Mar. 1945	Rupture	-6+13	24 S	T732p	7.8 Com. Conc.	13.8	Gravelly Clay	24	22,000	36,000	57,000				
"	PBT 65	31 Mar. 1945	Rupture	-6+91	95 S	T733p	10.2 " "	13.8	Silty Clay	24	28,000	47,000	-				
"	PBT 66	2 April 1945	Foundation Mod.	-6+13	24 S	T732p	———	13.8	Gravelly Clay	30	3,500	13,000	31,000				
"	PBT 67	3 April 1945	Foundation Mod.	-6+91	95 S	T733p	———	13.8	Silty Clay	30	7,000	19,000	35,000				
B	PBT 22	15 April 1945	Pavement Bearing Test - (Static Load)	10+23	22 S	T560p	4.3	42.5	Silty Clay	30	14,000	27,000	49,000	1.75	3.8	4.0	0.2
"	PBT 34	23 Aug. 1944		10+30	20 S	T574p	4.3	42.5			20,000	39,000	-				
"	PBT 61	20 April 1945		10+30	32 S	T728p	4.2	41.0			15,000	26,000*	45,000				
"	PBT 71	15 April 1944		10+50	22 S	T874a	4.2	41.4			18,000	34,000	59,000				
"	PBT 83	4 June 1945		10+50	17 S	T877a	5.0	32.2			26,000	45,000*	-				
B	PBT 48	28 Sept. 1944		14+86	52 N	T598ap	4.2	27.0			18,000	29,000	46,000	1.89	2.6	4.0	1.4
"	PBT 58	26 Mar. 1945		14+85	45 N	T727p	4.2	27.0			11,000	18,000	32,000				
"	PBT 79	28 April 1945		14+75	50 N	"	4.2	27.0			10,000	18,000*	32,000				
"	PBT 49	29 Sept. 1944		14+11	51 S	T633ap	3.6	24.1			17,000	34,000*	-				
"	PBT 57	25 Mar. 1945		14+30	39 S	T726p	4.2	23.0			10,000	19,000	36,000				
B	PBT 50	30 Sept. 1944		12+40	21 N	T643p	3.6	30.0			16,000	33,000*	59,000	1.5	2.8	4.0	1.2
"	PBT 62	28 Mar. 1945		12+42	12 N	T730p	3.4	27.2			9,000	15,000	30,000				
"	PBT 77	25 April 1945		12+65	30 N	T872a	4.8	28.8			13,000	23,000	40,000				
"	PBT 81	2 June 1945		12+65	16 N	"	4.8	28.8			16,000	29,000	-				
"	PBT 86	5 June 1945		12+62	17 N	"	4.8	28.8			9,000	22,000*	57,000				
B	PBT 63	29 Mar. 1945		10+25	125 N	T729p	1.8 Bit. Surf. Treat.	18.6			5,000	8,000	14,000				
"	PBT 80	29 April 1945		10+25	125 N	"	1.8 " " "	18.6			7,000	11,000	18,000				
C	PBT 45	25 Sept. 1944		7+36	24 N	T528p	4.2	40.0			18,000	48,000*	-	1.92	3.8	4.8	1.0
"	PBT 56	25 Mar. 1945		7+21	24 N	T721p	4.8	44.4			12,000	24,000	47,000				
"	PBT 46	26 Sept. 1944		8+85	24 N	T875a	4.6	37.4			30,000	50,000	-				
"	PBT 60	27 Mar. 1945		8+90	10 N	T712p	4.4	41.2			14,000	25,000*	43,600				
"	PBT 76	24 April 1945		8+75	20 N	T875a	4.6	37.4			17,000	33,000	58,000				
"	PBT 84	4 June 1945		8+75	17 N	"	4.6	37.4			26,000	46,000	-				
C	PBT 59	27 Mar. 1945		4+92	63 S	T731p	3.6	44.0			15,000	29,000*	52,000	1.59	4.0	4.8	0.8
"	PBT 73	23 April 1945		4+75	63 S	T878a	5.0	43.0			22,000	38,000	-				
"	PBT 85	4 June 1945		4+75	58 S	T876a	4.2	43.8			27,000	46,000*	-				
C	PBT 52	2 Oct. 1945		5+10	50 S	T594ap	4.2	44.0			26,000	43,000	-		4.0	4.8	0.8
C	PBT 75	25 April 1945		6+05	10 S	T723a	3.6	37.0			12,000	24,000	45,000		4.0	4.8	0.8
											DEFLECTION IN INCHES @ 20,000 LBS.						
											1st Load		10th Repetition				
B	PBT 47	27 Sept. 1944	Pavement Bearing (Repeating Load)	13+06	23 S	T560p	4.3	42.5		24	.054		.065		3.9	4.0	0.1
"	PBT 70	6 April 1945		10+05	10 S	"	4.3	42.5			.068		.097				
"	PBT 72	21 April 1945		10+60	22 S	T877a	5.0	32.2			.078		.120				
"	PBT 87	5 June 1945		10+60	17 S	"	5.0	32.2			.059		.077				
B	PBT 51	1 Oct. 1945		12+58	22 N	T643p	4.8	26.4			.063		.078		2.7	4.0	1.3
"	PBT 68	4 April 1945		12+65	14 N	T872a	4.8	28.8			.127		.157				
"	PBT 78	25 April 1945		12+75	20 N	T873a	4.2	25.8			.108		.155				
"	PBT 82	2 June 1945		12+75	16 N	"	4.2	25.8			.080		.116				
C	PBT 53	2 Oct. 1944		4+90	52 S	T876a	4.2	43.8			.050		.053		3.9	4.8	0.9
"	PBT 69	4 April 1945		5+11	63 S	T739a	4.2	37.8			.045		.071				
"	PBT 74	23 April 1945		4+65	63 S	T878a	5.0	43.0			.085		.090				
"	PBT 88	5 June 1945		4+65	58 S	"	5.0	43.0			.062		.077				

* Values used to determine maximum ratio.

(A) Bituminous Concrete unless otherwise noted.

DOW FIELD
SUMMARY OF
PLATE BEARING TESTS

TABLE 3

FROST INVESTIGATION
PIERRE AIRFIELD, PIERRE, SOUTH DAKOTA
SUMMARY OF PLATE BEARING TESTS

TEST AREA	TEST NO.	DATE	TYPE OF TEST	STATION LOCATION	OFFSET (in Feet)	NEAREST EXPLORATION	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)
							PAVEMENT	BASE	SUBGRADE		@ 0.05 inch Deflection	@ 0.10 inch Deflection	@ 0.20 inch Deflection				
A		14 Mar. 1945	Pavement Rupture	34/08 Apron	51' NE of SW Edge	TP-3D	7 PCC	9 GF	CL	24	30,000	52,000	70,000		1.3	3.5	3.7
A		24 Mar. 1945		33/96 "	76' " " " "	"	7 PCC	9 GF	CL		30,000	46,000	56,000				
A		31 Mar. 1945		33/97 "	152' " " " "	"	7 PCC	9 GF	CL		40,000	64,000	86,000				
A		15 Apr. 1945		33/96 "	167' " " " "	"	7 PCC	9 GF	CL		33,000	55,000	Failure				
A		14 Mar. 1945		34/36 Apron	51' " " " "	TP-3D	7 PCC	9 GF	CL		34,000	56,000	83,000		1.3	3.5	3.7
A		24 Mar. 1945		34/26 "	76' " " " "	"	7 PCC	9 GF	CL		30,000	44,000	61,000				
A		31 Mar. 1945		34/27 "	151' " " " "	"	7 PCC	9 GF	CL		40,000	60,000	Failure				
A		15 Apr. 1945		34/26 "	176' " " " "	"	7 PCC	9 GF	CL		35,000	56,000	Failure				
A		23 Apr. 1945	Subgrade Modulus On Base	37/34 Apron	26' " " " "	TP-3C	-	10 GF	13 CL;11 SF-CL;CL	30	4,000	7,000	11,000		1.5	3.5	3.5
A		24 Apr. 1945		34/95 "	39' " " " "	TP-4A	-	8 GF	6 CL; CH		5,000	9,000	15,000				
A		25 Apr. 1945		38/04 "	110' " " " "	TP-3B	-	11 GF	CL		4,000	7,000	12,000				
A		26 Apr. 1945		34/66 "	101' " " " "	TP-3D	-	12 GF	12 CH; CL		6,000	10,000	14,000				
A		23 Apr. 1945	Subgrade Modulus On Subgrade	37/34 Apron	26' " " " "	TP-3C	-	-	13 CL;11 SF-CL;CL		3,000	5,000	8,000		1.5	3.5	3.5
A		24 Apr. 1945		34/95 "	39' " " " "	TP-4A	-	-	6 CL; CH		5,000	9,000	15,000				
A		24 Apr. 1945		37/04 "	110' " " " "	TP-3B	-	-	CL		5,000	8,000	11,000				
A		26 Apr. 1945		34/66 "	101' " " " "	TP-3D	-	-	12 CH; CL		4,000	6,000	10,000				
B		13 Mar. 1945	Pavement Bearing (Static Load)	21/18	2' Rt. of ℄	TP-2A	6 BC	11 GF	CL	30	22,000	39,000	63,000		1.4	2.1	0.7
B		22 Mar. 1945		to	" " " "	"	" "	" "	"		25,000	40,000	63,000				
B		29 Mar. 1945		21/38	" " " "	"	" "	" "	"		25,000	40,000	62,000				
B		14 Apr. 1945		Taxiway #4	" " " "	"	" "	" "	"		30,000	49,000	73,000				
B		13 Mar. 1945		28/61	1.5' Rt. of ℄	TP-2B	6 BC	7 GF	CL		19,000	33,000	53,000		1.1	2.1	1.0
B		22 Mar. 1945		to	" " " "	"	" "	" "	"		13,000	23,000	36,000				
B		31 Mar. 1945		28/89	" " " "	"	" "	" "	"		17,000	27,000	46,000				
B		14 Apr. 1945		Taxiway #4	" " " "	"	" "	" "	"		21,000	37,000	58,000				
B		14 Mar. 1945		20/64	47' Rt. of ℄	TP-2A	1.5 BC	12 GF	CL		7,000	13,000	22,000		1.1	2.1	1.0
B		23 Mar. 1945		to	" " " "	"	" "	" "	"		8,000	15,000	27,000				
B		31 Mar. 1945		20/79	" " " "	"	" "	" "	"		9,000	16,000	28,000				
B		14 Apr. 1945		Taxiway #4	" " " "	"	" "	" "	"		12,000	21,000	35,000				
B		14 Mar. 1945		21/11	46' Lt. of ℄	TP-2A	1.5 BC	12 GF	CL		10,000	18,000	30,000		1.1	2.1	1.0
B		23 Mar. 1945		to	" " " "	"	" "	" "	"		9,000	16,000	29,000				
B		31 Mar. 1945		21/27	" " " "	"	" "	" "	"		12,000	20,000	34,000				
B		14 Apr. 1945		Taxiway #4	" " " "	"	" "	" "	"		11,000	19,000	33,000				
											Deflection in inches @ 25,000 lb. 1st. Load		10th Repetition				
B		13 Mar. 1945	Pavement Bearing (Repeated Load)	25/04	15' Rt. of ℄	TP-3A	6 BC	8 GF	CL	24	.120		.193		1.3	2.1	0.8
B		22 Mar. 1945		25/15	2' " " "	"	" "	9 GF	"		.127		.198				
B		30 Mar. 1945		24/96	1' " " "	"	" "	8 GF	"		.125		.175				
B		12 Apr. 1945		24/09	1.5' " " "	"	" "	11 GF	"		.127		.175				
B		12 Mar. 1945		25/30	45' Rt. of ℄	TP-3A	1.5 BC	12 GF	CL		.330		.453		1.1	2.1	1.0
B		23 Mar. 1945		29/73	45' " " "	TP-4B	" "	" "	"		.207		.295				
B		30 Mar. 1945		29/67	46' " " "	"	" "	" "	"		.155		.247				
B		12 Apr. 1945		29/06	44' " " "	"	" "	" "	"		.155		.205				

PCC - Portland Cement Concrete
BC - Bituminous Concrete

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

PIERRE AIRFIELD
SUMMARY OF PLATE BEARING TESTS

TABLE 4

FROST INVESTIGATION
WATERTOWN AIRFIELD, WATERTOWN, SOUTH DAKOTA
SUMMARY OF PLATE BEARING TESTS

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	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)
A		19 Mar. 1945	Pavement Rupture	- 10+30			8 PCC	22 SF-CL	OL	24	46,000	80,000	-				
A		2 Apr. 1945	" "	to			" "	" "	"		25,000	54,000	91,000		2.5	3.4	0.9
A		19 Apr. 1945	" "	- 10+70			" "	" "	"		46,000	77,000	-				
A		20 Mar. 1945	Pavement Rupture	- 10+30			8 PCC	22 SF-CL	OL		34,000	70,000	Failure				
A		2 Apr. 1945	" "	to			" "	" "	"		34,000	62,000	93,000		2.5	3.4	0.9
A		19 Apr. 1945	" "	- 10+70			" "	" "	"		42,000	72,000	-				
B		21 Mar. 1945	Pavement Bearing (Static Load)	- 4+75	20' Rt. of ℄	TP-3A	5 BC	8 SF	OL-CL	30	26,000	48,000	76,000				
B		4 Apr. 1945		to	" " " "	"	" "	" "	"		37,000	55,000	80,000		1.1	4.8	3.7
B		19 Apr. 1945		- 4+93	" " " "	"	" "	" "	"		35,000	57,000	83,000				
B		21 Mar. 1945		- 12+00	20' Lt. of ℄	TP-3B	5 BC	8 SF	SF-CL		24,000	44,000	77,000				
B		4 Apr. 1945		to	" " " "	"	" "	" "	"		27,000	45,000	72,000		1.1	4.8	3.7
B		20 Apr. 1945		- 12+45	" " " "	"	" "	" "	"		21,000	39,000	64,000				
B		21 Mar. 1945		- 4+75	43' Lt. of ℄	TP-3A	1.5 BC	12 SF	OL-CL		8,000	15,000	31,000				
B		4 Apr. 1945		to	" " " "	"	" "	" "	"		8,000	15,000	28,000		1.1	4.8	3.7
B		18 Apr. 1945		- 4+93	" " " "	"	" "	" "	"		11,000	21,000	40,000				
B		21 Mar. 1945		- 12+00	43' Rt. of ℄	TP-3B	1.5 BC	12 SF	SF-CL		8,000	16,000	30,000				
B		4 Apr. 1945		to	" " " "	"	" "	" "	"		8,000	16,000	29,000		1.1	4.8	3.7
B		20 Apr. 1945		- 12+57	" " " "	"	" "	" "	"		9,000	18,000	31,000				
											Deflection in inches @ 100,000 lb.						
											1st. Load		10th Repetition				
A		19 Mar. 1945	Pavement Bearing (Repeated Load)	- 10+71	59' Rt. of ℄	TP-1B	8 PCC	22 SF-CL	OL	24	.140		.165				
A		19 Apr. 1945		- 10+69	39' Lt. of ℄	TP-2B	" "	" "	"		.191		.214		2.5	3.4	0.9
A		19 Apr. 1945		- 10+39	39' " " "	"	" "	" "	"		.160		.202				
											Deflection in inches @ 25,000 lb.						
											1st. Load		10th Repetition				
B		20 Mar. 1945		- 4+13	20' Lt. of ℄	TP-3A	5 BC	8 SF	OL-CL		.166		.233				
B		3 Apr. 1945		- 4+62	20' " " "	"	" "	" "	"		.070		.088		1.1	4.8	3.7
B		20 Apr. 1945		- 4+72	20' " " "	"	" "	" "	"		.057		.097				
B		20 Mar. 1945		- 10+40	43' Rt. of ℄	TP-2B	1.5 BC	12 SF	SF-CL		.268		.345				
B		3 Apr. 1945		- 10+48	43' " " "	"	" "	" "	"		.255		.354		1.1	4.8	3.7
B		20 Apr. 1945		- 10+56	43' " " "	"	" "	" "	"		.240		.325				

PCC - Portland Cement Concrete
BC - Bituminous Concrete

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

WATERTOWN AIRFIELD
SUMMARY OF PLATE BEARING TESTS

TABLE 5

FROST INVESTIGATION
TRUAX FIELD, MADISON, WISCONSIN
SUMMARY OF PLATE BEARING TESTS

TEST AREA	TEST NO.	DATE	TYPE OF TEST	STATION LOCATION	OFFSET (in Feet)	NEAREST EXPLORATION	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)
							PAVEMENT	BASE	SUBGRADE		@ 0.05 inch Deflection	@ 0.10 inch Deflection	@ 0.20 inch Deflection				
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 GF	22 CL; 38 SF; CL	30	23,000	-	-				
A	PBE 2	20 Oct. 1944		2+54 E-W. "	12' N of ℄	TP-2	2.5 BC	8 CR; 17 GF	20 CL; 40 SF; CL		22,000	32,000*	-		2.3	3.9	1.6
A	PBE 3	29 Mar. 1945		2+52 E-W. "	6' N of ℄	TP-2	2.5 BC	8 CR; 16 GF	20 CL; 41 SF; CL		13,000	20,000*	30,000	1.6			
B	PBE 1	24 Nov. 1944		8+60 N-S.RWY	42' E of ℄	TP-3	2.5 BC	20 CR; 22 GF	CL		27,000	-	-		3.9	4.7	0.8
B	PBE 2	29 Nov. 1944		8+40 N-S. "	42' W of ℄	TP-4	2.5 BC	24 CR; 20 GF	CL		30,000	-	-				
B	PBE 3	30 Nov. 1944		12+42 N-S. "	42' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		31,000*						
B	PBE 4	28 Nov. 1944		12+58 N-S. "	44' W of ℄	TP-7	2.5 BC	24 CR; 23 GF	CL		30,000	-	-				
B	PBE 5	13 Mar. 1945		12+25 N-S. "	60' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		20,000	28,000	-				
B	PBE 6	16 Mar. 1945		12+38 N-S. "	60' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		14,000*	23,000	40,000				
B	PBE 7	23 Mar. 1945		12+28 N-S. "	65' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		19,000	27,000	41,000	2.2' @ 0.05" Defl.			
B	PBE 8	25 Mar. 1945		12+38 N-S. "	65' E of ℄	TP-10	2.5 BC	19 CR; 25 GF	CL		18,000	29,000	47,000		3.7	4.7	1.0
B	PBE 9	27 Mar. 1945		12+16 N-S. "	42' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		21,000	34,000	54,000				
B	PBE 10	30 Mar. 1945		12+12 N-S. "	50' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		20,000	32,000	49,000				
B	PBE 11	2 Apr. 1945		12+26 N-S. "	50' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		13,000	23,000	39,000				
C	PBC 1	14 Mar. 1945	Pavement Rupture	2+0 Apron	22' NW of SE Edge	TP-1	7 PCC	42 GF	CL	24	38,000	-	-				
C	PBC 2	15 Mar. 1945	" "	2+0 "	22' " " " "	TP-1	7 PCC	42 GF	CL		36,000	-	-				
C	PBC 3	17 Mar. 1945	" "	2+20 "	12' " " " "	TP-1	7 PCC	42 GF	CL		17,000	33,000	-		4.3	4.6	0.3
C	PBC 4	22 Mar. 1945	" "	2+80 "	140' " " " "	TP-13	7 PCC	48 GF	CL		27,000	44,000	-				
C	PBC 5	22 Mar. 1945	" "	3+00 "	140' " " " "	TP-13	7 PCC	48 GF	CL		37,000	58,000	-				
C	PBE 1	2 Nov. 1944	Subgrade Modulus	1+05 "	23' " " " "	TP-1	-	39 GF	CL	30	10,000	14,000	20,000				
C	PBE 2	6 Nov. 1944	" "	1+18 "	83' " " " "	TP-2	-	45 GF	CL		9,000	14,000	21,000		4.0	4.6	0.6
C	PBE 3	7 Nov. 1944	" "	3+85 "	118' " " " "	TP-3	-	51 GF	CL		8,000	11,000	17,000				
C	PBE 4	15 Nov. 1944	" "	3+68 "	33' " " " "	TP-4	-	31 GF	CL		7,000	10,000	-				
											Deflection in inches @ 20,000 lb.						
											1st. Load.		10th Repetition				
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 GF	22 CL; 38 SF; CL	24	.053		.077				
A	PBR 2	21 Oct. 1944		2+67 E-W. "	12' N of ℄	TP-2	2.5 BC	8 CR; 16 GF	20 CL; 40 SF; CL		.051		.075		2.3	3.9	1.6
A	PBR 3	25 Mar. 1945		2+60 E-W. "	6' N of ℄	TP-2	2.5 BC	8 CR; 16 GF	20 CL; 40 SF; CL		.085		.143				
B	PBR 1	23 Nov. 1944		8+40 N-S.RWY	42' E of ℄	TP-3	2.5 BC	20 CR; 22 GF	CL		.036		.048				
B	PBR 2	25 Nov. 1944		12+41 N-S. "	44' W of ℄	TP-7	2.5 BC	24 CR; 23 GF	CL		.039		.049				
B	PBR 3	14 Mar. 1945		12+31 N-S. "	60' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		.054		.088				
B	PBR 4	16 Mar. 1945		12+46 N-S. "	60' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		.055		.093				
B	PBR 5	27 Mar. 1945		12+35 N-S. "	65' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		.061		.105		3.7	4.7	1.0
B	PBR 6	26 Mar. 1945		12+44 N-S. "	65' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		.066		.094				
B	PBR 7	27 Mar. 1945		12+22 N-S. "	42' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		.043		.062				
B	PBR 8	31 Mar. 1945		12+20 N-S. "	50' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		.063		.082				
B	PBR 9	3 Apr. 1945		12+35 N-S. "	50' E of ℄	TP-10	2.5 BC	19 CR; 23 GF	CL		.079		.129				

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

GF)
SF) Casagrande's Soil Classifications
CL)

*Values used to determine maximum ratio.

TRUAX FIELD
SUMMARY OF PLATE BEARING TESTS

TABLE 6

FROST INVESTIGATION
1944 - 1945
SUMMARY OF TRAFFIC TEST DATA

AIRFIELD	TEST AREA	TRAFFIC TEST LOCATION		PAVEMENT			BASE					SUBGRADE				EVALUATION (NORMAL PERIOD)		FROST PENETRATION (FEET)	PLATE BEARING TESTS			TRAFFIC TESTS							REMARKS
		STATION	OFFSET TO ℄ OF TEST AREA	TYPE AND THICKNESS (INCHES)	1945 FROST HEAVE		CASAGRANDE CLASS. AND THICKNESS (INCHES)	ICE FORMATIONS	K OR CBR (IN PLACE)		PAVE. & BASE THICK. (INCHES)	CASAGRANDE CLASS.	ICE FORMATIONS	K OR CBR (IN PLACE)		RUNWAY WHEEL LOAD (POUNDS)	TAXIWAY WHEEL LOAD (POUNDS)		REPEATING LOAD RATIOS (E)		STATIC LOAD RATIOS (F)	TEST PERIOD	IDLE PERIOD	APPROX. PERIOD OF FROST MELTING (1945)		WHEEL LOAD (POUNDS)	NUMBER OF COVERAGES		
					TYPE	RANGE (FEET)			NORMAL PERIOD	FROST MELT. PERIOD				NORMAL PERIOD	FROST MELT. PERIOD				1st LOAD	10th LOAD				START	END		APPROX. DAILY	TOTAL	
FLEXIBLE PAVEMENT DOW FIELD	B-1	E-W Runway 11+40 to 12+50	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+	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.
	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+	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	
	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+	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 feet.
	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+	5.1	-	-	1.6	1 to 20 April	5,8 to 11, 18 and 19 April	15 March	10 April	60,000 60,000	15 45	186 594	
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)	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".
	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)	4.7	0.62	0.52	-	11 to 20 March	-	12 March	20 March	30,000 30,000	15 45	140 420	
PIERRE	B SHOULDER T-1	Taxiway 4 (22+0 to 23+50)	40' N. of ℄	BC 1.5	Concentrated	-0.01 to 0.02	12 GF	None	28	24	13.5	CL	Very few	14	12	15,000 (D)	15,000 (D)	2.1 (3 Feb.)				13 to 29 March	-	5 March	15 March	14,500**	15	248	
	T-4	(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	do				13 March	-	do	do	25,000**	42	42	
	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	do				do	-	do	do	14,500**	36	36	
	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	do				13 to 25 March	-	do	do	25,000**	15	168	Shoulder pavement suffered severe distress under all loading conditions.
	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	do	No tests made during normal period.			17 to 29 March	-	do	do	7,000**	45	624	
	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	do				do	-	do	do	7,000**	15	208	
	T-12	-	-	BC 1.5	do	do	do	do	do	do	do	do	do	do	do	do	do	do				30 March – 1 April	-	do	do	25,000**	15	42	
	T-2	Taxiway 4 (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	[illegible]	2.1 (3 Feb.)				13 to 20 March	-	5 March	15 March	25,000**	45	200	
	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	do				13 to 29 March	-	do	do	14,500	15	248	
	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	do				do	-	do	do	25,000	15	224	Considerable flexing of pavement surface under rolling wheel loads.
	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	do				do	-	do	do	14,500	45	720	
	T-10	(30+50 to 32+00)	15' S. of ℄	BC 5.5		-	do	do	do	do	do	do	do	do	do	do	do	do				17 to 29 March	-	do	do	7,000	45	416	
RIGID PAVEMENT TRUAX	C-1	Apron 3+00 to 4+50	53' 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	4.7				7 to 20 March 21 March – 3 April	- 1 April	12 March 12 March	20 March 20 March	15,000 25,000 30,000 30,000	15 45 15 45	210 630 234 585	
	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	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 515 coverages. Traffic discontinued because of imminent pavement failure.
PIERRE	A R1	Apron (33+50 to 35+00)	25' NE of SW edge	PCC 7 (B)	Uniform	0.01 to 0.02	9 GF	None	-	140	16	CL	Very few	-	110	30,000	25,000	3.5				14 to 29 March	-	5 March	15 March	14,500	15	240	
	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	do				do	-	do	do	14,500	45	720	
	R3	(37+50 to 35+00)	25' NE of SW edge	do	do	0.00 to 0.01	do	do	do	do	do	do	do	do	do	do	do	do				do	-	do	do	25,000**	45	810	Severe cracking after 2 days traffic.
	R4	(36+50 to 38+00)	do	do	do	do	do	do	do	do	do	do	do	do	do	do	do	do				do	-	do	do	25,000	15	270	
	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	do				30 March – 4 April	-	do	do	14,500	178	1611	
	R3	(33+50 to 35+00)	125' NF of SW edge	do	do	0.00 to 0.01	do	do	do	do	do	do	do	do	do	do	do	do				do	-	do	do	25,000**	178	1698	Failure due to pumping resulting from infiltration of surface water through pavement joints.

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

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

(C) EVALUATION CONTROLLED BY 2.5" 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.

TABLE 7

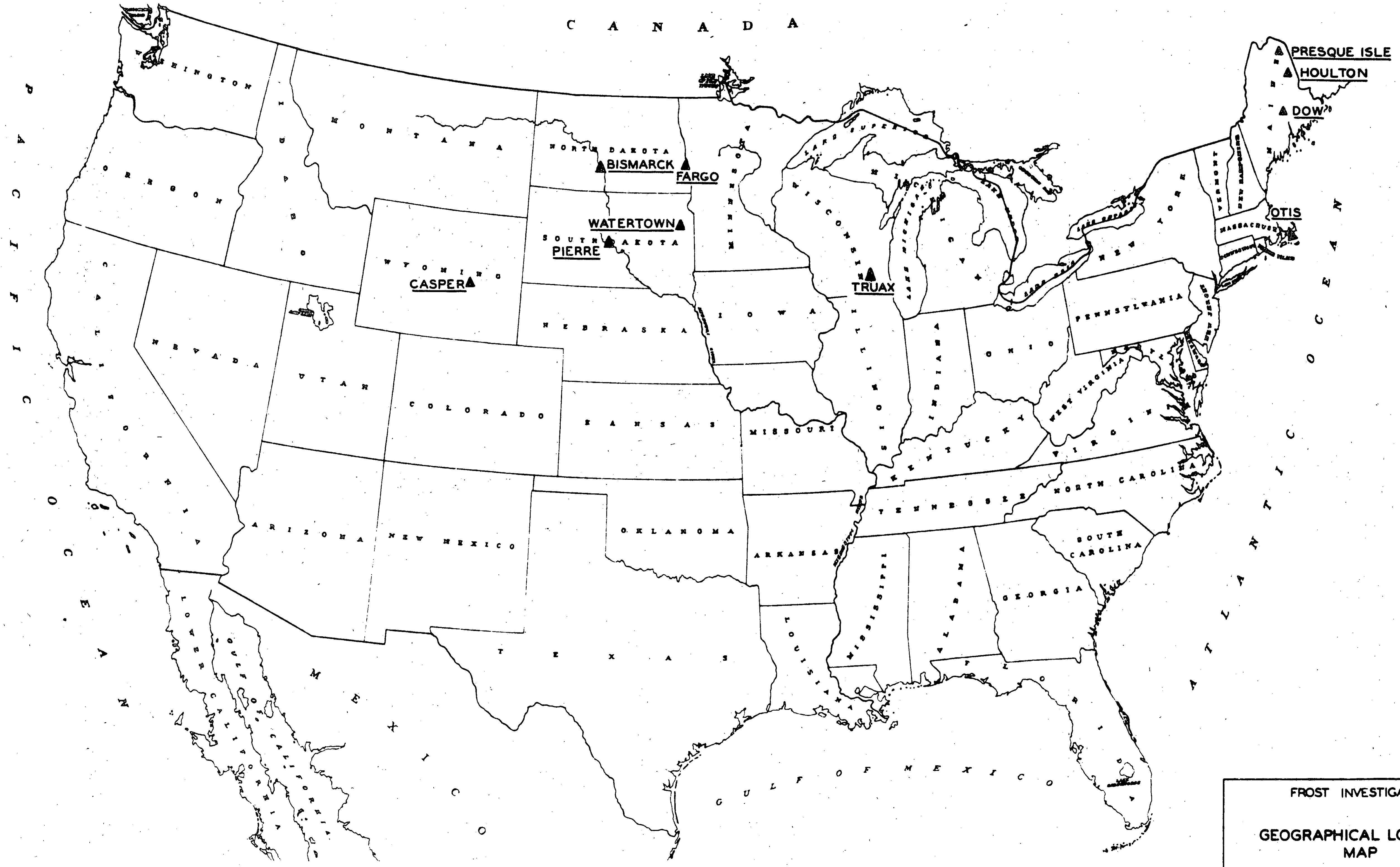
DATA SHOWING INFLUENCE OF WATER ON FROST ACTION 1944 - 1945

AIRFIELD	TEST AREA	ICE LENSES OBSERVED		PAVEMENT HEAVE (FEET)		DEPTH TO GROUND WATER IN WINTER (FEET)	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		SOURCE OF WATER FOR FROST ACTION
		IN BASE	IN SUBGRADE	AVERAGE	RANGE		FALL	WINTER	LIQUID LIMIT	PLASTIC LIMIT		NORMAL	1944	
PRESQUE ISLE	A	No lenses few crystals	Numerous-ranged from 1/8" to hairline	0.18	.05-.30	Below 6'	16.1	17.9	29	21	89	10"	14"	From water table
	B	No lenses few crystals	Numerous-ranged from 1/8" to hairline	0.10	0.10-0.55	Below 6'	15.7	14.8	29	21	89	10"	14"	From water table
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	14.7 GF, 8.3 GC	30-33 GF 36-30 GC	26 GF 10-13 GC	100	9"	17"	From water table
	B	None	None	0.00	-0.05 to +0.05	Below 6.5'	13.7	-	22 GF	18 GF	100	9"	17"	From water table
DOW	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	29-36 CL 19-21 GC	17 CL 17 GC	-	11"	16"	From water table
	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	31.1	29-36 CL	17 CL	100	11"	16"	From water table
	C	No lenses-crystals throughout	Numerous-ranged from 1/4" to hairline	0.10	0.00 to 0.25	Below 6'	22.0	19.3	29-36 CL	17 CL	100	11"	16"	From water table
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	17 SF -	15 SF Non Plastic	20 100	13"	18"	From soil underlying freezing soil
TRUAX	A	No lenses-few crystals	Lenses 1/16" to hairline	0.12	0.08 to 0.14	5.8'-6.0'	21.1	27	43 CL	23 CL	97	7"	6"	From water table
	B	No lenses-few crystals	Few hairline lenses	0.03	0.01 to 0.05	6.5'-7.5'	23.5	27	19-30 GF 44 CL	17-21 GF 24 CL	100	7"	6"	From water table
	C	Lenses 1/16" to hairline	Fine lenses	0.11	0.02 to 0.14	6.5'-7.5'	20	30	19-30 GF 38 CL	17-21 GF 20 CL	90	7"	6"	From water table
PIERRE	A	None	Minor-Not well defined	0.00	0.00 to 0.03	Below 25'	15.1	14.3	36-42 CL	20 CL	65	2.4"	2.85"	Infiltration through cracks in pavement and through pavement edges
	B	None	Small lenses and few crystals	-0.01	-0.02 to +0.03	Not Encountered	14.1	13.3	34-45 CL	18-20 CL	57	2.4"	2.85"	Same as above
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	15-29 SF-CL 17-20 SF	13-16 SF-CL 14-15 SF	50	4.4"	2.5"	-
	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	15-29 SF-CL	13-18 SF-CL	40	4.4"	2.5"	
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 OL-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
	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	32-38 SF-CL 30-43 OL-CL	20-24 SF-CL 18-27 OL-CL	61 65	4.4"	4.0"	
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	30 CL-SF 63 OH-CH 73-80 CH	18 CL-SF 33 OH-CH 30 CH	92 100 92	3.7"	3.5"	From water table
BISMARCK	A	None	Numerous in upper .3 of subgrade. Hairline thickness.	0.02	0.01 to 0.10	Perched water table 12'	16.8	18.1	18-19 SC 24-32 CL-ML	16 SC 17-22 CL-ML	49	2.6"	3.0"	Perched water table

TABLE 8

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY



FROST INVESTIGATION

GEOGRAPHICAL LOCATION
MAP

100 50 25 0 50 100 200 300
SCALE IN MILES

JUNE, 1945
FROST EFFECTS LAB. BOSTON, MASS.

PLATE 1

PRESQUE ISLE AIRFIELD
PRESQUE ISLE, MAINE

TEST AREA A

TEST AREA B

TURF AREA

HOULTON AIRFIELD
HOULTON, MAINE

TEST AREA A

TEST AREA B

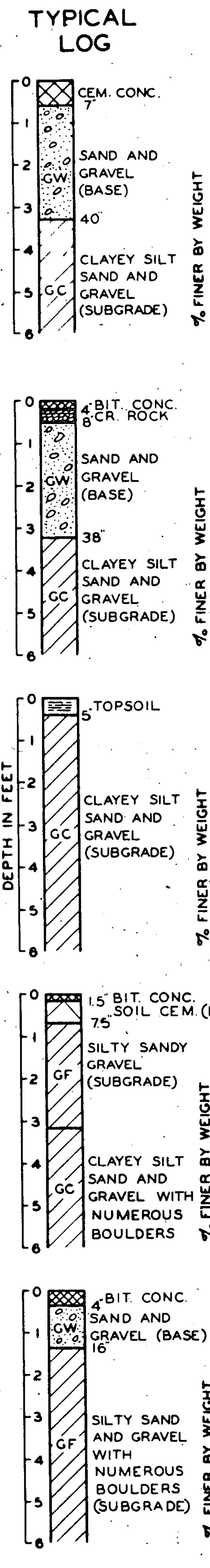


FIG.1

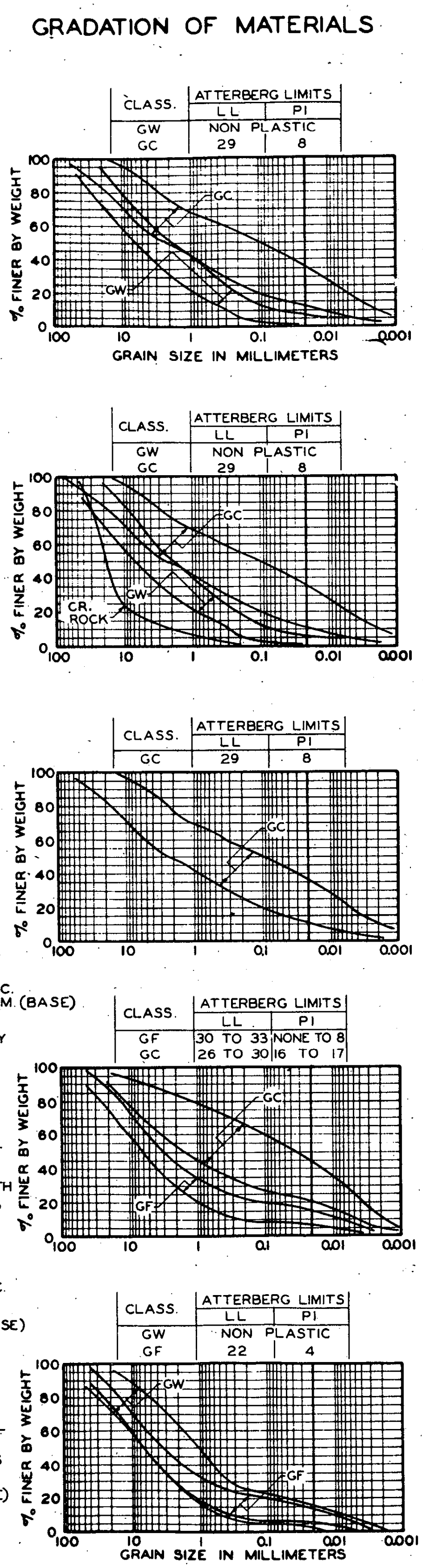


FIG.2

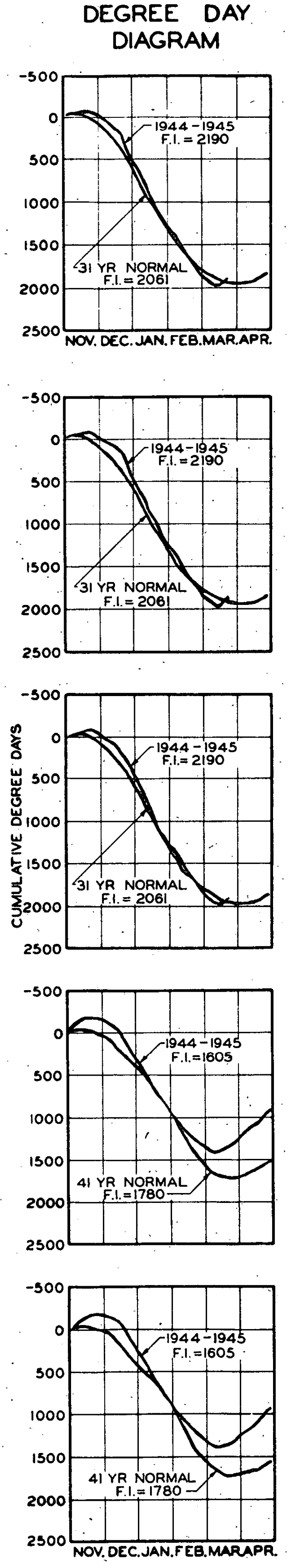


FIG.3

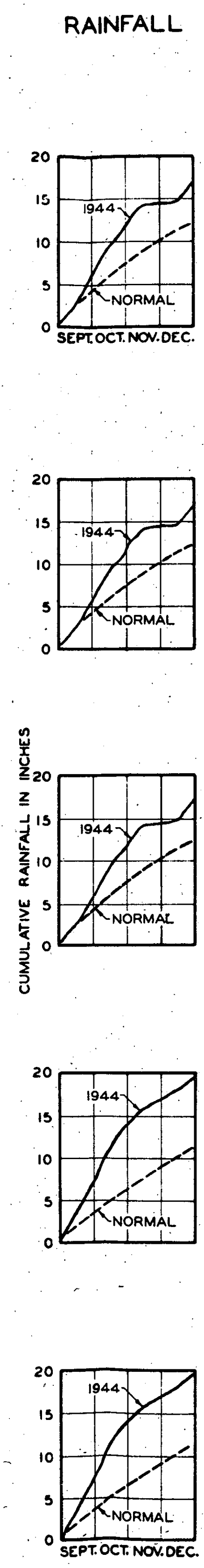


FIG.4

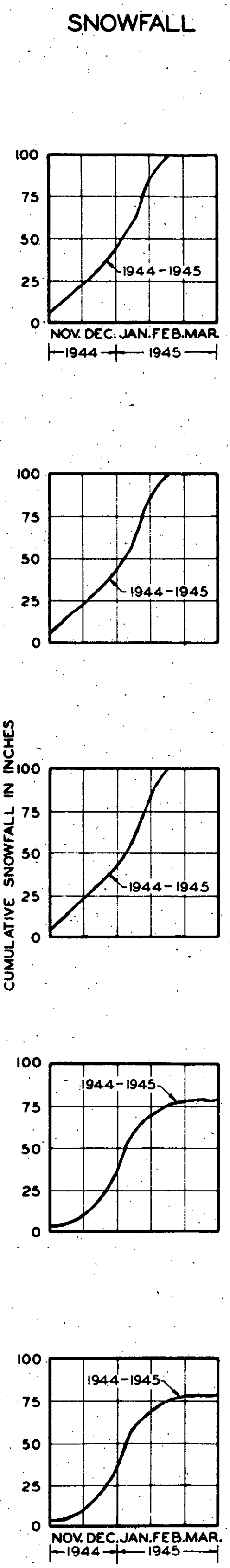


FIG.5

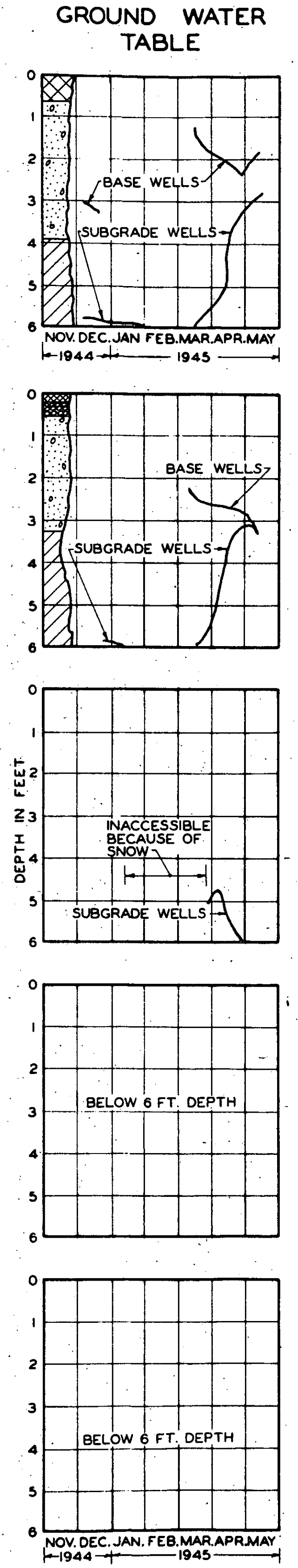


FIG.6

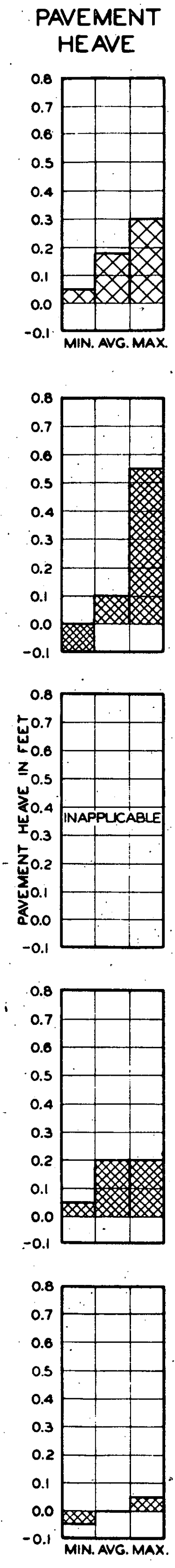


FIG.7

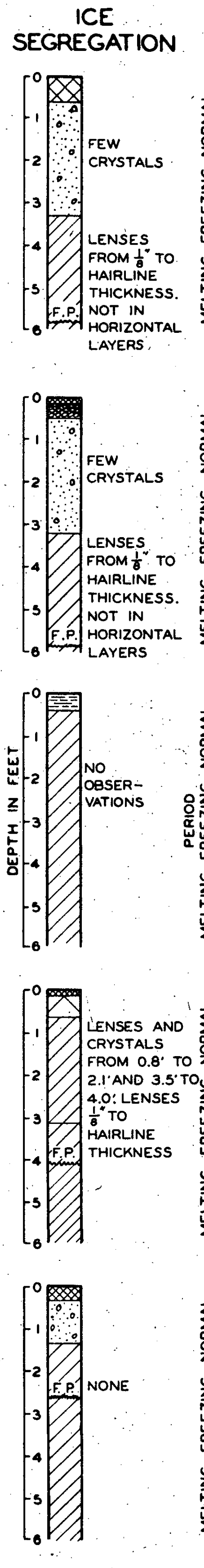


FIG.8

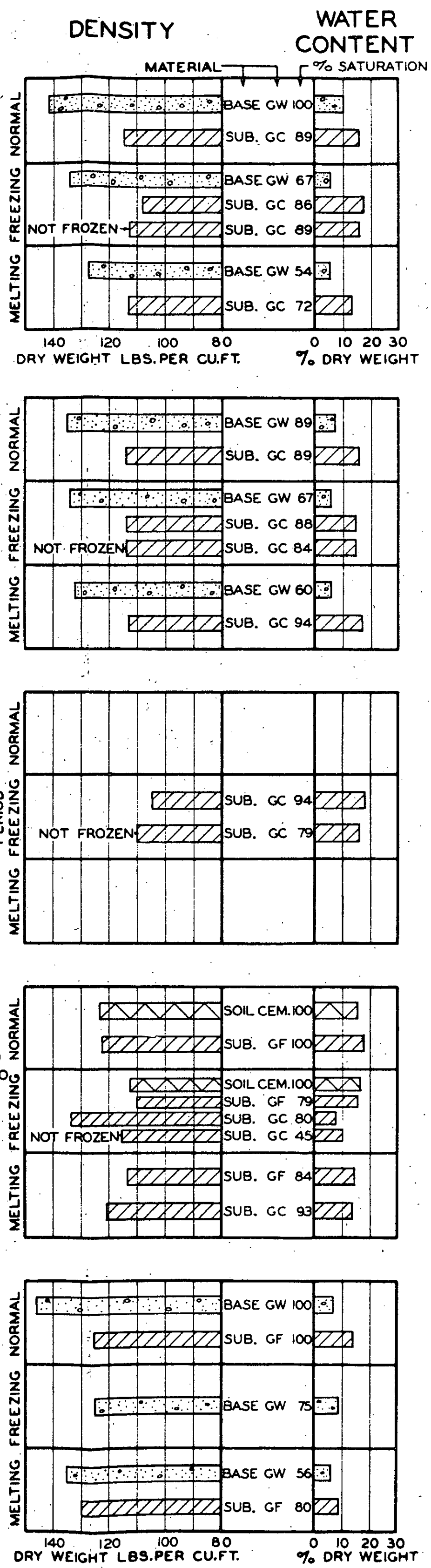


FIG.9

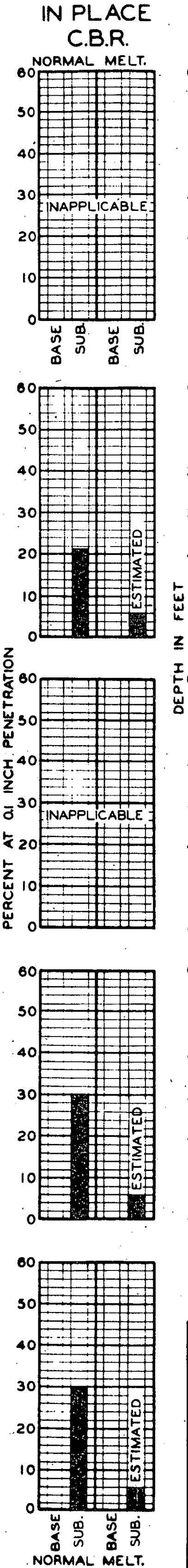


FIG.10

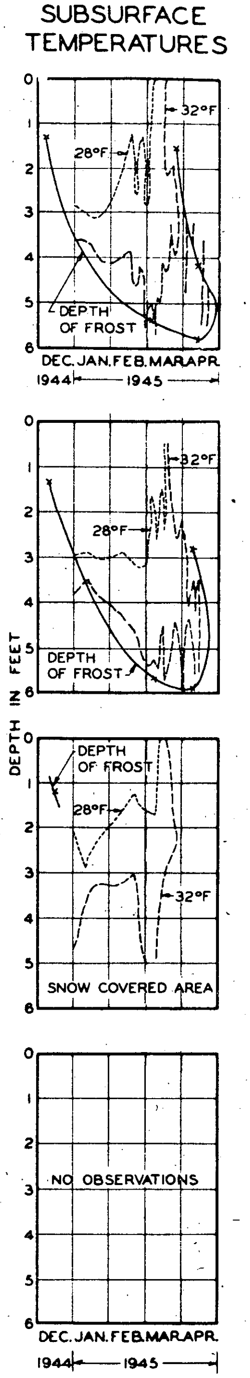


FIG.11

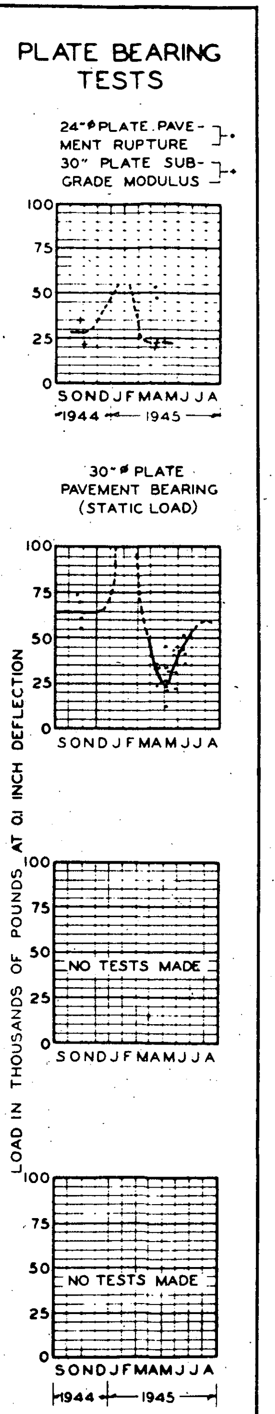


FIG.12

FROST INVESTIGATION
1944 - 1945
SUMMARY OF DATA
BOSTON DISTRICT
PRESQUE ISLE AIRFIELD
HOULTON AIRFIELD

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE, 1945

DOW FIELD - BANGOR, MAINE

TEST AREA A

TEST AREA B

TEST AREA C

TURF AREA

OTIS FIELD SANDWICH MASS. TEST AREA A

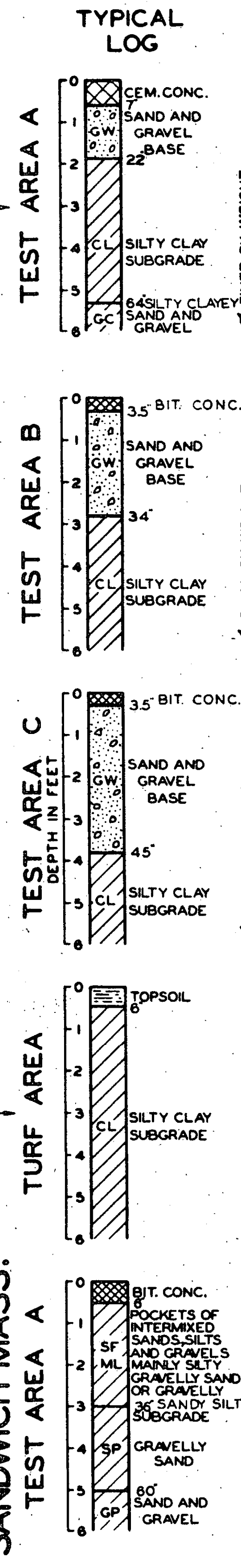


FIG.1

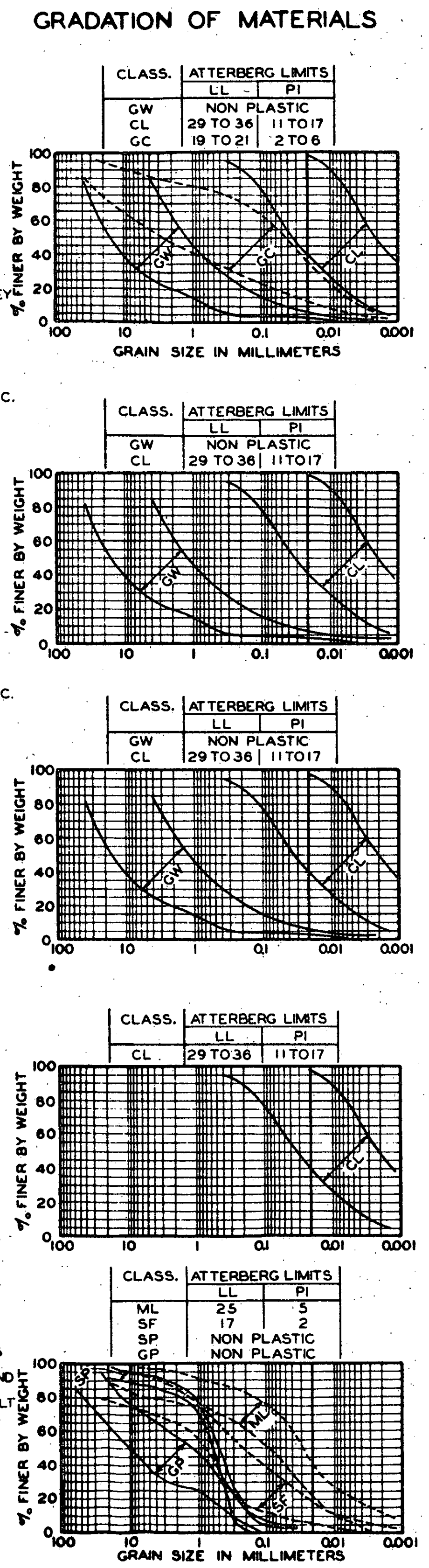


FIG.2

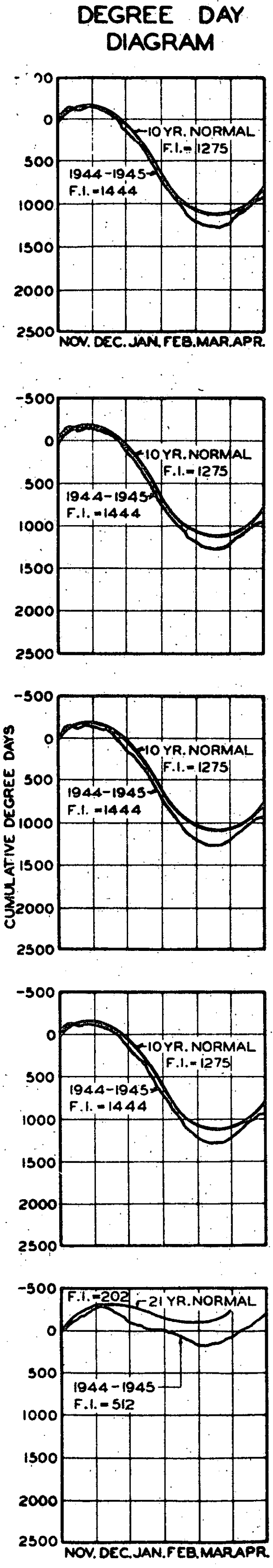


FIG.3

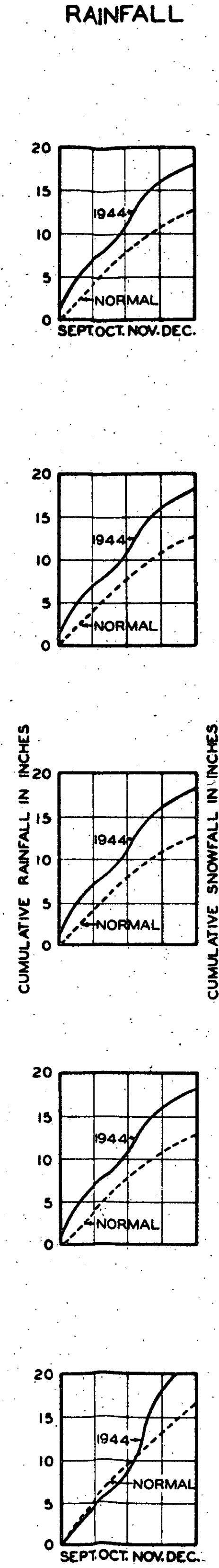


FIG.4

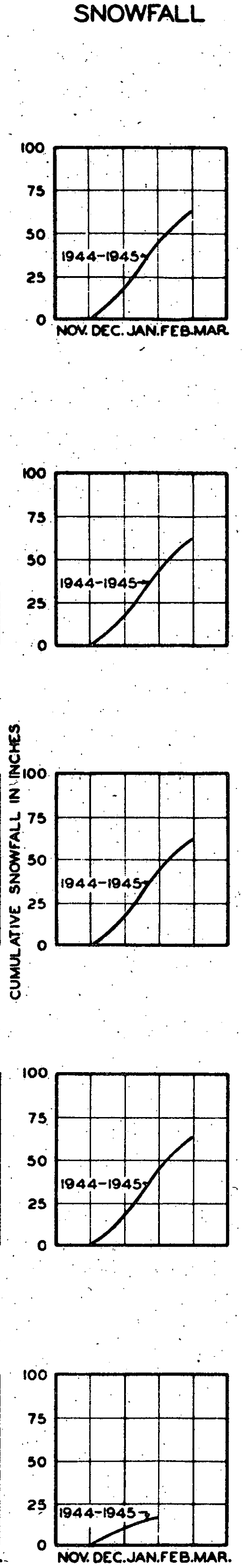


FIG.5

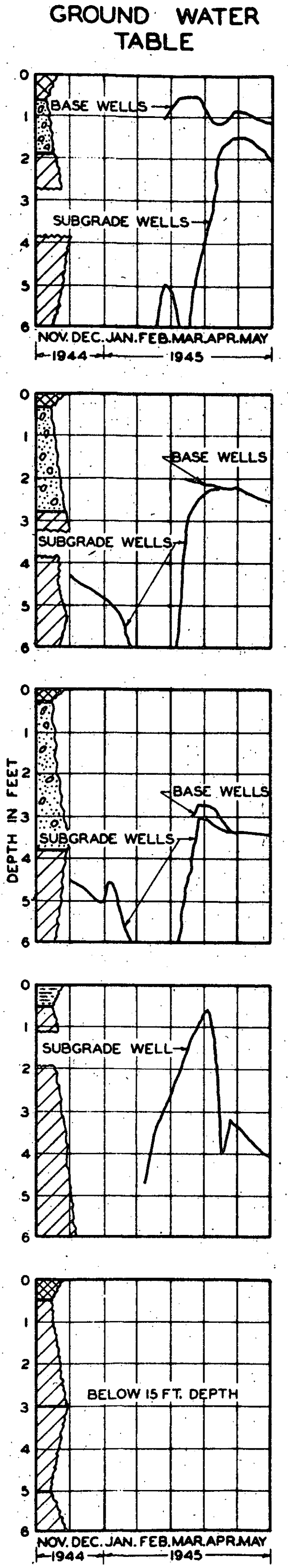


FIG.6

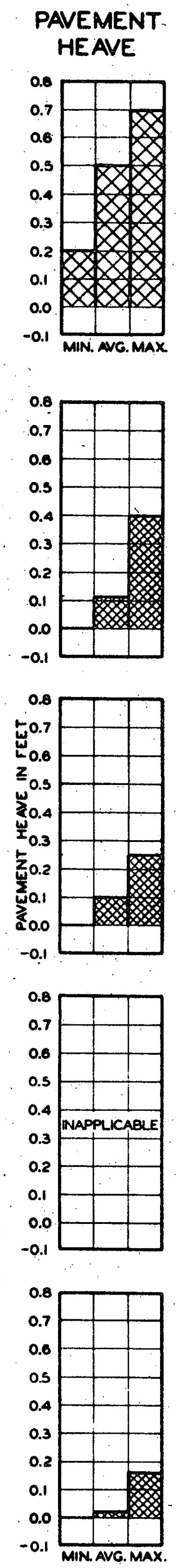


FIG.7

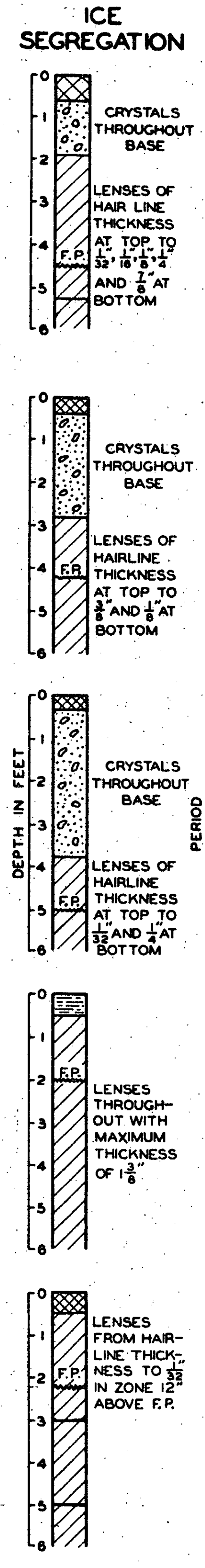


FIG.8

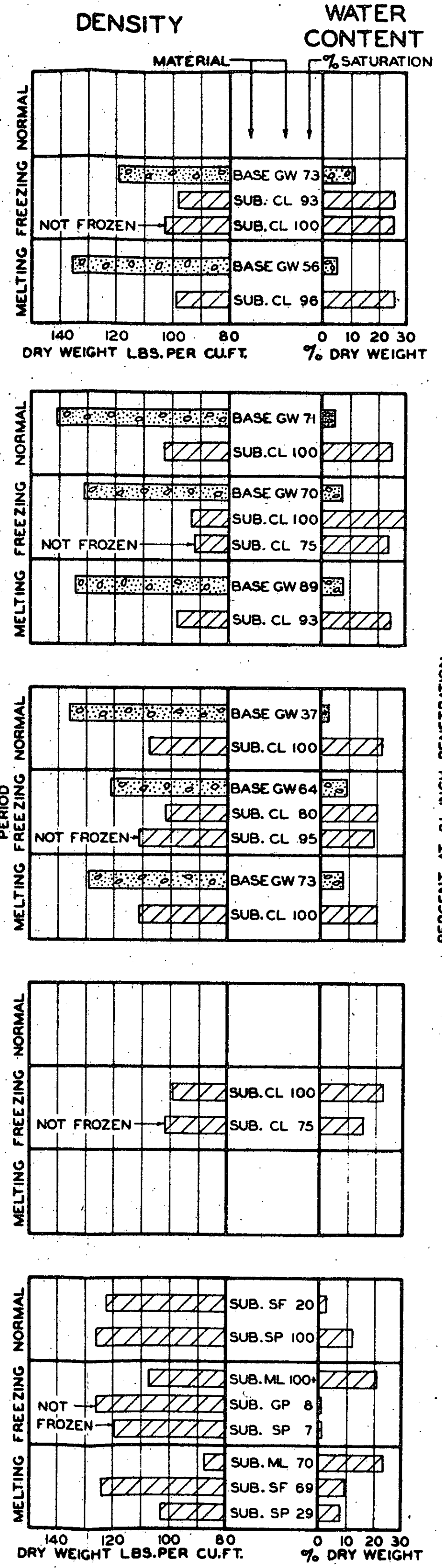


FIG.9

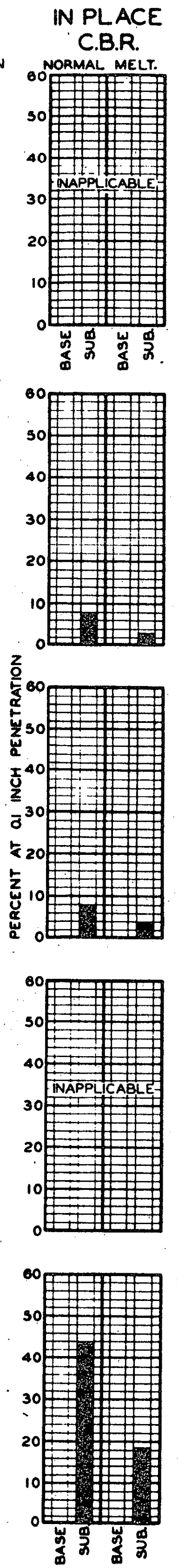


FIG.10

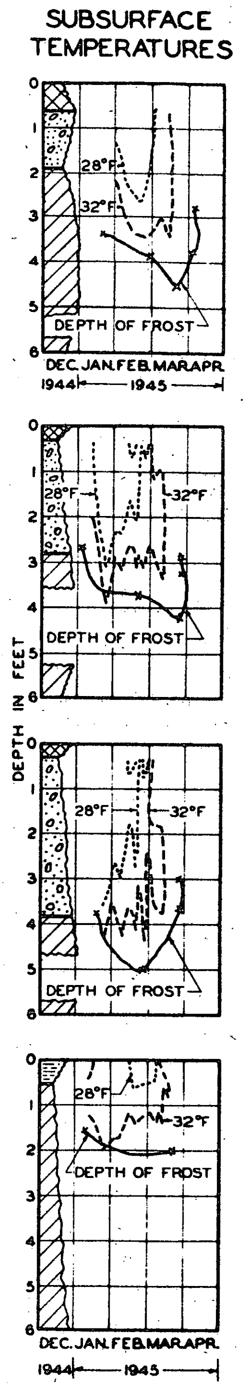


FIG.11

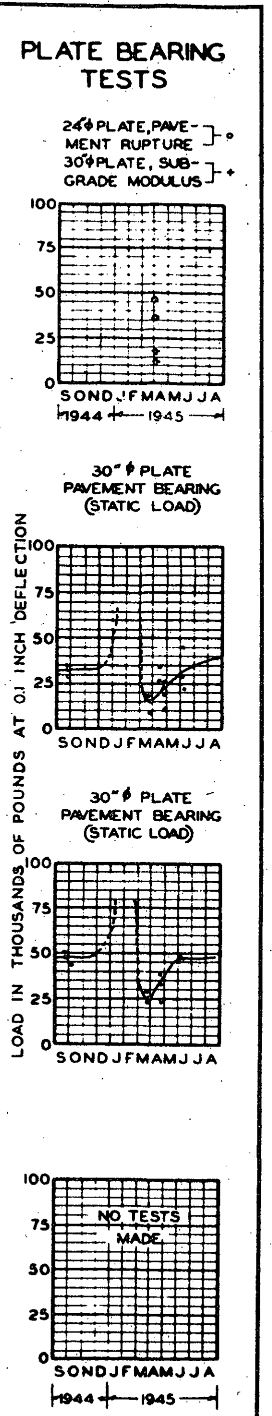


FIG.12

FROST INVESTIGATION
1944-1945
SUMMARY OF DATA
BOSTON DISTRICT
DOW FIELD
OTIS FIELD

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1945

PLATE 3

PIERRE AIRFIELD
PIERRE, SOUTH DAKOTA

TEST AREA A

TEST AREA B

TURF AREA

CASPER AIRBASE
CASPER, WYOMING

TEST AREA A

TEST AREA B

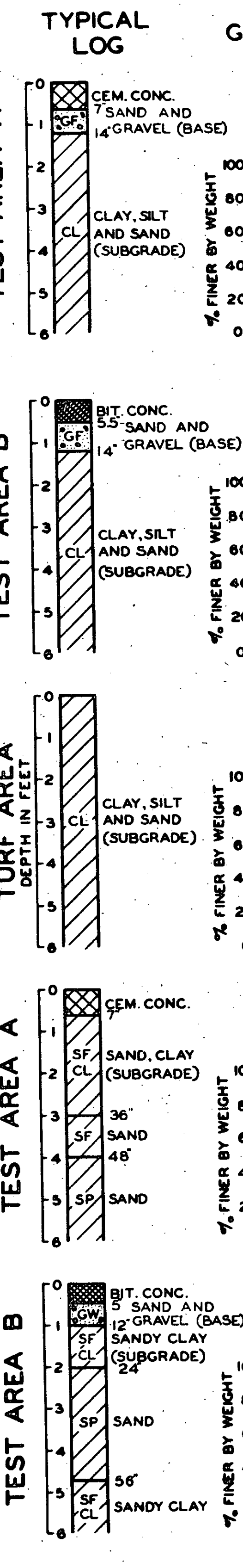


FIG.1

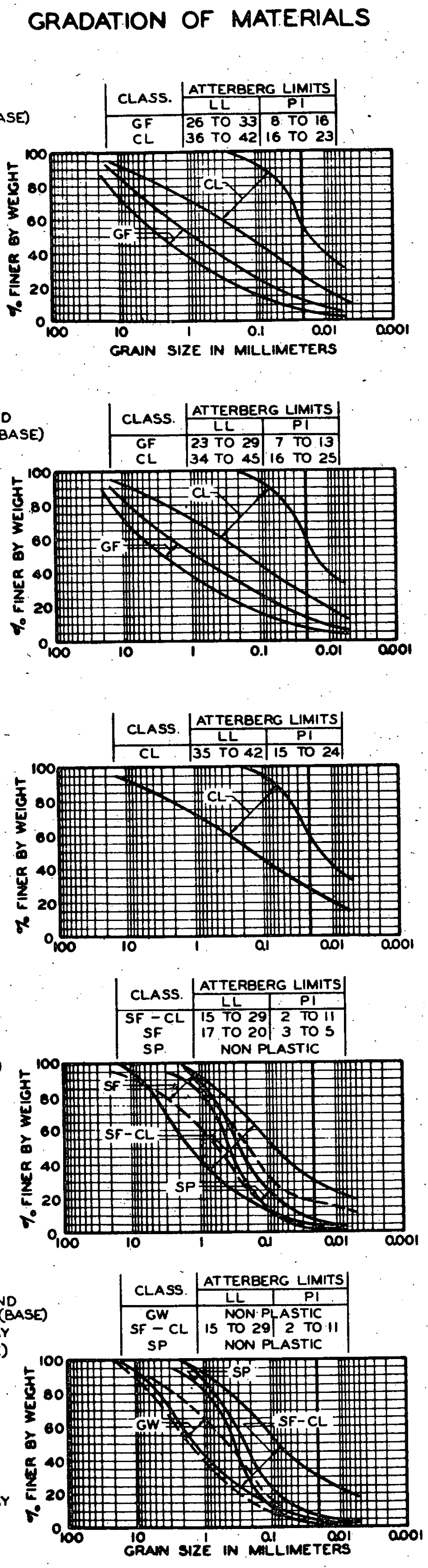


FIG.2

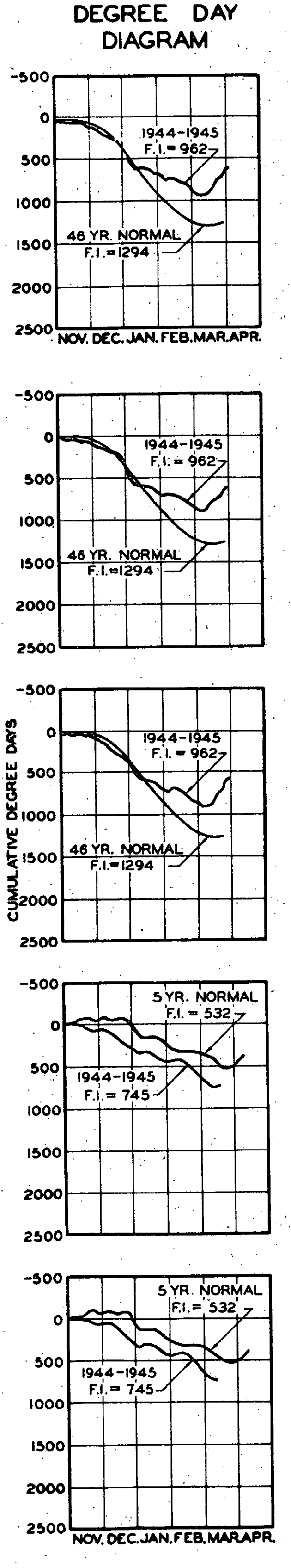
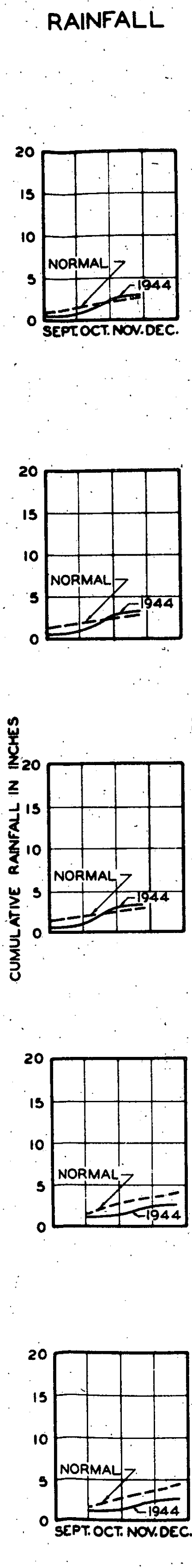


FIG.3



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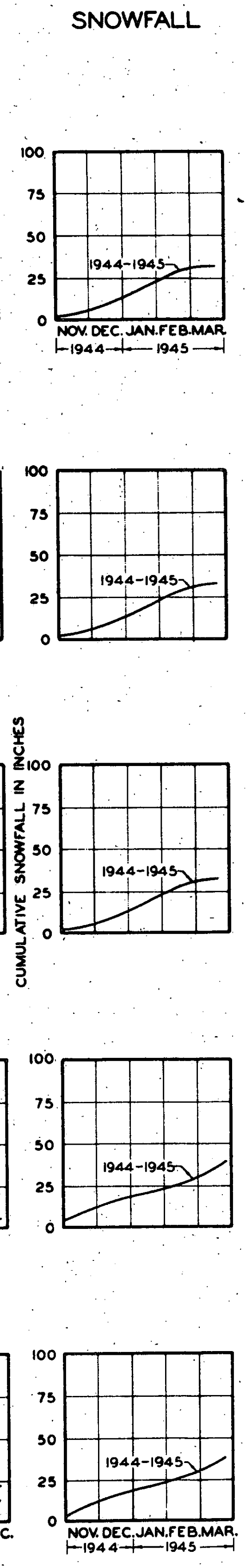


FIG.5

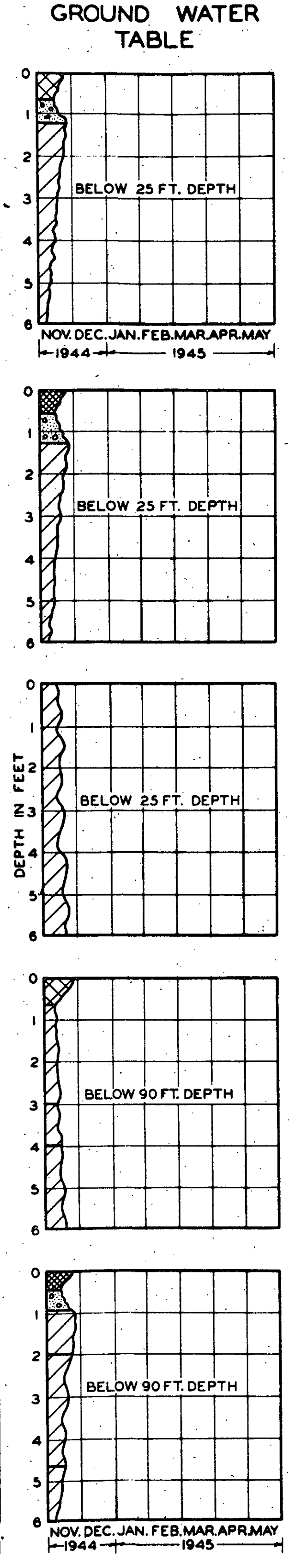


FIG.6

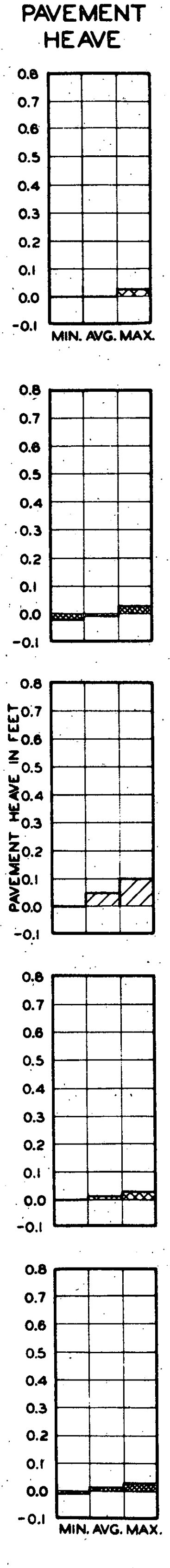


FIG.7

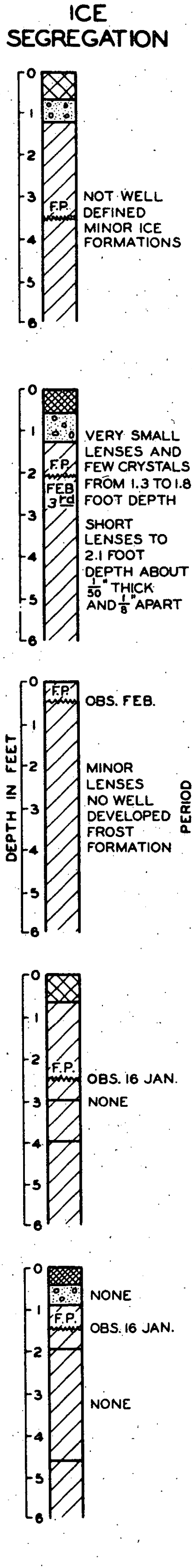


FIG.8

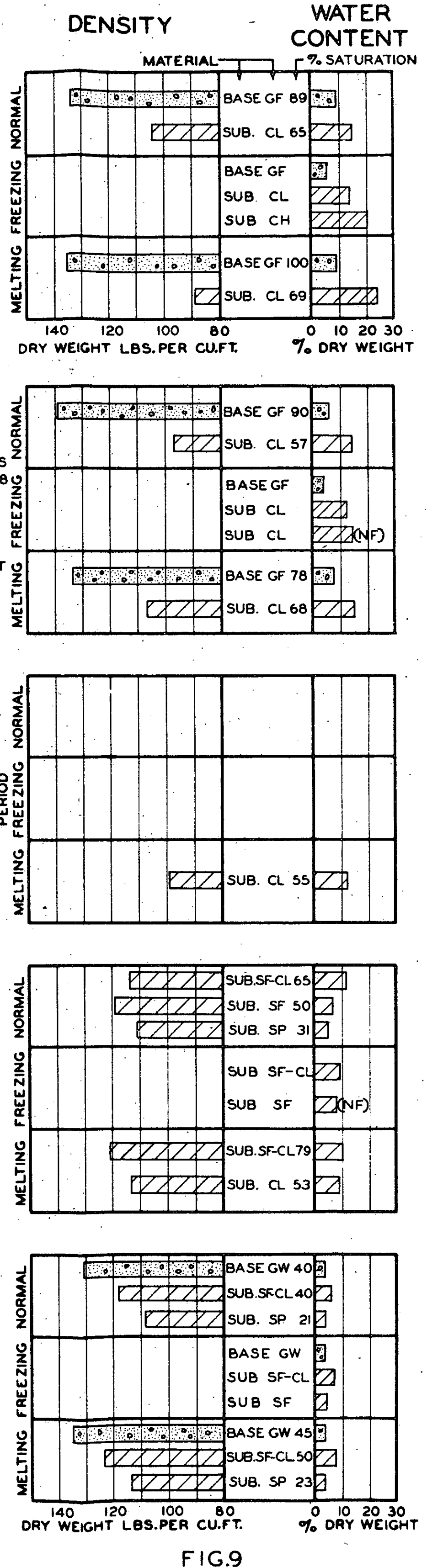


FIG.9

(NF) INDICATES NONFROZEN SOIL.

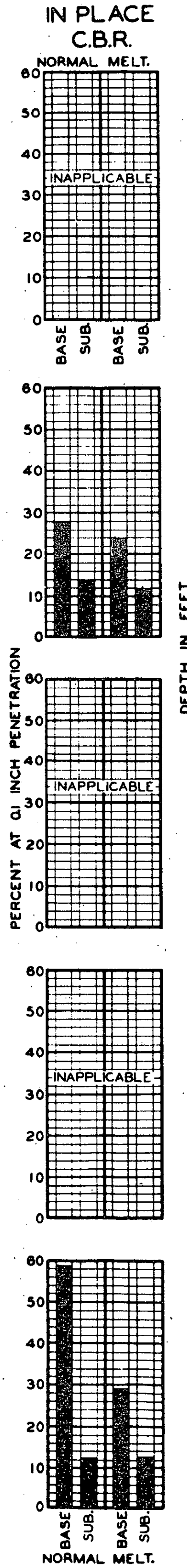


FIG.10

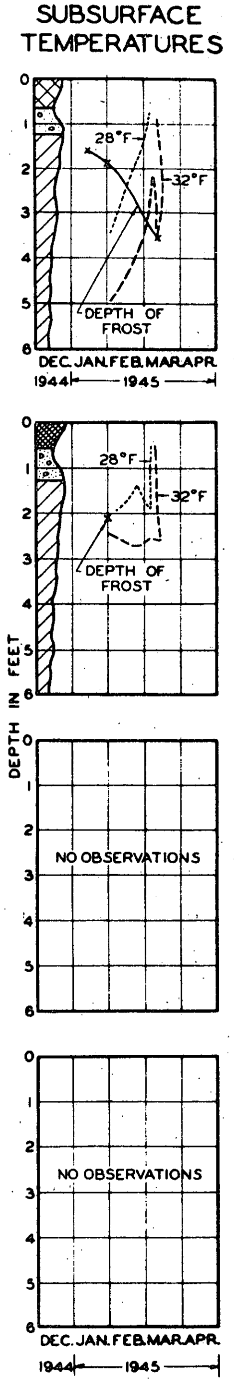


FIG.11

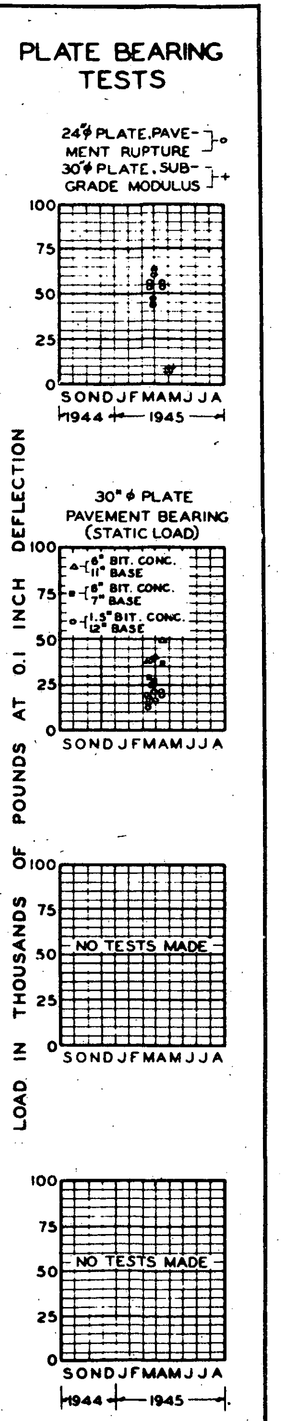


FIG.12

FROST INVESTIGATION

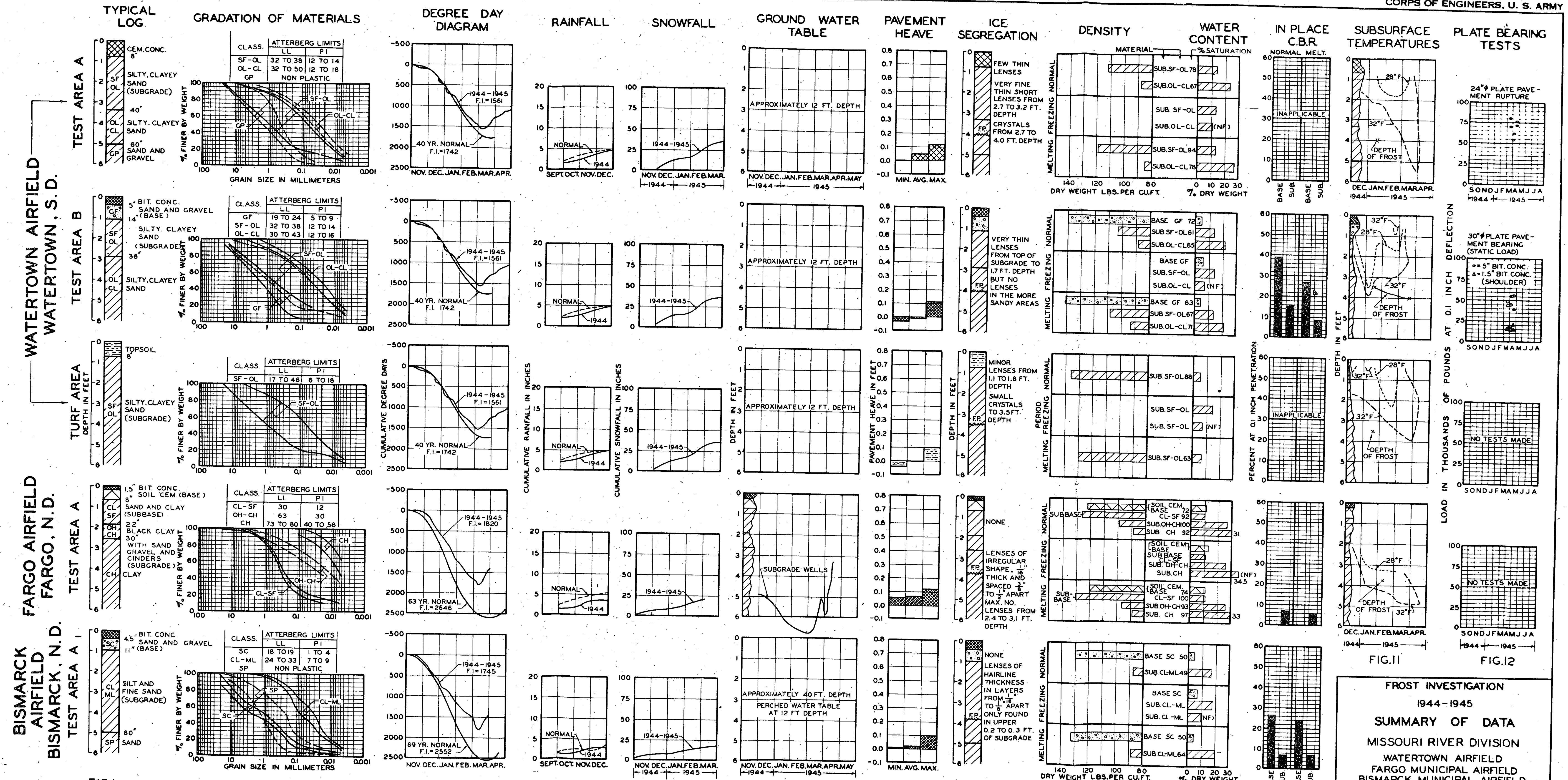
1944-1945

SUMMARY OF DATA

MISSOURI RIVER DIVISION
PIERRE AIRFIELD
CASPER AIRBASE

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1945

PLATE 4



Watertown Airfield, Test Area A

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

Watertown Airfield, Test Area B

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

Watertown Airfield, Turf Area

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

Fargo Airfield, Test Area A

CLASS.	ATTERBERG LIMITS LL	PI
CL-SF	30	12
OH-CH	63	30
CH	73 TO 80	40 TO 58

Bismarck Airfield, Test Area A

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

FIG.1 FIG.2 FIG.3 FIG.4 FIG.5 FIG.6 FIG.7 FIG.8 FIG.9 FIG.10 FIG.11 FIG.12

(NF) INDICATES NONFROZEN MATERIAL

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

TRUAX FIELD
MADISON, WISCONSIN

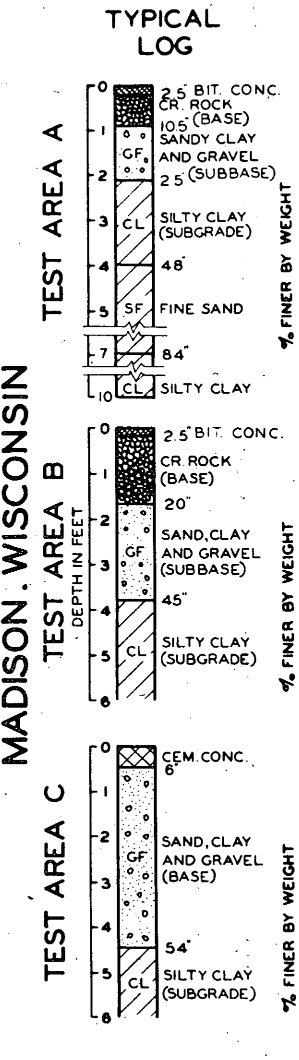


FIG.1

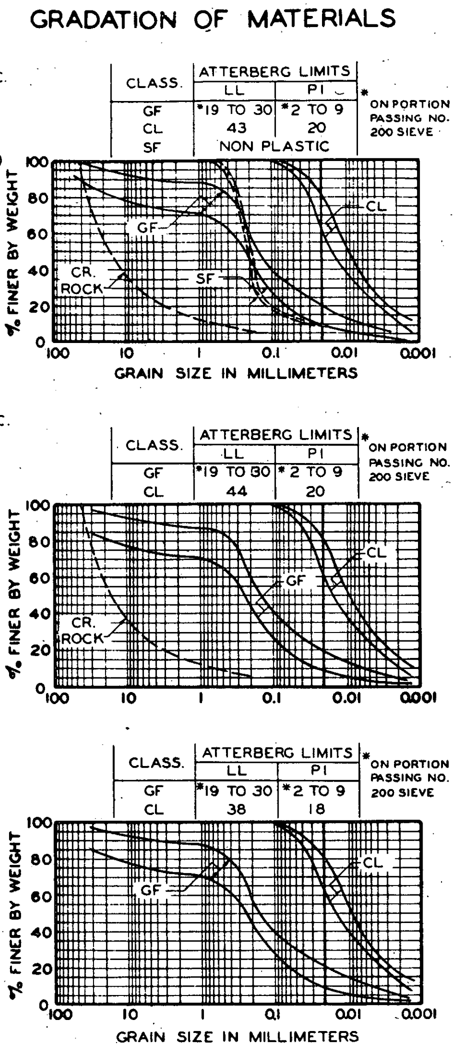


FIG.2

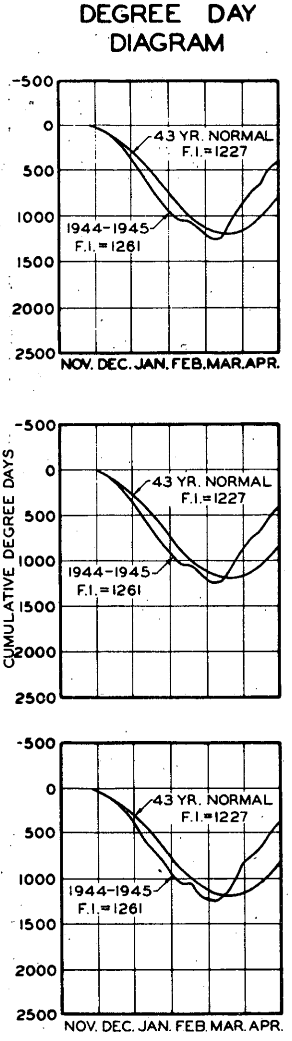


FIG.3

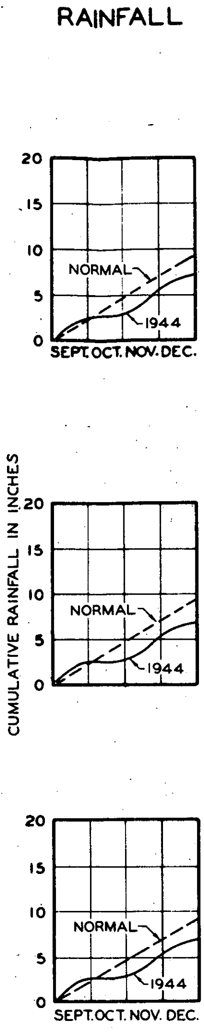


FIG.4

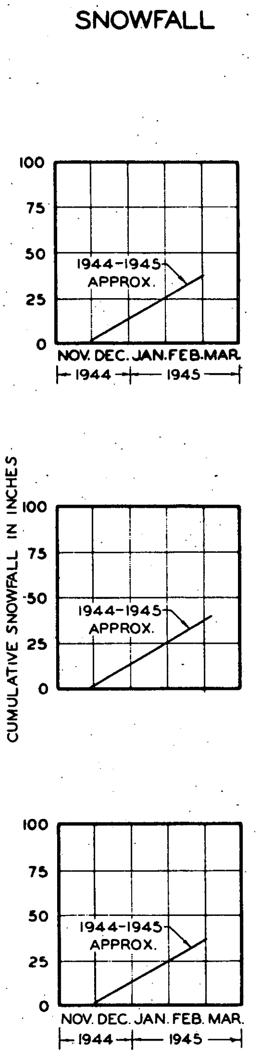


FIG.5

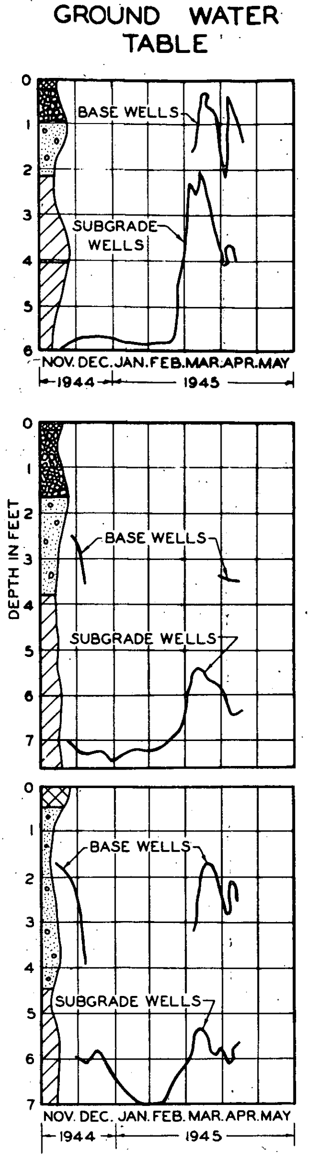


FIG.6

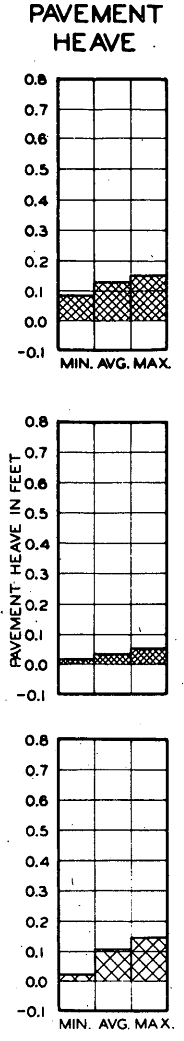


FIG.7

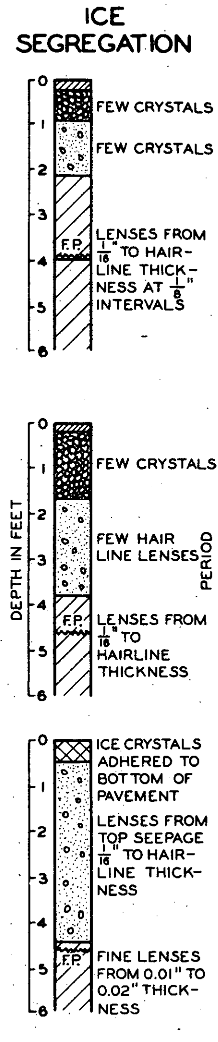


FIG.8

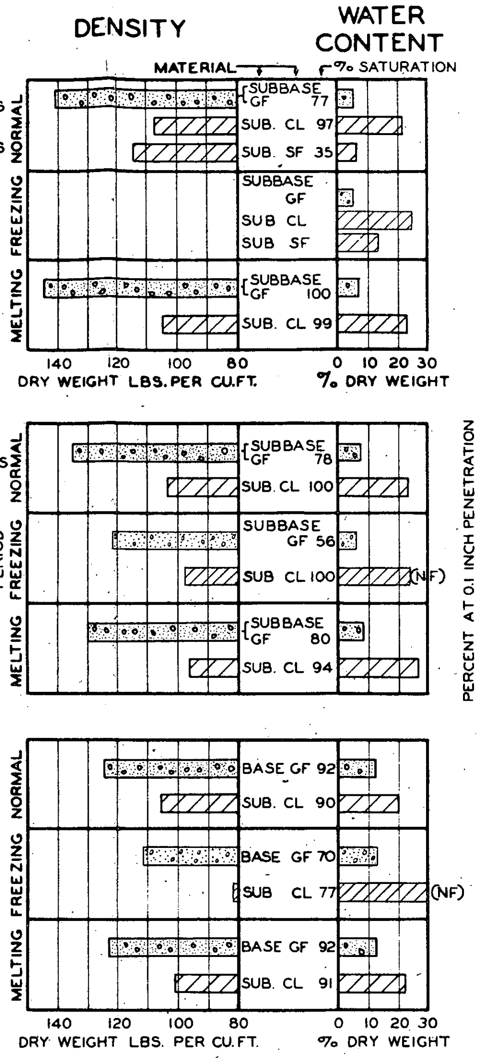


FIG.9
(NF) INDICATES NONFROZEN MATERIAL

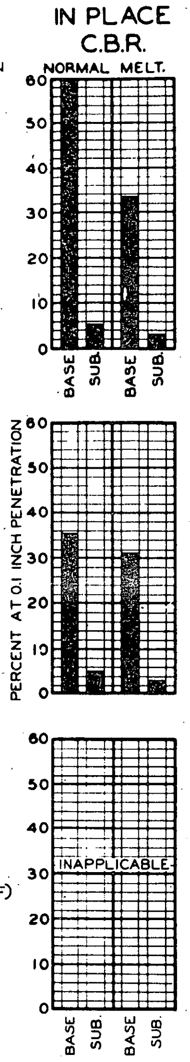


FIG.10

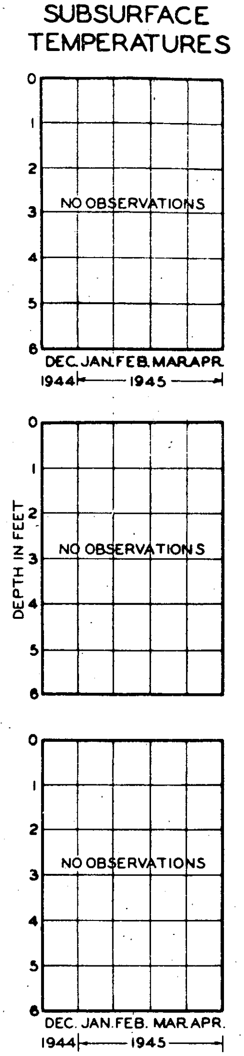


FIG.11

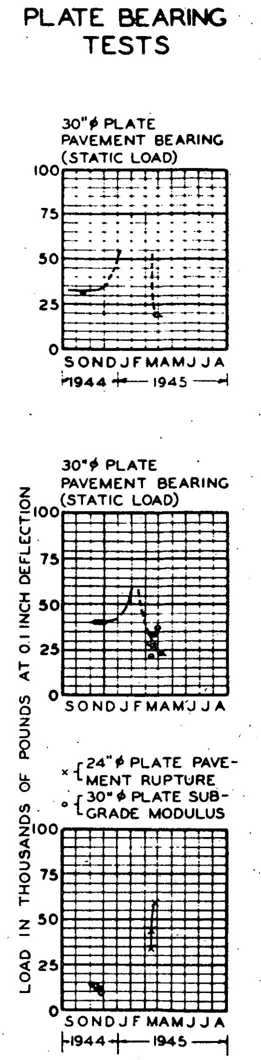
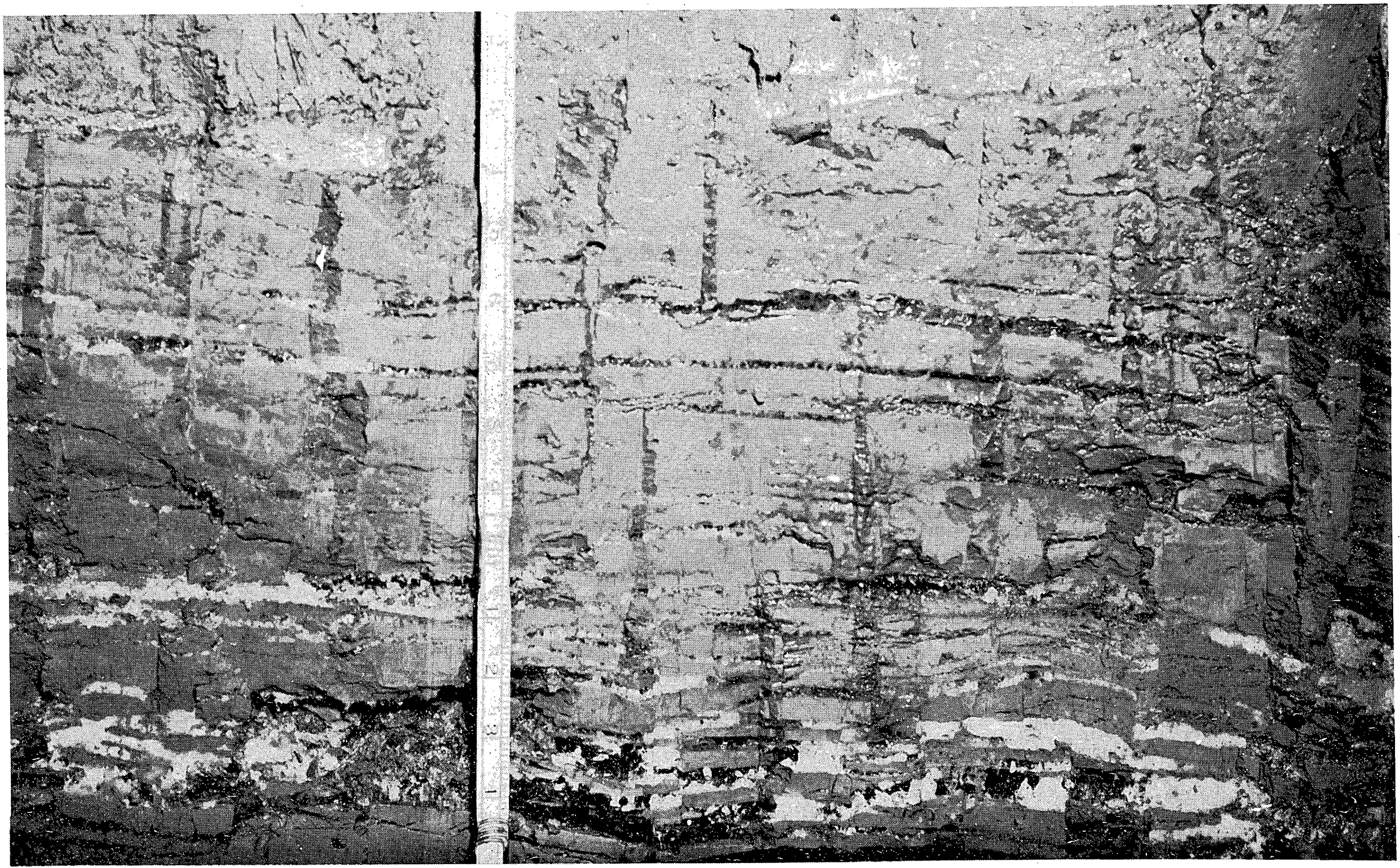


FIG.12

FROST INVESTIGATION
1944-1945
SUMMARY OF DATA
GREAT LAKES DIVISION
TRUAX FIELD

FROST EFFECTS LABORATORY. BOSTON, MASS. JUNE 1945

PLATE 7



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

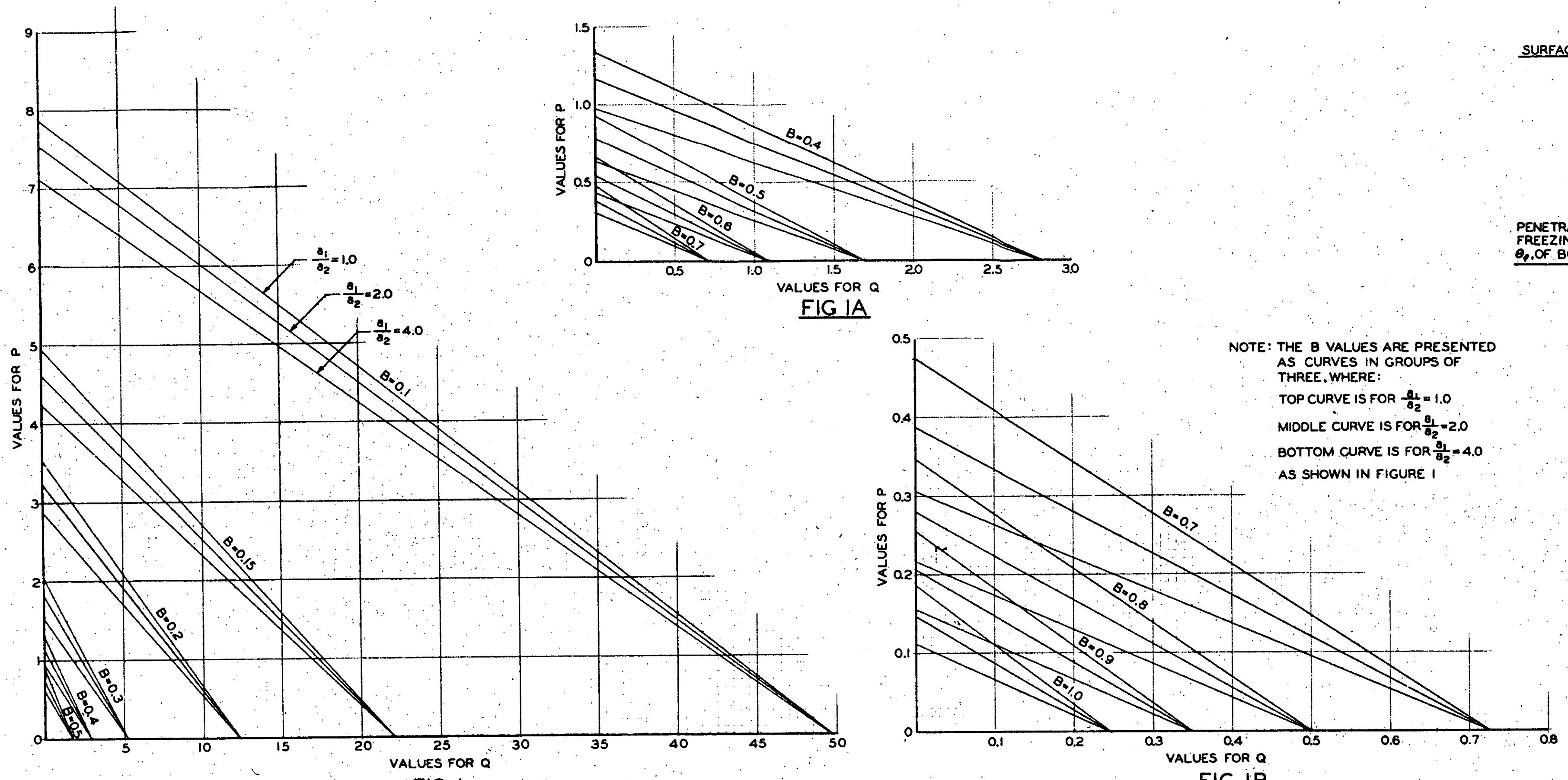


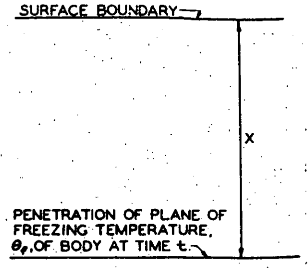
FIG. 1

FIG. 1A

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

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



TEMPERATURE AT SURFACE BOUNDARY EQUALS $\theta_0 > 32°F$ 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:

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

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

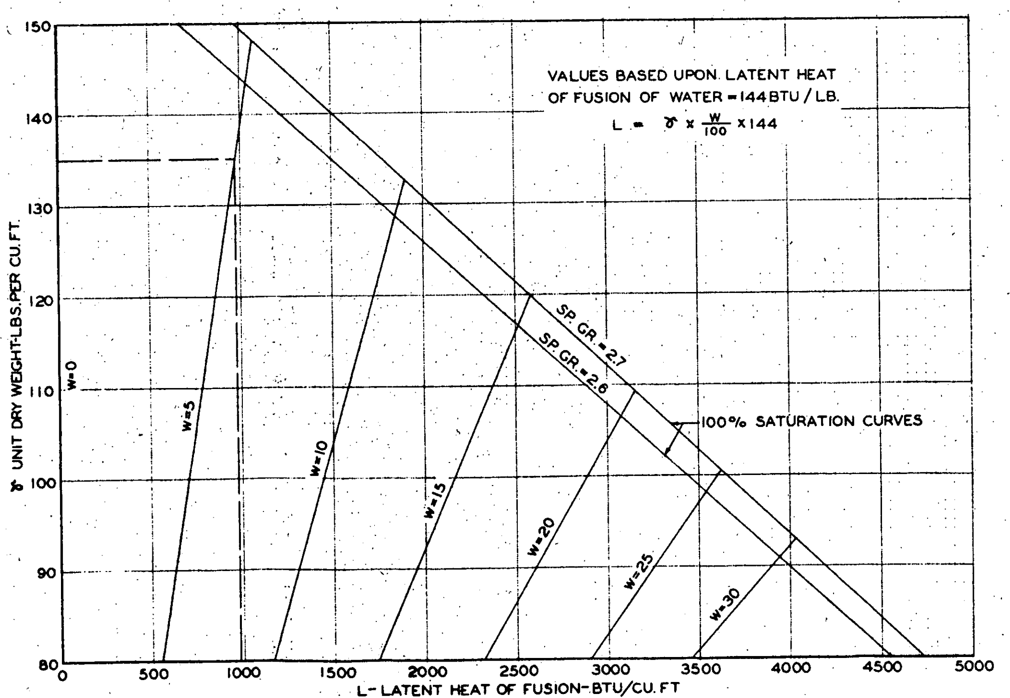
$$\frac{L}{C_1(\theta_f-\theta_s)}=Q$$

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

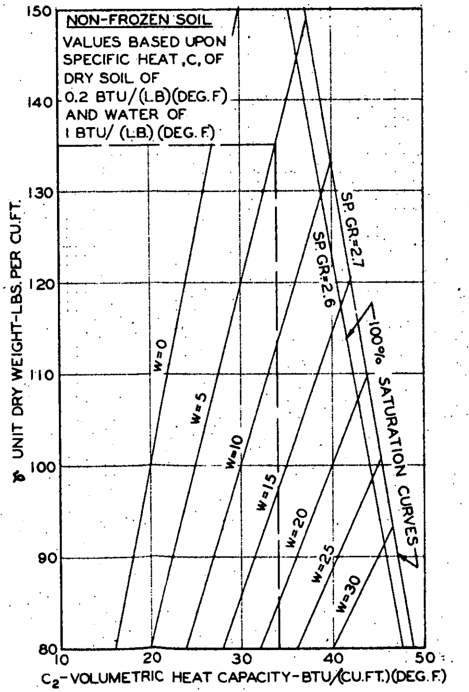


VALUES BASED UPON LATENT HEAT OF FUSION OF WATER = 144 BTU / LB.

$$L = \gamma \times \frac{w}{100} \times 144$$

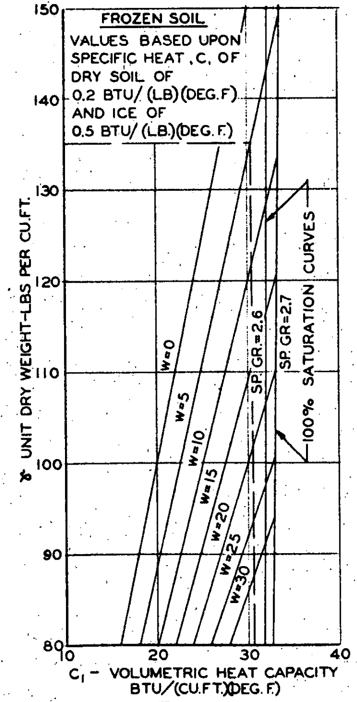
FIG. 3

LATENT HEAT OF FUSION VS UNIT DRY WEIGHT



NON-FROZEN SOIL
VALUES BASED UPON SPECIFIC HEAT, C, OF DRY SOIL OF 0.2 BTU/(LB)(DEG.F.) AND WATER OF 1 BTU/(LB)(DEG.F.)

FIG. 4



FROZEN SOIL
VALUES BASED UPON SPECIFIC HEAT, C, OF DRY SOIL OF 0.2 BTU/(LB)(DEG.F.) AND ICE OF 0.5 BTU/(LB)(DEG.F.)

FIG. 4A

HEAT CAPACITY VS UNIT DRY WEIGHT

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.

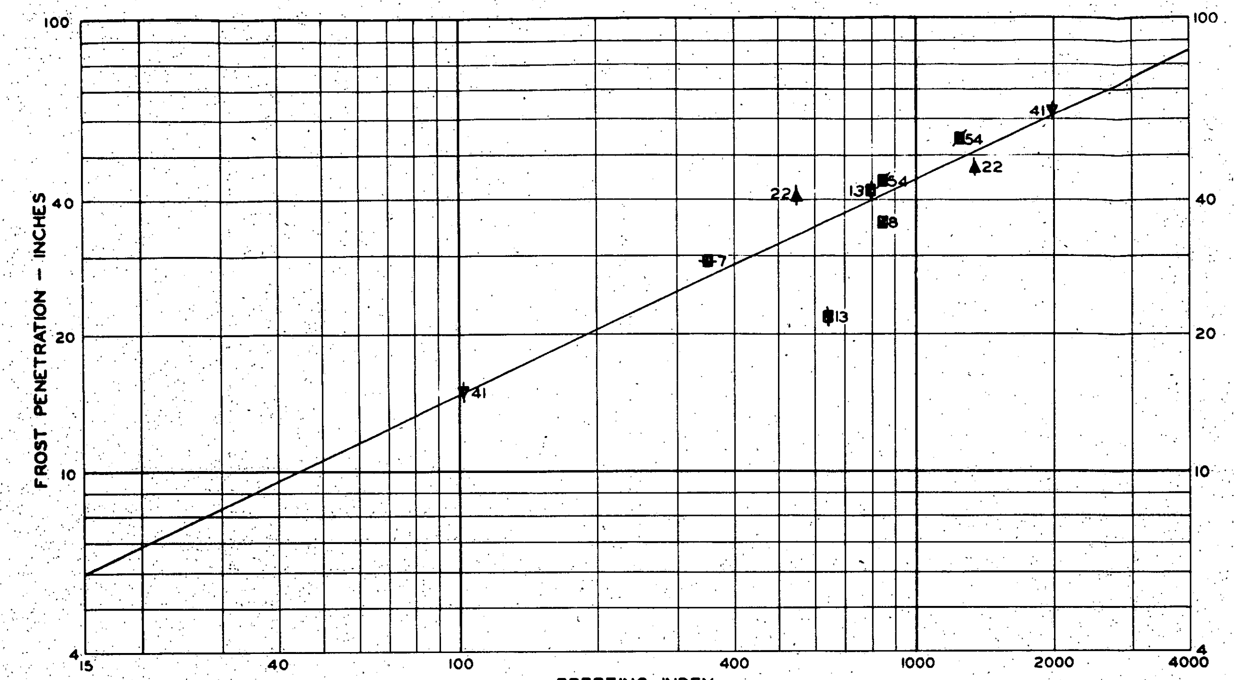
EXAMPLE FOR USE OF EQUATION

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

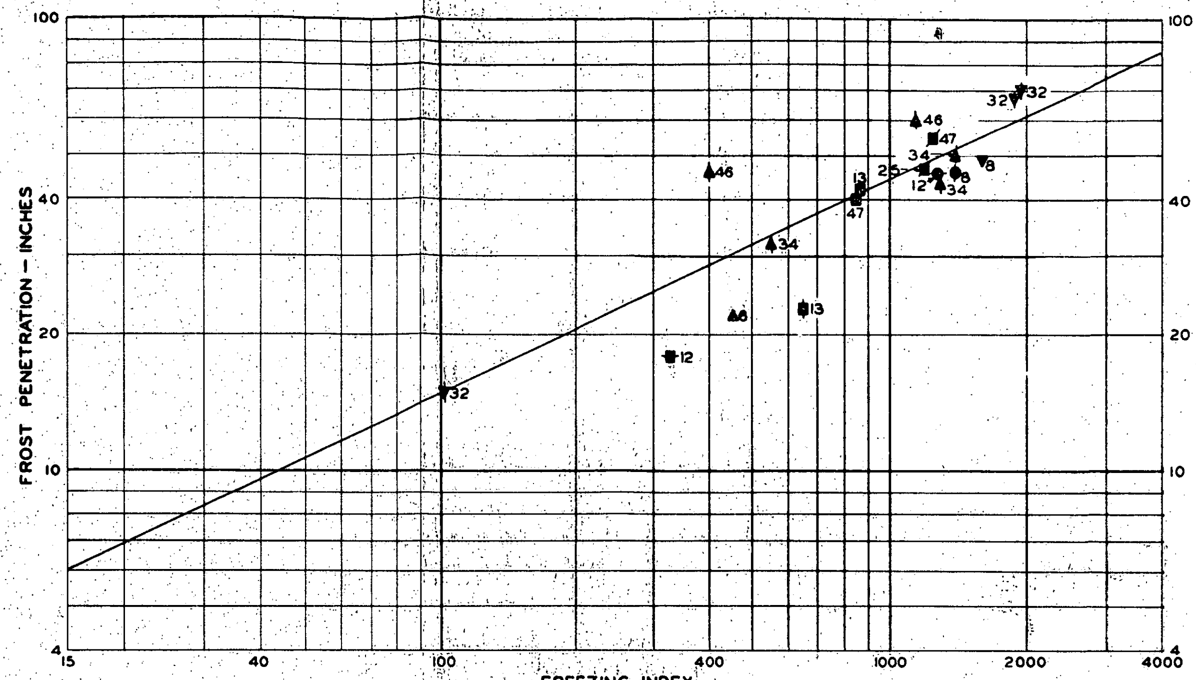
FROST INVESTIGATION

PREDICTION OF FROST PENETRATION

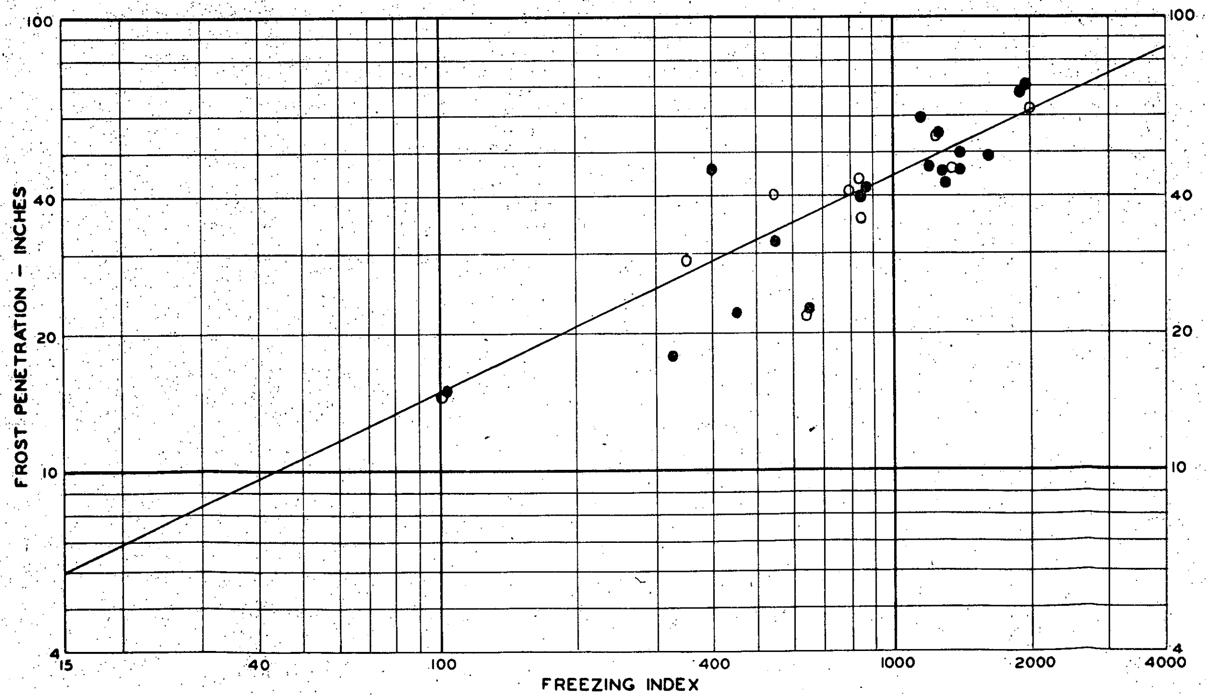
FROST EFFECTS LABORATORY, BOSTON MASS. JUNE 1945



FREEZING INDEX
RIGID PAVEMENT
FIG. 1



FREEZING INDEX
FLEXIBLE PAVEMENT
FIG. 2



FREEZING INDEX
RIGID AND FLEXIBLE
FIG. 3

LEGEND

▼ PRESQUE ISLE
▼ HOULTON
▲ DOW FIELD
▲ OTIS
■ TRUAX
■ PIERRE
■ CASPER
■ WATERTOWN
● FARGO
● BISMARCK
○ 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.

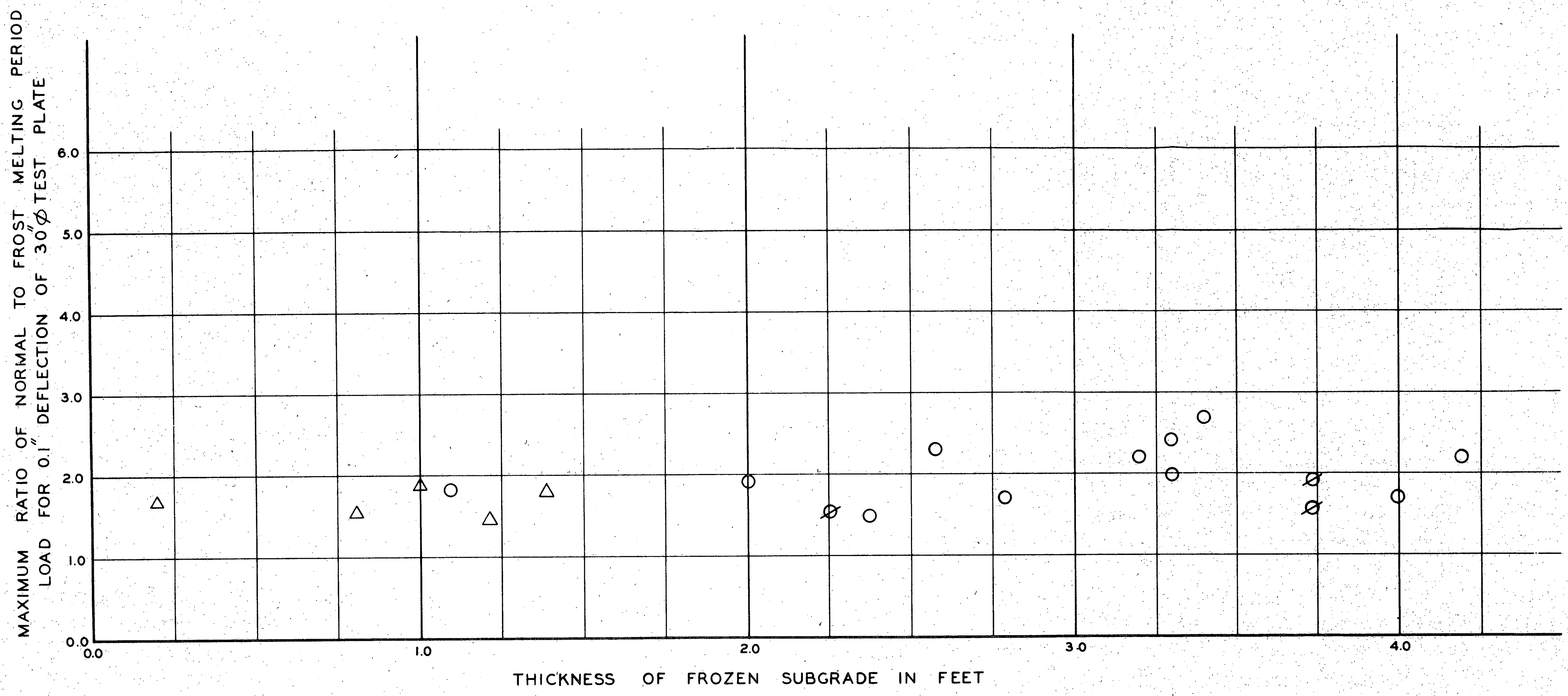
STRAIGHT LINE EQUALS THE DESIGN CURVE SHOWING COMBINED THICKNESS OF PAVEMENT AND BASE REQUIRED TO PREVENT FREEZING OF SUBGRADE RECOMENDED IN REVISIONS TO ENGINEERING MANUAL.

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

FROST INVESTIGATION
1944-1945

CORRELATION BETWEEN
FROST PENETRATION AND
FREEZING INDEX

FROST EFFECTS LABORATORY, BOSTON, MASS. JUNE 1945



	SITE	CLASS OF SUB-GRADE SOILS	FREEZING INDEX 1944 - 1945	WATER TABLE DEPTH (FT.)	
				FALL 1944	SPRING 1945
○	PRESQUE ISLE	CL	2190	6.0	3.0
Ø	TRUAX	SF AND CL	1260	6.0-7.0	0.5-6.0
△	DOW FIELD	CL	1244	4.5	2.0-3.5

NOTES:—

TESTS MADE ON TOP OF BITUMINOUS CONCRETE PAVEMENT.

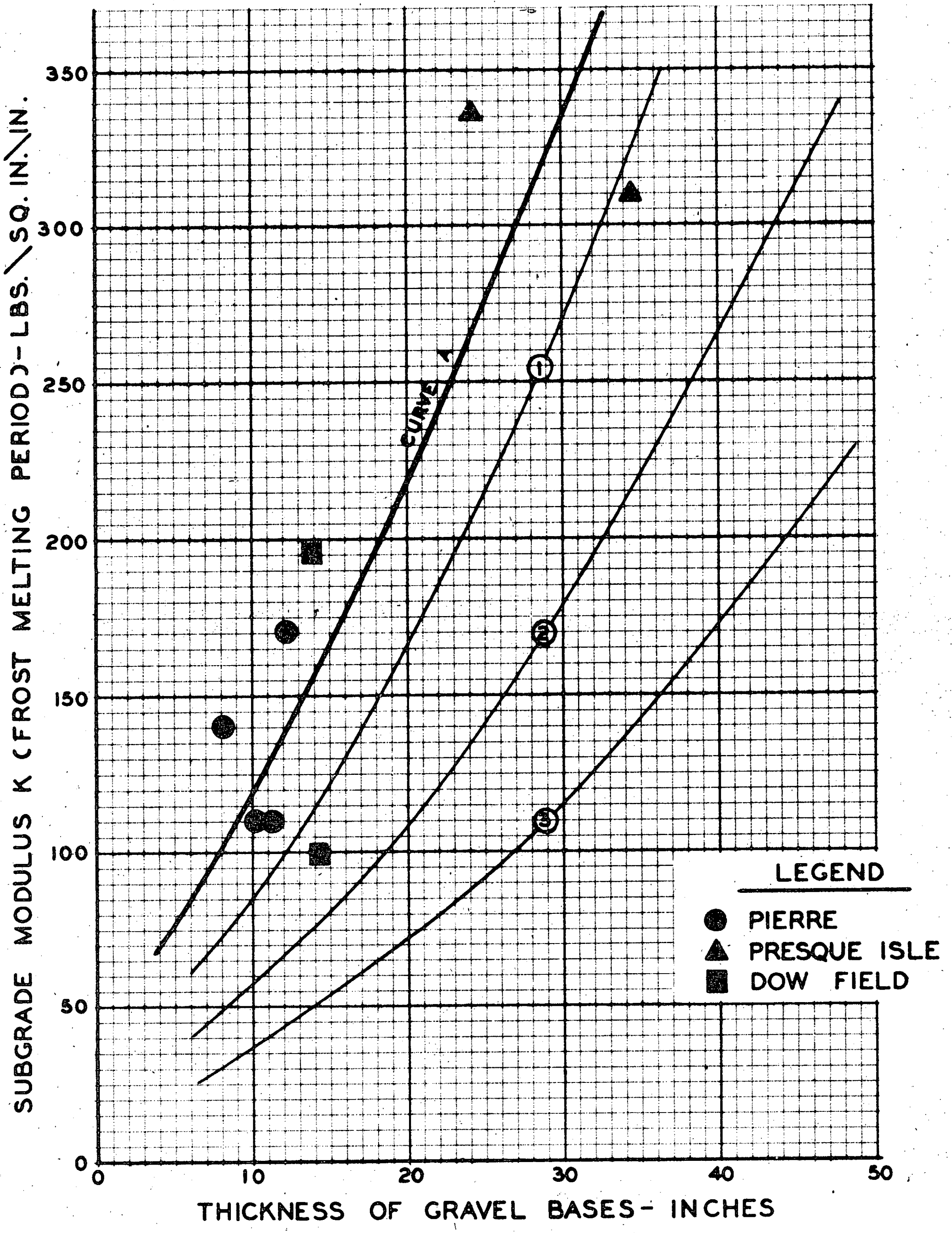
THICKNESS OF FROZEN SUBGRADE EQUALS TOTAL FROST PENETRATION IN FEET LESS COMBINED THICKNESS OF PAVEMENT AND BASE IN FEET.

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

PLATE 10



NOTE:

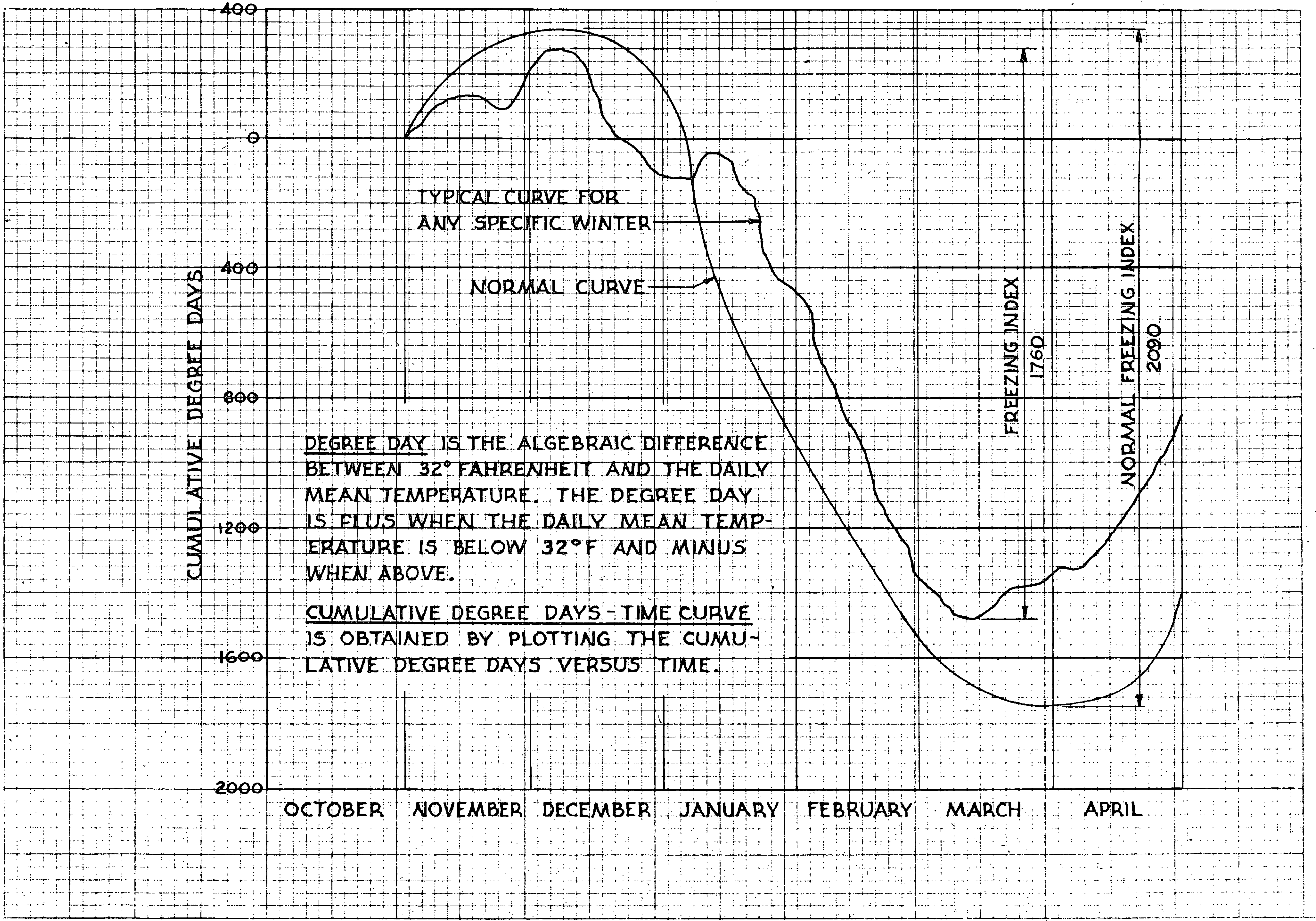
CURVES ① ② ③ ARE DESIGN CURVES OF "RECOMMENDED REVISIONS TO ENGINEERING MANUAL."

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

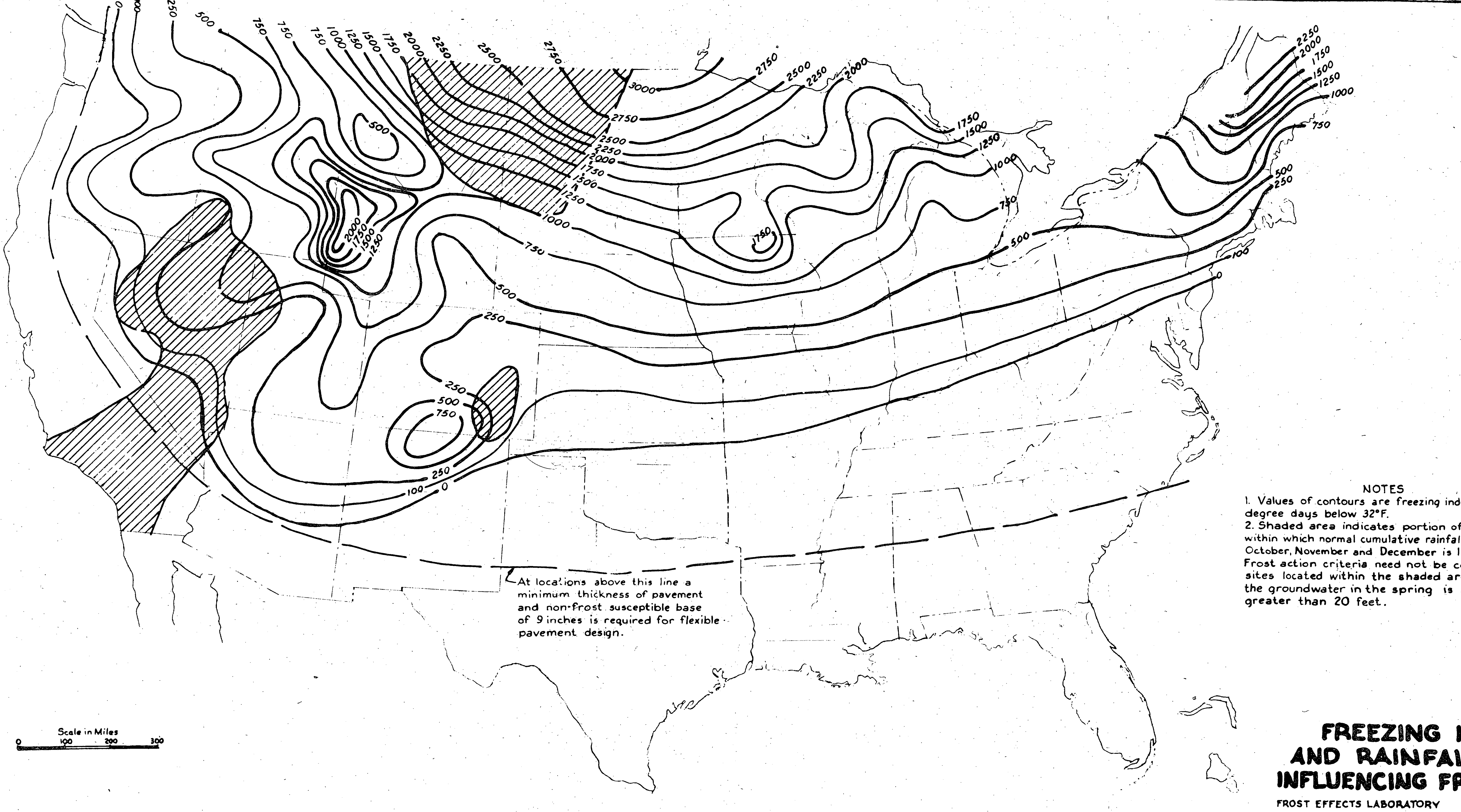
PLATE 11



DEGREE 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°F AND MINUS WHEN ABOVE.

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

PLATE 12



At locations above this line a minimum thickness of pavement and non-frost susceptible base of 9 inches is required for flexible pavement design.

NOTES

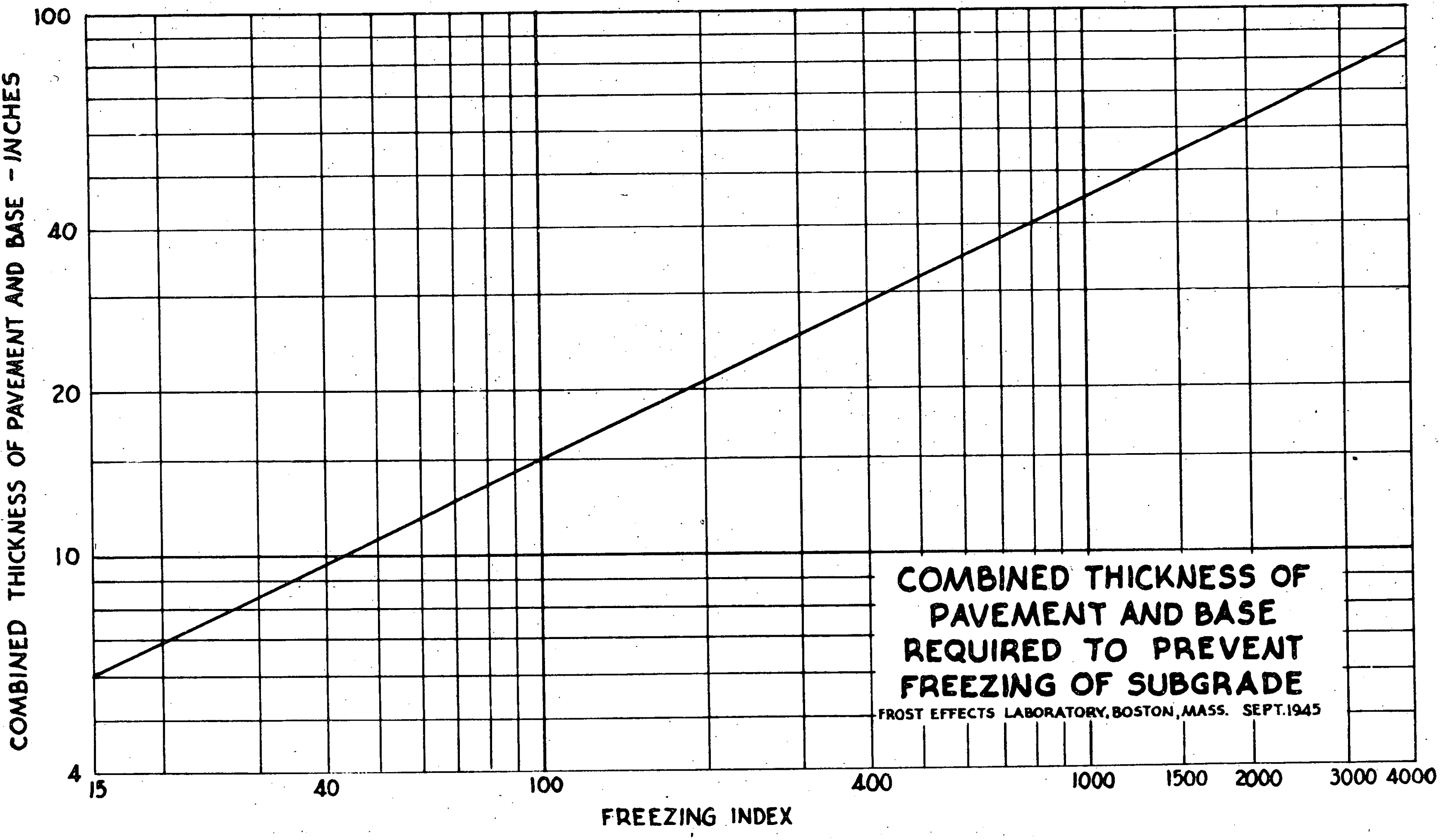
1. Values of contours are freezing index expressed in degree days below 32°F.

2. Shaded area indicates portion of United States within which normal cumulative rainfall for months of October, November and December is less than 2 inches. Frost action criteria need not be considered at sites located within the shaded area provided the groundwater in the spring is at a depth greater than 20 feet.

FREEZING INDEX AND RAINFALL DATA INFLUENCING FROST ACTION

FROST EFFECTS LABORATORY BOSTON, MASS

PLATE 13

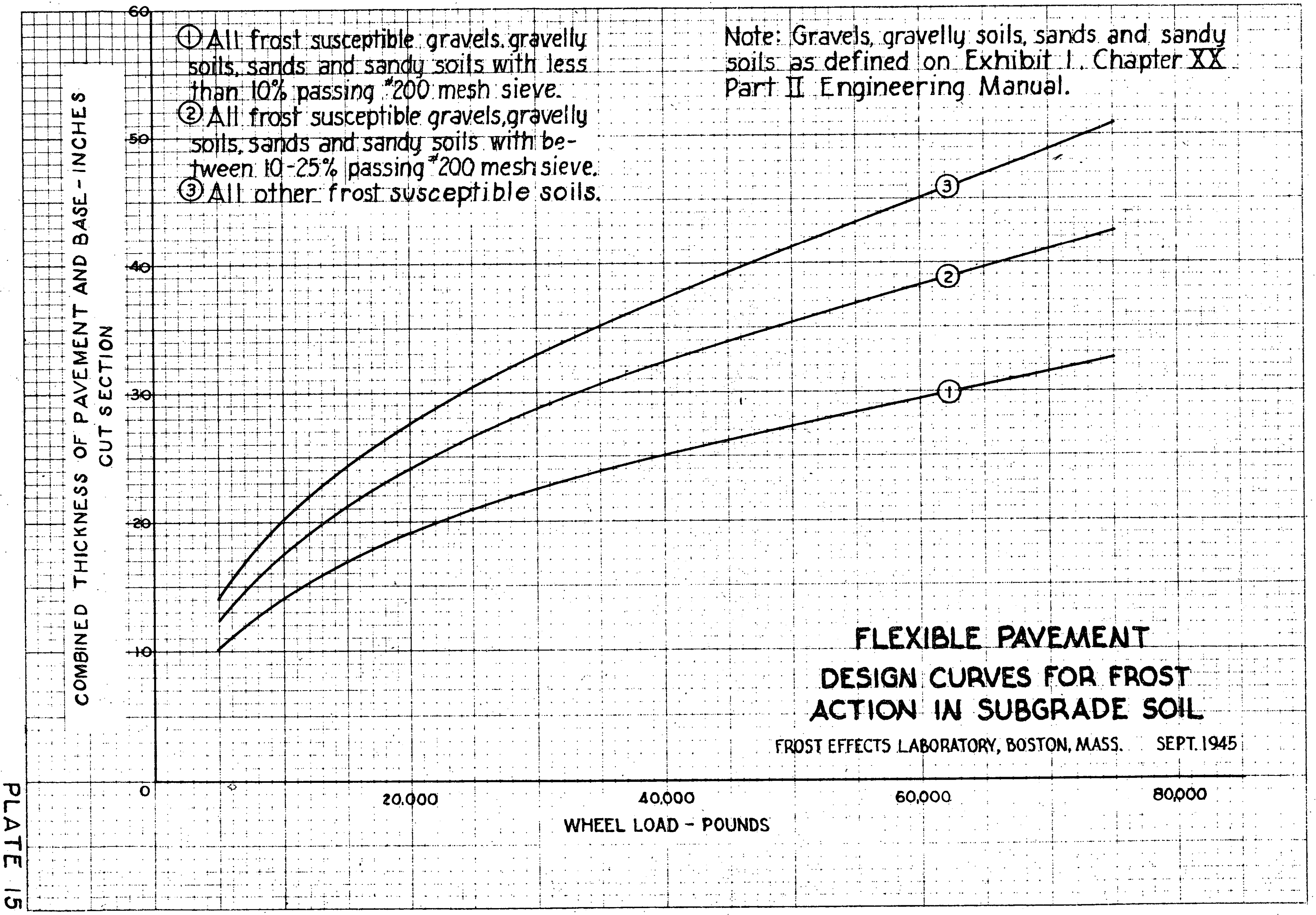


COMBINED THICKNESS OF PAVEMENT AND BASE REQUIRED TO PREVENT FREEZING OF SUBGRADE

FROST EFFECTS LABORATORY, BOSTON, MASS. SEPT. 1945

PLATE 14

PLATE 15



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.

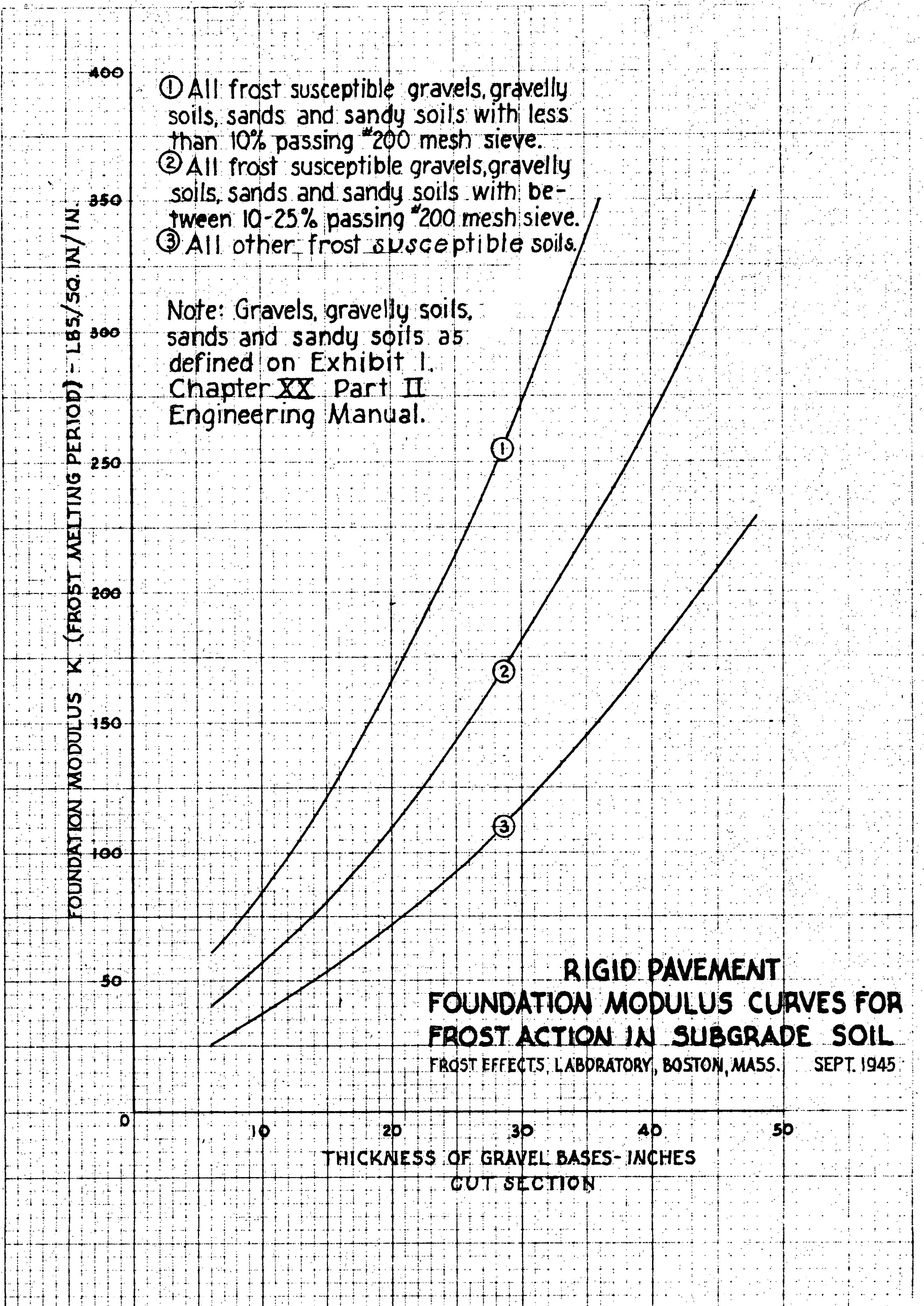
③ All other frost susceptible soils.

Note: Gravels, gravelly soils, sands and sandy soils as defined on Exhibit 1, Chapter XX Part II Engineering Manual.

FLEXIBLE PAVEMENT

DESIGN CURVES FOR FROST ACTION IN SUBGRADE SOIL

FROST EFFECTS LABORATORY, BOSTON, MASS. SEPT. 1945



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 Exhibit I. Chapter XX Part II Engineering Manual.

RIGID PAVEMENT
FOUNDATION MODULUS CURVES FOR FROST ACTION IN SUBGRADE SOIL
FROST EFFECTS LABORATORY, BOSTON, MASS. SEPT. 1945

PLATE 16