CORPS OF ENGINEERS
U.S. ARMY

FROST INVESTIGATIONS

FISCAL YEAR 1951

FIRST INTERIM REPORT OF FIELD INVESTIGATIONS AT FROST TEST SECTION LIMESTONE, MAINE

PREPARED BY
FROST EFFECTS LABORATORY
CORPS OF ENGINEERS, U. S. ARMY
NEW ENGLAND DIVISION, BOSTON, MASS.
FOR
OFFICE OF THE CHIEF OF ENGINEERS
AIRFIELDS BRANCH
ENGINEERING DIVISION
MILITARY CONSTRUCTION
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SYNOPSIS

A special frost test area 30 feet by 40 feet was constructed at Limestone Air Force Base, Limestone, Maine during the Summer of 1950. The test area consists of four test sections with varying thicknesses of pavement and base course constructed over the natural gravelly sandy clay subgrade. A program of tests was initiated in October 1950 to make continuous observations of the factors which are considered to influence frost action, such as air and subsurface temperatures, ground water conditions and soil characteristics.

Pavement heave was measured during the freezing period. Test pits were dug in the Fall of 1950 prior to freezing, and again at the start of frost melting period, to observe segregated ice and to determine effects of frost action on water contents and densities of the subgrade. Plate bearing tests were performed prior to freezing and are being performed continuously from the start of the frost melting period in late March 1951 until the pavement returns to normal in the Summer of 1951.

Data from studies completed up to 1 June 1951 are presented in this report. The trend of the available data indicates that: (1) after a marked reduction in strength at the start of frost melting, regain in subgrade strength was generally continuing at a uniform rate as of 1 June, (2) variations in thickness of pavement and base at the test sections had no appreciable effect on depths of frost penetration.

PART I - INTRODUCTION

1-01. Authorization. Frost investigations during Fiscal Year 1951 were authorized and funds allocated by Directive NED MIC 51-2, dated 11 October 1950, from the Chief of Engineers to the Division Engineer, New England Division. Instructions and Outline for Field Studies were transmitted as inclosure with letter dated 23 October 1950 from the Chief of Engineers to the Division Engineer, New England Division, Subject: "Instructions and Outlines for Investigational Projects, Fiscal Year 1951."

1-02. Purpose. The purpose of the Field Studies of Frost Investigations during Fiscal Year 1951 is to obtain information relative to the magnitude and the duration of the reduction in pavement supporting capacity due to frost action as measured by plate bearing tests, and to verify established criteria for the design and evaluation of pavements for airfields and highways.

1-03. Scope. Investigations are planned to a period of four to five years in order to encompass the full range of climatic conditions and to study the effect of controlling the ground water table at various elevations. To fulfill the purpose of the program, a test section was constructed at the Limestone Air Force Base, Limestone, Maine, with provisions made for performing plate bearing tests at selected locations to obtain comparative strength values at various periods during the year, and under varying ground water conditions. Additional areas are provided for excavation of test pits to measure density and water content variations, to study ice lens formation, and to perform California Bearing Ratio tests on the subgrade for the purpose of correlation with the other studies. Facilities have also been provided for water table control and observation.

The test section was constructed during the months of July, August and September 1950 and normal period tests were performed in October 1950. The normal period investigations included test pits to sample and obtain densities and in-place CBR values of subgrade material; the initial series of static and repeating load plate bearing tests were also performed. The readings of subsurface temperatures, ground water elevations in base and subgrade, and pavement surface elevations were initiated at the start of the normal period tests and are being made continuously at regular intervals. With the start of the frost melting period in the Spring of 1951, test pits were dug to observe ice segregation and to obtain density and water content data; plate bearing tests series were commenced and are continuing at approximately weekly intervals until the foundation materials have returned to normal strength.

This report presents the details of the test section and observation equipment together with the results of the tests performed to 1 June 1951.

1-04. Definitions.

Frost action is a general term used in reference to freezing of moisture in materials and the resultant effects on these materials and the structures of which they are a part.

Ice segregation in soils is the growth of bodies of ice during the freezing process, most commonly as ice lenses or layers oriented normal to the direction of heat loss, but also as veins and masses having other patterns.

Frost-susceptible soils are those in which significant ice segregation will occur when moisture is available and the requisite freezing conditions are present. (Previous information has indicated that most soils containing 3 per cent or more of grains finer by weight than 0.02 mm. are susceptible to ice segregation, and this limit has been widely applied to both uniformly and variably graded soils. Although it has been found that some uniform sandy soils may have as high as 10 per cent of grains finer than 0.02 mm. by weight without being considered frost susceptible, there is some question as to the practical value of attempting to consider such soils separately, because of their rarity and tendency to occur intermixed with other soils.)

<u>Non-frost-susceptible materials</u> are crushed rock, clean sandy gravel, gravel, slag, cinders, or any other cohesionless materials in which ice segregation does not occur under natural freezing conditions.

<u>Degree day</u>. Each degree in any one day that the daily mean air temperature varies from 32°F. is called a degree day. The difference between the daily mean temperature and 32°F. equals the degree days for that day. The degree days are minus when the daily mean temperature is below 32°F. and plus when above.

<u>Freezing season</u> is the period which starts with the first day in the Fall season, and ends with the last day in the Spring season for which the daily mean air temperature is below 32°F.

<u>Freezing index</u> is the number of degree days between the highest and lowest points on the cumulative degree days-time curve for one freezing season. It is used as a measure of the combined magnitude and duration of below-freezing air temperatures occurring during any given freezing season.

<u>Normal (mean) freezing index</u> is the average freezing index for a long period of record, usually 10 or more years. It is computed by averaging mean air temperatures for the period of record and preparing a single cumulative degree days-time curve representing a normal for the entire period.

Frost-melting period is an interval of the year during which the ice in the foundation materials is returning to a liquid state. It ends when all the ice in the ground has melted or when freezing is resumed. Although in the generalized case there is visualized only one frost melting period, beginning during the general rise of air temperatures in the Spring, one or more significant frost melting intervals may occur during a Winter season.

Normal period is the time of the year Summer and Fall when there is no reduction in strength of foundation materials due to frost action.

Period of weakening is an interval of the year which starts at the beginning of the frost-melting period and ends when the subgrade strength has returned to normal. Summer Values

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.

Per cent heave is the ratio, expressed as a percentage, of the amount of heave to the depth of frozen soil before freezing.

1-05. Acknowledgements. The Frost Investigations, of which the field studies at the Limestone Test Section are a part, are being conducted by the Frost Effects Laboratory for the Airfields Branch, Engineering Division, Military Construction, Office of the Chief of Engineers. The studies are under the administration of Mr. Gayle MacFadden, Chief, Airfields Branch, assisted by Mr. Thomas B. Pringle, Head, Runways Section and by Mr. Frank Hennion.

Colonel H. J. Woodbury is the Division Engineer, New England Division, Corps of Engineers, U. S. Army. Mr. John E. Allen is Chief of the Engineering Division to which the Frost Effects Laboratory is attached.

Mr. Kenneth A. Linell is Chief of the Frost Effects Laboratory. The studies are under the immediate supervision of Mr. James F. Haley, Assistant Chief, Frost Effects Laboratory.

Dr. Arthur Casagrande of Harvard University, Dr. P. C. Rutledge of Northwestern University, and Prof. K. B. Woods of Purdue University are the investigational consultants.

PART II - TEST SECTION

2-01. General. The test area is located at Limestone Air Force Base in Aroostook County, northern Maine, approximately four miles northwest of the town of Limestone as shown on the location plan on Plate 1. This site was selected for the investigation because the cold winters characteristic of this region produce a normal frost penetration depth of approximately six feet. The natural foundation materials of gravelly sandy clay (Glacial Till) are ideally suited for this investigation being of a highly frost susceptible nature. Other factors considered in the selection of this site were the availability of construction materials and equipment as a result of construction activities in the vicinity and the ready availability of a suitable area of Government-owned property.

2-02. Test Area. The test area, forty feet by thirty feet, consists of four test sections fourteen feet by eighteen and a half feet with base courses of seven, twelve, eighteen and twenty-four inches respectively over the natural subgrade. The base course consists of a lower layer of sandy gravel and an upper layer of crushed rock, which was choked, rolled and paved with a double surface treatment of sand and tar. (See Plate 1) Drainage swales are provided around the test area to take care of surface run-off. Subsurface drainage facilities consist of drainage trenches around the area and bisecting the area in one direction. A system of perforated corrugated metal pipe installed in the trenches is connected to a water supply well, in which the water level may be controlled, thereby allowing either drainage of the test area or maintenance of the ground water level at any height in either the subgrade or the lower part of the base.

A description of the subgrade, base course and paving materials and construction methods are contained in the following subparagraphs:

a. Subgrade. The subgrade material at the test area consists of a gravelly sandy clay (CL) glacial till with an average liquid limit of 21 and plasticity index of 6. The gradation range and average gradation of the subgrade soil is shown in Figure 1, Plate 2. Also shown on Plate 2, in Figures 4, 6 and 8, are the triaxial test results, and compaction and permeability characteristics of representative subgrade samples. Prior to construction of the test sections, the area was stripped for a depth of 1.5 to 3.5 feet to remove the topsoil and badly weathered till. The subgrade surface was compacted using an RD-7 crawler-type tractor, fine graded and rolled with 10 ton smooth-wheeled roller. Results of field density tests made of the top eight inches of subgrade before and after compaction are shown in the following tabulation:

GRAVELLY SANDY CLAY SUBGRADE DENSITIES

Section of Test Area	Before Compaction			After Compaction		
	Water Content %	Dry Density p.c.f.	Void Ratio e	Water Content %	Dry Density p.c.f.	Void Ratio e
7" Section	11.01	124.2	0.364	7.5-8.9 (8.2)	137.9-138.8 (138.4)	0.222-0.230 (0.226)
12" Section	10.80	124.2	0.364	9.6-10.2 (9.9)	136.2-138.1 (136.8)	0.228-0.242 (0.237)
18" Section	11.62	117.2	0.447	8.6-9.0 (8.8)	133.1-133.5 (133.3)	0.270-0.271 (0.270)
24" Section	11.91	115.2	0.470	9.2-9.6 (9.5)	131.6-135.8 (134.2)	0.250-0.290 (0.265)

Figures in ( ) denote average results.

b. Base Course. The base of each section was constructed using non-frost susceptible sandy gravel (GW) in the lower base. In its natural condition in the borrow pit, the material utilized for the sandy gravel base contained considerable fines and was considered to be a borderline frost susceptible soil. The fines were removed at the borrow pit by excavating the material beneath the groundwater table and allowing water and fines to drain from the clamshell bucket prior to loading. The upper base was constructed using crushed rock, the surface of which was then thoroughly choked with stone screenings. Gradation curves of the base course materials and choker aggregate are shown in Figures 2 and 3 on Plate 2. The results of triaxial shear, compaction and permeability tests performed on the gravel base materials are also shown in Figures 5, 7 and 9 on Plate 2. The thicknesses of upper and lower base materials in each of the four test sections are as follows:

Total Base Thickness Inches	Upper Base Crushed Rock Inches	Lower Base Sandy Gravel Inches
7	4	3
12	6	6
18	6	12
24	6	18

Base course materials were placed in layers with a maximum thickness of 6 inches. Each layer of sandy gravel base was compacted using 10 coverages of an RD-7 crawler-type tractor weighing 32,800 pounds and the surface of the crushed rock was rolled with a 10 ton smooth-wheeled roller. After compaction the density of the sandy gravel base material was determined at 20 locations by the water volume method. Values ranged from 130 to 136 lbs. per cu. ft. with an average of 133 lbs. per cu. ft. or 99 per cent of Providence Vibrated Density.

c. Pavement. The surface of the crushed rock base was covered with a tar-sand double surface treatment. An initial application of 0.5 gallons per square yard of RT-6 was applied and covered with 15 lbs. per square yard of sand. A second application of 0.25 gallons per square yard of RT-6 was then made and covered with 10 pounds per square yard of sand. The gradation of the sand used in surface treatment is shown in Figure 3, Plate 2.

2-03. Water Supply Well. A water supply well consisting of a section of a concrete pipe five feet in diameter is located adjacent to the test area. The well is connected to the perforated pipes in the trenches which bisect and are on the perimeter of the test area. A ball and cock valve arrangement attached to the water supply line controls the water level in the supply well - and thus the head of water in the perforated pipes - at any desired level between the lower part of the base course in the test area and approximately five feet below the subgrade surface. Valves and drains are installed to permit shutting off the water and draining the well and subgrade. A cross section of the well showing the details of construction is shown on Plate 1.

2-04. Thermocouples. Ten thermocouples are installed in each test section at depths of 0.25, 0.50, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0 and 7.0 feet. Thermocouples are of copper-constantan wire and each group of ten pairs of wires is encased in watertight plastic tubing. At the point of installation each individual thermocouple is encased in plastic tubing and the temperature measuring junction is hermetically sealed in plastic for a distance of approximately five inches making a complete watertight unit from the temperature measuring point to the switch box. Details of construction and installation are shown on Plate 3. The thermocouples from the point of installation to the point where they enter the instrument house are buried in the subgrade. All thermocouples are connected to a Leeds & Northrup Speedomax unit in the instrument house (See Figure 2, Plate 4). Values of temperature are read directly in degrees Fahrenheit by manually closing the switch for the desired thermocouple.

2-05. Observation Wells. Two wells have been installed in each test section to permit observation of water level in the base course materials and one well has been installed in the center of the test area for the determination of the elevation of the ground water level in the subgrade.

2-06. Subgrade Deflection Gages. Gages have been installed at six locations in each section to measure the subgrade deflection during plate loading tests. These gages, as shown on Plate 3, consist of steel rods attached to four inch square plates and of various heights depending on the thickness of pavement and base. Each square plate rests on a sand cushion on the subgrade surface and each steel rod is encased in a pipe which extends from approximately 3/4-inch above the steel plate to the pavement. The space between the gage rod and the pipe, the purpose of which is to prevent friction between the rod and the base materials, is packed with grease to prevent water from entering, freezing, and hampering the action of the gage. Positions of gages in 12-inch test section are shown on Plate 1. Gages in other sections are in same relative positions and numbering sequences are the same.

2-07. Loading Equipment. Reaction for the plate loading test is provided by a 27-inch WF steel beam anchored at the center and free to rotate horizontally over the areas of the test sections where plate bearing tests are conducted. The loading beam details and plate bearing test set-up are shown in Figure 1 on Plate 4 and on Plate 5. Reaction is obtained by cribbing one end of the beam and jacking against the other end. The beam is supported in a yoke which in turn is fastened to a 3-1/4 inch diameter steel rod grouted into bedrock. The anchor rod, with a 5½-inch diameter button at the lower end, extends through 20 feet of overburden in a 10-inch pipe casing and down 20 feet below the bedrock surface within an 8-inch diameter percussion-drilled hole. Infiltration of water hampered normal pressure grouting, so the tremie method was adopted to fill the annular space between the lower portion of the anchor rod and the rock surface and between the upper portion of the anchor rod and the inside wall of the casing. The tremie concrete consisted of one part cement, two parts sand and one part 1/2-inch maximum size pea gravel, and had an 8-inch slump. An admixture of Darex was used to improve the flowability of the mix which was placed through a $2\frac{1}{2}$-inch pipe by gravity with the lower end of the pipe kept at least five feet below the surface of the concrete in the hole.

2-08. Heave Reference Hubs. Three heave reference points have been installed in each section. The hubs consist of large round head railroad spikes driven into the pavement with the heads flush with the pavement surface. Locations in 12-inch test section are shown on Plate 1. Points in other sections are in same relative positions and numbering sequences are the same.

2-09. Bench Mark. The bench mark installed adjacent to the test area is constructed of a 3/4-inch diameter steel rod driven to a depth of approximately ten feet and encased in a grease-filled pipe for the top six feet to preclude movement due to frost action.

PART III - FIELD INVESTIGATIONS

3-01. General. After completion of the construction of the test area on 1 September 1950 the water level in the water supply well was controlled at an elevation a few inches above the subgrade surface. The water level was maintained at this elevation until the start of the freezing period when it was lowered to an elevation a few inches below the subgrade surface.

Field investigations at the test area were started during the latter part of October 1950. Test pits were dug in each of the four test sections to determine the density and water content of the base and subgrade soils and also to perform in-place CBR tests. The initial series of plate bearing tests was performed and initial readings of pavement surface elevation, subsurface temperatures and ground water elevations were made and continued throughout the Winter and Spring, following a prescribed schedule. Plate bearing tests were discontinued during the Winter months when the subgrade was frozen and were recommenced at the start of the frost melting period and are being continued at approximately weekly intervals until the subgrade returns to normal strength. Test pits were dug in each section after the start of frost melting to observe ice segregation, determine density and water content distribution in subgrade and to perform CBR tests on surface of the subgrade.

3-02. Weather Data. Weather data were obtained at the Air Force weather station located at the Operations Building approximately one mile north of the test area. Weather information consisted of observations of daily rainfall (includes water equivalent of snowfall), maximum and minimum daily temperatures, and average daily temperatures based on average of hourly temperatures. Daily temperature and rainfall records for the investigational year are plotted in Figures 1 through 3 on Plate 6. Records of average relative humidity, average wind velocity and hours of sunshine are being obtained but have not been presented in this report. These records, however, will be utilized to analyze penetration of frost during future freezing seasons when continuous records of pavement surface and subsurface temperatures will also be obtained.

The Winter of 1950-1951 was a particularly mild one from the standpoint of freezing temperatures. Cumulative degree day curves are plotted in Figure 4 on Plate 6, based on both daily mean temperatures and averages of hourly temperatures. Inappreciable difference is noted between these plots although similar plots for other localities may show major differences. The Freezing Index for the Winter of 1950-1951 was 1529 degree days compared with a Normal Freezing Index of 2417 degree days at Caribou, Maine, 10 miles southwest of Limestone, which is the location of the nearest weather station with a long period of record. The months of August, September and October 1950 were abnormally dry, having a deficiency of approximately 3 inches of rainfall below normal. Rainfall during the month of November, however, was 3.86 inches above normal.

3-03. <u>Groundwater Observations</u>. Depths to the groundwater surface in the subgrade observation well, located at the center of the test area, were determined twice each week. A plot of the groundwater elevations during the investigations in relation to the subgrade surface is shown on Plate 7.

It may be seen that the water level in the well was approximately 10 feet below the subgrade surface in early November and rose 7 feet by the end of December and a short time later water in the well was frozen. At the start of frost melting period late in March, the water level was at the subgrade surface and receded to a depth of 8 feet by the end of May. During this entire period the water level in the five foot deep gravel-filled trenches, which bisect and are at the perimeter of the test area, was maintained at approximately the elevation of the subgrade surface.

The fact that the water level in the subgrade well is not sensitive to the water level in the gravel-filled trenches is attributed to the imperviousness of the subgrade soil and the depth of the gravel packing in the well. Gravel packing in the well extends from depths of 8 feet to 13 feet below the bottoms of the gravel-filled trenches. The observation well readings indicate, however, that the water level in the subgrade was close to the subgrade surface when the water froze in the well and upon melting in the Spring the water level remained at the subgrade surface for several weeks.

Additional wells will be installed in the upper portion of the subgrade prior to the next freezing period, to give a more reliable measure of the level of the water source for ice segregation. Also, methods will be devised to permit determination of the head of water in the subgrade beneath the zone of freezing, throughout the freezing period.

The observation wells which extend to the bottom of the base course in each test section were dry during this investigational year.

3-04. Subsurface Temperatures. Daily readings of subsurface temperatures were made in each of the four test sections utilizing the copper-constantan thermocouples placed during construction of the test area. The readings were taken each day at approximately 1:00 P.M. Plots showing the depths below pavement surface of the 30, 31 and 32 degree Fahrenheit temperatures versus time for each test section are shown on Plates 8 through 11.

The extent of the frozen zone as revealed in test pits dug in each section during the latter part of March or early April have been plotted on Plates 8 to 11 inclusive. Based on these plots it is indicated that the temperature at the boundary between frozen and unfrozen soil was generally 30.5°F. It should be noted, however, that as shown on Plate 1 the test pit locations were approximately 8 feet from the thermocouple locations. The faces of the test pits which were logged and the thermocouples were both equidistant from the edge of the perimeter drainage trench.

3-05. Pavement Heave. Elevations of the three heave reference hubs in each test section were determined at regular intervals during the freezing and frost melting periods. The heave of each hub and average heave plotted against time are shown on Plates 8 through 11. The average maximum heaves for each test section were as follows:

Base Course Thickness Inches	Average of Maximum Heave Inches
7	5.0
12	4.5
18	4.9
24	3.7

3-06. Test Pit Explorations. Test pits located as shown on Plate 1 were dug in early October, 1950, and again at the start of the Frost Melting Period in the Spring of 1951. Plots of the density and water content determinations are shown on Plate 12. The boundary between the frozen and unfrozen material in the Frost Melting Period tests as shown on Plate 12, tends to be well defined by variations in water content and density. Water contents shown in Plots (B), Plate 12 were determined by drying the entire density sample weighing approximately 14 pounds, while water contents in Plots (C) are of full pint jar samples obtained for each 2 inches of depth, with stones larger than 1 inch in diameter eliminated from samples.

At the time the density determinations were made, in the Spring of 1951, the subgrade was completely frozen from the surface down to the depths shown on Plate 12. Density tests were performed using the water volume method. A hole approximately 6 inches in diameter and 6 inches deep was dug and lined with a thin rubber membrane and the volume of water required to fill the hole was measured. The dry weight of the soil removed from the hole was determined by oven drying the entire sample and weighing. Due to the fact the subgrade soil at the test section contains a relatively high per cent of gravel, it is particularly difficult to make density determinations in the frozen state. Using the density and water content results it was found that in two instances the degree of saturation of the subgrade computes to be in excess of 100 per cent. In both instances this occurred in the 12-inch section, in one case at from 32 to 38-inch depth and in the other from 44 to 50-inch depth. The density results at these two locations are questioned and the theoretical densities to give 100 per cent saturation are shown on Plate 12.

During the Frost Melting Period many ice lenses ranging from hairline thickness to over an inch were found on the faces of the test pits. The magnitude, depth, and orientation of lenses 1/32 inch or greater in thickness were determined and are shown on Plate 13. Generally the thicker ice lenses were located near the lower boundary of the frozen soil in each pit. Total thicknesses of the measured ice lenses and the measured heave for the same date are compared below:

Base Thickness Inches	Cumulative Thickness of Ice Lenses Inches	Average Measured Heave Inches
7	2.3	4.9
12	3.0	4.2
18	3.0	5.5
24	1.8	4.3

Variations between the observed heave and cumulative thickness of ice lenses are believed due to the many hairline ice lenses which were hardly discernible and too numerous to log. Photographs on Plate 14 illustrate in Figure 1 a large lens in a chunk sample and in Figure 2 the many seams left in the subgrade due to thawing of ice lenses.

The lower boundaries of the frozen zone in all sections were approximately at the same depth into subgrade (32"-34") except in the section with seven inches of base course in which the lower boundary of the frozen soil was at a somewhat higher elevation. Less penetration of frost at the test pit location in the seven inch section may be attributed to its position relative to the water supply well, which had a possible warming effect.

3-07. <u>California Bearing Ratio Tests.</u> In-place California Bearing Ratio tests were performed on the subgrade surface in conjunction with the test pit explorations during the normal and frost melting periods. A minimum of three tests were performed in each test pit. For comparison with field tests, laboratory California Bearing Ratio tests were performed on representative samples obtained from the subgrade surface in the test pits dug during the Fall of 1950. Field and laboratory CBR tests were performed in accordance with procedures outlined in Chapter 2, Part XII, Engineering

Manual, Military Construction, dated July 1946.

Results of both field and laboratory tests are presented on Plate 15. A summary of the average results of three tests in each test section is as follows:

Base Thickness (Inches)	California Bearing Ratio - Subgrade Surface	
	Normal Period	Frost Melting Period
7	25	11
12	26	16
18	25	18
24	19	20

At the time the frost melting period CBR tests were performed the subgrade of the 7-inch section had been completely melted for approximately a week, while in the 12-inch, 18-inch and 24-inch sections the depth to the top of frozen soil was 19 inches, 16 inches and 12 inches, respectively. The top boundary of the frozen soil has been estimated from the subsurface temperature plots on Plates 8 through 11.

There appears to be a consistent increase in the frost melting period CBR values with depth of base material. This might logically be attributed to the increased weight of base course forcing out the excess water more effectively as the subgrade melted, however, the water content values shown on Plate 15, each of which are average of four determinations, do not bear this out, being highest at the 24-inch section.

Laboratory CBR values are considerably higher than the in-place values where the molding water content was less than 8.3 per cent, however, when the molding water content was 10.3 per cent the laboratory CBR was equal to 3, or considerably lower than any of the field test results.

From this it is apparent that the laboratory CBR of the subgrade soil is very sensitive to molding water content, showing a considerable decrease with increase in molding content above approximately 8 per cent. A weak soil structure in the laboratory specimens is produced by the impact compaction method when the molding water content is a few per cent above optimum water content. During compaction of the subgrade surface in August 1950 ten water content determinations showed that the water content ranged from 7.5 to 10.2 per cent and averaged 9.1 per cent. The in-place CBR tests performed in October 1950 on the subgrade surface averaged 24 while the laboratory CBR value with molding water content of 9.1 per cent was approximately 25 from the plot of CBR vs. molding water content on Plate 15. The average field density of the upper subgrade in October 1950 was 129.6 lbs. per cu. ft. while the laboratory density at a molding water content of 9.1 per cent from the compaction test data is 131.5 lbs. per cu. ft. Thus it is indicated when compared on the basis of water contents during compaction the laboratory and field CBR values are approximately equal and variations due to differences in laboratory and field compaction methods are insignificant.

It is believed that the low laboratory CBR values which were obtained when the molding water contents were in the order of 10 per cent better approximate the subgrade strength that would occur if the pavement were subjected to repetitive traffic and the field moisture content was about 10 per cent. It was noted that a sample from the surface of the subgrade during the frost melting period tests, which was firm and gave relatively high CBR values, would suffer almost complete loss of stability immediately upon being remolded in the hand.

During the investigations made in connection with the construction of the pavements at Limestone Air Base field CBR results were obtained which are not closely comparable to the results obtained at the test section.

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Where the subgrade soil gradation and Atterberg limits were similar, the laboratory compaction and laboratory CBR results obtained in the previous investigations and as presented herein are practically identical.

Immediately following the frost melting period in 1947, in-place CBR tests were performed at several locations on the undisturbed subgrade soil at a depth of approximately 2 feet below natural ground surface. The results obtained during these tests were as follows:

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Dry Unit Weight lbs. per cubic ft.	Water Content %	In-place CBR
108	21.0	3.5
120	15.0	5.0
131	10.5	7.0

Field CBR tests were also performed on soil similar to the subgrade soil at the Frost Test Section during the Summer of 1947. These tests were made at a special test section constructed to determine the field compaction characteristics of the subgrade and base course material at the site. After compacting the subgrade using sheepsfoot rollers with 350 and 450 psi tamper pressures, in-place CBR tests were performed and the following results were obtained:

Dry Unit Weight lbs. per cubic ft.	Water Content %	In-place CBR
125.0	13.0	1.6
125.8	12.5	3.2
130.0	10.0	11.0
130.5	11.0	7.5

The reason for the differences between the field CBR test results at the Frost Test Section and those previously obtained is not clearly evident. Additional field CBR tests will be made at and adjacent to the Frost Test Section during Fiscal Year 1952 to obtain a more consistent body of data. This information is desired to determine whether or not the field CBR test is suitable for use during the frost melting period for the design or evaluation of flexible pavements. The average test results obtained during the Frost Melting Period in 1951 showed the subgrade CBR equal to 16 while the existing frost condition design curves are based on an assigned CBR of less than 3 for a subgrade soil of the type existing at the test section. Possibly a single season of freezing was insufficient to counter the effects of the compaction given in the previous Fall. Also the freezing of the upper 6 inches of the subgrade occurred in a period of only 3 to 4 days, resulting in comparatively litte ice segregation.

3-08. Plate Bearing Tests.

a. Test Procedures. Plate bearing tests were performed on the pavement surface using a 30-inch diameter steel bearing plate. A thin layer of Ottawa Sand was used to seat the bearing plate on the pavement. Plate deformations were measured by three dial extensometers placed 120 degrees apart on the outer edge of the plate. Subgrade deflection was measured by a dial extensometer placed on a subgrade deflection gage through a hole in the center of the bearing plate. Details of the subgrade deflection gage are shown on Plate 3. All four extensometers were attached to a steel beam supported approximately eight feet from each side of the bearing plate. Photographs on Plate 16 show the arrangement of the dials and the equipment set-up for test. A jack stand was used to distribute the load over the plate and provide a space for the extensometer placed over the subgrade deflection gage. Load was applied by jacking against the 27-inch WF beam using a 50 ton hydraulic jack controlled by an electrically driven hydraulic pump (Blackhawk Porto-Power Pump, P-182). A ball and socket joint was placed on top of the jack to reduce the eccentricity of loading on the bearing plate. The arrangement of the equipment during test is shown in Figure 1, Plate 4, and on Plate 5 which also shows the details of the reaction beam. One week prior to performing the normal-period tests all test locations were prestressed with ten repetitions of a 50,000 pound load. At the start of each individual test a seating load of 500 pounds was applied and held. Zero readings of the extensometers were then recorded.

Plate loading tests were of two types:

(1) Static Load Tests. Static load tests were performed by loading the plate in approximately five equal increments with each load increment held constant and the deflection of plate and subgrade recorded when the rate of plate deflection became less than 0.004 inches per minute. During the normal period static load tests a maximum load of 50,000 pounds was used regardless of deflection, because of initial difficulties with anchorage of the equipment. For the frost melting period static load tests the plate was loaded to a maximum load of 60,000 pounds or 0.2 inches deflection, whichever was reached first.

(2) Repeating Load Tests. Repeating load tests were performed by subjecting a 30-inch diameter plate to thirty loading cycles in a period of fifteen minutes. The load was rapidly applied in one increment and held constant for a period of approximately 20 seconds and then rapidly released. The deflection of the plate and subgrade was determined after the 1st, 5th, 10th, 20th and 30th repetitions with the load on the plate, and the permanent deformation was measured ten minutes after the release of the last repetition of loading.

In the repeating load tests the following constant loads were selected for the various test sections:

Section Base Thickness Inches	Test Load Pounds
7	10,000
12	15,000
18	30,000
24	50,000

b. Plate Bearing Tests Performed. Tests were performed at five positions on each of the four test sections. Test positions were centered over the subgrade deflection gages and were numbered 1 through 5 as shown on Plate 1 for the 12-inch section. The test positions in the other three sections were numbered in the same sequence as the 12-inch section, with the two positions nearest the beam support numbered clockwise, followed by the three positions away from the beam support also numbered clockwise.

Positions 1 and 2 were selected for repeating load tests, Positions 3 and 4 for static load tests and Position 5 for a repeating load test followed by a static load test. The same pattern of tests for like-numbered locations was used for each test section, with the tests in any one section being performed in the same day.

The plate bearing test program was initiated in October, 1950, to obtain the normal period pavement strength, at which time one complete series of tests was performed at each of the 20 test positions.

During the freezing season plate bearing tests were discontinued. At the start of the frost melting period tests were resumed, with one complete series of tests being performed at weekly intervals. The tests are being continued until the pavement returns to normal period strength.

c. Plate Bearing Test Results. Load deflection plots for static load tests and plots of number of repetitions versus deflection for the repeating load tests are shown on Plates 17 to 20 inclusive. The top two rows of plots across the top of the plates are for plate and subgrade deflections respectively at Positions 3 and 4. Plate and subgrade deflections for repeating load tests at Positions 1 and 2 are presented in middle two rows. The lower two rows of plots contain the results of the repeating load tests and of the static load tests which were performed immediately following the repeating load tests at Position 5. Each plate contains the results of all plate bearing tests performed at a specific test section up to approximately 1 June 1951. Deflections of the bearing plate and the subgrade surface beneath the center of the bearing plate have been plotted against load for the static load tests and against repetitions for the repeating load tests. Comparison of these plots shows the marked reduction in subgrade strength which resulted from frost melting early in April and the gradual increase in strength in succeeding weeks.

Plate bearing test results are summarized on Plates 21 through 24 on the basis of the ratio of frost melting to normal period loads at 0.05 inch deflections for the static load tests and on the basis of the ratio of normal to frost melting period deflections at the 30th repetition for the repeating load tests. The ratios presented are subject to modification after obtaining normal period results in the Fall of 1951. Results for the normal period of 1950 are based on only one test series which was performed approximately one month after filling the water supply well and so there may have been insufficient time for complete saturation of the subgrade. In view of this, quantitative ratios shown on Plates 21 through 24 may be subject to appreciable change; however, the shapes of the present plots which indicate the duration of weakening will be unchanged by revision of normal period data.

Actual deflections at the end of the 30th repetition in the repeating load tests are summarized on Plates 25 and 26. On Plate 25 are plotted deflections of plate and subgrade surface, for each of the sections, over the period of the field testing. On Plate 26 the differences between the plate and subgrade surface deflections in the 7-inch and 24-inch sections are compared. No summaries of this type have been prepared for other than the repeating load tests.

The static load test data presented on Plates 17 through 20 and on Plate 21 show that: (1) all sections were subject to approximately the same degree of weakening, (2) the 18-inch and 24-inch sections had not reached their maximum condition of weakening until after the initial test series in the Spring of 1951, (3) the four sections regained strength at approximately the same rate up to 1 June, and (4) all sections were still much weaker on 1 June than in the normal period of the preceding Fall.

The repeating load data presented on Plates 17 through 20, and 22 through 25 show: (1) deflections of plate and subgrade surface were progressive up to 30 repetitions of loading, (2) the increase in deflection with repetitions was most pronounced during the first part of the frost melting period and tended to be small to negligible during the normal period, (3) a number of tests on the 7, 12 and 18-inch sections showed rapid regain of strength during the first half of April, then approximately the same strength until early May, when strength was regained at an increased rate, (4) the subgrade deflection measurements generally tend to indicate greater loss in subgrade strength during the frost melting period than do the plate deflection measurements and the relative strength reached on 1 June tends also to be smaller for the subgrade deflection data (possibly the load versus subgrade deflection relationship for the normal period may not be representative), (5) in the repeating load tests, the subgrade deflections after 30 repetitions were approximately the same for all four test sections toward the end of May, although test loads and base course thicknesses were different in all the sections, (6) in the repeating load tests, the actual plate deflections at 30 repetitions exceeded the subgrade deflections by a considerably greater proportion in the 24-inch section than in the 7-inch section, apparently indicating thereby the greater stress distributing properties of the thicker base.

The test results obtained at the locations where a static load test followed 30 repeating load cycles are summarized on Plate 24. From these results it is indicated that: (1) the indicated reductions in subgrade strength were much less than at locations where static load tests were not preceded by repeating load tests (compare with Plate 21), and (2) results appear considerably more erratic than for the static tests alone, as regards relative positions of curves for the different sections, and as regards periods of maximum weakening and rates of regain of strength; however, part of this may be an illusion because ratios of higher order of magnitude tend to give bigger numerical differences between ratios and thus to magnify variations.

The greater strengths at the locations where the static load tests followed repeating load tests are attributed to the consolidation of the subgrade by the repetitive loads. It is conceived that the repeating load tests aided in forcing water from the melting segregated ice up into the base or in redistributing the water through the subgrade. Such a process would increase the subgrade strength which is indicated by the static load tests that followed. On the other hand repeating load tests performed over a plastic subgrade which is at a high degree of saturation, such as during the frost melting period, might have some tendency to cause weakening due to remolding. Weakening of plastic subgrades under repetitive traffic load has been noted during several of the accelerated traffic tests. Probably, however, traffic has a much more effective remolding action, because of the severe changes and reversals of stress and strain which occur, as compared with the plate loading test. At the Limestone Test Section the strengthening due to preloading and consolidation under the plate loading apparently outweighed any weakening effects which may have been produced by remolding. Under actual traffic this strengthening effect would not necessarily exist.

Caution that the plate bearing tests are not essentially strength test.

PART IV - COLD ROOM STUDIES

4-01. General. Two undisturbed cubic foot samples together with two disturbed bag samples of the gravelly sandy clay, (glacial till) subgrade material were obtained from the test pit explorations made in the Fall of 1950. The samples obtained were subjected to freezing tests in the cold room at the Frost Effects Laboratory to determine the relative frost susceptibility of the subgrade soil and to determine the relationship between the laboratory test results and the field behavior of the same soils frozen in-place.

4-02. Test Procedure*. The two undisturbed samples were trimmed to 6 inches in diameter and 6 inches high. The sides of the samples were well coated with petrolatum and placed inside 6-inch diameter waxed cardboard containers. Specimens were also prepared using each of the two disturbed samples, by molding to the desired densities in a 6-inch high inside diameter metal cylinder by applying static loads to movable pistons at each end of the cylinder. The remolded specimens were ejected, coated with petrolatum and placed in waxed cardboard containers. The undisturbed and remolded specimens were de-aired, saturated and placed in a freezing cabinet with the bottom of each sample resting on a porous stone connected to a water supply well. The level of the water in the water supply well was held constant at a height of 1/4 inch above top of the porous stone.

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* Detailed description of cold room equipment and test procedures are presented in the Second Interim Report of Cold Room Studies, Fiscal Year 1951, dated June 1951.

A surcharge of 0.5 psi was placed at the top of each sample and the sides of the samples were insulated with granulated cork. The bottoms of the samples were exposed to the cold room temperature of 38°F. ± $1\frac{1}{2}^{\circ}$F., while the temperature in the freezing cabinet at the tops of the samples was slowly depressed in decrements to freeze the specimens at an average rate of 1/4 inch per day.

4-03. Test Results. Gradation curves of the four samples of gravelly sandy clay subgrade soil are shown on Plate 27. Plots of heave and temperature versus time for the four test samples are shown on Plate 29. Water content distributions in the samples after freezing are shown on Plate 28.

A summary of the test conditions and test results is presented in the following table:

Sample No.	Per Cent Finer Than 0.02 mm.	Dry Unit Wt. pcf	Per Cent Heave	Average Rate of Heave mm/day
LST-2 Undisturbed	48	113	82	4.5
LST-3 Undisturbed	33	127	57	3.1
LST-4 Remolded	44	112	164	16.7
LST-5 Remolded	30	127	78	5.0

The per cent heaves and average rates of heave experienced at the field test section were as follows:

Section	Depth Frozen Feet (*)	Average Max. Heave Feet	Per Cent Heave	Average Rate of Heave mm/day
7"	3.0	.42	14	1.6
12"	3.1	.37	12	1.4
18"	3.8	.41	11	1.7
24"	3.1	.31	10	1.2

* Based on maximum penetration of 31°F. temperatures from Plates 8 through 11.

The large difference between the heave of the laboratory specimens and heave in the field is attributed to the unlimited supply of water at the bottom of the laboratory sample. The laboratory test is not intended to duplicate the field conditions of each specific case. Rather, it is a uniform and deliberately severe test used to measure the relative frost susceptibility of soils.

The four laboratory tests reported above indicate an average rate of heave in the range 4 to 8 mm/day, using the grouping proposed in the Second Interim Report of Cold Room Studies, which corresponds to a frost susceptibility classification of "High". In the present state of knowledge in this field, it is believed this adjective is adequately descriptive of the frost susceptibility of this material, heaving of the order of 10 to 15 per cent, under the water availability conditions existing.

However, as seems apparent from these and other tests, potential amount or rate of heave is not an adequate indicator of the loss of strength which may occur under a pavement during the frost melting period; the rate at which melt water may be drained or redistributed and strength regained must also be considered.

V. CONCLUSIONS

5-01. Conclusions. The observations and tests completed to date are not of sufficient duration to serve as a sound basis for conclusions; however, the following major trends are indicated from the available results:

a. Freezing Index. The difference between the values of the Freezing Indices, in northern Maine, computed using mean daily air temperatures and average of hourly air temperatures is insignificant.

b. Frost Penetration. Discounting the results at the 7-inch section, the depth of frost penetration into the subgrade at the test area is virtually independent of the base course thickness up to the 24-inch maximum base thickness.

c. Loss of Subgrade Strength.

(1) The strength of the subgrade at the test section was markedly weakened during the frost melting period and the regain in strength was gradual and was generally continuing at a uniform rate up to 1 June, the time of the latest available test results.

(2) Under static load tests, the subgrade had greater relative strength in the frost melting period at locations in which the tests immediately followed repetitive loadings than at locations which had not been subjected to repetitive loading. However, under traffic this strengthening effect would not necessarily exist.

d. Cold Room Tests. Per cent heaves and rates of heave of cold room test specimens are considerably greater than those experienced in the field. However, this does not invalidate the cold room test as a satisfactory standard for determining relative frost susceptibility of soils.

VI. RECOMMENDATIONS

6-01. Recommendations. It is recommended that field studies of the magnitude and duration of the reduction of pavement supporting capacity due to frost action initiated in Fiscal Year 1951 be continued to obtain additional information and to study other factors as shown below:

a. Continue plate bearing tests through succeeding seasons to ffect on obtain more conclusive normal period data and to determine the effect of a range of climatic conditions upon the period of weakening.

b. Control water level in the water supply well at an elevation slightly above the surface of the subgrade until start of freezing period in Fall of 1951 and then lower and maintain at an elevation slightly below surface of subgrade for remainder of fiscal year.

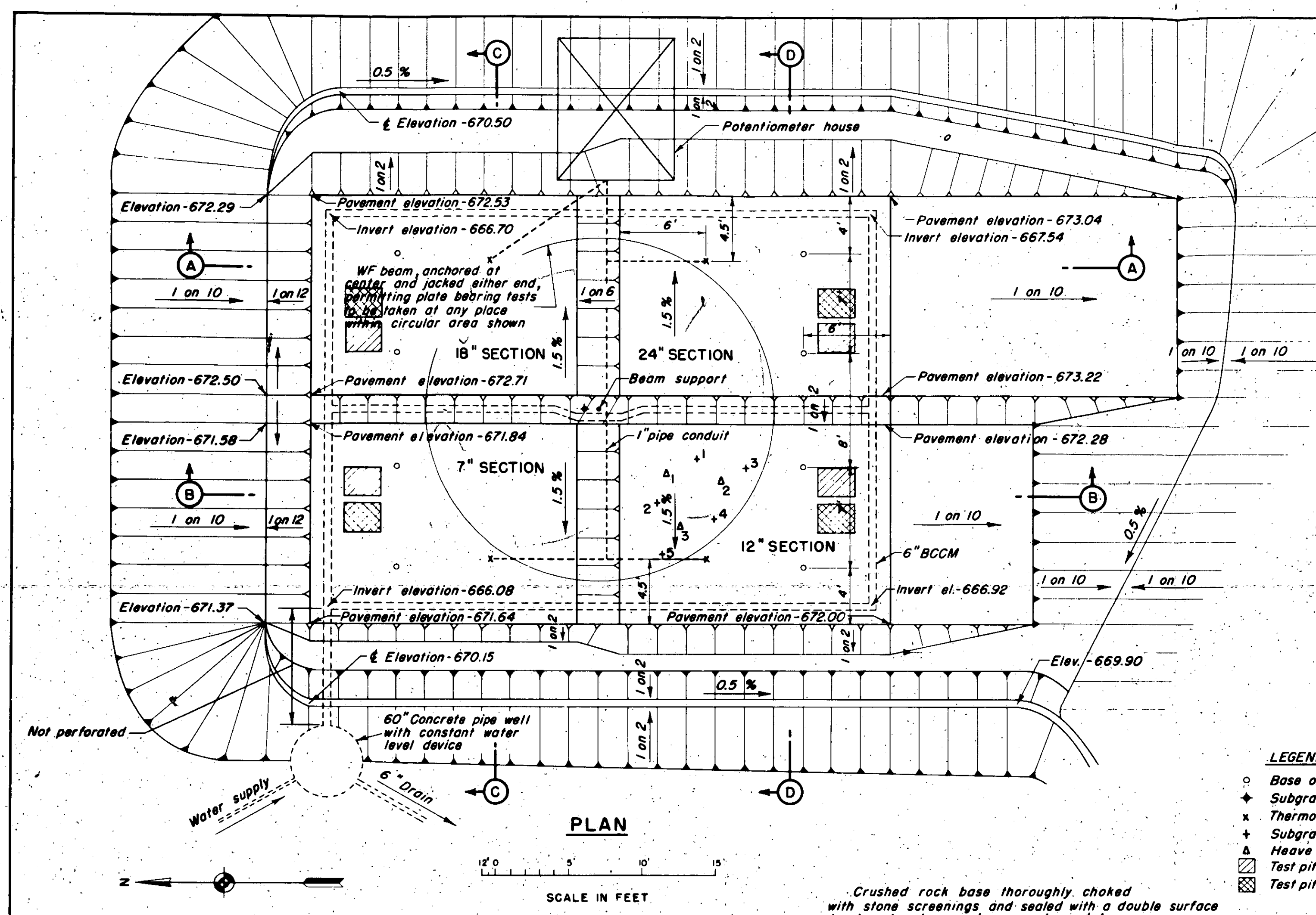
c. Install additional observation wells which will give a more complete and representative picture of the ground water conditions in the upper subgrade.

d. Obtain continuous records of air, pavement surface, and subsurface temperatures for studies of surface temperature transfer with the objective of improving methods of predicting depths of frost penetration beneath pavement surfaces.

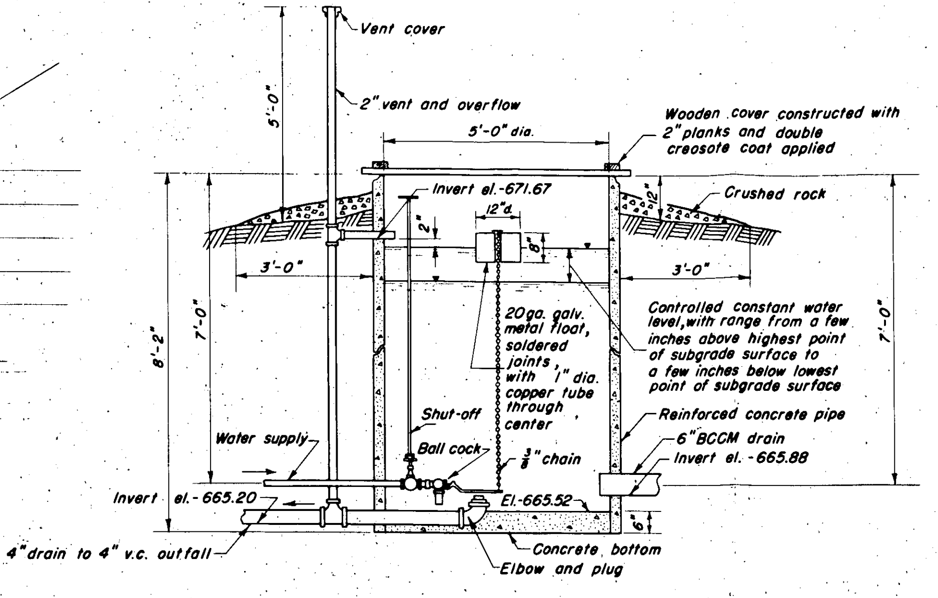
e. Excavate test pits during the normal period, time of maximum frost penetration and frost melting period to study variation in density and water content, formation of ice lenses and to measure depth of frost penetration.

f. Perform further field and laboratory CBR tests on this material to clarify results already obtained and to investigate particularly the sensitiveness of the subgrade to remolding.

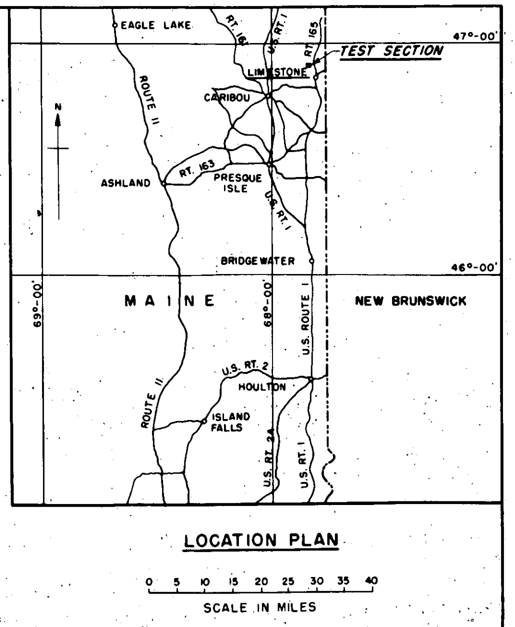
g. Measure temperature at boundary of frozen and unfrozen soil in test pits to obtain data on temperature of freezing of soil moisture.



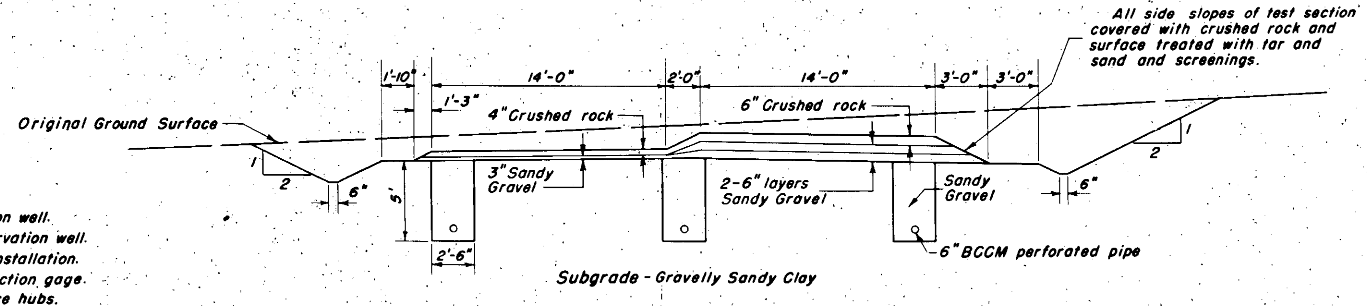
LEGEND -
- ○ Base observation well.
- ✦ Subgrade observation well.
- x Thermocouple installation.
- + Subgrade deflection gage.
- Δ Heave reference hubs.
- ▨ Test pit locations, Normal Period.
- ▩ Test pit locations, Frost Melting Period.



SECTION OF CONCRETE PIPE WELL

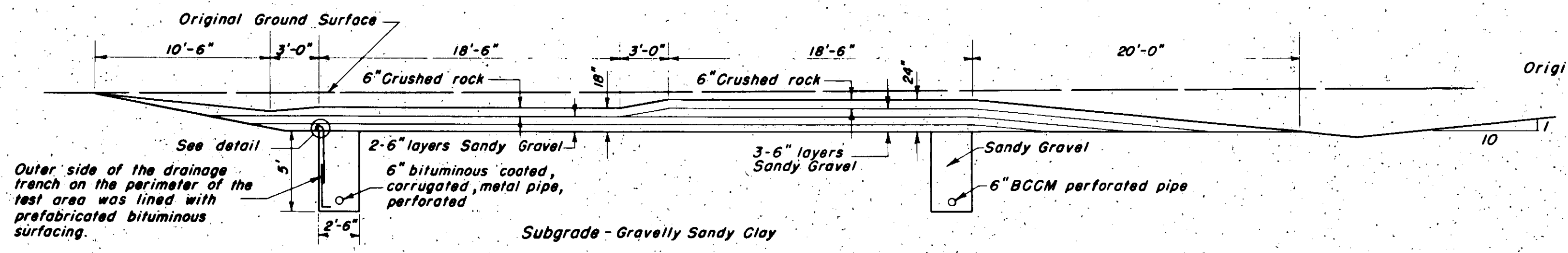


LOCATION PLAN

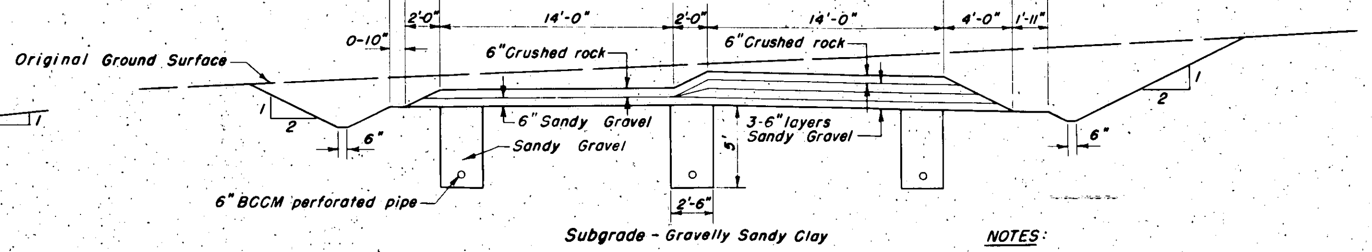


SECTION C-C

Crushed rock base thoroughly choked with stone screenings and sealed with a double surface treatment, using sand aggregate and tar.



SECTION A-A



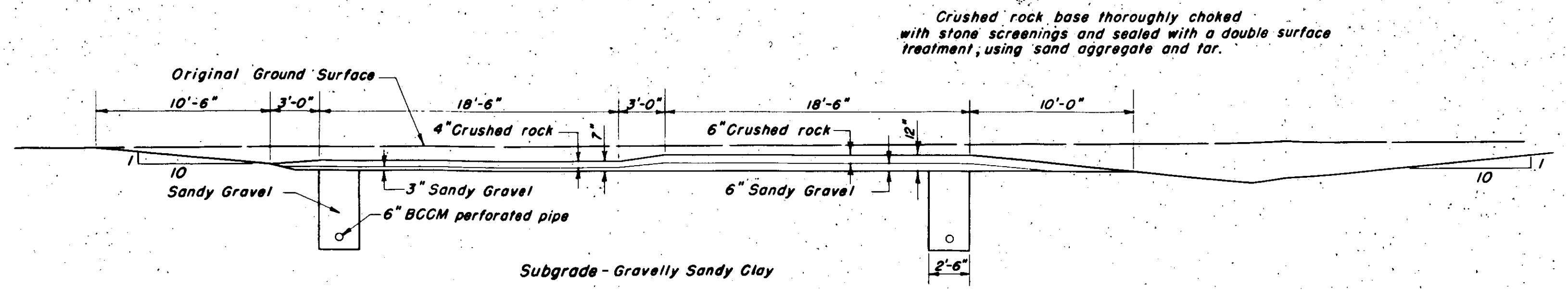
SECTION D-D

NOTES:

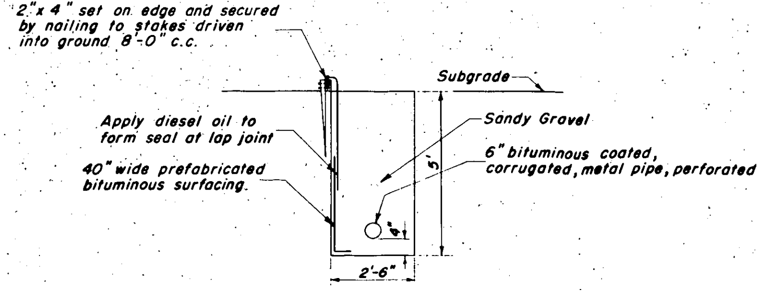
Positions of subgrade deflection gages, and heave reference hubs shown for 12" section also apply to 7", 18" and 24" sections.

Numbers beside subgrade deflection gages and heave reference hubs illustrate numbering system.

Crushed rock base thoroughly choked with stone screenings and sealed with a double surface treatment, using sand aggregate and tar.



SECTION B-B



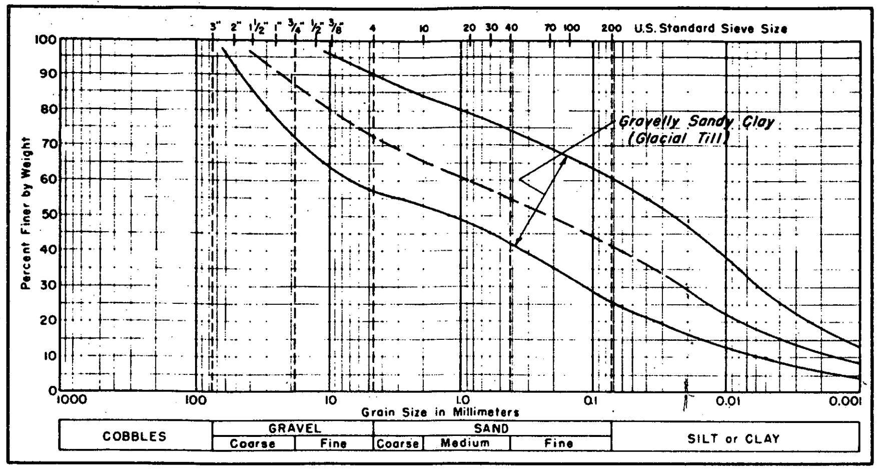
DETAIL OF PERIMETER DRAINAGE TRENCH

FROST INVESTIGATION
FISCAL YEAR 1950-1951
FROST TEST SECTION
LIMESTONE AIR FORCE BASE, LIMESTONE, MAINE

PLAN AND SECTIONS OF TEST AREA

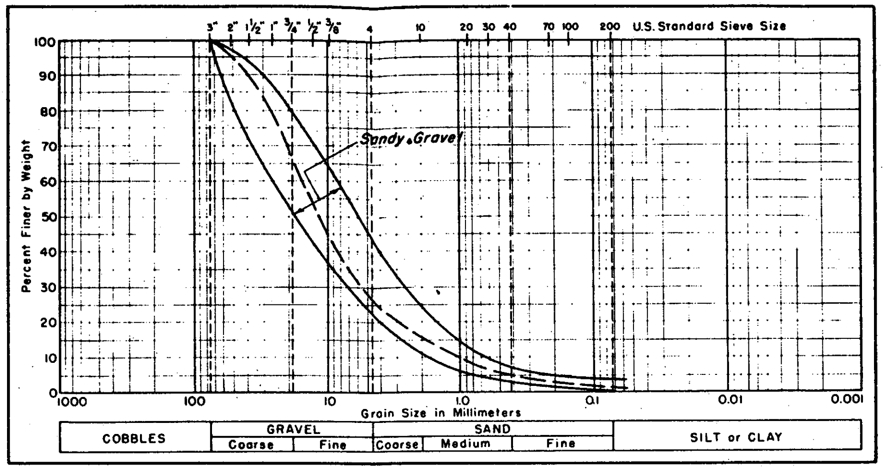
FROST EFFECTS LABORATORY
NEW ENGLAND DIVISION CORPS OF ENGINEERS
BOSTON, MASS. JUNE 1951

PLATE I



SUBGRADE

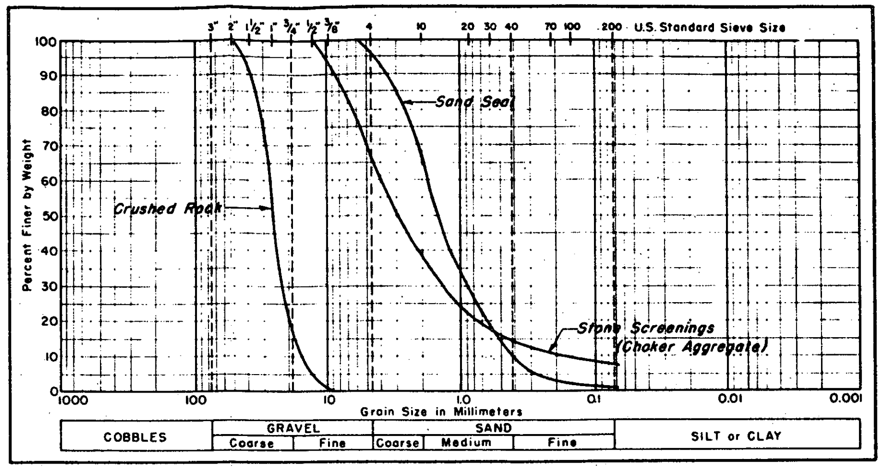
FIGURE 1



BASE

FIGURE 2

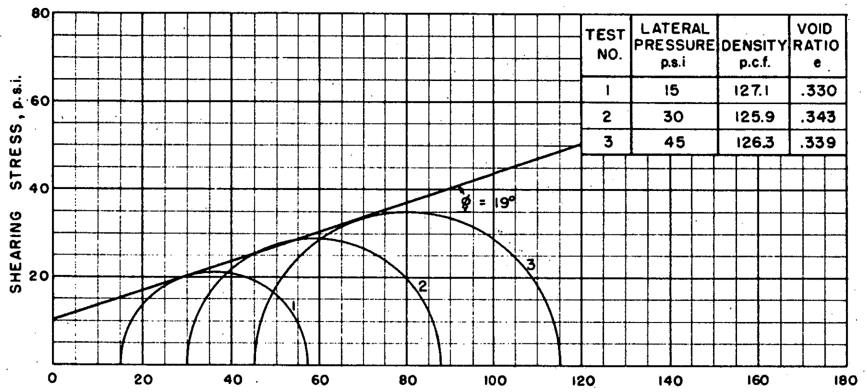
GRADATION RANGES FOR SUBGRADE AND BASE MATERIALS



PAVING MATERIALS

FIGURE 3

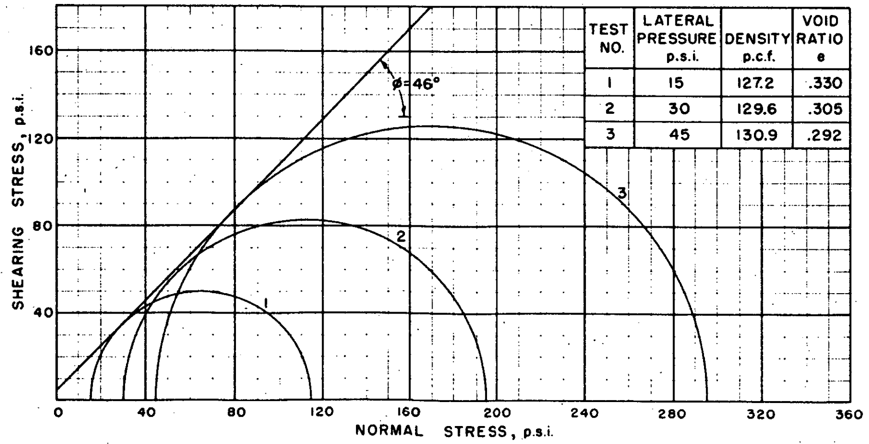
TYPICAL GRADATIONS OF PAVING AGGREGATES



TEST NO.	LATERAL PRESSURE p.s.i	DENSITY p.c.f.	VOID RATIO e
1	15	127.1	.330
2	30	125.9	.343
3	45	126.3	.339

SUBGRADE

FIGURE 4

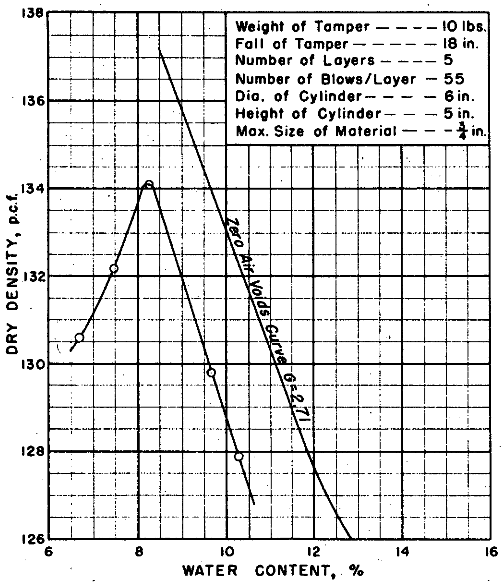


TEST NO.	LATERAL PRESSURE p.s.i.	DENSITY p.c.f.	VOID RATIO e
1	15	127.2	.330
2	30	129.6	.305
3	45	130.9	.292

BASE

FIGURE 5

TRIAXIAL SHEAR RESULTS



Weight of Tamper ———— 10 lbs.
Fall of Tamper ———— 18 in.
Number of Layers ———— 5
Number of Blows/Layer — 55
Dia. of Cylinder ———— 6 in.
Height of Cylinder ——— 5 in.
Max. Size of Material ——— ¾ in.

SUBGRADE

FIGURE 6

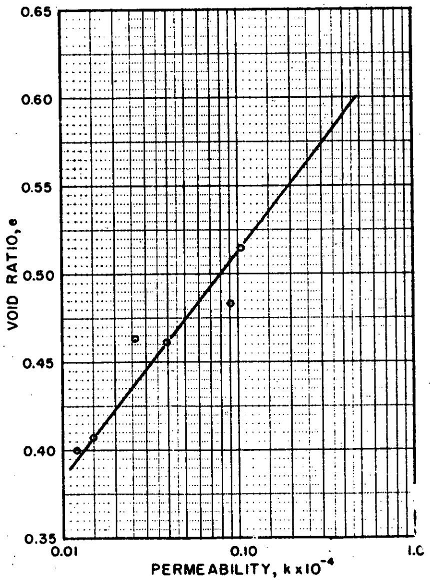
	MAXIMUM DENSITY p.c.f.	VOID RATIO e
RANGE	130.0-139.9	0.202-0.297
AVERAGE	134.9	0.249

NOTE:- Maximum Density obtained by Providence Vibrated Density Test.

BASE

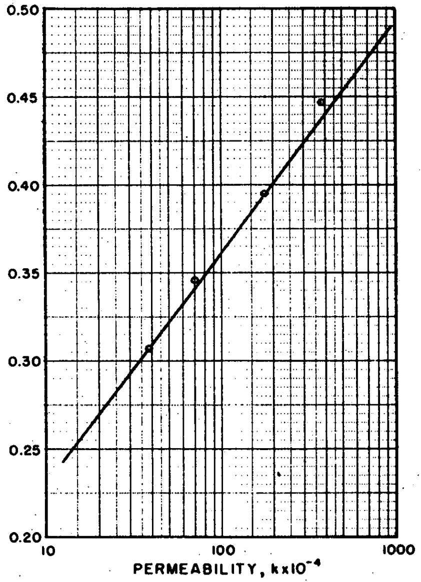
FIGURE 7

COMPACTION CHARACTERISTICS



SUBGRADE

FIGURE 8



BASE

FIGURE 9

PERMEABILITY vs VOID RATIO

NOTES:

Permeability Tests and Triaxial Tests performed on minus 1½ inch fraction of base and subgrade materials.

Triaxial Tests performed on 2.8 inch dia. samples at 0.03 inches per minute rate of strain. Mohrs Circle plots on Figures 4 and 5 represent maximum stress condition.

FROST INVESTIGATION
FISCAL YEAR 1950-1951
FROST TEST SECTION
LIMESTONE AIR FORCE BASE, LIMESTONE, MAINE

SOIL DATA SUMMARY

FROST EFFECTS LABORATORY
NEW ENGLAND DIVISION CORPS OF ENGINEERS
BOSTON, MASS.

FIG. 1 GENERAL VIEW OF TEST AREA SHOWING REACTION BEAM AND PLATE BEARING TEST SET UP.

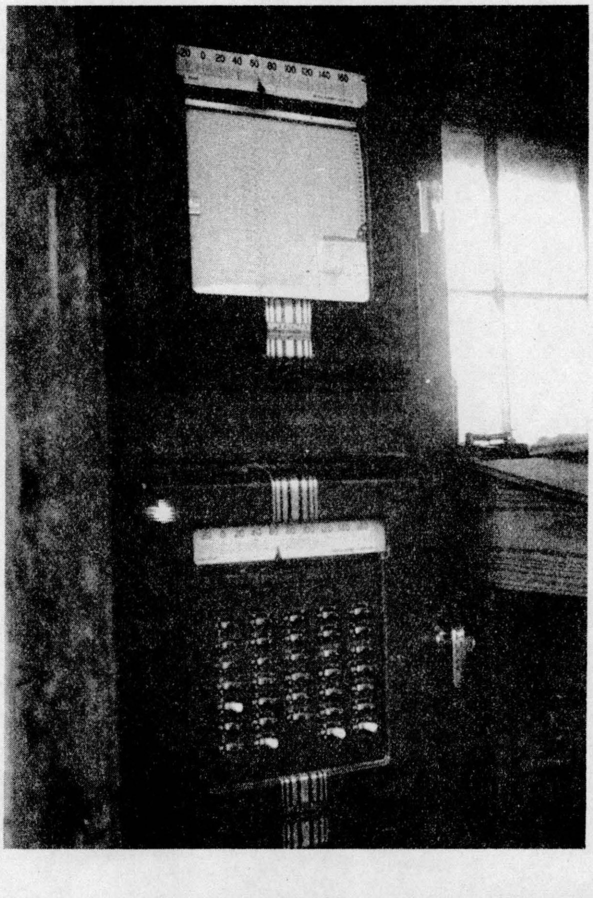
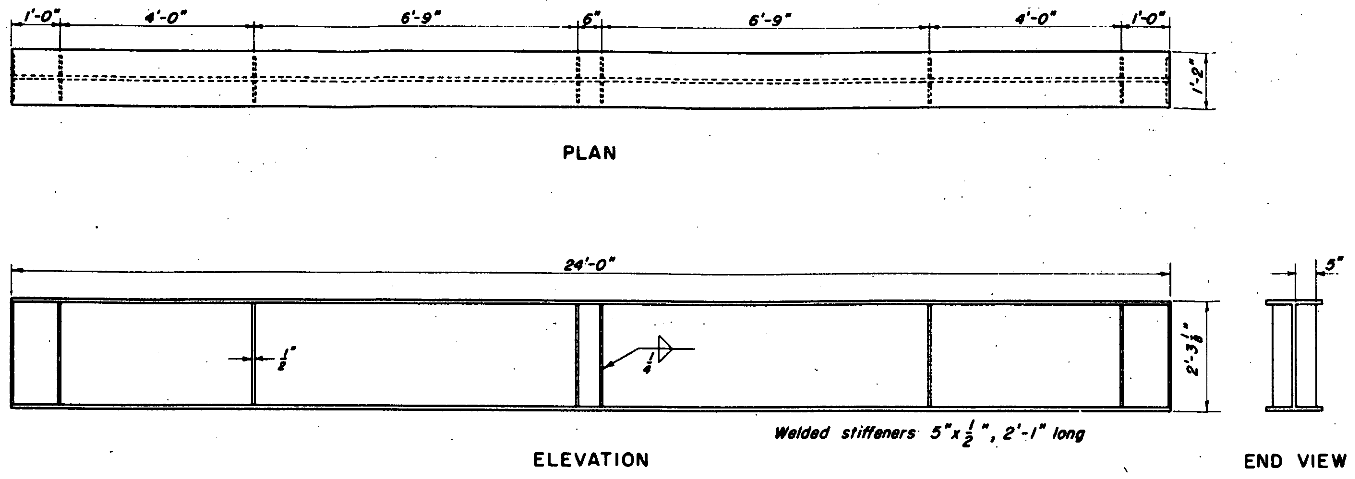
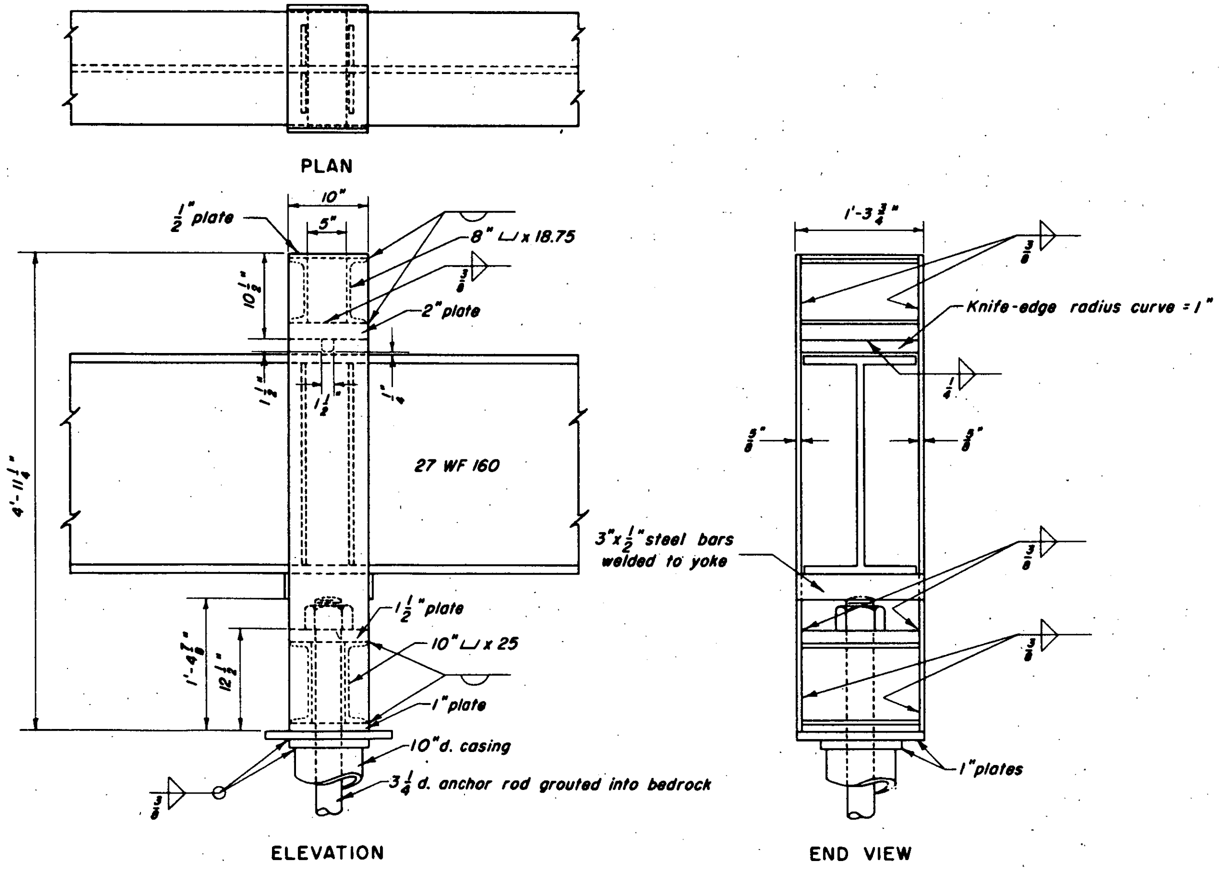


FIG. 2 VIEW OF TEMPERATURE MEASURING POTENTIOMETERS.



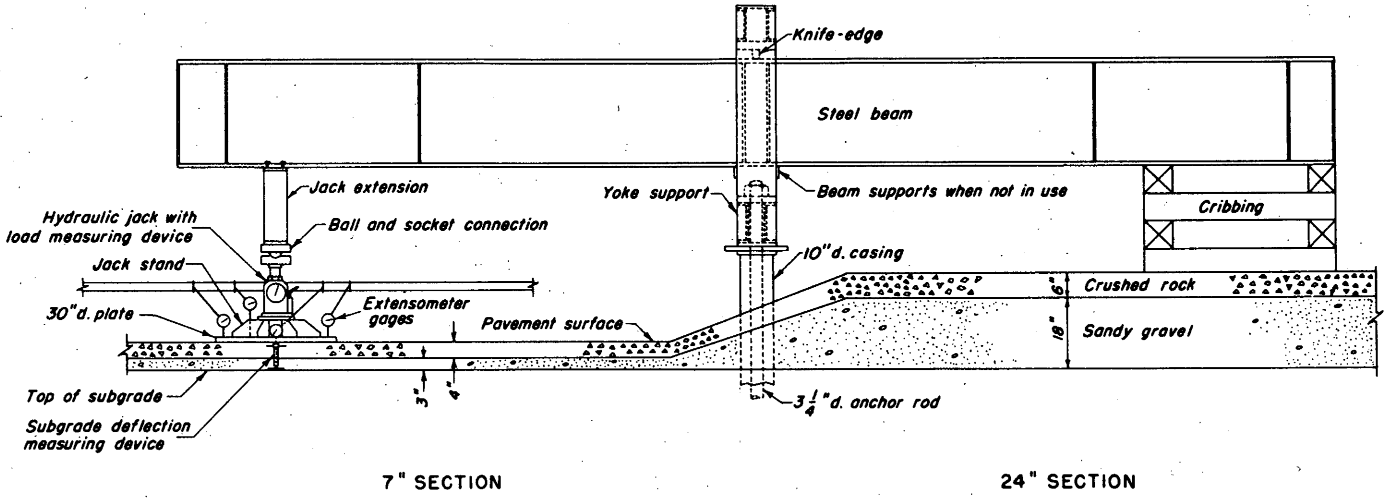
27 WF 160 BEAM DETAILS

SCALE: 1/2 INCH = 1 FOOT



CENTER BEAM SUPPORT DETAILS

SCALE: 1 INCH = 1 FOOT



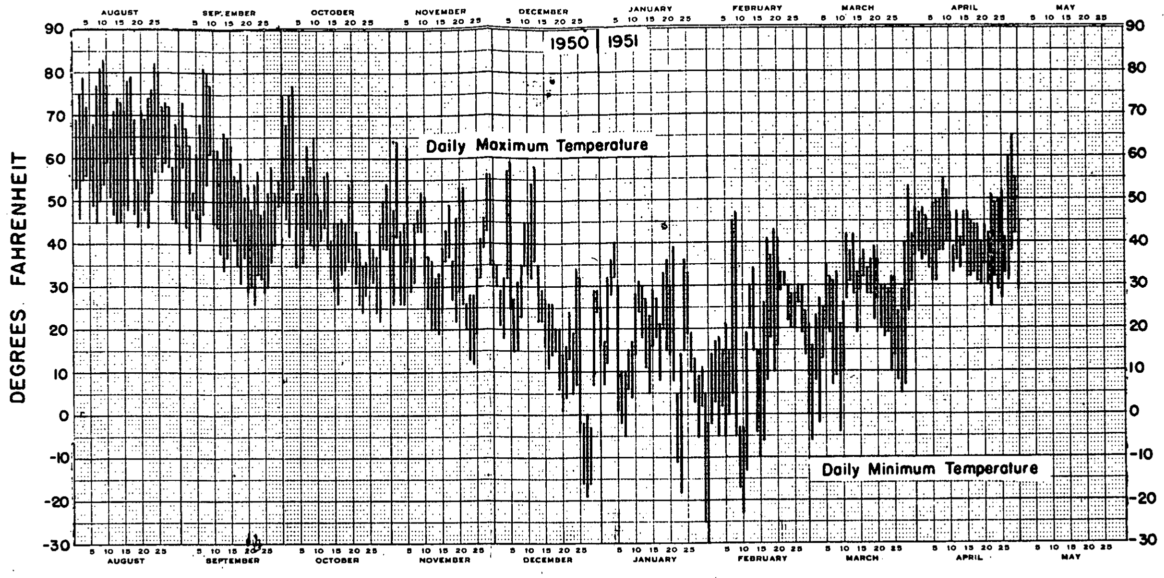
DIAGRAMMATIC PLATE BEARING TEST SET-UP

FROST INVESTIGATION
FISCAL YEAR 1950-1951
FROST TEST SECTION
LIMESTONE AIR FORCE BASE, LIMESTONE, MAINE

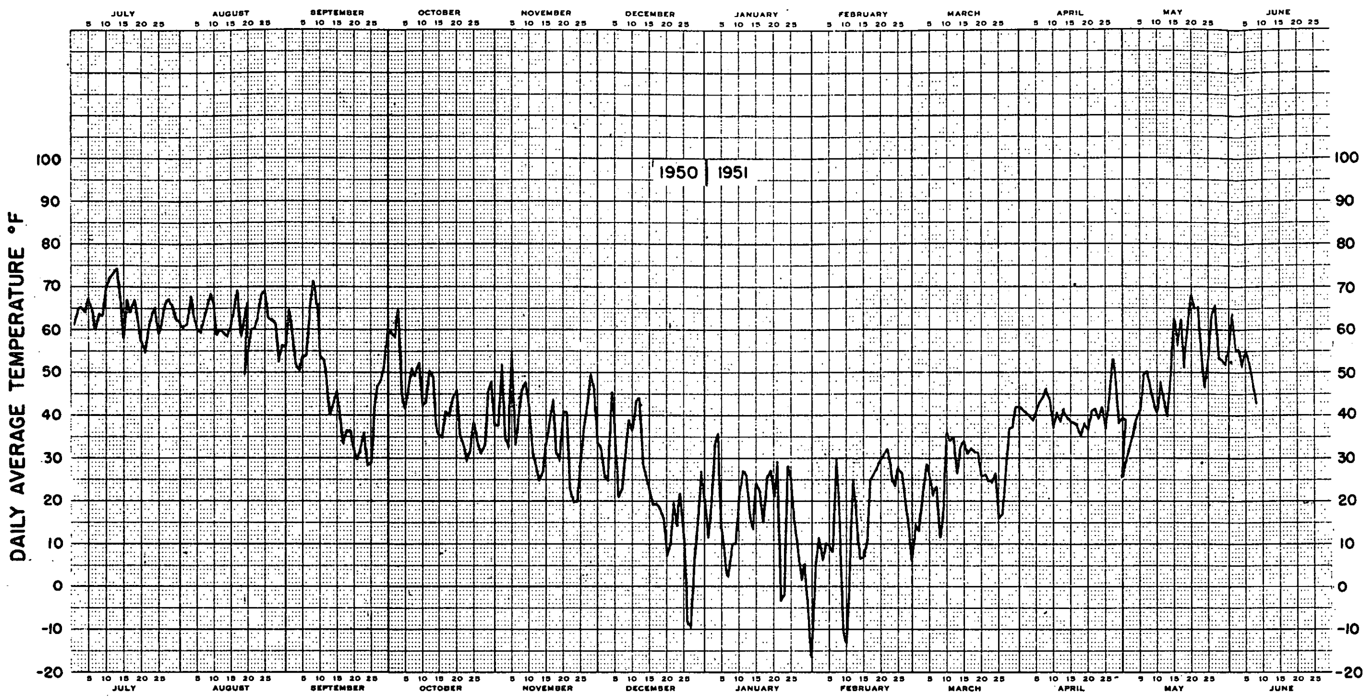
LOADING BEAM DETAILS
AND
PLATE BEARING TEST SET-UP

FROST EFFECTS LABORATORY
NEW ENGLAND DIVISION CORPS OF ENGINEERS
BOSTON, MASS. JUNE 1951

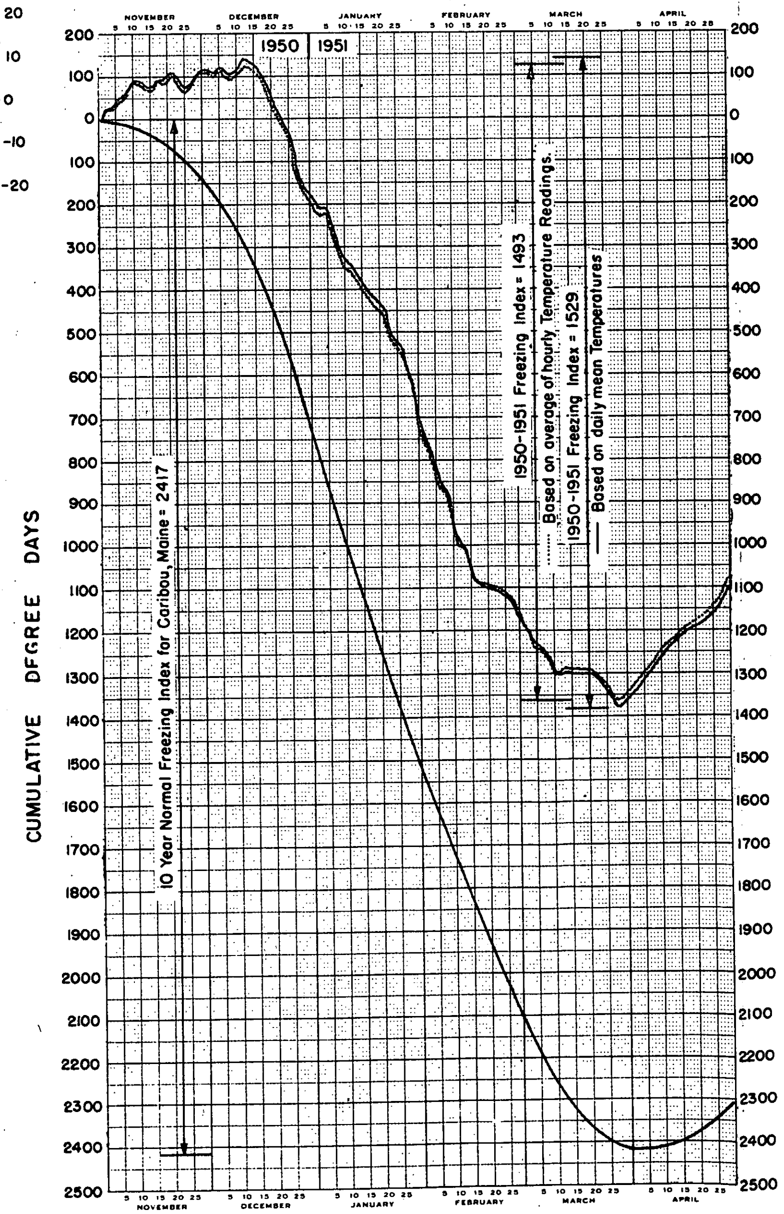
PLATE 5



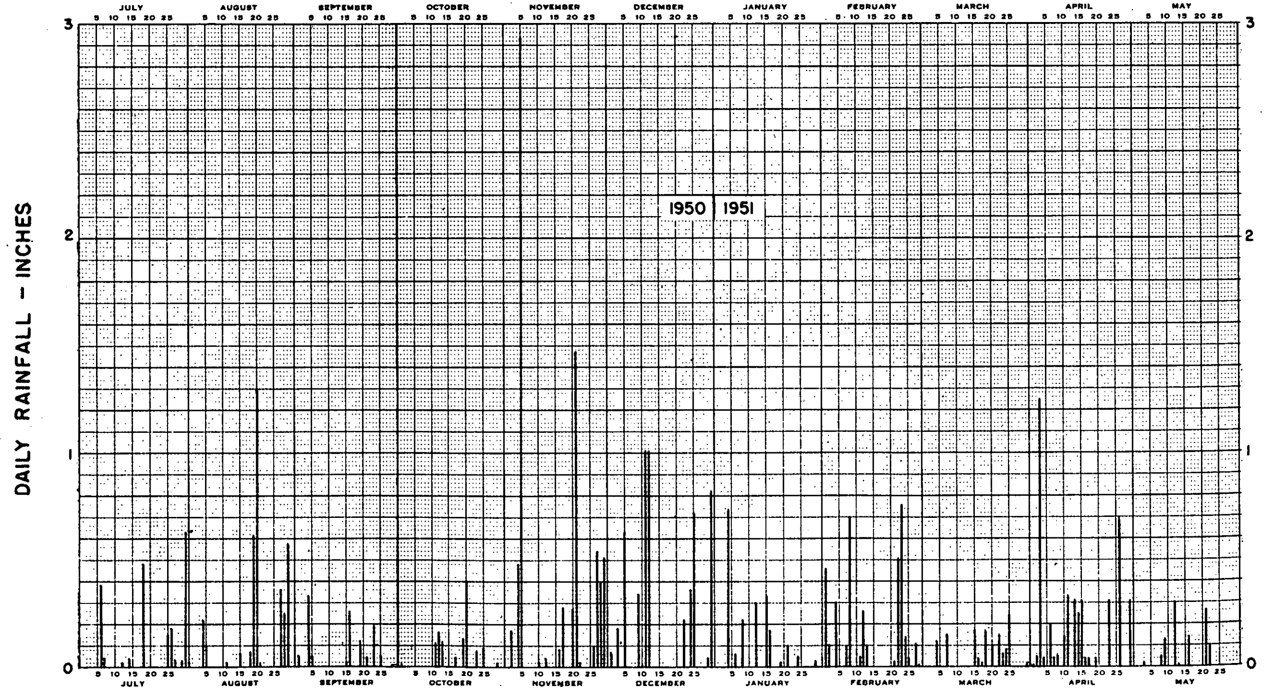
DAILY TEMPERATURE RANGE
FIG. 3



DAILY AVERAGE TEMPERATURE
FIG. 1



FREEZING INDEX
FIG. 4



DAILY RAINFALL
FIG. 2

SOURCE OF DATA:

U.S. Army Air Force Weather Station, Limestone Air Base, Limestone, Maine.

10 Year Normal Index, Caribou, Maine Weather Station, 10 miles southwest of Test Section.

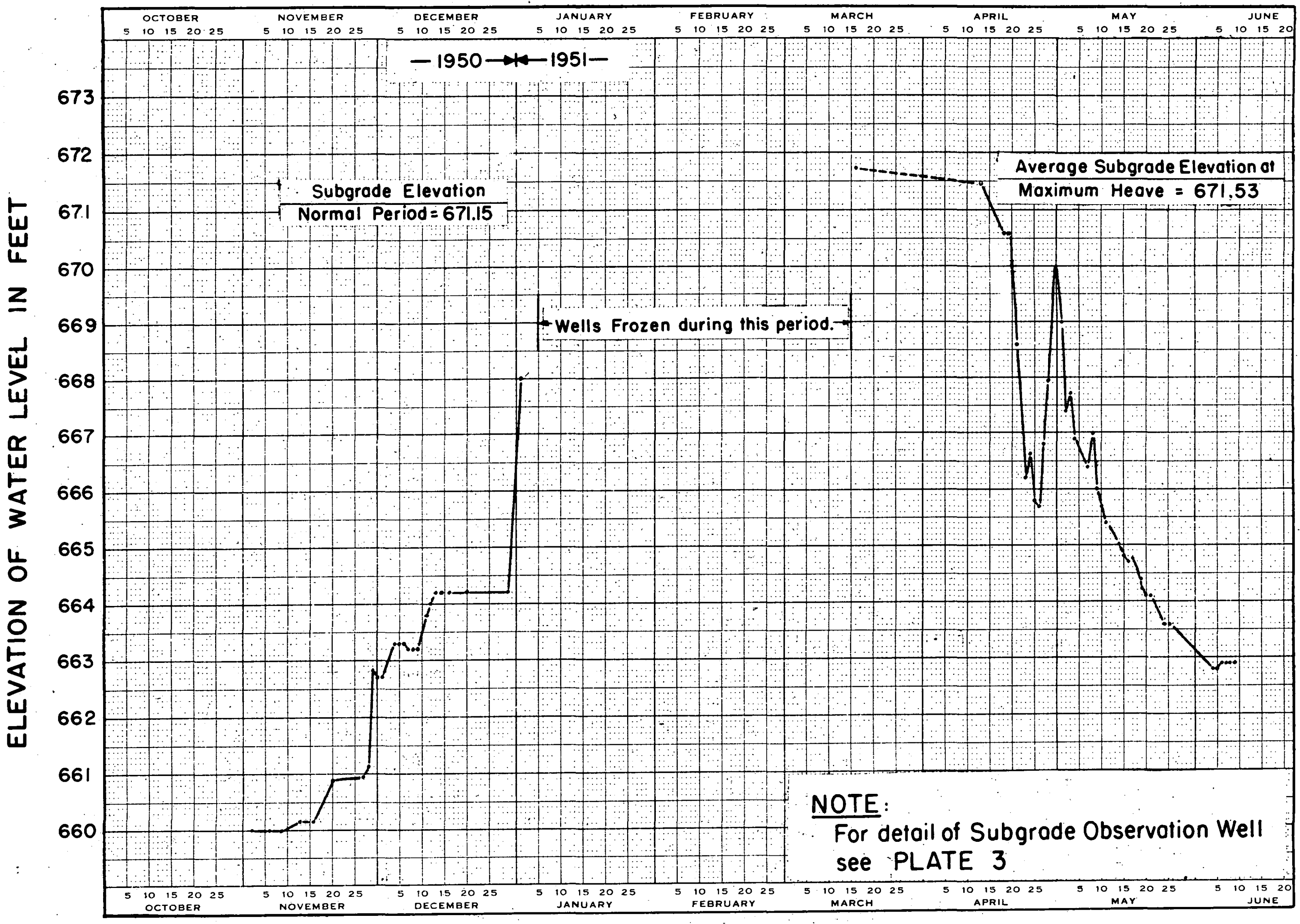
FROST INVESTIGATION
FISCAL YEAR 1951

FROST TEST SECTION
LIMESTONE AIR FORCE BASE LIMESTONE, MAINE.

WEATHER DATA

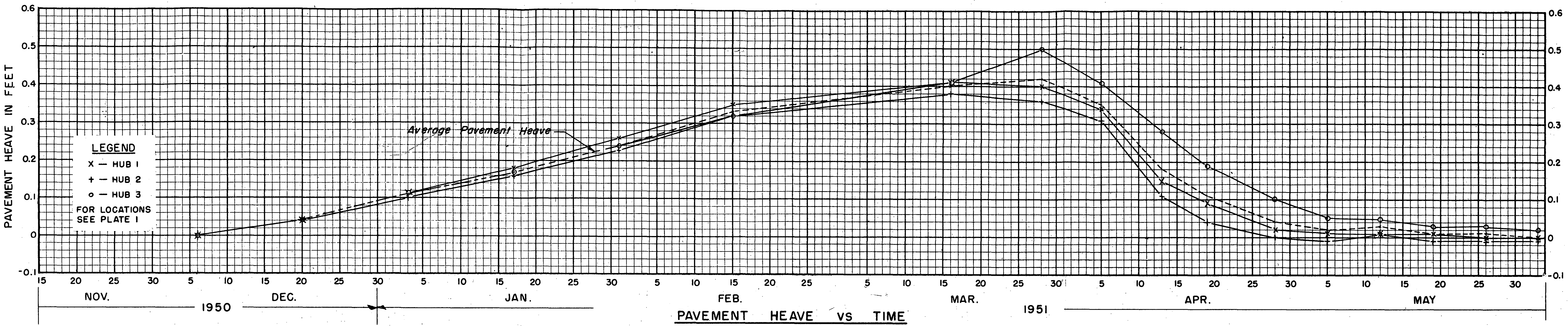
FROST EFFECTS LABORATORY
NEW ENGLAND DIVISION CORPS OF ENGINEERS
BOSTON, MASS.

PLATE 6

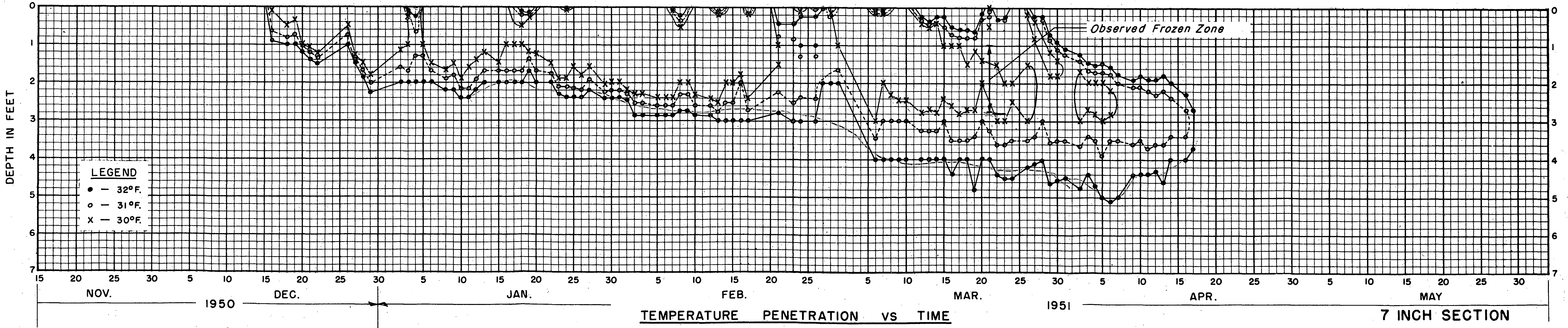


SUBGRADE OBSERVATION WELL DATA

PLATE 7



PAVEMENT HEAVE VS TIME

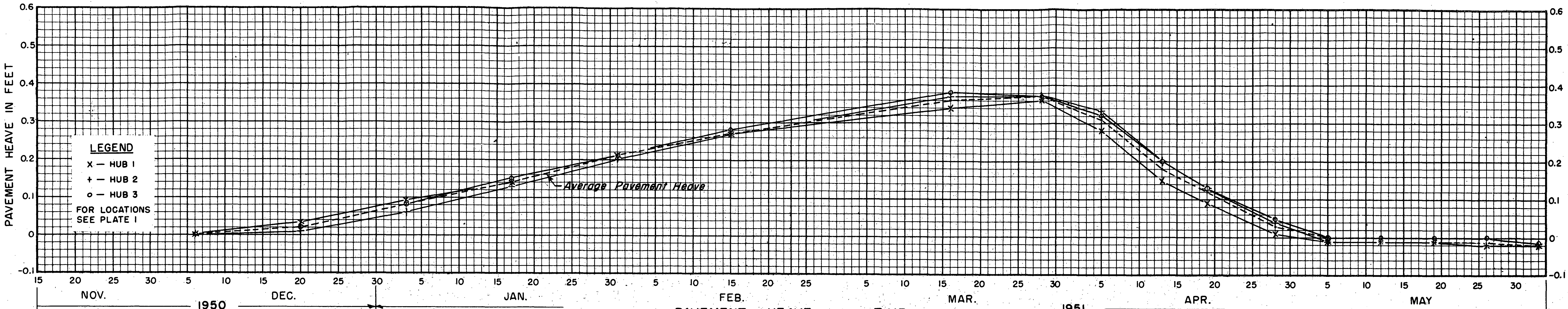


TEMPERATURE PENETRATION VS TIME

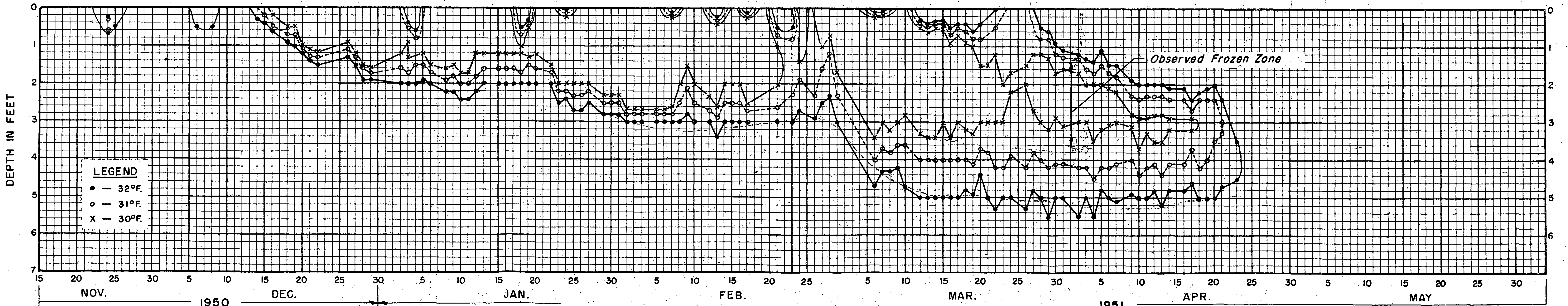
7 INCH SECTION

PAVEMENT HEAVE AND
TEMPERATURE PENETRATION VS TIME

PLATE 8



PAVEMENT HEAVE VS TIME

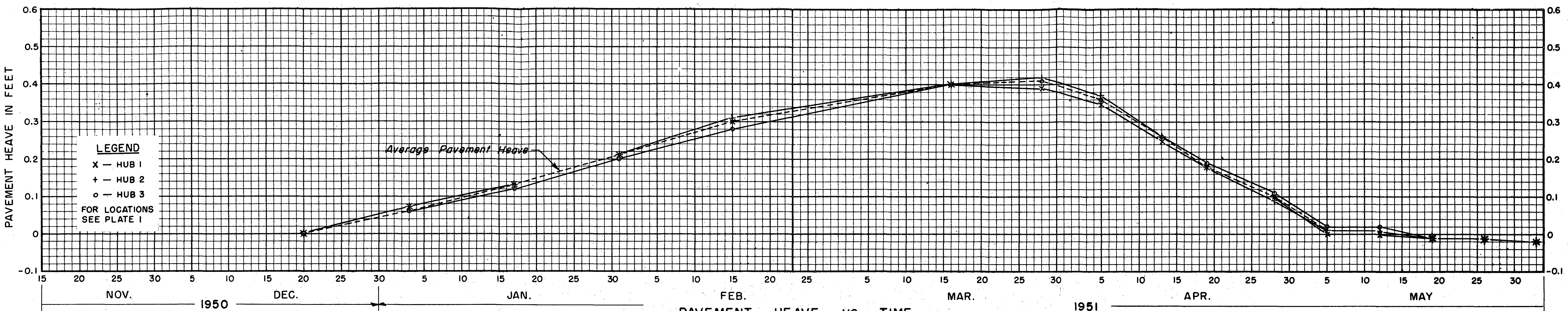


TEMPERATURE PENETRATION VS TIME

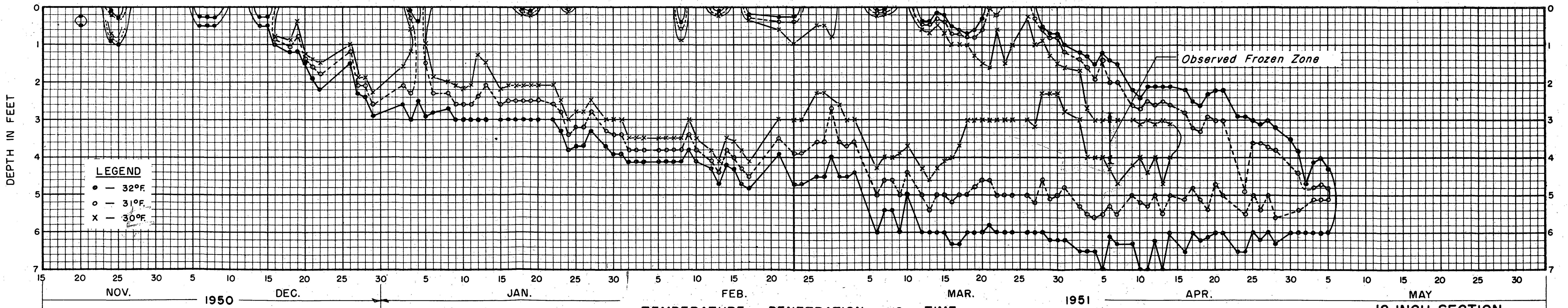
12 INCH SECTION

PAVEMENT HEAVE AND TEMPERATURE PENETRATION VS TIME

PLATE 9



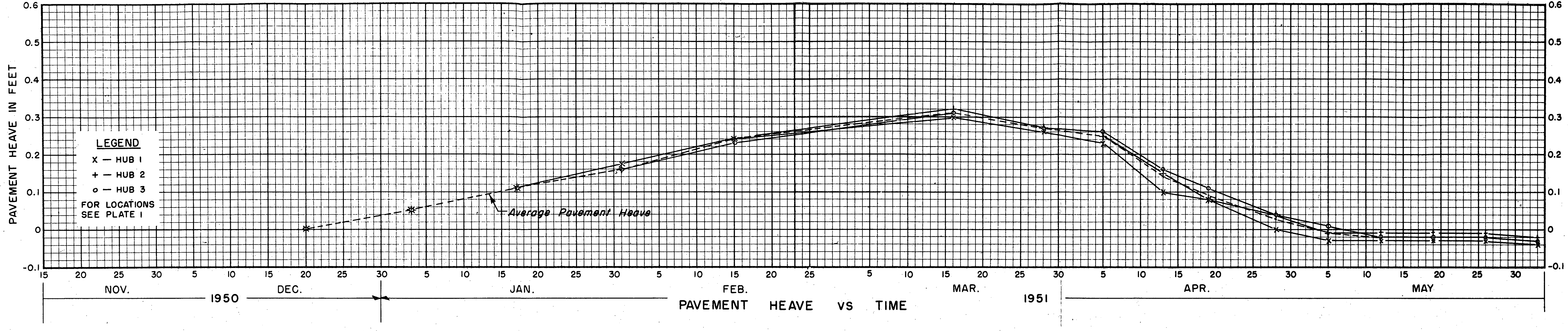
PAVEMENT HEAVE VS TIME



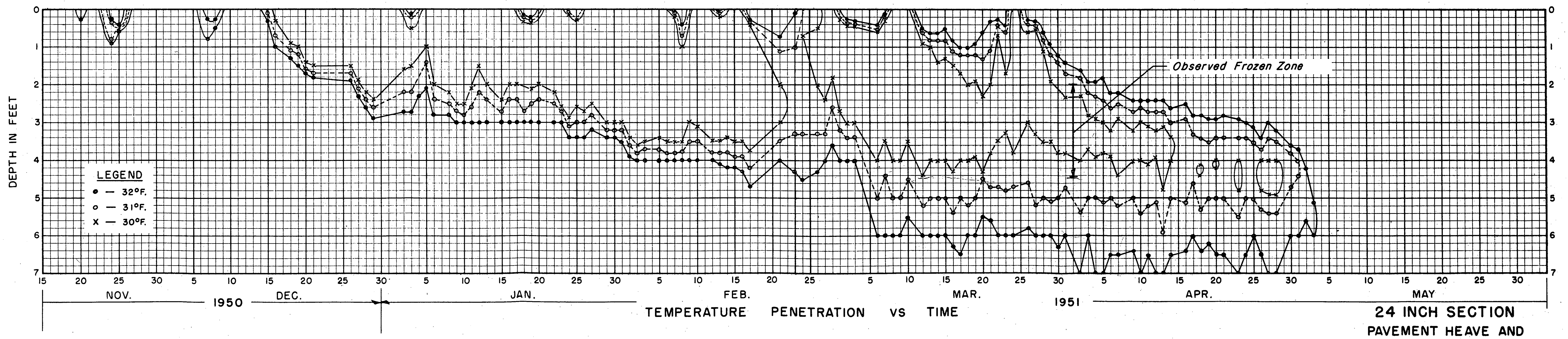
TEMPERATURE PENETRATION VS TIME

18 INCH SECTION
PAVEMENT HEAVE AND
TEMPERATURE PENETRATION VS TIME

PLATE 10



PAVEMENT HEAVE VS TIME

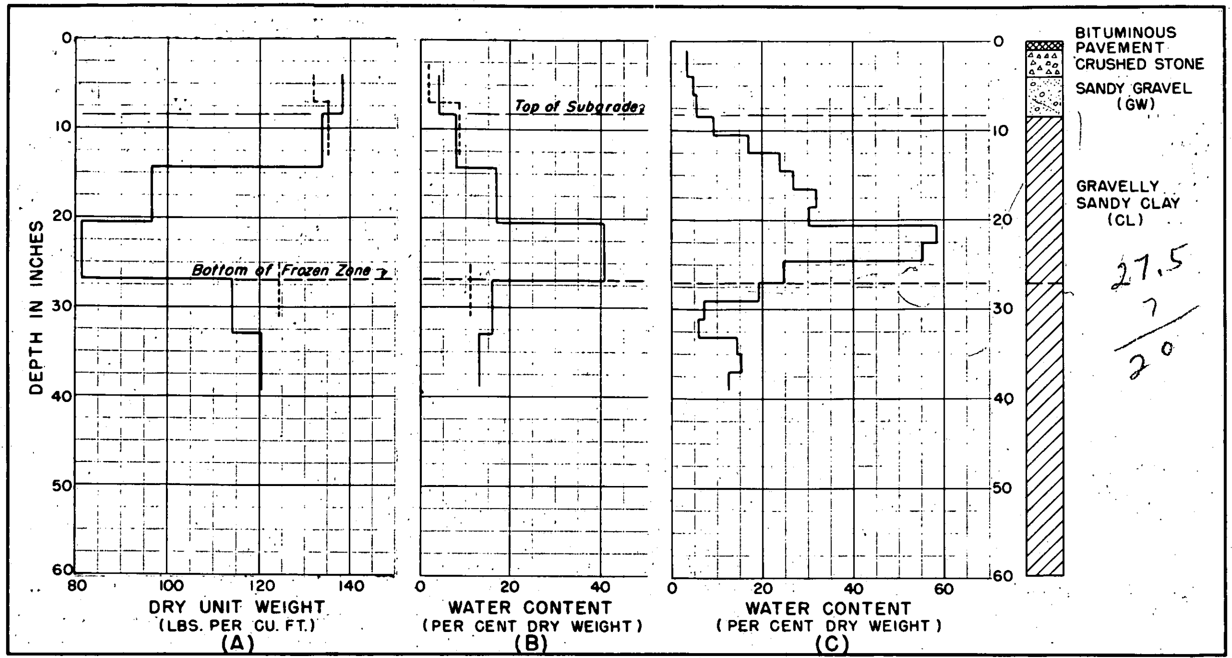


TEMPERATURE PENETRATION VS TIME

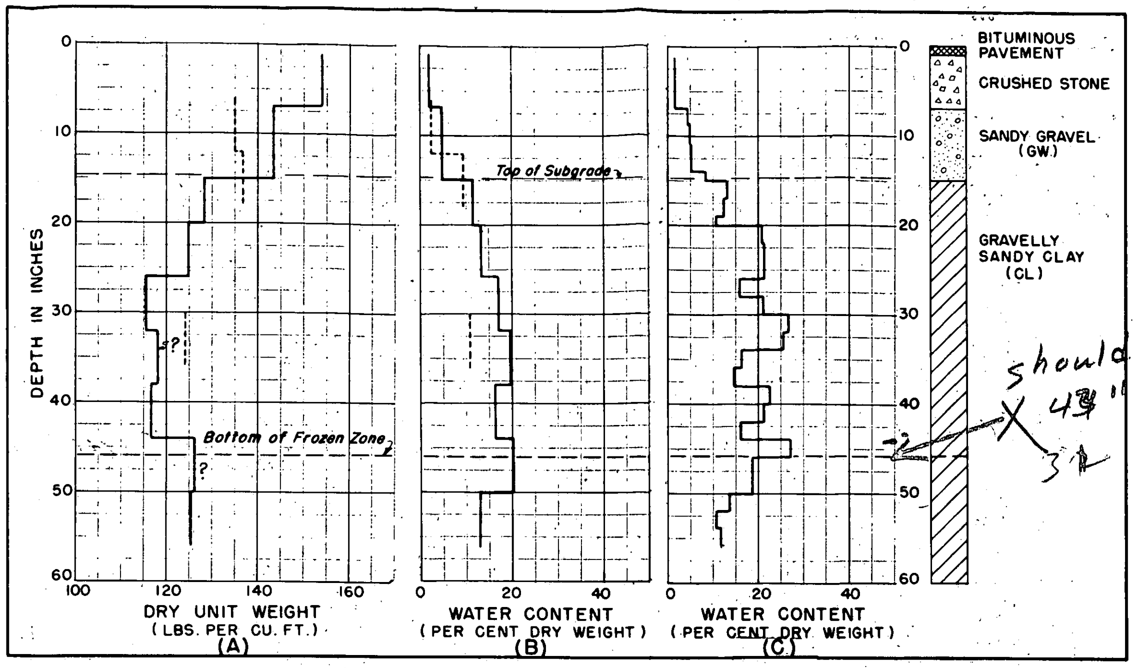
24 INCH SECTION

PAVEMENT HEAVE AND
TEMPERATURE PENETRATION VS TIME

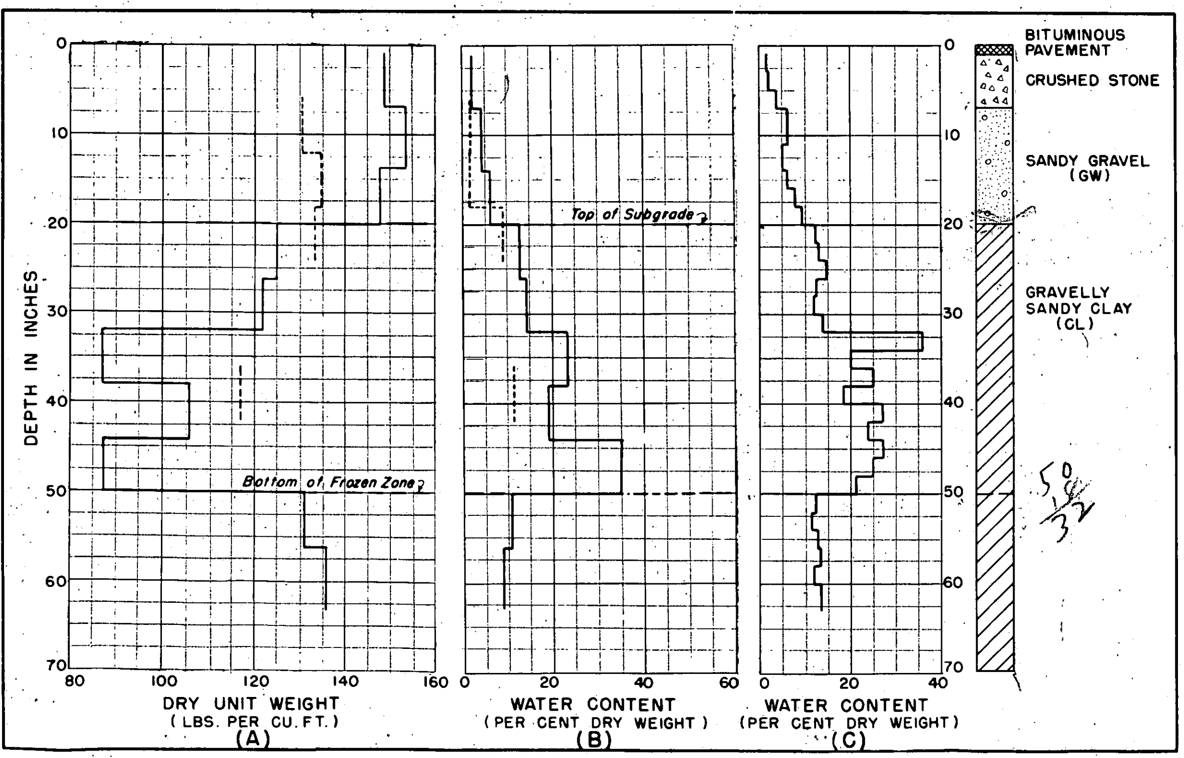
PLATE II



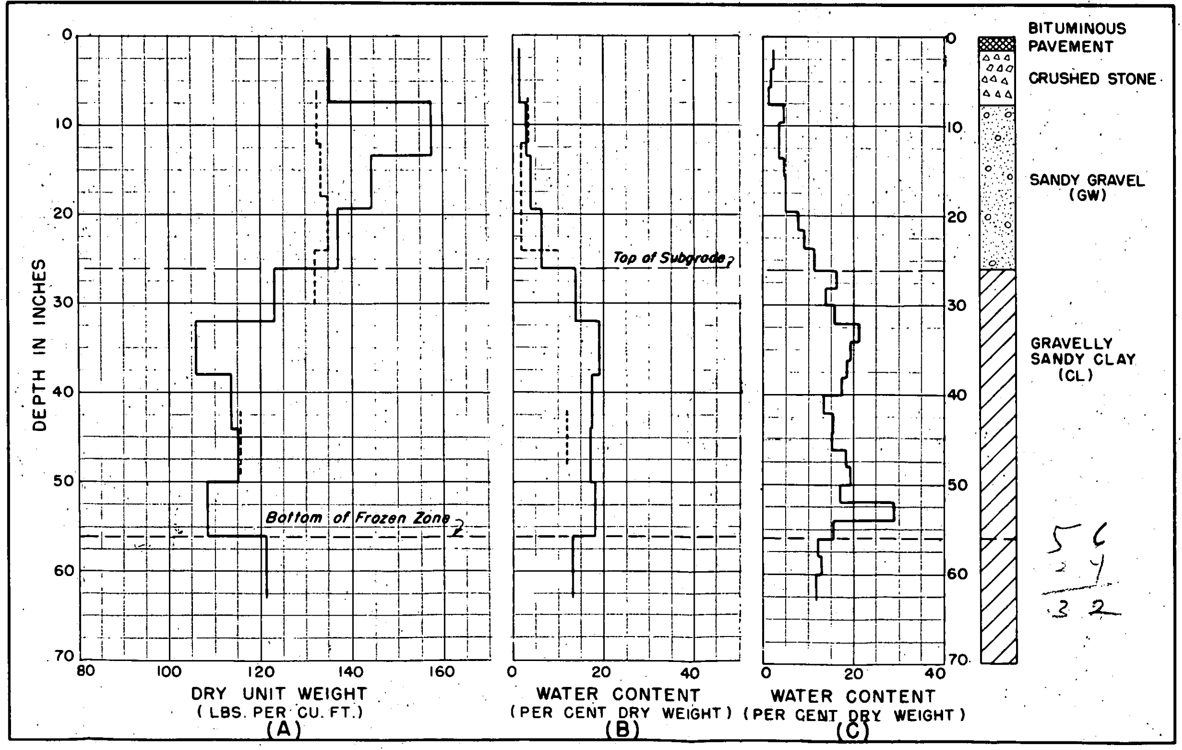
7 INCH SECTION



12 INCH SECTION



18 INCH SECTION



24 INCH SECTION

NOTES

(A) *Continuous density samples through frozen soil into unfrozen.*
(B) *Water content of density samples.*
(C) *Continuous water content determinations of small samples through frozen soil into unfrozen.*

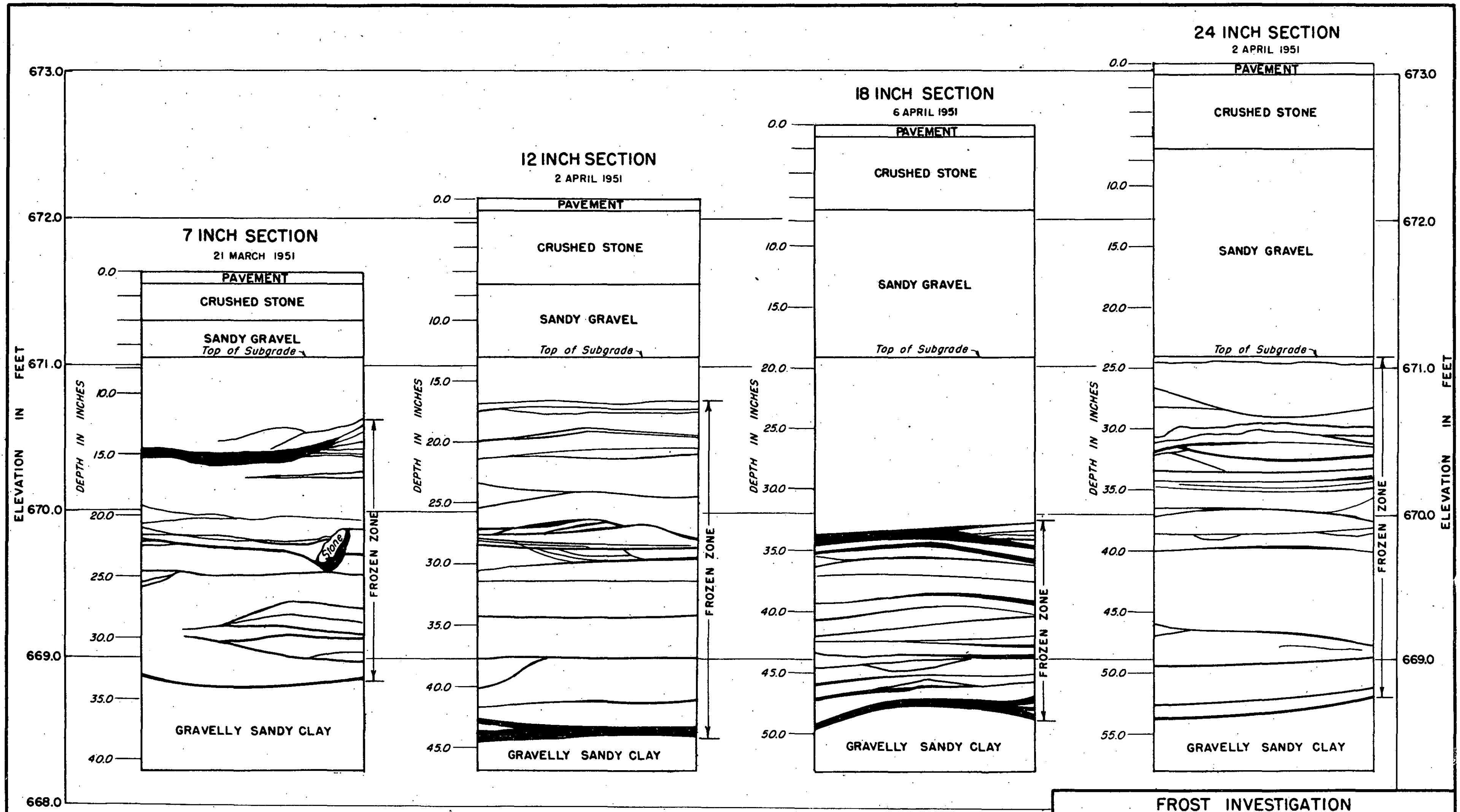
Solid lines indicate results of Frost Melting Period tests performed on dates as shown:
7 Inch Section — 17-21 March 1951.
12 Inch Section — 21-29 March 1951.
18 Inch Section — 28 March 1951 — 5 April 1951.
24 Inch Section — 22-30 March 1951.
Dotted lines indicate average normal period results obtained August and September 1950.

FROST INVESTIGATION
FISCAL YEAR 1950-1951
FROST TEST SECTION
LIMESTONE AIR FORCE BASE, LIMESTONE, MAINE

PROFILES OF WATER CONTENT-DENSITY

FROST EFFECTS LABORATORY
NEW ENGLAND DIVISION CORPS OF ENGINEERS
BOSTON, MASS.

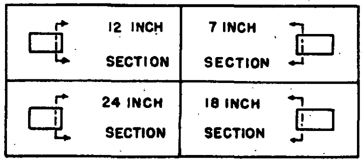
PLATE 12



NOTE:

Dates indicate day test pit logged.
$\frac{1}{32}$" minimum thickness of ice lens shown.

▬ Indicates location, thickness and extent of ice lenses and ice formations, in subgrade, to scale, at face of test pits.



LOCATION OF PROFILES
NOT TO SCALE

FROST INVESTIGATION
FISCAL YEAR 1950-1951

FROST TEST SECTION
LIMESTONE AIR FORCE BASE, LIMESTONE, MAINE

ICE LENS PROFILES

FROST EFFECTS LABORATORY
NEW ENGLAND DIVISION CORPS OF ENGINEERS
BOSTON, MASS.

PLATE 13

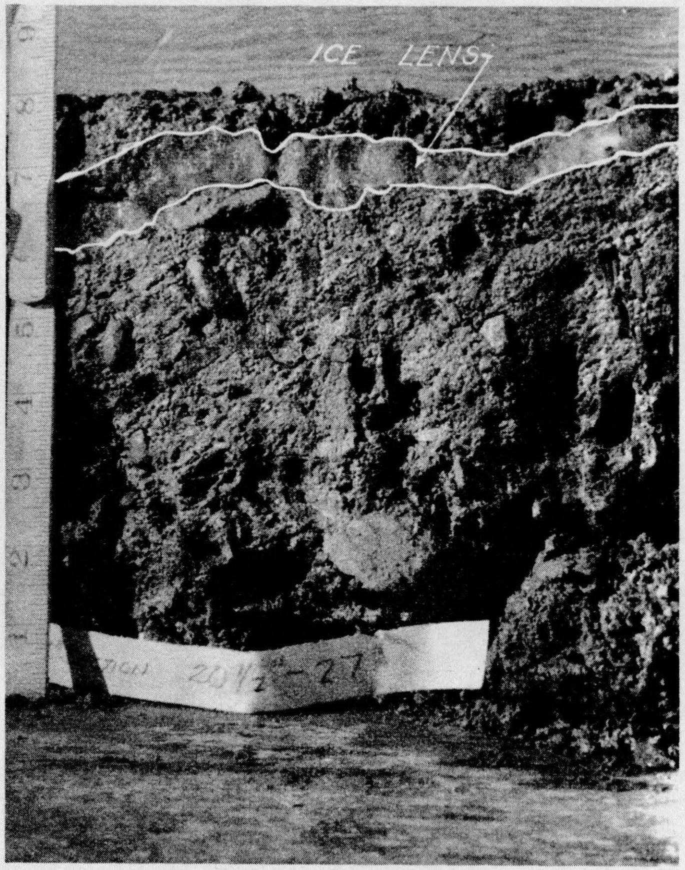


FIG. 1 ICE LENSES IN CHUNK SAMPLE FROM 7 INCH SECTION. SAMPLE TAKEN FROM 20-1/2 INCH TO 27 INCH DEPTH BELOW PAVEMENT SURFACE.

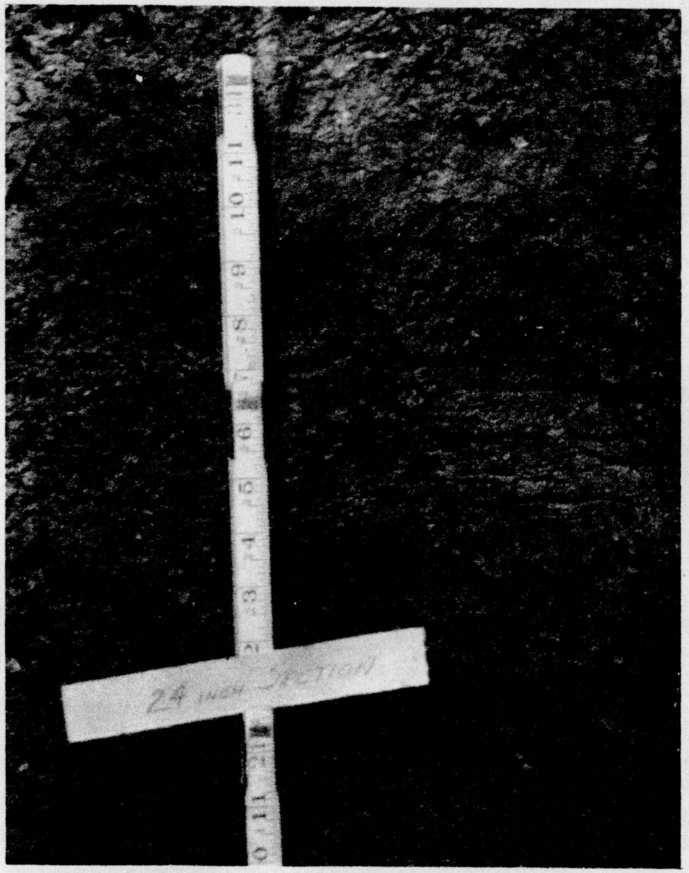
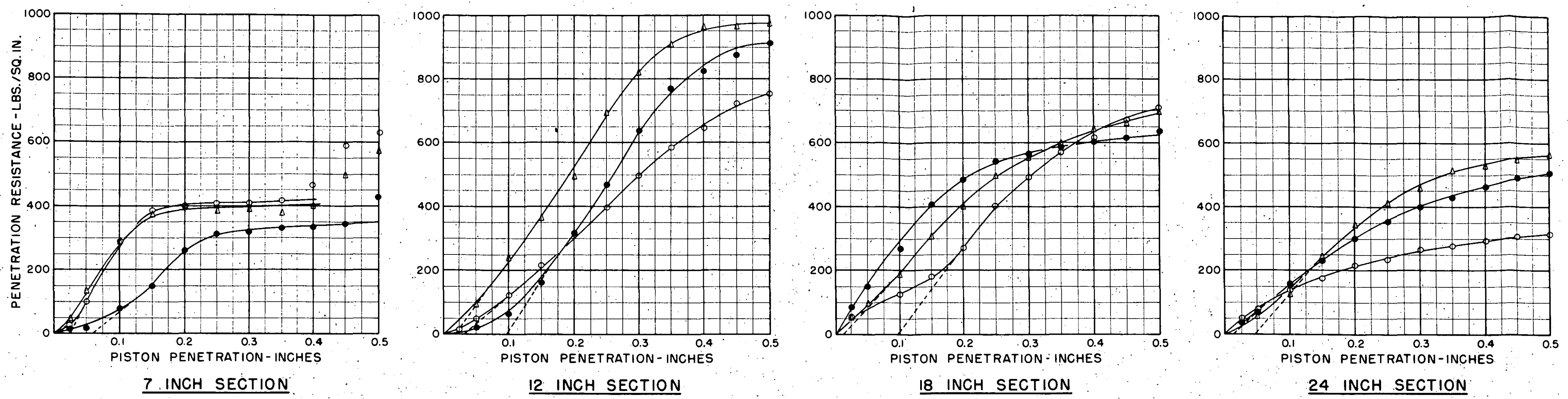


FIG. 2 VIEW OF HORIZONTAL CRACKS IN SUBGRADE OF 24 INCH SECTION DUE TO MELTING OF ICE LENSES.



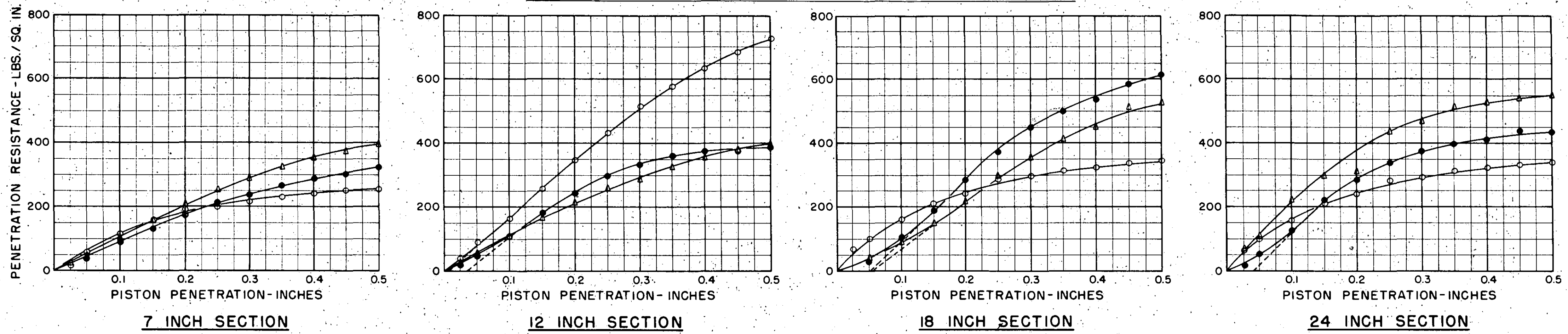
7 INCH SECTION

12 INCH SECTION

18 INCH SECTION

24 INCH SECTION

NORMAL PERIOD FIELD CBR TESTS - OCTOBER 1950



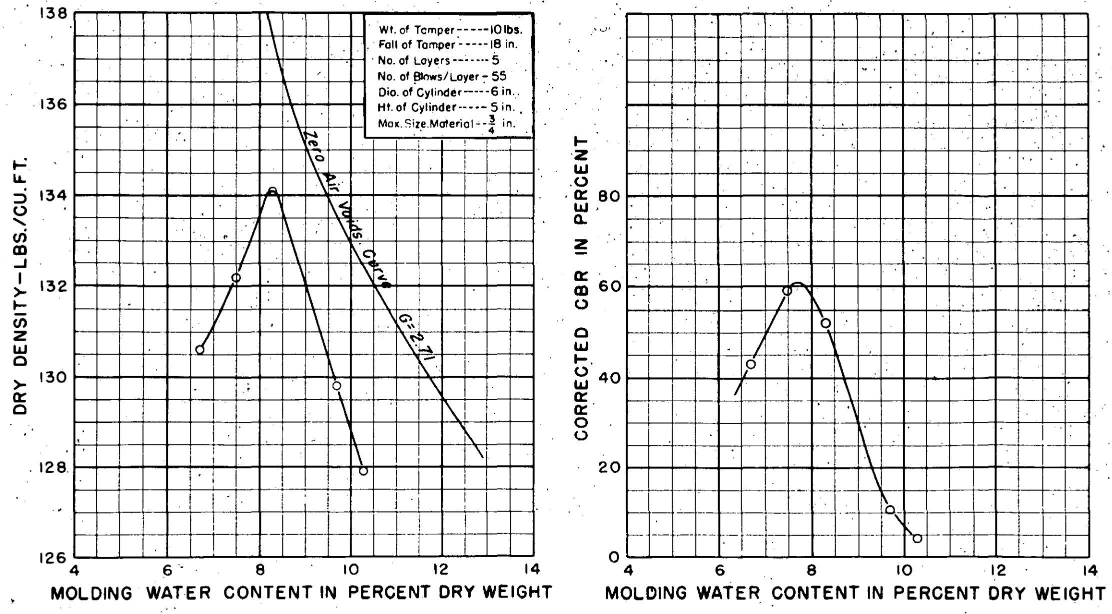
7 INCH SECTION

12 INCH SECTION

18 INCH SECTION

24 INCH SECTION

FROST MELTING PERIOD FIELD CBR TESTS - APRIL 1951



LABORATORY CBR AND DENSITY VS MOLDING WATER CONTENT

SUMMARY OF
FIELD CALIFORNIA BEARING RATIO TESTS

NORMAL PERIOD — OCTOBER 1950

SECTION OF TEST AREA	DEPTH IN INCHES	CORRECTED CBR IN PERCENT @ 0.1"	CORRECTED CBR IN PERCENT @ 0.2"	DRY DENSITY p.c.f.	WATER CONTENT %
7 INCH	7-13	17-35 (28)	21-27 (25)	128.7	9.6
12 INCH	12-18	19-32 (26)	25-43 (36)	129.6	8.5
18 INCH	18-24	22-27 (25)	29-32 (31)	130.7	10.6
24 INCH	24-30	14-25 (19)	14-27 (21)	124.9	11.7

NOTE:- Figures in ( ) denote average value.

SUMMARY OF
FIELD CALIFORNIA BEARING RATIO TESTS

FROST MELTING PERIOD — APRIL 1951

SECTION OF TEST AREA	DEPTH IN INCHES	CORRECTED CBR IN PERCENT @ 0.1"	CORRECTED CBR IN PERCENT @ 0.2"	DRY DENSITY p.c.f.	WATER CONTENT %
7 INCH	7-13	10-12 (11)	13-14 (13)	126.8	11.0
12 INCH	12-18	11-19 (16)	14-24 (19)	132.1	9.6
18 INCH	18-24	16-20 (18)	20-25 (22)	136.7	7.7
24 INCH	24-30	16-22 (20)	22-26 (24)	126.5	12.3

NOTE:- Figures in ( ) denote average value.

SUMMARY OF
LABORATORY CALIFORNIA BEARING RATIO TESTS

SAMPLE NO.	BEARING RATIO IN PERCENT @ 0.1"	BEARING RATIO IN PERCENT @ 0.2"	DRY DENSITY lbs./cu.ft. MOLDED	DRY DENSITY lbs./cu.ft. SOAKED	WATER CONTENT IN PERCENT MOLDED	WATER CONTENT IN PERCENT SOAKED
1	38 38	44 42	130.6	130.0	6.7	10.5
2	69 43	68 50	132.2	131.9	7.5	9.6
3	51 37	61 43	134.1	134.1	8.3	9.1
4	8 8	11 10	129.8	129.8	9.7	10.9
5	3 3	4 4	127.9	128.7	10.3	11.4

NOTE:- For each sample the top value denotes result of penetration of top of sample, bottom value for bottom of same sample.

NOTE:-

All California Bearing Ratio tests performed on Gravelly Sandy Clay (CL) subgrade.

FROST INVESTIGATION
FISCAL YEAR 1950-1951
FROST TEST SECTION
LIMESTONE AIR FORCE BASE, LIMESTONE, MAINE

CALIFORNIA BEARING RATIO TESTS

FROST EFFECTS LABORATORY
NEW ENGLAND DIVISION CORPS OF ENGINEERS
BOSTON, MASS.

PLATE 15

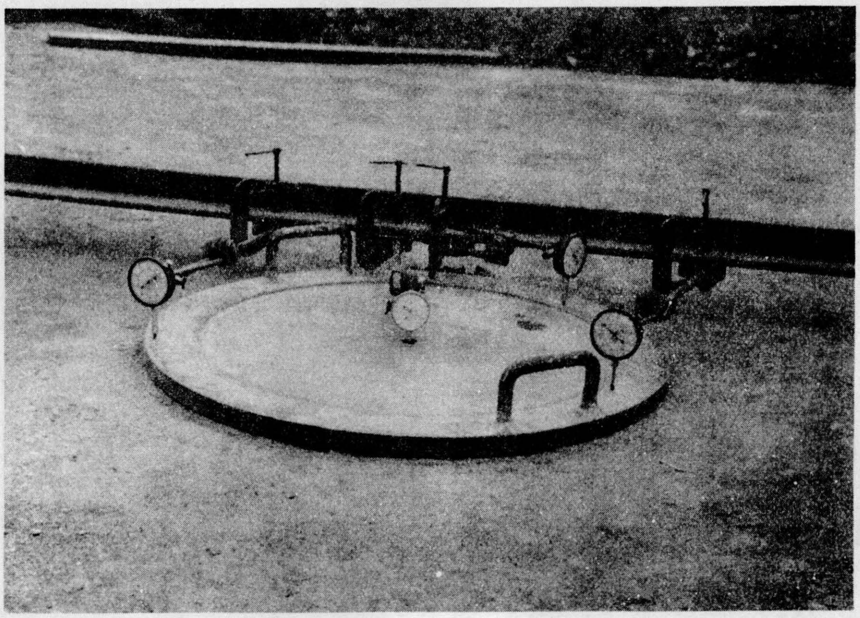


FIG. 1 SET UP OF PLATE AND EXTENSOMETER DIALS FOR PLATE BEARING TESTS.

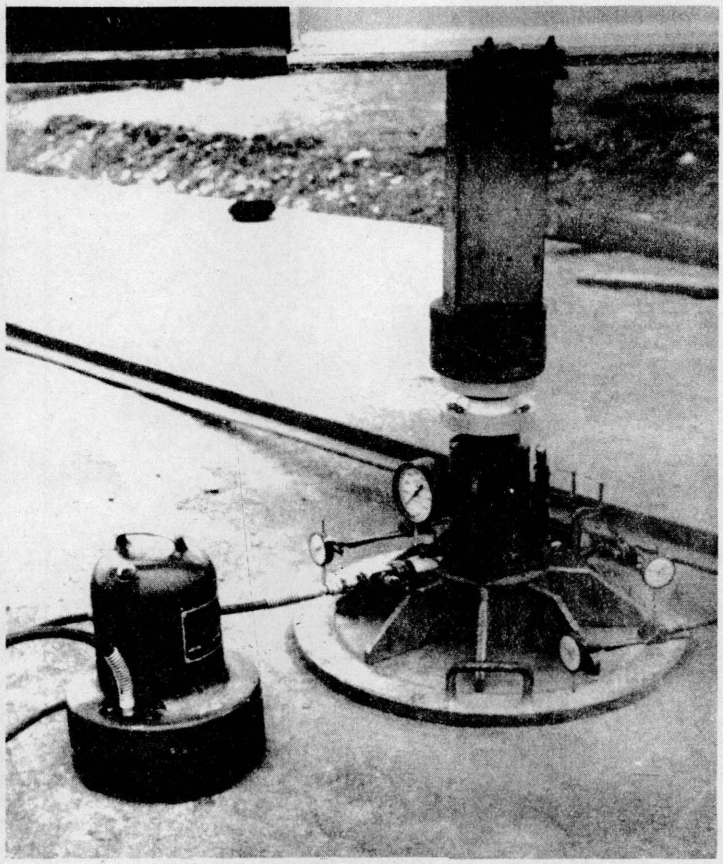
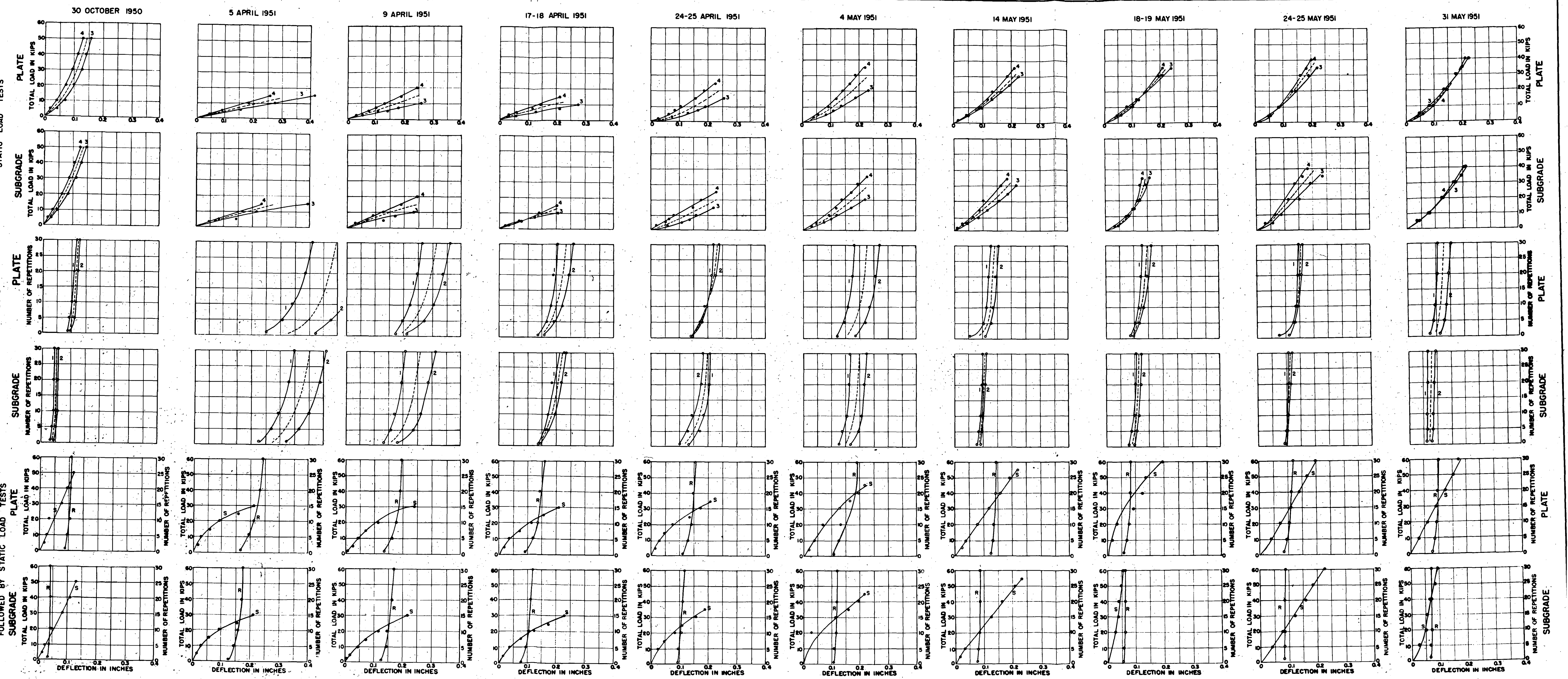


FIG. 2 PLATE BEARING TEST EQUIPMENT SET UP FOR TEST.



Repeating load tests performed at positions 1 and 2.
Static load tests performed at positions 3 and 4.
Repeating load tests, followed by static load tests, performed at position 5.
Numbers adjacent to curves indicate position test performed.

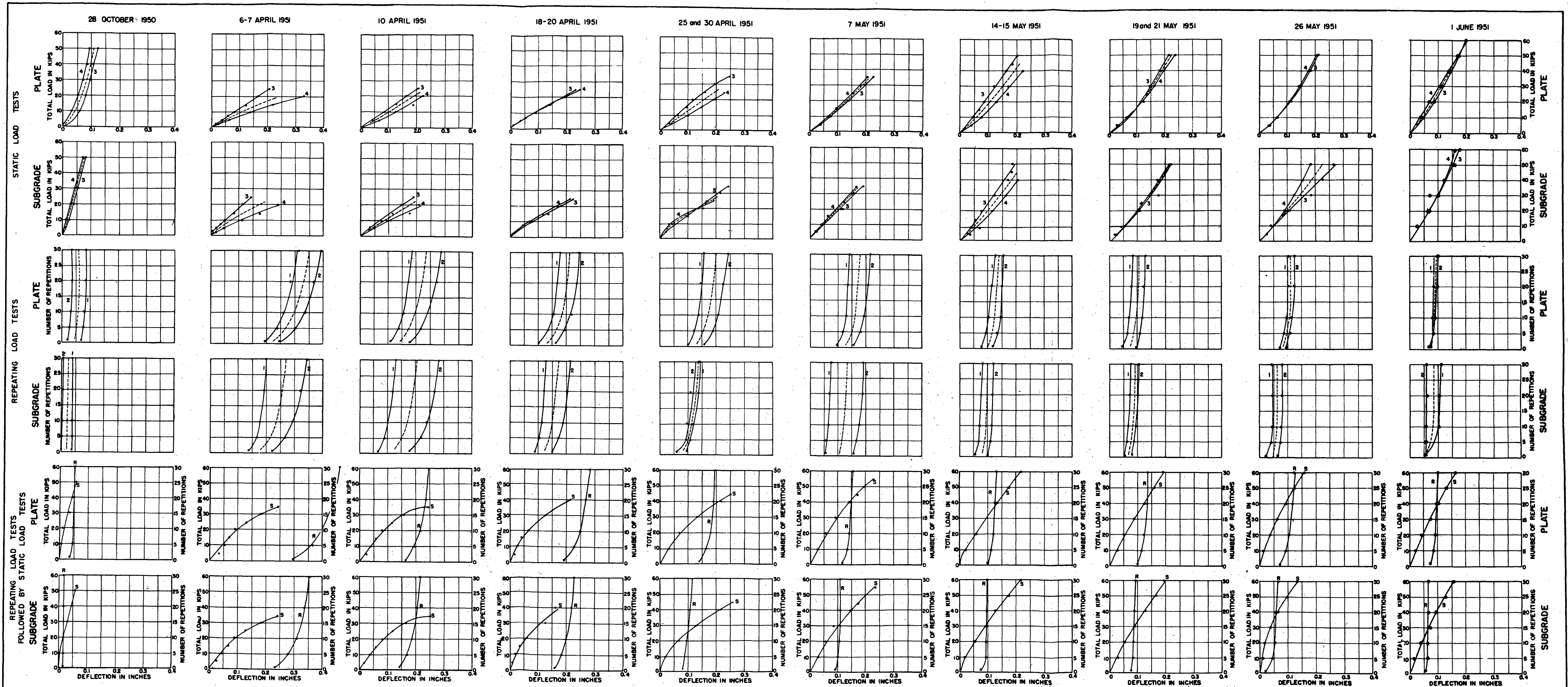
—— Denote actual test results.
---- Denotes average of tests.
R Denotes repeating load test at position 5.
S Denotes static load test at position 5.

All tests conducted with 30 inch diameter plate
Repeating load tests performed using 10,000 lb. load.
Dates denote days series were performed.

7 INCH SECTION
PLATE BEARING TESTS

FROST TEST SECTION LIMESTONE, MAINE

PLATE 17



Repeating load tests performed at positions 1 and 2.
Static load tests performed at positions 3 and 4.
Repeating load tests followed by static load tests performed at position 5.
Numbers adjacent to curves indicate position test performed.

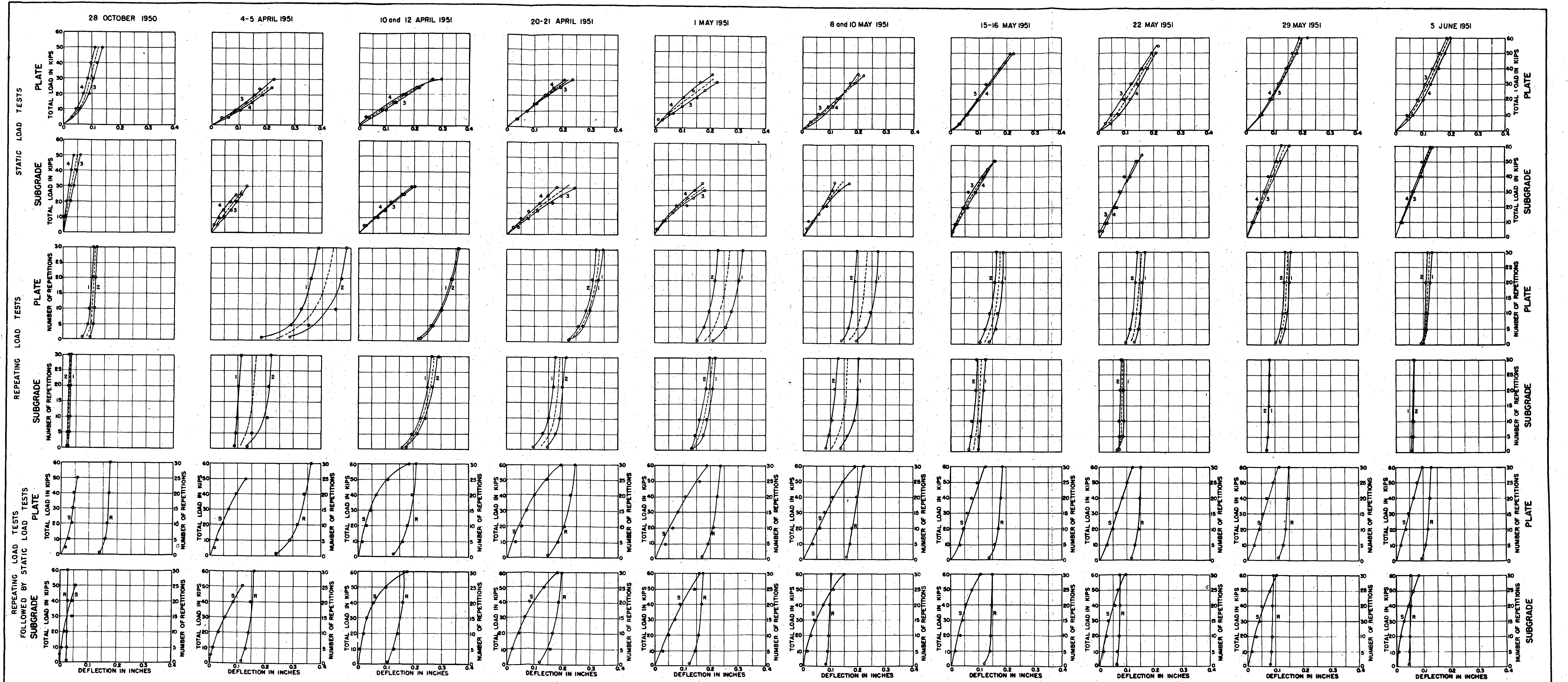
—— Denote actual test results.
----- Denotes average of tests.
R Denotes repeating load test of position 5.
S Denotes static load test at position 5.

All tests conducted with 30 inch diameter plate.
Repeating load tests performed using 15,000 lb. load.
Dates denote days series were performed

12 INCH SECTION
PLATE BEARING TESTS

FROST TEST SECTION LIMESTONE, MAINE

PLATE 18



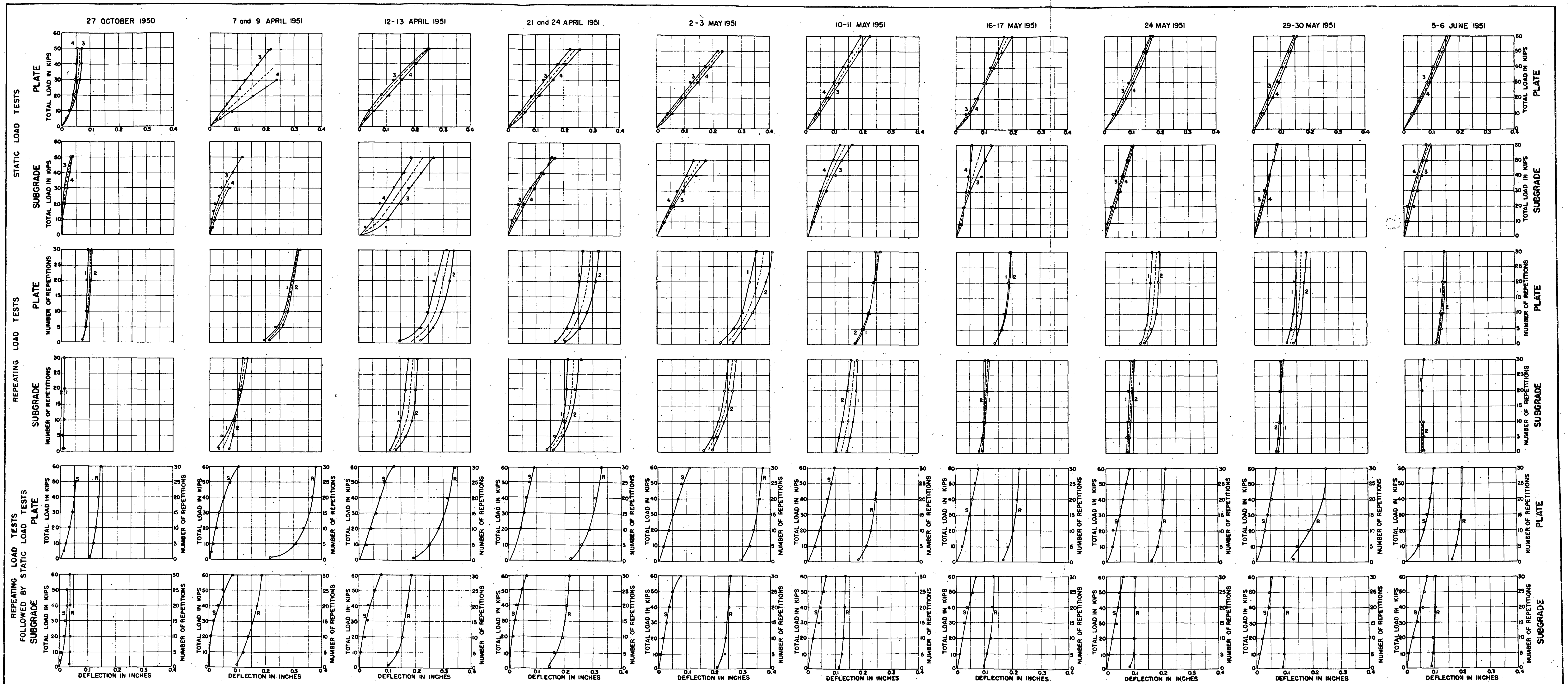
Repeating load tests performed at positions 1 and 2.
Static load tests performed at positions 3 and 4.
Repeating load tests followed by static load tests performed at position 5.
Numbers adjacent to curves indicate position test performed.

—— Denote actual test results.
- - - - Denotes average of tests.
R Denotes repeating load test at position 5.
S Denotes static load test at position 5.

All tests conducted with 30 inch diameter plate.
Repeating load tests performed using 30,000 lb, load.
Dates denote days series were performed.

18 INCH SECTION
PLATE BEARING TESTS

FROST TEST SECTION LIMESTONE, MAINE



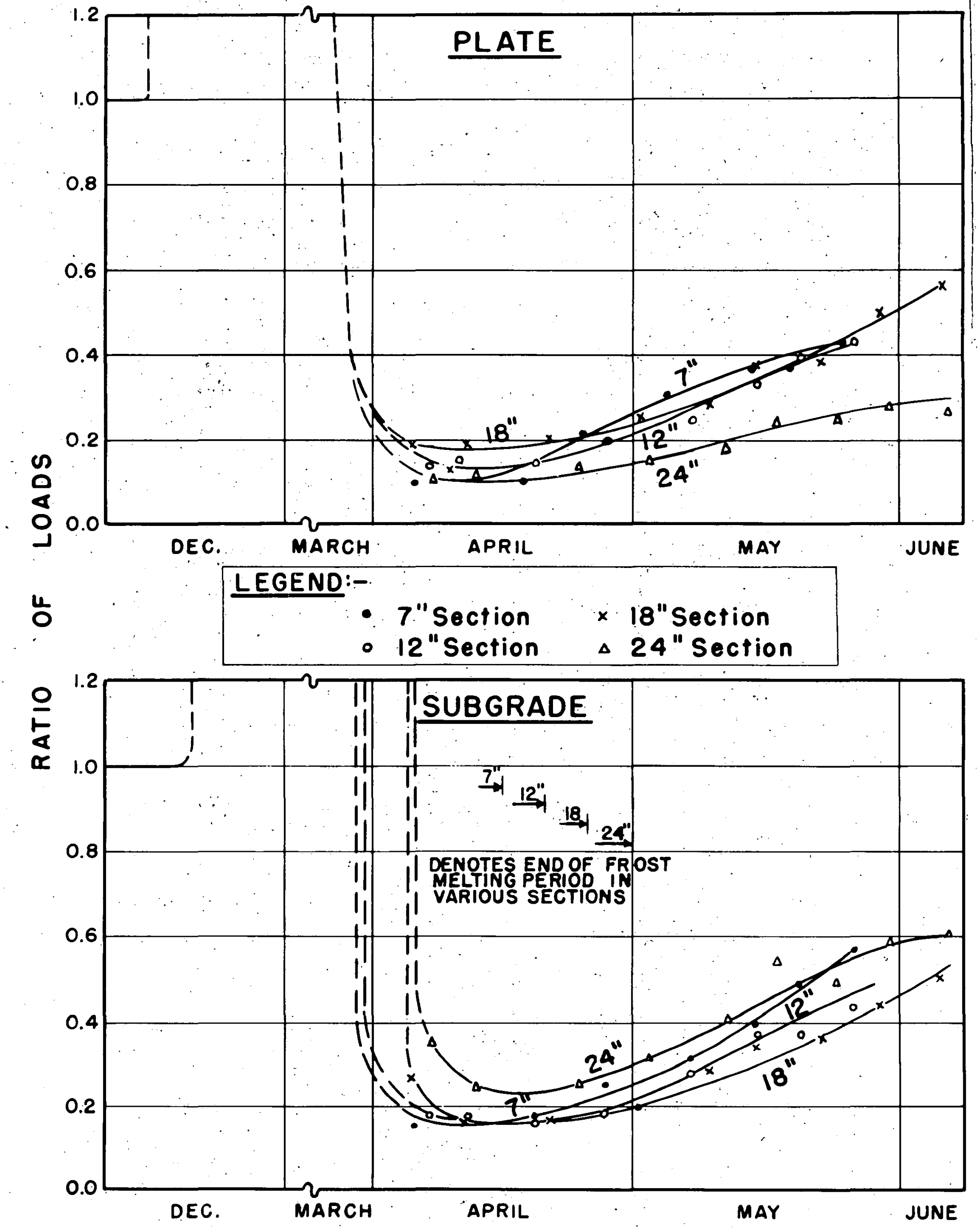
Repeating load tests performed at positions 1 and 2.
Static load tests performed at positions 3 and 4.
Repeating load tests followed by static load tests performed at position 5.
Numbers adjacent to curves indicate position test performed.

— Denote actual test results.
--- Denotes average of tests.
R Denotes repeating load test at position 5.
S Denotes static load test at position 5.

All tests conducted with 30 inch diameter plate.
Repeating load tests performed using 50,000 lb. load.
Dates denote days series were performed.

24 INCH SECTION
PLATE BEARING TESTS

FROST TEST SECTION LIMESTONE, MAINE

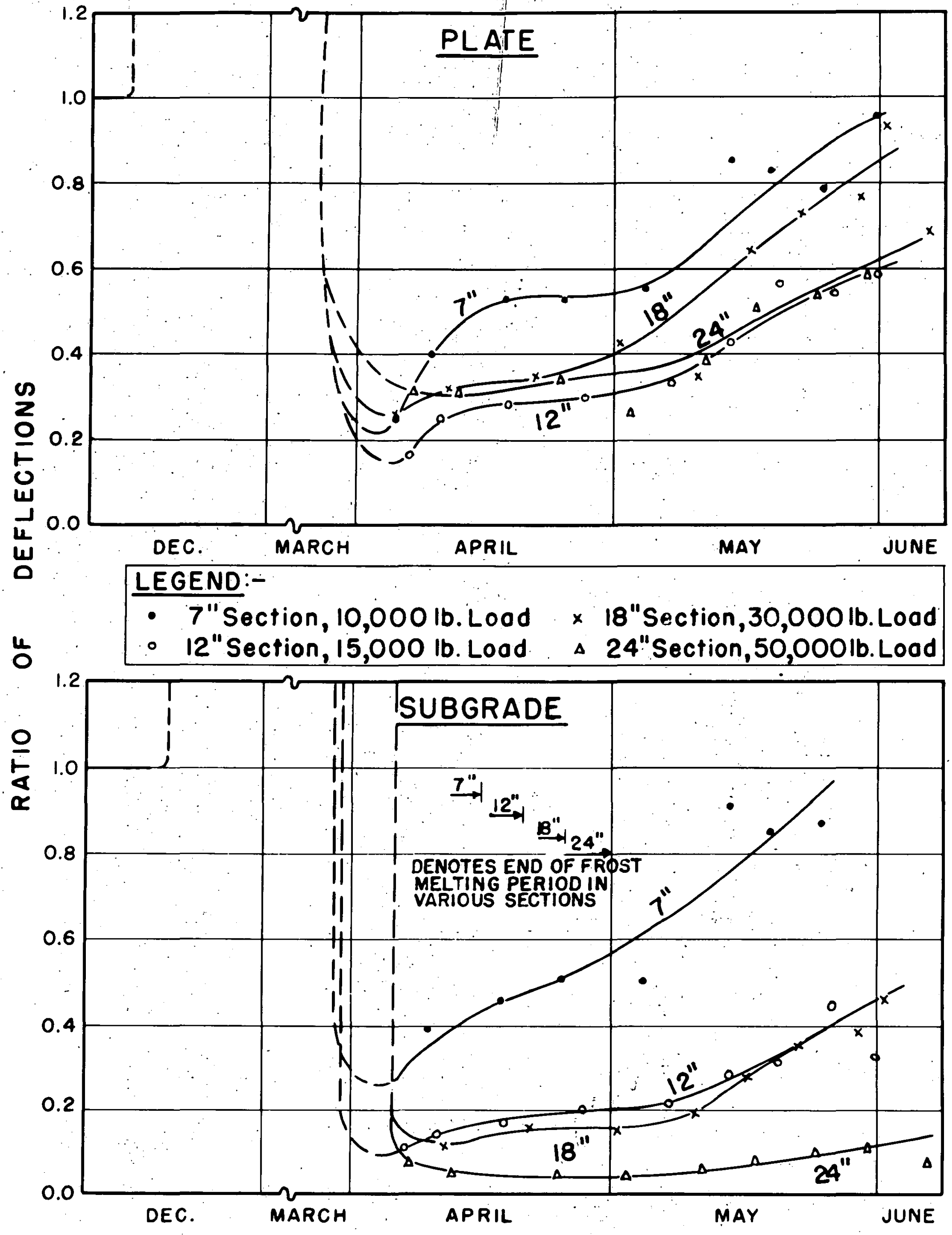


AVERAGE OF POSITIONS 3 AND 4

STATIC LOAD TESTS

(30 IN. DIA. PLATE)

RATIO OF FROST MELTING PERIOD TO NORMAL PERIOD LOADS AT 0.05 INCH DEFLECTION

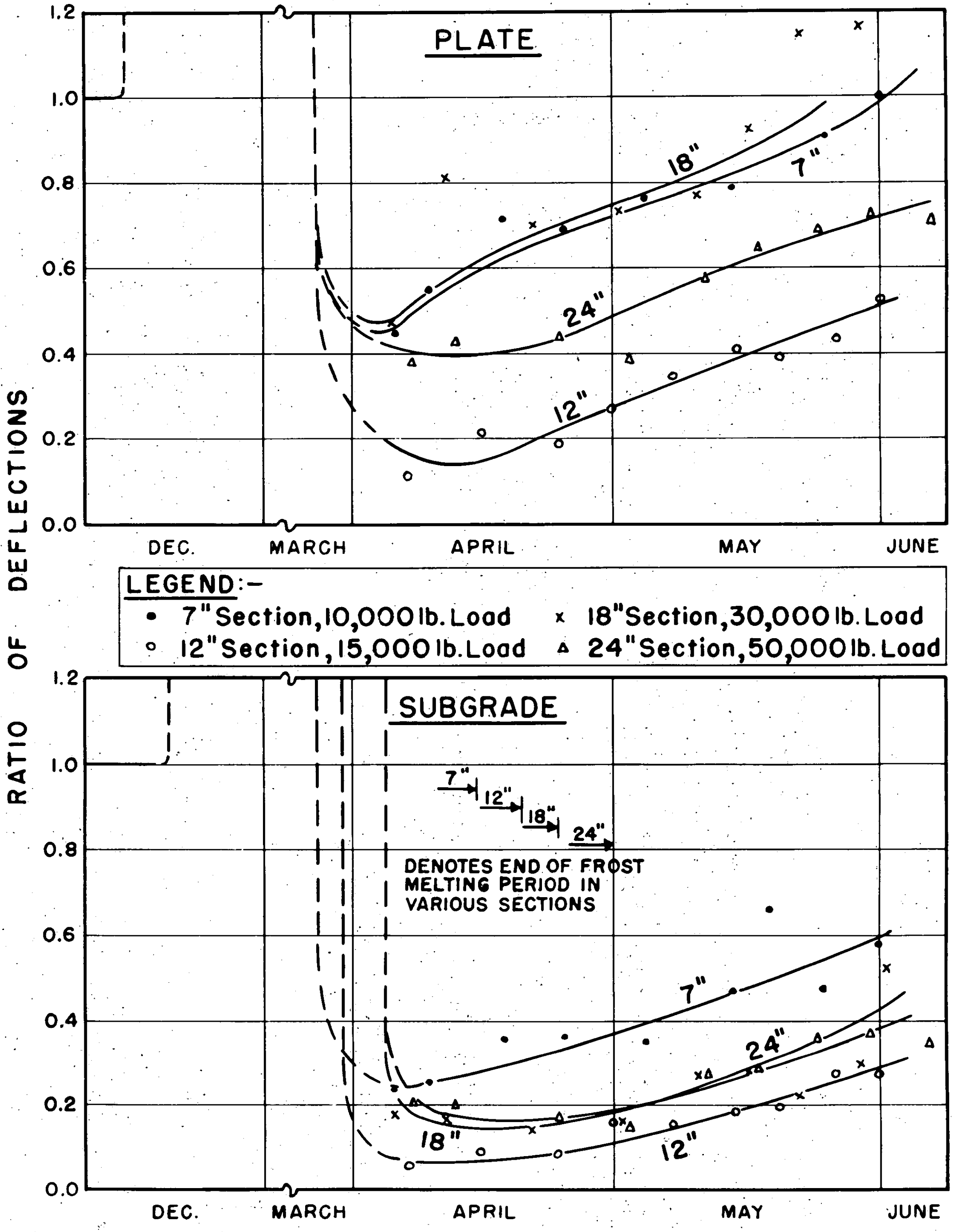


AVERAGE OF POSITIONS 1 AND 2

REPEATING LOAD TESTS

(30 IN. DIA. PLATE)

RATIO OF NORMAL PERIOD TO FROST MELTING PERIOD DEFLECTIONS AT 30TH REPETITION



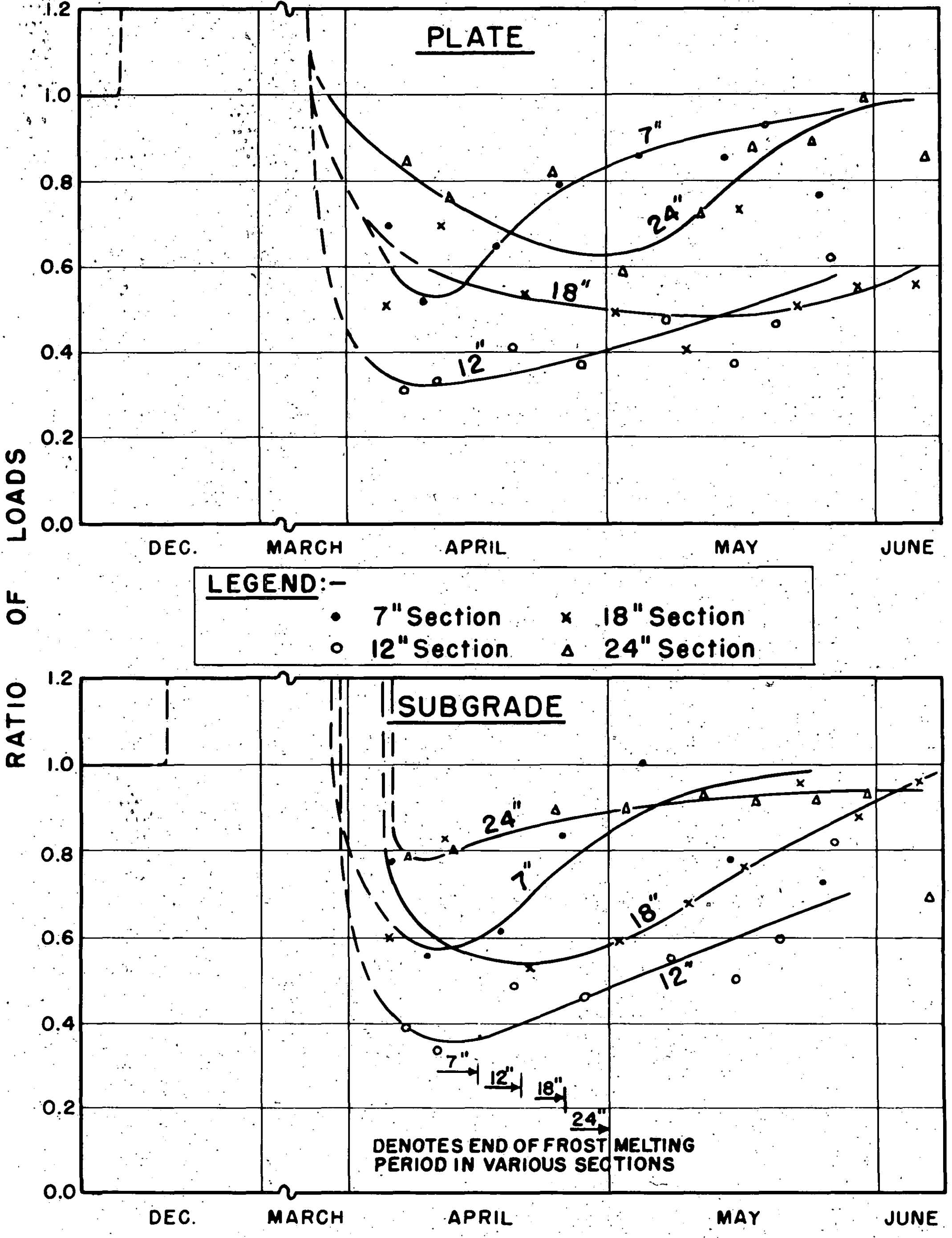
POSITION 5

REPEATING LOAD TESTS PRECEDED STATIC LOAD TESTS

(30 IN. DIA. PLATE)

RATIO OF NORMAL PERIOD TO FROST MELTING PERIOD DEFLECTIONS AT 30TH REPETITION

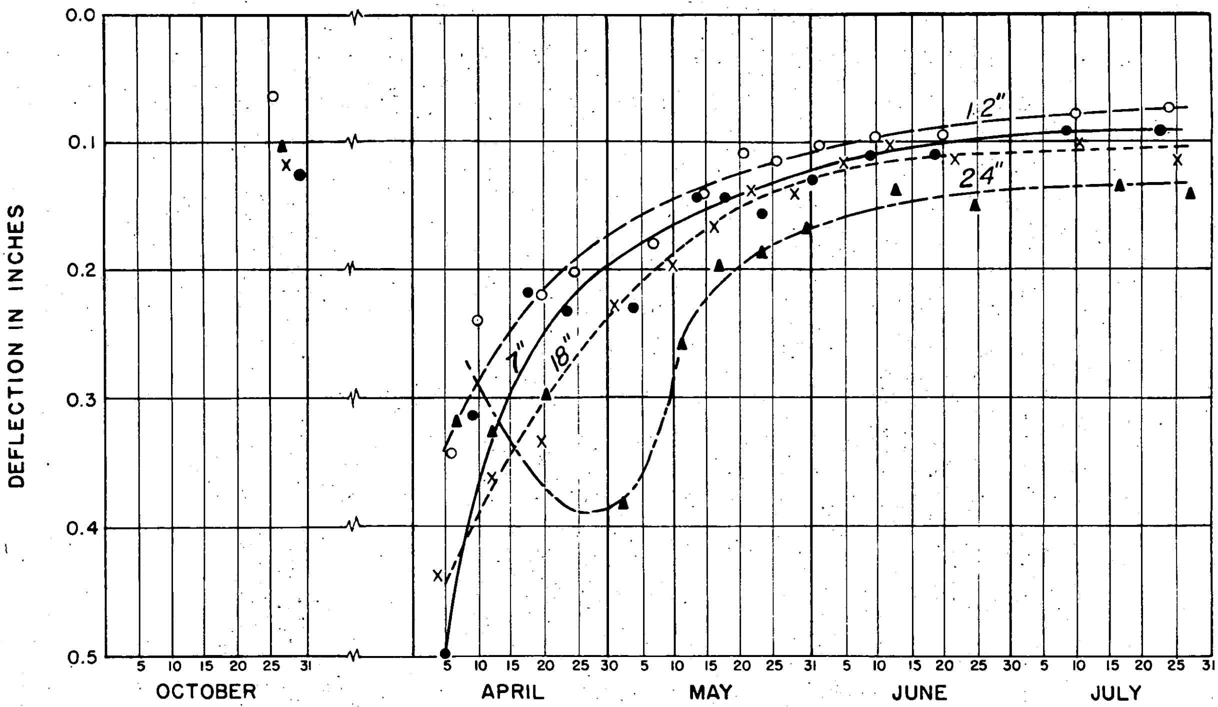
PLATE 23



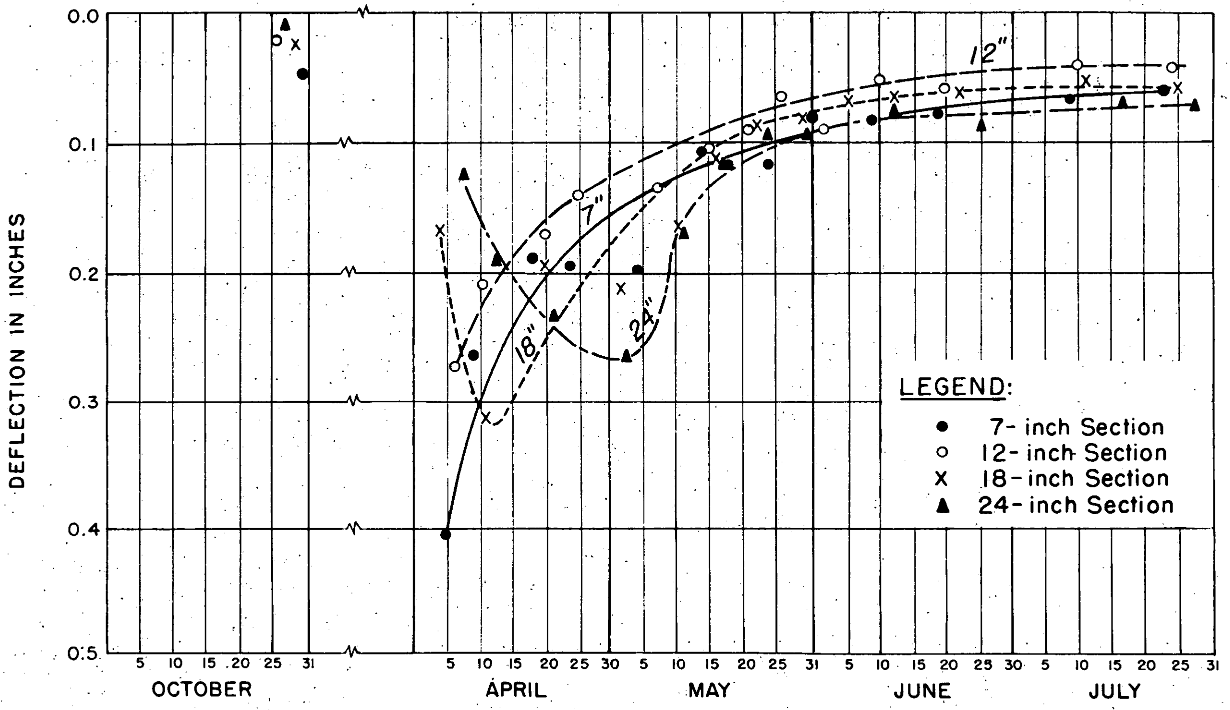
POSITION 5

STATIC LOAD TESTS PRECEDED BY REPEATING LOAD TESTS
(30 IN. DIA. PLATE)

RATIO OF FROST MELTING PERIOD TO NORMAL PERIOD LOADS AT 0.05 INCH DEFLECTION



PLATE

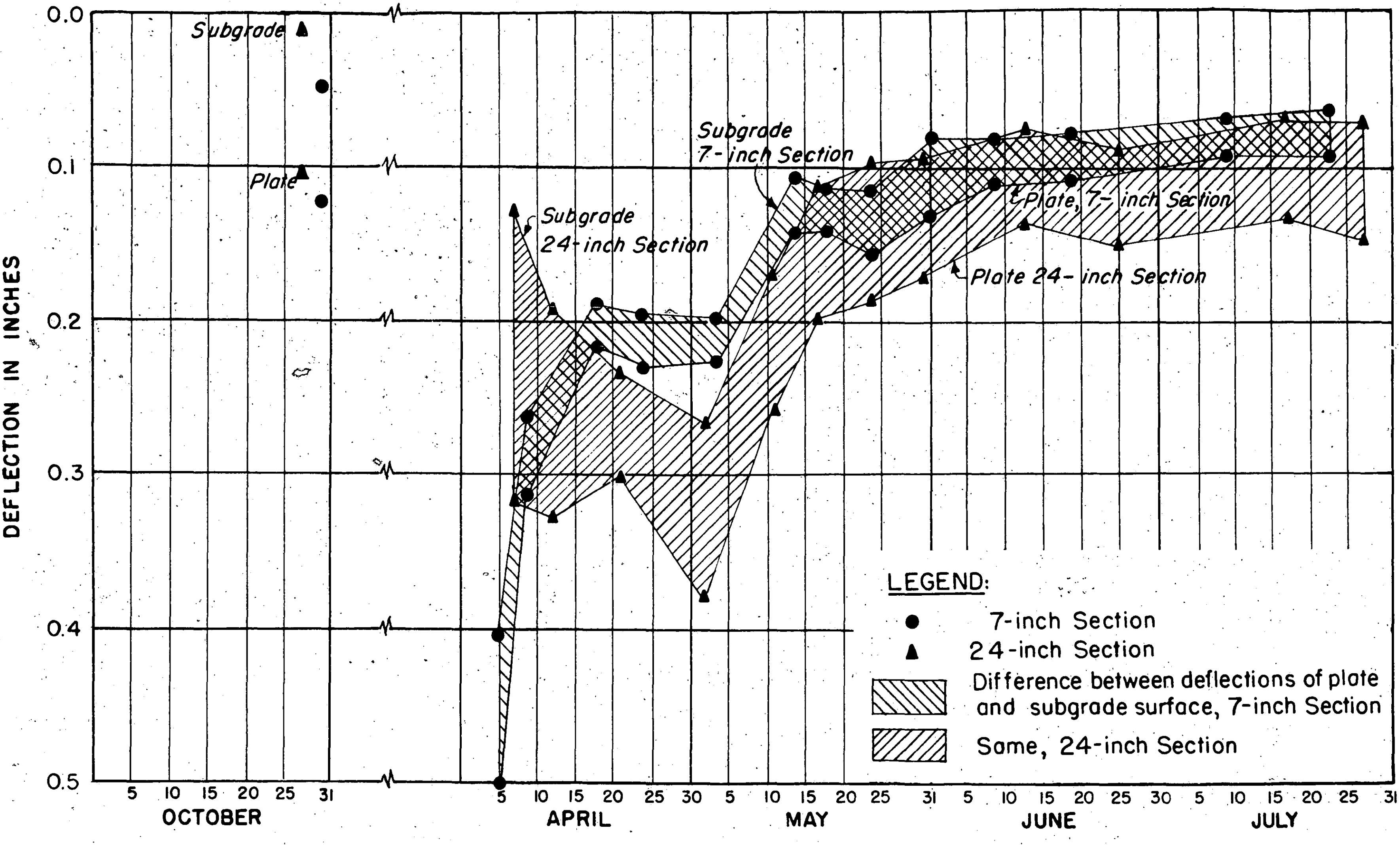


SUBGRADE

SECTION	REPEATING LOAD (lbs)
7- inch	10,000
12- inch	15,000
18- inch	30,000
24- inch	50,000

AVERAGE OF POSITIONS 1 AND 2
REPEATING LOAD TESTS
(30 IN. DIA. PLATE)

DEFLECTIONS OF PLATE AND SUBGRADE SURFACE AT 30TH REPETITION

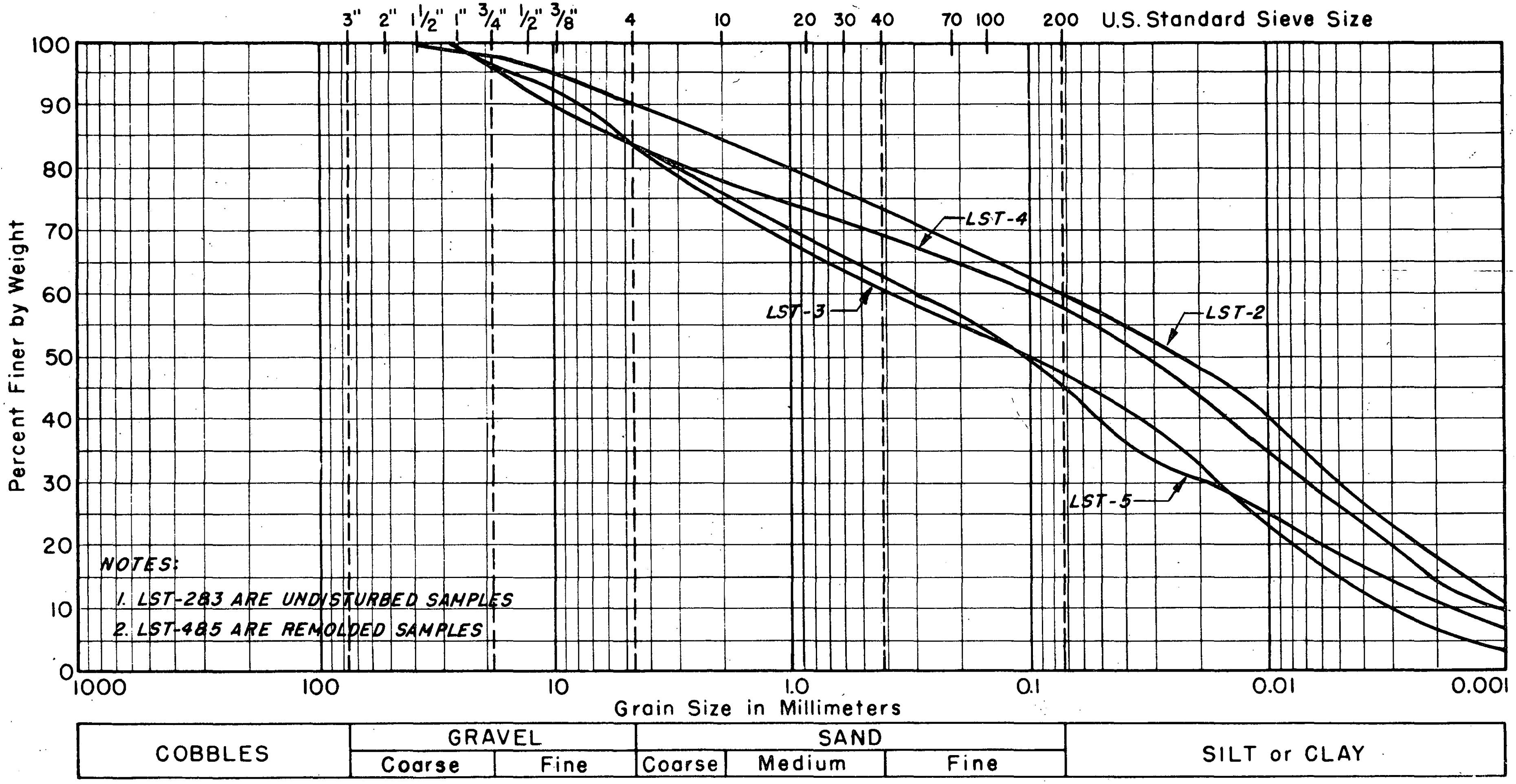


SECTION	REPEATING LOAD (lbs)
7-inch	10,000
24-inch	50,000

AVERAGE OF POSITIONS 1 AND 2
REPEATING LOAD TESTS
(30 IN. DIA. PLATE)

COMPARISON OF PLATE AND SUBGRADE
DEFLECTIONS AT 30TH REPETITION
7 IN. AND 24 IN. SECTIONS

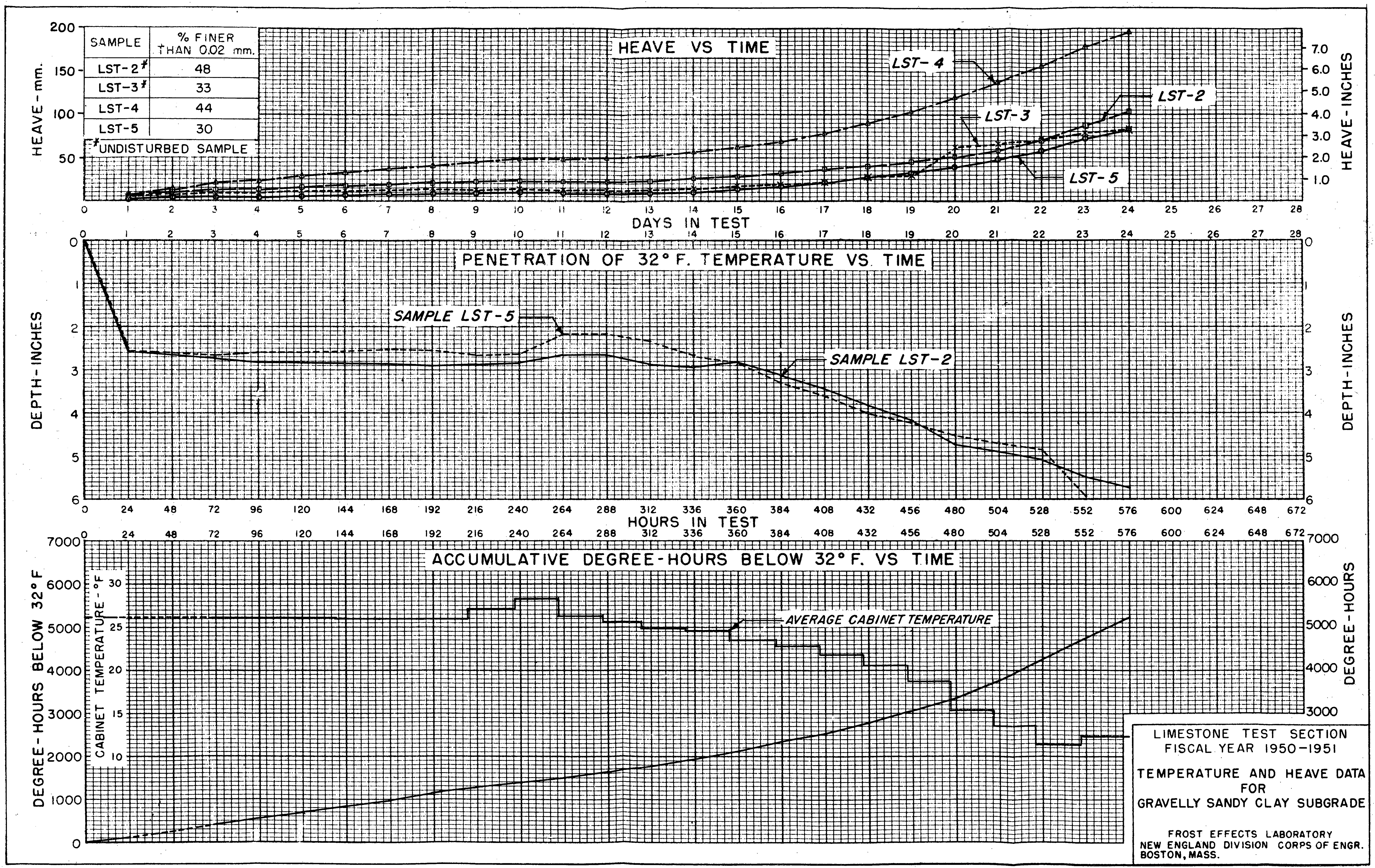
PLATE 26



GRADATION CURVES OF LIMESTONE SANDY GRAVELLY SUBGRADE SAMPLES

USED IN COLD ROOM TESTS

PLATE 27



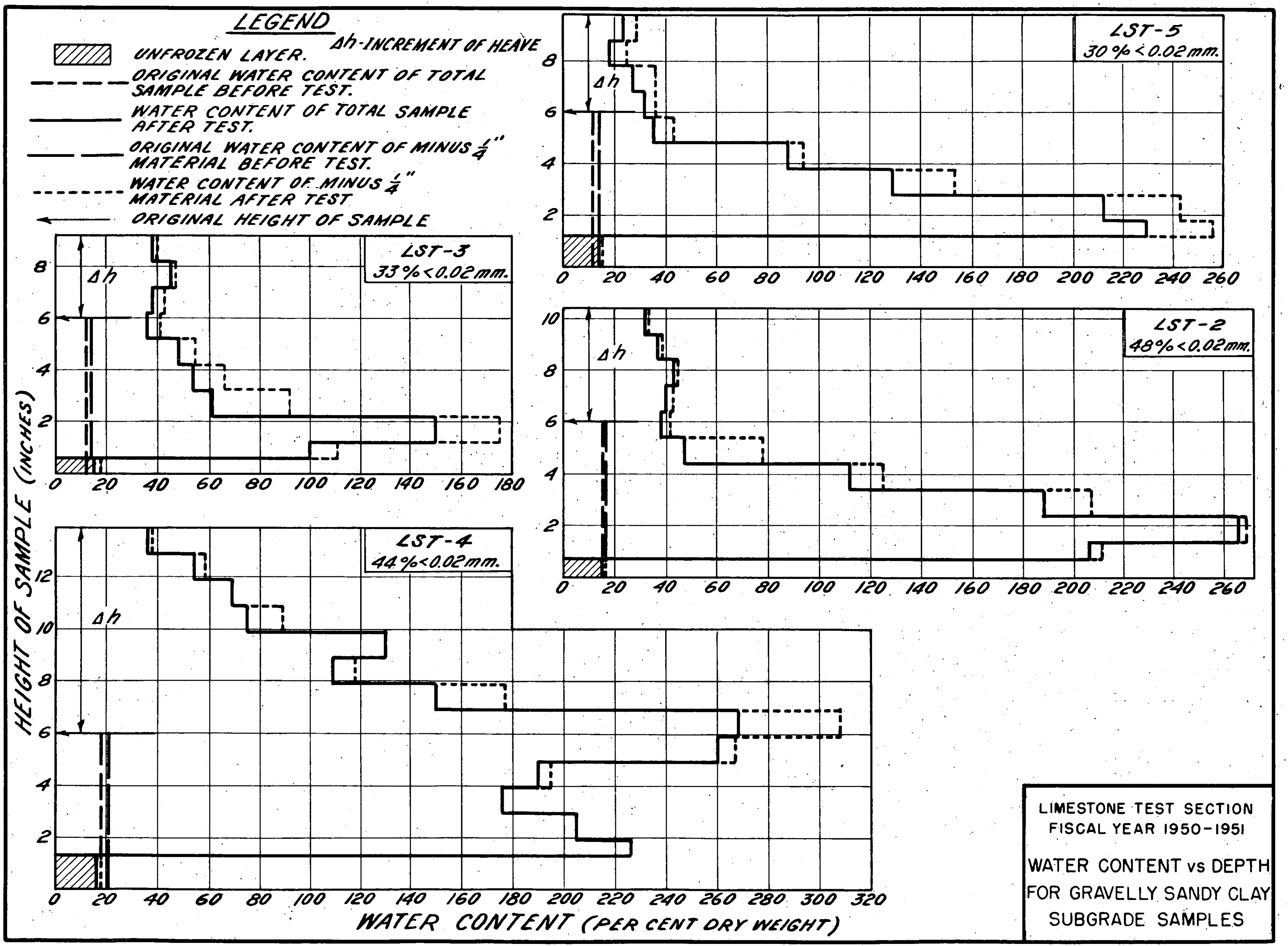
SAMPLE	% FINER THAN 0.02 mm.
LST-2[✝]	48
LST-3[✝]	33
LST-4	44
LST-5	30

[✝] UNDISTURBED SAMPLE

LIMESTONE TEST SECTION
FISCAL YEAR 1950-1951

TEMPERATURE AND HEAVE DATA
FOR
GRAVELLY SANDY CLAY SUBGRADE

FROST EFFECTS LABORATORY
NEW ENGLAND DIVISION CORPS OF ENGR.
BOSTON, MASS.



LIMESTONE TEST SECTION
FISCAL YEAR 1950-1951

WATER CONTENT vs DEPTH
FOR GRAVELLY SANDY CLAY
SUBGRADE SAMPLES

PLATE 29