Plate-Bearing Study of Loss of Pavement Supporting Capacity Due to Frost

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This paper summarizes field studies of the effect of frost action on the magnitude and duration of loss in pavement supporting capacity, measured by plate-bearing tests, as part of a comprehensive frost-investigation program initiated by the Corps of Engineers in 1944. The studies represent one phase of continuing field investigations initiated in the fall of 1950 at the Frost Test Area, Loring Air Force Base, Limestone, Maine, to improve methods for the prediction of the effects of frost action. The Frost Test Area, 30 by 40 feet in plan, consists of four test sections with various combined thicknesses of pavement and base course constructed on a natural gravelly sandy clay subgrade.

Plate-bearing tests at the Frost Test Area indicate the following results for the reported investigational period: (1) succeeding years of freezing and thawing decreased the normal period (fall) pavement supporting capacity progressively during successive years; (2) the quantitative loss of pavement supporting capacity is the same for each test section during frost-melting period when compared to the normal period supporting capacity for the specific test sections; (3) the duration of loss in pavement supporting capacity is approximately four months as measured by static loading test and about three months when measured by repeating load tests; (4) all repeating-load tests show good agreement, whereas static-load tests at locations where they are preceded by repeating-load tests indicate considerably less loss in pavement supporting capacity when compared with the test results from the static load test locations.

● IN northern latitudes, as well as in the Arctic and Subarctic regions, freezing and thawing of soils cause considerable damage to roads and airfields. Constantly increasing wheel loads and speeds of trucks and aircraft on roads and airfields, together with the demand that these facilities be kept in usable condition at all times, have brought about the need for improved design and construction of pavements for both airfields and roads. Freezing of the ground, especially where frost-susceptible soil types are present and water is readily available, will cause ice segregation resulting in possible non-uniform heave which in turn may cause damage to the pavement surface. The most severe damage associated with frost action occurs during frost-melting periods when the supporting soil loses a large proportion of its strength and may become practically liquid due to the melting of the segregated ice in the soil. With the strength of the supporting soil reduced, frost boils, pumping and pavement breakup may occur necessitating either halting of all traffic or restricting the traffic to lighter wheel loads.

To develop pavement design and evaluation criteria for such frost conditions, the Arctic Construction and Frost Effects Laboratory of the New England Division was established in 1944 by authority of the Chief of Engineers, Department of the Army, and was assigned the responsibility of carrying out the investigations under the supervision of the Airfields Branch, Engineering Division, Military Construction, Office of the Chief of Engineers. Extensive field investigations consisting of traffic tests, plate-bearing tests, California Bearing Ratio tests and supplementary observations have been conducted at various airfields in the northern part of the United States and extensive field data have been assembled to aid in the development of criteria.

The available field data, however, indicated the need for further field investigations under controlled conditions to determine the magnitude and duration of loss of pavement supporting capacity due to frost action as measured by plate bearing tests and to obtain temperature, ground water and heave data with the objective of improving methods for the prediction of the effects of frost action. To attain these objectives, a frost test area was constructed at the Loring Air Force Base, Limestone, Maine, during

September 1950 and a testing program, which was initiated upon completion of the test area, has been carried out continuously to the present time.

Studies, which are being conducted under controlled conditions, are intended to give a clearer understanding of frost action under field conditions and should result in the development of improved criteria for design and evaluation of pavements for airfields and highways. With the facilities available, a comparison of test results at selected points may be made on a year-round basis and the continuing study should encompass a range of climatic conditions.

The present paper is devoted mainly to a summary of the results of the plate-bearing tests which were performed to measure the magnitude and duration of reduction in pavement supporting capacity due to frost action.

DESCRIPTION OF TEST AREA

The Frost Test Area, shown in Figure 1, is located at Loring Air Force Base, Limestone, Maine. The 40- by 30-ft. test area consists of four test sections, fourteen by eighteen feet, with base courses of 7, 12, 18 and 24 inches, respectively, over a natural glacial till 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. In the fall of 1952, the area was resurfaced with approximately one inch of hot-mix asphaltic concrete to eliminate depressions and irregularities caused by previous test operations. Drainage swales are provided around the test area to take care of surface runoff water. Subsurface drainage facilities were also incorporated around the area and bisecting the area in the north-south direction. This system is built of perforated corrugated metal pipe installed in the trenches and connected to a water supply well in which the water level may be controlled to either

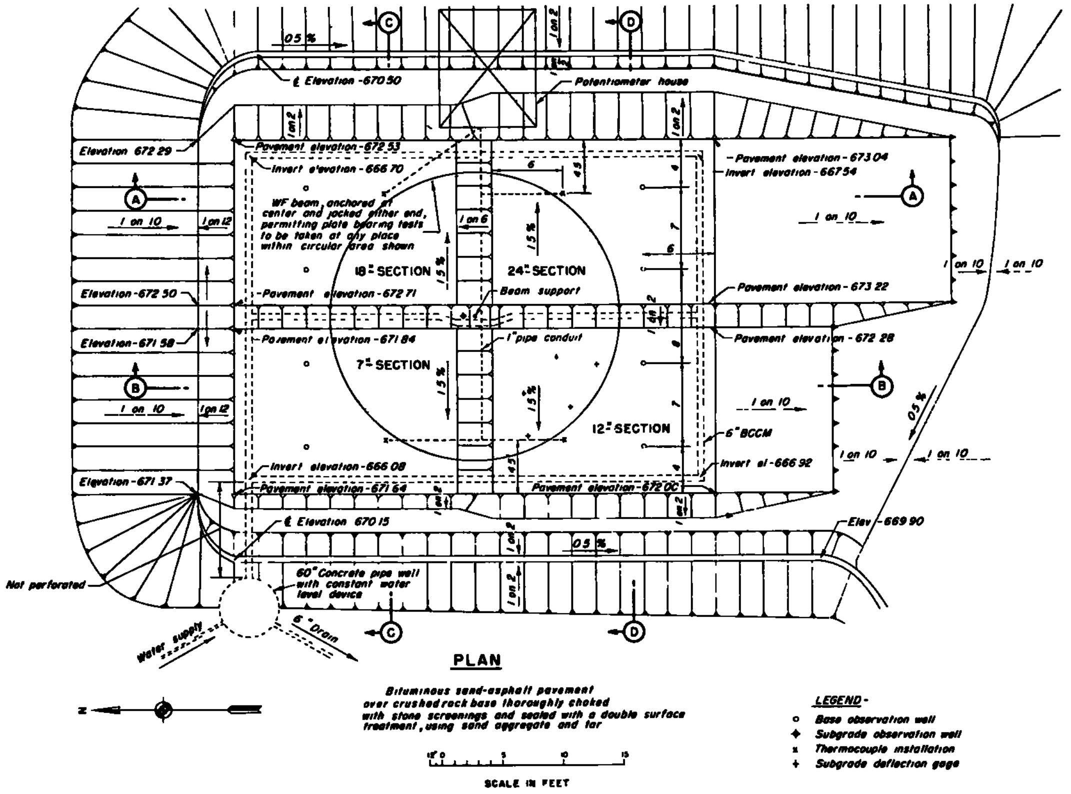

Figure 1.

drain the test area or maintain the ground water elevation at any height in the subgrade or the lower part of the base.

The subgrade material at the test area exposed after removal of topsoil and badly weathered subgrade soil was a gravelly sandy clay (CL) glacial till with an average liquid limit of 21 and a plasticity index of 6. This material is classified as of high frost-susceptibility in accordance with the classification system adopted as one factor to aid in in the comparison of the relative frost-susceptibility of soils subjected to standard laboratory freezing tests.[1]

The thickness of upper and lower base course 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

Copper-constantan thermocouples were installed in each test section to observe subsurface temperatures at depths of 0.25, 0.50, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0 and 7.0 feet beneath the pavement surface. Each group of thermocouples was encased in water tight plastic tubing and the measuring tip of each thermocouple was hermatically sealed to insure a water tight unit. The thermocouple leads terminated at temperature measuring units located in an instrument house adjacent to the test area.

Observation wells were installed in each section to observe fluctuation in the ground water level of both the base course and the subgrade.

Subgrade deflection gages were installed in each section to measure the subgrade deflection at five plate loading test locations. These gages, consisting of steel rods attached to four square inch square plates, rest on a sand cushion on the subgrade surface and the steel rod is encased in a pipe sleeve extending from approximately ¾ inch above the steel plate to the pavement surface. The space between the gage rod and the pipe sleeve was packed with grease to permit free movement of the rod and to prevent water from entering, freezing, and hampering the action of the gage. The gages were located in the same relative location and similarly numbered in each section.

Reaction for the plate loading tests 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 the plate bearing tests are conducted. Reaction is obtained by cribbing one end of the beam and jacking against the other end. The beam is supported by a yoke which in turn is fastened to a 3¼-inch-diameter steel rod grouted in a hole extending 20 feet into bedrock. The surface of the bedrock is 20 feet beneath the surface of the test area.

Additional installations at the test area consist of five heave reference points installed in each section and a bench mark installed adjacent to the area for use as a reference in heave measurements.

FIELD PLATE BEARING TESTS

Test Procedures

Upon completion of the construction of the test area in September 1950, the subgrade material was saturated by adjusting the water level in the water supply well to control the ground water level slightly above the subgrade surface. The water level was maintained at this position until freezing started and was then lowered to and maintained at an elevation slightly below the subgrade surface, until the middle of August 1952. Thereafter, the ground water was allowed to stabilize at its natural level which fluctuates between 11 and 14 feet below the subgrade surface.

Field investigations were initiated in the latter part of October 1950, which included

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[1] Haley, James F., "Cold Studies of Frost Action in Soils, A Progress Report," Soil Temperature and Ground Freezing, Highway Research Bulletin 71, Washington, D. C., 1953, pp, 1-18.

an initial series of plate bearing tests to determine normal period values of pavement supporting capacity. Plate-bearing tests were discontinued during the freezing season; however, observations were continued periodically of ground water, temperature and heave. Plate-bearing tests were resumed at the start of the frost melting period and continued periodically until the next freezing season. Prior to the freezing and during the frost melting season of each year, test pits were excavated to observe ice segregation, obtain moisture and density data and to perform CBR tests.

The plate-bearing tests were performed on the pavement surface using a 30-inch diameter 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 deg. apart on the outer edge of the plate. Subgrade deflection was measured by a single dial extensometer placed on the subgrade deflection gage through a hole in the center of the plate. All four extensometers were attached to a steel beam supported approximately eight feet from each side of the bearing plate. A jack stand was used to distribute the load over the plate and to provide a space for the extensometer placed over the subgrade deflection gage. The load was applied by jacking against the 27-inch WF beam with a 50-ton hydraulic jack controlled by an electrically driven hydraulic pump. A ball and socket joint, between the jack and beam, reduced eccentricity of loading on the bearing plate. A 500-lb. seating load was used at the start of each plate-bearing test.

Two types of plate-loading tests were conducted at each test section, namely: static load tests at two locations, repeating load tests at two locations and a repeating load test followed by a static load test at a fifth location.

The static load tests were performed by loading the plate in approximately five equal increments with each load increment held constant and the deflection of the plate and

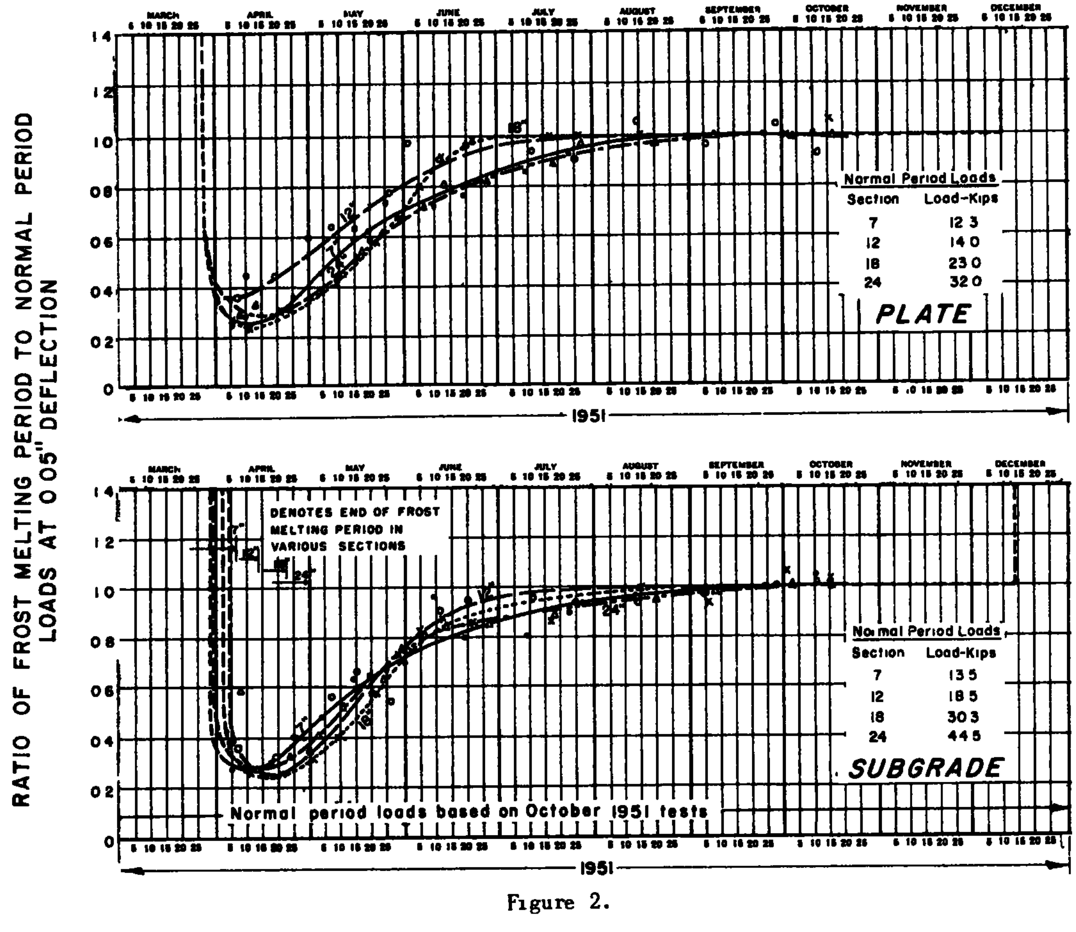

Figure 2.

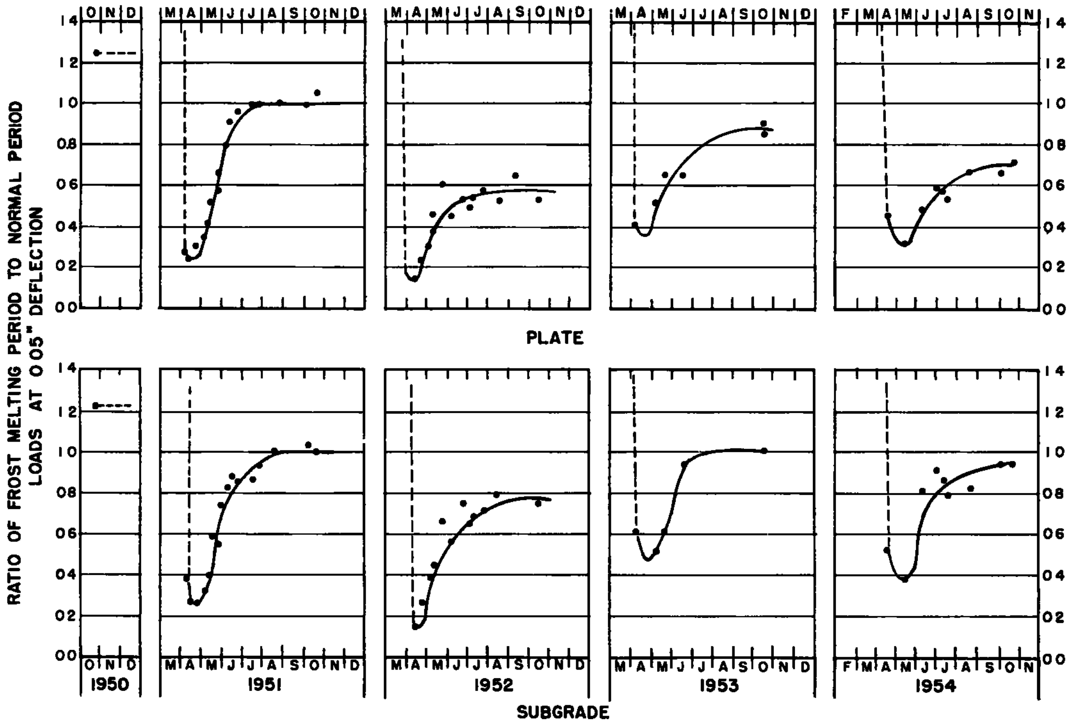

Figure 3. Static-load tests, 18-inch section. Note: all ratios based on 1951 normal period loads.

subgrade recorded when the rate of plate deflection became less than 0.004 inches per minute. A maximum load of 50,000 lb. was used regardless of deflection for the initial normal period static load tests of October 1950 due to difficulties with the anchorage of the loading beam. For all tests, thereafter, the plate was loaded to either a maximum of 60,000 lb. or to a deflection of 0.200 inches, whichever was attained first.

The procedure for conducting the repeating load tests was to subject the 30-inch-diameter plate to 30 loading cycles in a period of 15 minutes. A specified load was rapidly applied in one increment, 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 repetition of load. The permanent deflection was determined 10 minutes after the release of the repetition of loading. The following constant loads were selected for the various test sections:

Test Section Inches	Test Load per Repetition Pounds
7	10,000
12	15,000
18	30,000
24	50,000

Climatological Factors

During the investigational years, complete weather data were obtained from the Loring Air Force Base Weather Station at Limestone, Maine. Freezing indexes for the years 1950 through 1953 were 1,529, 1,926, 1,647 and 1,737 degree-days as compared to the ten year normal of 2,417 degree-days at the Caribou, Maine Weather Station located approximately 10 miles southwest of the test area. Differences in the seasonal average values of the other factors for the periods of test were so small that evaluation of each factor was not possible.

Results and Conclusions

In order to depict the seasonal changes in pavement supporting capacity, the ratios of frost melting period to normal (fall) period static loads required to deflect the bearing plate 0.05 inches are plotted against time. The repeating load tests are compared by plotting deflections under the 30th load repetition for each test series. A typical example of static load ratios for the four test sections is shown in Figure 2. The top plot illustrates the ratios based on deflections of the bearing plate (or pavement) and the lower plot shows the ratios based on deflections of the subgrade during 1951.

The ratios of frost melting period to normal period static load tests at the 18-inch base thickness section are summarized in Figure 3 for the investigational years from 1950 through 1954. These plots are typical of the ratios obtained at the other sections of the test area. The ratios for the various years shown thereon are based on the normal period loads required for 0.05 inches deflection during the fall of 1951.

It may be seen in Figure 3 that the load required to cause 0.05 deflection in the fall season progressively decreased from 1950 to 1952. The ground-water table in this period was controlled slightly below the subgrade surface. Allowing the ground water to seek its natural elevation and adding approximately an inch of pavement in the latter part of 1952 appears to have caused an increase in the 1953 normal static-period load ratios, which thereupon progressively decreased with succeeding years of study.

The plots also indicate that the loads required to cause 0.05 inch pavement or subgrade deflection at the time of maximum weakening ranged from 15 to 30 percent of loads required to cause 0.05 inch deflection during the normal period following a particular frost melting period. Furthermore, for the soil types and conditions existing at the test area, it appears that approximately 4 months are required for complete pavement recovery to normal supporting capacity. After reaching the maximum degree of weakening during the frost melting periods, strength recovery took place at a fairly rapid rate until the degree of pavement supporting capacity was approximately 10 percent below the normal value, then the recovery was quite gradual.

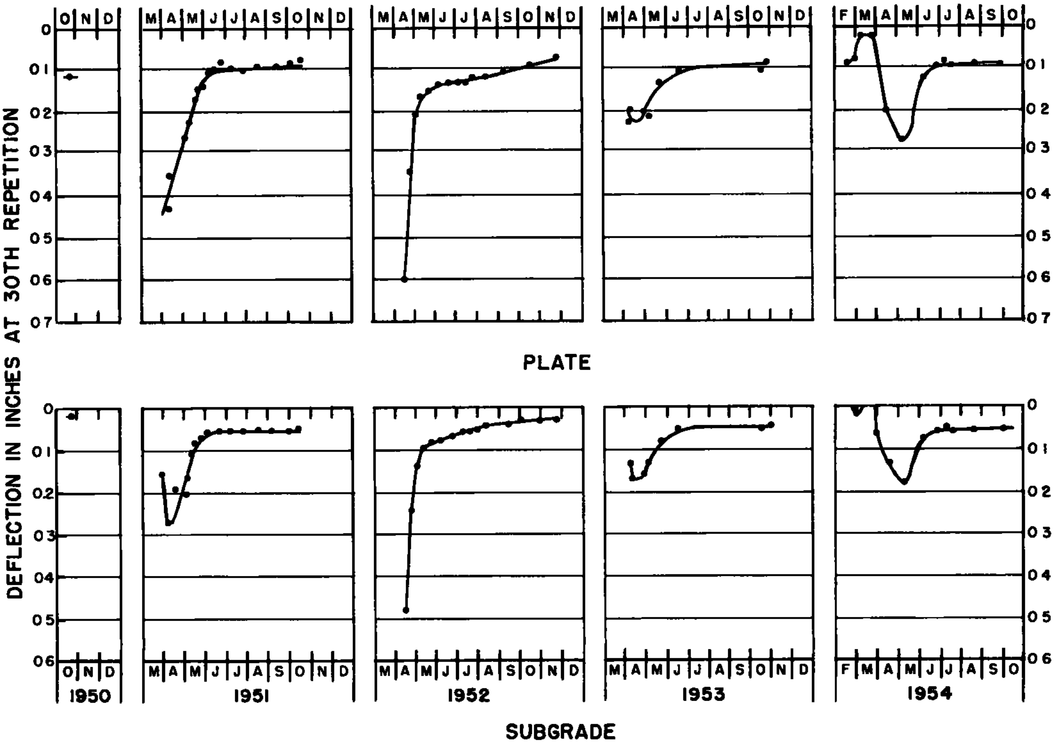

Figure 4. Repeating load tests, 18-inch section.

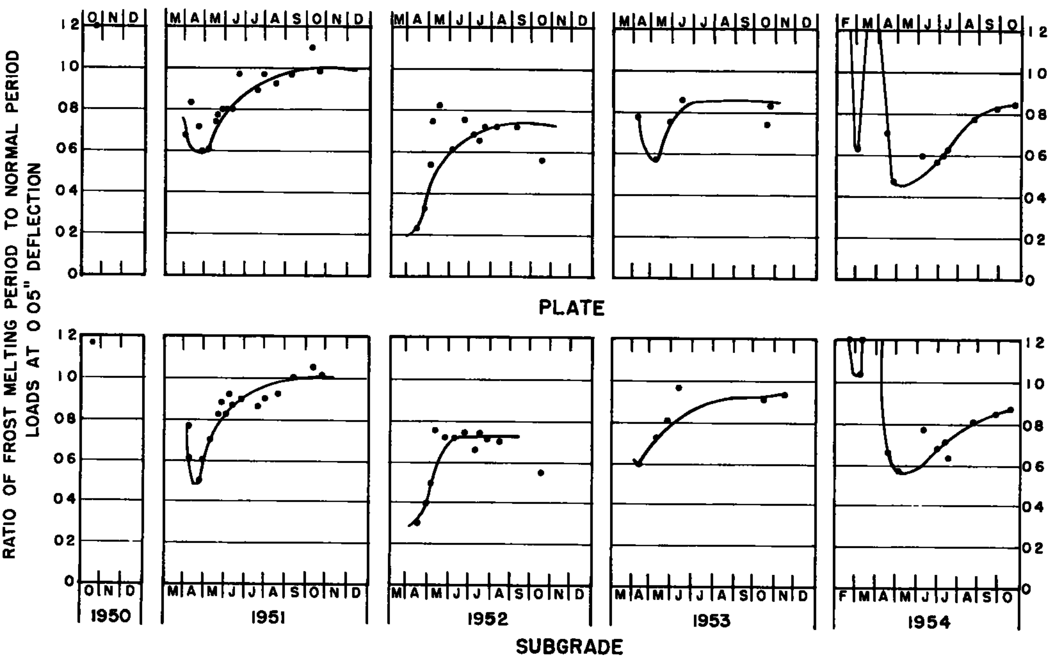

Figure 5. Static load tests preceded by repeating load tests, 18-inch section. Note: all ratios based on 1951 normal period loads.

Plots of the results of the repeating load tests at the 18-inch base thickness section shown on Figure 4 are typical of the results at the other sections. It was found that the pavement or subgrade deflections increase with increased number of repetitions up to 30 during the frost melting period but during the normal period increase in deflections was practically negligible after the first repetition of loading. The recovery of pavement supporting capacity is observed to be more rapid at repeating load test locations than at static load locations.

At locations where repeating load tests were followed by static load tests, it was found that the repeating load tests tended to consolidate the subgrade as shown on Figure 5 by the lesser deflections measured by static load tests at the 18-inch section for this test series as compared with the deflections obtained at the static load locations shown on Figure 3. The load required to cause 0.05 inch deflection in the normal period, however, similarly decreased progressively with succeeding years of tests. Approximately 50 to 60 percent reduction in the pavement supporting capacity of the static load test locations was noted at locations where static load tests were preceded by repeating load tests.

The results of the repeating load tests at the combined repeating load test and static load test locations at the 18-inch section, shown on Figure 6, indicate good agreement with the test results on Figure 4 for repeating load tests alone. These plots are typical of the results measured at the other sections of the test area.

The static and repeating-load plate-bearing test results indicate the magnitude and duration of subgrade weakening for the particular soil and loading conditions but do not necessarily provide a reliable measure of the reduction in the wheel load supporting capacity of pavements.

The consolidation of the subgrade soil by the repetitive loads in the repeating load tests apparently accelerated the rate of regain of subgrade strength as compared with the static load tests in which there was only one load application. Traffic, because of frequency of repetitions would also tend to consolidate and speed up the regain of subgrade strength. However, the traffic would possibly have a more adverse effect on the subgrade in its weakened condition during the frost melting period. The suddenly applied and short duration of the traffic load at a specific location would, for a saturated subgrade, result in a large increase in pore water stress with little or no increase in effective stress.

At the frost-test area, the major effect of repetitive loading appears to be consolidation as illustrated by the appreciably smaller loss of supporting capacity determined from the static-load tests at the combined repeating and static load test locations as compared to the static load test locations. The duration of loss in pavement supporting capacity determined by static load tests appears to be of the same length of time regardless of whether or not repeating load tests are performed at the location. All of the repeating load tests indicated a shorter duration or loss in pavement supporting capacity.

Reduction of normal period loads through succeeding years of test indicate that each year's freezing and thawing cycle has altered the structure of the glacial till subgrade at the frost-test area.

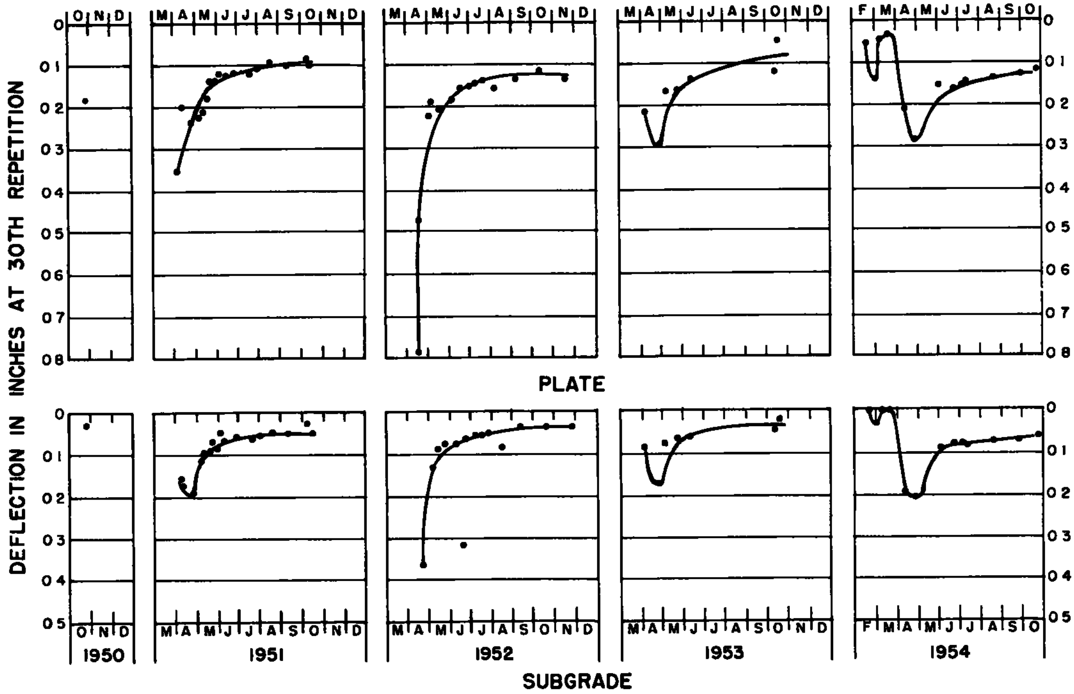

Figure 6. Repeating load tests followed by static load tests, 18-inch section.

Correlation of these data from the field studies with other frost investigational studies will result in more positive methods of determining the effects of frost action and the magnitude and duration of loss of pavement supporting capacity due to frost action. Also improved design and evaluation criteria will be developed resulting in improved and more dependable highway and airfield pavements.