this study, presupposes the generalities of any statements. With this in mind, the following conclusions have been drawn:

1. Soils and soil material in the A-3 class, consisting essentially of fine sands, when confined, show little loss of bearing power in the lower range of the contact pressures when subjected to freeze-thaw conditions. Little heaving occurs in these soils when subjected to freezing weather.
2. Silty materials, designated as A-4, appear to be the worst reactors; both in heaving characteristics and loss of bearing power.
3. Granular material, classified as A-1-a and A-1-b, show good support, especially for the lower contact pressures under conditions of freezing and thawing. Little heaving was measured when these soils were subjected to freezing weather.
4. Clayey soils and soil material exhibit varied reactions as to loss of bearing power under freeze-thaw conditions. In consideration of the relatively mild winter, these soils showed considerable heaving under freezing conditions.

Attention is called to the fact that this study is being continued through the coming winter (1950-51), when subsurface temperatures will be obtained and movements of plungers and slabs will be recorded.

The authors wish to express their appreciation to the New Jersey State Highway Department for encouraging and sponsoring this work, and to Rutgers University for use of the facilities in the College of Engineering.

INVESTIGATION OF THE EFFECT OF FROST ACTION ON PAVEMENT-SUPPORTING CAPACITY

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Synopsis

This paper presents studies made of the effect of frost action on pavement-supporting capacities as part of a comprehensive frost-investigation program initiated by the Corps of Engineers in 1944 to develop design and evaluation criteria for pavements constructed on subgrade soils subject to frost action. The studies described herein represent the first large-scale investigation directed toward the development of pavement design and evaluation criteria based on the weakened condition of thawed subgrade soils.

Investigations have been conducted at several airfield sites in the northern United States. Plate-bearing testa and in-place California-Bearing-Ratio tests have been performed during the normal and frost melting periods to determine the duration and magnitude of weakening due to melting of ice lenses. Accelerated traffic tests have been performed on both rigid and flexible pavements at four of the airfield sites during the frost-melting period, using wheel loads ranging from 7,000 to 60,000 lb.

Based on the results of these investigations, design curves and criteria have been established for the design and evaluation of flexible and rigid pavements on subgrades susceptible to frost action. Methods for recognizing conditions of soil, water, and temperature which are conducive to frost action and recommended design procedures, when frost conditions are encountered, are presented in Chapter 4, Part XII of the Engineering Manual entitled "Frost Conditions; Airfield Pavement Design" currently in use by the Corps of Engineers, U. S. Army.

The results of the traffic tests indicate that the design curves which have been developed by the Corps of Engineers for frost conditions, for both flexible and rigid pavements, provide adequate pavement design thicknesses to withstand the anticipated traffic with a margin of safety consistent with economical design.

During the extensive airfield-pavement evaluation program undertaken by the Corps of Engineers in 1943, the need for special pavement design and evaluation criteria which would take into account the loss in strength of subgrade soils in northern airfields during the frost-melting period became increasingly apparent. The Chief of Engineers therefore initiated a comprehensive program of frost investigations in the Spring of 1944, and the Frost Effects Laboratory of the New England Division was established and was assigned the responsibility of organizing and carrying out the investigations, under supervision of the Airfields Branch, Engineering Division, Military Construction, Office of the Chief of Engineers.

The purpose of the frost investigation program has been to provide test data and analyses to establish criteria and methods for the design and evaluation of airfield pavements where conditions are conducive to frost action, both in theaters of operation and in the United States.

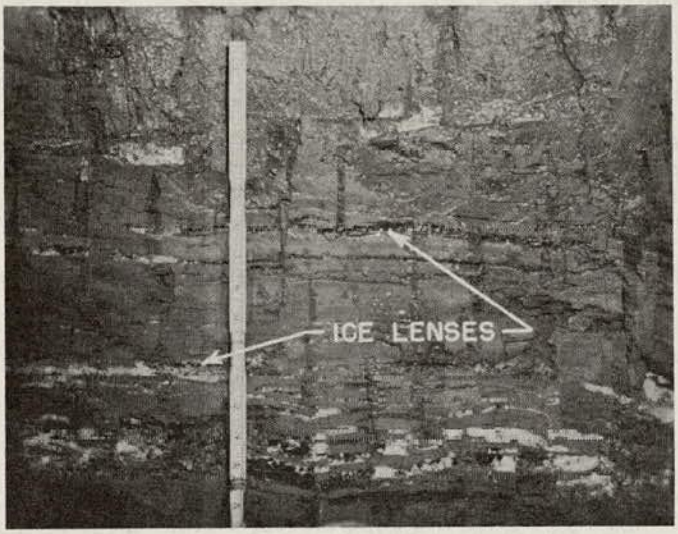

Figure 1. Ice Lens Formation in Cl Subgrade at Turfed Area - Dow Field, Bangor, Maine.

The results of the frost investigations have been published in detail in two previous reports: "Report on Frost Investigation 1944-1945," dated April 1947, and "Addendum No. 1, 1945-1947 to Report on Frost Investigation 1944-1945," dated October 1949. They contain results of investigations conducted during the fiscal years 1944 through 1947. A third major report has been prepared and will be published in the near future; it unifies and summarizes the principal results of observations and tests made and presents design and evaluation criteria for both airfield and highway pavements resulting from a study of the accumulated data.

Field investigations have been conducted at a total of 35 test areas at 17 airfields in the northern United States. The investigational sites were selected so as to encompass a wide range of the variables which influence frost action. At each test area explorations were made to determine classification of base and subgrade soils and surface and subsurface temperatures; ground-water elevations were measured throughout a number of freezing and thawing cycles. The soils were classified in accordance with the Airfield Soil Classification System shown on Table 1. The effects of frost action were observed by measuring pavement heave, determining changes in density and water content of the soils throughout the year, and observing the frost penetration and intensity of ice segregation in the subgrade soils by means of test pits (see Fig. 1). The data obtained in this manner were utilized to assist in establishment of criteria for recognizing soil types and ground-water conditions conducive to frost action and to correlate magnitude and duration of freezing temperatures with frost penetration. At several of the test areas, investigations were made of the reduction in strength of soils

TABLE 1
SOIL CLASSIFICATION FOR AIRFIELD PROJECTS

1		2	3	4	
MAJOR DIVISIONS		SOIL GROUPS & TYPICAL NAMES	GROUP SYMBOLS	GENERAL IDENTIFICATION	
				DRY STRENGTH	OTHER PERTINENT EXAMS.
COARSE GRAINED SOILS	Gravel and Gravelly Soils	Well Graded Gravel & Gravel-Sand Mixtures, Little or No Fines	GW	None	Gradation, Grain Shape
		Well Graded Gravel-Sand-Clay Mixtures, Excellent Binder	GC	Medium to High	Gradation, Grain Shape, Binder Exam. Wet & Dry
		Poorly Graded Gravel & Gravel-Sand Mixtures, Little or No Fines	GP	None	Gradation, Grain Shape
		Gravel with Fines, Very Silty Gravel, Clayey Gravel, Poorly Graded Gravel-Sand-Clay Mixtures	GF	Very Slight to High	Gradation, Grain Shape, Binder Exam. Wet & Dry
	Sands and Sandy Soils	Well Graded Sands & Gravelly Sands, Little or No Fines	SW	None	Gradation, Grain Shape
		Well Graded Sand-Clay Mixtures, Excellent Binder	SC	Medium to High	Gradation, Grain Shape Binder Exam. Wet & Dry
		Poorly Graded Sands, Little or No Fines	SP	None	Gradation, Grain Shape
		Sand with Fines, Very Silty Sands, Clayey Sands, Poorly Graded Sand-Clay Mixtures	SF	Very Slight to High	Gradation, Grain Shape, Binder Exam. Wet & Dry
FINE GRAINED SOILS Containing Little or No Coarse Grained Material	Fine Grained Soils Having Low to Medium Compressibility	Inorganic Silts & Very Fine Sands, Mo, Rock Flour, Silty or Clayey Fine Sands with Slight Plasticity	ML	Very Slight to Medium	Examination Wet (Shaking Test & Plasticity)
		Inorganic Clays of Low to Medium Plasticity, Sandy Clays, Silty Clays, Lean Clays	CL	Medium to High	Examination in Plastic Range
		Organic Silts & Organic Silt-Clays Of Low Plasticity	OL	Slight to Medium	Examination in Plastic Range, Odor
	Fine Grained Soils Having High Compressibility	Micaceous or Diatomaceous Fine Sandy & Silty Soils, Elastic Silts	MH	Very Slight to Medium	Examination Wet (Shaking Test & Plasticity)
		Inorganic Clays of High Plasticity, Fat Clays	CH	High	Examination in Plastic Range
		Organic Clays of Medium to High Plasticity	OH	High	Examination in Plastic Range, Odor
Fibrous Organic Soils with Very High Compressibility		Peat and Other Highly Organic Swamp Soils	Pt	Readily Identified	

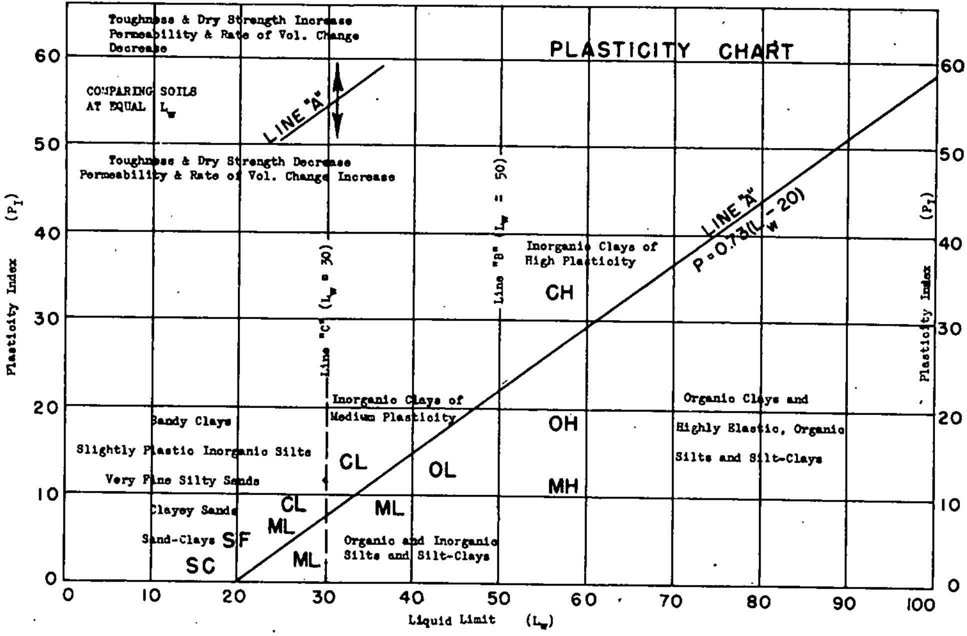

TABLE 1 (Cont'd)
SOIL CLASSIFICATION FOR AIRFIELD PROJECTS

1		5	6	7	8	9
MAJOR DIVISIONS		OBSERVATIONS AND TESTS RELATING TO MATERIAL IN PLACE	PRINCIPAL CLASSIFICATION TESTS (ON DISTURBED SAMPLES)	VALUE AS FOUNDATION WHEN NOT SUBJECT TO FROST ACTION	VALUE AS BASE DIRECTLY UNDER WEARING SURFACE	POTENTIAL FROST ACTION
COARSE GRAINED SOILS	Gravel and Gravelly Soils	Dry Unit Weight or Void Ratio, Degree of Compaction, Cementation, Durability of Grains, Stratification & Drainage Characteristics,	Mechanical Analysis	Excellent	Good to Excellent	None to Very Slight
			Mechanical Analysis, Liquid & Plastic Limits on Binder	Excellent	Fair to Excellent	Medium
			Mechanical Analysis	Good to Excellent	Poor to Good	None to Very Slight
			Mechanical Analysis, Liquid & Plastic Limits on Binder if Applicable	Good to Excellent	Poor to Good	Slight to Medium
	Sands and Sandy Soils	Ground Water Conditions, Traffic Tests, Large-Scale Load Tests or CBR Tests	Mechanical Analysis	Good to Excellent	Poor to Good	None to Very Slight
			Mechanical Analysis, Liquid & Plastic Limits on Binder	Good to Excellent	Poor to Good	Medium
			Mechanical Analysis	Fair to Good	Not Suitable	None to Very Slight
			Mechanical Analysis Liquid & Plastic Limits on Binder if Applicable	Fair to Good	Not Suitable	Slight to High
FINE GRAINED SOILS Containing Little or No Coarse Grained Material	Fine Grained Soils Having Low to Medium Compressibility	Dry, Unit Weight, Water Content & Void Ratio, Consistency - Undisturbed & Remolded, Stratification, Root Holes, Fissures, Etc., Drainage & Ground Water Conditions, Traffic Tests, Large Scale Load Tests, CBR Tests or Compression Tests	Mechanical Analysis, Liquid & Plastic Limits if Applicable	Fair to Poor	Not Suitable	Medium to Very High
			Liquid & Plastic Limits	Fair to Poor	Not Suitable	Medium to High
			Liquid & Plastic Limits From Natural Condition & After Oven Drying	Poor	Not Suitable	Medium to High
	Fine Grained Soils Having High Compressibility		Mechanical Analysis Liquid & Plastic Limits if Applicable	Poor	Not Suitable	Medium to Very High
			Liquid & Plastic Limits	Poor to Very Poor	Not Suitable	Medium
			Liquid & Plastic Limits From Natural Condition & After Oven Drying	Very Poor	Not Suitable	Medium
Fibrous Organic Soils with Very High Compressibility		Consistency, Texture and Natural Water Content		Extremely Poor	Not Suitable	Slight

NOTES: 1. Column 7, values are for subgrade and base courses except for base courses directly under wearing surface.

2. Values in Columns 7 and 8 are for guidance only. Design should be based on test results in accordance with text.

3. Unit weights in Column 13 are for soils with specific gravities ranging between 2.65 and 2.75.

4. In Column 12, the equipment listed will usually produce the required densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled. In some instances, several types of equipment are listed, because variable soil characteristics within a given soil group may require different equipment. In some instances, a combination of two types may be necessary.

a. Processed base materials and other angular materials. Steel wheeled rollers are recommended for hard angular materials with limited fines or screenings. Rubber tired equipment is recommended for softer materials subject to degradation.

b. Finishing. Rubber tired equipment as recommended for rolling during final shaping operations for most soils and processed materials.

c. Equipment size. The following sizes of equipment are necessary to assure the high densities required for airfield construction:

Crawler type tractor - total weight in excess of 30,000 pounds.

Rubber tired equipment - wheel load in excess of 15,000 pounds, wheel loads as high as 40,000 pounds may be necessary to obtain the required densities for some materials.

Sheepsfoot rollers - unit pressure (on 6 to 9 sq. in. foot) to be in excess of 350 pounds per square inch. Unit pressures as high as 700 pounds per square inch may be necessary to obtain the required densities for some materials.

LEGEND FOR GROUP SYMBOLS

G - Gravel
S - Sand
M - Mo. Very Fine Sand, Silt, Rock Flour
C - Clay
Pt - Peat
F - Fines, Matl <0.1mm
O - Organic
W - Well Graded
P - Poorly Graded
L - Low to Med. Compressibility
H - High Compressibility

Note:

The soil classification system shown on this table was used in classifying all soils during the frost investigations.

TABLE 1 (Cont'd)
SOIL CLASSIFICATION FOR AIRFIELD PROJECTS

1		10	11	12	13	14	15
MAJOR DIVISIONS		SHRINKAGE, EXPANSION, ELASTICITY	DRAINAGE CHARACTERISTICS	COMPACTION CHARACTERISTICS AND EQUIPMENT	SOLIDS AT OPT. COMPACTION LB. PER CU. FT. & VOID RATIO, e	CAL. BEARING RATIO FOR COMPACTED & SOAKED SPECIMEN	COMPARABLE GROUPS IN PUBLIC ROADS CLASSIFICATION
COARSE GRAINED SOILS	Gravel and Gravelly Soils	Almost None	Excellent	Excellent; crawler type tractor, rubber tired equipment, steel wheeled roller	>125 $e < 0.35$	>50	A-3
		Very Slight	Practically Impervious	Excellent; rubber tired equipment, sheepsfoot rollers	>130 $e < 0.30$	>40	A-1
		Almost None	Excellent	Good; crawler type tractor, rubber tired equipment, steel wheeled roller.	>115 $e < 0.45$	25-60	A-3
		Almost None to Slight	Fair to Practically Impervious	Good, close control essential; rubber tired equipment, sheepsfoot rollers.	>120 $e < 0.40$	>20	A-2
	Sands and Sandy Soils	Almost None	Excellent	Excellent; crawler type tractor, rubber tired equipment.	>120 $e < 0.40$	20-60	A-3
		Very Slight	Practically Impervious	Excellent; rubber tired equipment, sheepsfoot rollers	>125 $e < 0.35$	20-60	A-1
		Almost None	Excellent	Good, crawler type tractor, rubber tired equipment	>100 $e < 0.70$	10-30	A-3
		Almost None to Medium	Fair to Practically Impervious	Good, close control essential; rubber tired equipment, sheepsfoot rollers	>105 $e < 0.60$	8-30	A-2
FINE GRAINED SOILS Containing Little or No Coarse Grained Material	Fine Grained Soils Having Low to Medium Compressibility	Slight to Medium	Fair to Poor	Good to poor, close control essential; rubber tired equipment, sheepsfoot rollers	>100 $e < 0.70$	6-25	A-4 A-6 A-7
		Medium	Practically Impervious	Excellent; rubber tired equipment, sheepsfoot rollers	>100 $e < 0.70$	4-15	A-4 A-6 A-7
		Medium to High	Poor	Poor to good; rubber tired equipment, sheepsfoot rollers	> 90 $e < 0.90$	3-8	A-4 A-7
	Fine Grained Soils Having High Compressibility	High	Fair to Poor	Poor to very poor; sheepsfoot rollers.	<100 $e > 0.70$	<7	A-5
		High	Practically Impervious	Poor to good; sheepsfoot rollers.	> 90 $e < 0.90$	<6	A-6 A-7
		High	Practically Impervious	Very poor to fair; sheepsfoot rollers.	<100 $e > 0.70$	<4	A-7 A-8
Fibrous Organic Soils with Very High Compressibility		Very High	Fair to Poor	Compaction Not Practical			A-8

due to frost action and the effect of the reduction on pavement supporting capacity. Theoretical and cold-room studies of frost problems were also made.

The present paper is devoted to a summary of results of California Bearing Ratio, plate bearing, and traffic tests performed to measure the reduction in pavement supporting capacity resulting from frost action.

Previous Studies of Frost Action

Prior to undertaking the test program of the investigation, the results obtained by previous frost investigators were reviewed. The information secured from the available literature on frost action influenced the general development of laboratory and field investigational procedures.

Some early investigators attributed the expansion in volume of a soil mass to the expansion of the water originally contained in the soil voids. However, the expansion of the soil mass upon freezing would be only of the order of 3 percent if the total volume of a saturated soil was one-third water, whereas as great as 60 percent expansion in volume of soils due to freezing was reliably recorded. Observations also revealed an accumulation of layers or lenses of ice in some soils upon freezing. As a result, several investigators endeavored to study the physical phenomena of frost action. These studies were pioneered principally by Stephen Taber (1, 2, 3). University of South

Carolina, starting 1914, when his experiments in the field under natural freezing conditions showed that frost heaving was due to the growth of segregated ice in the soil, and that freezing soils draw water to the zone of ice-lense formation from outside sources.

From the results of extensive laboratory investigations commenced in 1927. Taber (4 to 7 inclusive) developed a hypothesis which he summarized on p. 173 in reference (7) as follows:

"Frost heaving is due to the growth of ice crystals and not to change in volume of water on freezing. Pressure is developed in the direction of crystal growth, which is usually determined chiefly by the direction of cooling. Excessive heaving results when water is pulled up through the soil to build up layers of lenticular masses of segregated ice, which grow in thickness because water molecules are pulled into the thin film that separates the growing columnar ice crystals from the underlying soil particles."

Field and laboratory investigations by Casagrande (8), Beskow (9), Winn and Rutledge (10), and others have essentially confirmed Taber's explanation of the physical phenomena of frost action in soils.

A considerable amount of literature exists concerning the effect of frost action on highway pavements, reported principally by state highway departments. Numerous instances are recorded of extensive highway damage caused by frost heaving, frost boils, and highway breakup. The frost boils, as referred to by highway engineers, are caused by a rapid thawing of an area of severe frost action beneath a flexible pavement. Such thawing occurs largely from the surface down and the excess water liberated from the thawed area is prevented from draining downward by the still-frozen underlying soil and ice layers. The excess water causes the thawed soil to become exceedingly soft. Likewise the pumping of water from joints in concrete slabs during the spring may be the result of excess water in the subgrade liberated from thawed ice layers.

Definitions

Description of the tests and analysis of results involve specialized use of certain terms and words. Definitions of these words and terms as used in this paper are:

Frost action is a general term used in reference to freezing of moisture in materials and the resultant effects on these materials and 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 penetration is the maximum depth from the surface to the bottom of the frozen zone.

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.

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 percent 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 percent 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. Cold room tests now in progress in the Frost Effects Laboratory are expected to result in improved knowledge concerning limits between frost susceptible and non-frost susceptible soils.)

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.

Traffic lane is the area of the pavement subjected to controlled test traffic, usually that portion of the test section over which one set of traffic equipment wheels pass.

Coverage is one application of the wheel load over each point in a traffic lane.

Equipment pass is one movement of the traffic equipment along the traffic lane; synonymous with "trip."

Acknowledgements

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Colonel H. J. Woodbury is the division engineer, New England Division, Corps of Engineers, U. S. Army. John E. Allen is Chief of the Engineering Division, to which the Frost Effects Laboratory is attached. The work was initiated and carried out during the period 1944-1946 under the direct supervision of William L. Shannon, then chief of the Frost Effects Laboratory. In 1946 Shannon was succeeded by the late Ralph Hansen. Acknowledgement is made of the contributions of numerous other personnel of the Frost Effects Laboratory during the period since 1944 in supervising field investigations and in preparing data and analyzing results.

The program was also assisted by personnel of the Great Lakes and Missouri River Divisions of the Corps of Engineers.

Dr. Arthur Casagrande of Harvard University and Dr. Philip C. Rutledge of Northwestern University were consultants on the investigation.

Weather data used were provided by the U. S. Weather Bureau, Department of Commerce. Assistance in performance of tests was received from U. S. Air Force and installations officers at the various test locations.

Effect of Frost Action on Supporting Capacity of Flexible Pavements

The supporting capacity of flexible pavements was investigated by means of in-place California Bearing-Ratio and plate-bearing tests conducted during the normal period and the frost-melting period and by traffic tests conducted during and after the frost melting period.

California Bearing-Ratio Tests

The field-test procedures for the CBR tests were as outlined in Chapter XX, Paragraph 20-18d, "CBR Tests on Soils in Place," U. S. Army, Corps of Engineers, Engineering Manual (March 1943).

In-place CBR tests were conducted on top of the base materials and the subgrade at a total of nine flexible-paved test areas. The tests were performed during the normal period in the fall of 1944 and repeated in the frost-melting period in the spring of 1945. The average CBR values for the normal period, in the summer and fall of 1944, and for the frost-melting period in the spring of 1945, generally showed a reduction in strength in both the frost susceptible base materials and frost susceptible subgrades. The results at these test areas are compared in the tabulation in the following page.

At the majority of the test areas the reductions in CBR values during frost melting are consistent with the intensity of ice segregation experienced in the materials tested. At Pierre the CBR tests were conducted in a portion of the test area which showed slight subsidence and no ice segregation. No ice lenses were observed at Casper while at Bismarck a few scattered lenses of hairline thickness were observed.

Plate Bearing Tests

The plate-bearing tests were of two types: static and repeating-load tests.

The static plate-bearing tests were conducted in the manner outlined in Chapter XX, Paragraph 20-41, Engineering Manual (March 1943) except that the 30-in. -diameter plate was placed directly on top of the bituminous concrete pavement. Loads were

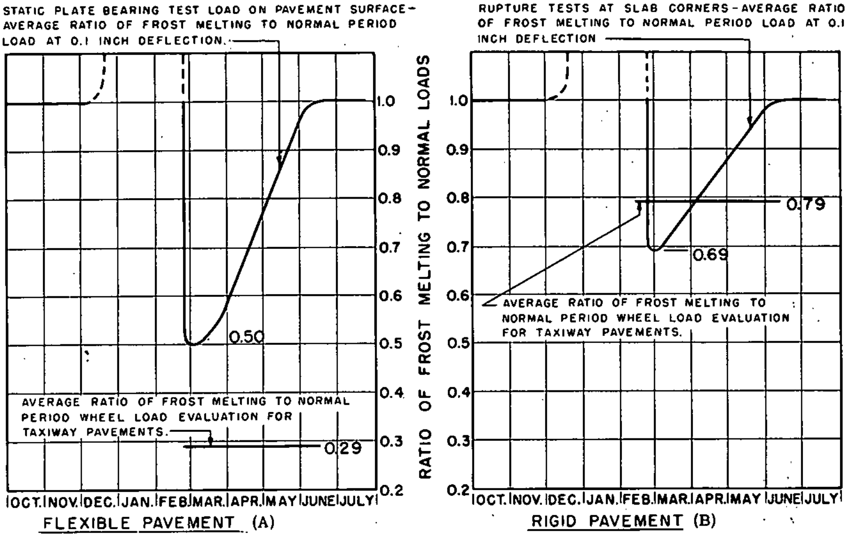
Site	Test Area	Material	Average CBR Normal Period	 Frost Melting Period
Otis Field, Camp Edwards, Massachusetts	A	ML Subgrade (GP and SP)	44	18
Truax Field, Madison, Wisconsin	A	GF Subbase	64	33
		CL Subgrade	4	2
Truax Field, Madison, Wisconsin	B	GF Subbase	41	31
		CL Subgrade	5	3
Watertown Airfield, Watertown, South Dakota	A	GF-SF Base	37	27
		OL-CL Subgrade	12	8
Pierre Airfield, Pierre, S. Dakota	B	GF Base	30	30
		CL Subgrade	12	16
Sioux Falls, Airfield Sioux Falls, South Dakota	A	GC Base	37	14
		CL Subbase	16	6
		CL-CH Subgrade	10	5
Fargo Municipal Airfield, North Dakota	A	CL-SF Subbase	15	8
		OH-CH Subgrade	7	5
Casper Air Base, Casper, Wyoming	B	GW Base	58	28
		SF-CL Subgrade	27	21
Bismarck Airfield, Bismarck, North Dakota	A	GF Base	24	21
		SF-ML Subgrade	24	18

applied to the plate in approximately five or six equal increments to a load in excess of the proportional limit or to the maximum permitted by the test equipment. Each increment was held constant until the rate of plate deflection was negligible.

The repeating-load tests used the same type and arrangement of testing apparatus as employed for the static-load tests, except that a 24-in. diameter plate was used on top of the bituminous pavement. A seating load of 3,500 lb. was applied for 5 min. and released. A load of 20,000 lb. was then rapidly applied in one increment. The load was maintained for 10 min. during which the deformation was measured at the end of 1/4, 1, 2-1/4, 6-1/4, and 10 min. The load was rapidly released, and deformation readings were taken at the end of a 5-min. period. The loading procedure was then repeated until ten load repetitions had been made. A 19-in. -diameter plate was used instead of a 24-in. -diameter plate during the normal period in the 1943-1944 investigations at Dow Field.

Static and repeating-load tests were performed at Dow, Presque Isle, Traux, Pierre, and Sioux Falls airfields during the fall and during and after the frost-melting period, in various years in the period from 1943 through 1947.

The results of the static-load tests performed on top of flexible pavements with the 30-in. -diameter plate, at areas where tests were carried out during both normal and frost melting periods, and covering all investigational years, are summarized on Table 2. The normal-period loads for 0.1-in. deflection tabulated in column 11 of the table are the averages of all tests performed between September 1 and the start of the freezing period. The frost melting period loads shown in column 12 are the average loads at 0.1-in. deflection of all tests performed during the two-week period in which the pavement showed minimum strength. Since the load-test data did not reveal any significant yearly variations in normal period results or frost-melting period results, the data were grouped to give more representative values. Column 13 shows the ratios between the frost melting period and normal period static load test values.



REDUCTION IN PAVEMENT SUPPORTING CAPACITY

NOTES:-

Curves based on static load tests from nine flexible paved test areas and from rupture tests on six rigid paved test areas at six airfields (Reference Tables 2 and 3).

Single wheel load evaluations (100psi tire pressure) for normal period based on airfield pavement design curves dated 13 June 1950 and evaluations for frost melting period using frost design curves dated 15 August 1950.

Figure 2.

Wheel-load evaluations for both normal and frost-melting periods and their ratios were determined for each test area included on Table 2, as shown in the last three columns. The normal period evaluations were based on in-place CBR test results in the flexible-pavement design curves for single-wheel loads with 100-psi. tire pressure and frost-melting period evaluations on frost-condition design curves currently in use.

The average of the ratios of frost-melting to normal-period static test loads for 0.1-in. plate deflections for the nine test areas shown on Table 2 is 0.50. The ratios of the frost condition to the normal-period wheel-load evaluations for these same pavements are consistently lower than the static-load ratios and average 0.29. These ratios are also shown on Figure 2(A), which presents a plot of the duration and magnitude of pavement weakening as determined by averaging the static-load test results from all the test areas. These results indicate that the reduction in pavement-supporting capacity due to frost melting as determined from static-load tests is considerably less than the reduction that is allowed for by the frost-condition design criteria for wheel-load traffic.

Since the normal-period design criteria are based on a large number of traffic tests and CBR tests and have been proven by satisfactory pavement performance after several years of traffic usage, the normal-period wheel-load evaluations shown in Table 2 are not considered to be excessive. Further, the results of traffic tests, presented

TABLE 2

SUMMARY OF STATIC LOAD TESTS ON SURFACE OF FLEXIBLE PAVEMENTS

Site	Test Area	Pavement Thickness (inches)	Base			Subgrade			Frost Penetration (feet)	Static Load Tests Load at 0.1 in. Deflection			Design Wheel Load		
			Classification	Thickness (inches)	Percent Finer than 0.02 mm.	Classification	Percent Finer than 0.02 mm.	Normal CBR		Normal Period	Frost Melting Period	Ratio Loads FM/N	Normal Period	Frost Melting Period	Ratio Design FM/N
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Dow	B	4.0	GW	27	3-6	CL	40-97	8	4.3	34,000 (4)	17,000 (3)	.50	80,000	27,000	.34
		3.5	"	40	"	"	"	"	4.3	41,500 (2)	26,000 (1)	.62	150,000	48,000	.32
	I & III	4.0	"	16	"	"	"	"	4.0	34,000 (3)	15,500 (2)	.42	33,000	11,000	.33
	C	4.0	"	43	"	"	"	"	4.7	44,000 (4)	26,000 (3)	.59	150,000	57,000	.38
		3.5	"	32	"	"	"	"	4.7	34,000 (1)	17,000 (1)	.50	106,000	33,000	.31
Presque Isle	C	4.5	Cr. Rock	3	-	GC	10-40	10	6.2	60,000 (1)	32,000 (4)	.53	108,000	27,000	.25
			GW	24	0-6										
	D	4.0	Cr. Rock	3	-	GC	"	"	5.8	49,000 (3)	24,000 (9)	.49	108,000	28,000	.26
			GW	24	0-6										
Truax	A	2.5	Cr. Rock	8	-	CL	60-80	5	3.9	36,000 (2)	14,000 (2)	.39	32,000	7,000	.22
			GF	16	10-20	SF	7								
	B	2.5	Cr. Rock	19	-	CL	60-80	4	4.9	51,500 (5)	24,000 (7)	.47	73,000	26,000	.36
			GF	23	10-20	SF	7								
Pierre	B	1.5	GF	12	6-14	CL	30-58	13	3.7	42,000 (1)	17,500 (7)	.37	27,000	5,500	.20
		6.0	GF	9	"	"	"	"	3.7	69,500 (1)	38,000 (8)	.55	35,000	6,500	.19
Sioux Falls	A	2.0	GC	10	6-12	CL (Subbase)	35-48	10	3.7	23,500 (1)	12,500 (3)	.53	14,000	4,000	.29
												Avg = .50			Avg = .29

NOTE: Design wheel loads for normal period were determined from the Flexible Pavement Design Curves (single wheel load, 100 psi. tire pressure) dated 13 June 1950.

Design wheel loads for frost conditions were determined from the Frost Design Curves dated 15 August 1950. The GF subbase material at Truax was frost susceptible and was considered to control frost condition design.

Figures in parentheses indicate number of tests used in computing the average loads at 0.10 inch deflection.

LEGEND: N - Normal Period
FM - Frost Melting Period

later in this paper, and service behavior studies of existing pavements demonstrate that the frost condition design criteria are not excessively conservative and have a margin of safety consistent with the duration of weakening. It is therefore believed that the degree of reduction in wheel-load supporting capacity of flexible pavements due to frost action as indicated by the design criteria for the normal and frost melting periods is essentially correct.

On the other hand, the static-load tests do not give a correct measure of the relative traffic-supporting capacity during the frost-melting period. The loss of pavement strength as measured by these static-load tests is not analogous to traffic loading for two reasons: (1) the gradually applied load used in the tests allows escape of water, consolidation, and build up of resistance in the subgrade soils, which influences to a great extent the frost-melting-period test results; and (2) the static-load tests do not reflect the weakening due to subgrade remolding under repetitive loading such as the pavement is subjected to under traffic usage. This remolding is particularly critical during the frost-melting period when excess or segregated water is available in the subgrade.

A measure of the duration of subgrade weakening is provided by the results of the plate-bearing tests, as is shown in Figures 3 through 12. Figures 3 through 9 present plots of repeating-load test results at Presque Isle, Truax, Dow, and Sioux Falls airfields. Figures 10 through 12 present results of static-load tests for Presque Isle, Truax, and Dow airfields for all investigational years, showing the ratio of frost-melting period load to normal-period load to produce 0. 1-in. deflection. The average penetrations of frost into the subgrade soils at the three sites covered in the latter three figures were: 3. 1 ft. at Presque Isle; 1. 5 ft. at Truax; and 1. 8 ft. at Dow. Based on the trend of static-plate-bearing-test data presented in Figures 10 through 12, the period required for the pavement to return from approximately 50 percent to 80 percent of normal strength was three months at Presque Isle, one and one-half months at Truax, and two months at Dow Field. Thus, the duration was approximately proportional to the depth of frozen subgrade at the three sites. The short time required to regain strength at Truax is also probably influenced by a fine-sand stratum underlying the silty clay, CL, subgrade.

A study of the plate-bearing-test data for all investigational years was made to determine the relationship between loads at deflections of 0. 05, 0. 1 and 0. 2-in. Plots showing the relationships between loads at 0. 1-in. deflection and 0. 2-in. deflection and between loads at 0. 05-in. deflection and 0. 2-in. deflection for the individual plate bearing tests are shown on Figure 13. These plots indicate that within the ranges of deflections analyzed the same relationship exists between loads for any two specific deflections during the normal as during the frost melting period.

Traffic Tests

Traffic tests were conducted on five flexible paved test areas at Dow, Truax, and Pierre airfields using wheel loads selected to bracket or approximate the evaluation of the specific pavements for frost-melting conditions. The equipment to obtain the various loads ranged from trucks to large, rubber-tired construction equipment. The application of traffic was made on the basis of a specified number of daily coverages during and after the frost-melting period to simulate continuous use of a pavement by aircraft. Based upon the best available information it was assumed that 15 coverages per day was equivalent to maximum runway use and 45 coverages per day was equivalent to maximum taxiway use. In all cases it was not possible with the available equipment to apply exactly 15 and 45 coverages; therefore, individual tests varied in the number of daily coverages. Traffic was started at the beginning of the frost-melting period and continued through the frost-melting period or until imminent failure had occurred. Measurements of the vertical deformation in the traffic test areas and observations of the behavior of the pavement were made daily. At the end of the traffic tests detailed measurements were made of the pavement surface and trenches were excavated in traffic test areas to observe and measure the relative positions and condition of the pave-

TABLE 3

SUMMARY OF RUPTURE TESTS ON RIGID PAVEMENT SLAB CORNERS

Site	Test Area	Pavement Thickness (inches)	Base			Subgrade		Frost Pen. (ft.)	Static Load Tests Load at 0.1 in. Deflection			Flex. Strength of Conc. (psi.)	Design Wheel Load				
			Classification	Thickness (inches)	Percent Finer than 0.02 mm.	Classification	Percent Finer than 0.02 mm.		Normal Period	Frost Melting Period	Ratio Loads FM/N		Normal Period		Frost Melting Period		Ratio Design FM/N
													Sub. Mod.	Load lb.	Sub. Mod.	Load lb.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
								1944 - 1945									
Dow	A	7.0	GW	13	3-6	CL	40-97	4.1	50,000 (2)	28,000 (2)	0.56	600	315	16,000	75	11,000	-
Truax	C	6.0	GF	40	10-20	CL	60-80	4.6	86,000 (1)	55,000 (5)	0.65	750	250	14,000	60	11,000	.79
								1945 - 1946									
Dow	F	7.0	GW	22.5	3-6	CL	40-97	4.5	40,000 (1)	27,000 (1)	0.67	600	315	16,000	120	12,000	.75
Presque Isle	A	8.0	GW	32	0-6	GC	10-40	5.8	60,000 (1)	47,000 (3)	0.78	690	340	27,000	170	21,000	.78
Truax	C	7.0	GF	39	10-20	CL	60-80	4.0	84,000 (1)	48,000 (1)	0.57	750	250	20,000	60	14,000	.70
	C	6.0	GF	53	10-20	CL	60-80	4.0	71,000 (1)	43,000 (2)	0.61	750	250	14,000	60	11,000	.79
Selfridge	A	11.0	GF	8	3	ML SF	34 20	2.9	85,000 (1)	61,500 (3)	0.72	735	165	50,000	55	39,000	.78
Pierre	A	7.0	GF	7	6-14	CL	30-58	4.0	44,000 (2)	37,000 (2)	0.84	700	120	15,000	55	13,000	.87
Sioux Falls	A	6.0	-	-	-	CH	55-83	3.5	35,000 (2)	28,000 (2)	0.80	675	48	9,000	30	8,000	.89
								1946 - 1947									
Dow	F	8.0	GW	19	3-6	CL	40-97	3.7	42,000 (3)	28,500 (2)	0.68	600	315	22,000	110	16,000	-
											Avg.=.69						Avg.=.79

NOTE: Design wheel loads for normal period were determined from the Rigid Pavement Design Curves (single wheel load, 100 psi. tire pressure) dated 13 June 1950.

Design wheel loads for frost conditions were determined from the Rigid Pavement Design Curves (single wheel loads, 100 psi. tire pressure) dated 13 June 1950, using subgrade moduli obtained from Frost Design Curves dated 15 August 1950. The GF base material at Truax was frost susceptible and was considered to control the design.

Figures in parentheses indicate number of tests used in computing the average loads at 0.10 inch deflection.

LEGEND: N - Normal Period
FM - Frost Melting Period

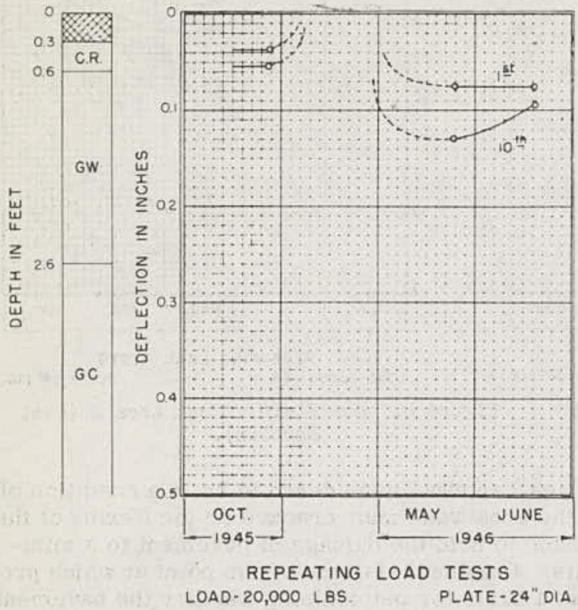


Figure 3. Presque Isle Airfield - Test Area C.

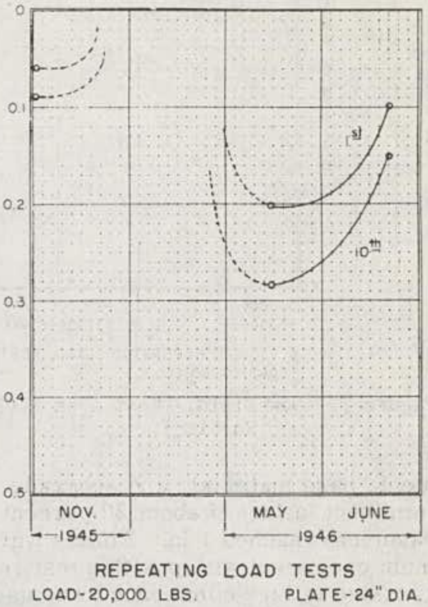


Figure 4. Presque Isle Airfield. Test Area D.

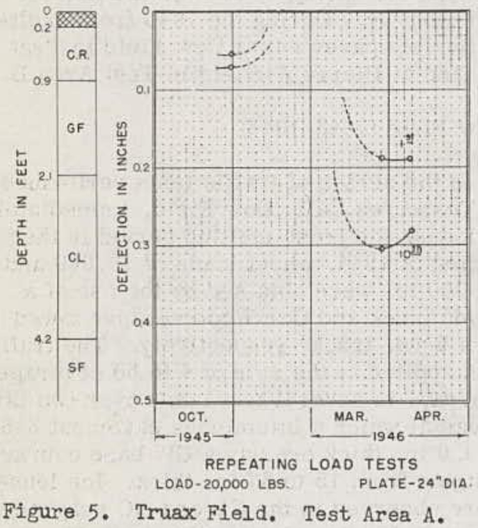


Figure 5. Truax Field. Test Area A.

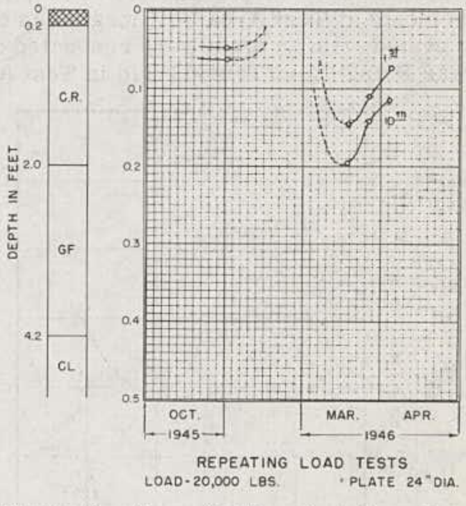


Figure 6. Truax Field. Test Area B.

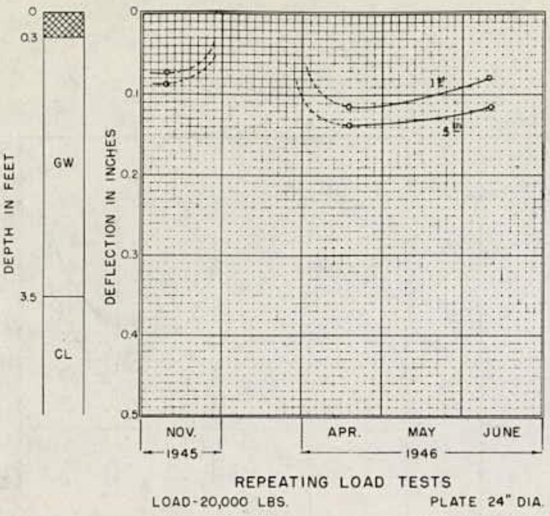


Figure 7. Dow Field. Test Area B (East Portion).

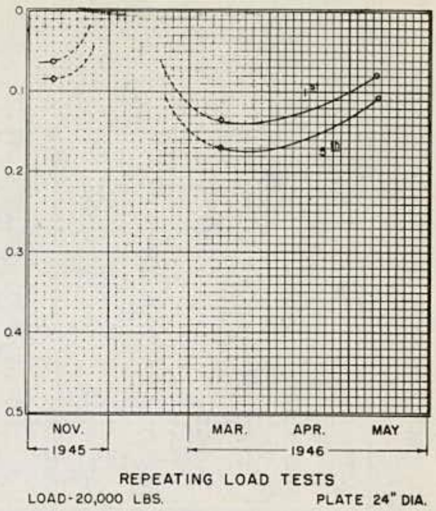


Figure 8. Dow Field. Test Area B (West Portion).

ment, base material, and subgrade. A test lane was considered to be in a condition of imminent failure if about 20 percent of the area was map-cracked or the flexing of the pavement reached 1 in. Efforts were made to hold the damage of pavement to a minimum consistent with positive test results. Imminent failure or the point at which progressive failure commenced was used as a basis for determining whether the pavement was satisfactory or unsatisfactory rather than complete failure which would leave the pavement impassable.

Traffic tests were conducted at Dow Field during the spring of 1944 on the flexible pavements at Test Area I-III located on the E-W Runway. During the 1945 frost-melting period, traffic tests were conducted on the flexible pavement at Dow Field in Test Areas B and C, at Truax Field in Test Area B, and at Pierre Airfield in Test Area B.

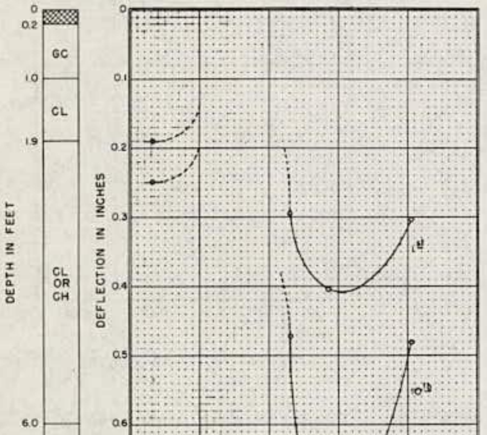


Figure 9. Sioux Falls Airfield. Test Area A.

Dow Field (1943-1944)

In the series of traffic tests performed at Test Area I-III, Dow Field, immediately following the frost-melting period in the spring of 1944, wheel loads of 10,000 and 20,000 lb. were obtained by the use of a 5-yd. truck and Gar Wood scraper towed by a 5-yd. truck, respectively. The traffic was applied at the rate of 4 to 50 coverages per day, to several test lanes over two large areas at which a bituminous pavement 3.5 to 4.0 in. thick overlay a GW base course ranging from 15 to 37 in. thick. Ice lenses were observed in the CL and GC subgrade soils during the winter prior to traffic test and were of hairline thickness near the top of the subgrade and increased to an average of 1/4-in. in thickness near the depth of maximum frost penetration which was generally about 2 ft. below the subgrade surface. The pavement heave in the test areas ranged from 0.00 to a maximum of 0.40 ft.

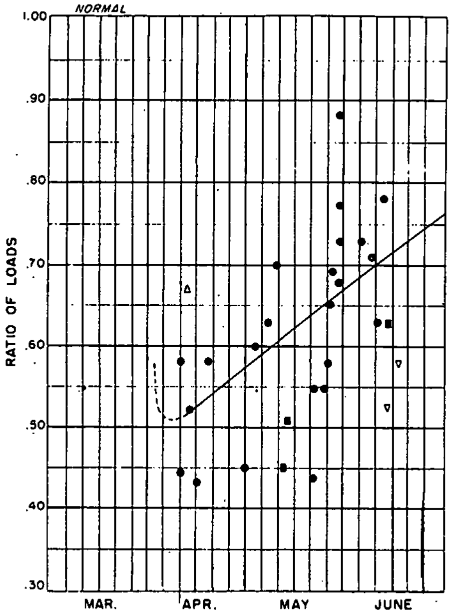


Figure 10. Presque Isle Airfield. 1944-1946.

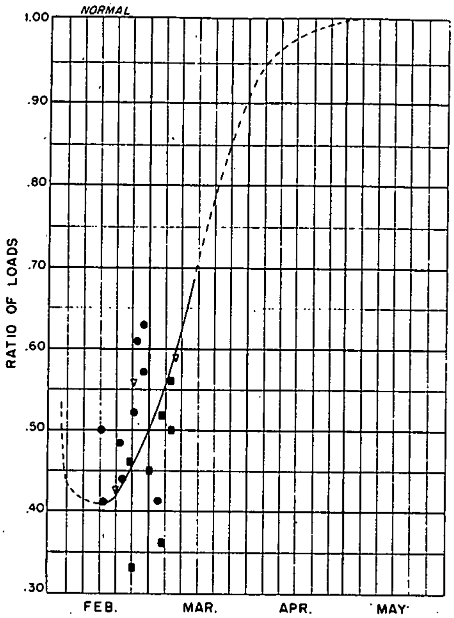


Figure 11. Truax Field. 1944-1946.

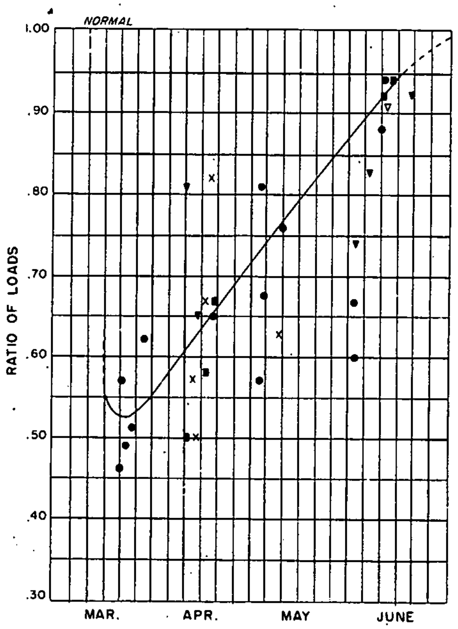


Figure 12. Dow Field. 1943-1947.

NOTES:

All repeating load tests performed on surface of bituminous pavement.

Figures 1 through 7 show the plate deflections, with the load on the loading plate, after the load repetition denoted adjacent to the curves.

Figures 8 through 10 show ratio of frost melting period load to normal period load at 0.1 inch deflection for static load test on flexible pavement surface, and foundation modulus tests on surface of base.

LEGEND:

x 1943-1944 (Static Load Tests)
● 1944-1945 " " "
■ 1945-1946 " " "
Δ 1944-1945 Foundation Modulus Tests
∇ 1945-1946 " " "
▼ 1946-1947 " " "
C.R. Crushed rock
▨ Bituminous pavement

TABLE 4. FROST INVESTIGATION 1944-1947
SUMMARY OF TRAFFIC TESTS

LINE	AIRFIELD	PAVEMENT TYPE AND THICKNESS (INCHES)	BASE				
			CLASS. AND THICKNESS (INCHES)	%FINER THAN 0.02 mm.	ICE SEGREGATION	K OR C.B.R. (IN PLACE)	
						NORMAL PERIOD	FROST MELT. PERIOD
1	Dow	B.C. 4.0	GW 15	3-5	None Observed	∞	-
2	(1943-44)	B.C. 4.0	GW 15		" "		-
3		B.C. 4.0	GW 15		" "		-
4		B.C. 4.0	GW 15		" "		-
5		B.C. 4.0	GW 15		" "		-
6		B.C. 4.0	GW 18		" "		-
7		B.C. 4.0	GW 18		" "		-
8		B.C. 4.0	GW 23		" "		-
9		B.C. 3.5	GW 30		" "		-
10		B.C. 3.5	GW 30		" "		-
11		B.C. 3.5	GW 36		" "		-
12		B.C. 3.5	GW 37		" "		-
13		B.C. 3.5	GW 19		None Observed		-
14		B.C. 3.5	GW 19		" "		-
15	(1944-45)	B.C. 4.0	GW 25-38		Crystals Throughout		-
16		B.C. 3.5	GW 34		" "		-
17		B.C. 5.0	GW 21		" "		-
18		B.C. 4.0	GW 25		" "		-
19		B.C. 3.5	GW 29-40		" "		-
20		B.C. 3.5	GW 28-51		" "		-
21		B.C. 3.5	GW 32-42		" "		-
22(a)		Bit.Tr.1.0	GW 20		No Data		-
23		Bit.Tr.1.0	GW 16-24		" "		-
24		Bit.Tr.1.0	GW 20		" "		-
25		B.C. 3.5	GW 21-30		Crystals Throughout		-
26		B.C. 3.5	GW 43-48		" "		-
27		B.C. 3.5	GW 44		" "		-
28		B.C. 3.5	GW 44-51		" "		-
29		Bit.Tr.1.0	GW 23		No Data		-
30	Truax	B.C. 2.5	Cr. Rock 19	-	Crystals in Cr. Rock	41 (GF)	31
31	(1944-45)	B.C. 2.5	GF 24	10-20	Few Hl. Lenses in GF	41	31
32		B.C. 2.0	CR. Rock 24	-	Crystals in Cr. Rock	41 (GF)	31
33		B.C. 2.0	GF 24	10-20	Few Hl. Lenses in GF	41	31
34	Pierre	B.C. 7.0	GF 6 Blended Cl Sub-base 6'	GF 6-14 CL 30-58	Few Crystals in Base and Sub-base	30	30
35	(1944-45)	B.C. 3.5	GF 8			30	30
36		B.C. 2.0	GF 12			30	30
37		B.C. 6.0	GF 9		Few Crystals in Base and Sub-base	30	30
38		B.C. 7.0	GF 7			30	30
39		B.C. 2.5	GF 12			30	30
40		B.C. 2.5	GF 11			30	30
41		B.C. 7.0	GF 8		Few Crystals in Base and Sub-base	30	30
42		B.C. 6.0	GF 8			30	30
43		B.C. 2.5	GF 13			30	30
44		B.C. 2.5	GF 12			30	30
45		B.C. 2.5	GF 9.5			30	30
46	Dow	P.C.C. 7.0	GW 16	3-5	None Observed	315	-
47	(1943-44)	P.C.C. 7.0	GW 15		" "	315	-
48		P.C.C. 7.0	GW 17		" "	315	-
49		P.C.C. 7.0	GW 17		" "	315	-
50		P.C.C. 7.0	GW 14		" "	315	-
51		P.C.C. 7.0	GW 14.5		None Observed	315	-
52		P.C.C. 7.0	GW 14.5		" "	315	-
53		P.C.C. 7.0	GW 18		" "	315	-
54		P.C.C. 7.0	GW 12		None Observed	315	-
55		P.C.C. 7.0	GW 13		" "	315	-
56		P.C.C. 7.0	GW 13		" "	315	-
57	Truax	P.C.C. 6.0	GF 36	10-20	Crystals and Numerous Lenses Hl.-1/16"	250	-
58	(1944-45)	P.C.C. 6.0	GF 36			250	-
59		P.C.C. 6.0	GF 36		Crystals and Numerous Lenses Hl.-1/16"	250	-
60		P.C.C. 6.0	GF 36			250	-
61		P.C.C. 6.0	GF 48			250	-
62		P.C.C. 6.0	GF 48			250	-
63	Pierre	P.C.C. 7.0	GF 9 Blended Cl Sub-base 6'	6-14	Hl. Lenses in Sub-base	120	-
64	(1944-45)	P.C.C. 7.0	GF 10		" " " " "	120	-
65		P.C.C. 7.0	GF 9		Hl. Lenses in Sub-base	120	-
66		P.C.C. 7.0	GF 10		" " " " "	120	-
67	Selfridge	P.C.C. 10.0	GF 18	3	Crystals Throughout	165	-
68	(1945-46)	P.C.C. 10.0	GF 11	3	" "	165	-

Flexural Strength of Concrete

Dow	600 psi
Truax	750 psi
Pierre	700 psi
Selfridge	735 psi

Hl. - Hairline
Cr. - Crushed

TABLE 4. FROST INVESTIGATION 1944-47 (Cont'd) SUMMARY OF TRAFFIC TESTS

LINE	SUBGRADE					FROST PENE-TRATION (FEET)	AVERAGE PAVEMENT HEAVE (FEET)
	CLASS.	%FINER THAN 0.02 mm.	ICE SEGREGATION	K OR C.B.R. (IN PLACE)			
				NORMAL PERIOD	FROST MELT. PERIOD		
1	CL	40-97	Few Thin Lenses	8	5	4.0	-
2	CL		" " "			4.0	-
3	CL		" " "			4.0	-
4	CL		" " "			4.0	-
5	CL		" " "			4.0	-
6	CL		" " "			4.0	0.25
7	GC	13-35	" " "	16	-	4.0	0.10
8	CL	40-97	" " "	8	5	4.0	0.20
9	CL		" " "			4.2	0.20
10	CL		" " "			4.2	0.15
11	CL		" " "			4.2	0.10
12	CL		" " "			4.2	0.05
13	CL		Few Thin Lenses			4.0	0.20
14	CL		" " "			4.0	0.20
15	CL		Crystals, Lenses Hl.-3/8"			4.2	0.25
16	CL		" " " "			4.2	0.25
17	CL		" " " "			4.2	0.25
18	CL		" " " "			4.2	0.25
19	CL		Crystals, Lenses Hl.-1/4"			5.2	0.15
20	CL		" " " "			5.2	0.15
21	CL		" " " "			5.2	0.15
22(a)	CL		No Data			-	-
23	CL		" "			-	-
24	CL		" "			-	-
25	CL		Crystals, Lenses Hl.-3/8"			4.2	0.25
26	CL		Crystals, Lenses Hl.-1/4"			5.2	0.10
27	CL		" " " "			5.2	0.10
28	CL		" " " "			5.2	0.10
29	CL		No Data			-	-
30	CL	60-80	Lenses, Hl.-1/20" occurring in all planes	5	3	4.7	0.20
31	CL	60-80		5	3	4.7	0.20
32	CL	60-80	Lenses Hl.-1/20" occurring in all planes	5	3	4.7	0.20
33	CL	60-80		5	3	4.7	0.20
34	CL	30-58	Short Fine Lenses	13	16	-	0.00
35	CL		" " "	13	16	-	-
36	CL		" " "	13	16	-	-
37	CL		Short Fine Lenses	13	16	-	0.00
38	CL		" " "	13	16	-	0.00
39	CL		" " "	13	16	-	-
40	CL		" " "	13	16	-	-
41	CL		Short Fine Lenses	13	16	-	0.00
42	CL		" " "	13	16	-	0.00
43	CL		" " "	13	16	-	-
44	CL		" " "	13	16	-	-
45	CL		" " "	13	16	-	-
					(c)		
46	GC	GC 13-35 CL 40-97	Lenses Hl.-1/4"	-	90	4.1	0.55
47	GC		" " "	-	85	4.1	0.55
48	GC		" " "	-	95	4.1	0.55
49	GC		" " "	-	95	4.1	0.55
50	GC		" " "	-	80	4.1	0.55
51	CL, GC		Lenses Hl.-1/4"	-	85	4.1	0.45
52	GC, CL		" " "	-	85	4.1	0.45
53	GC		" " "	-	100	4.1	0.45
54	CL		Lenses Hl.-1/4"	-	70	4.1	0.40
55	CL		" " "	-	75	4.1	0.40
56	CL, GC		" " "	-	75	4.1	0.40
57	CL SF below 6'	CL 60-80 SF 7	Numerous Fine Lenses	-	60	4.6	0.10
58	CL		" " "	-	60	4.6	0.10
59	CL		Numerous Fine Lenses	-	60	4.6	0.10
60	CL		" " "	-	60	4.6	0.10
61	CL		Not Frozen	-	60	4.6	0.10
62	CL		" "	-	60	4.6	0.10
63	CL, CH	CL 30-58 CH 56-78	Hl. Lenses	-	60	-	0.01
64	CL, CH		" "	-	65	-	0.01
65	CL, CH		Hl. Lenses	-	60	-	0.01
66	CL, CH		" "	-	65	-	0.01
67	ML, SF below 6'	ML 34 SF 20	Lenses Hl.-1/8"	-	100	2.9	0.03
68			" " "	-	70	2.9	0.08

Notes

Normal period thicknesses were determined from Flexible and Rigid Pavement Design Curves dated 13 June 1950. Pavement design thicknesses for Frost Conditions are based on Frost Design Curves, dated 15 August 1950.

The Per Cent of Design Thickness values denote the percentage ratio of the actual combined thickness of flexible pavement and base course to the design thickness or the percentage ratio of the actual rigid pavement slab thickness to the design thickness of slab. In cases where there were variations in the thickness of flexible pavement and base along a traffic test lane the least thickness was used when the pavement did not fail and the greatest thickness used when failure occurred in computing values of Per Cent of Design Thickness.

TABLE 4. FROST INVESTIGATION 1944-47 (Cont'd)
SUMMARY OF TRAFFIC TESTS

LINE	TRAFFIC TESTS														
	TEST PERIOD	COVERAGES						WHEEL LOAD	THICKNESS OF PAVE. + BASE (INCHES)	TAXIWAY OR RUNWAY	FROST PERIOD		NORMAL PERIOD		DESCRIPTION OF FAILURE
		1ST DAY	2ND DAY	3RD DAY	4TH DAY	AT START OF FAILURE	TOTAL AT END OF TEST				DESIGN THICKNESS	PER CENT OF DESIGN	DESIGN THICKNESS	PER CENT OF DESIGN	
1	5-7, 15-28 April	4	4	30	-	38	38	20,000	19	T	27	70	16	115	Progressive Cracking
2	5-7, 15-22 April	14	14	40	10	28	146	20,000	19	T	27	70	16	119	Progressive Cracking
3	5-7, 15-22 April	11	4	36	36	11	303	20,000	19	T	27	70	16	119	Progressive Cracking
4	5-7, 15-22 April	25	18	40	46	83	451	20,000	19	T	27	70	16	119	Progressive Cracking
5	8-20 April	26	1	4	4	< 26	72	20,000	19	R	27	70	17	136	Progressive Cracking
6	5-7, 15-22 April	25	18	40	26	95	523	20,000	22	T	27	82	16	138	Progressive Cracking
7	5-22 April	25	18	40	26	-	523	20,000	22	T	27	82	10	220	No Failure
8	5-22 April	25	18	40	46	-	451	20,000	27	T	27	100	16	169	No Failure
9	5-14 April	4	4	4	4	-	40	20,000	34	R	27	126	14	243	No Failure
10	5-14 April	14	14	14	14	-	130	20,000	34	R	27	126	14	243	No Failure
11	5-14 April	44	44	44	44	-	396	20,000	40	T	27	148	16	250	No Failure
12	5-14 April	34	34	34	34	-	306	20,000	41	T	27	152	16	256	No Failure
13	11 April - 5 May	15	50	50	50	500	965	10,000	23	T	19	121	11	209	Progressive Cracking
14	11 April - 5 May	15	50	50	50	-	965	10,000	23	T	19	121	11	209	No Failure
15	2-20 April	16	16	16	16	-	272	40,000	29-42	R	39	74	20	145	No Failure
16	2-20 April	62	62	62	24	-	796	40,000	38	T	39	98	22	173	No Failure
17	2-20 April	62	62	62	24	16	796	40,000	26	T	39	67	22	118	Progressive Cracking
18	2-20 April	46	46	46	8	16	524	40,000	29	T	39	74	22	132	Progressive Cracking
19	2-20 April	16	16	16	16	-	272	40,000	32-44	R	39	82	20	160	No Failure
20	2-20 April	62	62	62	62	-	848	40,000	32-54	T	39	82	22	146	No Failure
21	2-20 April	46	46	46	46	-	576	40,000	36-46	T	39	92	22	163	No Failure
22(a)	11-12 April	8	8	-	-	1	16	40,000	21	R	39	54	20	105	Progressive Cracking (a)
23	12 April	24	-	-	-	1	24	40,000	17-25	R	39	64	20	125	Progressive Cracking (a)
24	12 April	8	-	-	-	1	8	40,000	21	R	39	54	20	105	Progressive Cracking (a)
25	1 April	16-32	-	-	-	< 16	16-32	60,000	25-34	R	48	71	24	104	Progressive Cracking
26	1-20 April	16	16	16	16	-	186	60,000	47-52	R	48	98	24	196	No Failure
27	1-20 April	32	30	62	62	-	594	60,000	48	T	48	100	27	178	No Failure
28	1-20 April	16	30	46	46	-	408	60,000	48-54	T	48	100	27	178	No Failure
29	12 April	22	-	-	-	1	22	60,000	24	R	48	50	24	100	Progressive Cracking (a)
30	11-20 March	14	14	14	14	-	140	30,000	46(22)(b)	R	23	96	23	200	No Failure
31	11-20 March	42	42	42	42	-	420	30,000	46(22)(b)	T	23	96	26	177	No Failure
32	12 March-3 April	15	15	15	3	-	237	60,000	50(26)(b)	R	33	79	33	152	No Failure
33	12 March-3 April	45	45	45	10	145	710	60,000	50(26)(b)	T	33	79	36	139	Progressive Cracking
34	17-29 March	32	32	32	32	-	416	7,000	13	T	16	81	8	163	No Failure
35	17-29 March	48	48	48	48	200	624	7,000	12	T	16	75	8	150	Progressive Cracking
36	17-29 March	16	16	16	16	208	208	7,000	14	R	16	87	8	175	Progressive Cracking
37	13-29 March	16	16	16	16	-	248	14,500	15	R	23	65	8	188	No Failure
38	13-29 March	48	48	48	48	-	720	14,500	14	T	23	61	9	156	No Failure
39	13-29 March	16	16	16	16	240	240	14,500	15	R	23	65	8	188	Progressive Cracking
40	13-March	36	-	-	-	36	36	14,500	14	T	23	61	9	156	Progressive Cracking
41	13-26 March	42	42	42	42	200	508	25,000	15	T	31	48	13	115	Progressive Cracking
42	13-29 March	14	14	14	14	-	224	25,000	16	R	31	45	12	117	No Failure
43	13 March	42	-	-	-	< 42	42	25,000	16	T	31	52	13	123	Progressive Cracking
44	13-25 March	14	14	14	14	28	168	25,000	15	R	31	48	12	125	Progressive Cracking
45	14 April	42	-	-	-	< 42	42	25,000	12	T	31	42	13	92	Progressive Cracking
									THICKNESS OF SLAB ONLY						
46	25 April-5 May	4	4	4	4	-	45	20,000	7.0	R	8	68	7	100	No Failure
47	25 April-5 May	4	23	20	26	27	225	20,000	7.0	R	8	68	7	100	Progressive Cracking
48	25 April-5 May	8	27	24	30	35	270	20,000	7.0	T	9	78	8	88	Progressive Cracking
49	25 April-5 May	8	46	40	52	115	450	20,000	7.0	T	9	78	8	88	Progressive Cracking
50	25 April-5 May	4	23	20	26	110	225	20,000	7.0	R	8	68	7	100	Progressive Cracking
51	30 April-4 May	16	25	10	20	< 51	76	30,000	7.0	R	10	70	8	88	Progressive Cracking
52	30 April-4 May	16	25	10	20	17	76	30,000	7.0	R	10	70	8	88	Progressive Cracking
53	30 April-4 May	16	25	10	20	55	76	30,000	7.0	R	10	70	8	88	Progressive Cracking
54	27 April	37	-	-	-	2	37	40,000	7.0	T	13	54	11	64	Progressive Cracking
55	27 April	18	-	-	-	2	18	40,000	7.0	R	11	64	10	70	Progressive Cracking
56	27 April	2	-	-	-	2	2	40,000	7.0	R	11	64	10	70	Progressive Cracking
57	7-20 March	15	15	15	15	-	210	15,000	6.0	R	6	100	6	100	No Failure
58	7-20 March	45	45	45	45	-	630	15,000	6.0	T	7	86	6	100	No Failure
59	21 March-3 April	18	18	18	18	108	234	30,000	6.0	R	9	67	8	75	Progressive Cracking
60	21 March-3 April	45	45	45	45	270	585	30,000	6.0	T	10	60	9	67	Progressive Cracking
61	12-20 March	18	18	18	18	90	162	30,000	6.0	R	9	67	8	75	Progressive Cracking
62	12-20 March	45	45	45	45	90	405	30,000	6.0	T	10	60	9	67	Progressive Cracking
63	14-29 March	16	16	16	16	-	240	14,500	7.0	R	6	117	6	117	No Failure
64	14 March-4 April	48	48	48	48	-	1611	14,500	7.0	T	7	100	7	100	No Failure
65	14 March-4 April	54	54	54	54	108	1698	25,000	7.0	T	10	70	9	78	Progressive Cracking
66	14 March-4 April	18	18	18	18	-	270	25,000	7.0	R	9	78	8	88	No Failure
67	2-25 March	15	15	15	15	-	360	60,000(d)	10.0	R	10	100	9	111	No Failure
68	2-25 March	45	45	45	45	-	1080	60,000(d)	10.0	T	11	91	10	100	No Failure

Application of traffic was generally made at the rate of approximately 15 and 45 coverages per day which was considered equivalent to runway and taxiway operation respectively. The pavement design thicknesses were based on runway design curves when the maximum number of coverages were less than 30 per day and on taxiway design curves when the traffic lane was subjected to 30 or more coverages per day.

(a) Failure at one coverage on lines 22, 23, 24 and 29 due to inadequate thickness of wearing course. Subgrade showed appreciable deformation at end of tests.

(b) The OF subbase material at Truax was frost susceptible and was considered to control frost condition design.

(c) Subgrade moduli determined from Frost Design Curves, dated 15 August 1950.

(d) Traffic Test at Selfridge Air Force Base performed using 60,000 pound total load on B-29 dual wheel assembly.

Results of the traffic tests using the 20,000-lb. wheel load are shown in Lines 1 to 12 inclusive in Table 4. At five test lanes in which the combined thickness of pavement and base was 19 in., progressive cracking started after between 11 and 83 coverages. Progressive cracking commenced after 95 coverages along one lane with a pavement and base thickness of 22 in. These failures were all in areas with CL subgrade material. One lane with a combined pavement and base thickness of 22 in. was in satisfactory condition after 523 total coverages in an area with GC subgrade material (see Line 7, Table 4), although the wearing course stripped to some extent in one area and shifted laterally, which was attributed to the circular traffic pattern used at this test lane. The 20,000-lb. wheel did not cause failure at the five remaining lanes in which the combined thickness of pavement and base ranged from 27 to 41 in. and overlay a CL subgrade. It is indicated by this test series that a combined thickness of pavement and base between 22 and 27 in. in thickness is required over the CL subgrade material in Test Area I-III to satisfactorily support traffic of a 20,000-lb. wheel load in the frost-melting period. From the Engineering Manual, the frost condition design thickness at this test area for a 20,000-lb. wheel load is 27 in. Assuming a 24-in. thickness of pavement and base is at the boundary between safety and failure the subgrade CBR value during the test period was of the order of 5 percent, according to the flexible pavement design curves dated June 13, 1950. A 24-in. pavement and base thickness is 89 percent of the 27-in. frost-condition design thickness. The results of the traffic tests using the 10,000-lb. wheel load are shown on lines 13 and 14 on Table 4. The 10,000-lb. wheel load equipment was routed around a 90-ft. diameter circular tract with combined pavement and base thickness of 23 in. Minor flexing and cracking occurred at three locations representing 25 percent of the total test track. Failure principally consisted of ravelling at longitudinal construction joints and sliding and minor deformation of wearing course. The failures are attributed principally to the short-radius circular traffic pattern and local weaknesses in pavement and base course, although visible flexing in the three distressed areas of 0.3 in. and maximum permanent deformation of 0.7 in. possibly were due to excessive subgrade deformation since the combined thickness of pavement and base was 23 in. or only 4 in. more than the frost condition design thickness for a 10,000-lb. wheel load.

Dow Field (1944-1945)

Traffic tests were conducted with 40,000 and 60,000-lb. wheel loads on the flexible pavements at Test Areas B and C respectively which were located along the E-W Runway. The equipment used to obtain the traffic wheel loads consisted of the rubber-tired scraper shown on Figure 14. The tests were started on April 1, 1945, near the end of the frost-melting period and continued to April 20, 1945. Tests were conducted both on the runway, where the pavement was 3.5 in. in thickness on base ranging in thickness from 21 to 51 in., and on the runway shoulder area which had 1-in. bituminous-treated wearing course on a base 16 to 24 in. in thickness. During the winter of 1944-1945 frost penetrated into the CL subgrade to a depth of approximately 4.5 ft. below the pavement surface. Numerous ice lenses from hairline to 3/8-in. in thickness were observed in the subgrade and resulted in fairly uniform pavement heave averaging 0.20 ft.

Results of the series of tests with the 40,000- and 60,000-lb. wheel loads are presented in lines 15 to 29 inclusive on Table 4. Where the pavement and base thickness was relatively uniform along a test lane only one figure is shown, and when a variation in thickness occurred along a test lane, two figures are shown to denote the range.

The frost condition design thickness for a 40,000-lb. wheel load with the subgrade condition at these two test areas is 39 in. The traffic tests results show progressive cracking occurred in all six lanes under the 40,000-lb. wheel load where the pavement and base thickness was less than 29 in. Three of these lanes had a bituminous-treated wearing course which did not withstand one coverage; however, the tests were continued and excessive subgrade deformation indicated the base thickness was also inadequate for the wheel load. The 3.5-in. thick pavement remained in satisfactory condition under

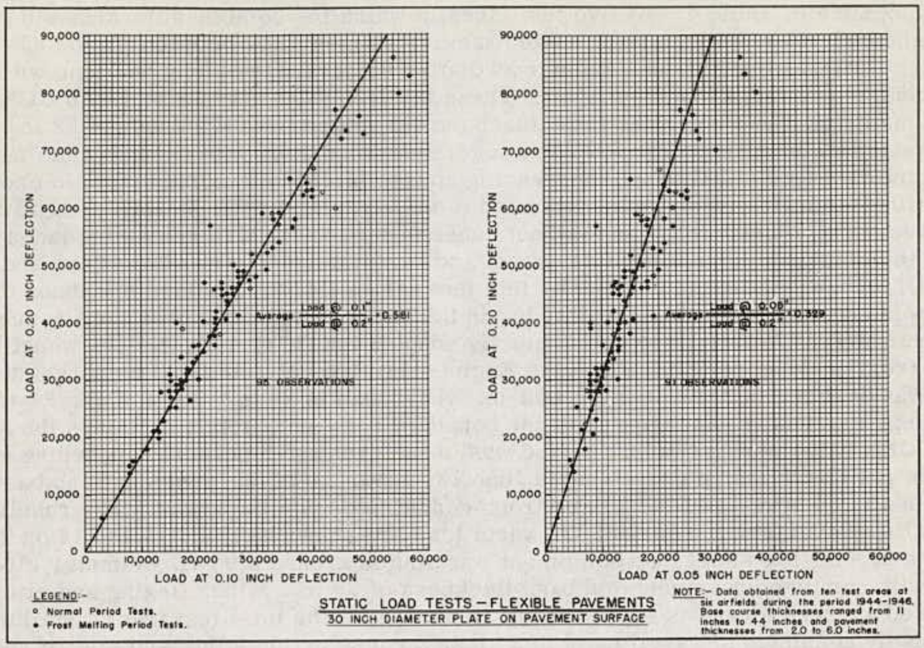


Figure 13.

as high as 62 coverages per day of the 40,000-lb. wheel load traffic at the four lanes where the pavement and base thickness was in excess of 32 in. Assuming 32 in. is the boundary between a satisfactory and unsatisfactory thickness, the subgrade CBR was of the order of 4.5 according to the flexible pavement design curves. A 32-in. pavement and base thickness is 82 percent of the 39-in. frost condition design thickness. Figure 15 shows a failed portion of a test lane after being subjected to 40,000-lb. wheel-load traffic.

The traffic tests using a 60,000-lb. wheel load showed that a pavement and base thickness of 34 in., which is 71 percent of the 48-in. design thickness, was not adequate, while three lanes which had pavement and bases 98 percent and greater of the design thickness gave satisfactory performance. The thickness of pavement and base that is just adequate to support traffic of the 60,000-lb. wheel load is thus bracketed between 71 percent and 98 percent of the design thickness of 48 in. Using these two limiting percentages, the CBR value of the subgrade as computed from the design curve was between 3 and 5 percent.

In the bituminous surface treatment area tested under the 60,000-lb. wheel load, failure of the wearing course occurred after one coverage, and after 22 coverages there was ample evidence of failure due to subgrade deformation, which is consistent with the other test results since the base was only 50 percent of that required by frost condition design.

Truax Field (1944-1945)

Traffic tests using 30,000- and 60,000-lb. single-wheel loads provided by large, rubber-tired construction equipment were conducted at Test Area B, Truax Field, during the frost-melting period in March 1945. At the area tested with the 30,000-lb. load, the total pavement and base thickness was 46 in., consisting of 2-1/2 in. of bituminous pavement, 20 in. of crushed rock base and 24 in. of sand-clay-gravel subbase. The test lane where the 60,000-lb. wheel load was applied had 2 in. of pavement, 24 in. of crushed rock base and 24 in. of sand-clay-gravel subbase. Frost penetrated to a depth of 52 in. in the area during the winter of 1944-1945. Test pits dug at the time of maximum frost penetration revealed several ice lenses hairline to 1/16-in. in thickness in the subbase and numerous fine ice lenses in the CL subgrade. The average pavement heave in the test area was 0.20 ft.

The results of the tests are summarized in lines 30 to 33 inclusive on Table 4. No failure or pavement distress was obtained using the 30,000-lb. wheel load at a rate of 14 daily coverages for 10 days. According to the frost condition design criteria a combined thickness of pavement and base of 33 in. is required to support 30,000-lb. wheel-load traffic, based on loss of strength in the CL subgrade during frost melting. The thickness provided at the test area was 46 in. or 137 percent of the design requirement. The subgrade, however, does not control the frost condition design as the frost susceptible subbase material with an average of 16 percent of grains finer than 0.02 mm. must be considered in evaluating the pavement at the test area. From the frost condition design curves a soil with the gradation of the Truax subbase material requires a combined thickness of pavement and base of 23 in. to compensate for weakening during the frost melting period. Since the area did not fail with a 22-in. base over the frost-susceptible subbase the safety of the design curve is substantiated although the margin of safety is not revealed.

In the area tested with the 60,000-lb. wheel load, no failure or distress occurred due to 15 daily coverages and 237 total coverages. In the test lane receiving approximately 45 coverages per day up to a total of 710 coverages, flexing up to 1/4-in. was recorded, and, although the pavement surface showed no cracks, the permanent deformation varied from 1.0 to 1.5 in. Progressive cracking commenced after 145 coverages in the test equipment turnaround area but did not become appreciable at the cessation of traffic at 710 coverages. This failure is recorded on line 33, Table 4, but because no progressive cracking occurred in the straight lane the pavement is believed to be at the borderline of adequacy for taxiway operation with a 60,000-lb. wheel load.

The design thickness based on loss of strength in the CL subgrade soil at the 60,000-lb. wheel load test area is 48 in. compared with 50 in. provided at the test area. A base thickness of 32 in. is required by the frost condition design criteria to allow for frost melting in the subbase material as compared to only 26 in. provided at the test area. The subbase was therefore theoretically the most likely source of failure as the actual

Figure 14. Traffic Test Equipment for 60,000-lb. Wheel Load. Dow Field, Bangor, Maine.

pavement was 79 percent of design based on subbase and 104 percent based on subgrade. In either case the design curves are verified within reasonably close limits. Since cracking and deformation were minor the measurements and explorations after the traffic test did not conclusively ascertain the source of these failure symptoms. If the observed defects were due to excessive subgrade deformation the CBR during period of test was slightly less than 3, while in the event the cracking was due to the subbase the CBR was about 5. 5, based on the CBR design curves.

Pierre Airfield (1944-1945)

Traffic tests using 7,000, 14,500, and 25,000-lb. wheel loads were conducted at Test Area B, Pierre Airfield immediately following the frost melting period in the spring of 1945. The equipment used to obtain the various wheel loads consisted of large, rubber-tired construction equipment and trucks. Traffic test lanes were located both on a taxiway pavement where slight pavement subsidence occurred during the freezing period and on adjacent shoulder areas where the pavement heave averaged approximately 1/4-in. The combined thickness of pavement and base in the test area averaged 15 in., consisting of a bituminous concrete pavement 6 to 7 in. thick on the taxiway and 2 to 3 in. thick on the shoulder area, on a sandy gravel GF base course. An 8-in. thickness of sandy clay CL overlay a silty clay CL subgrade. Explorations made during the freezing period revealed that the frost penetrated the silty clay subgrade for an average depth of 1 ft. Ice lens formations were not discernible in the sandy gravel base or the sandy clay subbase materials but a few short fine ice lenses were present in the silty clay subgrade.

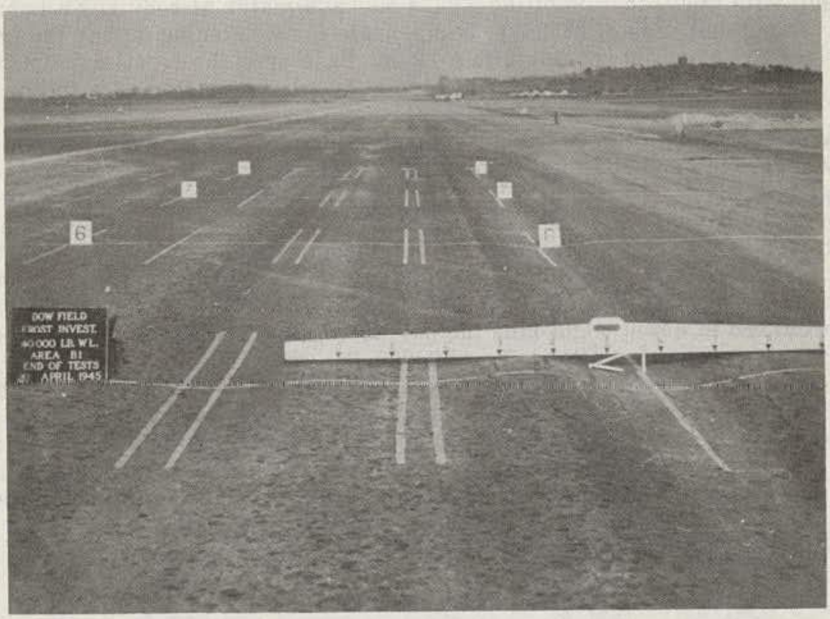
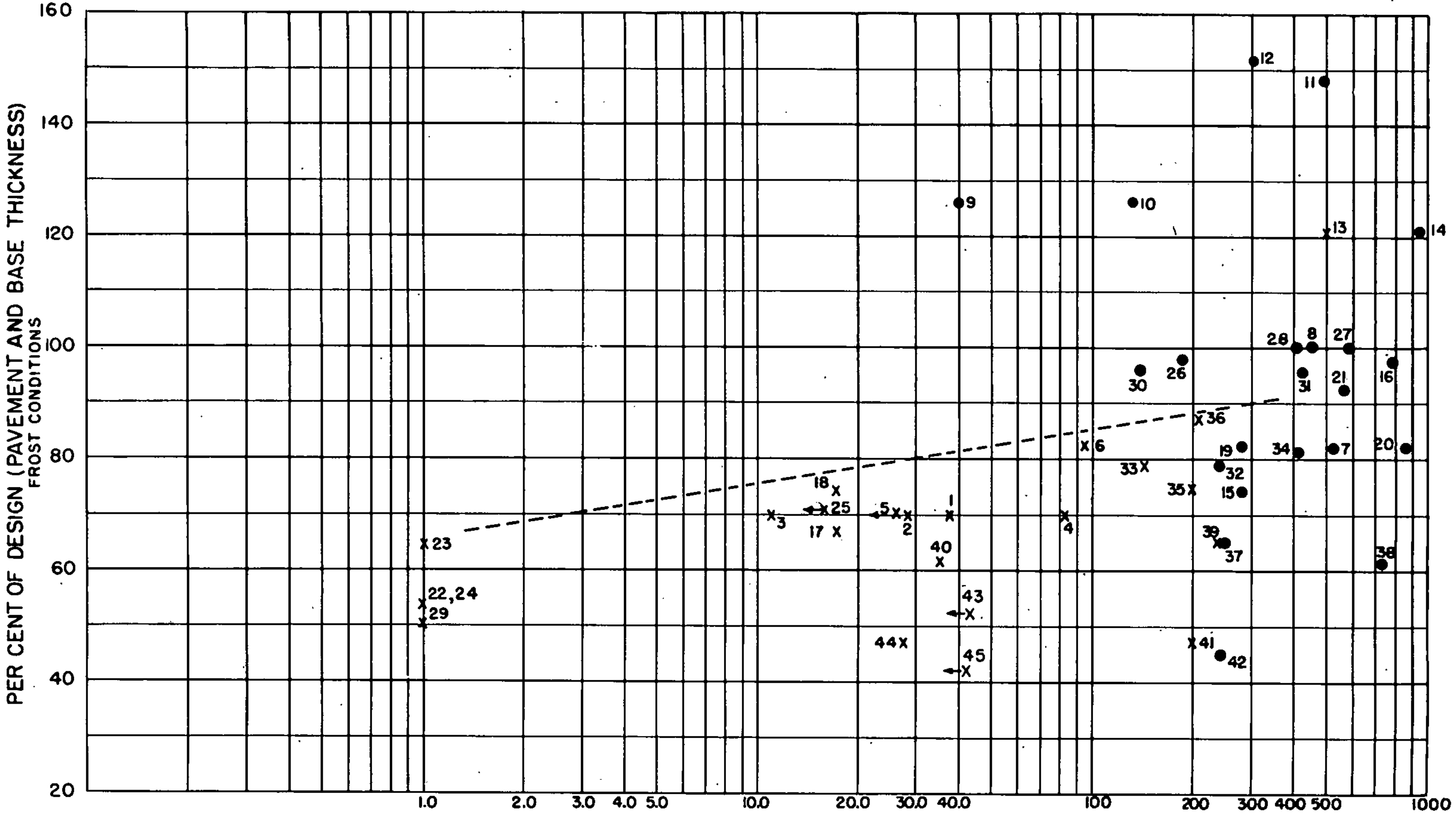


Figure 15. Condition of 4 in. Bituminous Concrete Pavement After 524 Coverages of 40,000 -lb. Wheel Load in 17 Days (see line 18, Table 4). Dow Field, Bangor, Maine.

The results of the traffic tests at both the taxiway and shoulder areas are presented in lines 34 to 45 inclusive on Table 4. On the shoulder areas, where minor pavement heave had been recorded, progressive cracking followed by rutting occurred under the 7,000, 14,500, and 25,000-lb. wheel loads applied at approximate rates of both 15 and 45 coverages per day. The taxiway pavement which had subsided and which had no discernible ice lenses in the subgrade soil withstood traffic of all three wheel loads



LEGEND:

X Pavement Failed or at Imminent Failure.

● Pavement Satisfactory.

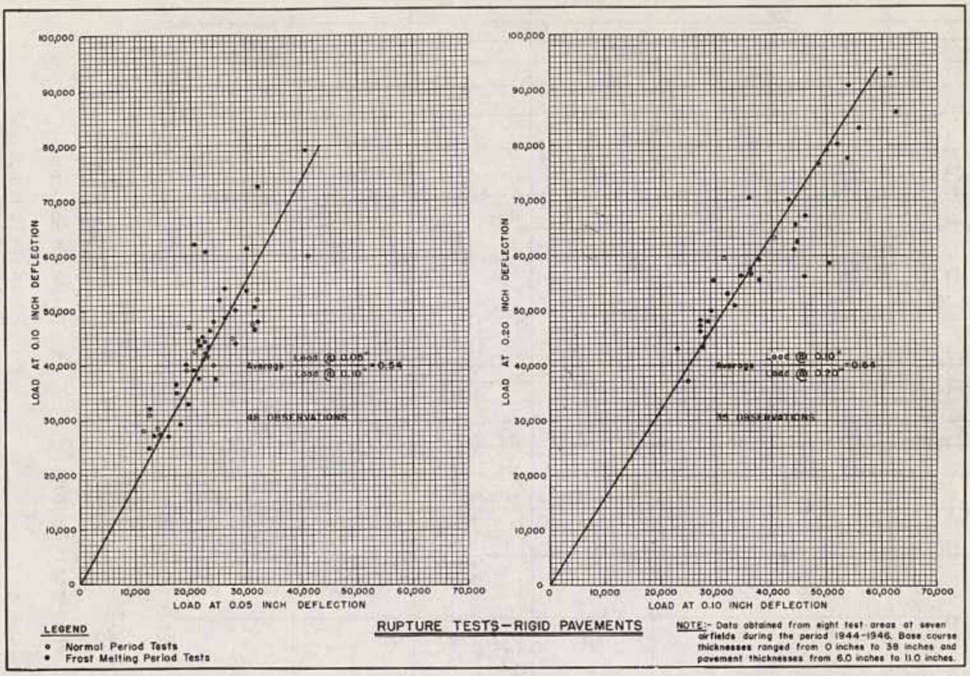
←X Pavement Failed at less than Indicated Number of Coverages.

NOTES:-

Data obtained from accelerated traffic tests performed during the frost melting period on flexible pavements at Dow, Truax, and Pierre Airfields.

Numbers adjacent to plotted points refer to line numbers on Table 4.

Figure 16.



RUPTURE TESTS—RIGID PAVEMENTS

NOTE:- Data obtained from eight test areas at seven airfields during the period 1944-1946. Base course thicknesses ranged from 0 inches to 38 inches and pavement thicknesses from 6.0 inches to 11.0 inches.

Figure 17.

except one lane where progressive cracking occurred after 200 coverages of the 25,000-lb. wheel load at the rate of 42 coverages per day.

The frost condition design thicknesses shown on Table 4 were based on weakening of the sandy clay subbase material and in all cases the actual combined pavement and base thickness in the test areas was less than was required by the frost condition design criteria. Pavement failures in the areas of pavement heave are therefore consistent with the design although thin wearing surface thicknesses at these areas may have been a contributing cause. The one failure in the area of pavement subsidence was at the maximum coverages of the heaviest wheel load. Test trenches dug at completion of the tests revealed that the surface of the subbase material had deformed to a profile similar to the pavement deformation profile. This failure of the subbase material is not necessarily attributed to frost melting, since the failure indicated the actual CBR of the subbase during the test period was about 12 percent which corresponds closely with the laboratory CBR value of this material at actual field density.

Summary of Traffic Tests on Flexible Pavements

Traffic test data from all flexible paved test areas are summarized in Figure 16, which shows the relationship between the percentage ratio of the actual pavement and base thickness to the Corps of Engineers frost condition design thickness for the specific traffic test wheel load, the number of traffic coverages and the pavement behavior. The plotted points are numbered to correspond with line numbers on Table 4 where the details of the traffic tests are presented. Figure 16 demonstrates that unless the pavement and base thickness was at least 75 percent of the frost condition design thickness progressive cracking commenced within 240 and, in most cases, within 100 coverages of the traffic test wheel. The only exceptions to this are Points 37, 38, and 42 at Pierre which were in areas of pavement subsidence and for which the applicability of the frost condition design criteria is therefore in doubt. No pavement failures occurred where the actual pavement was greater than 90 percent of the design requirement. The frost condition design criteria are very conclusively substantiated by the traffic test results, and pave-

ment and base thicknesses that are barely safe are generally indicated to be between 80 and 90 percent of the thicknesses required by the present frost condition design criteria. The margin of safety that is indicated as being present in the existing criteria is believed justified to allow for heavy traffic usage in emergencies, and as a preventative against excessive maintenance expenditures.

Effect of Frost Action on Supporting Capacity of Rigid Pavements

The supporting capacity of rigid pavements was investigated by means of pavement rupture tests conducted during the normal period and the frost-melting period and by traffic tests conducted during and after the frost-melting period.

The pavement rupture tests were made by loading a 24-in. diameter plate 1/ placed on the surface of the pavement at a corner of a slab made by the intersection of a longitudinal construction joint and a transverse expansion joint. The edge of the plate was about three inches inside the slab edges. The test procedure was as follows: the plate was seated on a thin layer of sand, two extensometers were placed in a line bisecting the right angle formed by the pavement joints, and the load was applied in increments to give successive loads of 20, 30, 35, 40, 45, 50, 55, and 60 thousand pounds. If the available load was not sufficient to cause failure, the load was released and reapplied by increments. The procedure was repeated until rupture occurred or for a total of five repetitions.

Pavement rupture tests were conducted during the normal and frost melting periods for at least one investigational year at Dow, Truax, Presque Isle, Selfridge, Pierre, and Sioux Falls airfields. In addition pavement rupture tests were performed during the frost-melting period in 1945 at Watertown Airfield.

Results of the tests conducted during both the frost melting and normal periods are summarized on Table 3. A comparison of the loads causing 0. 1-in. deflection during the normal and frost melting periods, tabulated in columns 10 and 11 of Table 3, respectively, shows a consistent reduction in pavement strength during the frost-melting period, the average ratio of frost-melting to normal-period load at 0. 1-in. deflection for all test areas being 0. 69. Approximately the same ratio between frost-melting and normal-period loads was found to exist at . 05-in. and 0. 2-in. plate deflections. This may be understood from examination of Figure 17, which shows that consistent relationships hold between test loads at . 05 and 0. 1 in. and between 0. 1 and 0. 2 in., which are about the same for the frost-melting period as for the normal period.

For purposes of analysis, wheel-load evaluations of the pavements at the locations of the rupture tests were made for both normal and frost-melting periods using the latest Corps of Engineers design curves for single-wheel loads with 100-psi. tire pressure. The wheel load evaluations for each test area are shown in columns 15 and 17 of Table 3. The average ratio of the frost melting to normal-period wheel-load evaluations is 0. 79 as shown on Table 3 as compared with the average ratio of weakening of 0. 69 indicated by the pavement rupture tests. A comparison of the ratios of frost-melting period to normal-period rupture test loads and design wheel loads is presented in Figure 2B. Although the ratios of weakening by both methods of approach are of the same order, the load at 0. 1-in. deflection on the bearing plate was on the average four times greater than the design wheel load for the same period. Since the rupture tests were carried either to the maximum loading capacity of the equipment or to slab failure which was in all cases at deflection in excess of 0. 1 in., the rupture loads in all instances were many times greater than the design wheel loads.

Consideration of the factors involved indicates that in these static loading tests on rigid pavements, as in the comparable tests on flexible pavements, many influences exist which tend toward rendering an incorrect ratio for the reduction in pavement supporting capacity, in relation to that determined by actual traffic testing. Nevertheless the agreement between the values 0. 79 and 0. 69 here obtained for rigid pavements

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1/ A 19-in. diameter plate was used instead of a 24-in. diameter plate for the rupture tests at Dow Field during the normal period in the fall of 1944.

is clearly better than for the comparable situation for flexible pavements. As shown on Figure 2, the pavement-rupture tests do demonstrate well the pavement weakening that results from frost melting and indicate the duration of the weakening period.

Traffic Tests

Traffic tests were conducted on portland cement concrete pavements at Dow, Truax, Pierre, and Selfridge airfields using wheel loads consistent with the evaluations of the specific test area. The wheel loads were provided by loaded trucks, Tournapulls, and scrapers. The equipment was the same as that used for the traffic tests conducted concurrently on bituminous concrete pavements. The assumptions as to traffic frequency were also the same as for flexible pavements; that is 15 coverages per day was considered equivalent to the maximum operation for runways, and 45 coverages per day was considered equivalent to the maximum operation for taxiways. The nearest practical figures to these were used. The test lane was located with its center line over a construction joint and the traffic pattern was so designed as to gradually attain by steps the maximum coverages in the test lane. Traffic tests were generally started just before the beginning of the frost-melting period and continued through the frost-melting period or until imminent failure occurred. A test lane was considered to be inadequate to support the traffic-test wheel load if pavement cracking became progressive with additional application of traffic.

Traffic tests were conducted at Dow Field on the rigid pavement at Test Area A immediately following the frost-melting period during the spring of 1944. During the frost-melting period in the spring of 1945 traffic tests were conducted at Test Area C, Truax Field and Test Area A, Pierre Airfield. Traffic tests were also conducted on rigid pavement at Test Area A, Selfridge Field, during the frost-melting period in the spring of 1946.

The results of the traffic tests on portland-cement concrete pavements at Dow, Truax, Pierre, and Selfridge Airfields are discussed and correlated with design criteria in the following paragraphs:

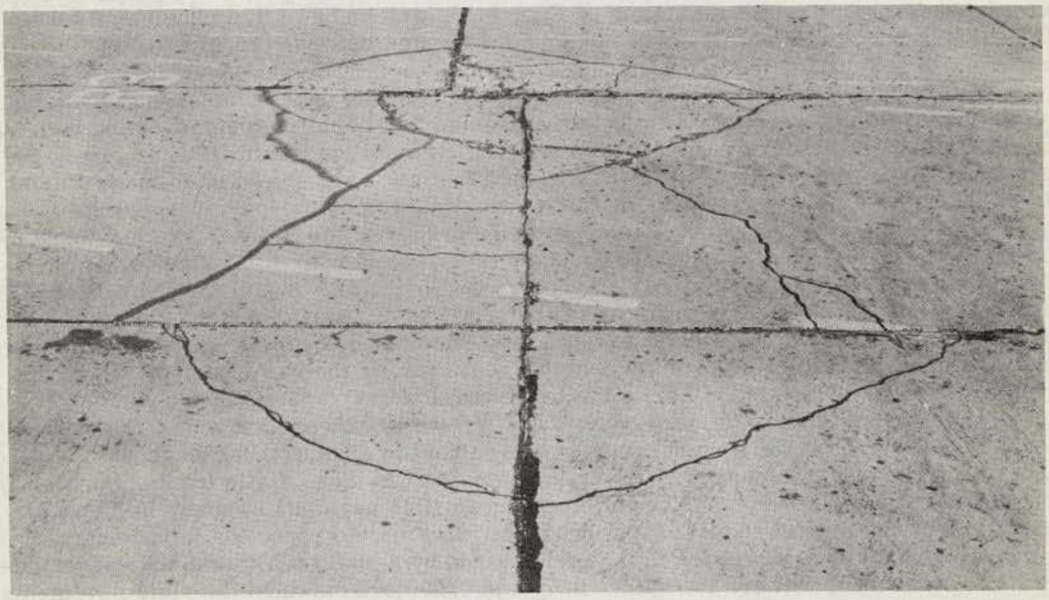


Figure 18. Condition of 7 in. Concrete Slab After 54 Coverages per Day for 15 Days and 178 Coverages per Day for 5 Days of 25,000-lb. Wheel Load (see line 65, Table 4). Pierre Airfield, Pierre, South Dakota.

Dow Field (1943-1944)

In the series of traffic tests conducted at Test Area A, Dow Field during and immediately following the frost-melting period in the spring of 1944, wheel loads of 20,000 30,000 and 40,000 lb. were applied at between 4 and 52 coverages per day along several lanes on the 7-in. thick concrete slab. The equipment used to obtain the wheel loads consisted of a Gar Wood scraper towed by a 5-ton truck, which was the same equipment used for the 60,000-lb. wheel-load traffic tests on flexible pavements. This equipment is shown in the photograph on Figure 14. The wheel loads were varied as required by the removal or addition of ballast on the scraper. The GW base course, which varied between 12 and 17 in. in thickness within the area, had no ice formations during the winter of 1943-1944. Ice lenses in the CL and GC subgrade soils were of hairline thickness near the top of the subgrade and increased to an average of 1/4-in. in thickness near the depth of maximum frost penetration, which was approximately 2 ft. below the subgrade surface. The maximum pavement heave within the test area ranged from 0.40 to 0.55 ft.

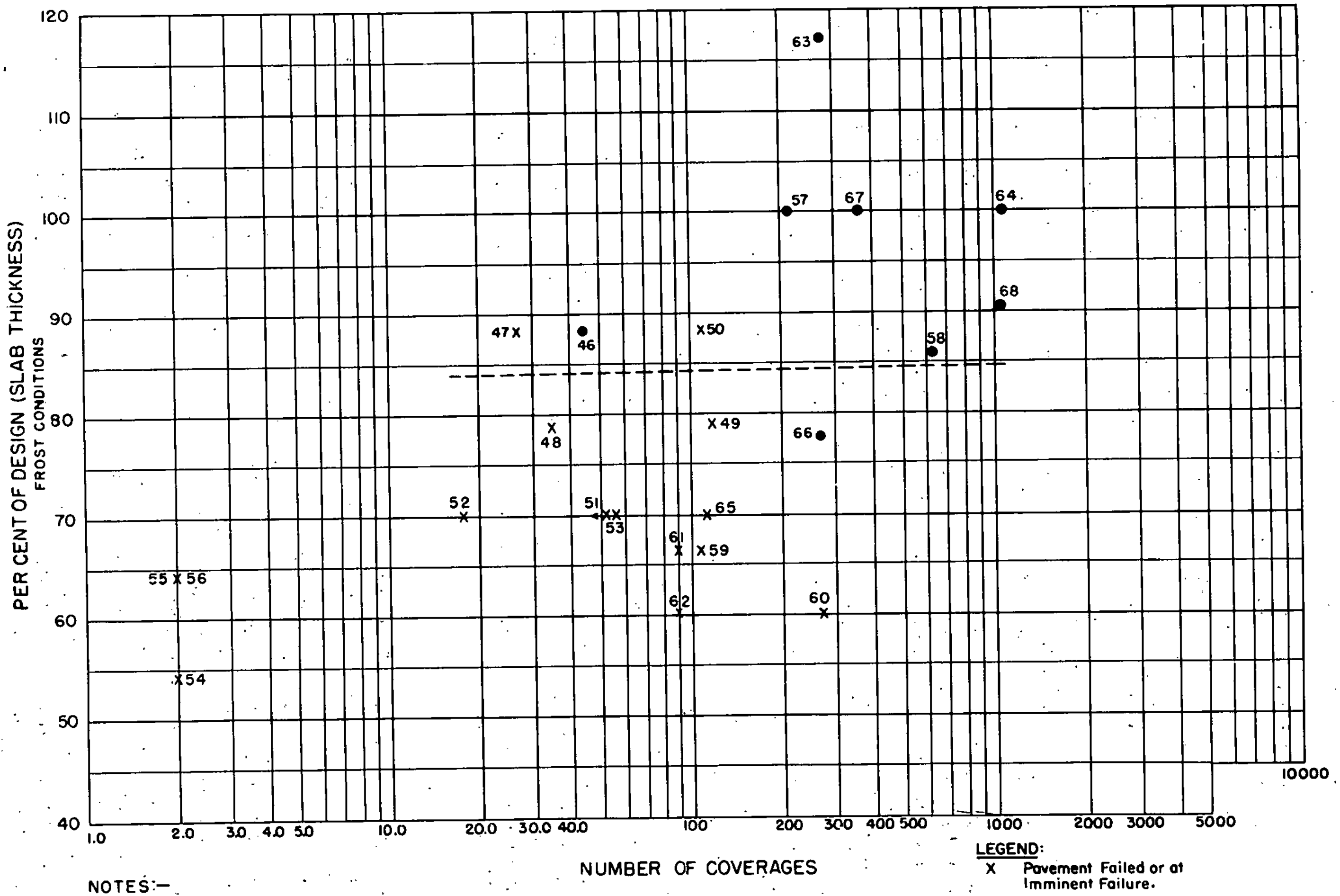
Progressive cracking of the slabs occurred, as shown in lines 46 to 56 inclusive on Table 4, in all test lanes except one, which withstood four daily coverages of the 20,000 -lb. wheel load for 9 days. When traffic of the 20,000-lb. wheel load was applied in excess of 25 coverages per day, a few transverse cracks and cracks at slab corners appeared after a few days of traffic. Cracking became progressive and it was considered that the pavement had failed although the pavement withstood as many as 450 coverages and was not badly damaged. The cracking of the pavement under the 30,000-lb. wheel-load traffic was more severe, and widespread pavement break-up resulted after few coverages of the 40,000-lb. wheel load. Pumping of water at joints occurred in all test lanes after a few coverages of traffic.

The frost-condition design thicknesses for rigid pavements at the traffic-test area for runway traffic of 20,000, 30,000, and 40,000-lb. wheel loads are 8 in., 10 in. and 11 in. respectively, and for taxiway traffic of 20,000, and 40,000-lb. wheel loads are 9 and 13 in. Since the pavement was 7 in. thick and failure occurred at all test wheel loads except at the lane subjected to four coverages per day of the 20,000-lb. wheel load, the results were consistent with the design criteria. Except for the 20,000-lb. wheel load, however, the loads were excessively heavy to provide a close check of the criteria. Although failure was considered to have occurred under traffic of the 20,000-lb. wheel load the cracking was relatively minor and it is believed the pavement would have been adequate for wheel loads slightly less than 20,000 lb.

Truax Field (1944-1945)

The 6-in. rigid pavement at Test Area A, Truax Field, was subjected to approximately 15 and 45 coverages per day of both 15,000- and 30,000-lb. wheel loads during the frost-melting period in the spring of 1945. The wheel loads were obtained by loaded trucks and Tournapulls and loaded scrapers, the same as used for the traffic tests conducted concurrently on the bituminous concrete paved areas. During the winter prior to the traffic tests, ice lenses from hairline to 1/16-in. in thickness were present in the sand-clay-gravel, GF, base course material, particularly in the upper portion of the base. Since the base course ranged from 36 to 48 in. thick and frost penetrated approximately 55 in. below the surface of the pavement, the depth of silty clay, CL, subgrade frozen varied from 0 to approximately 1 ft. Numerous fine ice lenses were present in the portion of the subgrade frozen. The pavement heave was relatively uniform and averaged 0.10 ft.

The traffic test results are summarized in lines 57 to 62 inclusive, Table 4, which show that the pavement satisfactorily withstood 15,000-lb. wheel-load traffic applied at both 15 and 45 coverages per day. Progressive failure commenced after a total of 90 coverages of 30,000-lb. wheel-load traffic applied at 18 and 45 coverages per day although the subgrade had not been frozen under the test lanes (see lines 61 and 62, Table 4). It is indicated, therefore, that failure was the result of frost melting



NOTES:—

Data obtained from accelerated traffic tests performed during the frost melting period on rigid pavements at Dow, Truax, Pierre and Selfridge Airfields.

Numbers adjacent to plotted points refer to line numbers on Table 4.

Figure 19.

in the base course. Pumping of water through the joints and cracks occurred during the application of both the 15,000- and 30,000-lb. wheel loads up to March 17 and then pumping ceased. Fines were carried up through the joints and cracks by this pumping action and undoubtedly resulted in loss of subgrade support. It is believed that loss of fines would have been prevented by the use of a free-draining base-course material.

A test series using a 30,000-lb. wheel load at a rate of 18 and 45 coverages per day was started on March 21, 1945 (see lines 59 and 60, Table 4). Progressive cracking commenced after 108 total coverages applied at the rate of 18 per day and 270 total coverages applied at the rate of 45 per day. Pumping at joints and cracks did not occur and the cracking was much less severe and took place more gradually than the similar test series, lines 61 and 62, Table 4, which had been started on March 12. Therefore, it is indicated that some of the excess water drained from the base and that the pavement rapidly regained strength. The short period of time required for the pavement to regain strength at Truax Field is also demonstrated by plate bearing test results plotted on Figure 11.

The traffic test results indicate that the pavement thickness required by frost condition design is adequate. The existing 6-in. slab was satisfactory to support a 15,000-lb. wheel load, while the frost condition design thickness for taxiway traffic is 7 in., and for runway traffic is 6 in., for the conditions at the test area. Failure under the 30,000-lb. wheel load was to be expected as the slab thickness was only 60 to 67 percent of the 10-in. and 9-in. frost-condition design thicknesses for taxiway and runway traffic respectively.

Pierre Airfield (1944-1945)

The 7-in. portland-cement concrete pavement at Test Area A, Pierre Airfield, was subjected to heavy construction equipment traffic of 14,500-and 25,000-lb. wheel loads applied at the rates of approximately 15 and 45 coverages per day starting on March 14, 1945, which was at the end of the frost-melting period. During the winter of 1944-1945 a few very fine ice lenses were present in the sandy clay subbase and silty clay subgrade materials which resulted in a fairly uniform pavement heave of 0.01 ft.

The summary of traffic test data presented in lines 63 to 66 inclusive, Table 4, shows that the pavement satisfactorily withstood traffic of the 14,500-lb. wheel load applied at both 16 and 48 daily coverages. The pavement also proved adequate to support traffic of the 25,000-lb. wheel load applied at 18 coverages per day, but failure did occur after two days of traffic by the 25,000-lb. wheel load applied at 54 coverages per day.

Pumping of water occurred at the joints during traffic tests and it was noted that pumping and pavement cracking increased following a rainfall, indicating that infiltration of water through the pavement might also have weakened the supporting capacity of the pavement. Since frost action was minor at this test site, the failure under the 25,000-lb. wheel load is not necessarily attributed to frost melting.

Selfridge Field (1945-1946)

In the series of traffic tests conducted on the 10-in. slab at Test Area A, Selfridge Field, during the frost melting period in the spring of 1946, a 60,000-lb. load on a B-29 dual-wheel assembly was applied at the rates of 15 and 45 coverages per day. The center lines of the wheels were spaced at 3.08 ft. apart. During the winter of 1945-1946, ice lenses from hairline to 1/8-in. in thickness were present in the sandy silt , ML subgrade. The average pavement heave in the test lane subjected to 15 coverages per day was 0.03 ft., while in the lane subjected to 45 coverages per day the average heave was 0.08 ft.

The traffic test results summarized in lines 67 and 68, Table 4, show that the pavement was satisfactory for the traffic applied. Pavement cracking did not occur in either test lane with exception of slight spalling along the longitudinal and transverse dummy joints.

The existing 10-in. pavement at the test area was equal to the pavement thickness required by frost condition design criteria for runway traffic, while the design curves for taxiway traffic required an 11-in. slab thickness. The satisfactory performance of the pavement under traffic up to 45 coverages per day indicates the criteria require adequate slab thicknesses for the conditions tested.

Summary of Traffic Tests on Rigid Pavements

The traffic test data from all rigid-pavement test areas are plotted on Figure 19, which shows the relationship between the percentage ratio of the actual slab thickness to the frost condition design thickness for the traffic-test wheel load, the number of traffic coverages and pavement behavior. The design thicknesses were determined using values of subgrade moduli from Corps of Engineers frost-condition design curves dated August 15, 1950 and rigid pavement design curves dated June 13, 1950. The plotted points are numbered to correspond with line numbers on Table 4 where the details of the traffic tests are presented.

The data from rigid pavement tests is much more limited than that obtained from flexible pavement tests as presented in Figure 16. From the available data, however, it may be seen that failure occurred in all test lanes except one when the existing pavement was less than 85 percent of that required by frost-condition design criteria for the traffic-test wheel loads. The exception was at Pierre where limited frost action occurred; the pavement withstood 18 coverages per day of a 25,000-lb. load (point 66), but failed under 54 coverages per day of the same wheel load (point 65).

There were two instances of failure where the slab thickness was 88 percent of that required by the frost condition design criteria. These failures occurred under the 20,000-lb. wheel-load traffic at Dow Field (points 47 and 50). The failed test lanes were subjected to approximately 26 coverages per day and slab design thickness of 8 in. was based on runway design curves. Based on taxiway design curves, these two lanes had slab thicknesses 78 percent of that required by design. Although the intensity of frost action at Dow Field was more severe than at the other traffic test sites the failure at 88 percent of runway design thickness is partially attributed to application of traffic at a rate greater than is anticipated by runway design criteria. At adjacent test lanes slabs of the same thickness with similar base and subgrade conditions withstood 20,000-lb. wheel-load traffic applied at a rate of 4 coverages per day (point 46) and failed when traffic was applied at more than 30 coverages per day (points 48 and 49).

Based on the available traffic test data on rigid pavements, satisfactory pavement performance resulted when the slab thickness along the test lane was in excess of 90 percent of that required by Corps of Engineers frost condition design criteria, while failures generally occurred when the slab thickness was less than 80 percent of frost condition design requirement.

Conclusions

Based on the results of CBR tests, plate-bearing tests, and traffic tests, to determine the effect of frost action on pavement supporting capacity, it is concluded that:

(1). Marked reduction in pavement supporting capacity occurs during the frost-melting period, after which the pavement gradually returns to normal strength as excess water escapes from the zone of frost melting, or as melt water from segregated ice is redistributed through the subgrade soil.

(2). The plate-bearing test is not a reliable measure of the percent reduction of traffic-wheel-load supporting capacity of flexible pavements in the frost-melting period.

(3). The ratio of the safe wheel load during the period of maximum weakening due to frost action, to the safe wheel load during the normal period, is approximately 0. 3 for flexible pavements and approximately 0. 8 for rigid pavements.

(4). Where frost-susceptible subgrades exist, combined thicknesses of flexible pavement and base course and rigid-pavement slab thicknesses that are at the boundary between satisfactory and unsatisfactory are indicated to be of the order of 80 to 90 percent of the thicknesses required by the frost condition design criteria which are presented in Chapter 4, Part XII of the Engineering Manual.

(5). The Engineering Manual frost-condition design criteria are reasonable, the small indicated factor of safety being considered justified to allow for heavy-traffic usage in emergencies and for other variations from assumed conditions, and as a preventative against excessive maintenance expenditures.

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