FROST ACTION STUDIES OF THIRTY SOILS IN NEW JERSEY

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Synopsis

Slab-movement and penetration-resistance studies were conducted on 30 soils exposed to fall, winter, and spring (1949-1950) weather conditions in central New Jersey. Samples of 6 cu. yd. each were compacted and topped with a 6-in.-thick concrete slab. Weighted plungers, passing through holes in the concrete slab, rested on the underlying sample. Elevations of slabs and plungers were recorded for a period of six months. Plunger penetration and slab movement are correlated with soil classification. High moisture content appeared to be as detrimental as freeze-thaw action.

The studies described in this report were initiated by the Joint Highway Research Project, Rutgers University and the New Jersey State Highway Department, to examine, qualitatively, the relative reaction of thirty New Jersey soil materials to weather conditions encountered during the Winter of 1949-50. Although, for the test period, temperatures were above normal and the depth of frost penetration was less than normal, it is believed that the findings serve to point up the significance of soil conditions that prevail when temperatures hover near freezing point.

The thirty soil specimens included residual derivatives from shale, basalt, and gneiss; and transported materials of marine, lacustrine, and glacial origin. The Engineering soil test values are listed in Table 1. Grain-size accumulation curves are plotted in Figures 1, 2 and 3. These materials were selected to represent the more prevalent soils in the Coastal Plain and Appalachian provinces of New Jersey.

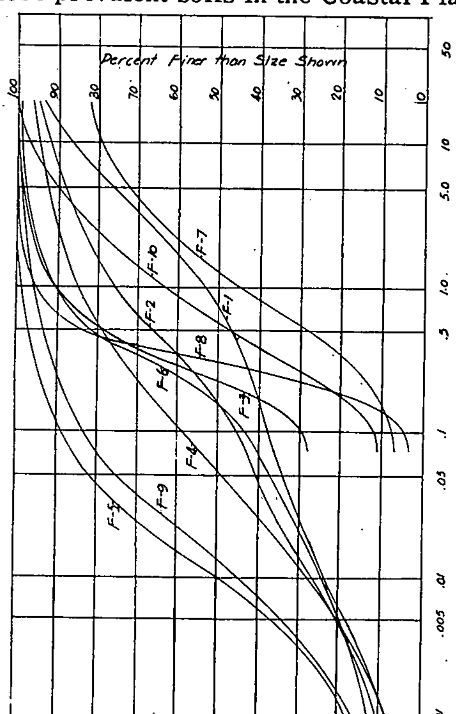

Figure 1. Grain Size Accumulation Curves Soils F-1 Thru F-10.

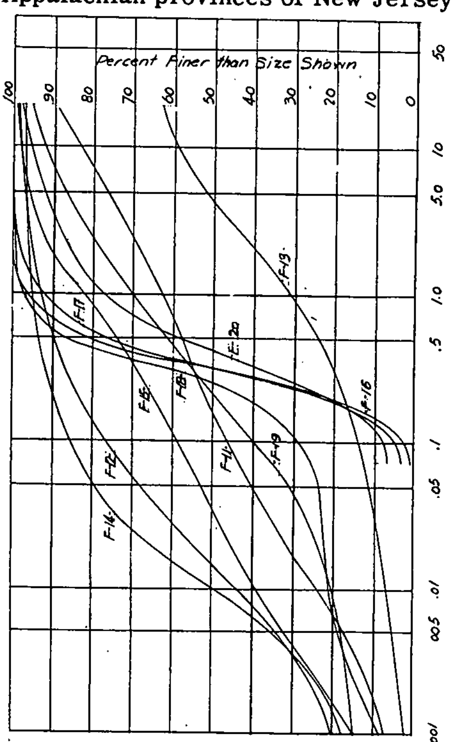

Figure 2. Grain Size Accumulation Curves Soils F-11 Thru F-20.

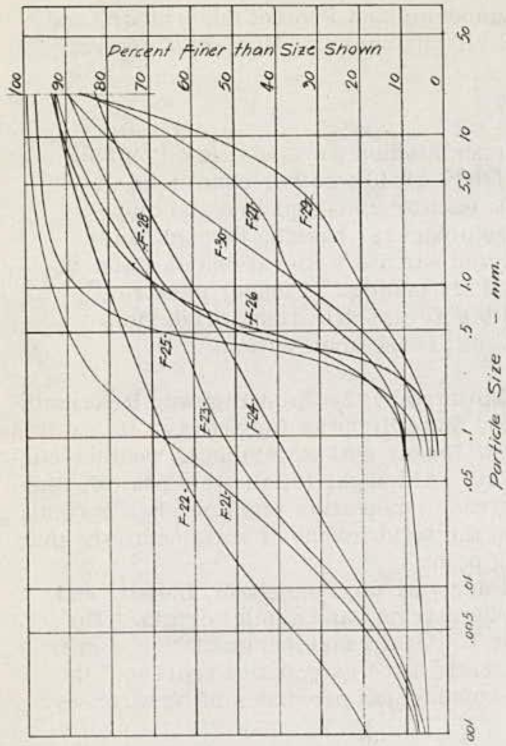

Figure 3. Grain Size Accumulation Curves Soils F-11 Thru F-30.

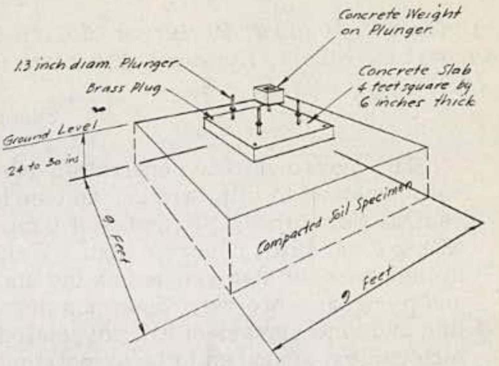

Figure 4. Frost Study Installation.

It is estimated that the twenty soil series listed in Table 1, cover 70 to 80 percent of the state's area. Group classification 1/ ranges from A-1-a to A-7-6, with group indices from 0 to 15.

Samples of the thirty soils (approximately 6 cu. yd. each) were compacted in a 24 to 30-in. deep trench, in 6-in. layers, using a pneumatic tamping device. The final dimensions of the soil specimen were 9 ft. sq. The top surface was leveled at approximately the natural ground surface and finished by rolling with a 400-lb. lawn roller.

A concrete slab, 4-ft. sq. by 6-in. thick, was cast on the center of each 9-ft. sq. soil specimen. The slabs were provided with four brass plugs located near the corners, and four one-and-one-half-in. diameter, brass-tube-lined, vertical holes at the quarter points of each diagonal. Monel-clad-steel plungers 1. 3 in. in diameter, were placed through the holes so as to bear on the prepared soil surface. The upper half of the clearance space between plunger and brass liner was packed with water-repellant grease, which was also plastered generously around the plunger above the slab to exclude water from rain and melting snow. The four plungers on each soil specimen were loaded with concrete weights to develop contact pressures on the soil of 25, 50, 75 and 100 psi. respectively. Additional sample material, placed around the slab, simulated the shoulder material along the edge of pavement slabs.

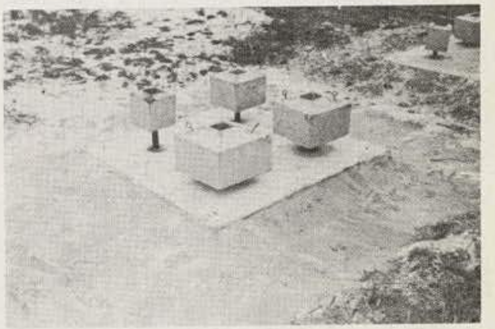

Figure 5. Concrete Slab and Weighted Plungers.

Dimensions and arrangements of each installation are shown in Figure 4. A photo of a single installation appears in

1/ Harold Allen et al., "Report of Committee on Classification of Materials for Subgrades and Granular Type Roads," Proceedings, Twenty-Fifth Annual Meeting, Highway Research Board, January, 1946.

Figure 5. Level readings at each corner of all slabs, and on the top of each of the weighted plungers, were recorded five times every two weeks, from November 1 (excepting installations F-27, 28, 29 and 30 which were completed November 28) to the end of April. Maximum and minimum daily temperatures were read at points 6 in. and also 6 ft. above the ground surface. A graphic, running record was plotted for each soil specimen, as shown in Figure 6. Daily weather and ground conditions were noted.

Some thought was given to applying statistical analysis methods to the many data recorded graphically on Figure 6 and its 29 counterparts. However, the lack of precise

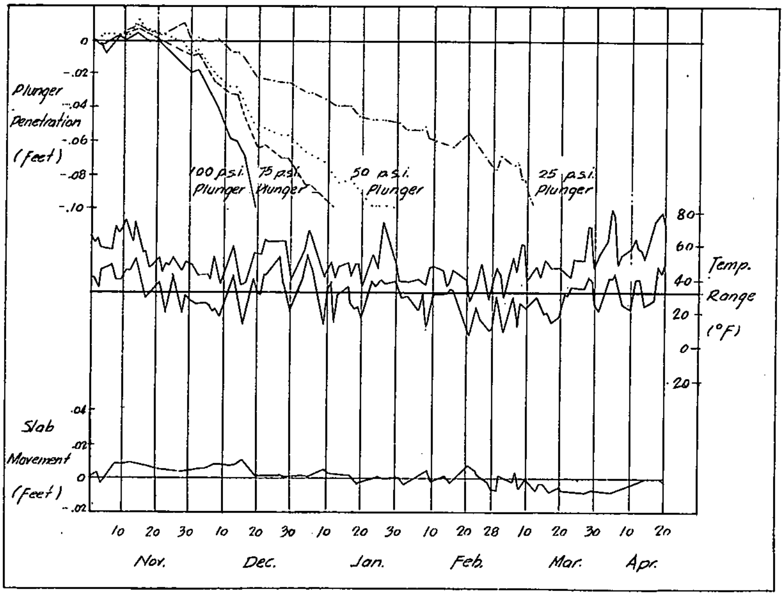

Figure 6. Typical Graphic Record - Soil F-10.

records on two important variables, subsurface temperature and moisture conditions, discounted the value of the statistical approach, and accordingly, the data were analyzed by plotting the length of time required for each plunger to attain a penetration of 0. 10 ft. This particular value was selected because, in the majority of cases, the rate of penetration increased perceptibly as penetration approached 0. 10 ft. When penetration reached or exceeded 0. 10 ft., the concrete weight was removed and readings discontinued. Nine of the 30 installations are shown in Figure 7, which was taken after many of the plungers had penetrated the maximum permissable amount. Note that, in many cases, the weights have been removed.

Figures 8, 9, and 10 show the duration of weighted plunger operation for the thirty soil specimens. The length of operation of the plungers on each specimen has been indicated by triple-line hatching for the period during which the penetration of the 100 psi. plunger was less than 0. 10 ft., by cross-hatching when the 75 psi. plunger was operating, by single-hatching when the 50 psi. plunger remained in operation, and by a blank bar when only the 25 psi. plunger was operative. The 0. 10 penetration value was normally attained by the 100, the 75, the 50, and finally, the 25 psi. plunger in the indicated sequence. Plungers reaching 0. 10 penetration out of the indicated sequence are identified on the bar diagrams by a line across the bar and a figure such as 25, 50, 75, or 100, denoting plunger pressure. A triangular arrowhead at the end of the bar indicates that one or more plungers had not attained the limiting penetration when readings were discontinued at the end of April. The brief periods of freezing weather in the middle of December and at the end of February are reflected in the number of plungers that exceeded the 0. 10-ft. penetration values at approximately the same dates.

Figure 11, Cumulative Degree-Day Curve, has been plotted with the same time-scale as Figures 8, 9, and 10. The term degree-day is obtained by taking the algebraic difference between 32 F. and the daily mean temperature. This value is plus when the daily mean temperature is below 32 F. and minus when above. The number of degree-days for one day is this algebraic difference. By plotting the cumulative degree-days versus time, the Cumulative Dgree-Day Curve is obtained. The Freezing Index is the maximum ordinate of the Cumulative Degree-Day Curve.

Slab movement corresponded roughly with plunger movement, but the difference in movement, as measured for the various soil specimens, was much less than the movement of the weighted plungers. Hence, the latter was utilized as a basis for analysis.

Figures 8, 9, and 10 demonstrate the superiority of granular soils in resisting winter weather conditions, and also the definitely poorer performance of silt-clay soils. Seven of the eleven materials classed as A-1-a, A-1-b and A-3 (specimens F-7, 8, 10, 16, 17, 20, 25, 26, 28, 29, and 30) continued to support one or more plungers for the duration of the test period.

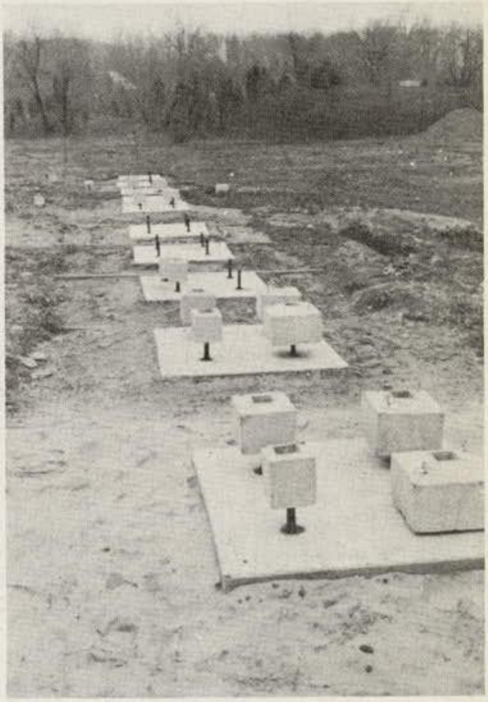

Figure 7. Arrangement of Field Installations.

With few exceptions, the fourteen soils classed as A-4, 5, 6, or 7, supported the more heavily weighted plungers for less than a week. The most erratic performer was the A-2-4 class. Specimens F-13 and F-27 exhibited a resistance to penetration comparable to the A-1-a and A-1-b soils. In contrast, specimens F-1 and F-18 showed less resistance than some of the A-4, 5, 6, and 7 materials. The test values in Table 1 reveals the reason for the wide range of A-2-4 soil performance. Note that specimens F-13 and F-27 bearly miss classification as A-1-a materials. Note also that specimens F-1 and F-18 are near the opposite end of the A-2-4 classification range. It appears reasonable to conclude that the A-2-4 class is too broad to accept as a significant guide in estimating frost reaction.

The characteristic winter in New Jersey includes several short-duration freezing periods, with interveneing periods of non-freezing temperatures. During the latter, temperatures are sufficiently high to completely thaw the ground, but not high enough to promote rapid evaporation from the ground surface. Also, the rainfall rate, approximately 4 in. per month, is nearly uniform throughout the year. Consequently, during much of the winter period, many soil materials are in a condition approaching saturation. It is believed that this may be responsible for the softening of pavement subgrade in climates where the freezing index is small.

The relatively mild winter of 1949-50, when coupled with the qualitative nature of

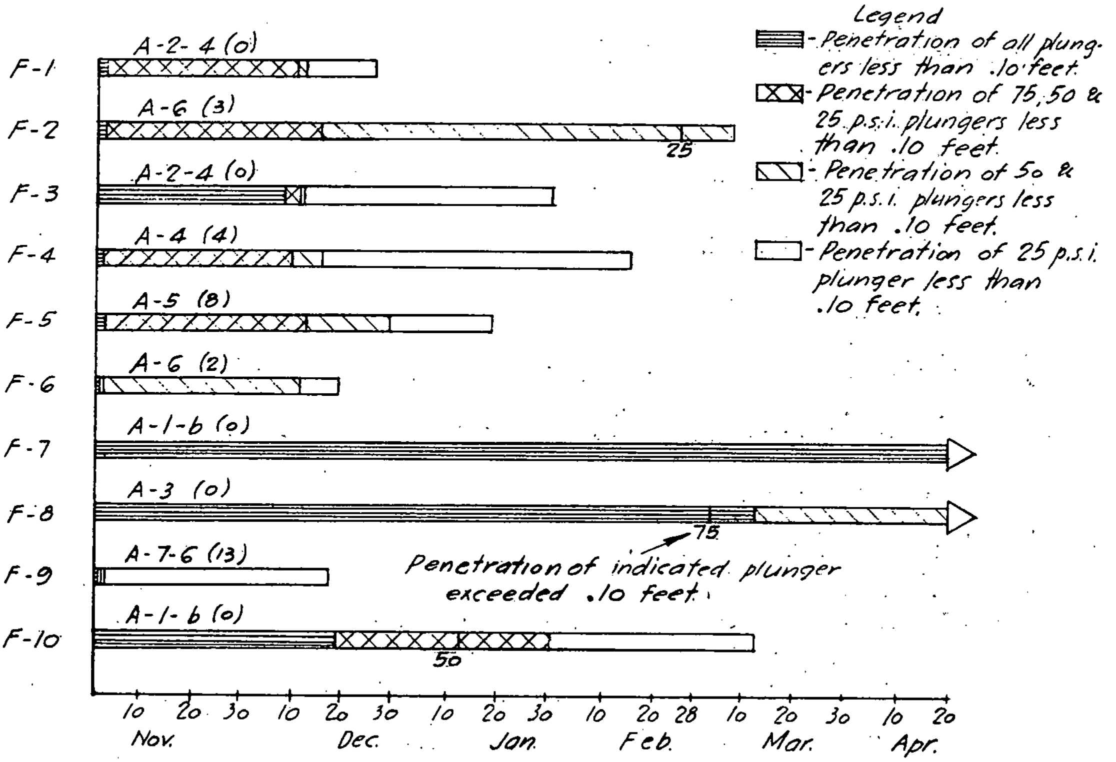

Figure 8. Duration of Weighted Plunger Operation - Soils F-1 Thru F-10.

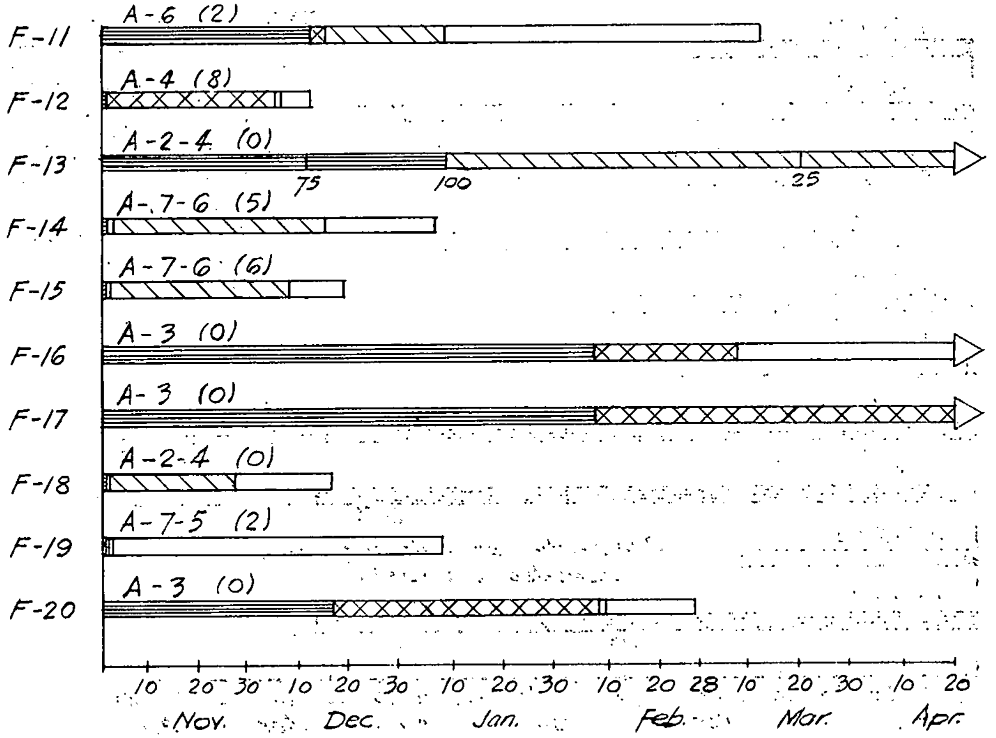

Figure 9. Duration of Weighted Plunger Operation - Soils F-11 Thru F-20.

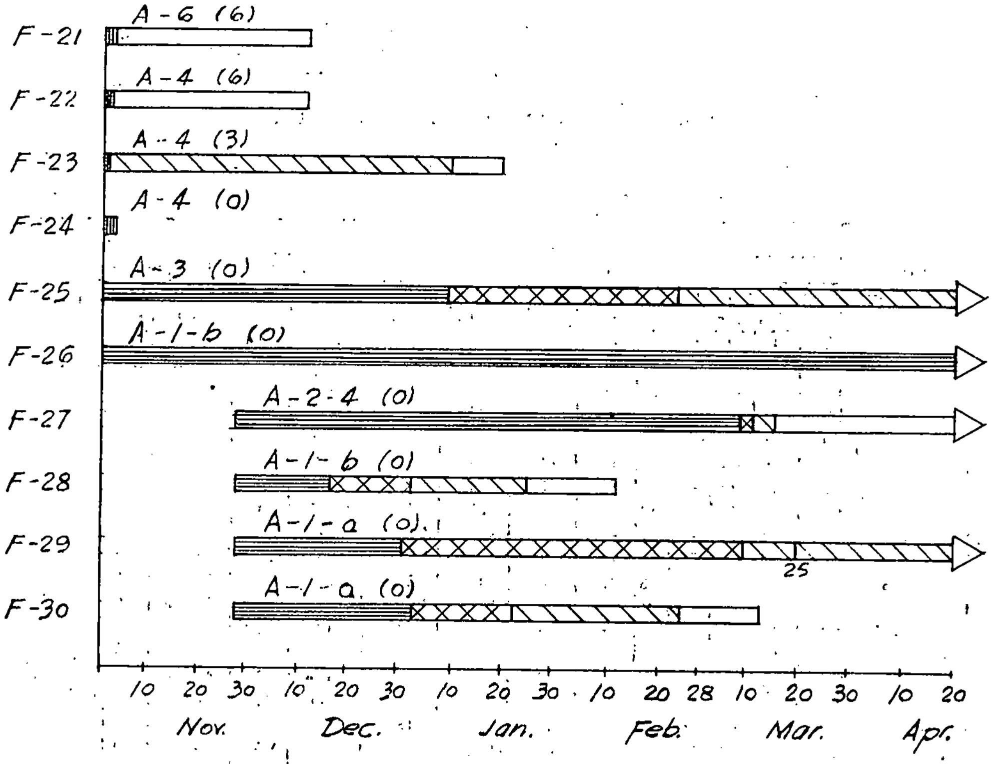

Figure 10. Duration of Weighted Plunger Operation - Soils F-21 Thru F-30.

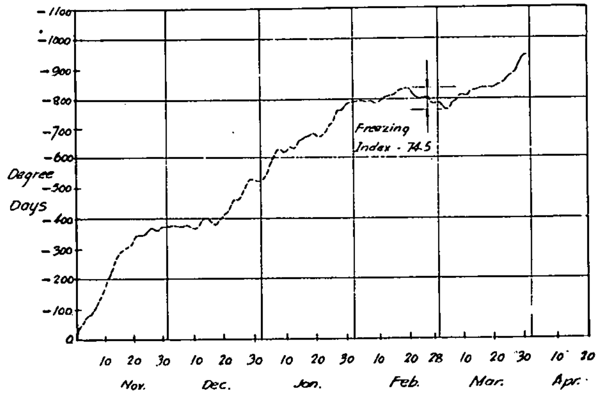

Figure 11. Cumulative Degree-Day Curve.

TABLE 1.

SUMMARY OF SOIL TEST DATA

Sample No.	Agronomic Name (as mapped 1917-27)	Test Results: Sieve Analysis, Cumulative Percent Passing ¾	4	10	40	200	Hyd. Anal.: Silt Sizes %	Clay Sizes %	Physical: Minus No. 40 L.L. %	P.I. %	Proctor: Max. Dens. p.c.f.	Opt. m.c. %	HRB Designation: Subgrade Group	Group Index	Remarks
F-1	Penn	94	76	63	46	35	16	19	31	7	106	17	A-2-4	0	
F-2	Wethersfield	94	86	82	64	43	19	23	32	16	119	13	A-6	3	
F-3	Dunellen	100	98	95	76	27	--	--	16	0	120	12	A-2-4	0	
F-4	Gloucester	96	90	86	79	56	31	21	25	6	109	16	A-4	4	
F-5	Whippany	100	100	100	98	83	43	37	41	7	100	22	A-5	8	
F-6	Sassafras	99	95	93	79	42	20	21	28	12	117	14	A-6	2	
F-7	Sassafras	88	67	61	28	7	--	--	N.L.	N.P.	120	12	A-1-b	0	
F-8	Sassafras	100	100	98	78	4	--	--	N.L.	N.P.	106	15	A-3	0	
F-9	Hagerstown	100	99	98	92	83	42	34	43	20	101	20	A-7-6	13	
F-10	Merrimac	100	90	77	41	11	--	--	N.L.	N.P.	125	9	A-1-b	0	
F-11	Chester	89	74	70	55	46	26	16	33	11	109	18	A-6	2	
F-12	Elkton	99	97	95	89	79	45	31	28	10	108	16	A-4	8	
F-13	Montalto	63	49	36	23	12	6	5	32	9	114	17	A-2-4	0	Grading meets A-1-a group req.
F-14	Croton	97	80	73	68	64	23	27	41	21	100	21	A-7-6	15	
F-15	Lansdale	99	87	85	69	55	21	32	41	15	95	26	A-7-6	6	
F-16	Lakewood	100	100	100	73	1	--	--	N.L.	N.P.	102	15	A-3	0	
F-17	Lakewood	100	99	98	64	3	--	--	N.L.	N.P.	106	14	A-3	0	
F-18	Collington	100	100	100	80	26	10	15	32	8	105	23	A-2-4	0	
F-19	Collington	96	91	87	69	39	12	18	48	14	97	27	A-7-5	2	
F-20	Portsmouth	99	87	84	56	7	--	--	N.L.	N.P.	118	10	A-3	0	
F-21	Holyoke	99	98	96	89	60	32	20	27	12	116	14	A-6	6	
F-22	Washington	93	88	85	76	64	25	36	31	10	104	18	A-4	6	
F-23	Dutchess	93	84	72	61	52	26	18	31	9	110	15	A-4	3	
F-24	Dover	82	72	66	54	37	20	14	31	9	112	16	A-4	0	
F-25	Subbase Sand Hills	97	96	93	54	6	--	--	N.L.	N.P.	106	15	A-3	0	
F-26	Subbase Farrington	93	86	78	36	10	--	--	N.L.	N.P.	120	12	A-1-b	0	
F-27	Subbase Nixon	85	48	40	24	10	3	6	25	7	122	12	A-2-4	0	Close to A-1-a
F-28	Subbase Perrineville	94	78	71	41	2	--	--	N.L.	N.P.	108	16	A-1-b	0	
F-29	Subbase Top Jamesburg	87	35	26	12	3	--	--	N.L.	N.P.	123	10	A-1-a	0	
F-30	Subbase Bot. Jamesburg	89	66	48	17	4	--	--	N.L.	N.P.	119	13	A-1-a	0	

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.