Corps of Engineers' Pavement Design In Areas of Seasonal Frost

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Definitions pertaining to design for frost conditions are presented. Conditions necessary for ice segregation and the need for considering the effects of frost action in pavement design are discussed. In addition, discussions are presented on frost-susceptible soils, the detrimental effects of frost action and investigational procedures for determining frost susceptibility and its magnitude. Base course composition requirements are discussed and frost design procedures are presented with examples. Also, requirements for field control of construction for frost conditions and standard laboratory frost susceptibility test procedures are given.

• SUBSTANTIAL design, construction, operation and maintenance difficulties were experienced by the Department of the Army in regions of seasonal frost and permafrost during World War II. The special problems of constructing pavements in these regions were especially apparent in the northern part of the 48 States, Canada and Alaska. As a result, the Frost Effects Laboratory was organized in the New England Division of the Corps of Engineers in 1944 and the Permafrost Division was established in the St. Paul district in 1945. These two organizations carried out extensive separate investigations in the period 1944 through 1953, and their successor organizations, the Arctic Construction and Frost Effects Laboratory, and now the U.S. Army Cold Regions Research and Engineering Laboratory, have continued these studies. Thus, the Corps of Engineers has carried out special investigations to improve the design of pavements in frost regions for nearly 20 years. In this time a great deal has been learned about the performance of pavements subject to frost action. Although much of the Corps of Engineers' effort has been aimed at development of designs to accommodate the great increases in weight and speed of aircraft and the requirements for longer and smoother runways, the design principles which have evolved are also applicable to roads and highways, even though the latter involve a much smaller range of wheel loadings. The first design criteria developed in these investigations were issued in the mid-1940's and successive revisions have been made in intervals since then.

This report summarizes the current practices (1). It includes three appendices which discuss the Corps of Engineers Standard Laboratory frost susceptibility test, field control of pavement construction for frost conditions, and design of base course drainage. Design examples are also given.

Paper sponsored by Committee on Frost Heave and Frost Action in Soils.

DEFINITIONS

The following specialized frost terms are used by the Corps of Engineers:

Frost and Soil Terms

Frost action. —A general term for freezing and thawing of moisture in materials and the resultant effects on these materials and structures of which they are a part or with which they are in contact.

Frost boil. —The breaking of a localized section of a highway or airfield pavement under traffic, and ejection of subgrade soil in a soft and soupy condition caused by the melting of the segregated ice formed by frost action.

Frost heave. —The raising of a surface due to formation of ice in the underlying soil.

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

Frost-susceptible soil. —Soil in which significant detrimental ice segregation will occur when the requisite moisture and freezing conditions are present.

Non-frost-susceptible materials. —Cohesionless materials such as crushed rock, gravel, sand, slag and cinders in which significant detrimental ice segregation does not occur under normal freezing conditions.

Ice segregation. —The growth of ice as distinct lenses, layers, veins and masses in soils, commonly, but not always oriented normal to the direction of heat loss.

Pavement pumping. —The ejection of water and soil through joints, cracks and along edges of pavements caused by downward slab movements actuated by the passage of heavy axle loads over the pavement after the accumulation of free water beneath the pavement.

Period of weakening. —An interval of the year which starts at the beginning of the frost-melting period and ends when the subgrade strength has returned to normal summer values.

Base or base course. —As used herein, all non-frost-susceptible material between the pavement surfacing layer and the subgrade. For frost design purposes, any frost-susceptible materials underlying the base, whether subbase, embankment, or natural in-place soils, are considered as subgrade.

Temperature Terms

Average daily temperature. —The average of the maximum and minimum temperatures for one day or the average of several temperature readings taken at equal time intervals during one day, generally hourly.

Mean daily temperature. —The average of the average daily temperatures for a given day for several years.

Degree-days. —The degree-days for any one day equals the difference between the average daily air temperature and 32 F. The degree-days are minus when the average daily temperature is below 32 F (freezing degree-days) and plus when above (thawing degree-days). Figure 1 shows curves obtained by plotting cumulative degree-days against time.

Freezing index. —The number of degree-days between the highest and lowest points on a curve of cumulative degree-days versus time for one freezing season. It is used as a measure of the combined duration and magnitude of below freezing temperatures occurring during any given freezing season. The index determined for air temperatures at 4.5 ft above the ground is commonly designated as the air freezing index, and that determined for temperatures immediately below a surface is known as the surface freezing index.

Design freezing index. —The average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years are not available, the air freezing index

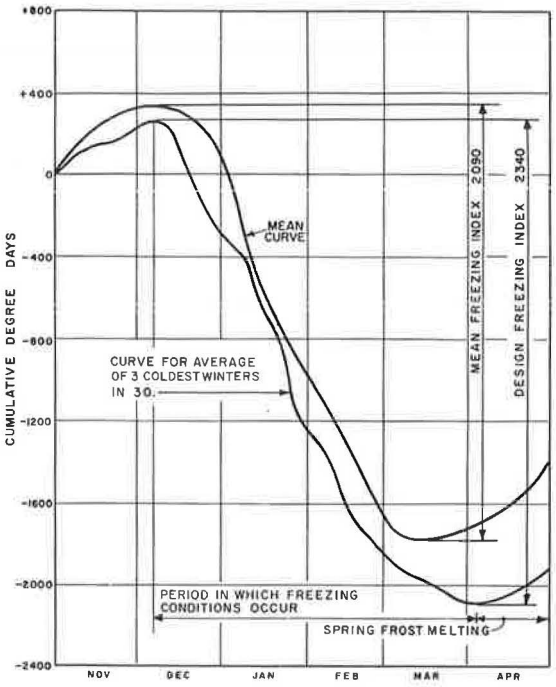


Figure 1. Determination of freezing index.

for the coldest winter in the latest 10-year period may be used. To avoid the necessity for adopting a new and only slightly different freezing index each year, the design freezing index at a site with continuing construction need not be changed more often than once in 5 years unless the more recent temperature records indicate a significant change in thickness design requirements for frost (Fig. 1).

Mean freezing index. — The freezing index determined on the basis of mean temperatures. The period of record over which temperatures are averaged is usually a minimum of 10 years (preferably 30) and should be the latest available (Fig. 1).

NEED FOR CONSIDERING EFFECTS OF FROST IN PAVEMENT DESIGN

The detrimental effects of frost action in subsurface materials are manifested by non-uniform heave of pavements or other structures during the winter as a result of ice segregation, and by loss of strength of affected soils with a corresponding reduction in load-supporting capacity during the period of weakening which ensues. Other related detrimental effects are possible loss of compaction, development of permanent roughness, restriction of drainage by the frozen strata, and cracking and deterioration of the pavement surface. In pavements, these effects may result in hazardous operational conditions, excessive maintenance, or pavement destruction.

Except in cases such as airfield pavement overrun areas where other criteria are specifically established, Corps of Engineers' design policy for permanent-type pavements requires that they be designed so that there will be no interruption of traffic at any time due to differential heave, reduction in load-supporting capacity, or deterioration of the pavement resulting from frost action.

CONDITIONS NECESSARY FOR ICE SEGREGATION

Three conditions of soil, temperature, and water must be present simultaneously in order for ice segregation to occur in the subsurface materials:

(a) The soil must be frost susceptible.

(b) Freezing temperatures must penetrate the soil. In general, the thickness of ice layers is inversely proportional to the rate of penetration of freezing temperature into the soil.

(c) A source of water must be available, such as an underlying ground water table, infiltration, an aquifer, or the water held within the voids of fine-grained soils.

The degree of ice segregation which will occur in any given case is markedly influenced by environmental factors such as transitions between cut and fill, lateral flow of water from side of cuts, and localized pockets of perched ground water.

DESCRIPTION OF ICE SEGREGATION IN SOILS

A strong attraction exists between unfrozen water immediately below the plane of freezing and ice crystals forming at the freezing plane. The water flowing to the cry-

stals solidifies on the crystals as new ice. Continuing crystal growth leads to formation of an ice lens. A lens continues to grow in thickness in the direction of heat transfer, and at the same time laterally, until ice formation at a lower elevation cuts off the source of water, or until the temperature of the soil just below the surface of ice formation rises above the normal freezing point.

EXTENT OF FREEZING CONDITIONS IN THE NORTHERN HEMISPHERE

The extent and distribution of freezing conditions in the Continental United States, based on U. S. Weather Bureau data, are shown in Figures 2, 3 and 4.

The relationship between mean air freezing index and values computed on various other statistical bases is shown in Figure 5.

Distribution of freezing conditions in Canada, Alaska and Greenland is shown in Figures 6 and 7.

FROST-SUSCEPTIBLE SOILS

The potential intensity of ice segregation in a soil is dependent to a large degree on its void sizes, and for pavement design purposes may be expressed as an empirical function of grain size as follows:

> Most inorganic soils containing 3 percent or more of grains finer than 0.02 mm in diameter by weight are frost susceptible for pavement design purposes. Gravels, well-graded sands and silty sands, especially those approaching the theoretical maximum density curve, which contain 1 1/2 to 3 percent finer by weight than 0.02 mm size should be considered as possibly frost susceptible and should be subjected to a standard laboratory frost-susceptibility test (Appendix B) to evaluate actual behavior during freezing. Uniform sandy soils may have as high as 10 percent of grains finer than 0.02 mm by weight without being frost susceptible. However, their tendency to occur interbedded with other soils usually makes it impractical to consider them separately.

Soils classed as frost susceptible under the above criteria or determined as such by standard laboratory freezing tests, may be expected to develop significant ice segregation if frozen at normal rates with free water readily available.

Figure 8 shows results of laboratory frost susceptibility tests performed at the former Arctic Construction and Frost Effects Laboratory on natural soil gradations ranging from well-graded gravels to fat clays, using the standardized freezing procedure. Average daily rate of heave is plotted against percentage finer by weight than the 0.02 mm size. Test specimens were 6 in. high and 6 in. in diameter and were frozen with water made available at the base. The soils are representative of materials found in frost areas. The grain size distribution, dry unit weight, void ratio, uniformity and curvature coefficients, Atterberg limits, average rate of heave and frost susceptibility classification for each test specimen are given in Table 1.

The four diagrams at the left side of Figure 8 show individual test results for each of the four major soil groups: gravel, sand, silt and clay. A family of overlapping envelopes is shown at the right of Figure 8, which depicts the laboratory test results by various individual soil groupings as defined by the Unified Soil Classification System. A frost susceptibility adjective classification scale relating the degree of frost susceptibility to the exhibited laboratory rate of heave is shown at the left side of the latter diagram. Because of the severity of the laboratory test, the rates of heave shown in Figure 8 are not rates which may be expected under normal field conditions. Soils which heave in the standard laboratory tests at average rates up to 1 mm per day are considered satisfactory for use under pavements in frost areas unless unusually severe conditions of moisture availability and temperature are anticipated. In Figure 8, soils classed as non-frost susceptible under the criteria given at the start of this section are not necessarily free from susceptibility to frost heaving. Also, soils which are

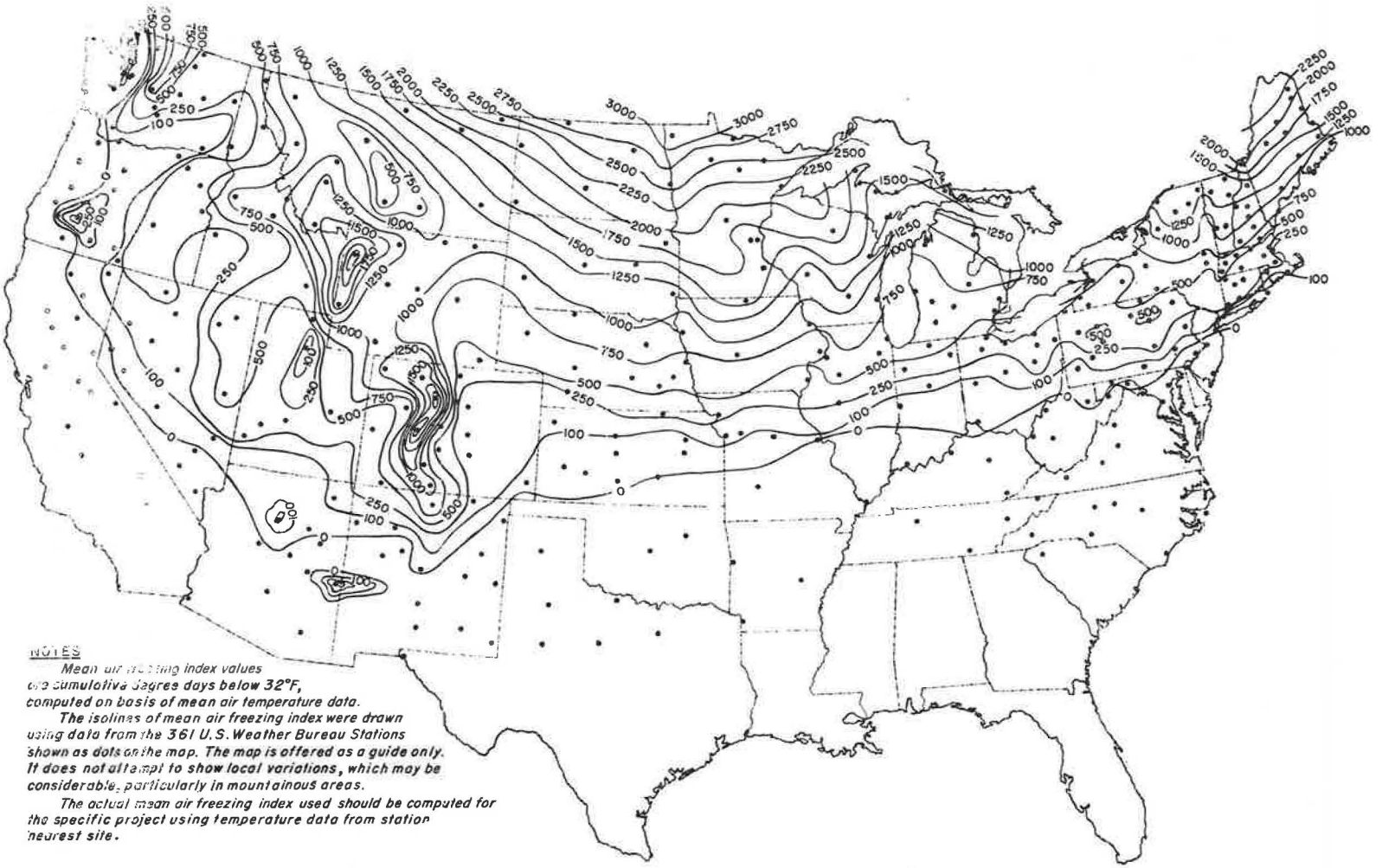


Figure 2. Distribution of mean air freezing index values in Continental United States.

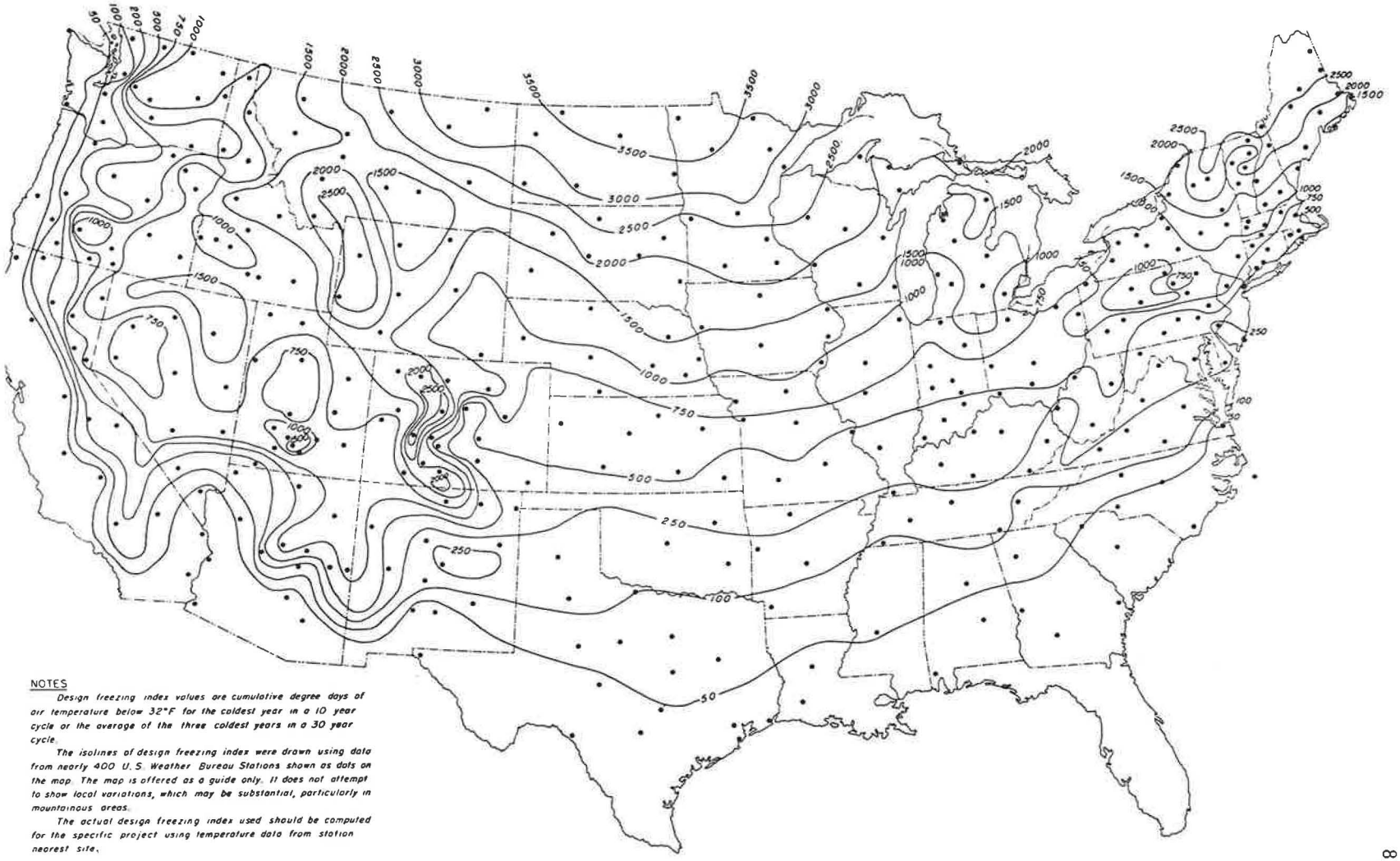


Figure 3. Distribution of design freezing index values in Continental United States.

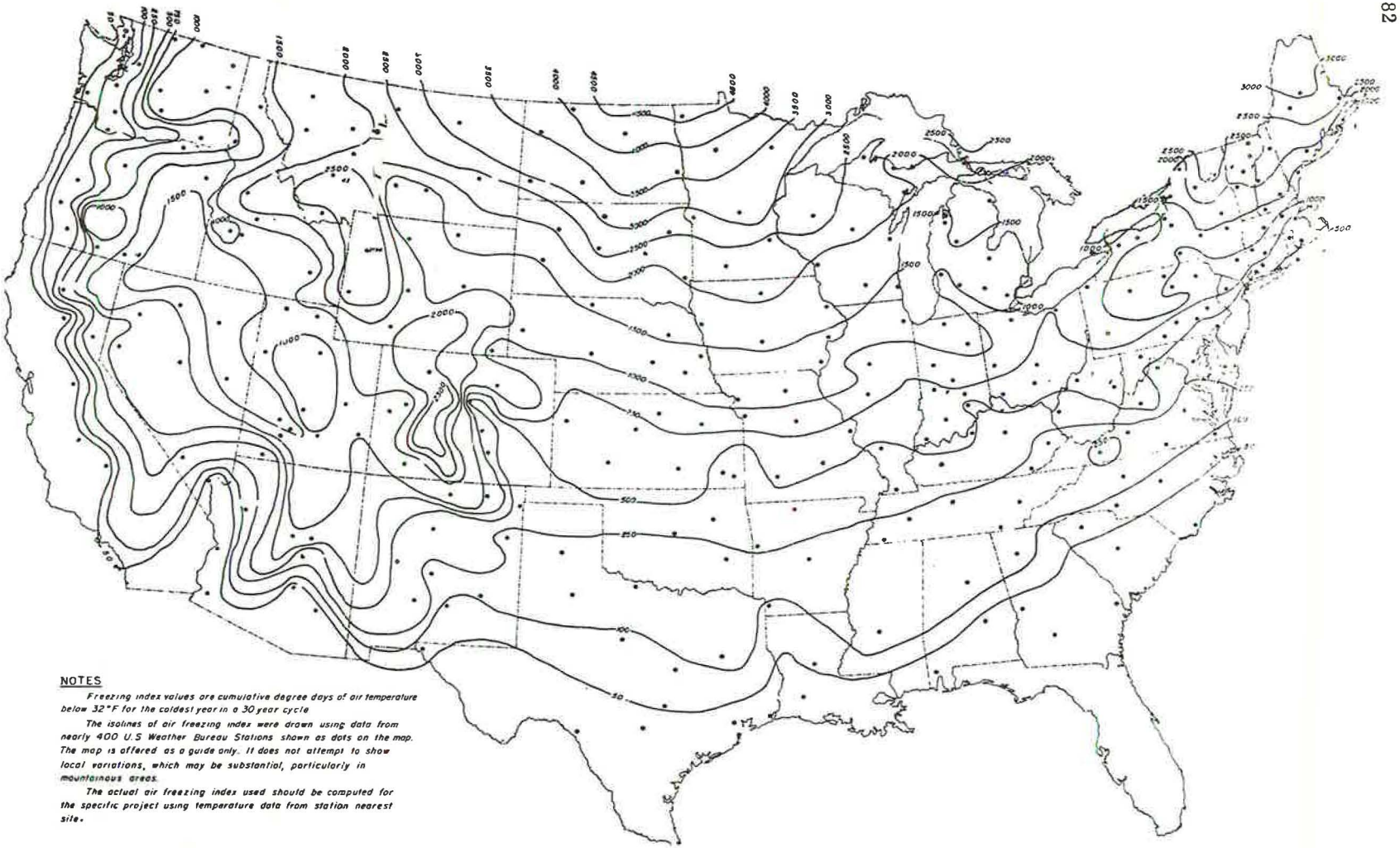
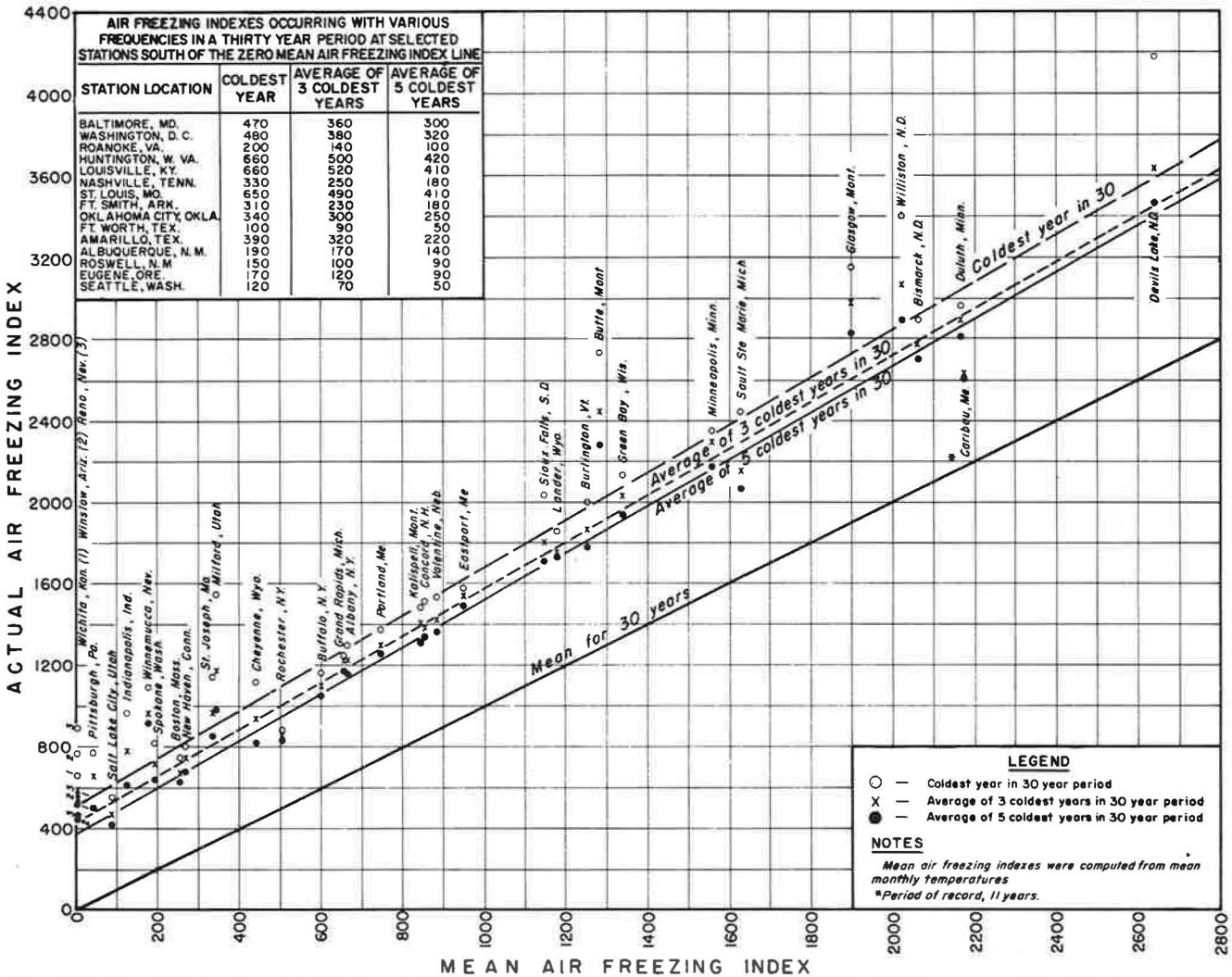


Figure 4. Distribution of air freezing index values in Continental United States for the coldest year in 30.



AIR FREEZING INDEXES OCCURRING WITH VARIOUS FREQUENCIES IN A THIRTY YEAR PERIOD AT SELECTED STATIONS SOUTH OF THE ZERO MEAN AIR FREEZING INDEX LINE

STATION LOCATION	COLDEST YEAR	AVERAGE OF 3 COLDEST YEARS	AVERAGE OF 5 COLDEST YEARS
BALTIMORE, MD.	470	360	300
WASHINGTON, D. C.	480	380	320
ROANOKE, VA.	200	140	100
HUNTINGTON, W. VA.	660	500	420
LOUISVILLE, KY.	660	520	410
NASHVILLE, TENN.	330	250	180
ST. LOUIS, MO.	650	490	410
FT. SMITH, ARK.	310	230	180
OKLAHOMA CITY, OKLA.	340	300	250
FT. WORTH, TEX.	100	90	50
AMARILLO, TEX.	390	320	220
ALBUQUERQUE, N. M.	190	170	140
ROSWELL, N. M	150	100	90
EUGENE, ORE.	170	120	90
SEATTLE, WASH.	120	70	50

Figure 5. Relationship between mean air freezing index and freezing indexes during colder years for 30 consecutive years.

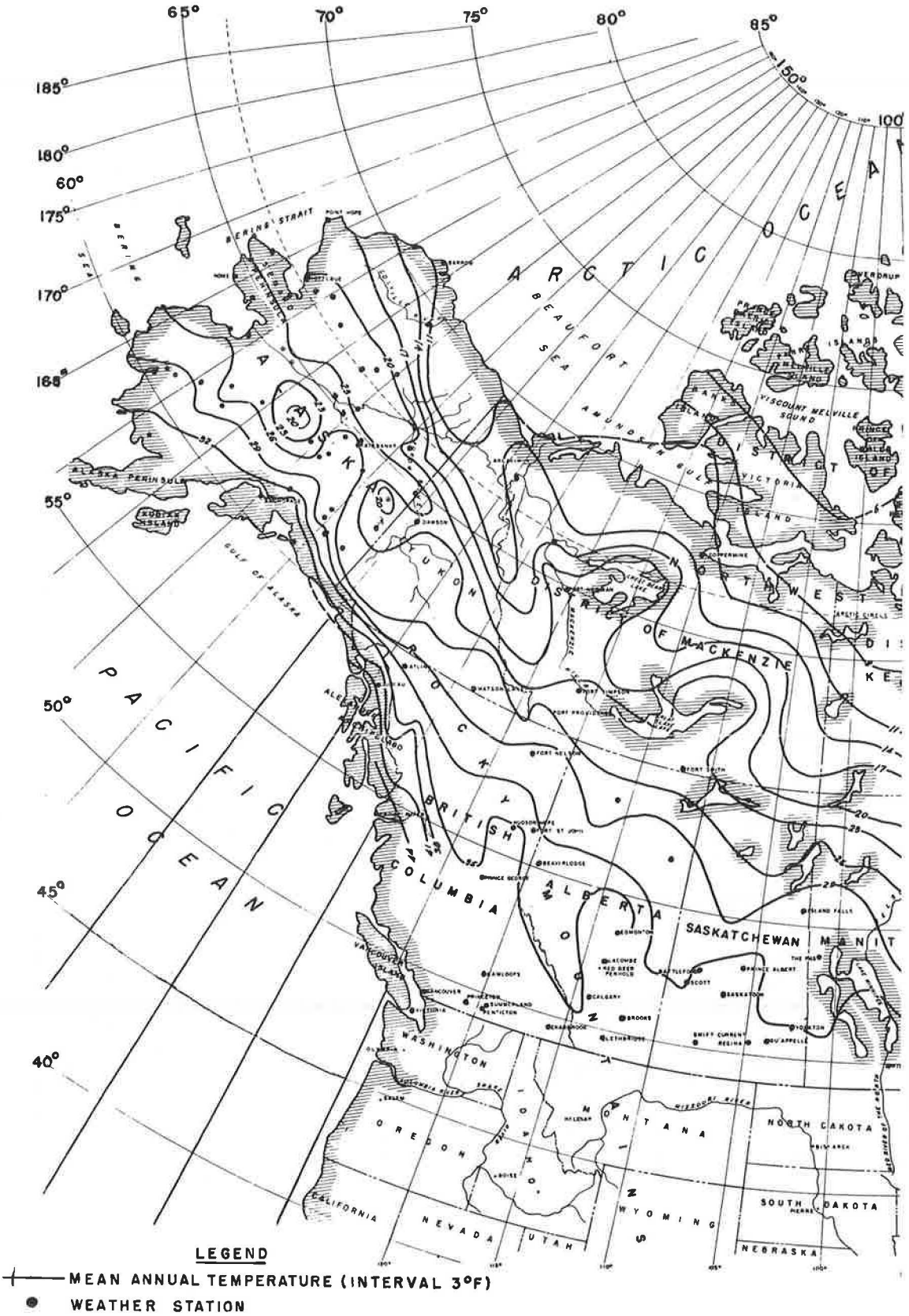
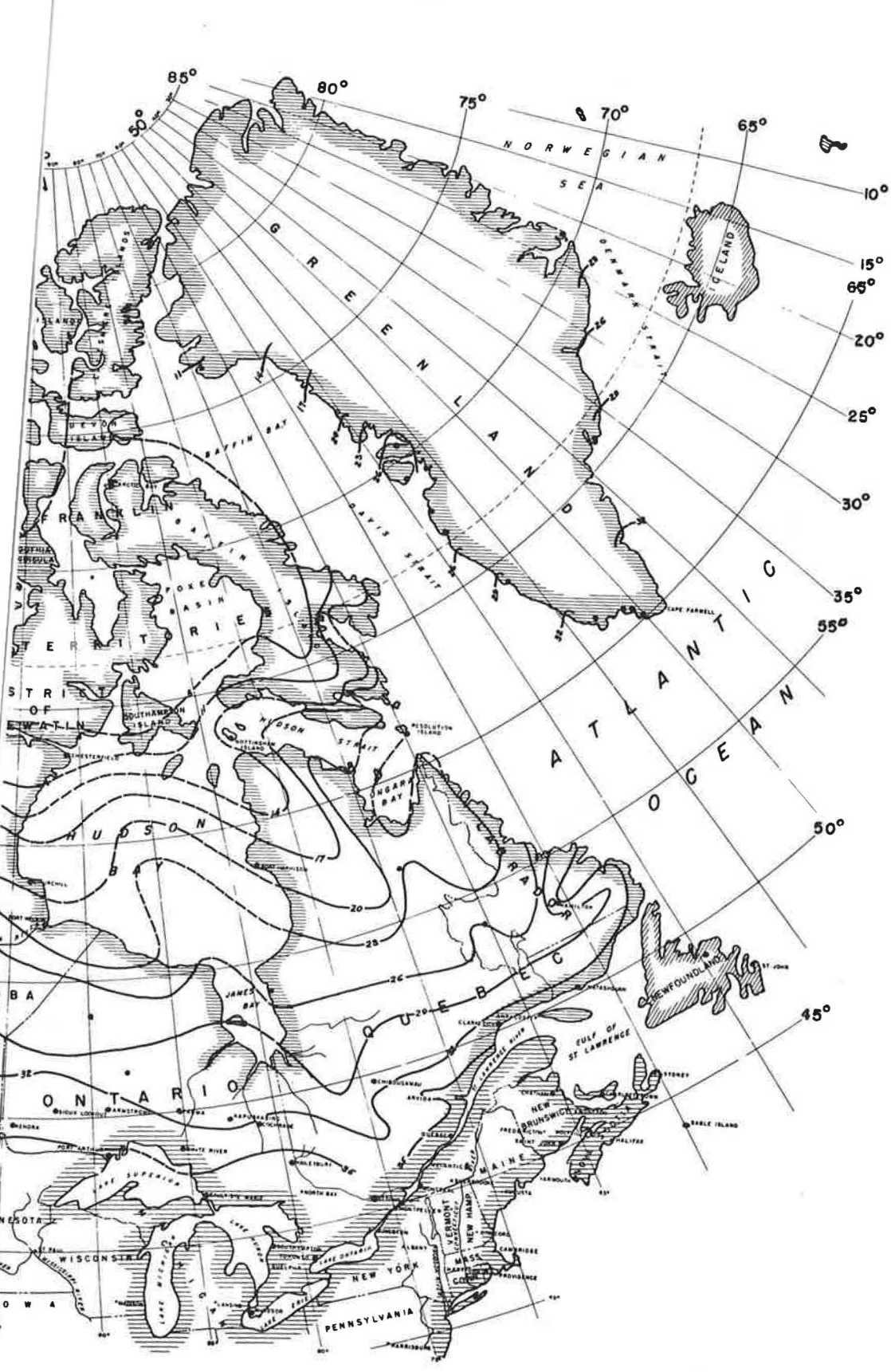


Figure 6. Isolines of mean annual



perature in Canada, Alaska and Greenland.

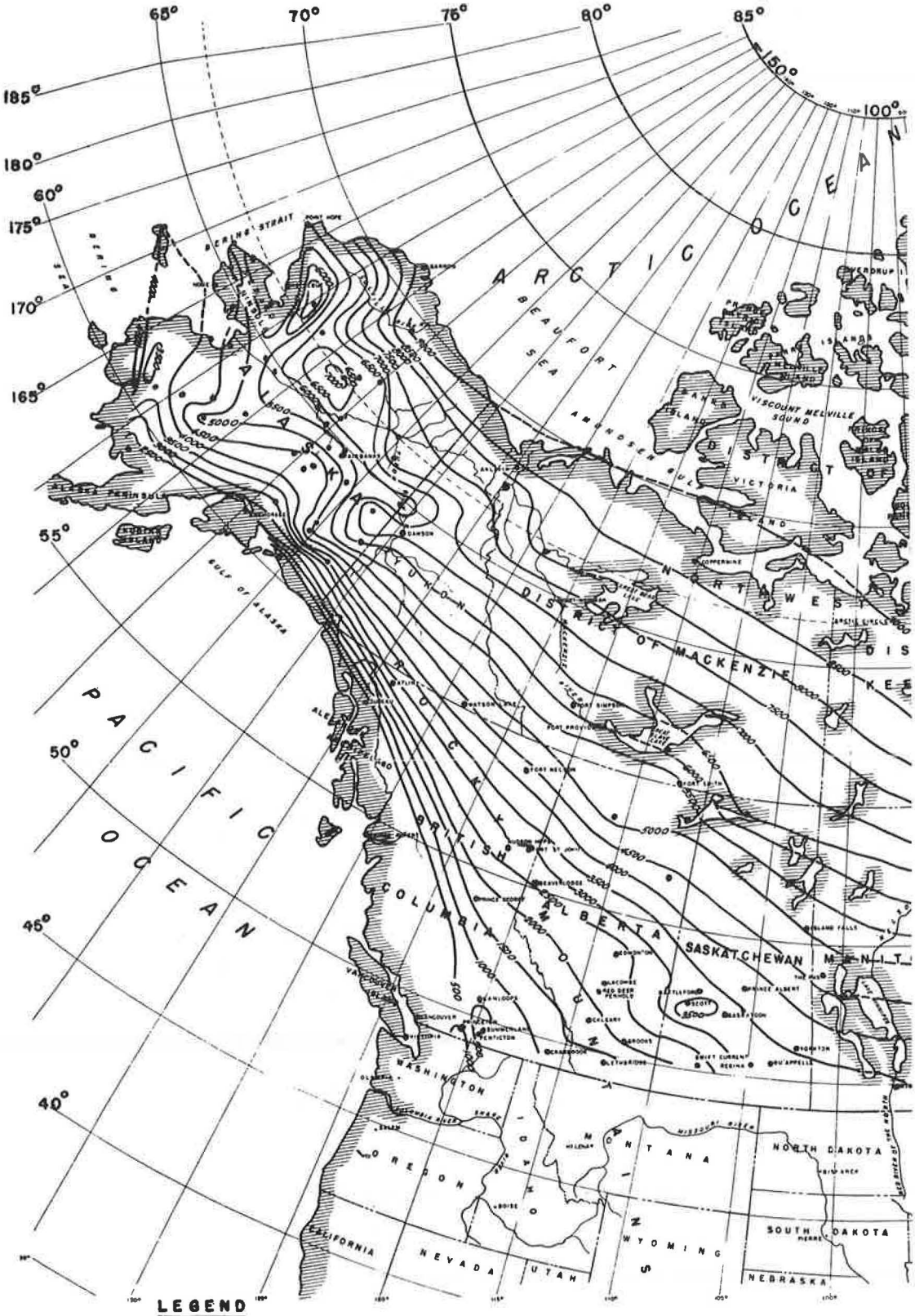


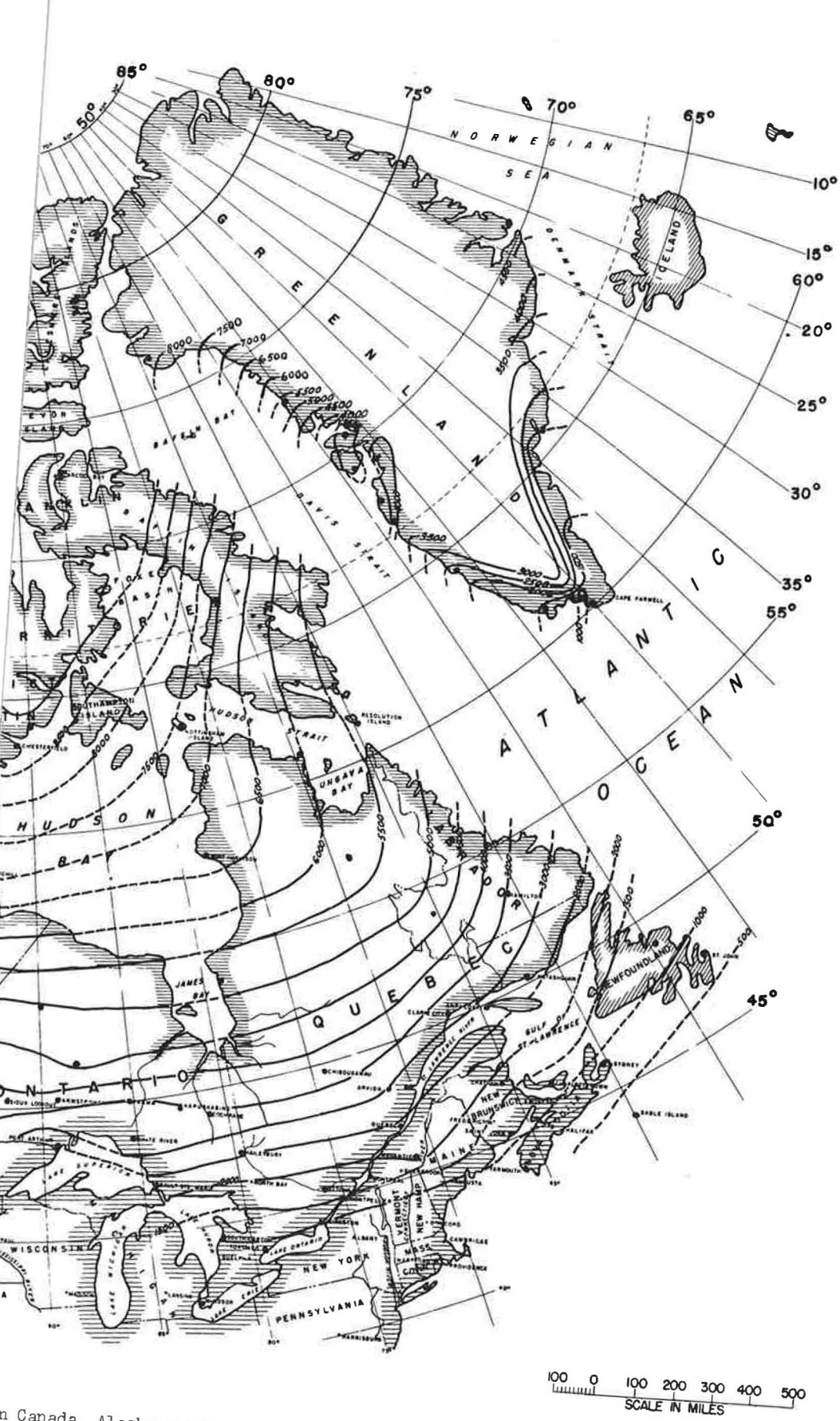
Figure 7. Isolines of mean freezing

Silty GRAVELS	GM	2-1/2	55	28	28	15	6.3	4.1	2.0	139	0.218	167	0.9	Non-plastic		2.9	Medium
		1	58	51	38	27	10	5.0	2.2	127	0.338	270	0.1	"	"	4.4	High
Clayey Sandy GRAVELS	GP-GC	3/4	37	25	14	11	6.6	5.0	3.2	134	0.265	145	16	24.9	8.7	2.0	Medium
		3/4	33	23	15	12	8.7	6.9	(5.0)	131	0.250	315	32	22.3	8.1	1.2	Low
Clayey Silty GRAVELS	GM-GC	1-1/2	54	45	30	20	15	9.0	5.0	129	0.320	485	1.9	24.8	6.8	3.7	Medium
Clayey GRAVELS	GC	1-1/2	48	42	36	22	17	15	12	133	0.252	4000	1.2	42.6	24.6	3.4	Medium
						SANDS											
SANDS and Gravelly SANDS	SW	2	53	36	13	3.8	1.8	1.4	0.9	129	0.277	20	1.1	Non-plastic		0.8	Very low
		2	58	40	15	4.9	2.3	1.5	1.1	136	0.254	23	1.3	"	"	2.4	Medium
		2	58	40	15	4.9	2.3	1.5	1.1	136	0.250	23	1.3	"	"	2.2	Medium
	SP	1-1/2	59	50	20	2.1	1.0	0.8	0.5	130	0.281	24	0.3	Non-plastic		0.4	Negligible
		1-1/2	59	50	20	2.1	1.0	0.8	0.5	130	0.283	24	0.3	"	"	0.3	Negligible
		1	72	24	7.0	3.0	1.3	0.9	0.5	139	0.440	5.3	2.0	"	"	0.2	Negligible
		2	85	70	8.6	3.6	1.3	1.2	(1.0)	116	0.469	3.4	0.2	"	"	0.6	Very low
		2	70	47	6.9	3.4	1.4	1.3	(0.9)	125	0.368	4.7	1.3	"	"	0.5	Negligible
		1-1/2	72	68	36	4.5	1.8	1.4	1.0	124	0.338	5.1	0.7	"	"	0.3	Negligible
		1-1/2	72	68	36	4.5	1.8	1.4	1.0	125	0.329	5.1	0.7	"	"	0.6	Very low
Silty Gravelly SANDS	SW-SM	3/4	57	42	16	5.0	1.4	(1.0)	(0.5)	111	0.532	27	1.1	Non-plastic		0.1	Negligible
		1	68	48	12	5.6	2.9	2.3	1.8	117	0.467	10	1.0	"	"	1.5	Low
		1-1/2	68	60	11	7.0	3.5	2.3	1.2	128	0.365	6.7	1.4	"	"	0.9	Very low
		2	69	52	20	9.6	3.8	(2.1)	(1.8)	135	0.268	28	1.8	"	"	2.8	Medium
		2	68	55	26	9.1	4.0	2.9	1.8	139	0.214	31	1.1	19.3	4.3	2.7	Medium
		2	68	55	26	9.1	4.0	2.9	1.8	138	0.224	31	1.1	19.3	4.3	2.5	Medium
		1-1/2	70	60	29	9.7	4.4	3.2	2.5	131	0.285	24	1.2	Non-plastic		1.2	Low
		1	57	31	20	8.7	5.0	3.5	2.0	144	0.179	43	1.1	"	"	6.3	High
		1-1/2	57	48	30	12	8.7	7.1	5.8	137	0.253	183	1.1	19.0	2.0	1.3	Low

TABLE 1

STANDARD LABORATORY FROST-SUSCEPTIBILITY TESTS ON NATURAL SOILS[a] (Continued)

UNIFIED SOIL CLASSIFICATION		MAX. SIZE	GRAIN SIZE[b] mm-% Finer							INITIAL DRY UNIT WEIGHT[c]	INITIAL VOID RATIO	COEFFICIENTS		ATTERBERG LIMITS		AVERAGE RATE OF HEAVE	FROST SUSCEPTIBILITY CLASSIFICATION[e]
SOIL TYPE	SYMBOL	in.	4.76	2.00	0.42	.074	0.02	0.01	.005	pcf	e	C_u[d]	C_c[d]	LL	PI	mm/day	
					SANDS (Cont'd)												
Silty Gravelly, SANDS (Cont'd)	SP-SM	3/4	60	55	39	9.7	1.8	0.8	-	137	0.246	62	0.2	Non-plastic		1.4	Low
		2	84	67	11	5.3	1.9	1.7	(1.0)	121	0.421	4.0	1.6	"	"	0.6	Very low
		-	-	100	71	8.8	2.2	1.3	-	114	0.473	4.3	1.5	"	"	0.2	Negligible
		-	-	100	86	5.0	2.6	2.4	1.8	115	0.450	2.0	0.9	"	"	0.1	Negligible
		-	-	-	100	6.3	2.6	2.2	1.7	109	0.516	1.9	1.0	"	"	0.1	Negligible
		-	-	-	100	6.3	2.6	2.2	1.7	109	0.514	1.9	1.0	"	"	0.3	Negligible
		1-1/2	73	48	11	5.2	2.7	2.2	1.8	129	0.316	8.1	0.9	"	"	0.5	Negligible
		3/4	66	50	18	6.0	2.8	1.7	1.0	133	0.278	15	0.9	"	"	1.3	Low
		1-1/2	74	51	25	6.9	3.2	2.7	1.8	127	0.329	15	0.6	"	"	1.1	Low
		1-1/2	77	57	27	7.1	3.3	3.0	2.6	127	0.329	13	0.7	"	"	1.3	Low
		3/4	99	97	84	10	3.3	3.0	2.0	113	0.484	3.4	1.8	"	"	0.8	Very low
		3/4	99	97	84	10	3.3	3.0	2.0	112	0.487	3.4	1.8	"	"	0.8	Very low
		1-1/2	98	98	80	8.8	3.3	2.0	0.9	108	0.518	2.8	1.4	"	"	0.8	Very low
		-	-	100	82	9.0	3.4	2.0	0.9	106	0.542	2.8	1.4	"	"	0.4	Negligible
		-	-	100	82	9.0	3.4	2.0	0.9	105	0.552	2.8	1.4	"	"	0.4	Negligible
		2	56	44	17	6.0	3.5	2.4	-	140	0.222	28	0.7	"	"	3.6	Medium
		1	66	49	22	6.5	3.9	3.8	3.0	134	0.238	17	0.9	"	"	0.8	Very low
		3/4	79	69	13	8.1	4.1	3.7	1.5	128	0.361	6.4	3.2	"	"	1.0	Low
		3/4	92	90	67	9.0	4.5	2.9	1.8	115	0.438	4.2	1.2	"	"	0.9	Very low
		3/4	92	90	67	9.0	4.5	2.9	1.8	119	0.396	4.2	1.2	"	"	2.7	Medium
		1-1/2	92	90	67	9.0	4.5	2.9	1.8	120	0.367	4.2	1.2	"	"	5.2	High
		3/4	71	63	46	10	4.5	4.0	1.8	138	0.215	20	0.3	"	"	1.9	Low
		1-1/2	59	55	39	8.5	4.5	2.5	1.6	134	0.280	6.0	0.2	"	"	1.4	Low
		1	80	54	24	6.5	4.9	3.8	3.0	135	0.228	15	0.8	"	"	1.0	Low
		1	63	51	30	7.0	5.0	3.0	2.0	137	0.212	28	0.4	"	"	1.1	Low
		1	71	55	27	7.8	5.0	4.0	3.2	132	0.250	16	0.6	"	"	1.2	Low
		2	61	50	29	9.7	5.1	4.2	3.1	130	0.289	52	0.7	"	"	2.1	Medium
		2	94	93	83	10	5.6	5.0	3.6	120	0.364	3.0	1.5	"	"	2.3	Medium
Silty SANDS	SM	-	100	99	95	28	1.5	1.2	0.9	107	0.567	2.5	0.9	"	"	0.1	Negligible
		-	100	99	95	28	1.5	1.2	0.9	109	0.540	2.5	0.9	"	"	0.1	Negligible
		-	-	-	100	33	2.5	(2.0)	-	112	0.551	1.6	1.0	"	"	1.7	Low
		-	-	-	100	33	2.5	(2.0)	-	111	0.565	1.6	1.0	"	"	0.9	Very low
		-	-	100	86	20	2.5	(1.8)	-	115	0.458	4.1	1.2	"	"	0.2	Negligible
		-	100	99	95	20	3.8	2.2	-	114	0.434	3.7	1.3	"	"	2.2	Medium



n Canada, Alaska and Greenland.

TABLE 1

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UNIFIED SOIL CLASSIFICATION		MAX. SIZE	GRAIN SIZE[b] mm-% Finer							INITIAL DRY UNIT WEIGHT[b]	INITIAL VOID RATIO	COEFFICIENTS		ATTERBERG LIMITS		AVERAGE RATE OF HEAVE	FROST SUSCEPTIBILITY[e] CLASSIFICATION
SOIL TYPE	SYMBOL	in.	4.76	2.00	0.42	.074	0.02	0.01	.005	pcf	e	C_u[d]	C_c[d]	LL	PI	mm/day	
						GRAVELS											
GRAVELS and Sandy GRAVELS	GW	1	40	25	5.0	1.5	0.7	0.4	0.2	124	0.395	14	1.0	Non-plastic		0.5	Very low[f]
		3/4	49	30	10	3.0	0.8	0.8	0.5	109	0.589	17	1.4	"	"	0.1	Negligible[f]
		1-1/2	30	13	6.0	2.9	1.1	0.7	0.4	126	0.462	8.2	1.7	"	"	0.1	Negligible
		2	40	26	10	3.7	1.9	1.5	0.9	132	0.249	22	1.6	"	"	0.8	Very low
		3/4	49	36	12	4.7	2.4	1.7	0.9	138	0.231	20	1.1	"	"	2.2	Medium
		3/4	42	29	13	4.9	2.4	(1.7)	(0.9)	131	0.296	33	2.4	"	"	1.0	Low
		3/4	42	29	13	4.9	2.4	(1.7)	(0.9)	131	0.300	33	2.4	"	"	1.0	Low
		3/4	35	17	7.0	4.8	2.6	1.5	1.0	130	0.322	8.2	1.8	18.0	3.0	0.7	Very low
		3/4	35	17	7.0	4.8	2.6	1.5	1.0	132	0.309	8.2	1.8	18.0	3.0	0.3	Negligible
		3/4	49	32	11	4.9	3.2	2.6	2.0	137	0.237	24	1.4	Non-plastic		2.0	Medium
		2	40	27	8.0	4.6	3.7	3.3	2.7	135	0.255	17	1.0	"	"	1.6	Low
	GP	3/4	46	36	17	1.4	0.4	0.3	0.2	144	0.188	57	0.4	Non-plastic		1.7	Low[f]
		3/4	46	36	17	1.4	0.4	0.3	0.2	140	0.218	57	0.4	"	"	2.2	Medium[f]
Silty Sandy GRAVELS	GW-GM	2	42	33	19	5.7	2.0	1.3	1.0	139	0.200	87	1.1	Non-plastic		0.4	Negligible
		3/4	42	29	14	5.3	2.1	1.2	0.7	120	0.446	38	2.2	"	"	0.1	Negligible
		3/4	42	29	14	5.3	2.1	1.2	0.7	121	0.435	38	2.2	"	"	0.1	Negligible
		3/4	42	33	18	7.0	2.5	1.9	1.3	140	0.228	59	1.7	17.8	2.4	0.6	Negligible
		3/4	44	32	18	7.0	2.9	2.1	1.5	140	0.230	57	2.0	17.8	2.4	1.2	Low
		3/4	49	36	17	8.0	3.2	(2.2)	(1.5)	134	0.274	57	2.1	Non-plastic		1.1	Low
		3/4	49	36	17	8.0	3.2	(2.2)	(1.5)	132	0.288	57	2.1	"	"	1.2	Low
		2	53	40	20	7.4	3.5	2.5	1.3	139	0.231	48	1.0	"	"	2.6	Medium
		2	53	40	20	7.4	3.5	2.5	1.3	141	0.222	48	1.0	"	"	2.1	Medium
		3/4	51	34	12	5.5	4.0	3.3	2.3	137	0.237	22	1.3	"	"	1.9	Low
		3	47	30	13	7.5	4.3	3.2	1.8	132	0.267	47	2.2	"	"	2.5	Medium
		3/4	44	33	14	7.0	4.5	3.1	2.5	140	0.220	32	1.3	16.8	4.7	1.3	Low
		1	48	32	9.0	5.6	4.6	4.1	3.1	134	0.259	16	1.0	Non-plastic		2.0	Medium
		2	44	32	16	7.2	5.4	3.8	2.4	121	0.401	67	2.1	38.6	2.7	2.4	Medium
	GP-GM	2	27	19	10	5.2	3.1	2.0	1.2	121	0.401	40	4.7	38.6	2.7	1.1	Low
		2	47	40	23	9.1	3.2	2.1	1.5	136	0.233	120	0.6	Non-plastic		1.4	Low
		2	51	36	12	5.8	3.3	2.5	1.8	141	0.218	23	0.8	"	"	2.6	Medium
		2	51	36	12	5.8	3.3	2.5	1.8	141	0.221	23	0.8	"	"	2.2	Medium
		2	56	47	32	11	3.7	3.0	2.0	142	0.199	101	0.3	"	"	1.3	Low
		3/4	54	47	32	10	4.0	2.2	1.5	143	0.194	81	0.4	"	"	1.5	Low
		2	45	38	25	11	6.8	6.0	4.0	135	0.262	258	0.7	"	"	1.4	Low
		2	45	38	25	11	6.8	6.0	4.0	135	0.260	258	0.7	"	"	1.2	Low
		2	37	30	20	12	8.5	6.5	5.1	128	0.315	310	3.1	25.7	3.6	1.9	Low

		3/4	79	57	27	14	4.2	2.6	-	133	0.300	47	1.9	"	"	1.2	Low
		3/4	67	52	31	14	4.4	2.6	-	143	0.202	62	0.9	"	"	2.4	Medium
		-	-	-	100	21	4.5	2.5	1.0	106	0.578	3.0	1.1	"	"	0.3	Negligible
		-	-	-	100	21	4.5	2.5	1.0	105	0.593	3.0	1.1	"	"	0.6	Very low
		-	-	100	86	26	5.1	(2.4)	-	114	0.467	27	1.3	"	"	0.7	Very low
		3/4	66	61	45	17	5.2	3.7	2.4	135	0.258	47	0.4	"	"	2.3	Medium
		3/4	66	61	45	17	5.2	3.7	2.4	137	0.244	47	0.4	"	"	4.2	High
		3/4	66	61	45	17	5.2	3.7	2.4	136	0.252	47	0.4	"	"	2.1	Medium
		-	100	99	85	27	7.0	(3.0)	-	117	0.450	6.9	1.2	"	"	1.1	Low
		-	100	99	85	27	7.0	(3.0)	-	111	0.521	6.9	1.2	"	"	0.6	Very low
		2	84	80	47	13	7.5	5.3	3.6	123	0.374	17	1.9	"	"	1.7	Low
		2	76	72	49	17	7.8	4.5	3.0	122	0.384	28	1.4	"	"	1.8	Low
		3/4	98	98	94	29	8.2	5.4	3.7	109	0.560	4.0	1.8	"	"	1.0	Low
		-	-	100	97	48	8.8	4.0	-	120	0.419	4.0	0.8	"	"	1.3	Low
		2	58	46	27	14	8.9	7.5	6.0	128	0.312	250	2.2	21.9	3.0	0.8	Very low
		-	-	100	88	13	11	9.5	7.7	114	0.375	20	7.5	Non-plastic		2.3	Medium
		3/4	78	70	53	23	11	7.5	4.5	131	0.290	38	1.3	"	"	3.3	Medium
		3/4	71	65	34	23	11	6.3	4.0	136	0.280	95	2.2	21.6	2.9	2.5	Medium
		3/4	73	69	47	20	12	9.0	6.9	145	0.243	71	1.8	14.1	2.2	2.5	Medium
		3/4	73	69	47	20	12	9.0	6.9	144	0.248	71	1.8	14.1	2.1	2.9	Medium
		3/4	68	62	45	23	14	9.1	1.2	127	0.333	14	1.2	Non-plastic		4.8	High
		3/4	97	97	75	38	14	(7.0)	-	112	0.483	17	0.8	"	"	4.3	High
		3/4	90	85	79	28	15	12	9.0	130	0.300	36	4.2	"	"	1.3	Low
		3/4	97	91	73	31	17	(14)	(13)	124	0.374	280	18	18.3	2.8	6.3	High
		1-1/2	81	75	58	33	19	12	6.5	119	0.404	56	0.9	20.7	0.9	1.9	Low
		3/4	92	88	79	35	22	15	1.9	139	0.216	55	1.9	14.4	1.6	1.0	Low
Clayey Silty SANDS	SM-SC	1	71	55	28	16	9.0	6.0	4.3	131	0.292	108	3.7	24.1	5.9	1.6	Low
		3/4	65	55	39	22	14	10	7.0	148	0.215	310	0.9	16.1	4.3	2.5	Medium
		3/4	65	55	39	22	14	10	7.0	146	0.223	310	0.9	16.1	4.3	3.3	Medium
		1-1/2	91	79	48	23	15	13	11	120	0.378	225	13	22.0	4.6	1.3	Low
		1-1/2	62	50	33	22	15	10	5.5	135	0.267	400	2.7	22.0	6.1	2.5	Medium
		1-1/2	98	97	62	21	16	14	12	118	0.403	137	14	21.8	6.0	1.1	Low
		3/4	98	95	68	29	18	16	14	119	0.393	195	11	22.0	6.1	1.9	Low
		1-1/2	94	89	75	44	21	15	10	134	0.282	33	1.3	16.8	5.1	1.7	Low
		1-1/2	94	89	75	44	21	15	10	135	0.290	33	1.3	16.8	5.1	1.7	Low
		1-1/2	94	89	75	44	21	15	10	136	0.267	33	1.3	16.8	5.1	1.5	Low
		1-1/2	83	76	63	46	30	25	18	127	0.334	188	0.8	21.1	6.0	5.0	High
		1-1/2	87	76	62	48	32	24	15	127	0.334	100	0.2	21.1	6.0	3.1	Medium
		3/4	84	77	65	50	36	30	21	133	0.279	225	1.0	21.1	6.0	1.5	Low
Clayey SANDS	SC	1/2	98	90	33	18	9.5	7.5	5.5	123	0.374	72	3.2	30.7	10.5	1.1	Low
		3/4	73	68	55	35	23	20	15	134	0.272	500	1.7	24.7	8.1	1.3	Low
		3/4	76	72	60	41	24	18	13	139	0.237	191	1.1	24.0	11.0	0.5	Negligible
		3	82	77	66	48	30	23	17	130	0.293	115	0.9	20.7	7.2	2.2	Medium
		3/4	98	94	78	48	31	(25)	(22)	114	0.478	-	-	28.7	10.7	1.7	Low
		3/4	80	72	58	44	35	31	22	139	0.234	310	0.1	18.6	9.2	1.3	Low

TABLE 1

STANDARD LABORATORY FROST-SUSCEPTIBILITY TESTS ON NATURAL SOILS[a] (Continued)

UNIFIED SOIL CLASSIFICATION		MAX. SIZE	GRAIN SIZE[b] mm-% Finer							INITIAL DRY UNIT WEIGHT[c]	INITIAL VOID RATIO	ATTERBERG LIMITS		AVERAGE RATE OF HEAVE	FROST SUSCEPTIBILITY CLASSIFICATION[e]
SOIL TYPE	SYMBOL	in.	4.76	2.00	0.42	.074	.02	.01	.005	pcf	e	LL	PI	mm/day	
						SILTS									
SILT	ML	-	-	100	99	54	6.0	(4.0)	(2.5)	102	0.688	Non-plastic		0.3	Negligible
		-	100	99	91	53	13	(6.0)	(3.5)	112	0.484	"	"	0.7	Very low
		-	-	-	100	95	27	10	(4.0)	106	0.626	26	3.0	1.2	Low
		-	-	-	100	95	27	10	(4.0)	103	0.668	26	3.0	1.5	Low
		-	-	-	100	99	53	25	15	113	0.501	23.7	4.0	9.8	Very high
		-	-	-	100	99	53	25	15	113	0.501	23.7	4.0	10.0	Very high
		3/4	95	94	91	87	54	40	28	104	0.590	32.8	8.1	13.9	Very high
		-	-	100	99	97	60	22	10	105	0.611	26.6	0.1	11.0	Very high
		-	-	100	99	97	60	22	10	106	0.589	26.6	0.1	15.9	Very high
		-	-	100	99	97	60	22	10	108	0.567	26.6	0.1	26.0	Very high
		3/4	97	96	92	83	60	44	28	101	0.611	36.0	5.1	3.5	Medium
Clayey SILT	ML-CL	-	-	-	100	98	60	37	22	123	0.389	25.3	5.8	2.2	Medium
		-	-	-	100	86	61	34	14	105	0.643	24.1	5.9	7.9	High
		-	-	100	96	90	67	36	16	101	0.685	25.0	6.0	12.3	Very high
		-	-	100	96	90	67	36	16	101	0.662	25.0	6.0	14.0	Very high
		-	-	-	100	99	73	37	13	107	0.577	23.7	6.0	1.7	Low
		-	-	-	100	99	73	37	13	106	0.596	23.7	6.0	3.7	Medium
		-	100	99	93	85	73	47	23	101	0.674	26.0	5.0	14.0	Very high
SILT w/organic	ML-OL	-	-	-	100	91	38	12	6	98	0.737	Non-plastic		3.1	Medium
						CLAYS									
Gravelly and Sandy CLAYS	CL	3/4	82	77	70	62	40	31	23	133	0.352	25.6	7.9	4.8	High
		3/4	95	-	87	64	43	-	-	115	0.468	41.0	18.0	1.3	Low
		-	-	-	100	96	49	38	30	109	0.569	30.0	11.7	4.5	High
		1/4	98	97	90	61	49	41	34	110	0.536	43.8	20.3	14.0	Very high
		1/4	98	97	90	61	49	41	34	113	0.504	43.8	20.3	1.3	Low
		1/4	98	97	90	61	49	41	34	117	0.456	43.8	20.3	1.5	Low
		1/4	98	97	90	61	49	41	34	118	0.441	43.8	20.3	2.2	Medium
		3/4	96	96	93	86	51	38	27	118	0.424	26.4	8.4	6.2	High
		3/4	85	84	82	78	53	40	30	119	0.429	27.6	9.5	6.5	High
		3/4	97	95	90	80	60	48	36	125	0.403	28.6	12.6	1.2	Low
		3/4	97	95	90	80	60	48	36	125	0.395	28.6	12.6	1.5	Low
		3/4	97	95	91	81	61	50	35	126	0.389	29.6	13.6	1.4	Low
		1-1/2	94	92	88	80	64	52	37	117	0.448	30.0	12.0	10.0	Very high
		1-1/2	94	92	88	80	64	52	37	118	0.431	30.0	12.0	3.3	Medium

Gravelly and Sandy CLAYS w/organic	CL-OL	3/4	84	80	72	56	44	35	25	130	0.328	23.0	7.0	6.5	High
		3/4	84	80	72	56	44	35	25	130	0.324	23.0	7.0	4.0	High
		3/4	86	81	73	57	50	42	30	129	0.336	21.0	7.0	7.8	High
		3/4	86	81	73	57	50	42	30	130	0.328	21.0	7.0	7.3	High
Lean CLAYS	CL	-	100	99	98	91	33	(24)	(19)	113	0.474	28.0	12.0	4.0	High
		-	-	100	98	91	58	41	31	117	0.485	36.5	16.8	1.4	Low
		-	-	-	100	97	60	43	34	116	0.518	31.3	15.2	2.2	Medium
		-	-	-	-	100	67	37	29	115	0.476	28.0	8.6	2.5	Medium
		-	-	-	-	100	67	37	29	118	0.448	28.0	8.6	3.8	Medium
		-	-	-	-	100	67	37	29	120	0.424	28.0	8.6	1.8	Low
		-	-	-	-	100	67	37	29	123	0.385	28.0	8.6	2.1	Medium
Lean CLAYS w/organic	CL-OL	-	-	100	99	96	65	48	35	98	0.644	37.0	13.0	4.1	High
		-	-	100	99	96	65	48	35	99	0.630	37.0	13.0	5.3	High
		-	-	100	99	96	65	48	35	99	0.627	37.0	13.0	4.2	High
Fat CLAYS	CH	-	-	100	99	74	61	52	42	105	0.715	55.0	37.0	0.8	Very low

NOTES: (a) See Notes on figure 8, Summary of Average Rate of Heave vs. Percentage Finer than 0.02 mm Size for Natural Soil Gradations.

(b) Numbers in parentheses indicate estimated values.

(c) To nearest full pound.

(d) $C_u = \frac{D_{60}}{D_{10}}$

$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$

(e) With respect to rate of heave.

(f) Not shown on applicable plot on figure 8

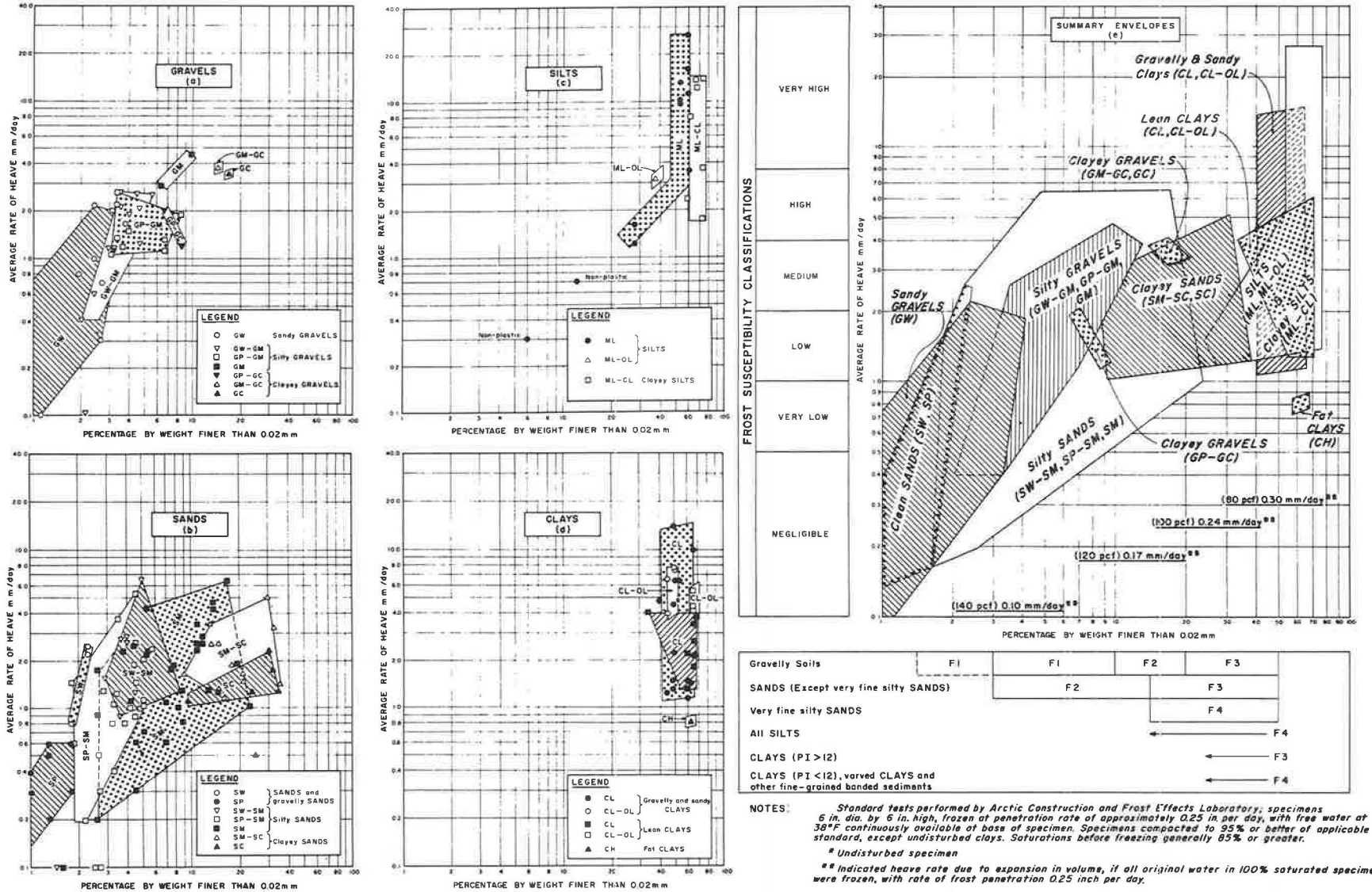


Figure 8. Summary of average rate of heave vs percentage finer than 0.02 mm size for natural soil gradations.

classed as acceptable, but which approach 1.0 mm per day rate of heave in laboratory tests should be expected to show some measurable frost heave under average field conditions. These facts must be kept in mind when applying the criteria to other than normal pavement practice, and when considering subsurface drainage measures.

The data presented in Table 1 may be used for general guidance to estimate the relative frost susceptibility of similar soils. However, a standard laboratory frost susceptibility test on a sample of the specific soil will give a more accurate evaluation.

Soils are classified into four groups for frost design purposes (Table 2). Soils are listed in approximate order of increasing susceptibility to frost heaving and/or weakening as a result of frost melting. However, the order of listing subgroups under Groups F3 and F4 does not necessarily indicate the order of susceptibility to frost heaving of these subgroups. There is some overlapping of frost susceptibility between groups. The soils in Group F4 are of especially high frost susceptibility.

The F1 group is intended to include frost-susceptible gravelly soils which in the normal unfrozen condition have traffic performance characteristics of GW and GP type materials with the noted percentages of fines. The F2 group is intended to include frost-susceptible soils which in the normal unfrozen condition have traffic characteristics of GM, SW, SP or SM type materials with fines within the stated limits. Occasionally GS or SC materials may occur within the F2 group, although they will normally fall in the F3 category. The basis for division between the F1 and F2 groups is that F1 materials may be expected to show higher bearing capacity than F2 materials during thaw, even though both may have experienced equal ice segregation.

Varved clays consisting of alternate layers of silts and clays are likely to combine the undesirable properties of both silts and clays. These and other stratified fine-grained sediments may present a problem in selection of overall frost classification for design purposes. Because such soils are likely to heave and soften more readily than homogeneous soils with equal average water contents, the classification of the material of highest frost susceptibility should be adopted for design purposes. Usually this will place the overall deposit in the F4 category.

Under special conditions the frost group classification adopted for design may be permitted to differ from that obtained by application of the previous frost group defini-

TABLE 2

FROST DESIGN SOIL CLASSIFICATION

Frost Group	Soil Type	Percentage Finer Than 0.02 mm by Weight	Typical Soil Types Under Unified Soil Classification System
F1	Gravelly	3 to 10	GW, GP, GW-GM, GP-GM
F2	(a) Gravelly	10 to 20	GM, GW-GM, GP-GM
	(b) Sands	3 to 15	SW, SP, SM, SW-SM SP-SM
F3	(a) Gravelly	>20	GM, GC
	(b) Sands, except very fine silty sands	>15	SM, SC
	(c) Clays, PI >12	—	CL, CH
F4	(a) All silts	—	ML, MH
	(b) Very fine silty sands	>15	SM
	(c) Clays, PI < 12	—	CL, CL-ML
	(d) Varved clays and other fine-grained, banded sediments	—	CL and ML; CL and ML and SM; CL, CH and ML; CL, CH, ML and SM

tions, if the difference is not greater than one frost group number and if complete justification for the variation is presented. Such justification may take into account special conditions of subgrade moisture or soil uniformity, in addition to soil gradation and plasticity, and should include data on performance of local pavements. For example, some pavements constructed on varved clay subgrades in which the soil deposit and the depth to ground water table are uniform show comparatively good performance under frost conditions. In such case, adoption of F3 classification in lieu of F4 for design purposes may be justified. However, care must be used in attempting to translate highway experience into airfield applications, and vice versa, and in evaluating experience based on seasons which are warmer and/or drier than normal, or on drainage conditions which will not be applicable to the case in point.

DETRIMENTAL EFFECTS OF FROST ACTION

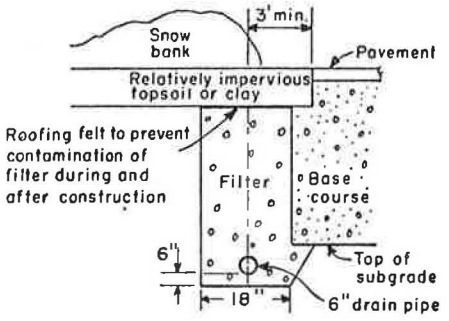
Heaving

Frost heave, indicated by the raising of the pavement, is directly associated with ice segregation and is visible evidence on the surface that ice lenses have formed in the subgrade, base materials, or both. Heave may be uniform or non-uniform depending on variation in the character of the soils and the ground water conditions underlying the pavement.

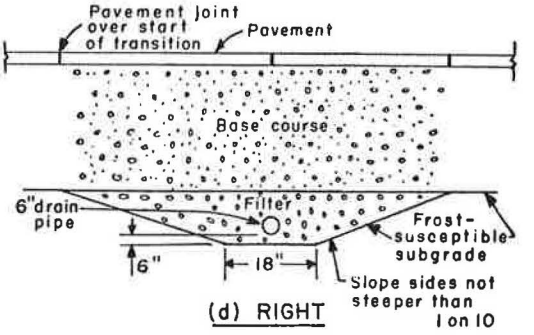
Uniform heave is the raising of adjacent areas of a pavement surface by approximately equal amounts so that the initial shape and smoothness of the surface remains substantially unchanged. Typical conditions conducive to uniform heave may exist in a section of pavement constructed with a fairly uniform stripping or fill depth, uniform ground water depth and horizontally uniform soil characteristics.

When non-uniform heave occurs, there are appreciable differences in the heave of adjacent areas resulting in objectionable unevenness or abrupt changes in grade at the pavement surface. Conditions conducive to irregular heave occur, for example, at locations where subgrades vary between clean non-frost-susceptible sands and silty frost-susceptible materials, at abrupt transitions from cut to fill sections with the ground water close to the surface, or where excavation cuts into water-bearing strata. Drains, culverts or utility ducts placed under pavements on frost-susceptible subgrades frequently result in abrupt differential heaving. Placing such facilities beneath pavements should be avoided wherever possible. Where this cannot be avoided, construction should be in accordance with methods such as indicated in Figure 9d. All drains or similar features should be placed first and the base course materials carried across them without break to obtain maximum uniformity of pavement support. The practice of constructing the base course and then excavating back through it to lay drains, pipes, etc., is unsatisfactory because a marked discontinuity in support will result. It is almost impossible to compact material in a trench to the same degree of compaction as the surrounding base course material. Also, the amount of fines in the excavated and backfilled material may be increased by incorporation of subgrade soil during the trench excavation or by manufacture of fines by the added handling. The poor experience record of combination drains (those intercepting both surface and subsurface water) indicates that the filter material should never be carried to the surface as shown in Figure 9c. Recommended practices are shown in Figures 9a and 9b. Inserted items such as drain inlets in pavements, and fueling hydrants and pavement lighting systems in airfields, are likely to be locations of abrupt differential heave with resultant pavement distress and loss of smoothness. Differences in pavement thickness and/or composition inevitably produce differences in commencement of heave, rate of heave and total heave of the frozen materials.

When interruptions in pavement uniformity cannot be avoided, the best design solutions are use of a sufficiently thick non-frost-susceptible base or use of long transitions. No specific dimensional standards for transition sections have been established. However, transition lengths should vary directly with the speed of traffic and the amount of heave differential. For rigid pavements, transition sections should begin and end directly under pavement joints and should never be shorter than one slab length. For example, at a heavy-load airfield where 1-in. heave differentials may be expected



(a) RIGHT



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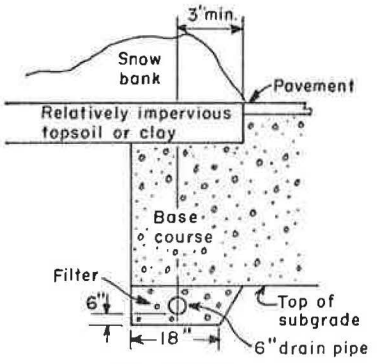

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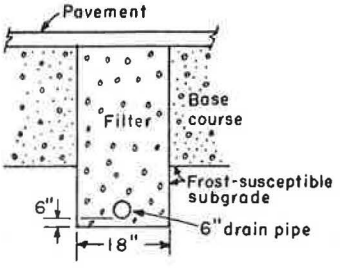
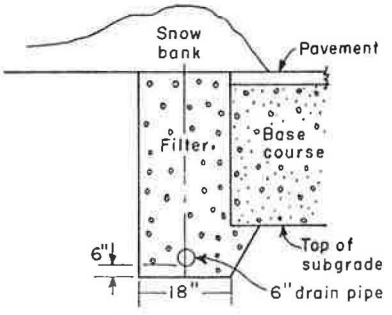


(e) WRONG

Under frost conditions, non-uniformity produced by detail (e) is likely to result in differential heave and pavement cracking.

SUBDRAINS UNDER PAVED SURFACES



(c) WRONG

Under winter conditions, thaw water accumulating at edge of pavement may feed into base course in detail (c). This detail is poor because filter provides poor surface and is subject to clogging; drain is also located too close to pavement to permit easy repair.

SUBDRAINS ALONG PAVEMENT EDGES

NOTE:

For additional details on design of subdrains and filter courses see EM 1110-345-282.

Figure 9. Subdrain details for cold regions.

at changes from one subgrade soil condition to another, gradual changes in base thicknesses should be effected over distances of 200 ft for the runway area, 100 ft for taxiways, and 50 ft for aprons. Pavements designed to lower standards of frost heave control, such as airfield overruns, have less stringent requirements, but nevertheless may need transition sections.

Other possible measures to modify the effects of heave are use of insulation to control depth of frost penetration in limited areas, and use of dowel and slab reinforcement to insure pavement continuity where any doubt remains concerning the design. Reinforcement will not reduce heave or prevent cracking. However, reinforcement will help to hold pavement tightly closed and to assure satisfactory structural performance.

Transitions between cut and fill and changes in character or stratification of subgrade soils should also receive special attention in field control (Appendix A).

Thawing and Reduction in Pavement Supporting Capacity

When ice segregation occurs, reduction of the strength of the soil with a corresponding reduction in load-supporting capacity of the pavement develops during frost-melting periods, particularly early in the spring when thawing is occurring at the top of the subgrade and the rate of melting is rapid. As shown in Figure 10, ice melting from the surface downward releases water which cannot drain through the still frozen soil below or redistribute itself readily. Excess moisture from the wet and softened subgrade soil moves upward into the base course and laterally to the nearest drain. If drainage provisions are inadequate, the base course may become completely saturated. If this occurs, the bearing capacity of the base is substantially reduced, the effects of possible subsequent frost action are increased, water and fines may be pumped through joints and cracks, and accelerated deterioration of the surfacing may occur. Therefore, it is essential that base courses

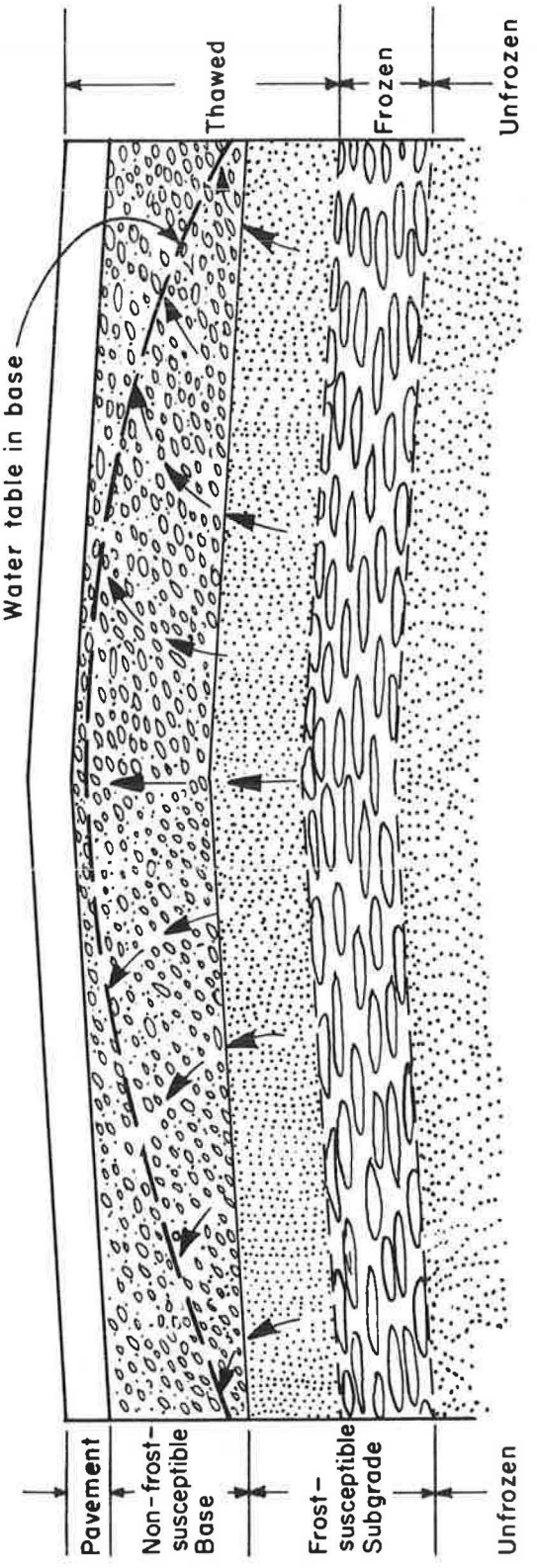


Figure 10. Moisture movement upward into base course during thaw.

in frost regions be designed in strict accordance with the drainage criteria of Ref. (2), pertinent parts of which are abstracted in Appendix C. The possible effects of restriction of subsurface drainage by frozen soils should be considered at all points in drainage design.

Supporting capacity may be reduced in clay subgrades even though significant heave has not occurred, because water for ice segregation is extracted from the voids of the unfrozen clay below and the resulting shrinkage of the latter largely balances the volume of the formed ice lenses. Also, traffic may cause remolding or hydrostatic pressures within the pores of the soil during the period of weakening, thus resulting in further reduced subgrade strength.

The degree to which a soil loses strength during a frost-melting period and the length of the period depend on the type of soil, temperature conditions, amount and type of traffic, moisture supply during fall, winter and spring, and drainage conditions.

Effect of Frost Action and Low Temperatures on Pavement Surface

The most obvious structural effect of frost action on the pavement surface is the formation of random cracking and roughness as the result of differential frost heave. Studies of rigid pavements have shown that cracks may develop more rapidly during and immediately following the spring frost-melting period, as a result of differential thaw, than during the period of active heave itself. For airfield pavements it is especially important that uncontrolled cracking be reduced to an absolute minimum, because deterioration and spalling of the edges of working cracks are a source of debris which may seriously damage jet aircraft. This may be accomplished by control of such elements as base composition and thickness, slab dimensions, horizontal uniformity of base and subgrade materials, uniformity of subsurface moisture conditions, and in special situations, by use of reinforcement and limitation of pavement type. The importance of uniformity cannot be overemphasized, and although true for all pavements, it is particularly important for airfield pavements.

Cracking may also result, particularly in flexible pavements, from shrinkage of the pavement and base under extreme low temperatures. In very cold regions, cracks from this source may penetrate not only the pavement but the underlying materials. As stated, this is essentially a flexible pavement problem because there is no jointing system for control of such stresses. Unfortunately, when the most severe tensile stresses develop, flexible pavements are least ductile. Shrinkage cracking in flexible pavements is not regarded as a structural problem. The only remedial measures considered necessary in seasonal frost areas are periodic sealing of cracks when entrance of surface moisture may be detrimental or when raveling of crack edges may produce surface debris, and resurfacing at required intervals.

INVESTIGATION PROCEDURE

The field and laboratory investigations conducted in accordance with Ref. (3) will usually provide sufficient information to determine whether a given combination of soil and water conditions beneath the pavement will be conducive to frost action. Particular attention should be given to the degree of horizontal variation of subgrade conditions. This involves both soil and moisture conditions and is difficult to express simply and quantitatively. Subgrades may range from uniform conditions of soil and moisture in which variations from point to point are so slight as to result in negligible differential frost heave and thaw settlement, to extremely variable conditions in which frequent and abrupt changes occur between low or negligible and high or very high frost-heave potential. The procedures for determining whether or not the conditions necessary for ice segregation are present at a proposed site follow.

Soil

As stated, the frost susceptibility of soils may be estimated from the percentage of grains finer than 0.02 mm by weight or by laboratory freezing tests. The Corps of Engineers presently requires that such freezing tests in connection with its projects be

be carried out by or under the supervision of the U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, N. H.

Temperature

Air freezing index values should, so far as possible, be based on actual air temperatures obtained from a station located in close proximity to the construction site. This is desirable because differences in elevations, topographical position, nearness to cities, bodies of water or other sources of heat may cause considerable variations in air freezing indexes over short distances. These variations are of greater relative importance to design in areas with a design freezing index of less than 1,000 (i.e., mean air freezing index of less than about 500) than they are farther north.

Daily and mean monthly air temperature records for all stations which report to the U. S. Weather Bureau are available at the various Weather Bureau section centers. In general, one of these centers is located in each State. The mean air freezing index may be based on mean monthly air temperatures, but average daily air temperatures are used to compute the design freezing index. Computation of values for determination of the design freezing index may be limited to consideration of only the coldest years in the desired cycles. These years may be selected by inspection of the tabulation of average monthly temperatures for the nearest first order weather station. A "Local Climatological Data" summary containing this tabulation for the period of record is published annually by the Weather Bureau for each of the approximately 150 U. S. first order stations. If the temperature record of the station in closest proximity to the construction site is not of sufficient duration to permit the determination of mean or design index values, the available data are related, for the same period, to that of the nearest station or stations of adequate record. Site index working values may then be computed based on this established relationship and the indexes for the more distant station or stations.

Depth of Frost Penetration

The depth to which freezing temperatures will penetrate the surface of a pavement kept clear of snow and ice depends principally on the magnitude and duration of below freezing air temperatures, properties of the underlying materials, and the amount of water which becomes frozen. The curves in Figures 11 and 12 may be used to estimate values of frost penetration beneath paved areas. They have been computed for an assumed 12-in. thick PCC pavement using the modified Berggren formula (4) and correction factors derived by comparison of theoretical results with field measurements under different conditions. The curves yield maximum depths to which the 32 F temperature will penetrate from the top of the pavement under total winter freezing index values in indefinitely deep homogeneous materials for the indicated density and moisture content properties. Variations due to use of other pavement types and of PCC pavements of lesser thicknesses may be neglected. Where individual analysis is desired or unusual conditions make special computation desirable, the modified Berggren formula may be applied (see Notes, Fig. 11). Neither this formula nor the curves in Figures 11 and 12 are applicable for determining transient penetration depths under partial freezing index values. Values obtained by use of Figures 11 and 12 should be verified whenever possible by observations in the locality under consideration. Methods of estimating frost penetration depths beneath surfaces other than pavements kept free of snow and ice are discussed in Ref. (5).

Water

A potentially troublesome water supply for ice segregation is present if the highest ground water table at any time of the year is within 5 ft of the proposed subgrade surface or the top of any frost-susceptible base materials used. A water table within this depth or less may be considered indicative of relatively adverse ground moisture conditions. When the depth to the uppermost water table is in excess of 10 ft throughout the year, ice segregation and frost heave may be expected to be reduced. Although the reduced frost heave may be tolerable for flexible pavements, it may not be so for rigid

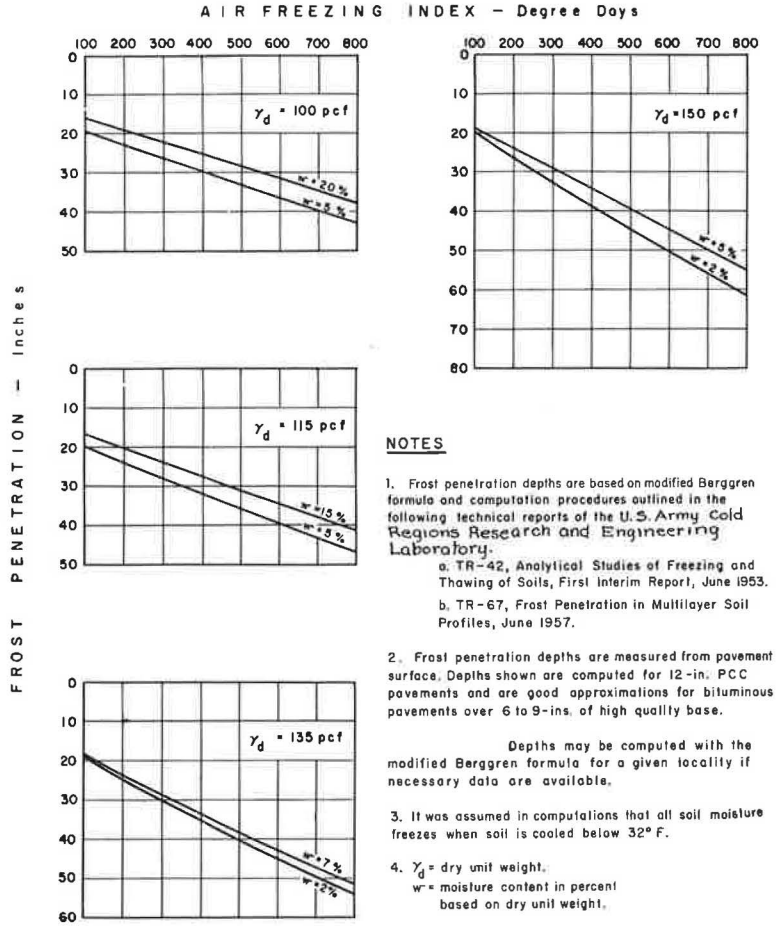


Figure 11. Relationships between air freezing index and frost penetration into granular, non-frost-susceptible soil beneath pavements kept free of snow and ice for freezing indexes below 800.

pavements because of the cracking which may result in the latter, even under reduced heave. In homogeneous clay soils, the water content which the clay subgrade will attain under a pavement is usually sufficient to provide water for some ice segregation, even with a remote water table. Closed system laboratory tests on silt, clays and tills, corresponding to a field condition of a very deep water table, indicate that detrimental ice segregation is unlikely if the moisture content of these soils is below 70 percent of the saturation value. Full advantage can rarely be taken of this, however, because moisture contents near full saturation may occur in the top of the frost-susceptible subgrade from surface infiltration through pavement and shoulder areas or from other sources.

In addition to the conditions stated, it is necessary to consider all reliable information concerning past frost heaving and performance during frost-melting periods of airfield and highway pavements constructed in the area being investigated, with a view toward modifying the frost-design requirements.

BASE COURSE COMPOSITION REQUIREMENTS

All base course materials lying within the determined design depth of frost penetration must be non-frost-susceptible. The dimensions and permeability of the base course

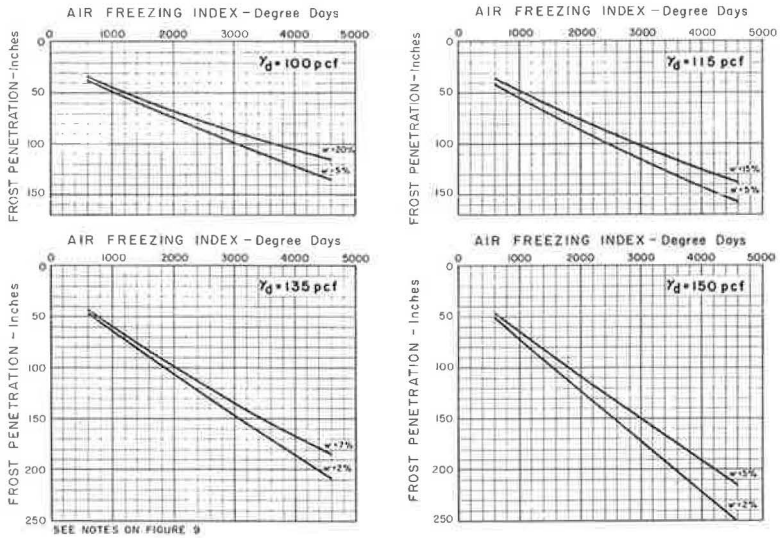


Figure 12. Relationships between air freezing index and frost penetration into granular, non-frost-susceptible soil beneath pavements kept free of snow and ice.

should satisfy the base course drainage criteria given in Appendix C, as well as the thickness requirements for frost design. Thicknesses indicated by frost criteria should be increased if necessary to meet subsurface drainage criteria. Base course materials of borderline frost-susceptible quality should be tested frequently after compaction to insure that the materials meet these design criteria. Where the combined thickness of pavement and base over a frost-susceptible subgrade is less than that required under the limited subgrade frost penetration design method, the following additional design requirements apply:

Filter Over Subgrade

For both flexible and rigid pavements, at least the bottom 4 in. of base should consist of non-frost-susceptible sand, gravelly sand, screenings, or similar material. It should be designed as a filter between the subgrade soil and overlying base course

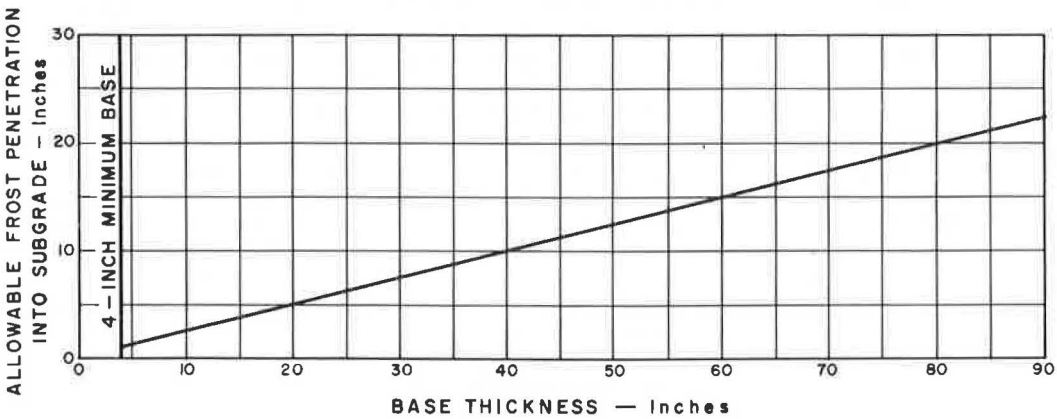


Figure 13. Allowable subgrade frost penetration in design freezing index year for limited subgrade frost penetration design method.

material to prevent mixing of the frost-susceptible subgrade with the base during and immediately following the frost-melting period. This filter is not intended to serve as a drainage course. The gradation of this filter material is determined in accordance with criteria presented in Appendix C, with the added overriding limitation that the filter material shall, in no case, have more than 3 percent by weight finer than 0.02 mm. Experience shows that a fine-grained subgrade soil will work up into an improperly graded overlying gravel or crushed stone base course under the kneading action of traffic during the frost-melting period, if a filter course is not provided between the subgrade and the overlying material. Experience and tests indicate that non-frost-susceptible sand is especially suitable for this filter course. The 4-in. minimum filter thickness is dictated primarily by construction requirements and limitations. Greater thicknesses are specified when required to suit field conditions. Over weak subgrades, a 6-in. or greater thickness may be necessary to support construction equipment and provide a working platform for placement and compaction of the base course.

Filter Under Pavement Slab

For rigid pavements, the 85 percent size (the size particle for which 85% of the material by weight is finer) of filter or regular base course material placed directly beneath pavements is required to be equal to or greater than 2.00 mm in diameter (No. 10 U. S. Standard Sieve Size) for a minimum thickness of 4 in. The purpose of this requirement is to prevent loss of support by pumping soil through the joints.

DESIGN OF PAVEMENTS FOR FROST ACTION

The design of pavements in frost areas may be based on either of two basic concepts: (a) control of surface deformation resulting from frost action, or (b) provision of adequate bearing capacity during the most critical climatic period. Under the first concept, sufficient combined thickness of pavement and non-frost-susceptible base must be provided to eliminate or limit to an acceptable amount, subgrade frost penetration and effects thereof. Under the second concept, the amount of heave which will result is neglected and design is based solely on the anticipated reduced strength of the subgrade during the frost-melting period. The following three design methods have been derived from these concepts and are described in detail: complete protection method; limited subgrade frost penetration method; and reduced subgrade strength method.

The reduced subgrade strength method is the most commonly used design procedure for roads, with added thickness of non-frost-susceptible pavement and base used as needed to control heave or insure adequate subsurface drainage. The two procedures are also helpful in road design by establishing limits for frost protection effectiveness. The limited subgrade frost penetration method may sometimes be directly employable in highways.

The first step in determination of design thickness is to select the appropriate design method or methods from Table 3, which summarizes the conditions for which each of the above methods is applicable. The degree of horizontal variability of subgrade soil and moisture conditions may be classified into one of four categories: uniform; slightly variable; variable; or extremely variable. Definitions of these adjective categories are given under the respective adjective headings in Table 3. The distinctions are purely qualitative. Selection of the adjective category involves judgment; it must be based on careful analysis of past performance of pavements in the area and thorough study of site exploration data. An airfield may fall entirely into one adjective category, or it may have to be divided into a number of areas for separate design consideration. Once an adjective category has been chosen, the design approaches which are applicable may be determined from Table 3.

It should be noted that the requirement for sufficient bearing capacity during the normal period (summer and fall) as determined by non-frost design, takes precedence over the frost-design criteria if the former requires greater combined thickness than that obtained by the frost-design methods.

TABLE 3

SUMMARY OF METHODS FOR DESIGN OF AIRFIELD PAVEMENTS FOR FROST CONDITIONS

Design Method	Horizontal Variability of Subgrade Soil and Moisture Conditions			
	Uniform Variations affecting heave potential virtually undetectable by ordinary methods of investigation. Negligible differential frost heave and thaw settlement may be anticipated under reduced subgrade strength design.	Slightly Variable Small variations of subgrade conditions apparent by ordinary methods of investigation.	Variable Subgrade conditions moderately variable. Widespread cracking of rigid pavements and appreciable surface deformation would be expected if reduced subgrade strength design method were used.	Extremely Variable Very large, frequent and abrupt changes in subgrade frost heave potential not permitting use of transition sections.
Complete protection				Applicable only under exceptionally adverse conditions for F3 and F4 subgrades.
Limited subgrade frost penetration[a, b, c]	Required for flexible and rigid pavements: (1) Over F4 subgrade soils (except as noted in Col. (4) below). (2) Over other frost-susceptible subgrade soils when: (a) Cracking of rigid pavements or unacceptable pavement roughness caused by non-uniform frost heave may be expected with lesser design thickness, or (b) Limited subgrade frost penetration design requires less combined thickness or is otherwise more economical than reduced subgrade strength design.			
Reduced subgrade strength[a, b, c]	Applicable for flexible and rigid pavements over F1 thru F3 subgrades when objectionable differential heave or cracking will not occur.[a]	Applicable for flexible pavements over F1 thru F3 subgrades when objectionable differential heave or cracking will not occur.	Applicable for flexible pavements over F1 thru F4 subgrades when pavements are minor, slow speed, and non-critical and heave can be tolerated, except not to be used for F4 subgrade under adverse moisture conditions.	

[a] Transition sections required at any substantial and abrupt changes in subgrade frost heave potential which would produce unacceptable pavement roughness and cracking.

[b] When indicated combined thickness exceeds 72 inches, consider alternatives: (1) limiting total thickness to 72 inches, and, in rigid-type pavements, using steel reinforcement, (2) reduced slab dimensions or (3) base of higher moisture retention. OCE approval required for use of alternatives or thickness over 72 inches.

[c] Thickness intermediate between reduced subgrade strength and limited subgrade frost penetration design values may be adopted when justification based on field experience or special conditions of the design is provided.

[d] Special provision for rigid pavements over uniform subgrades: Instead of base equal to slab thickness, 4-in. minimum base is allowed over F1, F2, F3 subgrades when: (1) Design freezing index 1,000 or, (2) Subgrade is susceptible to pumping and water table is below 10 feet; however, base drainage criteria must be met.

NOTE: Design of highway pavements should be based generally on the Reduced Subgrade Strength Design Method, with additional thickness (based on local field data and experience) used where necessary to keep pavement heave and cracking within tolerable amounts. Where such added thicknesses are used for highways they should not exceed values obtained by the Limited Subgrade Frost Penetration Design Method. Thickness reduction up to 10% may also be allowed on substantial highways fills when justified by field data and experience.

Complete Protection

Under this method of design, surface deformation resulting from frost action is eliminated by providing sufficient thickness of non-frost-susceptible base to completely protect underlying frost-susceptible soils from freezing. This method is used only in exceptional situations, when the subgrade soil is F3 or F4, soil and moisture conditions are horizontally extremely variable, and the limited subgrade frost penetration method will not provide adequate control of heave and cracking.

The combined thickness of pavement and non-frost-susceptible base required for complete protection is the value a (Fig. 14).

Limited Subgrade Frost Penetration

This is the normal method of design for control of surface deformation. It attempts to hold deformations to small, acceptable values, instead of eliminating them completely. It is applicable primarily for slightly variable and variable subgrade conditions which would produce unacceptable cracking of rigid pavements and pavement roughness if the reduced subgrade design method were used. However, it may sometimes be applicable for more uniform subgrade conditions. The combined thickness of rigid or flexible pavement and non-frost-susceptible base course determined by this method should always be used in the following cases:

(1) Over group F4 subgrade soils.

(2) Over other frost-susceptible subgrade soils.

(a) When cracking of rigid pavements or unacceptable pavement roughness caused by non-uniform frost heave may be expected with lesser design thickness.

(b) When limited subgrade frost penetration design requires less combined thickness or is otherwise more economical than reduced subgrade strength design.

Exceptions are those cases where the subgrade conditions are so extremely variable that the complete protection method must be used, or when flexible paved areas in which the effects of appreciable non-uniform heave and cracking are not considered detrimental. At some sites it may be possible to correct the causes of non-uniform heave by the removal of isolated pockets of frost-susceptible soils for the full depth of frost penetration, or by providing gradual transitions at abrupt changes in subgrade conditions. In these cases a lesser combined thickness of pavement and base than required for limited subgrade frost penetration may be used, and design should then be based on reduced subgrade strength. Exception from the full thickness requirements of the limited subgrade frost penetration design method is not permitted where subgrade soils are group F4 under adverse moisture conditions.

The design freezing index should be used in determining the combined thickness of pavement and base required to limit subgrade frost penetration. As with any natural climatic phenomenon, winters which are colder than average occur with a frequency which decreases as the degree of departure from average becomes greater. A mean freezing index cannot be computed where temperatures in some of the winters do not fall below freezing. A design method has been adopted, therefore, which utilizes the average air freezing index for the three coldest years in a 30-year period (or for the coldest winter in 10 years of record) as the design freezing index to determine the thickness of protection that will be provided.

Except in special situations, it is not necessary to construct airfield pavements entirely to prevent frost penetration into the subgrade. Therefore, the following design method permits a small amount of frost penetration into frost-susceptible subgrades for the design freezing index year.

(1) Estimate average moisture contents in base course and subgrade at start of freezing period and dry unit weight of base.

(2) From Figures 11 or 12, as applicable, determine frost penetration a, which will occur in a base material of unlimited depth beneath a 12-in. thick PCC pavement or average bituminous pavement kept free of snow and ice in the design freezing index year. Use straight-line interpolation where necessary. For PCC pavements greater than 12

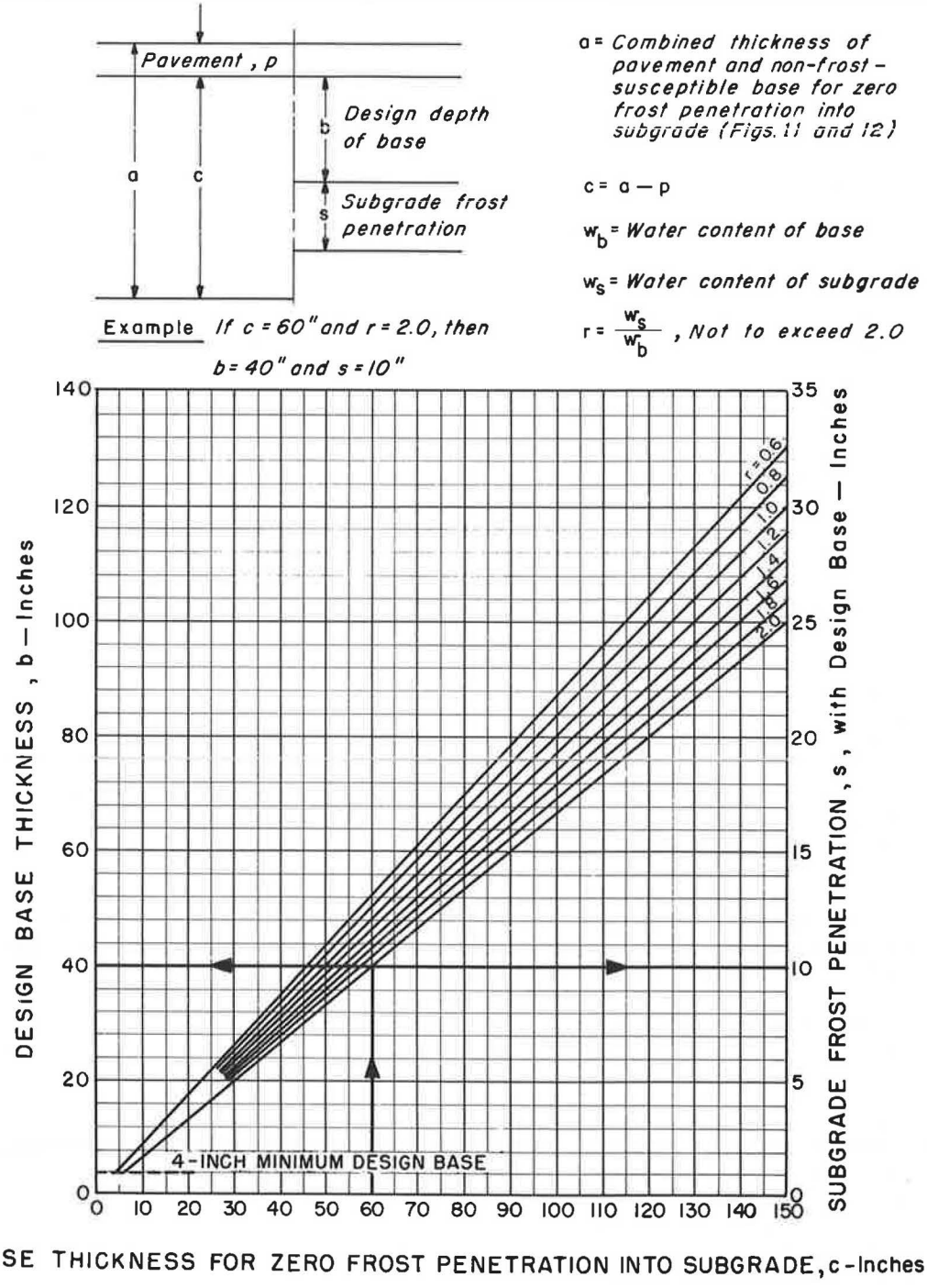


Figure 14. Design depth of non-frost-susceptible base for limited subgrade frost penetration.

in. in thickness, deduct 10 degree-days for each inch of pavement exceeding 12 in. from the design freezing index before entering Figures 11 or 12 to determine frost penetration a. The extra concrete pavement thickness is then added to the determined frost penetration.

(3) Compute base thickness c (Fig. 14) required for zero frost penetration into the subgrade (complete protection) as follows:

$c = a - p$, where p = thickness of portland cement concrete or bituminous concrete.

(4) Compute ratio $r = \frac{\text{water content of subgrade}}{\text{water content of base}}$

(5) Enter Figure 14 with c as abscissa and at applicable value of r, find on left scale design base thickness b which will result in allowable value of subgrade frost penetration s shown on right scale. If r (computed in (4) above) is equal to or exceeds 2.0, use 2.0 in Figure 14.

(6) Values of b and s should show reasonable agreement with plot in Figure 13, which illustrates the basic subgrade frost penetration assumption on which this design procedure is based.

This procedure will result in sufficient thickness of material between the frost-susceptible subgrade and the pavement, so that for average field conditions, subgrade frost penetration of the amount s should not cause excessive differential heave and cracking of the pavement surface during the design freezing index year. The reason for limiting r to a maximum of 2.0 is because not all of the moisture in fine-grained soils will actually freeze at freezing temperatures.

The bottom 4 in. of the design base of thickness b must be designed as a filter, unless the selected base course material already fulfills the filter criteria.

When the maximum combined thickness of pavement and base required by this design procedure exceeds 72 in., special study should be made of alternatives such as the following:

(1) limiting total combined thickness to 72 inches and using steel reinforcement to prevent large cracks in rigid pavements; (2) limiting the maximum slab dimensions (as to 15 ft) without use of reinforcement; (3) reduction of the required combined thickness by use of a base of non-frost-susceptible uniform fine sand with high moisture retention in the drained condition in lieu of more free-draining material.

The first two alternatives would entail a greater surface roughness than obtained under the basic design method because of greater subgrade frost penetration. With respect to the third alternative, it should be noted that base course drainage requirements (Appendix C) must still be met.

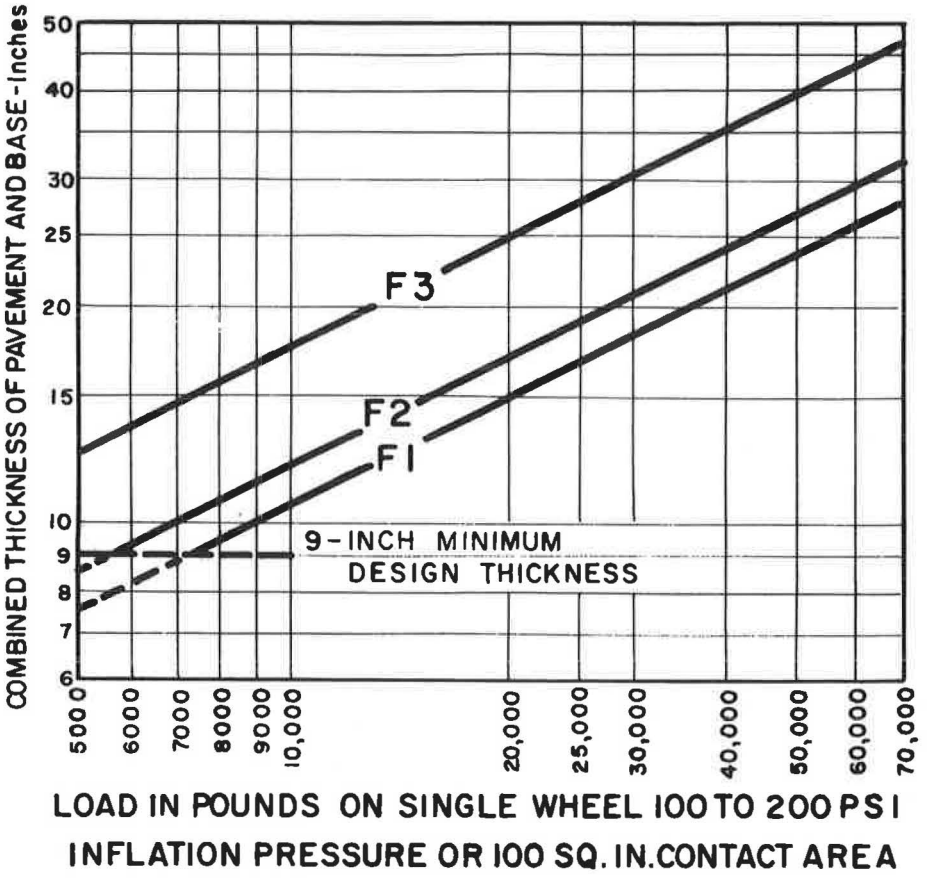
Less total thickness of pavement and base than indicated by the basic design method may also be used if definite justification, based on local experience or special conditions of the design, is provided.

Reduced Subgrade Strength

Thickness design may also be based on the reduction in subgrade strength which occurs during thawing of soils affected by frost action. This design method usually permits less thickness of pavement and base than that needed for limited subgrade frost penetration. The method may be used for both flexible and rigid pavements on F1, F2, and F3 soils when the subgrade is horizontally uniform (or slightly variable for flexible pavements) and significant or objectionable differential heaving and resultant cracking will not occur. The method may also be used over F1 through F4 horizontally variable subgrades for flexible-type pavements of a minor, slow-speed and non-critical character in which heave and its effects can be tolerated. When the reduced subgrade strength method is used for F4 subgrade soils, the combined pavement and base thicknesses should be determined by using the design curves for F3 soils in Figures 15 through 21. When a thickness determined by the reduced subgrade strength method exceeds that

GROUP	DESCRIPTION
F1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 20 PER CENT FINER THAN 0.02 mm. BY WEIGHT.
F2	SANDS CONTAINING BETWEEN 3 AND 15 PER CENT FINER THAN 0.02 mm. BY WEIGHT.
F3	(a) GRAVELLY SOILS CONTAINING MORE THAN 20 PER CENT FINER THAN 0.02 mm. BY WEIGHT. (b) SANDS, EXCEPT VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PER CENT FINER THAN 0.02 mm. BY WEIGHT. (c) CLAYS WITH PLASTICITY INDEXES OF MORE THAN 12. (d) VARVED CLAYS EXISTING WITH UNIFORM SUBGRADE CONDITIONS.
F4	(a) ALL SILTS INCLUDING SANDY SILTS. (b) VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PER CENT FINER THAN 0.02 mm. BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF LESS THAN 12. (d) VARVED CLAYS EXISTING WITH NON-UNIFORM SUBGRADE CONDITIONS

NOTE FOR DESIGN OVER F4 SUBGRADE SOILS SEE TEXT

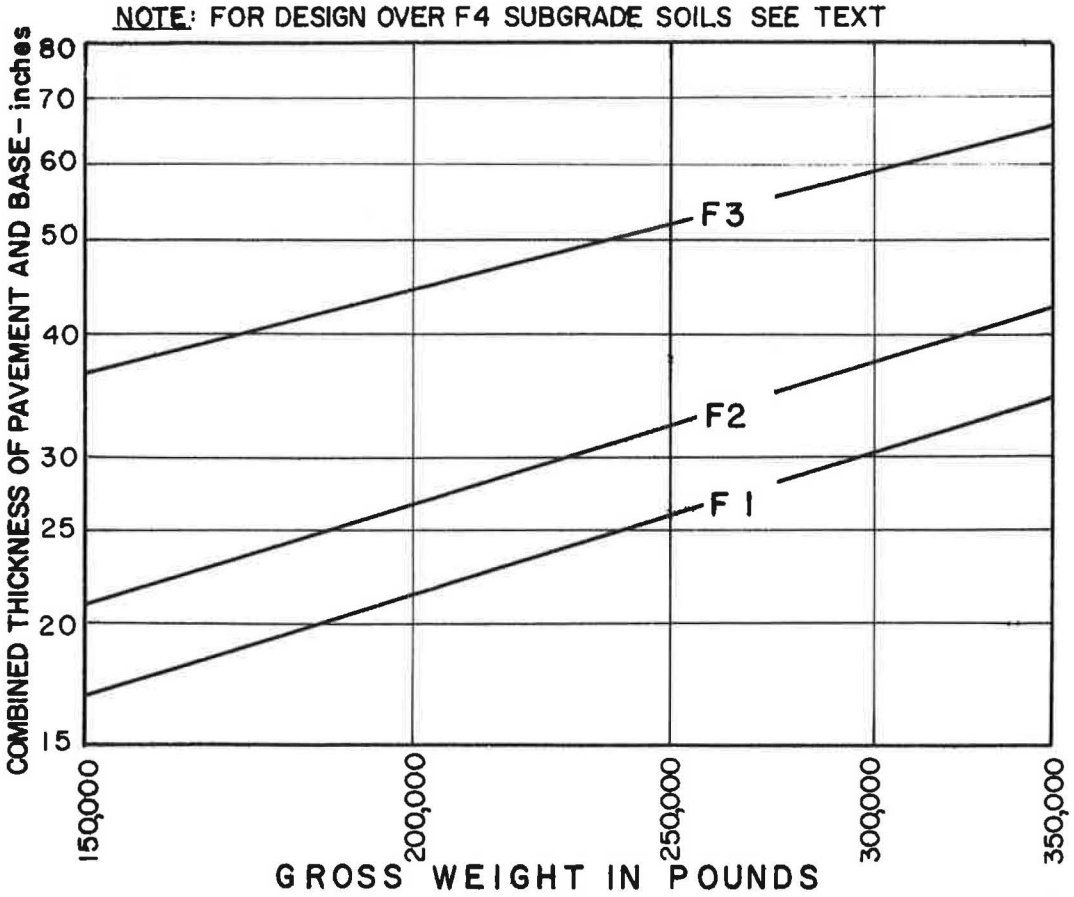


THE THICKNESS WILL BE REDUCED 10 PER CENT FOR RUNWAY INTERIOR (AREA BETWEEN 1000 FOOT SECTION AT EACH END)

Figure 15. Frost condition reduced subgrade strength design curves for flexible pavements.

GROUP	DESCRIPTION
F1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 10 PERCENT FINER THAN 0.02mm BY WEIGHT
F2	(a) GRAVELLY SOILS CONTAINING BETWEEN 10 AND 20 PERCENT FINER THAN 0.02mm BY WEIGHT (b) SANDS CONTAINING BETWEEN 3 AND 15 PERCENT FINER THAN 0.02mm BY WEIGHT
F3	(a) GRAVELLY SOILS CONTAINING MORE THAN 20 PERCENT FINER THAN 0.02mm BY WEIGHT (b) SANDS, EXCEPT VERY FINE SILTY SANDS, CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF MORE THAN 12
F4	(a) ALL SILTS (b) VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02mm BY WEGHT (c) CLAYS WITH PLASTICITY INDEXES OF LESS THAN 12 (d) VARVED CLAYS AND OTHER FINE-GRAINED BANDED SEDIMENTS.

NOTE: FOR DESIGN OVER F4 SUBGRADE SOILS SEE TEXT



THE THICKNESS WILL BE REDUCED 10 PERCENT FOR RUNWAY INTERIOR (AREA BETWEEN 1000 FOOT SECTION AT EACH END)

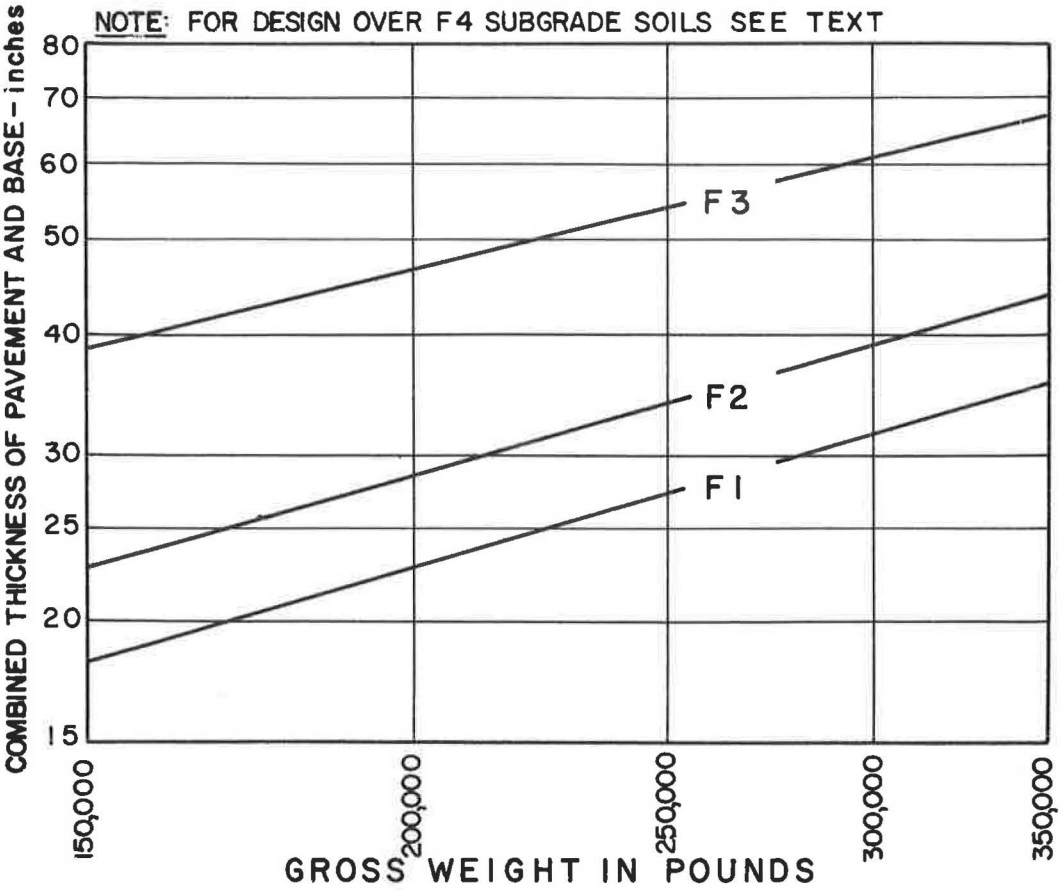
BOEING 707

TWIN TANDEM ASSEMBLY-TRICYCLE GEAR

SPACING 34 in., CONTACT AREA 236 sq. in. EACH WHEEL

Figure 16. Frost condition reduced subgrade strength design curves for flexible pavements.

GROUP	DESCRIPTION
F 1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 10 PERCENT FINER THAN 0.02 mm BY WEIGHT
F 2	(a) GRAVELLY SOILS CONTAINING BETWEEN 10 AND 20 PERCENT FINER THAN 0.02 mm BY WEIGHT (b) SANDS CONTAINING BETWEEN 3 AND 15 PERCENT FINER THAN 0.02 mm BY WEIGHT
F 3	(a) GRAVELLY SOILS CONTAINING MORE THAN 20 PERCENT FINER THAN 0.02 mm BY WEIGHT (b) SANDS, EXCEPT VERY FINE SILTY SANDS, CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF MORE THAN 12
F 4	(a) ALL SILTS (b) VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF LESS THAN 12 (d) VARVED CLAYS AND OTHER FINE-GRAINED BANDED SEDIMENTS.



THE THICKNESS WILL BE REDUCED 10 PERCENT FOR RUNWAY INTERIOR (AREA BETWEEN 1000 FOOT SECTION AT EACH END)

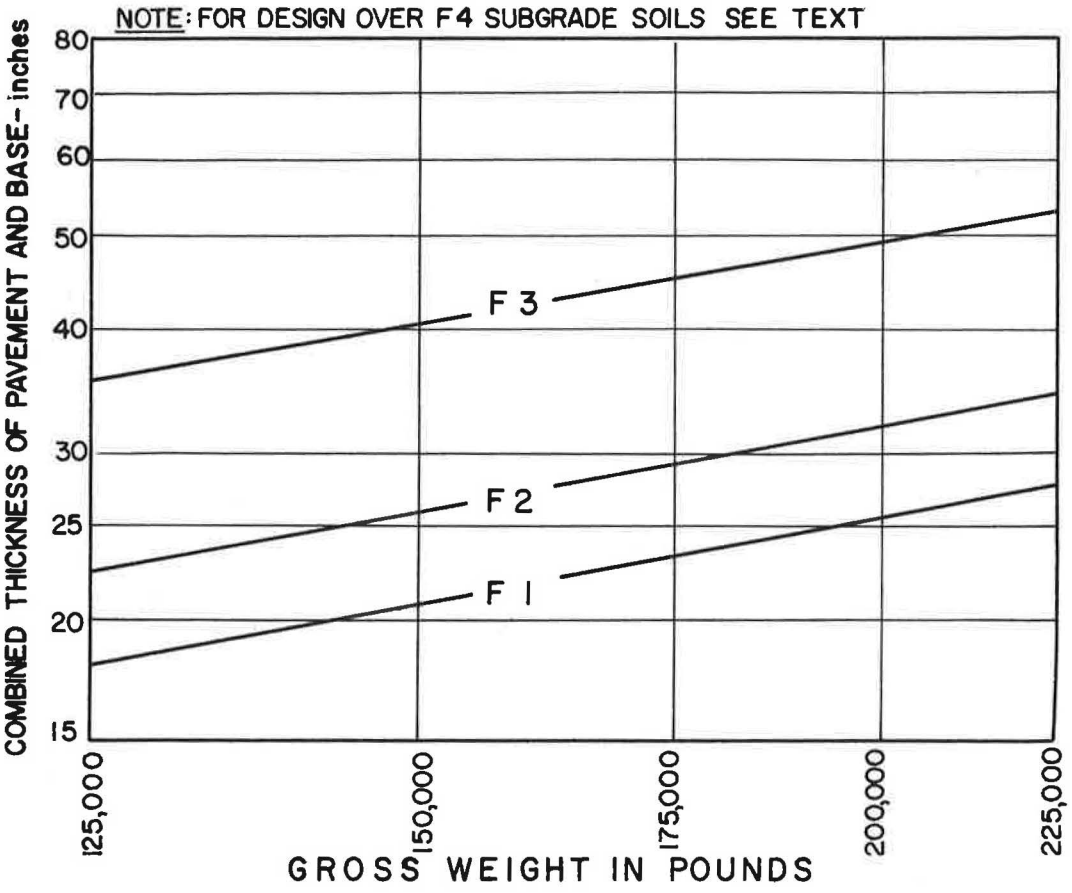
DOUGLAS DC-8

TWIN TANDEM ASSEMBLY-TRICYCLE GEAR

SPACING 30 in., CONTACT AREA 228 sq. in. EACH WHEEL

Figure 17. Frost condition reduced subgrade strength design curves for flexible pavements.

GROUP	DESCRIPTION
F 1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 10 PERCENT FINER THAN 0.02 mm BY WEIGHT
F 2	(a) GRAVELLY SOILS CONTAINING BETWEEN 10 AND 20 PERCENT FINER THAN 0.02 mm BY WEIGHT (b) SANDS CONTAINING BETWEEN 3 AND 15 PERCENT FINER THAN 0.02 mm BY WEIGHT
F 3	(a) GRAVELLY SOILS CONTAINING MORE THAN 20 PERCENT FINER THAN 0.02 mm BY WEIGHT (b) SANDS, EXCEPT VERY FINE SILTY SANDS, CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF MORE THAN 12
F 4	(a) ALL SILTS (b) VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF LESS THAN 12 (d) VARVED CLAYS AND OTHER FINE-GRAINED BANDED SEDIMENTS.



THE THICKNESS WILL BE REDUCED 10 PERCENT FOR RUNWAY INTERIOR (AREA BETWEEN 1000 FOOT SECTION AT EACH END)

CONVAIR 880

TWIN TANDEM ASSEMBLY-TRICYCLE GEAR

SPACING 22.5 in., CONTACT AREA 152 sq. in. EACH WHEEL

Figure 18. Frost condition reduced subgrade strength design curves for flexible pavements.

GROUP	DESCRIPTION
F1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 10 PERCENT FINER THAN 0.02 mm BY WEIGHT
F2	(a) GRAVELLY SOILS CONTAINING BETWEEN 10 AND 20 PERCENT FINER THAN 0.02 mm BY WEIGHT (b) SANDS CONTAINING BETWEEN 3 AND 15 PERCENT FINER THAN 0.02 mm BY WEIGHT
F3	(a) GRAVELLY SOILS CONTAINING MORE THAN 20 PERCENT FINER THAN 0.02 mm BY WEIGHT (b) SANDS, EXCEPT VERY FINE SILTY SANDS, CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF MORE THAN 12
F4	(a) ALL SILTS (b) VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF LESS THAN 12 (d) VARVED CLAYS AND OTHER FINE-GRAINED BANDED SEDIMENTS.

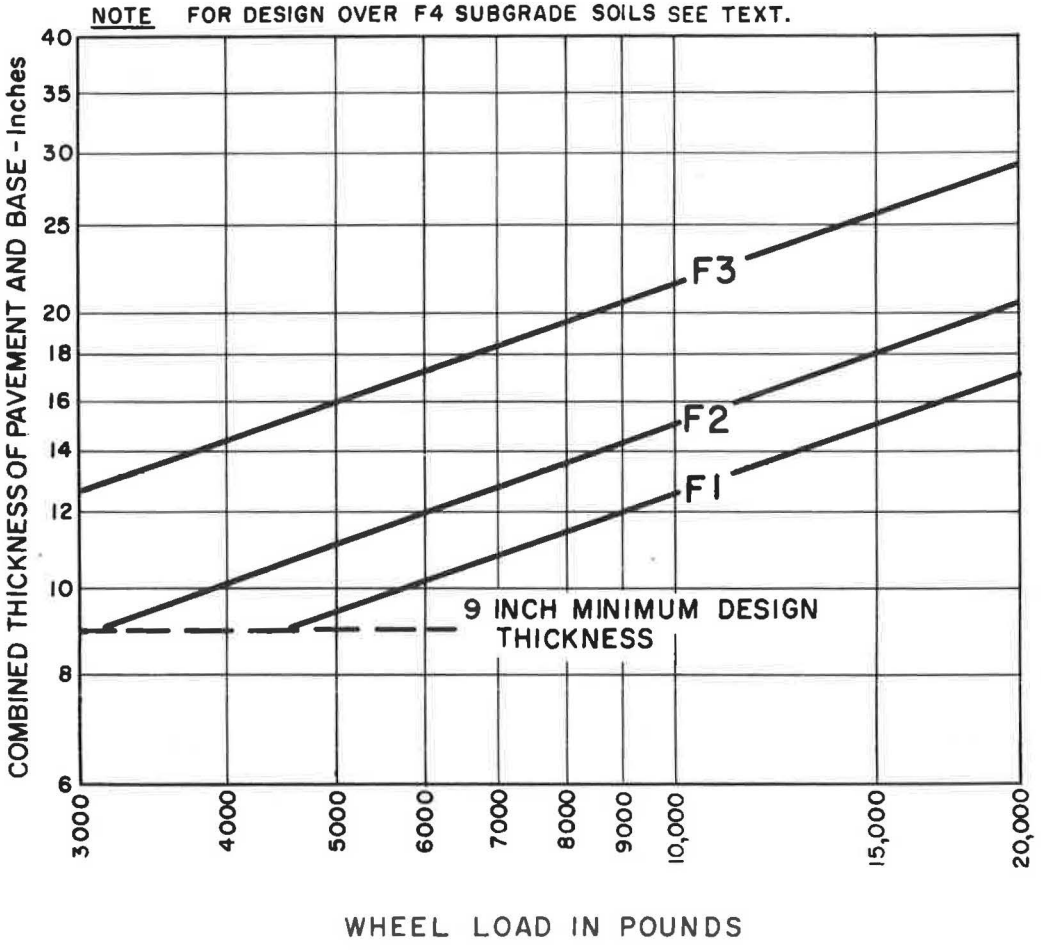


Figure 19. Frost condition reduced subgrade strength design curves for flexible highway pavements.

GROUP	DESCRIPTION
F 1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 10 PERCENT FINER THAN 0.02 mm BY WEIGHT.
F 2	(a) GRAVELLY SOILS CONTAINING BETWEEN 10 AND 20 PERCENT FINER THAN 0.02mm BY WEIGHT. (b) SANDS CONTAINING BETWEEN 3 AND 15 PERCENT FINER THAN 0.02 mm BY WEIGHT.
F 3	(a) GRAVELLY SOILS CONTAINING MORE THAN 20 PERCENT FINER THAN 0.02 mm BY WEIGHT (b) SANDS, EXCEPT VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT. (c) CLAYS WITH PLASTIC INDEXES OF MORE THAN 12.
F 4	(a) ALL SILTS (b) VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF LESS THAN 12 (d) VARVED CLAYS AND OTHER FINE-GRAINED BANDED SEDIMENTS.

NOTE: FOR DESIGN OVER F4 SUBGRADE SOILS SEE TEXT.

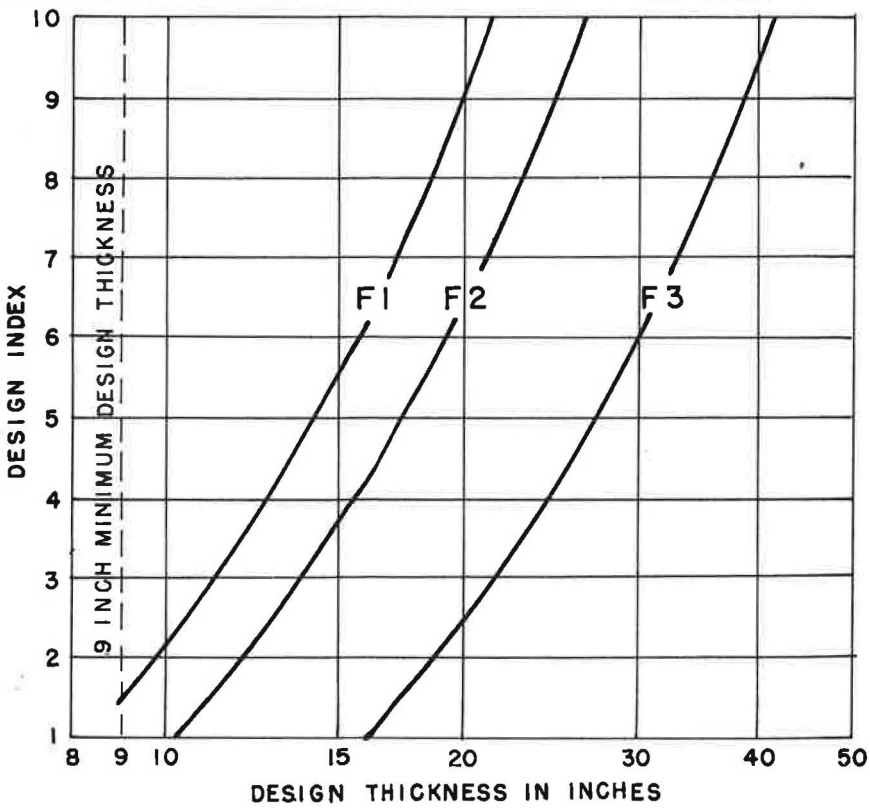


Figure 20. Frost condition reduced subgrade strength design curves for flexible highway pavements.

GROUP	DESCRIPTION
F1	GRAVELLY SOILS CONTAINING BETWEEN 3 AND 10 PERCENT FINER THAN 0.02 mm BY WEIGHT
F2	(a) GRAVELLY SOILS CONTAINING BETWEEN 10 AND 20 PERCENT FINER THAN 0.02 mm BY WEIGHT (b) SANDS CONTAINING BETWEEN 3 AND 15 PERCENT FINER THAN 0.02 mm BY WEIGHT
F3	(a) GRAVELLY SOILS CONTAINING MORE THAN 20 PERCENT FINER THAN 0.02 mm BY WEIGHT (b) SANDS, EXCEPT VERY FINE SILTY SANDS, CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF MORE THAN 12
F4	(a) ALL SILTS (b) VERY FINE SILTY SANDS CONTAINING MORE THAN 15 PERCENT FINER THAN 0.02 mm BY WEIGHT (c) CLAYS WITH PLASTICITY INDEXES OF LESS THAN 12 (d) VARVED CLAYS AND OTHER FINE-GRAINED BANDED SEDIMENTS.

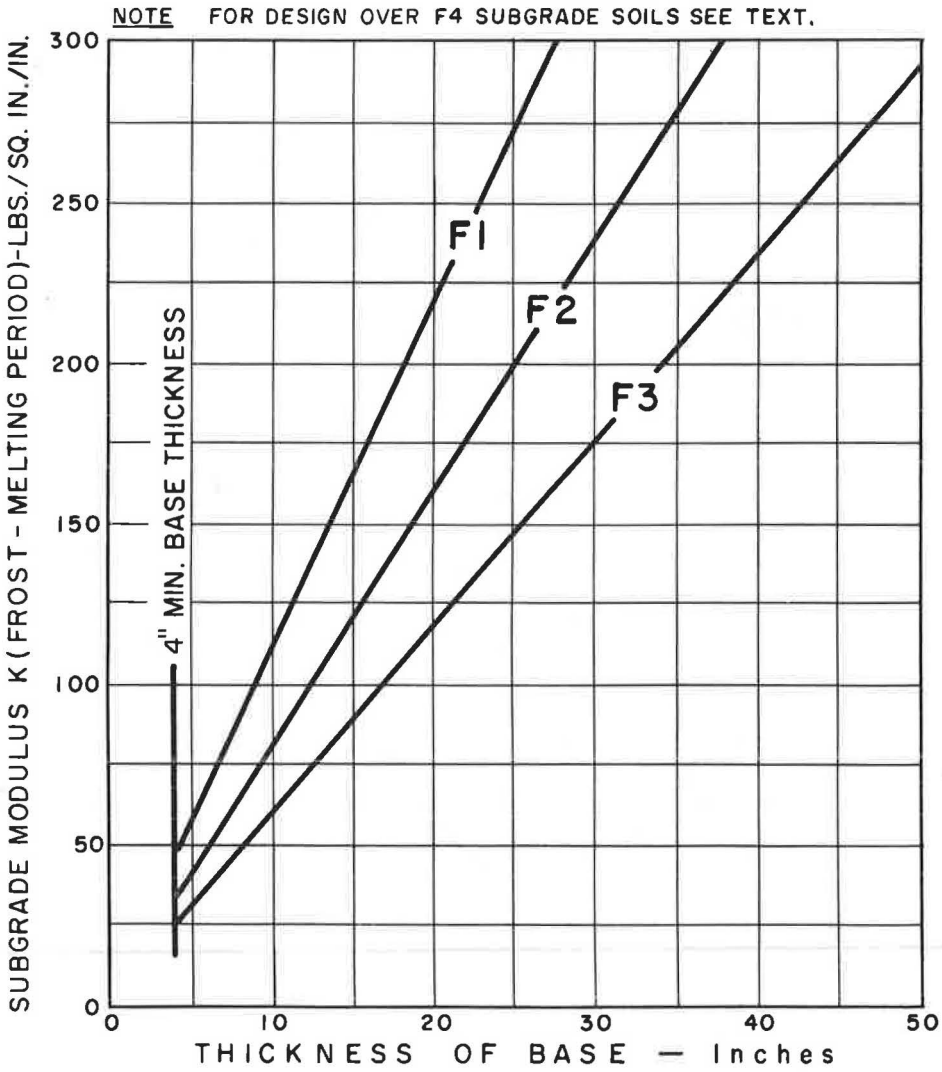


Figure 21. Frost condition reduced subgrade strength design subgrade modulus curves for rigid airfield and highway pavements.

determined for limited subgrade frost penetration or for complete protection, the applicable smaller value should be used, provided it is at least equal to the thickness required for non-frost conditions.

In situations where use of the reduced subgrade strength method might result in objectionable surface roughness or pavement cracking caused by frost heave, but use of the limited subgrade frost penetration design is not considered necessary, intermediate design thicknesses may be used as necessary to prevent objectionable heaving, provided justification is offered on the basis of frost heaving experience developed from existing airfield and highway pavements where climatic and soil conditions are comparable.

(1) Flexible Pavements. In the reduced subgrade strength method of design, the curves in Figures 15 through 18 are used to determine the combined thickness of flexible pavement and non-frost-susceptible base required for aircraft wheel loads and wheel assemblies. Figures 19 and 20 are used for highway design in combination with Ref. (6).

Figure 19 shows no consideration to repetition of loading or to methods for combining the effects of widely varying load. It is used to design pavements for a specified single wheel load selected on the basis of engineering judgment and experience, to represent the anticipated traffic.

Normal Corps of Engineers' practice is to design flexible pavements for roads, streets and similar areas based on a design index. This index represents all traffic expected to use the pavement during its life. It is based on typical magnitudes and compositions of traffic reduced to equivalents in terms of repetition of an 18,000-lb single-axle dual tire load. Development of this method for flexible pavements is given in Ref. (7). Figure 20 shows the required thickness of flexible pavement for the soils of groups F1, F2, F3 and F4 and various design indexes, selection of which is discussed in Ref. (6).

The curves for highways require greater combined thicknesses than the curves for equivalent single-wheel aircraft loadings because of the higher frequency of load applications. General field data and experience indicate that on the relatively narrow embankments of highways, reduction in strength of subgrades during frost melting may be less in substantial fills than in cuts because of better drainage conditions and less intense ice segregation. If local field data and experience show this to be the case, then a reduction in combined thickness of pavement and base of up to 10 percent may be permitted for highways on substantial fills. In no case should the combined thickness of pavement and non-frost-susceptible base be less than 9 in. where frost action is a consideration.

(2) Rigid Pavements. Where frost penetration is permitted in a horizontally uniform frost-susceptible subgrade beneath a rigid pavement, a non-frost-susceptible base course at least equal in thickness to the slab should be used, except for the following conditions:

(a) Where subgrade soils of groups F1, F2, and F3 occur under horizontally uniform conditions (Table 3) and the design freezing index is less than 1,000, the minimum thickness of the non-frost-susceptible base should be 4 in., designed in accordance with the combined filter requirements discussed earlier.

(b) Where soils of groups F1, F2, and F3 subject to pumping occur under horizontally uniform conditions and the depth to the water table is greater than 10 ft, the minimum thickness of the non-frost-susceptible base should be 4 in., designed in accordance with the combined filter requirements.

The base course drainage criteria of Appendix C may require use of base course thicknesses greater than those outlined.

The thickness of concrete pavement should be determined in accordance with Ref. (8) for airfields and Ref. (9) for highways, using the modulus of subgrade reaction for the frost-melting period, $\bar{k}_f$ (Fig. 21), which shows values of equivalent subgrade reduced strength in relation to the thickness of base. If the tested non-frost subgrade modulus value, k, is smaller than the subgrade modulus k_f (Fig. 21), the test value should govern the design. Plate bearing tests performed during the frost-melting period are difficult to evaluate and should not be attempted. Development of rigid pavement thickness requirements for military roads and streets, based on the design index, is given in Ref. (10).

DESIGN FOR STABLIZED RUNWAY OVERRUNS

Frost Condition Requirements

A runway overrun pavement must be designed to withstand occasional emergency aircraft traffic in the form of short or long landings, aborted takeoffs, and possible barrier engagements. The pavement must also serve various maintenance vehicles, such as crash trucks and snowplow equipment. The design of an overrun must provide: adequate stability for infrequent aircraft loading during the frost-melting period; adequate stability for "normal" traffic of snow removal equipment and other maintenance vehicles during frost-melting periods; and sufficient thickness of frost-free base or subbase materials to prevent objectionable heave during freezing periods.

Overrun Design for Reduced Subgrade Strength

In order to provide adequate strength during frost-melting periods, a combined thickness of flexible pavement and non-frost-susceptible base and subbase course should be used, which will be 75 percent of the thickness required for frost capacity operations, based on reduced subgrade strength (Figs. 15-18). The thickness established by this procedure should have the following limitations:

(1) It should not be less than that required for non-frost condition design in overrun areas as determined from Ref. (3).

(2) It should not exceed the thickness required under the limited subgrade frost penetration design method, unless greater thickness is required by the first limitation. For the current principal assembly loadings, use of the tabulation of overrun design thicknesses which follow will avoid the necessity of entering the curves referenced previously.

Overrun Design for Control of Surface Roughness

In addition to establishing the necessary thickness for strength, it may become necessary in some instances to provide additional thickness to restrict maximum differential frost heave to an amount which is reasonable for these emergency areas (generally not more than 3 in. in 50 ft). In selecting a design for restricting frost heave, consideration must be given to type of subgrade material, availability of water, depth of frost penetration, and local experience. In the absence of reliable information on frost heave based on local experience, the following criteria derived from limited tests at Dow and Presque Isle Air Force Bases provide a guide to frost heave limitations for runway overruns:

TABLE 4

COMBINED THICKNESS OF FLEXIBLE PAVEMENT AND BASE (IN.)*
(Equal to 75% of Frost Capacity Operation Thickness)

	F1 Subgrade	F2 Subgrade	F3, F4 Subgrade
188,000 lb, twin-tandem assembly, tricycle gear, spacing 22.5 in., 152 sq in. contact area each wheel (Convair 880).	18	24	36
296,000 lb, twin-tandem assembly, tricycle gear, spacing 34 in., 236 sq in. contact area each wheel (Boeing 707).	23	29	45
310,000 lb, twin-tandem assembly, tricycle gear, spacing 30 in., 228 sq in. contact area each wheel (Douglas DC-8).	24	30	47

*These thicknesses exceed those required for normal operation of snowplow and crash-truck equipment.

(1) For a type F3 subgrade, differential heave can generally be controlled to 3 in. in 50 ft by providing a thickness of non-frost-susceptible base and subbase course equal to 60 percent of the thickness required by the limited subgrade frost penetration design method.

(2) For well-drained subgrades of the F1 and F2 frost types, smaller thicknesses are satisfactory for control of heave. However, unless the subgrade is non-frost-susceptible, the minimum thickness of pavement and base course in overruns should not be less than 40 percent of the thickness required for limited subgrade frost penetration design.

These criteria apply only if they require a combined pavement and base thickness in excess of that described previously for adequate load-supporting capacity.

EXAMPLES OF PAVEMENT DESIGN

Example 1

Design both flexible and rigid class A highway pavements to carry vehicles consisting of 75 percent passenger cars and panel and pick-up trucks, 15 percent two-axle trucks, and 10 percent three-, four- and five-axle trucks, under frost conditions, using the following information:

Design freezing index—800.
Pavement (from normal period design): 3-in. bituminous concrete or 8-in. portland cement concrete.
Base material:
- non-frost-susceptible;
- dry unit weight, 135 pcf;
- moisture content in fall, 5 percent.

Subgrade:
- lean clay;
- plasticity index, 15;
- moisture content, 30 percent;
- uniform conditions;
- normal period CBR, 8 percent.

Highest ground water—3 ft below top of subgrade.
Concrete flexural strength, 700 psi.

The subgrade soil falls into frost group F3.

(1) Flexible Pavement.

Limited Subgrade Frost Penetration.—From Figure 11 the estimated depth of frost penetration below the pavement surface, for base material of 135 pcf dry unit weight, 5 percent moisture content, and unlimited depth, is 52 in. Subtracting the 3 in. of wearing surface, the penetration in base-type material would be 49 in. From Figure 14, required actual base thickness under this design method is 32 in., using a ratio of subgrade to base moisture content of 2.0, the maximum permitted. About 8 in. penetration into subgrade may be expected 1 year in 10. Required combined thickness of pavement and base under the limited subgrade penetration method is 32 + 3 = 35 in.

Reduction in Subgrade Strength.—From Ref. (6), flexible pavement design index is 6. From Figure 20, 30 in. combined thickness of pavement and non-frost-susceptible base are required by the reduction in subgrade strength method for this group F3 subgrade soil. This is 5 in. less than required by the limited subgrade frost penetration method.

Since subgrade conditions are expected to produce uniform heave, the 30-in. thickness is the proper choice. At least the bottom 4 in. of the base should be graded to provide filter action against the subgrade.

(2) Rigid Pavement.

Limited Subgrade Frost Penetration.—From Figure 11, the estimated depth of frost penetration with base of unlimited depth is 52 in. Subtracting the 8-in. slab thickness applicable for normal period design, the penetration in base materials only would be 44 in. From Figure 14, the required actual base thickness is 29 in., which will allow about 7 in. of frost penetration into the subgrade 1 year in 10. Required combined thickness of pavement and non-frost-susceptible base = 29 + 8 = 37 in.

Reduction in Subgrade Strength.—Because the design freezing index is less than 1,000 and subgrade is of a type which produces uniform heave, exception permitting a minimum 4-in. base course to protect against loss of support by pumping is applicable. From Figure 21, the reduced-strength subgrade modulus is 25 psi per in. From Ref. (9), rigid pavement design index is 5, and corresponding required slab thickness is 10 in. after rounding to the next full inch of thickness.

The combined thickness of 10 + 4 = 14 in. is more economical than that obtained by the limited subgrade frost penetration method. However, the design must also be analyzed for conformance with the base drainage criteria of Ref. (2) and Appendix C; these may prove governing. Also, the reduced subgrade strength design can be used only if local experience, records, and study of the specific subgrade conditions indicate that objectionable differential heave and cracking of pavements will not occur. Note that consideration of local experience and records must take into account the severity of freezing conditions actually experienced during the period of record. Frequently these conditions may be well below the design freezing index level.

Example 2

Design flexible and rigid pavements for the following conditions:

Aircraft—Boeing 707, gross weight 296,000 lb, twin-tandem assembly, tricycle gear, spacing 34 in., contact area 236 sq in. each wheel.
Design freezing index—3,000 degree-days.
Subgrade material:
- clay (CL);
- plasticity index, 18;
- water content, 25 percent (avg.);
- normal period CBR, 8;
- normal period subgrade modulus, K - 400 psi/in. (corresponds to test value on top of base of final design thickness).
- Subgrade shows moderate differential heave character in existing pavements and is, therefore, classed as horizontally variable.

Base course material:
- high quality base material (flexible pavement only), graded crushed aggregate, normal period CBR = 100;
- remainder of base non-frost-susceptible sandy gravel (GW), normal period CBR, 50;
- avg. dry unit weight, 135 pcf;
- avg. water content after drainage, 5 percent.

Highest ground water—3 ft below surface of subgrade.
Concrete flexural strength, 650 psi.

(1) Flexible Pavement.

Limited Subgrade Frost Penetration Method.—The subgrade is frost group F3. Table 3 indicates that this design method is applicable for the horizontally variable subgrade condition. From Figure 12, to prevent any freezing of subgrade in the design freezing index year (complete protection), the combined thickness of pavement and base a is 140 in. From Ref. (3), the required flexible pavement thickness p is 4 in. Therefore, thickness of base c for zero penetration of subgrade is 136 in. The ratio of subgrade to base water content r is over 2.0. A ratio of 2.0 is used in Figure 14, which yields a required base thickness b of 91 in. The required combined

thickness of pavement and base to limit subgrade frost penetration is 91 + 4 = 95 in. As shown in Figure 14, this will allow about 23 in. of frost penetration into the moderately variable F3 subgrade on an average of 1 year in 10. (Because this is limited subgrade frost penetration design, the same total thickness would apply for all traffic areas.)

This design will limit pavement heaving, cracking, and loss of subgrade strength to tolerable amounts, provided all other requirements are met, such as use of non-frost-susceptible base material, uniformity of the base course as placed, subsurface drainage meeting the criteria of Ref. (2), and use of appropriate transitions at any substantial and abrupt changes in the foundation characteristics.

Because the indicated combined thickness exceeds 72 in., further investigation should be made to attempt to locate a non-frost-susceptible base course material of lower unit weight and/or higher moisture retention. It could be used in lieu of the sandy gravel for at least a substantial part of the base thickness to reduce the amount of frost penetration and hence the design thickness requirements. If this is not successful, a special analysis should be made for each traffic area using all available data, including performance records of other pavements under similar conditions, to determine whether surface roughness of the flexible pavement for each specific case under design freezing index conditions would be excessive if only 72-in. combined thickness is used.

Reduced Subgrade Strength Method.—Referring to Table 3, this design method should not be used when horizontally variable subgrade conditions exist.

About 34-in. combined thickness would be required during the normal period. Thus, the 95-in. thickness determined by the limited frost penetration method is applicable, unless some reduction can be achieved by further analysis.

(2) Rigid Pavement.

Limited Subgrade Frost Penetration Method.—Table 3 indicates this method is applicable. The required pavement thickness p, based on the normal period k = 400 psi/in., is 18 in. Every inch of concrete pavement in excess of 12 in. reduces the design freezing index by 10 degree-days. In this example, the reduction = 10 (18-12) = 60 degree-days. Therefore, the modified freezing index = 3,000 - 60 = 2,940. From Figure 12, the combined thickness of 12-in. pavement and base a required to prevent any freezing of the subgrade is 138 in. Addition of the originally deducted 6-in. thickness of pavement results in a combined thickness of pavement and base of 144 in. Therefore, the thickness of base c required for zero frost penetration into the subgrade is 126 in. From Figure 14, the required design base thickness b is 84 in., which permits a corresponding subgrade frost penetration s of 21 in. in the design year. Because the indicated combined thickness of 84 + 18 = 102 in. exceeds 72 in., special analysis is required for possible reduction of base thickness. The possible use of steel reinforcement, reduced slab dimensions, or base material with smaller unit weight and/or higher moisture retention are considered appropriate.

In the exceptional case of an extremely variable subgrade or of design requirements so stringent that complete protection is required, a combined thickness of 144 in. would be needed using this particular base material. In such case, an attempt should be made again to provide a non-frost-susceptible base material of smaller unit weight and/or higher moisture retention in order to reduce this thickness.

Reduced Subgrade Strength Method.—As indicated in Table 3, this method is not applicable for rigid pavements under horizontally variable subgrade and moisture conditions.

Example 3

Design an overrun pavement for the following conditions:

Aircraft—Boeing 707, gross weight 296,000 lb, twin-tandem assembly, tricycle gear, spacing 34 in., contact area 236 sq in. each wheel.
Design freezing index - 600 degree-days.
Subgrade material:
uniform sandy clay (CL);

plasticity index, 18;
water content, 20 percent (avg.);
normal period CBR, 15.

Base course material:
non-frost-susceptible sandy gravel (GW);
avg. dry unit weight, 135 pcf;
avg. water content after drainage, 5 percent.

Highest ground water—4 ft below surface of subgrade.

For reduced subgrade strength during the frost-melting period, the required combined thickness for F3 subgrade is 45 in.

Under limited subgrade frost penetration design method, using the same computation procedures outlined above and neglecting effect of any surface treatment, the required thickness is 29 in. which would allow about 7 in. of frost penetration into the subgrade 1 year in 10.

ACKNOWLEDGMENT

The design of pavement for frost conditions reported herein is based on studies carried out under the overall direction of the Civil Engineering Branch, Engineering Division, Military Construction, Office, Chief of Engineers. Mr. Thomas B. Pringle is Chief.

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Appendix A

FIELD CONTROL OF PAVEMENT CONSTRUCTION FOR FROST CONDITIONS IN AREAS OF SEASONAL FREEZING

Field control of airfield and highway pavement construction in areas of seasonal freezing should give specific consideration to conditions and materials that will result in detrimental frost action. Ideally, contract plans and specifications should provide for special treatments, such as removal of unsuitable materials encountered, with sufficient information included to identify those materials and specify necessary corrective measures. However, construction operations will quite frequently expose frost-susceptible conditions at isolated locations of a degree and character not revealed by even the most thorough subsurface exploration program conducted during the design phase. It is essential, therefore, that personnel assigned to field construction control be made aware of their responsibility to recognize situations that require special treatment whether or not anticipated by the designing agency.

Subgrade Preparation

Where laboratory and field investigations indicate that the soil and ground water conditions will not result in ice segregation in the subgrade soils, the pavement design is based on the assumption that the soils will not heave during the winter or weaken during the frost-melting period. The construction inspection personnel should check the validity of the design assumptions, and if pockets of frost-susceptible material or wet subgrade conditions are revealed of which the design agency was not cognizant, remedial measures should be initiated. Gradation tests should be performed on any questionable materials encountered during grading operations, and all pockets of frost-susceptible soils in an otherwise non-frost-susceptible subgrade should be removed to the full depth of frost penetration and replaced with materials of the same type as the surrounding soil. Clean granular soils are little affected by frost action. These materials should be employed in situations where seasonal freezing will affect the construction.

At any site where the subgrade conditions are recognized as favorable for frost action, personnel should be alert to observe whether the field conditions as found are in accordance with the design assumptions regarding drainage, gradation and character of materials. Where the design permits freezing of the subgrade materials, the inspector has the responsibility of insuring that the special frost protection measures are adequate and that design provisions are adhered to. One condition that is often left in the hands of the field inspection forces is the case of a subgrade which consists of soils of variable degrees of frost susceptibility. Areas in such a subgrade requiring supplementary design measures can only be defined as to location during grading operations. It may be necessary either to remove a pocket of highly frost-susceptible material for the full depth of frost penetration, or if this is impractical, to provide transition zones between the areas of high and low frost susceptibility so as to minimize non-uniform pavement heave. In general, abrupt changes in subgrade conditions should always be avoided by providing transitions, particularly in high-speed pavements such as runways. Frequent trouble sources in addition to abrupt variations in soil characteristics, are sudden changes in ground water conditions, changes from cut to fill, and locations of under-pavement pipes, drains, or culverts. At the transition between cut and fill sections the topsoil and humus materials should be completely removed for the ultimate depth of frost penetration in otherwise non-frost-susceptible materials, even though specifications may not require general stripping in fill areas.

Special attention should be given to wet areas in the subgrade, and special drainage measures should be installed as required. The need for such measures arises most frequently in road construction where it may be necessary to provide intercepting drains to prevent infiltration into the subgrade from higher ground adjacent to the road.

In areas where rock excavation is required, the character of the rock and seepage conditions should be considered. In any case, the excavations should be made so that positive transverse drainage is provided and no pockets are left on the rock surface which will permit ponding of water within the maximum depth of freezing. The irreg-

ular ground water availability created by such conditions may result in markedly irregular heaving under freezing conditions. It may be necessary to fill drainage pockets with lean concrete. Rock subgrades where large quantities of seepage are involved should be blanketed with a highly pervious material to permit the escape of water. Frequently the fractures and joints in the rock contain frost-susceptible soils. These materials should be cleaned out of the joints to the depth of frost penetration and replaced with non-frost susceptible material. If this is impractical, it may be necessary to remove the rock to the full depth of frost penetration.

Base Course Construction

Where the available base course materials are positively non-frost-susceptible, the base course construction control should be in accordance with normal practice. In instances where the base course material selected for use is of borderline frost susceptibility (usually materials having 1½ to 3 percent of grains finer than 0.02 mm by weight), frequent gradation checks should be made to insure that the materials meet the design criteria. If it is necessary for the contractor to exercise selection in the pit in order to obtain suitable materials, his operations should be inspected at the pit. It is more feasible to reject unsuitable material at the source when large volumes of base course are being placed. It may be desirable to stipulate thorough mixing at the pit, and if necessary, stockpiling, mixing in windrows and spreading the material in compacted thin lifts in order to insure uniformity. Complete surface stripping of pits should be enforced to prevent mixing of detrimental fine soil particles or lumps in the base material. The gradation of materials taken from the base after compaction, such as density test specimens, should be determined particularly at the start of the job and checked frequently to see if fines are being manufactured in the base under the passage of the base course compaction equipment. Base course materials exhibiting possible serious degradation characteristics may warrant construction of a test embankment to study the manufacture of fines under the proposed or other compactive efforts. Mixing base course materials with frost-susceptible subgrades should be avoided by making certain that the subgrade is properly graded and compacted prior to placement of base course, by insuring that the first layer of base course provides filter action against penetration of subgrade fines under traffic, and by the elimination of kneading action caused by overcompaction or insufficient thickness of the first layer of base course. Experience has shown that excessive rutting by hauling equipment tends to cause mixing of subgrade and base materials. This can be greatly minimized by the frequent rerouting of material-hauling equipment. After completion of each lift of base, a careful visual inspection should be made before placing additional material to insure that areas with high percentages of fines are not present. These areas may be frequently recognized both by visual examination of the materials, and by observations of their action under compaction equipment, particularly when the materials are wet. The materials of any areas which do not meet specification requirements for frost conditions should be removed and replaced with suitable material. Use of a leveling course of fine-grained material should not be used as a construction expedient to choke open-graded base courses, to establish fine grade or prevent overrun of concrete. Because the base course receives high stresses from traffic, this prohibition is essential so that there will be no weakening during the frost-melting period.

Action should be taken to vary the base course thickness to provide transitions, when necessary, and to avoid abrupt changes in pavement supporting conditions.

Appendix B

STANDARD LABORATORY FROST SUSCEPTIBILITY TEST PROCEDURE

Molding of Specimens

Soil specimens for standard laboratory frost susceptibility tests are generally prepared in a slightly tapered (5.50 to 5.75 in. inside diameter) 6-in. high steel molding cylinder with removable base. The steel cylinder is lubricated with silicone grease

and a light coat of paraffin prior to molding to facilitate ejection of the soil specimen. The soil is compacted to an approximate height of 6 in. and to a predetermined dry unit weight by means of a static load and/or vibration. Undisturbed specimens of cohesive soils are prepared by trimming to a uniform diameter and height of about 6 in., respectively.

Two methods are used in molding specimens to the desired dry unit weight. Relatively cohesionless, coarse-grained soils, such as sands and sandy gravels, are generally prepared by an adaptation of the Providence Vibrated Density Test Method (11). In this method, a predetermined weight of soil is placed in the steel cylinder and a load of approximately 1,000 lb is applied by a piston at each end and a heavy spring at the top. The soil within the steel cylinder is compacted by vibrating the cylinder with hammer blows on the sides. Fine-grained soils, such as uniform fine sands, silts and glacial tills are compacted by tamping in layers using the modified AASHO (12) or the Corps of Engineers Airfield Density Test (3) procedures, Appendix C.

Cohesionless soils are either molded dry and then wetted, or are molded at a low moisture content which improves the apparent cohesion and aids specimen handling after molding. For field construction design purposes, cohesive soils are molded at the optimum moisture content and to the dry unit weight determined by the Modified AASHO Test or Corps of Engineers Airfield Density Test, depending on the anticipated field conditions or requirements. For evaluation of the frost potential of materials under existing pavements, subgrade soils obtained from beneath the pavements are tested either in an undisturbed condition or are recompacted in the laboratory to approximately field dry unit weight and moisture conditions.

The remolded specimens are removed from the steel molding cylinder by piston pressure at the bottom of the specimen and are fitted snugly into open-ended tapered lucite cylinders (wider at the upper end) lined with cellulose acetate strips, 1.5 in. wide and 0.007 in. thick. The acetate strips are coated on each side with silicone grease and lapped horizontally in a telescopic manner. This is done to minimize friction between the specimen and cylinder when heave takes place during freezing. Specimens prepared by cutting from undisturbed samples are not tapered because of the difficulty of obtaining a uniform taper manually. Such specimens are fitted snugly into parallel-walled cylinders of lucite or of waxed, laminated heavy cardboard lined with lubricated acetate strips.

Saturation of Specimens

All specimens tested in the open system are saturated prior to freezing. Saturation is carried out in the cold room at a temperature of 38 F. Both ends of the lucite cylinder containing the soil specimen are covered with filter papers, porous discs (3/8 in. thick) and capped with snug-fitting shallow brass pans which have nipples extending out from the center for connection of tubing. A rubber sleeve-like membrane, 0.02 in. thick, is slipped around the cylinder and a rubber band wound firmly around the membrane over the entire height of the cylinder to seal the specimen against leakage during the air evacuation and the subsequent saturation period. The specimen is first evacuated of air simultaneously from the top and bottom. It is then saturated from the bottom with de-aired water.

Thermocouples in Specimens

Thermocouples are inserted at 1-in. intervals along the longitudinal axis, including top and bottom, in one of the specimen groups in a test cabinet, and at the top and bottom only in one additional specimen. The former installation provides an accurate record of the temperature gradient and the day-by-day advance of freezing temperature into the specimen. The latter installation provides a double check of the start and completion of the freezing test period. The thermocouples are inserted through the side of the specimen container. The entrance points are sealed with a mastic or other suitable waterproofing material. The specimens are placed in freezing cabinets containing cooling plates around three sides at the top. Each cabinet can accommodate up to four 6-in. diameter specimens. A water supply is connected to the bottom of each specimen

through the nipple provided on the brass receptacle. The nipple protrudes through a bottom sheet metal pan and grillwork into the open space beneath the freezing cabinet which is about 38 F, the cold room temperature. The free water level in the bottom cap is adjusted and maintained at a height of $\frac{1}{4}$ to $\frac{3}{8}$ in. above the bottom of the specimen. The top brass caps, porous stones and filter papers are removed and the space around the specimens is filled loosely with granulated cork leaving the top surface of the specimens exposed to the cabinet air temperature.

Pressure

All specimens are frozen under a pressure load (lead weights) of 0.5 psi to simulate field conditions consisting of a 6-in. combined thickness of base and pavement. A thin steel base plate ($\frac{1}{8}$ in. thick) is placed on top of the specimen and firmly seated to provide a uniform contact. Four lugs are attached to the base plate to raise the lead weights $1\frac{1}{2}$ in. so that the air may circulate over the top of the specimen.

Freezing Test Procedure

Prior to freezing, the specimens are tempered for 18 to 24 hours at 38 F. Initial freezing is obtained by rapidly lowering the air temperature in the freezing cabinet to about 20 F until crystallization of the soil is visible on the surface. To insure crystallization, the surfaces are seeded with pulverized ice. At this time, the thin 6-in. diameter steel base plates and weight (both tempered at 28 F) are placed on each specimen to provide the necessary pressure intensity. The specimens are then gradually frozen from the top to bottom by sufficiently decreasing the cabinet air temperature to obtain a rate of the 32 F isotherm of about $\frac{1}{4}$ to $\frac{1}{2}$ in. per day. Heave measurements are taken daily with a meter stick or an extensometer placed on a designated point on the surcharge weights over the specimens.

Examination of Specimens

On completion of the freezing tests, usually 24 days, the specimens are removed from the cabinet and containers and are weighed, measured and split longitudinally in two sections. Measurements for amount of heave, and observations for the location, distribution and magnitude of ice lens formations are made on one section. The other section is photographed and retained for supplemental laboratory tests. The water content distribution is obtained for every inch of specimen depth.

Supplementary Laboratory Tests

The following standard laboratory tests are performed on all materials tested, for correlation with the average rate of heave: gradation, permeability, specific gravity, Atterberg limits (if applicable), and compaction characteristics.

Evaluation of Frost Susceptibility

The standard laboratory frost susceptibility test was designed to subject the soil to a severe combination of conditions conducive to frost action and results in virtually the maximum rate of ice segregation and heave which the soil can exhibit under natural field conditions. The results are not usually quantitatively representative of actual heave to be expected in the field. The test procedures are considered satisfactory, however, for determining the relative degree of frost susceptibility of various soils, with the possible exception of unweathered clays which may show unduly low heave for at least the first cycle of freezing. In clays which are unfissured and have not previously been frozen, the rate of heaving may be low initially, but as the clay is repeatedly thawed and frozen and becomes fissured, the rate of heaving may become much greater.

Rate of heave has been found to be relatively independent of rate of freezing over the range of employed freezing rates. Therefore, average rate of heave has been utilized as the basis for expression, comparison, and evaluation of test results. The following tentative scales of average rate of heave have been adopted for rates of freezing between $\frac{1}{4}$ in. and $\frac{3}{4}$ in. per day:

Average Rate of Heave mm/Day	Frost Susceptibility Classification
0-0.5	Negative
0.5-1.0	Very low
1.0-2.0	Low
2.0-4.0	Medium
4.0-8.0	High
Greater than 8.0	Very high

The evaluation given by the standard freezing test should be considered empirical in nature. Average rate of heave does not represent a simple and fundamental physical value because such factors as pressure and moisture availability vary continuously during the test.

Appendix C

DESIGN OF BASE COURSE DRAINAGE

Basis for Design

Where frost action occurs in the subgrade beneath the pavement, base drainage is required. To simplify the analysis of drainage of base courses, it is assumed that the base course is fully saturated and no inflow occurs during drainage, the subgrade constitutes an impervious boundary, and the base course has a free outflow into the drain trench.

Maximum Rate of Discharge

The following equation may be used to determine the maximum rate of discharge for a saturated base course of dimensions shown in Figure 22:

$$q = kH\frac{H_0}{D60}$$

where:

k is the coefficient of horizontal permeability in feet per minute;
H, H_0, and D are dimensions (Fig. 22) in feet; and
q is the peak discharge quantity in cfs per lineal foot of drain.

Degree of Drainage

Degree of drainage is defined as the ratio, expressed as a percent, of the amount of water drained in a given time to the total amount of water that is possible to drain from the given material. Base course design should be based on the criterion that a degree of drainage of 50 percent in the base course should be obtained in not more than 10 days. The following formula may be used to determine the time required for a saturated base course to reach a degree of drainage of 50 percent:

$$t = \frac{n_e D^2}{2880kH_0}$$

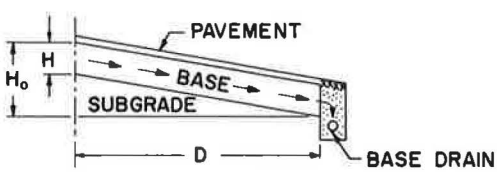

Figure 22. Design of base course drainage.

where:

t is time in days for 50 percent drainage;
n_e is the effective porosity of the soil;
D and H_0 are dimensions (Fig. 22) in feet; and

k is coefficient of permeability of the soil parallel to direction of seepage flow in feet per minute.

The application of the preceding formula may be illustrated by the following example. Assuming a section as shown in Figure 22, let:

$$n_e = 0.1$$
$$D = 75 \text{ ft}$$
$$H_0 = 3.6 \text{ ft}$$
$$k = 1 \times 10^{-2} \text{ ft per min}$$

Then:

$$t = \frac{0.1 \times 75 \times 75}{2880 \times 0.01 \times 3.6} = 5.4 \text{ days}$$

Coefficient of Permeability of Base Materials

The base materials generally used immediately beneath airfield pavements consist of sand and gravel, sand, crushed rock, partially crushed gravel and sand, slag, cinders, etc. In many cases the base will consist of several layers, each of different base material. The coefficient of permeability of sand and gravel courses graded between limits usually specified for stabilized material depends principally on the percentage by weight of sizes passing the 200-mesh sieve. The following tabulation may be used for preliminary estimates of average coefficients of permeability for remolded samples of sand and gravel bases:

Percent by weight passing 200-mesh sieve	Coefficient of permeability for remolded samples (ft per min)
3	10^{-1}
5	10^{-2}
10	10^{-3}
15	10^{-4}
25	10^{-5}

The coefficient of permeability of crushed rock and slag, each without many fines, is generally greater than one foot per minute. The coefficient of permeability of sand, and sand and gravel mixtures may be approximated from Figure 23.

The coefficient of permeability of a base in a horizontal direction (parallel to compaction planes) may be 10 times greater than the average value tabulated previously, the average value based on determinations on remolded samples. For uniformly graded sand bases, the coefficient of permeability in a horizontal direction may be about four times greater than the value determined by tests on remolded samples. Very pervious base materials such as crushed rock and slag with few fines, have substantially the same coefficient of permeability in a vertical and horizontal direction.

In all cases for final design, the coefficient of permeability of the material used for base should be determined by laboratory tests. The preceding values are presented as a general guide for preliminary design computations.

When more than one material is used in a given base, the weighted coefficient of horizontal permeability determined in accordance with the following formula results in a reasonable design value.

$$k = \frac{k_1 d_1 + k_2 d_2 + k_3 d_3, \text{ etc.}}{d_1 + d_2 + d_3, \text{ etc.}}$$

where:

k is the weighted coefficient of horizontal permeability;

k_1, k_2, k_3, etc., are the coefficients of horizontal permeability of individual base materials in feet per minute; and

d_1, d_2, d_3, etc., are the thicknesses of the individual layers in feet.

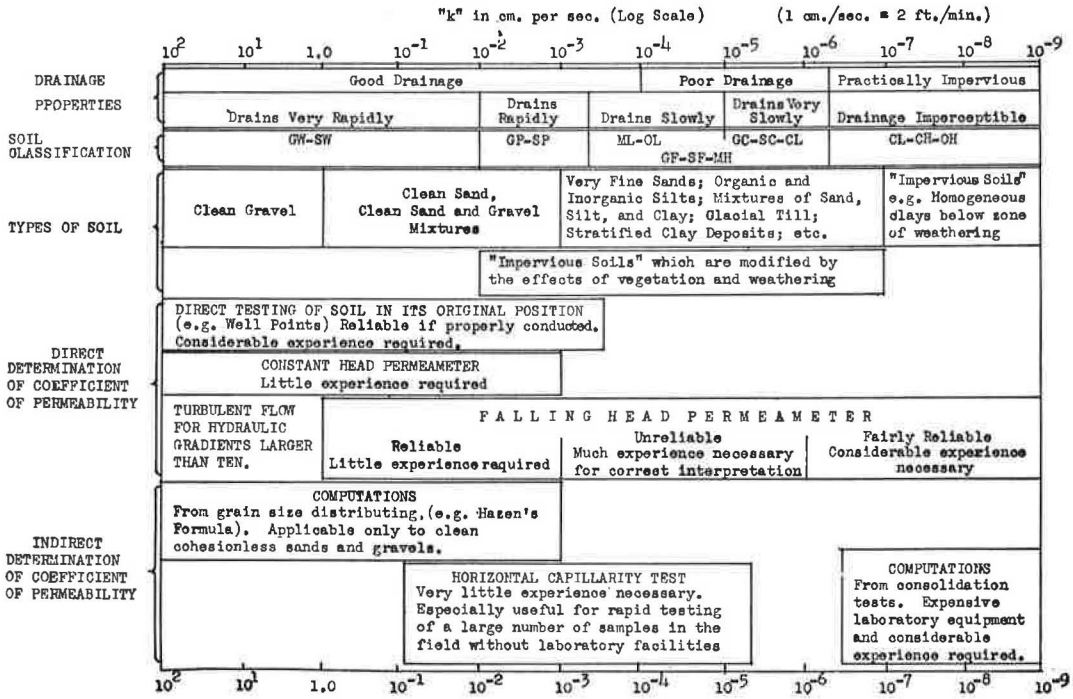

Figure 23. Permeability chart.

Spacing of Drains

Where the time determined for degree of base course drainage of 50 percent is greater than 10 days, the spacing between drains should be decreased until the time for drainage is 10 days or less, a more pervious base material should be selected, or a greater thickness of base should be used in the design.

In general, for most runway and taxiway bases of a width from crown to edge of not more than 75 ft, a single line of base drains along the edges should meet the design criteria. It may be necessary on wider base widths, or where reasonably pervious base course material is not locally available, to install intermediate lines of drains to provide satisfactory base drainage.

Base Course Filter Design

To prevent the movement of particles from the protected soil into or through the filter or filters, the following condition must be satisfied:

$$\frac{15\% \text{ size of filter material}}{85\% \text{ size of protected soil}} \leq 5$$

and

$$\frac{50\% \text{ size of filter material}}{50\% \text{ size of protected soil}} \leq 25$$

The preceding criteria are used when protecting all soils except medium to highly plastic clays without sand or silt partings, which by the preceding criteria may require multiple-stage filters. For these clay soils, the d_{15} size of the filter may be as great as 0.4 mm and the preceding d_{50} criteria disregarded. This relaxation in criteria for protecting medium to highly plastic clays allows the use of a one-stage filter material.

However, the filter must be well graded, and to insure nonsegregation of the filter material, the coefficient of uniformity should be not greater than 20 (Fig. 24).

Depth of Cover Over Drains

The depth of cover over drains is dependent on loading and frost requirements. (EM 1110-345-283 lists the cover requirements for different design wheel loads.) With respect to frost in areas of seasonal freezing, the depth of cover to the centerline of the pipe should be not less than the depth of frost penetration determined from Figures 11 or 12, based on the design freezing index for the particular location. The trench for subdrains should be backfilled with free-draining, non-frost-susceptible material. Within the depth of frost penetration, gradual transitions should be provided between non-frost-susceptible trench backfill and frost-susceptible materials of drains placed under traffic areas to prevent detrimental differential heave, particularly for the case of frost condition pavement design based on reduced subgrade strength.

Discussion

G. Y. SEBASTYAN, Head, Engineering Design Section, Air Services, Construction Branch, Canadian Department of Transport.—The paper submitted by Messrs. Linell, Hennion and Lobacz was studied with great interest by the engineers of the Engineering Design Section of the Construction Branch, Canadian Department of Transport. The authors did an exceptional job in compiling and making available to the engineering profession, the U. S. Corps of Engineers' design procedures relating to the design of flexible and rigid pavements in areas of seasonal frost. Because almost all Canadian airport pavements are in areas affected by seasonal frost, it was thought interesting and worthwhile to compare the experience and procedures of the Canadian Department of Transport with those given in the subject paper.

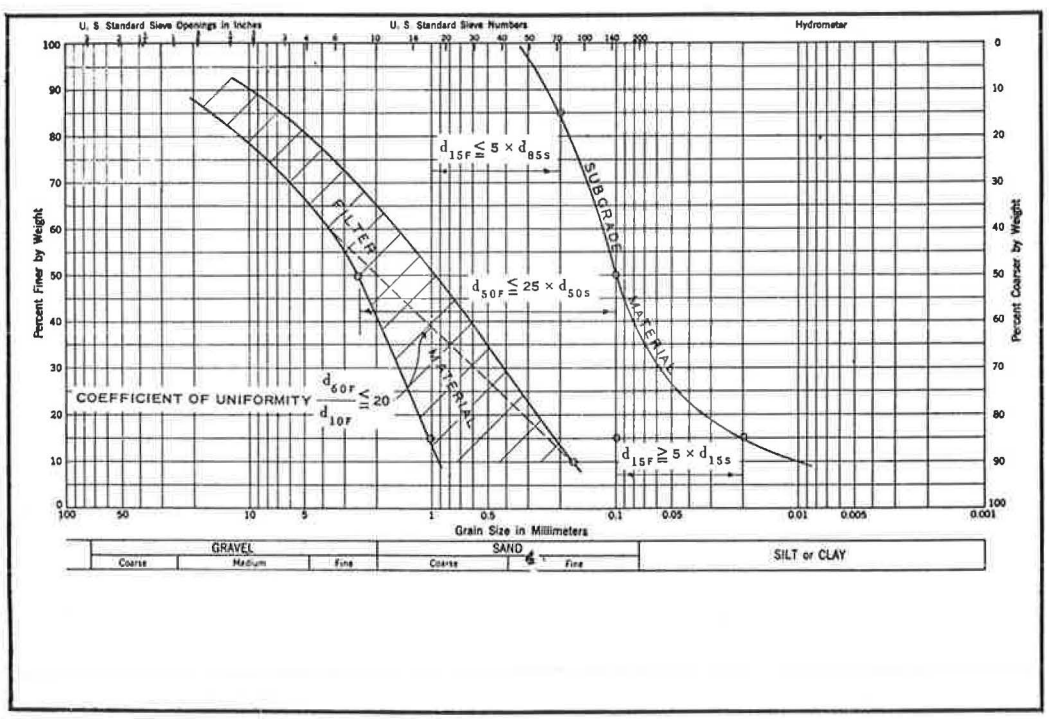

Figure 24. Design example for filter materials.

It is emphasized that the Canadian Department of Transport's design and evaluation procedures are related to Canadian environments and aircraft traffic conditions.

There are three major points discussed herein:

1. The Canadian Department of Transport's frost protection design criteria are based on the 10-yr average freezing index. It is the U. S. Corps of Engineers' practice to use a 10-yr maximum index or the average of three coldest years in 30 years as a design criterion. For Canadian conditions, a comparison was made (Fig. 25) for the 10-yr average and the 10-yr maximum freezing indices. The ratio of 10-yr maximum over 10-yr average freezing index is between 1.5 (FI.1000) and 1.2 (FI.4000).

2. It is the Canadian Department of Transport's design procedure to determine the minimum combined flexible or rigid pavement structure thickness (wearing surface, base and subbase) on the basis of approximately half the expected frost penetration.

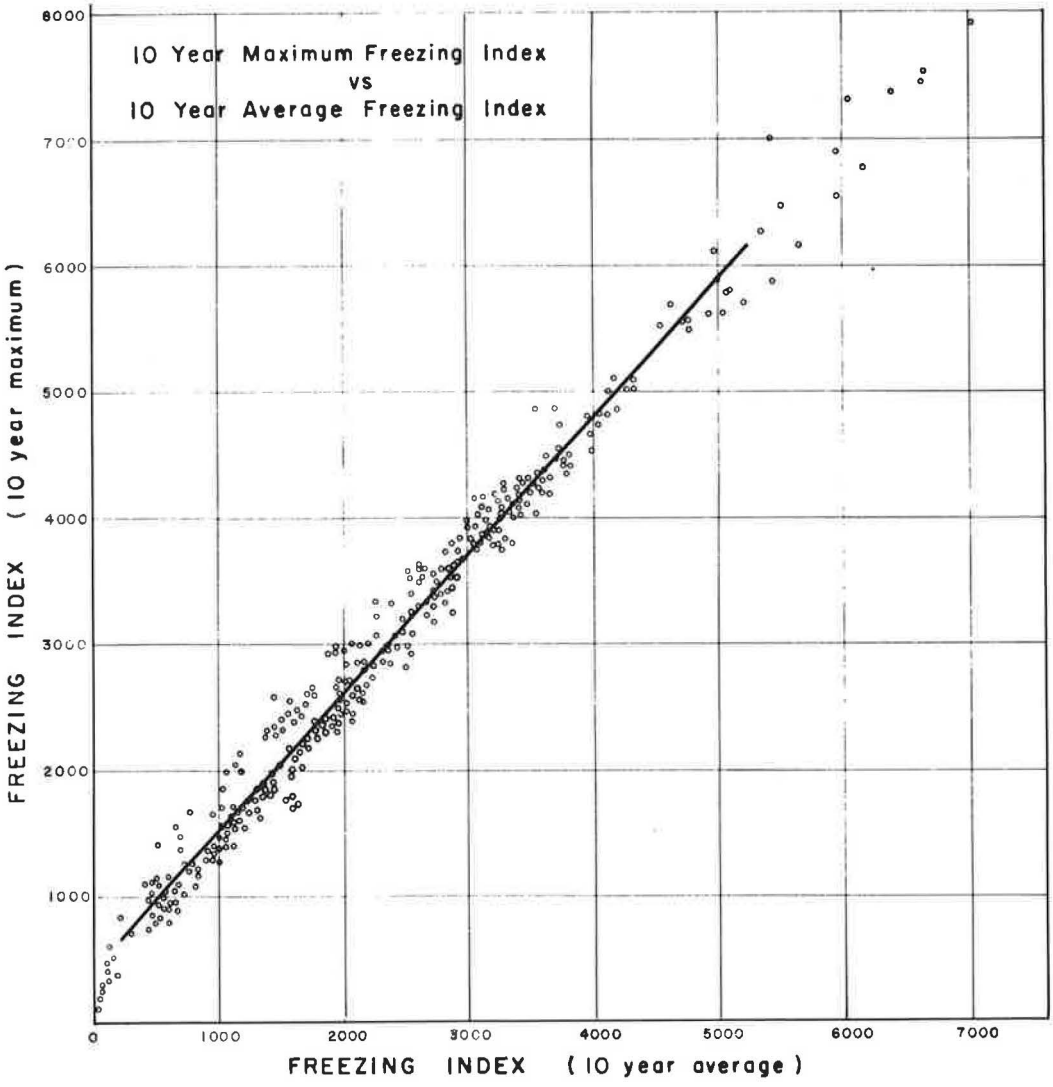

Figure 25. Department of Transport freezing indices for various Canadian meteorological stations.

This thickness is determined from the Department of Transport's design freezing index and the correlation shown in Figure 26.

3. It is the Canadian Department of Transport's design procedure to determine the thickness of necessary pavement structures on the basis of subgrade strength established by repetitive plate load tests (subgrade in equilibrium moisture conditions). Such tests are generally performed during the summer and fall. The design value used is the fall strength reduced by a spring load-carrying capacity reduction factor. The spring reduction factor is not considered to allow for the actual maximum strength reduction during the spring. Because the load-carrying capacity is a function of a number of repetitions of loading, a limited degree of overloading during the spring period is considered permissible. When the freezing index is higher than 500 (10-yr average) and no actual spring strength test data are available, subgrade fall load-carrying capacity values are reduced by silty clay and clay soils, 15%-45%; silt, very fine sand, and all frost-susceptible combinations of both, 45%-50%; medium and coarse sand, 10%; and gravel, 0%.

The actual spring reduction factor chosen within the range given above will depend on the performance of the existing pavements, the uniformity of the subgrade soil, moisture conditions of the subgrade, and the height of the ground water table. The most reliable source of information is the regular condition reports received on the condition of the pavement in question. Examples of such condition reports for flexible and rigid pavements are given in Figures 27 and 28.

In accordance with the U. S. Corps of Engineers' design procedure, silty clay and clay soils (CL & CH) are designated as F3 and F4 soils for which the Corps of Engineers' design charts give maximum frost protection.

Condition reports for 52 Canadian airports have been examined where the subgrade is silty clay or clay soil. The condition reports on these sites indicate that pavement distress due to frost damage is rarely experienced when the subgrade is uniform and the pavement thickness is sufficient to meet the minimum thickness requirement (Fig. 26).

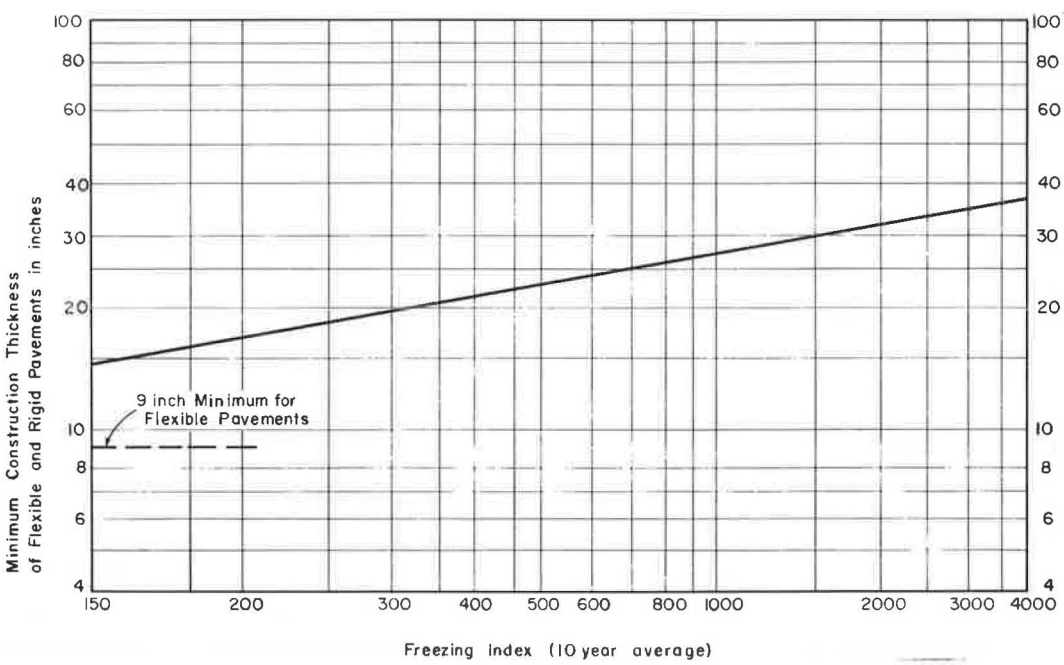

Figure 26. Minimum depth of frost protection for flexible and rigid pavements.

TABLE 5

COMPARISON OF U.S. CORPS OF ENGINEERS AND THE CANADIAN DEPARTMENT OF TRANSPORT DESIGN METHODS FOR FLEXIBLE AND RIGID PAVEMENTS[1]

Pavement Type	Design Method		Pavement Thickness (in.)				Total Cost ($ million)	Comparison of Costs (%)[2]
	Type	Agency and Criterion	Asphalt or P.C.C.	Crushed Base	Granular Base	Total		
Flexible	Strength	Department of Transport	4	12	27	43	4.476	100
		U.S. Corps of Engineers	4	12	57	73	6.856	153
	Frost	Department of Transport	4	12	18	34	3.766	100
		U.S. Corps of Engineers:						
		Complete protection	4	12	139	155	13.336	354
		Limited subgrade penetration	4	12	89	105	9.386	248
		Reduced subgrade strength	4	12	37	53	5.276	118[3]
Rigid		Department of Transport	10	6	18	34	6.078	100
		U.S. Corps of Engineers[4]	15	15	—	30	7.49	124

[1] Design aircraft = DC-8; 240k at 168 psi (DOT), and at 121 psi (USED).
[2] Dept. of Transport cost = 100%.
[3] Percentage based on DOT strength design equals 100%. Reduced subgrade strength design would not be used, as normal strength design requires greater thickness.
[4] Reduced subgrade strength.

AIRPORT "A"

RUNWAY 10 - 28 TAXIWAY -- APRON --

		NONE	MINOR	MAJOR	SEVERE
HAIR	Cracking Type	X			
LONGITUDINAL (Inc. Joints)	Cracking Type		X		
TRANSVERSE	Cracking Type		X		
CHICKEN WIRE (Approx. 3")	Cracking Type	X			
ALLIGATOR (Approx. 6")	Cracking Type	X			
LESS THAN 1/16 inch	Crack Widths		X		
LESS THAN 1/8 inch	Crack Widths		X		
LESS THAN 1/4 inch	Crack Widths			X	
STRIPPING		X			
RAVELLING		X			
RUTTING		X			
DISTORTION		X			
LONGITUDINAL	Deformation	X			
TRANSVERSE	Deformation	X			
SKIN PATCHES		X			
DEEP PATCHES		X			
SUB GRADE SETTLEMENT			X		
FROST HEAVE		X			
SURFACE ROUGHNESS			X		

IN YOUR OPINION THE GENERAL CONDITION IS:-

A	100%	VERY GOOD	CHECK ONE
B	80%	X GOOD	
C	60%	FAIR	
D	40%	POOR	
E	20%	VERY POOR	
	0%		

DRAINAGE (4) Imperfectly drained soil, good surface drainage. Surface and sub-drainage are in good working condition.

REMARKS Worst section of cracking is between 10 end and N-S Taxi.

DATE 22 Feb. 1960 OBSERVER R. Tracy

Figure 27. Department of Transport flexible pavement condition report.

AIRPORT B

RUNWAY 07-25 TAXIWAY - APRON -

		NONE	MINOR	MAJOR	SEVERE
CORNER	Cracking	X			
EDGE	Cracking	X			
LATERAL	Cracks	X			
LONGITUDINAL	Cracks		X		
SCALING & SPALLING		X			
JOINT STEPPING OR FAULTING		X			
CONCRETE DISINTEGRATING		X			
PUMPING		X			
LOSS OF JOINT FILLING		X			
SUBGRADE SETTLEMENT		X			
FROST HEAVE			X	See remarks	
SIDE SLIPPAGE			X		

IN YOUR OPINION THE GENERAL CONDITION IS:-

A	100%	VERY GOOD	CHECK ONE
B	80%	X GOOD	
C	60%	FAIR	
D	40%	POOR	
E	20%	VERY POOR	
	0%		

DRAINAGE (4) Imperfectly drained soil. Subdrainage in fair working condition. Surface drainage in good working condition.

REMARKS Differential frost heave at construction joint Sta. 103+00.

DATE February 19, 1960 OBSERVER S. Patton

Figure 28. Department of Transport rigid pavement condition report.

TABLE 6

COMPARISON OF U.S. CORPS OF ENGINEERS' AND THE CANADIAN DEPARTMENT OF TRANSPORT DESIGN METHODS FOR FLEXIBLE AND RIGID PAVEMENTS[1]

Pavement Type	Design Method		Pavement Thickness (in.)				Total Cost ($ million)	Comparison of Costs (%)[2]
	Type	Agency and Criterion	Asphalt or P.C.C.	Crushed Base	Granular Base	Total		
Flexible	Strength	Department of Transport (field in place CBR = 2.6, 15% SRF)	4	12	45	61	5.90	100[3]
		U.S. Corps of Engineers (lab soaked CBR = 2.3, 95% Dens.)	4	12	65	81	7.49	127[3]
	Frost	Department of Transport (minimum total thickness)	4	12	18	34	3.76	100
		U.S. Corps of Engineers:						
		Complete protection	4	12	139	155	13.34	355
		Limited frost penetration	4	12	89	105	9.38	250
		Reduced subgrade strength	4	12	47	63	6.06	103[4]
		72-in. total thickness	4	12	56	72	6.76	180
Rigid		Department of Transport (frost protected)	12	6	16	34	6.68	100[3]
	Frost	U.S. Corps of Engineers:						
		Complete protection (concrete strength f = 605 psi)	9	6	140	155	15.35	230
		Complete protection (f = 510)	11	6	138	155	15.94	239
		Limited frost penetration (f = 605)	9	6	90	105	11.38	170
		Limited frost penetration (f = 510)	11	6	88	105	11.99	179
		Reduced subgrade strength (f = 605)	16	6	10	32	7.75	116
		Reduced subgrade strength (f = 510)	18	6	12	36	8.67	130
		Reduced subgrade strength (f = 605, 015% steel)	14	6	10	30	8.95	134
		Reduced subgrade strength (f = 510, 015% steel)	15	6	12	33	9.79	146
		72-in. total thickness (f = 605)	9	6	57	72	8.76	131
		72-in. total thickness (f = 510)	11	6	55	72	9.38	140
		72-in. total thickness (f = 605, 015% steel)	8	6	58	72	9.59	143[3]
		72-in. total thickness (f = 510, 015% steel)	9	6	57	72	10.09	151[3]

[1]Design aircraft = DC-8; 315k at 168 psi.
[2]Department of Transport Cost = 100%.
[3]These designs would probably be used.
[4]Percentage based on DOT strength design equals 100%. Reduced subgrade strength design would not be used as normal strength design requires greater thickness.

Using the two different design methods, a parallel design analysis has been performed for a typical Canadian airfield constructed in 1958. The data given in Table 5 are self-explanatory and point out the considerable difference in pavement thickness requirements and construction costs of the two methods.

It should be pointed out that in the comparison, military and civil requirements are included which might not be fully comparable. There is also considerable difference between U. S. Military and Canadian Civil traffic density.

DATA SHEET

1. Assumed design aircraft.—DC-8 240k at 168 psi D.O.T. and at 121 psi USED
2. Subgrade soil.—CL (clay, silt and stone)
   CBR (measured) = 2.2 (soaked, undisturbed)
   Subgrade fall value × 16.1k (derived from unsoaked CBR tests)
   Spring reduction = 15%

Modulus of subgrade reaction, k ≈ 125 pci (derived from unsoaked CBR tests—CBR = 3.9)
Moisture content, Wn = 25% (measured)

3. Freezing Index.—2,736 d.d. 10-yr avg and 3,580 d.d. 10-yr max.
4. Base Course.—Moisture content, Wn = 7% γd = 130 pcf
5. Unit Weights:
   Granular base—γd = 130 pcf
   Crushed stone base—γd = 140 pcf and
   Asphalt—γd = 150 pcf
6. Total area of pavement surface = 8,110 × 10^3 ft?
7. Estimated costs:
   Cost per ton of granular = $1.80
   Cost per ton of crushed = $2.15
   Cost per ton of asphalt = $5.50
   Cost per cubic yard of concrete = $15.34
   Cost per lineal foot of construction joints = $0.20
8. Total footage of construction joints.—Based on all previous construction = 1,000,000 linear ft.

DATA SHEET

1. Design aircraft.—DC-8 315k at 168 psi
2. Subgrade soil.—CL (F-3 frost group)
   Lower quartile point field in place CBR = 2.6
   Lower quartile point remoulded soaked lab CBR = 2.3 (compacted to 95% mod. AASHO density)
   Horizontal variability of subgrade soil conditions taken to be slightly variable.
   D.O.T. spring reduction factor of 15%
   Moisture content 25%
3. Freezing index.—2,736 d.d. 10-yr avg, 3,580 d.d. 10-yr max.
4. Base course properties.—(For determining depth of frost penetration) Density 130 pcf, 7% moisture
5. Unit weights:
   Granular base - 130 pcf
   Crushed stone base - 140 pcf
   Asphaltic concrete - 150 pcf
6. Total area of pavement.—8.11 million sq ft
7. Material costs:
   PCC slab (including cement) = $15.34 per cu yd
   Asphaltic concrete (including bitumen) = $2.50 per ton
   Crushed gravel = $2.15 per ton
   Granular base = $1.80 per ton
   Concrete joints = $0.20 per lf
   Reinforcing steel = $0.15 per lb
8. Total length of concrete joints.—1,000,000 ft.

O. L. STOKSTAD, Design Development Engineer, Michigan Highway Department.—A significant feature of this paper by Linell, Hennion and Lobacz is that it describes design practices for building pavements which will provide uniform service without seasonal load restrictions. It was not too many years ago that highway engineers in areas of seasonal frost accepted spring load restrictions as inevitable. Slowly, as experience and knowledge were gained concerning the use of various soil materials, the selection and processing of free-draining granular material has permitted the economical construction of pavements for all-season use by any design axle load.

Eighteen years ago, when development of the techniques described was started, the first undertaking was to convert earlier highway experience into techniques which would

be adequate for airfield needs. This objective has apparently been accomplished without sacrificing significance for the highway engineer. Procedures described not only satisfy airport needs, but they satisfy highway requirements imposed by Michigan soil and climatic conditions quite well.

After 18 years of study, no chemical treatment for frost action has worked its way into standardized practices. Methods described rely on the control of drainage and the selection of suitable construction materials as a means for controlling the detrimental influence of frost action on the character of foundation support. The examples given for both flexible and rigid pavement designs under conditions of frost range widely from a frost index of 600 to 3,000.

Of particular interest to highway engineers is the fact that airport pavement studies involve a much greater range of axle loads than loads to be carried by highway pavements. This fact eliminates the need for extrapolating when using airport criteria concerning axle load weights to be carried. The repetition of axle loads is another matter. In dealing with this subject, highway engineers talk in terms of millions, and airport engineers think in terms of thousands.

To compensate for this difference in load repetition, it has become customary in this area when using U. S. Engineering Department design criteria, to assume that airport wheel loads and highway axle loads are equivalent insofar as pavement strength requirements are concerned.

The authors are to be complimented on the thoroughness with which procedures are described. The paper shows why U. S. Engineering Department manuals serve as excellent guides in developing local pavement design and construction procedures.

K. A. LINELL, F. B. HENNION and E. F. LOBACZ, Closure—The authors wish to thank O. L. Stokstad and G. Y. Sebastyan for their excellent discussions. Mr. Stokstad's observations on the development of frost design technique bring up several interesting points. One of the problems which confronted engineers in converting earlier highway experiments or experience to the design of pavements for military aircraft was spring load restrictions. It was obvious that restrictions could not be placed on military aircraft operations. Therefore, design criteria had to be developed to provide pavements that would accommodate the design load during the several weeks in the spring when the thawing subgrade soils were at their minimum strength. The solution appeared simple—anticipate the amount of traffic that would be applied during the period of subgrade weakening and provide sufficient thickness of non-frost-susceptible base and subbase material to prevent over stressing the weakened subgrade soil. The nub of the problem lies in determining the strength of the pavement components—base, subbase, and subgrade material under variations of temperature, moisture, and soil composition in relation to the effects of load and load repetitions. These factors provided an interesting problem which is still consuming considerable time and effort.

Chemical treatment to preserve strength of soil during periods of thawing has been studied for a number of years. Various chemicals have been found effective in reducing the detrimental effects of frost action. The problem which remains unsolved is the development of a procedure for effectively dispersing and retaining the chemicals in the soil.

The authors were pleased to note that the procedures presented correlate quite well with those of Michigan, a State that has played a leading role in the development of frost design criteria for highways.

Mr. Sebastyan's discussion on the differences in frost protection requirements for airfields under the design procedures presented, and those of the Canadian Department of Transport have been reviewed with interest. Although the authors do not have the detailed design procedures of the Canadian Department of Transport at hand, it appears that basically the differences result from different assumptions of traffic density and the rather stringent requirement of surface smoothness for jet aircraft, especially military jets, incorporated in the Corps of Engineers' requirements.

At first thought it might seem that the relatively colder climate in much of Canada, as compared with the major part of the United States, might possibly be responsible for some

of the differences in practice. Long periods of steady, intense cold are, for example, less destructive to pavements with respect to accumulative thaw weakening effects than are climatic conditions involving frequent intermediate cycles of freeze and thaw. The longer thaw weakening period which occurs in areas of deep frost penetration is probably less damaging to pavements than multiple shorter periods in which weakening is concentrated at shallower depths. Also, less ice lens growth per unit depth may be experienced when frost penetrates quite rapidly through the upper part of the subgrade in a very cold region, as compared with the lensing which may develop in the more southerly frost areas where freezing temperatures may barely penetrate the upper layers of the subgrade and advance at very slow rates. Study of freezing index data shows, however, that the ranges of freezing conditions which the design procedures are aimed at in both countries (with the inclusion of Alaska) are not greatly different. Therefore, the procedures should be comparable in this respect.