Frost Considerations in Highway Pavement Design: East-Central United States

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Pavement design considerations for frost conditions in the east central States are summarized, on the basis of facts furnished by the individual States. States included in the east central area are Wisconsin, Michigan, Illinois, Indiana, Ohio, Kentucky, Tennessee, Mississippi, Alabama, and Georgia. Factors influencing frost conditions are presented, such as soils and climate, including frost depth and precipitation. Design considerations for spring thaw support-loss as well as for detrimental frost heaving are discussed. Design loads and spring load restrictions are included. Use of granular subbase and subbase type, depth, and drainage are also discussed. The report compiles the bases for design considerations for frost as reported by the east central States and indicates whether design is based on experience, theoretical concepts, or both, and reports the extent of research performed by the States. Frost considerations with regard to design of culverts and structures are also included. In summary, the paper reports the extent of the frost problem in the east central States, discusses the influencing factors which cause the problem, and presents the methods and design techniques used by the various States in providing satisfactory pavement design.

• THE OBJECT of this report is to present current design considerations for highway pavements in frost areas of the east central States. Theories or details of research studies concerning frost action are not included because there are many excellent HRB and Corps of Engineers publications on the subject.

Questionnaires were sent to the east central States (Fig. 1) to determine current design practices for frost action. The first was an essay type seeking general information on the extent of the problem, research and use of findings, and basic design considerations for frost. A more detailed questionnaire pertaining to specific design practices was then circulated. This information (Tables 1 and 2) allows comparison of current design practices for similar climate and soils.

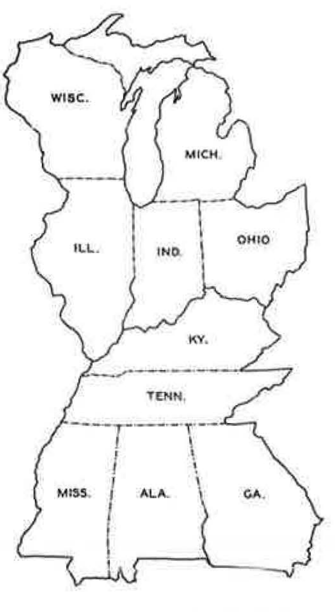

Figure 1. East central States.

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TABLE 1
QUESTIONS REGARDING FROST INFLUENCE IN DESIGN
Parenthesized numbers refer to additional data as presented on the following pages

STATE	WHAT CRITERIA, METHODS OR TECHNIQUES ARE USED IN PAVEMENT DESIGN TO PROVIDE FOR EFFECTS OF FROST?	TO WHAT EXTENT IS PAVEMENT DESIGN IN FROST AREAS BASED ON THEORETICAL CONCEPTS AND TO WHAT EXTENT IS IT BASED ON EXPERIENCE?	WHAT STUDIES OR RESEARCH HAVE BEEN CONDUCTED IN RELATION TO EVALUATION OF FROST DAMAGE?	TO WHAT EXTENT HAVE RECENT RESEARCH FINDINGS BEEN USED IN PAVEMENT DESIGN?	ARE RIGID AND FLEXIBLE PAVEMENTS TREATED DIFFERENTLY IN REGARD TO DESIGN FOR FROST?	DOMINANT SOIL CONDITIONS ESPECIALLY IN RELATION TO TEXTURE AND ORIGIN.
ALABAMA Edward Eiland, Ass't Mat'ls and Research Engineer	We do not have a frost problem in Alabama except in about ten of the counties in the northern part of the state.	We do not consider frost action in any of our base and pavement designs. (1)	—	—	—	—
GEORGIA John M. Wilkerson, Jr., State Road Design Engineer	Subgrade drainage is the most serious design problem. To control the water, a granular subbase is provided in all major pavement designs which carries through from shoulder slope to shoulder slope on a gradient steeper than the pavement crown. In the northern third of the state, particular emphasis is given to the granular material under the shoulder to assure adequate drainage to the ditch.	Experience has shown that any pavement deterioration due to freezing is due to free moisture in the pavement. If the problem of adequately draining the subgrade is solved, as a by-product, failures caused by freezing are eliminated.	None	We feel that if we eliminate this main cause of damage from frost, i.e., moisture, we will have accomplished all that is necessary to combat frost damage. Cretaceous limestone aggregates which freeze and thaw are not used in the northern two-thirds of the state.	One basic design consideration for secondary roads is that the use of portland cement as an additive to native soils increases the stability and waterproofs the base to the extent that they will not absorb moisture. We have no record of a base course, having been stabilized with portland cement, ever failing due to freezing.	High water table is a serious problem in two-thirds of the state.
ILLINOIS E. L. Sherertz, Engineer of Design	Average frost penetration, HRB soil classification with group index, soil drainage classification and volume of truck traffic are the four indices used in the construction of charts contained in the Illinois manual "Policy on Design Thickness of Subbase, Base and Surface Courses for Highways" (Table 3 and Fig. 6). Frost penetration directly influences required subbase thickness. (2)	Current design practice is based almost entirely upon past experience.	No recent research programs on frost action. Over the years, various District highway laboratories have investigated frost heaves, and have developed data which has proved very helpful in the design of pavement structures.	The Illinois Division of Highways currently has the recently released "AASHO Interim Guide for the Design of Flexible Pavement Structures" under study to determine its adaptability to the Illinois program. It is anticipated that a similar study will be made of the AASHO guide for the design of rigid pavement when it is released. The Department reviews new procedures as they are developed to keep abreast of new methods and to check them against Illinois experience.	Rigid and flexible pavements are treated similarly in Illinois current design practice.	The greater part of Illinois has been glaciated one or more times, and soils are typical of those developed on moraines, till plains, and outwash plains. The northeastern corner of Illinois is possessed of extensive deposits of granular materials. Such materials are not prevalent further to the south and west. Central Illinois soils are more typically developed on till plains. (3)
INDIANA W. T. Spencer, Soils Engineer, Materials & Tests	This is a difficult question to answer. However, frost does affect, directly or indirectly, some of the following factors: a - Thickness of flexible pavement, b - Design of subbases and bases, c - Drainage of subbases, d - Shoulder design of paved or surfaced shoulders, e - Increased structural requirements, f - Higher quality aggregates, etc.	Primarily based on experience.	Numerous spring "break-up" surveys made by the Joint Highway Research Project, Purdue University	Adequate drainage of subbases or bases.	Yes. Flexible pavement design recognizes the reduced bearing values of various subgrades in the spring.	Predominant soils classify A-4, A-6, or A-7-6. Included are beach and dune sands in northwest area, glacial drift to south of central Indiana, and residual soils of silts, silty clays, and clays in the lower central area.

TABLE 1 (cont.)
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KENTUCKY W. B. Drake, Director of Research	The use of free-draining low plasticity base materials. We do not consider frost action as a primary factor in our pavement designs, undoubtedly it has effected adequate structural thickness in these designs.	Practically 100 percent on experience in the area.	A study of existing flexible pavements "Investigation of Field & Laboratory Methods for Evaluating Subgrade Support in the Design of Highway Flexible Pavements." (4)	Recent research findings have been checked in conjunction with design practices.	Insulation courses of from 3 to 6 in. depths are used under concrete pavements. Flexible pavements are constructed over graded aggregate base courses. Base drainage is provided for in both types of pavements.	Residual soils derived from limestone and sand - stones are most prevalent.
MICHIGAN A. E. Matthews, Engineer of Soils	Grade heights are maintained 5 ft. above water tables, poorly drained soils, and peat deposits. Relatively thick free-draining granular subbases are provided. Based on pedological soil classifications, design charts provide quantities for excavation of frost-susceptible materials and quantities for under drains to control seepage or capillary water. The exact locations and quantities are determined during construction, as needed. On roads which are to be reconstructed, frost heave logs are made and corrections are recommended.	Primarily based on experience. Thickness design is based on soil conditions and anticipated traffic volumes and types. Although pavement design has resulted directly from experience, design charts have been prepared which correlate the adopted thicknesses with soil strength indices such as CBR.	Pavement condition surveys, including evaluation of frost damage and subgrade support are being carried on. An intensive research program concerning frost damage was conducted in the early 1930's. A research project investigating the amount of limestone fines in limestone bases in now in progress. Preliminary reports indicate that limestone fines are more subject to frost action than natural soil binder.	Research findings relative to frost action are compared to present practices and the findings are incorporated if there is an apparent need.	Basically there are no differences. The thicker subbases required for flexible pavements are needed to provide pavement support during the spring breakup period. A rigid pavement provides more "bridging" action over unstable soils.	Michigan is a glaciated state with soils ranging from sands and gravels to loams to clays and silty clays. Many peat deposits are present. Limestone, sandstone, and igneous bedrock are present in some parts of the state.
MISSISSIPPI J. P. Steinwinder, Jr., Roadway Design Engineer H. O. Thompson, Testing Engineer	The upper layers of the pavement system under the pavement subject to freezing temperatures are generally cement-treated on main highways. From a design standpoint the primary objective is wheel load capacity and not frost penetration. Generally all designs are for all season conditions. The design varies with wheel load frequency and traffic volume expected.	—	No data	Based on experience and research, bases and subbases are being cement-treated. The local material being treated with cement consists of sand-clay, semi-gravel, and/or clay gravel. Crushed stone for roadbuilding purposes is not available within the state.	—	Predominant soils range from heavy clays to silty clays. Mississippi is a sedimentary state and the surface contains a great many soil groups. A soil profile before and after grading is required on each project for design purposes.

TABLE 1 (cont.)

QUESTIONS REGARDING FROST INFLUENCE IN DESIGN

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OHIO W. J. Cremean, Engineer of Location & Design and H. E. Marshall, Engineer-Geologist	The primary technique used in pavement design for prevention of detrimental frost effects is that of providing additional subbase thickness in soils known to be susceptible to frost action. Special consideration is also given to the utilization of subdrainage systems to the best advantage in these locations. (5)	Pavement design practice in frost areas is based primarily upon experience; however, some attention is given to the theoretical concepts and necessary adjustments are made for situations which fall out of the realm of the ordinary.	No formal studies or research have been conducted in relation to evaluation of frost damage in recent years.	As previously state, our pavement design in frost areas is largely a matter of application of facts established from past observations and experience. Research findings are reviewed and incorporated in design in those instances where established procedures need further refinement. The Corps of Engineers manuals and HRB publications of this subject have been of much benefit in our studies of frost conditions.	The conventional rigid pavement designs in use are 9 and 10 in. reinforced concrete pavement on 6 in. granular subbase. Flexible pavement thicknesses are determined on a project to project basis and have varying subbase thicknesses. Experience in Ohio has indicated the desirability of providing a thickness of granular subbase equal to one-half the depth of frost penetration for the prevention of frost-heaving. The depth of insulating material over and above that used in the original design is determined from the anticipated depth of frost penetration in a given area.	The frost susceptible soils are commonly of glacial origin, but may be found outside the glaciated portions of the state.
TENNESSEE R. S. Patton, Engineer of Surveys and Design	Inasmuch as frost penetration in Tennessee will vary from only 4 to 6 in. in depth, we do not take account of frost in our pavement design. (6)	Our soils are classified, using the Bureau of Public Roads numbering system, and based upon our previous experiences with soils of the various types encountered, we use varying thicknesses of mineral aggregate bases under both our concrete and bituminous pavements. (6)	— (6)	— (6)	— (6)	The dominant soils in the eastern and middle sections of the state are clay resulting from the decomposition of limestone. The dominant soils in the western part of the state are clay and sand in their natural state. None of these soils provide a satisfactory subgrade for pavement insofar as their load bearing capacities are concerned.
WISCONSIN J. S. Pilty, Engineer of Design	Soils have been catalogued in relation to frost susceptibility with a range of F0 to F4 where the higher numerical figure indicates the greater susceptibility. Soils engineers provide classification. Where adverse conditions are too general for elimination by cover fill, undercutting, or other economically feasible means, a granular subbase is added to the design as a correction factor.	Major developments have been based on experience with theoretical concepts cautiously taken into consideration for new designs which go beyond the scope dictated by experience. Design, in general, is based on the concept that the strength elements will not alleviate the effects of the frost action so it is necessary to take due consideration of total pavement depth and heavy vehicle traffic volumes.	—	The material compiled through national collaboration of the member states of AASHO is being intensely studied to the extent that designs are being cross-checked with a view toward elimination of as much guesswork as possible.	Not inclined to differentiate between pavement types. Since we consider good granular subbase as a structural element of flexible designs, it is more often than not that the required total depth is attained in the structural design. This would be the major difference from the rigid design since granular material added for depth protection against frost would not normally be required as a strength element in that design.	Difficult to name a dominant soil. The glacial soils cover most of the state and range from silts and clays to gravels. The southwest part of the state consists of non-glaciated soils where the parent rock consists of limestone or sandstone.

DATA SUPPLEMENTING TABLE 1 (Frost Influence in Design)

Alabama

(1) Frost action is not considered in any base and pavement designs. In the northern part of the State where there is some damage, it is concentrated only in the thin surface treatment type pavements and usually occurs about once every ten years. No damage has been reported to the high type pavements; that is, concrete or 4 in. of asphalt. The thin pavements are repaired by the application of a liquid seal and chip course.

Illinois

(2) Frequently, additional precautions are taken by removal and replacement of frost heaving soils, or utilization of subgrade drainage installations.

(3) Subsequent to the glacial age, a mantle of loess covered nearly all of Illinois. The depths of the loess vary from close to 50 ft adjacent to the major river valleys on the western side of the State to depths of such insignificance in some other areas that they may prove difficult if not impossible to detect. Many of the morainic deposits are rather complex in character in that there is a complex interbedding of materials of different grain sizes. These areas frequently necessitate the employment of short cut and fill sections in highway building, and consequent cutting of several different soil types in a relatively short distance. Such conditions are usually associated with the more severe differential frost heaves.

Kentucky

(4) This study did not deal with frost action and frost heave directly, but took into account the effect of these actions in the performance of the pavements.

Ohio

(5) The following is from Ohio's design manual:

> "E-150.00 FROST HEAVING SOILS
>
> .10 Frost heaving may occur under certain conditions of moisture and temperature in any soil which contains more than about 15 percent passing a No. 200 mesh sieve; however, it is common only in some of the very fine dirty sands, sandy silts, and silts (A-3a, A-2, A-4). In the sands and sandy silts, sufficient protection is usually afforded by adequate drainage. For the class A-4b soils, particularly in all new construction, it is advisable to replace a portion of this material with non-frost susceptible granular material. Material meeting I-22 requirements is usually used for this replacement. In the northern part of the state and in local areas where frost conditions appear to be especially severe, 18 in. of subbase should be used beneath the usual 8 or 9 in. pavement. In the central and southern part of the state, a thickness of 12 in. of frost resistant material beneath the pavement should be adequate in most cases."

Note that the effects of frost are given special attention where A-4b high silt-content soils make up the subgrade. For other soils, frost is only considered in a general way as it may affect the supporting strength of the subgrade.

Tennessee

(6) To sum up the whole matter, this department does not feel that frost action is of sufficient importance to be taken into consideration in the design of either pavements or structures. Although no definite studies or research have been conducted to evaluate frost damage, field forces in the maintenance division report such damage. To date, such damage, if any, has been so small that it is not felt necessary to take frost action into consideration in the design and construction of either roadways or bridges.

TABLE 2
DETAILED DESIGN DATA

Parenthesized numbers refer to additional data as presented on the following pages

STATE	Do you use Granular Subbase over non-granular soils? Yes or No	Reason: Spring Thaw Support Loss	Reason: Load Distribution	Reason: Pumping Control	Reason: Reduce Differential Heaving	Thickness Rigid: Pri.	Thickness Rigid: Sec.	Thickness Flexible: Pri.	Thickness Flexible: Sec.	Type: Open Graded	Type: Dense Graded	Gradation: Sieve Size	Gradation: % Passing	Subbase Drainage: Through Shoulder To Slope	Subbase Drainage: Under Drains	Does water table influence your grade height? Yes or No	Reason: Frost Damage	Reason: Subgrade Softening	Height Maintained Above Water Table	Are spring load restrictions required to project softened subgrades during the frost melting period? Yes or No	Restricted: Single Axle, lbs	Restricted: Tandem Axle, lbs	Normal: Single Axle, lbs	Normal: Tandem Axle, lbs	Do frost bumps (frost heaves) occur in your State? Serious Enough to Require Correction	Type of Treatment: Re-place	Type of Treatment: Mix	Type of Treatment: Raise Grade	Type of Treatment: Other	Does frost in any way influence design of Culverts? Yes or No	In What Way?	Do you require that structure footings be placed below the depth of normal frost penetration? Yes or No	Depth	Average frost penetration for your State: North Part	South Part
ALABAMA Edward Elland, Ass't Mat'ls and Research Engineer	Yes	—	Yes	Yes	—	6"	Not used	12"	6"	X		2" 1" 4 10 40 60 200 (1)	100 75-100 30-80 15-55 30-95 20-80 10-40	Yes	Yes	Yes	Yes	Yes	2"	No	—	—	18,000	32,000	No	—	—	—	—	No	—	No		3"	0"
GEORGIA John M. Wilkerson, Jr., State Road Design Engineer	Yes (2)	No	Yes	Yes	No	8"	0	6" & 8"	6"	X	Seldom	2" 1 1/2" 3/4" No. 10	100 95-100 30-90 25-40 (3)	Yes	Yes (where needed)	Yes	No	Yes	Keep W.T. 12" below bottom of sub-base	No	—	—	20,340	40,680	Rarely	Yes	—	—	—	Yes	Selected Backfill	Yes	Below frost line, if any.	4"	0
ILLINOIS E. L. Sherertz, Engineer of Design	Yes	Yes	Yes	Yes	Yes	0"-14" (4)	0"-14" (4)	0"-14" (4)	0"-13" (4)		X	1" 1/2" 4 8 16 200 (Crushed stone)	100 60-90 40-60 25-50 20-40 5-15	No. French drains sometimes used.	Only used where it appears necessary.	Yes	No	Yes	3 1/2" (5)	—	Not restricted on primary, variable on secondary.	Not restricted on primary, variable on secondary.	18,000	32,000	Yes (6)	Yes	Yes	Yes	Drainage	No	—	Yes	4'	54" max.	6" min.
INDIANA W. T. Spencer, Soils Engineer, Materials & Tests	Yes	Yes	Yes	Yes		5" - 7 1/2"	4" min.	5"-10"	4"-6"	X	X	2 1/2 30 200	100 55 (7)	Yes	Yes	Yes	Yes	Yes	3'	Very Seldom	—	—	18,000	32,000	Yes (8)	Yes	Yes	Yes	—	Yes	2' of cover over pipe	Yes	Indefinite	25"	10"
KENTUCKY W. B. Drake, Director of Research	Yes (9)	Yes	Yes	Yes	No	6"	3"-5"	13" Base	8" Base	—	X (10)	1" 3/4" 3/8" No. 4 No. 10 No. 40 No. 200	100 70-100 50-80 35-65 25-50 15-30 5-15	Yes (for interstate)	Yes (for primary & secondary)	Yes	Yes	Yes	3'-5'	Yes (11)	—	—	—	—	No	—	—	—	—	No	—	Yes	18"	12"	9"
MICHIGAN A. E. Matthews, Engineer of Soils	Yes	Yes	Yes	Yes	Yes	14"	14"	25" Subbase 11" Base	18" Subbase 7" Base	X		2 1/2" 1" No. 100 Loss by washing	100 60-100 0-30 0-7	Yes	Yes (12)	Yes	Yes	Yes	4'-5'	No (13)	75% of normal for rigid, 65% of normal for flexible	75% of normal for rigid, 65% of normal for flexible	18,000	26,000 (32,000 on main routes)	Yes	Yes	Yes	Yes	—	Yes	(14)	Yes	5' below ground cover.	54"	40"
MISSISSIPPI J. P. Steinwinder, Jr., Roadway Design Engineer, H. O. Thompson, Testing Engineer	Yes (15) (16) (17)	No	Yes	No	No	0-18"	0-18"	3"-25"	3"-19"	X (18)	X (18)	4 10 40 60 270 Silt Clay	100 25-100 20-100 15-85 4-35 0-20 0-20	Yes	Yes (19)	Yes	No	Yes	3'-4'	No (20)	—	—	18,000 (21)	32,500	Yes (22)	Yes	—	—	Chemical treatment	No	—	Yes	1' 6"	3"	1"
OHIO W. J. Cremean, Engr. of Location & Design, H. E. Marshall, Engr.-Geologist	Yes	Yes	Yes	Yes	Yes	6"-24" (23)	Not used	4"-18" (23)	4"-12" (23)	X	X (24)	3" 2" 1" 200 (25)	100 90-100 70-100 0-15 (25)	No	Yes (26)	(27)	No	No	—	Yes (28)	14,300	24,500	19,000	32,500	Yes (29) (30)	Yes	—	—	—	No	—	Yes	4'	24"	10"
TENNESSEE R. S. Patton, Engineer of Surveys and Design	Yes	No	Yes	Yes	No						(31)	1 1/4" 1" 3/8" 4 16 100	100 95-100 50-80 35-65 20-40 8-15	Yes	Yes					No (32)			18,000	32,000	No					No	(33)	(34)		6" max.	4" max.
WISCONSIN J. S. Pilty, Engineer of Design	Yes (34)	Yes	Yes	—	Yes	6"-9"	6"-9"	6"-12"	6"-12"	X (35)		Grade 1 No. 4 No. 40 No. 100 No. 200 (36)	100 0-75 0-15 0-8	Yes (37)	Do not use underdrains where it is feasible to drain thru shoulder to slope.	Yes	Yes	Yes	4' ±	Yes	(38)	(38)	18,000 (39)	30,400 (39)	Yes	Yes	—	Yes	—	No	—	Yes	4'	60"-70"	40"-50"

DATA SUPPLEMENTING TABLE 2 (Detailed Design Data)

Alabama

(1) In addition to the sieve requirements, subbase material is further limited as follows: clay, 20 percent maximum; liquid limit, 26 maximum; plasticity index, 6 maximum.

Georgia

(2) Subbase is also used to provide for subgrade drainage.

(3) The gradation for subbase material is varied from job to job to utilize local materials.

Illinois

(4) Subbase thickness for Interstate routes or routes having more than 1,600 trucks per day ranges from 6-in. minimum to 14-in. maximum. Depth of subbase is based on drainage, frost penetration, and soil type. No subbase is required over adequate native granular subgrade soils. If other soils are involved, 4-in. minimum subbase is used under rigid pavement and 3- to 4-in. minimum under flexible depending on class of highway.

(5) The height of grade above the water table may be varied with the anticipated depth of frost penetration.

(6) Differential frost heaves have been experienced over wide areas in Illinois, but in general, it may be stated that such differential heaving increases in frequency and severity in the northern sections. Experience indicates that the worst heaves are associated with cut sections or in zones of transition from cut to fill. Localized heaves have been experienced during periods of severe cold that have heaved differentially several inches and constitute a definite hazard to the motorist. The spring breakup is a real problem in these areas.

Indiana

(7) Indiana specifications provide for two types of subbase:

C1102.1. Gradation Requirements for Type 1 (Open-Graded)

Sieve sizes through which substantially all material passes. Approx. top size.	Total Percent Passing Sieves Having Square Openings									
	2-1/2"	2"	1-1/2"	1"	3/4"	1/2"	No. 4	No. 8	No. 30	No. 200
2"	100	95-100	75-98	60-90	50-85	40-80	25-60	15-45	5-25	0-5*
1-1/2"		100	95-100	75-98	60-90	45-85	25-65	15-50	5-25	0-5*
1"			100	90-100	75-98	60-90	30-70	20-55	5-30	0-5*
1/2"			100			90-100	50-90	30-70	10-40	0-5
No. 4			100				95-100	80-95	20-55	0-5

* In addition to its other requirements, the amount passing the No. 30 sieve shall not be less than two times the amount passing the No. 200 sieve.

C1102.2. Gradation Requirements for Type II (Dense-Graded)

Passing the 2-in. square sieve, percent 95-100
Passing the No. 4 square sieve, percent............... 35-100
Passing the No. 30 not more than 55

The material shall contain sufficient binding material (that portion passing the No. 200 sieve) to compact satisfactorily; however, such binding material shall not be less than 5 percent. If a method of draining the subbase material in place is provided, then the binding material shall be between 5 and 10 percent. If a method of draining the subbase material in place is not provided, then the binding material may exceed 10 percent provided the fraction passing the No. 200 sieve is not greater than one-half the fraction passing the No. 30 sieve, nor greater than one-fifth the fraction retained on the No. 30 sieve.

(8) The most severe differential frost heave problems are generally encountered in localized areas of wet, extremely fine sands and silts and may be found anywhere in Indiana. These materials are generally excavated to depth of 2 to 3 ft below subgrade.

Kentucky

(9) Primarily load distribution and pumping control.

(10) Dense-graded aggregate used for base for flexible and as a subbase for rigid.

(11) Very light initial treatment pavements are not adequate for frost penetration, and it has been the policy to restrict loads for spring thaw conditions on some of these.

Michigan

(12) Drainage of subbase through shoulder to slope is standard. However, in urban sections where curb and gutter is used, underdrains are used for subbase drainage.

(13) On the older trunklines, load limits are required. For the past few years, all roads have been designed for year-round legal loads.

(14) Depth of cover over pipe. Selected backfill.

Mississippi

(15) Subbase also used to prevent the intrusion of fine-grained soils into the base course and maintain moisture content more uniform for all seasons.

(16) Have in the past but discontinuing this practice on expansive fine-grained very plastic soils.

(17) When required by reference on chart (not shown), any subgrade (design soil) with CBR of 5 or less shall be lime-treated; except that when a project contains a few short, isolated sections of subgrade material, the thickness shown on the charts (not shown), in the zero treatment column, may be used.

When the subgrade material (design soil) has a CBR of 6 to 10 and the soil and weather conditions warrant, consideration will be given to the use of lime treatment or of plating material classified as a 4-6 plastic or better. Plating material will not be considered a part of the structure thickness.

The granular subbase shown in the charts may be reduced or eliminated if economically justified, by any of the following: (a) increasing depth of treated subgrade; (b) increasing depth of treated base; and (c) providing soil-cement or cement-treated subbase. (The depth in each case to be equal to 75 percent of the depth of replaced granular subbase.)

(18) This gradation is an example of Class 9, Group C; maximum liquid limit, 30; maximum plasticity index, 10.

(19) Use underdrains when necessary for proper subbase drainage.

(20) Loads are restricted on some secondary roads where the structure thickness is inadequate for legal loads during the spring season.

(21) Legal wheel load limit of 9,000 lb.

(22) Occasionally have frost heaves on D.B.S.T. pavements, but not serious enough to influence our design.

Ohio

(23) The thicker subbases are used over silt soils only (more than 50 percent silt and plasticity index less than 10).

(24) Most Ohio subbase material is natural sand and gravel and is fairly dense graded.

LEGEND FOR SOILS MAP

PODZOL SOILS

CA	Caribou
IM	Iron River - Milaca
OT	Ontonagon - Trenary
RR	Roselawn - Rubicon

GRAY-BROWN PODZOLIC SOILS

CBL	Clinton - Boone - Lindley
FL	Fairmount - Lowell
HF	Hagerstown - Frederick
MB	Miami - Crosby - Brookston
MK	Miami - Kewaunee
MWZ	Muskingum - Wellston - Zanesville
PA	Porters - Ashe
PC	Plainfield - Coloma
W	Westmoreland
WM	Wooster - Mahoning
SP	Spencer

WIESENBODEN, GROUND WATER PODZOL, AND HALF-BOG SOILS

LB	Leon - Bladen
NM	Newton - Maumee
TV	Toledo - Vergennes
CPB	Coxville - Portsmouth - Bladen

ALLUVIAL SOILS

A	Alluvial soils

PLANOSOLS

PV	Putnam - Vigo - Clermont

PRAIRIE SOILS

CC	Carrington - Clyde
CW	Clarion - Webster
TM	Tama - Marshall

RED AND YELLOW PODZOLIC SOILS (Lateritic Materials)

DB	Dickson - Baxter
DDC	Decatur - Dewey - Clarksville
GM	Greenville - Magnolia
MG	Memphis - Grenada
MH	Maury - Hagerstown
NR	Norfolk - Ruston
SSR	Susquehanna - Savannah - Ruston
TI	Tifton - Irvington
NS	Norfolk sands
GA	Georgeville - Alamance

LITHOSOLS AND SHALLOW SOILS (Humid)

HM	Hartsells - Muskingum
TF	Talladega - Fannin
UM	Upshur - Muskingum
RI	Undifferentiated rough, stony land and shallow Podzols (forested)

BOG SOILS

P	Peat and Muck

RENDZINA SOILS

SV	Sumter - Vaiden

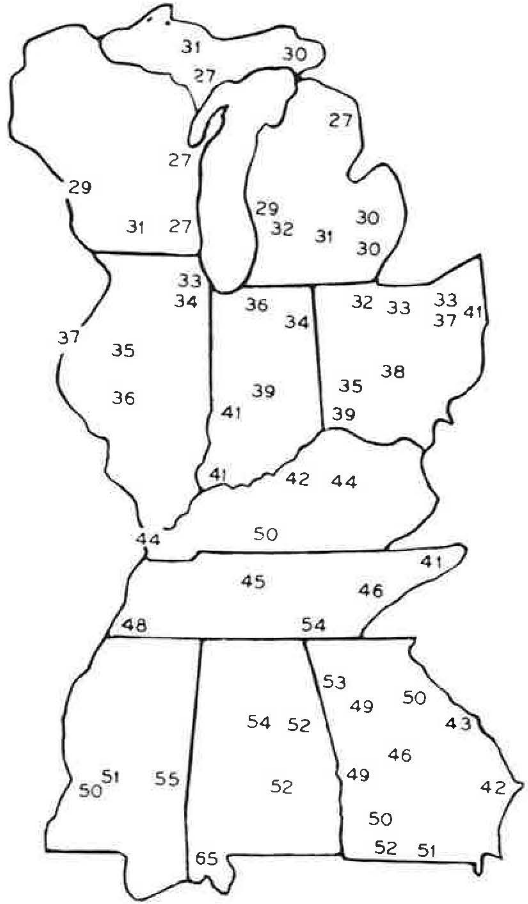


Figure 3. Average annual precipitation in inches: 1921-1950 (U.S. Department of Commerce, Weather Bureau records).

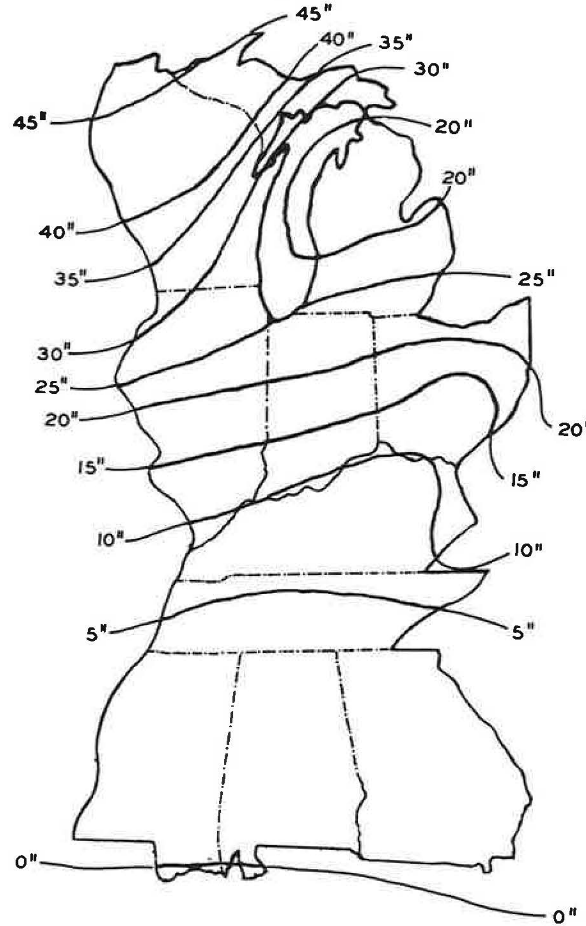


Figure 4. Average annual frost penetration, in inches (based on State averages after U.S. Weather Bureau).

than three-quarters of the thickness of such subbase course or layer being placed. The liquid limit of the material shall not be greater than 25 and the plasticity index shall not be more than 6.

(37) There is evidence that the subbase drainage may be blocked at shoulder by topsoil added for seeding.

(38) Wisconsin law states that gross weight limitations on Class "B" highways are 60 percent of the Class "A" tolerated weights.

(39) Statutory excluding tolerances.

SOILS AND CLIMATE

In the section of the United States considered in this report, the geology and soils have a wide range. The geology varies from the glaciated areas of Michigan, Wisconsin, and the northern parts of Ohio, Indiana, and Illinois to the mountainous regions of Kentucky, Tennessee, and northern Georgia, and the alluvial deposits of Mississippi and the residual deposits of the southern States.

There is also great variation in soil textures throughout the area, ranging from sands and gravels to loams to clay and silty clay, as well as bedrock regions of the mountainous areas. The great soils groups consist of the following: podzols, gray-brown podzols, groundwater podzols, prairie soils, planosols, red and yellow podzols or laterites, lithosols (humid), chernozems, and rendzinas. With this wide range of soils, it is difficult to draw conclusions or to make comparisons. The States in which the frost problem is most severe are those in which the podzol, gray-brown podzol, or groundwater podzol soils predominate. A generalized soil map of the region is shown in Figure 2.

Climatic conditions within the east central States vary extremely from northern Michigan on the Canadian border to southern Mississippi on the Gulf of Mexico. For this reason, no attempt at generalization would be significant in relation to pavement design throughout the area. For climatic conditions within any given State, Figures 3 and 4 show average annual precipitation and average annual frost penetration, respectively.

CONCLUSIONS

In the opinion of the writers, considerations for frost effects in pavement design fall essentially in two categories:

1. Spring thaw support loss, or the loss of bearing capacity of the natural subgrade soil, as the frost leaves the ground in spring.

2. Frost heaving during the freezing period which may cause cracking and destruction of the pavement or in severe cases may even be hazardous to traffic.

By far the more important of the two is the problem of loss of support at the time the frost leaves the ground. In some cases, it appeared that answers to the questionnaires did not discuss this aspect to the extent expected, possibly because it is more an indirect effect and occurs after the frost has left. It is noted, however, that all States use a granular subbase over non-granular soils. And in most cases, the thickness depends on soil classification, group index, CBR, etc. By such means the soils which undergo the greatest strength loss in the presence of water require the strongest pavement design. It appears, therefore, that even in the southern States other sources of moisture such as precipitation and water table notwithstanding, pavement design does provide protection against support loss during the frost melting period. In a northern State such as Michigan, there is no question that the weakest subgrade condition which must be designed for occurs during the frost melting period and is a direct result of the excess moisture accumulation caused by frost action.

Figure 5. Extreme example of pavement damage resulting from frost action.

The second important design consideration for frost effect is protection against heaving. In all but the most uniform of frost-susceptible soils, heaving can cause pavement cracking and shortened pavement life (Fig. 5). Generally coincident with heaving is a rough riding surface. In extreme cases, local frost heaves are dangers to traffic. Subbase thicknesses which provide for load distribution during the spring thaw also automatically provide a cushion which helps to damp differential frost heaving. Michigan, for example, with extremely variable glacial soils and deep frost penetration, designs for pavement smoothness and added pavement life by use of subbase thicknesses adequate to reduce a large percentage of the minor differential heaving caused by variable soil textures. Wisconsin, Michigan, Illinois, Ohio, Indiana, and Mississippi reported that frost bumps or sharp frost heaves are a problem serious enough to require correction. The prime solution to the problem in all States seems to be replacement of the heaving soil with a non-heaving material. Mississippi also reported chemical treatment.

Although it is assumed that the subject of paving aggregates is beyond the scope of this symposium, chert, soft stone, iron concretions, etc., are destructive aggregates which must be considered in pavement design in frost areas. Air entrainment in portland cement concrete is a similar consideration.

Although the southernmost States of Alabama, Georgia, and Mississippi generally report that frost is of very little consequence, their reports do reveal certain design considerations which, although not primarily established for frost reasons, do provide protection against the minor freezing conditions which occur.

Mississippi generally cement-treats the upper layers of the pavement system under the pavement subject to freezing temperatures, although they report that from a design standpoint the primary consideration is wheel-load capacity and not frost penetration.

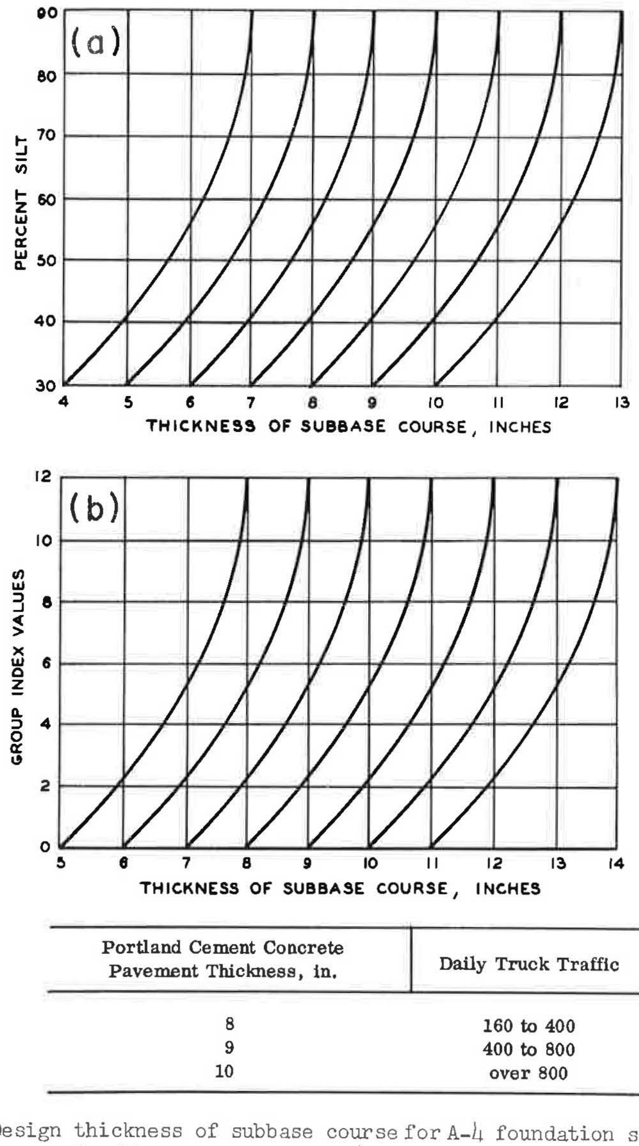
Georgia reports that high water table in two-thirds of the State causes subgrade drainage to be the most serious design problem and that by adequately draining the subgrade, any failures caused by freezing are eliminated as a by-product. Georgia further reported that on less-traveled roads, native soils are stabilized by portland cement thereby waterproofing them to the extent that water is not absorbed, thus eliminating any damage due to freezing. Also interesting is Georgia's experience with cretaceous limestone which cannot be used in the northern two-thirds of the State because the material freezes and even heaves with only a light freeze of short duration.

Of the ten States in the east central area, it appears that Illinois is the only one that employs design criteria using a frost penetration index in establishing individual pavement design. As can be seen from Table 3 and Figure 6, pavement thickness is determined by four factors, namely: soils classification, drainage, average frost penetration, and volume of truck traffic. Table 3 and Figure 6 are included in the Illinois "Policy on Thickness Design of Subbase, Base and Surface Courses for Highways."

TABLE 3
SUBBASE COURSE THICKNESSES IN INCHES
FOR USE WITH PORTLAND CEMENT CONCRETE PAVEMENT
ON HIGHWAYS CARRYING 160 TO 800 TRUCKS DAILY
From Illinois "Policy on Design Thickness of Sub-base, Base and Surface Courses for Highways" as revised September 29, 1951

Foundation Soils Group Classification	Good Drainage			Fair Drainage			Poor Drainage			Very Poor Drainage		
	Average Frost Penetration, in.			Average Frost Penetration, in.			Average Frost Penetration, in.			Average Frost Penetration, in.		
	0-18	18-36	36-54	0-18	18-36	36-54	0-18	18-36	36-54	0-18	18-36	36-54
A-1-a	0	0	0	0	0	0	0	0	0	0	0	0
A-1-b	0	0	0	0	0	0	0	0	0	0	0	0
A-3	0	0	0	0	0	0	0	0	0	0	0	0
A-2-4	0-4*	0-4*	0-4*	0-4*	0-4*	0-4*	0-6**	0-6**	0-6**	0-6**	0-6**	0-6**
A-2-5	0-4*	0-4*	0-4*	0-4*	0-4*	0-4*	0-6**	0-6**	0-6**	0-6**	0-6**	0-6**
A-2-6	4	4	4	4	4	4	6	6	6	6	6	6
A-2-7	4	4	4	4	4	4	6	6	6	6	6	6
A-4	4	4	4	4-7[a]	5-8[a]	6-9[a]	6-9[a]	7-10[a]	8-11[a]	8-11[a]	9-12[a]	10-13[a]
A-5	5	5	5	5-8[b]	6-9[b]	7-10[b]	7-10[b]	8-11[b]	9-12[b]	9-12[b]	10-13[b]	11-14[b]
A-6	4	4	4	4	4	4	6	6	6	6	6	6
A-7-5	4	4	4	4	4	4	6	6	6	6	6	6
A-7-6***	4	4	4	4	4	4	6	6	6	6	6	6

a. see Fig. 6a
b. see Fig. 6b
* Use 4 in. when material is not well graded and plasticity index exceeds 6.
** Use 6 in. when material is not well graded, plasticity index exceeds 6, and drainage is poor or very poor.
*** A-7-6 soils composed of peat and muck should not be used as foundation soil.



Portland Cement Concrete Pavement Thickness, in.	Daily Truck Traffic
8	160 to 400
9	400 to 800
10	over 800

Figure 6. (a) Design thickness of subbase course for A-4 foundation soil; and (b) design of subbase course for A-5 foundation soil (2).

One of the more prominent conclusions which can be made from information supplied by the east central States involves the extent to which design is based on theoretical concepts or on experience. The reply from Wisconsin generally typifies the latter group in that "the major developments for design against frost have been based on experience, with theoretical concepts cautiously taken into consideration...."

From a review of the tabulated answers, it appears also that nearly all the States provide drainage for their subbase sections by means of through-shoulder drainage or underdrains, at least on primary routes. In the opinion of the writers, this is an extremely important consideration in maintaining subgrade stability, especially during the critical frost melting period.

As a final conclusion, it is noted that the replies regarding research performed or in progress indicate only a slight amount of activity in this area. It occurs to the writers, however, that the term research is probably being interpreted as intense, formal programs of field or laboratory investigation. And it could be interpreted that lack of this activity indicates poor engineering—which may not necessarily be the case. In fact, many engineers believe that in many respects the pavements now in existence constitute the only dependable sources of information on which to base future designs, and the writers believe this is the case with most of the States reported here in the east central area. In Michigan, certainly, the dominant feeling is that the performance of in-service roads furnishes the best information for future design.

REFERENCES

1. Jenkins, Belcher, Gregg, and Woods, "The Origin, Distribution and Airphoto Identification of U. S. Soils." Fed. Aeronautics Admin. Tech. Dev. Rpt. No. 52 (May 1946).
2. "Policy on Design Thickness of Sub-base, Base and Surface Courses for Highways." Illinois Div. of Highways (Rev. Sept. 29, 1951).

Discussion

K. B. WOODS, Purdue University.—The authors are to be complimented for putting together good design information for frost conditions in the east central States. The answers to the questionnaires and material from other sources produce reasonably good boundaries for the problem for this area. It will be interesting to see how this material fits in with the remaining portions of the United States and with the material from Canada.

This discusser has studied the frost problem in the midwest for the past 30 years and offers some additional information as a supplement to this paper. Figure 7 (1) is an engineering soils map of the region under discussion and can be used as an addition to the authors' soils map of east central States (Fig. 2). It is to be noted that this soils map is a combination of geologic, pedologic, and textural classifications. It lends itself readily to use in pavement design for frost conditions. The following are a few illustrations:

Young Drift Soils

Many frost problems are encountered in transition between cut and fill sections in the till plains (Crosby-Brookston soils). The textural difference between the silty "A" horizon and the plastic "B" horizon is great. The problem is less severe with modern design because high-level grade lines are used, thus avoiding the problem in transitions.

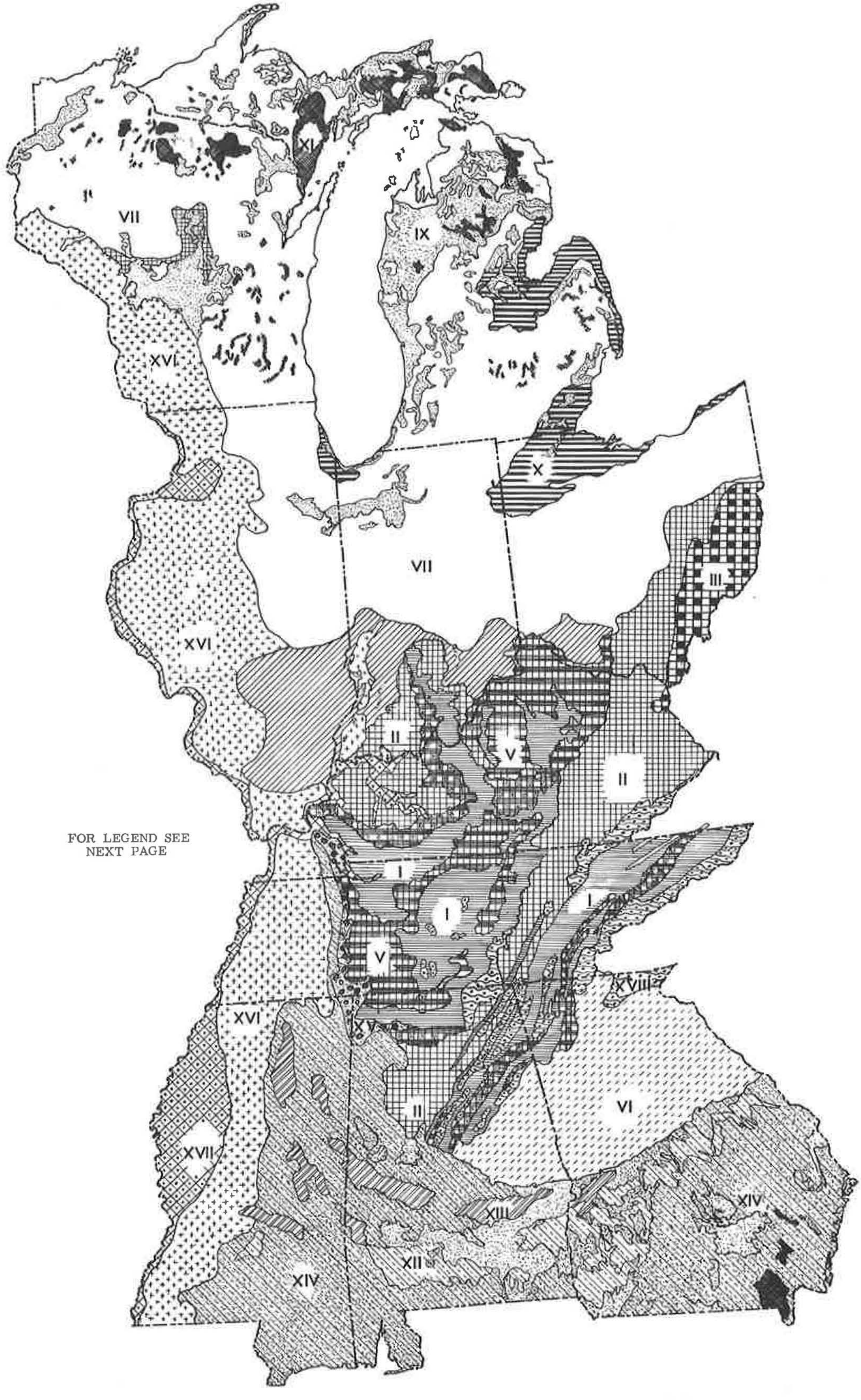
Also, in this region there are many deposits of shallow sands on till. Here, too, the frost problem can be severe in the transition area. This is noticeably true in northwestern Indiana, many areas of Michigan, and, of course, in large areas of southern Ontario.

Old Drift

The old drift of the region under consideration is confined to southern Illinois, southern Indiana, and a small portion of southwestern Ohio. This soil area is generally flat but where erosion has cut through the "A" and "B" horizons by way of deep gullies or even small streams, highways crossing these areas frequently are in trouble when the grade line cuts through the transition between these horizons.

Windblown Silt and Young Drift

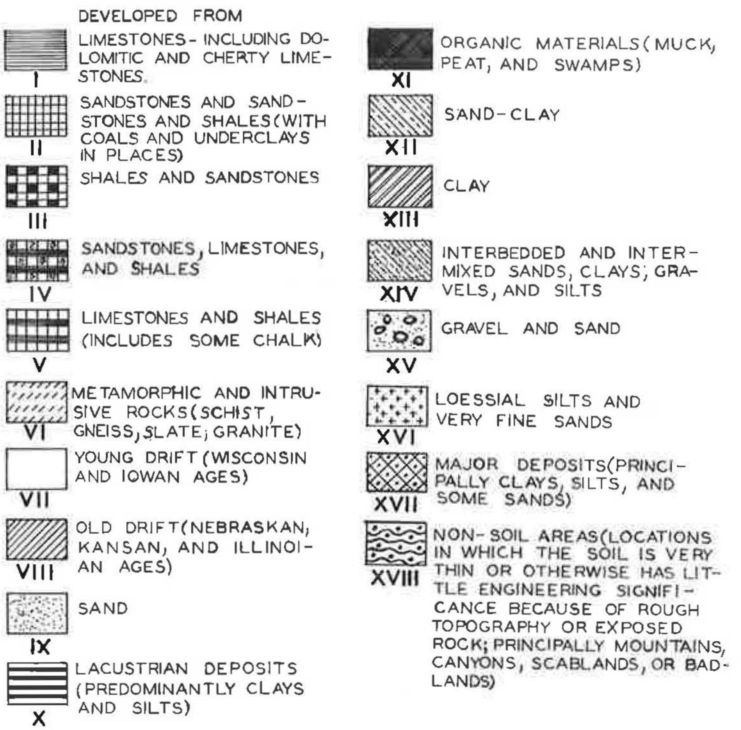
The region under consideration has substantial deposits of loess and the frost problem is of considerable magnitude in western Wisconsin, western Illinois, and in



FOR LEGEND SEE NEXT PAGE

Figure 7. Engineering soils map of east central States (1).

LEGEND FOR SOILS MAP



smaller sections in southwestern Indiana. The silts are quite permeable and when a highway grade line is established close to the transition between the silt and the underlying drift, serious water problems frequently are encountered. Consequently, frost problems are to be expected unless corrective design techniques are employed.

Summary

In those areas where the frost penetration is sufficient to require design considerations, transition zones between soils of unlike textures should receive attention. These layers may be of natural origin such as a natural interbedded-layered system or in cut sections through natural soil profiles.