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FOREWORD

THIS bulletin presents factual information on the main features of design methods currently in use by the various state highway departments for the thickness of flexible pavements.

The information was compiled from the results of a nation-wide survey begun in 1949 immediately following the publication of the Highway Research Board's Current Road Problems 8-R. The survey was undertaken in view of the great variety of approaches being utilized and for the purpose of indicating the desirability of a certain measure of standardization of the essential features of the methods.

As pointed out in the report, the material gives only a generalized picture of the manner in which the problem is being handled by the states. It is the plan of the committee to sponsor reports for presentation at future meetings of the Highway Research Board that will describe the methods in detail. In the meantime, if additional information is desired regarding a particular method, it may be obtained by corresponding directly with the state highway department concerned.

The committee plans to continue the work of compiling data and anticipates that another nation-wide survey will be made in about 5 yr.

Report of Committee on Flexible-Pavement Design

FLEXIBLE-PAVEMENT-DESIGN PROCEDURES OF THE STATE HIGHWAY DEPARTMENTS

● DURING the early days of road building the design of flexible pavements was based largely upon the experience and judgment of the engineer. Coming to a realization that the character of the subgrade soil was an extremely important factor affecting pavements, highway engineers in the 1920's began looking for methods of classifying the earth material. During this period the pedological system of classification was introduced. In 1929 the Bureau of Public Roads system of soil-group classification was developed, and in the early 1930's several states inaugurated the practice of varying the thickness of flexible pavements in accordance with the character of the soil as determined by this system of classification.

In 1935 the idea of evaluating the soil for design purposes by means of small-scale strength tests was advanced. The feasibility of using such tests received considerable impetus as a result of work done in connection with the design of airport pavements during World War II. The result was the development by several states of empirical methods of design employing such tests as the CBR, the North Dakota cone, and the triaxial compression.

During the war and immediately following, the Committee on Flexible-Pavement Design of the Highway Research Board sponsored the presentation of a series of papers which dealt with several new methods of design that were being developed (see references at end of this report). Included were papers describing the methods of state highway departments in Colorado, Kansas, North Carolina, Wyoming, Texas, Michigan, and New Mexico. A wide-spread interest was manifested in these methods of design, and it was not long before many other state highway departments proceeded to revise their procedures or to develop new ones.

In view of this growing interest, the committee in 1949 decided to make a nation-wide survey of flexible-pavement-design practices. Each state was requested by letter to furnish a descriptive statement of the details of its procedure. From the information thus obtained a tabulation of the essential features of all the methods was prepared. The tabulation included the following information: (1) procedures for classification of soils; (2) procedures for obtaining soil characteristics; (3) soil-strength tests; (4) method of evaluating traffic, climate, and subgrade soil; (5) method of evaluating thickness of pavement components; and (6) seasonal load restrictions.

Copies of the tabulation were returned to the states for checking and amplification. Some additions and corrections were made and the copies were again returned to the states for clarification of certain items and final clearance before being published.

At the January 1951 meeting of the Highway Research Board, the status of this activity was discussed by the committee and a decision made to publish the information in tabulated form only. Accordingly, the material was appended to the annual report of the committee and printed in the February 1951 issue of Highway Research Abstracts. Also, a general summary of the same data was presented in a paper at the Fifth Annual Florida Highway Conference, May 14 - 15, 1951, by A. C. Benkelman.

At the time the tabulation was published in Highway Research Abstracts, the information relating to the methods of evaluating the thicknesses of individual components of the pavement was not complete. In some cases the information related principally to methods used to determine the quality of the materials. The tabulation was resubmitted to the states with the

Summary of State Highway Departmen

State	General: Do you classify soils as a standard procedure? Yes	No	Method	Do you run soil constants as a standard procedure? Yes	No	Do you run soil strength tests? Yes	No	Method	Method of evaluation: Traffic	Climate	Subgrade	Thickness of pavement component: Wearing course	Base
Alabama	X		PRA HRB 1946	X		X		CBR Since 1936	Volume % heavy trucks	Free draining Low capillary materials	CBR and HRB curves (1946)	Traffic Gradation Stability	Traffic CBR Type of subbase
Arizona	X		HRB	X LL, PL PI			X		Vol and character	Free draining bases in frost areas	PI and % passing No 200 sieve	2" on primed base is standard practice	*3" is standard practice
Arkansas	X		HRB	X			X		Volume		Group Index	Traffic volume Wheel load	Traffic volume Wheel load
California		X		X LL, PL PI		X		Hveem stabilo-meter	Equivalent 5,000-lb wheel loads		Hveem Stabilometer	Cohesiometer and Hveem Stabilometer	Hveem Stabilometer
Colorado	X		HRB	X		X		*CBR	Vol and character	Depth frost and moisture conditions	CBR modified and Group Index	Cohesiometer Hveem Stabilometer	Hveem Stabilometer
Connecticut	X		Textural		X		X		Volume	Subbases for frost	Textural soil type	Experience and judgment	Experience and judgment
Delaware	X		HRB	X		X		CBR	Vol and character	Subbases for frost	CBR and Group Index	Experience Type of traffic	Experience CBR Type of traffic
Florida	X		PRA	X		X		Florida bearing test	Volume	12-inch friable subbase on plastic soils	Florida bearing test (30-60psi)	Experience	Experience
Georgia	X		Ga. Standard No 9032 (density and vol change)	X LL&PI on base			X	Florida bear-ing on sand, bit read mix only	Volume	Depth subbase varies with soil moisture	Ga Standard No 9032 (density and vol change)	Comparison with com-pleted projects in same locality and same con-ditions	Type and density of traffic
Idaho	X		HRB	X		X		Hveem stabilo-meter adop-ted August 1950	Volume	Experience	HRB soil groups	Traffic volume	Traffic, climate, subgrade soil
Illinois	X		HRB	X		X		CBR NDC modified	9,000-lb wheel loads and volume	Frost and ground water conditions	CBR, NDC and Group Index	Varied with traffic	Min standard for granular bases
Indiana	X		HRB Pedological Texture	X		X		CBR for special cases since 1950	Wheel load and volume	Frost and rainfall	HRB soil groups, CBR for special cases	Experience and judgment	Experience and judgment
Iowa	X		PRA Pedological	X		X		Iowa Shear Test	Volume		PRA soil groups, Iowa Shear Test	Hveem stabilometer	Bit base Hveem Stabilometer
Kansas	X		Textural Pedological	X		X		Triaxial Compres-sion	Wheel load and volume	Rainfall	Triaxial compression	Triaxial compression test	Triaxial compression test
Kentucky	X		HRB	X		X		CBR	Equivalent 5,000-lb. wheel loads	Not critical	CBR modified	Experience	CBR
Louisiana	X		PRA	X		X		Direct shear, unconfined compression, CBR	'8,000-lb. axle load	Drainage Low capillary materials	PRA soil groups	Experience	Experience
Maine		X	PRA		X		X		Volume	Thick gravel bases to combat frost	Experience and judgment	2' - 3"	Varies with traffic 0-6"
Maryland	X		PRA modified and GI	X			X		Traffic volume Max wheel load 11,200 lbs	Subbase and drainage for frost and moisture	PRA, HRB-GI, Interpolated CBR	Traffic volume Experience	Traffic volume Experience
Massachusetts	X		PRA		X		X		Wheel load	12-inch gravel sub-base course to combat frost	Detailed field soil surveys	Experience	Experience
Michigan	X		Pedological		*X		*X		Volume determines thickness and type of surface	Soil classification considers climate	Detailed field soil surveys	Volume of traffic	Volume of traffic
Minnesota	X		PRA Textural	X LL, PI		X		CBR modified	9,000-lb wheel load with restrictions	Subbases for frost	CBR modified	Experience 1¼" - 3"	CBR modified
Mississippi	X		PRA modified	X							PRA soil groups and Group Index	Marshall stability Modified compaction	Marshall stability Modified compaction
Missouri	X		HRB Pedological	X		X		CBR in special cases	Volume commercial	Not considered critical factor	Density, CBR and Group Index	Depends on type of pavement and traffic	Thickness chart based on GI of subgrade

ƚrocedures for Designing Flexible Pavements

				Miscellaneous				
	Quality of pavement components			Approx years method used	Load restrictions in spring		Remarks	State
Subbase	Wearing course	Base	Subbase		Primary roads	Secondary roads		
·pe of subgrade .R .B curves	Gradation Stability Marshall	CBR Gradation Soil constants	CBR Soil constants	14	18,000-lb axle load	None	Some work done in attempt to correlate CBR and HRB design curves on subgrade soils Not in full agreement.	Alabama
and %-200 of subgrade ɟerience	Grading, PI AASHO T-101 Experience	PI, grading and experience with special attention to -200	Same as for base	15	None	None	* Base thickness increased when PI and/or -200 of subbase are sub-standard.	Arizona
oup Index of subgrade	Marshall stability	Gradation PI and LL	Gradation PI and LL	8	None	None		Arkansas
eem Stabilometer	Hveem Stabilometer Gradation Swell and stripping	Hveem Stabilometer Gradation, PI and sand equivalent	Hveem Stabilometer Gradation and sand equivalent	*4	No	No	* Sand equivalent test in use for one year	California
ɾeem Stabilometer	Hveem Stabilometer	Hveem Stabilometer	Hveem Stabilometer	8	No	No	Use of stabilometer just inaugurated. *CBR used on all but A-1 and A-3 soils which are evaluated by stabilometer as if they were part of pavement system	Colorado
ɟpth sufficient to provide ·y, firm, uniform ·ring	AASHO T-104 LA wear Gradation	AASHO T-104 LA wear Gradation	Gradation and PI	10	None	None	Standard pavement sections, variable thicknesses of subbase	Connecticut
·R and/or frost ·uirements	Marshall, triaxial and experience	Experience, waterbound macadam is standard	Grading, PI and CBR	10	Yes, if frost conditions warrant	Yes, if frost conditions warrant	Limited mileage of flexible pavements	Delaware
ɟerience	Hubbard-Field stability for dense graded plant mixes	AASHO density and particular specification for material	Not generally used	10	None	None	18,000-lb axle load year round for all roads	Florida
aterials available d. 9032	ASTM D-1075-49 T ASTM D-1074-49 T AASHO T-98-49 Hubbard-Field	Grading, LL, PI, density and volume change	Grading, density and volume change	5	None	None	Standard pavement sections, variable thickness of base and subbase	Georgia
sed in lieu of base	Hveem Stabilometer LA wear, gradation, LL, PI	Gradation LL and PI LA wear	Gradation LL and PI	12	Yes	Yes	Adopting stabilometer soils in 1951	Idaho
D Cone, CBR and roup Index	Marshall stability	CBR	CBR	5	Yes (At discretion of Department)	Yes (At discretion of Department)	Working toward use of soil bearing strength, soil analyses, drainage and climate data.	Illinois
xperience and ɟdgment	Class "A" agg	Class "A" or ' B" agg	Class "A", "B" or "C" agg.		No	No, except in extreme cases		Indiana
·ensity					* Yes	Control by counties	*At discretion of Commission	Iowa
·riaxial compression est	Triaxial compression test	Triaxial compression test	Triaxial compression test	8	Yes	Yes		Kansas
.BR	LA wear Marshall	LA wear Soundness	LA wear	6	No	By special order following hard winters		Kentucky
·xperience	Marshall stability flow	Screen tests Atterburg tests	PRA soil classification	18	No	No	Now using PRA soil classification, working towards HRB soil groups	Louisiana
·ravel base, 18"-24"	Penetration macadam or bituminous concrete	Crushed stone or bituminous concrete base	Gravel	20	No	Yes		Maine
·affic volume Experience	Specifications Marshall Hubbard-Field	Specifications Gradation LA wear Soil constants	Specifications Gradation and/or soil constants	7	*Yes	* Yes	Thickness and quality varied in accordance with conditions involved. *Where needed.	Maryland
xperience	Gradation LA wear	Gradation LA wear	Gradation		No	No	PRA classification used frequently for evaluation.	Massachusetts
·etermined by soil ˈteries	Stability - Hubbard-Field Durability - Experience	Gradation Percent crushed	Visual examination Gradation Drainability	16	*Yes	*Yes	* Soil constants or strength tests are run only for special designs or research purposes * To protect old construction	Michigan
CBR modified	Cold water abrasion Marshall stability Gradation, Shale-abrasion of agg	CBR modified, Gradation and PI ratio 200/40 not more than 4	CBR modified Gradation and PI	6	Yes	Yes	Plate-bearing tests also used for evaluation of existing roads and design thickness of base	Minnesota
				14	No	No	Original Marshall machine developed in Mississippi Highway Department Lab	Mississippi
Not included as standard practice	Hubbard-Field Hveem Stabilometer	AASHO M 147-49 Type 1	When used - GI max density	7	None	Controlled by local conditions	Studying possibility of revising GI based on field capacity of subgrade	Missouri

State	General: Do you classify soils as a standard procedure? Yes	No	Method	Do you run Soil constants as a standard procedure? Yes	No	Do you run soil strength tests? Yes	No	Method	Method of evaluation: Traffic	Climate	Subgrade	Thickness of pavement components: Wearing course	Base
Montana	X		HRB	X		X		CBR and/or Florida bearing	Volume wheel load	Frost, rainfall and water table	Group Index	Traffic Volume Wheel load Quality	Traffic Volume Wheel load Quality of base and subbase
Nebraska	X		HRB Pedological	X			X	•	5,000- and 7,000-lb. wheel loads	Rainfall	Group Index and drainage	From charts correlating experience and judgment with traffic rainfall, drainage conditions and soil classification.	From charts correlating experience and judgment with traffic, rainfall, drainage conditions and soil classification.
Nevada	X		PRA modified	X			X		Volume and percentage of heavy traffic	Temperature and rainfall	PRA soil groups	Determined from soil constants and climatic conditions	Determined from soil constants and climatic conditions
New Hampshire	X		HRB		X		X		Volume determines thickness and type of surface	Subbases for frost	HRB soil groups	Experience	Combined thickness of base and subbase depends on frost susceptibility of subgrade
New Jersey	X		Textural		X	X		CBR	Volume loadings	Subbase and drainage for frost and moisture	CBR	Experience and judgment	Experience and judgment
New Mexico	X		HRB	X		X		CBR	Wheel load	Increase thickness in irrigated areas	CBR modified, PI and % passing No. 200 sieve, "R" value	Marshall and stabilometer for hot mix	CBR, "R" value and sand equivalent
New York	X		Textural Pedological Geological		X		X	No	Wheel load and volume	Bank run gravel subbases for frost	Detail field soil survey	Experience	Experience
North Carolina	X		HRB Pedological	X		X		Plate bearing	Wheel load	Additional thickness in mountain areas	Plate bearing tests	Plate-bearing tests and experience	Plate-bearing tests
North Dakota	X		PRA, HRB and ND method (latter governs)	X (When time permits)		X		NDC	9,000-lb. wheel load volume	Soil selection, and pit run subbase, reinforcement when required	NDC and experience	Subgrade bearing determined by ND cone which resul total base and surface thickness obtained from ND de by experience	
Ohio	X		Ohio Std. (PRA system modified)	X		X		CBR	Volume commercial	Heavy subbases on silt for frost	CBR and Group Index	Total pavement thickness based on GI and CBR of subgrade Thickness of various components based on exp	Total pavement thickness based on GI and CBR of subgrade Thickness of various components based on exp
Oklahoma	X		HRB	X		X		CBR	9,000-lb. wheel load		CBR, HRB and Group Index	Hveem Stabilometer	CBR
Oregon	X		HRB	X		X		Triaxial and modified stabilometer	Volume	Experience	Group Index and modified stabilometer	Volume of traffic	Traffic and type of subgrade
Pennsylvania	X		HRB	X			X		Volume % trucks	Experience	HRB soil groups	Volume traffic % trucks	Volume traffic % trucks
Rhode Island	X		PRA Casagrande		X		X				PRA soil groups		
South Carolina	X		PRA	X			X		Volume		Field surveys		
South Dakota	X		HRB	X			X		Volume commercial	Rainfall, surface and subsurface drainage, frost action	Soil constants and Group Index	Marshall and experience Quality base and subgrade Vol commercial traffic	Experience Vol commercial traffic, 6-12" clay-bound processed gravel
Tennessee	X		PRA	X			X		Volume % heavy trucks	Not considered critical factor	PRA soil groups	Experience	Experience
Texas	X		PRA	X		X		Triaxial	Avg. of ten heaviest wheel loads per avg. day		Triaxial compression	Triaxial compression	Triaxial compression
Utah	X		PRA HRB	X		X		CBR	12,000-lb. primary, 7-12,000-lb. secondary axle loads	Local conditions	HRB and CBR	Hveem and Marshall	HRB as guide with addition to satisfy local conditions
Vermont	X		Field survey		X		X		Wheel load Traffic count	12"-24" gravel subbase used	Field surveys	Experience	Experience and judgment
Virginia	X		PRA HRB	X		X		CBR modified	Max. wheel load		CBR modified	Experience Traffic pattern	CBR modified
Washington	X		AASHO M-145-49	X LL, PI		X		Hveem stabilometer	Equivalent 5,000-lb wheel loads	Rainfall and frost penetration	Hveem Stabilometer	Cohesiometer and Hveem Stabilometer	Hveem Stabilometer
West Virginia	X		HRB	X			X		Volume commercial, Equivalent 5,000-lb. wheel loads		Field CBR and plate bearing tests	Experience and judgment	Experience and judgment
Wisconsin	X		Pedological		X		X		Volume	Experience	Field surveys and observations	Volume and type of traffic	Volume and type of traffic
Wyoming	X		HRB	X		X		CBR modified	Equivalent 5,000-lb wheel loads	Rainfall, position water table and frost action	CBR modified	Total thickness based on soil CBR. Experience and quality of materials available	Total thickness based on soil CBR. Experience and quality of materials available

				Miscellaneous				
	Quality of pavement components			Approx years method used	Load restrictions in spring		Remarks	State
bbase	Wearing course	Base	Subbase		Primary roads	Secondary roads		
subgrade penetration r table, Local performance	Florida bearing Montana cone Comp. strength Density Vol swell	Wear Grading Soil constants on -40 and -200	GI, CBR Piping ratio with respect to the subgrade					Montana
charts correlating rience and judgment raffic, rainfall, age conditions and lassification	Modified Hubbard-Field	Bit -Mod. Hubbard-Field, crushed rock, etc , gradation, soundness, abrasion loss, plasticity constants.	Gradation Plasticity constants	6	Restricted only once in past 15 years	Restricted only once in past 15 years	*Triaxial tests on experimental and exploratory basis only	Nebraska
rmined from soil ants and climatic tions	Hveem Stabilometer	Hveem Stabilometer	Hveem Stabilometer	15	No	No		Nevada
ined thickness of and subbase ds on frost ptibility of subgrade	Type determined by traffic and hauling distance	Quality is not varied intentionally although less supervision might be given on poorer classes of material		20	Agreement with truckers limits gross load to 10 tons on certain routes	Agreement with truckers limits gross load to 10 tons on certain routes		New Hampshire
plus experience dgment	Experience and judgment	Experience and judgment	CBR plus experience and judgment	7	No	No	Density and void content tests.	New Jersey
as base				7			"R" value and sand equivalent introduced this year as a check on previous method.	New Mexico
of subgrade and of frost pene- n	Experience	Experience	Gravel - Gradation and soundness	5	No	*Yes	*As required by local conditions.	New York
-bearing tests	Gradation of aggregates and Hubbard-Field	Soil constants Gradation of aggregates Bit - Hubbard-Field	Soil constants	7	*None	*None	*Certain roads are restricted as necessary	North Carolina
mines the rve, and	ND specifications Asphalt Inst. recommendations Hubbard-Field and Marshall tests	Bit base same as surface, gravel stab. base, ND specs	Pit run gravel subbase, ND specs	8	Yes	Yes		North Dakota
pavement thick- based on GI and of subgrade ness of various onents based on exp	Controlled by specification based on Ohio experience	Controlled by specification based on Ohio experience	Controlled by specification based on Ohio experience	6	No	Yes		Ohio
grading and PI	Hveem Stabilometer	CBR and Hveem Stabilometer	CBR, grading and PI	5	No	No		Oklahoma
of subgrade rience	Gradation	Abrasion Gradation LL and PI	Gradation LL and PI Experience	10	None	Yes	Load restrictions based on bearing tests being made	Oregon
rience	Traffic Experience	Traffic Experience	Granular materials Gradation Max. LL -30 Max. PI -6	10	No	Yes (certain roads)	No subgrade specifications Controlled construction of embankments	Pennsylvania
					None	None		Rhode Island
								South Carolina
rience ty subgrade " pit run gravel	Marshall standard tests	Extrusion test LA abrasion LL and PI	Clean gravel Gradation PI	20	Yes		Marshall method - 1 year Soil analysis - 5 years	South Dakota
rience	Stability test	Stability Quality of materials	PRA soils	15	None	None	Information from 1947 HRB survey 18,000-lb axle load.	Tennessee
ial compression	Hveem Stability and % voids	Triaxial compression	Triaxial compression	5	None	None	Geological and agricultural soil maps used to reduce amount of testing.	Texas
as guide with ion to satisfy conditions				3	Yes (Depending on local conditions)	Yes (Depending on local conditions)		Utah
nin depth fic volume conditions	Gradation and stability of materials	Traffic volume Experience	Control of % of wear % of stone % of fines			Yes 300 lb. per " tire width - local control		Vermont
modified	Hubbard-Field Marshall and specifications	CBR modified and specifications	CBR modified and specifications	CBR 4	Yes	Yes	Working on correlation of CBR vs soils and wheel loads	Virginia
m Stabilometer	Specification tests Extraction tests Stabilometer and Cohesiometer values	Specification tests Field inspection of construction methods	Specification tests Field inspection of construction methods	1	Yes (At discretion of District Engineer)	Yes (At discretion of District Engineer)	Recently changed from CBR to stabilometer	Washington
erience and gment		Grading, LL, PI and LA	Grading, LL, PI and LA	3	Yes	Yes	Standard pavement section - procedure now being revised.	West Virginia
logy of soils	Hubbard-Field and Marshall	Graded 1½" -200 -12% passing No.200 sieve	Permeable Freely draining	10	No On roads of present design standards	No On roads of present design standards	Method considers a thermo-dynamic theory of moisture movements	Wisconsin
e as wearing se and base	Gradation, dust ratio, LA abrasion, LL and PI Wyoming stability test	Gradation, dust ratio, LA abrasion, LL and PI Wyoming stability test	CBR modified Gradation, LL and PI cementing value	5	None	None		Wyoming

request that they furnisn the committee detailed information regarding the items of both thickness and quality.

Although descriptions of a number of the methods of thickness design have been published, it is the plan of the committee to sponsor reports on other methods for presentation at future meetings of the Board. Also the committee hopes that it will be possible periodically to obtain reports from the states describing how their methods are working out in practice.

RESULTS OF LAST SURVEY

The discussion which follows concerns the latest tabulation of material, dated March 1952, and entitled "Summary of State Highway Procedures for Designing Flexible Pavements". The items discussed are handled in same sequence as the column headings shown in the tabulation. A separate summary table has been prepared for each item of information listed. A number of descriptive terms which appear in the discussion and tables are defined as follows:

HRB[1] - Highway Research Board soil classification

PRA - 1942 - U. S. Bureau of Public Roads soil classification (formerly the Public Roads Administration).

GI - Group Index

CBR - California Bearing Ratio test

NDC - North Dakota Cone test

LA - Los Angeles wear test

LL - Liquid limit

PI - Pasticity index

[1]This classification of soils and soil-aggregate mixtures for Highway purposes, formerly identified as HRB, is now officially known as AASHO Designation M145-49.

Table 1 (a)

Soil Classification methods used as a standard procedure.

Method	Number of states
HRB	16
HRB and pedological	3
HRB, pedological and textural	1
PRA-1942 or PRA modified	10
PRA-1942 and HRB	4
PRA modified and HRB	1
PRA-1942 and pedological	1
PRA-1942 and textural	1
PRA-1942 and Casagrande	1
Pedological	2
Textural	2
Textural and pedological	1
Textural, pedological and geological	1
Field survey	1
AASHO	1
Density and volume change	1
Total	47

Table 1 (b)

Number of states using the various methods of soil classification.

Method	Number of states
HRB	25
PRA-1942 or PRA modified	18
Pedological	9
Textural	6
Miscellaneous	5

Table 2 (a)

Soil strength tests made by the various states.

Test	Number of states
CBR or CBR modified	15
CBR and/or Florida bearing	1
CBR and NDC modified	1
CBR, direct shear and unconfined compression	1
Hveem stabilometer	3
Triaxial compression	3
Triaxial compression and modified stabilometer	1
Florida bearing	2
Iowa shear	1
NDC	1
Plate bearing	1
Total	30

Table 2 (b)

Number of states making the various soil strength tests.

Test	Number of states
CBR or CBR modified	18
Hveem stabilometer	4
Triaxial compression	4
Florida bearing	3
NDC or NDC modified	2
Miscellaneous	4

R value - Resistance value of the soil
AASHO - American Association of State Highway Officials
Bit. - Bituminous

SOIL CLASSIFICATION PROCEDURES, SOIL TEST CONSTANTS AND SOIL STRENGTH TESTS

Tables 1(a) and 1(b) contain the data received in answer to the question "Do you classify soils as a standard procedure, and if so, what method is used?" In Table 1(a) the methods and combinations of methods used by the states are listed; and in Table 1(b) the same data are briefed further to show how many states use each individual method.

Table 3 (a)

Methods of evaluating traffic used by the various states.

Method	Number of states
Volume	12
Volume and wheel load	8
Volume and character	7
Volume of commercial vehicles	3
Volume loadings	1
Volume of commercial vehicles and equivalent wheel load	1
Equivalent wheel load	4
Wheel load	8
Axle load	2
Total	46

Table 3 (b)

Number of states using the various methods of evaluating traffic.

Method	Number of states
Volume	32
Wheel load	16
Character	7
Equivalent wheel load	5
Axle load	2

All states except one make a general practice of classifying soils according to some standard procedure. The most-widely used method or system is the HRB which is used alone by 16 states and along with other methods by nine other states. The PRA-1942 system is used alone by ten states and in conjunction with other methods by eight states, while the pedological and textural methods are used by nine and six states, respectively. Several other methods, including the Casagrande system of soil classification, geological, field soil survey and AASHO, are also used.

Table 4 (a)

Means by which climate is considered by the various states.

Item	Number of states
Frost penetration	11
Frost penetration and rainfall	5
Frost penetration, rainfall and water table	2
Frost penetration and water table	1
Rainfall	2
Rainfall, drainage and frost penetration	1
Rainfall and temperature	1
Experience	5
Soil moisture	3
Soil classification	1
Drainability of soil	3
Total	35

Table 4 (b)

Number of states considering the various items with relation to climate.

Item	Number of states
Frost penetration	20
Rainfall	11
Experience	5
Drainability of soil	4
Water table	3
Soil moisture	3
Miscellaneous	2

Soil test constants, such as the liquid and plastic limits, are obtained as standard procedures by 38 states. Some type of soil strength test is made by each of 30 states as indicated in Table 2(a). In this table the various types of tests and combinations thereof are listed according to state usage, while in Table 2(b) the same information is tabulated on a basis of individual tests. The CBR test or modified CBR test is run by 18 states. Other tests which are used by as many as two to four states each are: the Hveem stabilometer, triaxial compression, Florida bearing, and North Dakota cone. The Iowa shear, plate-bearing, direct-shear and unconfined-compression tests are each used by a single state.

EVALUATION OF TRAFFIC, CLIMATE AND SUBGRADE

Traffic is considered in connection with pavement thickness design by 46 states. In Table 3(a) the various ways in which this item is handled are summarized. Twelve states consider volume alone; eight, volume and wheel load; seven, volume and character of traffic; three, volume of commercial vehicles; one, volume loadings; and one, volume of commercial vehicles and equivalent wheel load. The magnitude of the wheel load is the basis for consideration by eight states; equivalent wheel loads are used by four; and design axle loads by two states. The same information is shown in Table 3(b) in such a manner as to indicate the number of states using the various methods. In all, 32 states consider volume of traffic; sixteen, wheel load; seven, the character of traffic; five, equivalent wheel load; and two, the axle load.

Climate or its effect is taken into account in the design of flexible pavements by 35 of the states. The factors considered in this regard are listed in Table 4(a). Eleven states are concerned with depth of frost penetration alone; five, with this factor in combination with rainfall; two, with frost penetration, rainfall and elevation of the ground-water table; and one, with frost penetration and water-table elevation. Two states consider rainfall

Table 5 (a)

Methods used in evaluating the subgrade for design purposes.

Method	Number of states
Field soil surveys	6
PRA-1942 soil classification	4
CBR modified	4
CBR and HRB soil classification	3
HRB soil classification	3
GI	2
Hveem stabilometer	2
Triaxial compression	2
CBR and GI	2
CBR modified and GI	1
CBR, NDC and GI	1
CBR, HRB and GI	1
Field CBR and plate bearing	1
CBR, GI and density	1
CBR modified, PI, percent passing 200 sieve and R value	1
CBR only	1
PRA-1942 soil classification, HRB - GI and CBR	1
PRA-1942 soil classification and GI	1
PRA-1942 soil classification and Iowa shear	1
GI and drainage	1
GI and modified stabilometer	1
GI and soil constants	1
Plate bearing	1
NDC and experience	1
PI and percent passing 200 sieve	1
Florida bearing	1
Textural soil types	1
Experience and judgment	1
Georgia standard	1
Total	48

Table 5 (b)

Number of states using the various methods of evaluating the subgrade.

Method	Number of states
GI	13
CBR	11
HRB soil classification	7
CBR modified	6
PRA-1942 soil classification	7
Field soil survey	6
Hveem stabilometer	3
NDC	2
Plate bearing	2
Triaxial compression	2
PI and percent passing 200 sieve	2
Experience and judgment	2
Miscellaneous	8

Table 5 (c)

Summary of methods of evaluating the subgrade grouped in general categories.

Category	Number of states
1. Physical characteristics of the soil	33
2. Strength tests of the soil	30
3. Detailed field soil survey	6
4. Miscellaneous	3

only; one state considers the combination of rainfall, drainage and frost; one state the factors of rainfall and temperature. Five states reported evaluating climate by experience; three, soil moisture; and three, drainability of the soil. The various items are listed individually in Table 4(b) in order to indicate the extent to which each is taken into account. Apparently the effects of frost and rainfall are by far the most-widely considered items, since these factors are observed by 20 and 11 states, respectively.

Table 6 (a)

Methods of evaluating wearing course thickness

Method	Number of states
Experience or experience and judgment	16
Traffic volume	6
Traffic and experience	3
Cohesiometer and Hveem stabilometer	3
Traffic volume and wheel load	2
Hveem stabilometer	2
Hveem stabilometer and Marshall	2
Triaxial compression	2
Experience and plate bearing	1
Marshall stability (modified)	1
Traffic, gradation and stability	1
Traffic and type pavement	1
Traffic, experience, rainfall and soil classification	1
Soil constants and climatic conditions	1
Experience and quality of materials	1
Marshall, experience, traffic and quality of materials	1
Total	44

Table 6(b)

Number of states using the various methods of evaluating wearing course thickness.

Method	Number of states
Experience or experience and judgment	23
Traffic	15
Hveem stabilometer	7
Marshall	4
Cohesiometer	3
Triaxial compression	2
Quality of materials	2
Miscellaneous	9

Table 7 (a)

Methods of evaluating base course thickness.

Method	Number of states
Experience and judgment	10
Hveem stabilometer	4
CBR and CBR modified	4
Triaxial compression	2
Traffic volume	2
Traffic volume and experience	2
Traffic volume and wheel load	2
Traffic volume and type	2
Traffic and type subgrade	1
Traffic, climate and subgrade	1
Traffic volume, wheel load and quality of materials	1
Traffic, CBR and type subbase	1
CBR, R value and sand equivalent	1
CBR, experience and quality	1
Experience, CBR and type traffic	1
Experience, traffic, rainfall and drainage conditions	1
GI of subgrade	1
GI and CBR of subgrade	1
Marshall stability, modified compaction	1
Soil constants and climate	1
Frost susceptibility of subgrade	1
NDC on subgrade and design curves	1
HRB soil classification as a guide	1
Minimum standards for granular bases	1
Total	44

Table 7 (b)

Number of states using the various means of evaluating base course thickness.

Method	Number of states
Experience and judgment	15
Traffic	14
CBR or CBR modified	9
Hveem stabilometer	4
Wheel load	3
Triaxial	2
GI of subgrade	2
Quality of materials	2
Climate	2
Miscellaneous	13

The importance of the role that the character of the subgrade soil plays in the design of flexible pavements is evident from the fact that all 48 states utilize some means of considering this factor. The methods or tests and combinations of them reported are indicated in Table 5(a). There are six states who base their evaluation on field soil surveys alone; four use the PRA -1942 soil classification system; and four use the modified CBR test. The CBR test, together with the HRB soil classification system, and the HRB system by itself are used by three states each. The group index method, Hveem stabilometer test, triaxial-compression test, and the CBR test in conjunction with the group-index method are each used by two states. The remaining 20 procedures are each utilized by single states.

The data in Table 5(b) show the prevalence of usage of the individual methods. The group-index method, which is used by 13 states, is the most-widely accepted. The CBR test is used by 11 states. The HRB and PRA-1942 soil classification systems each are used by seven states. The modified CBR test and field soil surveys are each used by six, and the Hveem stabilometer by three states. Several methods are used by two states, while a number of miscellaneous methods are used by only one state each.

Table 8 (a)

Methods of evaluating subbase thickness.

Method	Number of states
Experience and judgment	10
Hveem stabilometer	3
CBR or CBR modified	3
Triaxial compression test	2
Experience and type subgrade	2
CBR and/or frost requirements	1
CBR, experience and judgment	1
CBR, R value and sand equivalent	1
CBR, grading and PI	1
CBR, experience and quality of materials	1
Type subgrade, CBR and HRB curves	1
NDC, CBR and GI	1
GI of subgrade	1
GI of subgrade, frost penetration, water table and experience	1
HRB soil classification and experience	1
Traffic volume and soil conditions	1
Geology of soils	1
Experience, PI and percent passing 200 sieve	1
Soil series	1
Experience, traffic, rainfall, drainage conditions and soil classification	1
Soil constants and climatic conditions	1
Frost susceptibility of subgrade	1
Plate bearing	1
Type subgrade and depth of frost penetration	1
Materials available	1
Used in lieu of base	1
Density	1
Gravel base, 18-24 inches	1
Total	44

Table 8 (b)

Number of states using the various methods of evaluating subbase thickness.

Method	Number of states
Experience and judgment only	18
CBR or CBR modified	11
Frost requirements or penetration	4
Group Index	3
Hveem stabilometer	3
Traffic volume	3
Soil constants	3
Type or quality of subgrade	2
Triaxial compression	2
HRB soil classification	2
Climate	2
Quality	2
Miscellaneous	9

A summary of the methods of evaluating the subgrade is given in Table 5(c), where all the procedures are grouped into several broad categories: physical characteristics of the soil, strength tests, and field soil surveys. Replies from 33 states indicated that analyses of the physical characteristics of the soils are made. Thirty states make one or more of the several strength tests. Six states employ detailed field soil surveys.

EVALUATION OF THICKNESS OF PAVEMENT COMPONENTS

Tables 6, 7, and 8 concern the methods in use to determine the thickness of the individual components of the pavement, i. e., the wearing course, the base course and the subbase.

As shown in Table 6(a), 44 states each utilize a method for designing the thickness of the wearing surface. One state uses 2 in. and another uses 2 to 3 in., as standard thickness.

Surface thickness design is based upon experience or experience and judgment, in 16 states, and upon the volume of traffic

Table 9 (a)

Methods of evaluating wearing course quality.

Method	Number of states
Marshall stability	4
Marshall and Hubbard-Field stability	4
Hveem stabilometer	3
Hubbard-Field stability	3
Experience and judgment	3
Marshall stability and gradation	2
Traffic, availability of materials and experience	2
Marshall, triaxial compression and experience	1
Marshall and LA wear	1
Marshall, gradation and abrasion	1
Hveem stabilometer, gradation, swell, and stripping	1
Hveem and Hubbard-Field stability	1
Hveem, gradation, soil constants and LA wear	1
Hveem and percent voids	1
Hveem, cohesiometer and extraction	1
Hubbard-Field, ASTM and AASHO specifications	1
Hubbard-Field and gradation	1
Gradation only	1
Gradation and LA wear	1
Gradation, soil constants and experience	1
Gradation and stability	1
Gradation, dust ratio, LA wear, soil constants and Wyoming stability	1
Gradation, LA wear and soundness	1
Triaxial compression	1
Florida bearing, Montana cone, compressive strength, density and volume of swell	1
Total	39

Table 9 (b)

Number of states using the various means of evaluating wearing course quality.

Method	Number of states
Marshall stability	13
Gradation	12
Hubbard-Field stability	10
Hveem stabilometer	8
Experience and judgment	7
LA wear and abrasion	6
Soil constants	3
Triaxial compression	2
Traffic	2
Swell of materials	2
Availability of materials	2
Miscellaneous	13

in six states. Three states used the cohesiometer and Hveem stabilometer data. Two states each use the following: traffic volume and wheel load, Hveem stabilometer test, Hveem stabilometer and Marshall tests and the triaxial-compression test. A number of miscellaneous methods are used by other states.

Table 6(b) further summarizes the methods employed for determining the thickness of the wearing course. It shows that experience and traffic are the most common basic considerations since they are employed by 23 and 15 states, respecitvely. Less extensively used are the Hveem stabilometer test by seven states; the Marshall test by four states; the cohesiometer test by three states; the triaxial compression test by two states; and quality of materials tests by two states.

It was noted that three states reported that the over-all thickness of pavement, i. e., wearing course, base course and subbase course, was determined by certain characteristics or tests of the subgrade and that the thicknesses of various pavement components were determined by other means, such as experience, traffic volume, and quality of materials.

As shown in Table 7(a), 44 states use some method of determining the thickness of the base course. Ten use judgment and experience; four the Hveem stabilometer test; four, the CBR test; and two states used each of the following: the triaxial-compression test, traffic volume, traffic volume and experience, traffic volume and wheel load, and traffic volume and its character. There were a total of 16 other

Table 10 (a)

Methods of evaluating base course quality.

Method	Number of states
Gradation, soil constants and abrasion	6
Experience and judgment	4
Gradation and soil constants	3
Hveem stabilometer	2
Traffic and experience	2
Gradation and LA wear	2
AASHO specifications	2
Triaxial compression	2
Gradation, soil constants and experience	1
Gradation, soil constants, density and volume change	1
Gradation and percent crushed	1
Gradation only	1
Gradation, dust ratio, abrasion, soil constants and Wyoming stability	1
CBR, gradation and soil constants	1
CBR only	1
CBR modified, gradation, and soil constants	1
CBR and Hveem stabilometer	1
CBR modified and specifications	1
Hveem stabilometer, gradation, soil constants and sand equivalent	1
LA wear and soundness	1
Extrusion, LA wear and soil constants	1
Stability and quality of materials	1
Stability and specifications	1
Total	38

Table 11 (a)

Methods of evaluating subbase course quality.

Method	Number of states
Gradation and soil constants	6
Gradation, CBR or CBR modified and soil constants	3
PRA-1942 soil classification	2
CBR or CBR modified	2
Gradation, soil constants and experience	2
Hveem stabilometer	2
Triaxial compression	2
CBR and soil constants	1
CBR, judgment and expreience	1
Gradation, soil constants and LA wear	1
CBR modified, gradation, soil constants and cementing value	1
Gradation and wear	1
Gradation only	1
Hveem stabilometer, gradation and sand equivalent	1
Gradation, density and volume change	1
GI and maximum density	1
GI, CBR and piping ratio with respect to subgrade	1
LA wear	1
Visual examination, gradation and drainability	1
Gradation and soundness	1
Soil constants	1
Pit run gravel - ND specifications	1
Experience	1
Clean gravel, gradation and soil constants	1
Permeability	1
Total	37

Table 10 (b)

Number of states using the various means of evaluating base course quality.

Method	Number of states
Gradation	19
Soil constants	16
Abrasion	11
Experience and judgment	7
CBR or CBR modified	5
Hveem stabilometer	4
Unnamed stability	3
Hubbard-Field (for bituminous types)	2
Triaxial compression	2
Miscellaneous	11

Table 11 (b)

Number of states using the various means of evaluating subbase course quality.

Method	Number of states
Gradation	20
Soil constants	16
CBR or CBR modified	9
Judgment and experience	4
Abrasion	3
Granular materials specified	3
Group Index	2
Triaxial compression	2
Drainability	2
Miscellaneous	6

procedures, each of which was employed by a single state.

The various means of designing thickness of the base course are further summarized in Table 7(b). As in the case of the wearing course, experience and traffic in 15 states and 14 states, respectively, were the factors most commonly considered. The CBR test or some modification of it was used by nine states; the Hveem stabilometer by four; wheel load by three and the triaxial-compression test, group index of subgrade, quality of materials and climate by two states each. In addition, there were 13 other methods, miscellaneous in nature, reported to be in use.

Procedures for designing subbase thickness are reported to be in use by 44 states. Included were 28 different procedures or methods, as listed in Table 8(a). Ten states, based the determination of subbase thickness on experience and judgment. Three used the Hveem stabilometer and CBR test or CBR modification of the CBR. Two states used the triaxial-compression test. Two states base their methods on experience and type of subgrade. The remaining 23 states use various procedures embodying some of the above mentioned tests and combinations thereof. Table 8(b) shows the number of states that make use of each method. The experience-and-judgment method is used by 18 states; the CBR test or some modification of it, by 10 states; while frost penetration is the controlling factor in four states. The group index of the subgrade, Hveem stabilometer, traffic volume and soil constants are each used by three states. Two states each consider and use the type or quality of the subgrade, the triaxial-compression-test values, the HRB soil-classification system, climate and quality of materials. Nine other miscellaneous methods are employed by single states.

EVALUATION OF QUALITY OF PAVEMENT COMPONENTS

Data concerning methods of evaluation of the qualities of wearing, base, and subbase courses are summarized in Tables 9, 10, and 11. Replies to the question concerning quality of wearing course indicated that 39 states approach this problem in 25 different ways. Methods used by more than one state are as follows: the Marshall stability test or the Marshall and Hubbard-Field tests jointly, by 4 states; the Hveem stabilometer test, the Hubbard-Field test and the experience-judgment-method each by three states; and the Marshall test in conjunction with the studies of gradation and availability of the materials, traffic and experience, each by two states. Eighteen other states reported a variety of different methods.

In Table 9(b) the various means of evaluating wearing course quality are summarized and arranged to indicate the number of states making use of each. The Marshall stability test, gradation, and the Hubbard-Field test are used by 13, 12, and 10 states respectively. The Hveem stabilometer, experience and judgment, and abrasion tests (the Los Angeles wear test and other) were used by eight, seven, and six states, respectively. The soil constants are employed by three states, while the triaxial-compression test, traffic, swell of materials and availability of materials are the bases used by two states

Table 12

Approximate period of usage of current design procedure

States	Number of states	Time period Years
Maine, New Hampshire and South Dakota	3	20
Michigan	1	16
Arizona, Louisiana, Nevada and Tennessee	4	15
Alabama and Mississippi	2	14
Idaho	1	12
Connecticut, Delaware, Florida, Oregon, Pennsylvania and Wisconsin	6	10
Arkansas, Kansas and North Dakota	3	8
Maryland, Missouri, New Jersey, New Mexico and North Carolina	5	7
Kentucky, Minnesota, Nebraska and Ohio	4	6
Colorado, Georgia, Illinois, New York, Oklahoma, Texas and Wyoming	7	5
California and Virginia	2	4
Utah and West Virginia	2	3
Washington	1	1

Table 13

Number of states imposing load restrictions during the spring months.

Geographical location	Primary system		Secondary system	
	States restricting	Total states	States restricting	Total states
New England	1	6	3	6
Middle Atlantic	4	7	6	7
South	0	8	0	8
North Central	6	10	7	10
Central	1	5	1	5
Northwest	2	5	3	5
West and Southwest	1	7	1	7
Totals	15	48	21	48

each. In addition, there are 13 other approaches followed by single states.

As shown in Table 10(a), 38 states reported methods of evaluating base course quality. There are about 23 different approaches involved. Gradation, the soil constants and abrasion are considered by six states, experience and judgment by four, and gradation and the soil constants by three. A number of methods, including the Hveem stabilometer test, traffic and experience, gradation and Los Angeles wear, AASHO specifications and the triaxial compression test are each utilized by two states. The remainder of the states use a variety of approaches.

A summary of the methods used to evaluate the quality of the base course is given in Table 10(b). Nineteen states consider gradation, 16 the soil constants and 11 abrasion tests. Experience and judgment, the CBR test or its modification, Hveem stabilometer test and other stabilometer tests are used by seven, five, four, and three states, respectively. The Hubbard-Field test is mentioned by two states as being utilized for bituminous bases and the triaxial-compression test is also used by two states. There are 11 miscellaneous methods used by one state each.

There are 25 different procedures for evaluation of the subbase quality listed in Table 11(a). These procedures were reported by 37 states. Gradation and the soil constants are used together by six states, while three states consider these two items plus the CBR test or a modification thereof. The following items or tests are each considered by two states: the PRA-1942 soil classification system, the CBR test by itself, gradation combined with the soil constants and experience, the Hveem stabilometer test, and the triaxial-compression test. The other 18 methods shown in this table are each used by only one state.

The summary in Table 11(b) shows that gradation of the subbase material is widely accepted as a factor in design. It is utilized by 20 states. The soil constants are used in 16 states, the CBR or CBR modified in nine states, followed by judgment and experience in four, abrasion tests in three. The group index, triaxial-compression test, and drainability of the material, are used in two states each. Three states indicated that granular materials are specified, while some six states use various other means or methods of evaluating the subbase.

MISCELLANEOUS INFORMATION

In making the survey, the states were requested to furnish information regarding two incidental items. The first was the periods of use in their current design methods. The second concerned the enforcement of load restrictions during the spring months for both primary and secondary highways. The data submitted are summarized in Tables 12 and 13.

As shown in Table 12, the period of use of the current methods of thickness design of the states ranges from 1 to 20 yr. The State of Washington, in the spring of 1951, modified its method to substitute the stabilometer for the CBR test in evaluating the subgrade soil. Thus the period of use of their current method is listed as 1 yr. (to March 1952). In contrast, Maine, New Hampshire, and South Dakota have employed their current methods for a period of 20 yr. Some 30 states have revised their methods or adopted new methods since the start of World War II, 12 of them within the last 5 yr.

A summary concerning load restrictions in the spring is contained in Table 13. The states have been grouped according to geographical location. All the states that qualified their affirmative responses in any manner are included in the category of imposing load restrictions. A total of 15 states reported the use of restrictions under certain conditions on primary roads; and 21 on secondary roads. Seasonal restrictions are most common in the north-central states where six of ten states lower the load limits on the primary system, and seven of ten on the secondary system. None of the southern states follow this practice. Considering the northwestern, mid-Atlantic and north-central groups of states, a total of 12 and 16 of the 22 states impose load restrictions on their primary and secondary roads respectively. Comparatively few states in the other designated sections impose any seasonal restrictions on loads.

SUMMARY

The information in this report was obtained by correspondence with the state highway departments. Since so many factors and circumstances have entered into the design and construction of flexible pavements, it is not a simple matter to obtain information exactly of the character desired. Undoubtedly many states found it difficult to give specific answers to certain questions. Other states experienced trouble in interpreting some of the questions. The fact that some states were in the process of revising their methods of design or trying to establish new methods made it difficult for them to supply the information requested.

For these reasons the information as tabulated may not represent adequately or completely how some states are handling the over-all problem of design or some particular phase of it. In this connection, it should be emphasized that the data reported are intended to give principally a generalized picture of the essential features of the methods in use. If more detailed information is desired, it should be obtained by corresponding directly with the state highway departments concerned.

The committee feels that the results of this survey are of particular value in indicating the great variety of approaches being used by the highway departments in the design of flexible pavements. The work serves to emphasize the need for studying the service behavior of pavements that have been designed and built in accordance with the given methods and also emphasizes the need for a further comparing of methods by developing designs of pavement for the same attendant conditions. Studies of this nature should eventually result in a certain measure of standardization of our design methods. The desirability of this can hardly be questioned.

It is the plan of the committee to continue the work of compilation of factual data on this problem and to make another survey within a period of about 5 yr.

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