PRESENT DESIGN PRACTICE AND CONSTRUCTION DEVELOPMENTS IN FLEXIBLE PAVEMENTS

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SYNOPSIS

The term "flexible pavements" might properly include quite a variety of surfacing materials, but for purposes of this paper they are considered as those bituminous types of surfaces which are mudless and dustless at all seasons of of the year.

As a result of questionnaire study to the various State highway departments, some interesting conclusions have been reached.

The importance of the design of subgrade is becoming generally recognized and that the correct method of determination of thickness of pavement should be predicated upon bringing subgrade values up rather than attempting to build massive bases down.

The development of types of surfaces has gone through a certain cycle and is rather intimately related to the development of equipment.

The influence of traffic under load distribution has greatly modified the design of pavements and has made possible the effective carrying of traffic under volumes which would have been destructive if the balloon tire had not been invented and become universally available on all motor driven equipment.

The selection of type of surface also should take into account all aggregate available locally. Cognizance should be taken of the fact that stone and gravel vary in size according to geological formations, and surfaces should be designed so as to use most economically the complete plant output. An illustration of this better use of plant output, and at the same time vastly improving the road structure, is the growing use of stone screenings of approximately 1½ inches thickness as an insulation layer between the natural subgrade and the pavement proper.

Methods for accurately evaluating subgrade values are still needed. Several States have methods of making such tests which apparently give good results. One interesting development is the attempt of one State to design the thickness of base courses in accordance with the soil characteristics, such as plastic limit, liquid limit, etc.

An encouraging note from this review of practice is the intensive attention which is being given to the design of the subgrade, which after all must carry the load, and which until recent years has been almost entirely overlooked as an element in pavement design.

There have been several papers presented in recent years on the design of flexible pavements and reference is made to some of them in the references appended to the end of this discussion. These studies have taken up various aspects of the problem ranging from the design of paving mixtures themselves to formulae for stress distribution. While untreated gravel and stone layers are often thought of as flexible type pavements, the modern conception includes only types which are mudless and dustless at all seasons of the year. Hence, this discussion will apply solely to the bituminous types of surfaces, with untreated gravel and stone considered only as foundation courses.

The matter of stress distribution will not be touched upon in this paper; (1) because a great deal of what might be said has already been covered in previous papers, notably the one by Mr. Benkelman before the 17th Annual Meeting of the Highway Research Board in 1937, and (2) because there are other studies currently being carried on, one by Mr. Goldbeck and another by Prof. Spangler. The Asphalt Institute contemplates a research beginning this coming year on still another phase of this study.

The design of flexible pavements, however, has been much influenced by a number of collateral factors which but recently have been taken into account, and a brief discussion of some of them may be of interest. The so-called flexible types of pavement form today the larger portion of the highway system of the country. According to April, 1939 issue of *American Highways,* such surfaces number 176,818 miles out of a total of 274,830 miles of all weather surfaces on the state systems, or 64 percent.

In order to ascertain the trends of present construction practice, a questionnaire was addressed to the state highway departments. The replies are shown in Tables 1 to 6 in such detail as space will permit. The comments accompanying the replies indicate that a very definite technique of foundation design is developing. The older practice of making heavier pavements to care for bad soil conditions is giving way to the cheaper and better practice of building subgrades having high bearing power. This is the outstanding development of recent years and while it is required for all types of pavements, the benefits show up markedly in the flexible type because thickness may be reduced in almost direct proportion to subgrade improvement.

SUBGRADE DESIGN

Of the several methods, the first is densification of the natural soils themselves. The effect of such procedure is often the equivalent of several inches of pavement. Many states now call for subgrades to be consolidated to 90 percent or 95 percent density as measured by the Proctor test. The paper by Ira B. Mullis, entitled "Principles Applying to Highway Road Beds," appearing in the September, 1938 *Proceedings,* American Society of Civil Engineers, is worthy of careful study. As a result of wide study of surface failures, Mr. Mullis states that "no case (failure) is recalled in which the bulk density of the *roadbed* was in excess of 1.50."

$$\text{Bulk density} = \frac{\text{dry weight in grams}}{\text{bulk volume in cu. cms.}}$$

In other words by building subgrades to densities maintainable the year around above this figure no pavement troubles occur.

One state, Florida, definitely calls for a subgrade of 30 lb. minimum bearing power. Several states require that soils of the A-4 to A-7 class be covered with some pervious material or be in some way modified. Arizona suggests a new method of determining base thickness according to soil characteristics. This is shown in Table 7.

The state authorities frankly say that Table 7 is to be taken as a guide only, awaiting longer experience.

Minnesota has a real frost problem, and in Table 8 is shown their design procedure.

For many years the writer has called attention to the wasteful practice of unclassified excavation, whereby the weathered top soils are so frequently thrown away and the unstable subsoils are left as the subgrade on which a pavement is to be placed. Most of the ills which have surrounded pavement construction of all types have been due to subsequent subgrade movement which could be largely prevented by selecting material from weathered soils. Inasmuch as these soils are relatively cheap, a layer of 12 in. or more in depth can be placed for a fraction of the cost of a pavement and yet the effect is equivalent to a substantial thickness in pavement. Selected subgrades having high stability, of course, lead to thinner surface sections and resultant economy and freedom from maintenance.

An interesting report is noted from Texas where tests are made to detect suitable deposits of materials for subgrade construction. This describes "the

State	Thickness of surface	Type of base	Thickness of base	Subgrade treatment	Remarks
	In.		*In.*		
Alabama	2	Clay gravel, top soil, sand clay—chert.	6	None—which was a mistake	Not used at present—but a good type.
Arizona	2 to 3	Rock—gravel	0 to 15	According to soil properties	See Table 6.
Arkansas	1 (average)	Sand clay gravel, crushed stone, W. B. macadam.	6 to 10	Satisfactory soil layer	Additional base when needed.
California					
Colorado					
Connecticut					
Delaware	2	Trafficbound slag, gravel or stabilized soil.	8		
District of Columbia					
Florida	1½	Sand clay or Florida limerock	6 to 8	30 lb. bearing value soil	Used as retread.
Georgia	2	Top soil, sand clay pebble soil	8 in. stabilized	Where needed	Not much used.
Idaho					Not used.
Illinois	2½	Gravel or crushed stone	6		
Indiana	2½ to 3½	W. B. macadam stabilized base or old pavements.	6 to 8	Drainage with 6 in. open joint tile.	Base receives bit. prime coat, and aggregate back fill where needed.
Iowa					
Kansas					None constructed recently.
Kentucky	2	Stone base or stabilized base	4 to 8	Type base varies with subgrade	Base course 2 ft. wider than surface.
Louisiana					
Maine					
Maryland	2	Macadam or old pavements	8 for new macadam	2 screenings stabilized	Base sealed with bit prime coat.
Massachusetts	2	Gravel	6 to 12		
Michigan	2	Macadam or gravel	6 to 8	Bad soil removed—sand sub-base.	Mostly county projects.
Minnesota	2				Only one job laid this type.
Mississippi					None.
Missouri					
Montana					
Nebraska					
Nevada					
New Hampshire	3	Selected gravel	6 to 9	Stabilized with gravel.	
New Jersey	1½ to 2	Macadam or gravel	4 to 6	None.	
New Mexico	1½ to 2	Crushed or pit run rock, gravel, caliche	6 to 8	Material manipulated, watered, rolled to secure full compaction.	
New York	2½	Bituminous treated stone	Usually old macadam widened		
North Carolina					Do not use.
North Dakota					
Ohio	2½	Old macadam	6 to 9		Sometimes 3 to 5 traffic bound base.
Oklahoma					
Oregon					
Pennsylvania	2	Napped stone or commercial stone	6 to 8	Unsuitable subgrade material removed—base thickness increased.	
Rhode Island	2½	Water bound macadam	5½	Careful drainage, extra foundation where needed.	
South Carolina					
South Dakota	2	Crushed gravel or rock, (stabilized)	4 or more	Rolling	Base sealed with road oil.
Tennessee					
Texas					
Utah					Not used.
Vermont	2½	Gravel	12 to 24	Bituminous prime coat.	Mixed surface treatment.
Virginia	1¼	Traffic bound macadam or crushed or screened gravel.	6-8 or 10-9-10	As needed	
Washington					Do not construct.
West Virginia	1 to 1½	Stone or slag	8 in two courses	Extra base and stone drains; sometimes creek gravel for base.	
Wisconsin					
Wyoming	1½ to 2	Crushed rock or gravel	Varies with soil condition	95 percent maximum density compaction.	

TABLE 2
Thickness of Base and Surface for Road-Mix (Dense Graded Type)

State	Thickness of surface	Type of base	Thickness of base	Subgrade treatment	Remarks
	In.		*In.*		
Alabama	2	Clay gravel, top soil, sand clay, chert	6	None, which was mistake.	Base too thin—type not used today.
Arizona	2 to 3	Rock—gravel	0 to 15	According to soil properties	See Table 7.
Arkansas	2¼ (average)	Sand, clay, gravel—crushed stone—W. B. macadam.	6 to 10	Satisfactory soil layer—or additional base.	
California	3	Crusher run stone or gravel or imported material.	6 (average)		
Colorado	1½	Gravel or crushed rock	6 or more	If necessary.	
Connecticut					
Delaware					
District of Columbia					
Florida	6	Natural soil	None	Subgrade of 30 lb. value or more.	Sand mixtures.
Georgia	2	Top soil, sand clay, pebble soil	8 (stabilized)	Where needed	Not much used.
Idaho	2½	Crushed gravel or rock	6 to 12		
Illinois	2½	Gravel or crushed stone	6		Base receives bituminous prime coat.
Indiana	3	Crushed stone or gravel	3	Careful drainage, use of 6 in. open tile drains aggregate back fill.	
Iowa					
Kansas	2¾ (average)	Stabilized soil, soil aggregate mix, pit run aggregate.	4 to 12	Fills carefully placed to 90 percent Proctor.	Selected borrow 12 in.-18 in. depth.
Kentucky					
Louisiana					
Maine	1½	Gravel	12 to 30		
Maryland	4 to 6	Natural soil	None		Sand mixtures.
Massachusetts					
Michigan	2½	Gravel	6 to 8	Bad soils removed, sandy soils replaced, mostly county projects.	
Minnesota					Not laid—see Table 6.
Mississippi	6	Selected sand clay	12 to 15	None.	Carefully controlled gradation.
Missouri	1½	Clay bound aggregates	4	4 in. depth bituminous stabilization.	
Montana	1½ to 2½	Crushed aggregates, 100 percent pass 2½, 25-50 percent pass ¼ in.	8 to 24 loose	Not over 12 percent 200 mesh in base course.	
Nebraska	1¼ to 3 (1⅝ average)	Natural subgrade		Over A-2 to A-5 soils only.	Also a 5 in. sand mix in sandy soils.
Nevada	2½	Graded gravel, crushed or uncrushed	4 to 8	Base increased on poor soils.	Complete soil analysis made.
New Hampshire		No surfaces originally built this	type, but many miles surface	treatments with sand cover are	
		now 2 to 3 in. thick.			
New Jersey					None.
New Mexico	2 to 2½	¾ by 2 in. aggregate	8 (two courses)	Material manipulated, watered, rolled to secure compaction.	
New York					
North Carolina	¾ to 2				Used to resurface old roads only.
North Dakota	1½	Stabilized gravel	4 to 6	Compaction with sheepsfoot roller.	
Ohio	2	Old macadam	6 to 9		Sometimes 3 to 5 in. traffic bound macadam.
Oklahoma	1½	Gravel or crushed stone	6 or more		
Oregon	2½	Pit run or screened gravel	6 to 12	None	Base thickness determined by conditions.

TABLE 2—Continued

State	Thickness of surface	Type of base	Thickness of base	Subgrade treatment	Remarks
	In.		*In.*		
Pennsylvania	2	Napped stone or commercial stone	6 to 8	Unstable soils removed, or stabilized—increased base thickness.	
Rhode Island	2	Gravel	6	Drainage and extra foundation where necessary.	
South Carolina	2	Crushed rock or gravel (stabilized)	4 or more	Base courses receive bituminous prime and used a year before surfacing.	
South Dakota	...	...	...	...	...
Tennessee	...	...	...	...	...
Texas	1½ or more	Gravel, caliche, stabilized soil	6 or more	Stabilized where needed with selected soils or oil.	
Utah	1½ to 2½	Gravel	12 min.	Materials consolidated as per AASHO. 1½ in. surface on secondary roads.	
Vermont	2½	Gravel	12 to 24	Bituminous prime coat.	
Virginia	1¼	Water bound macadam	10-9-10	Where needed, 6 to 10 in. selected material.	
Washington	2	Crushed rock or selected sand gravel with rock top.	12 to 20	Place layer fine granular material.	Base thickness according to subgrade.
West Virginia	1½	Stone or slag	8	Extra base, stone drains where needed; sometimes creek gravel bases.	
Wisconsin	2	Gravel	4 to 6	Where required 12 to 24 in. selected material.	
Wyoming	1½ to 2	Gravel or crushed rock	According to soil and moisture	95 percent maximum density compaction.	

TABLE 3

THICKNESS OF BASE AND SURFACE FOR PENETRATION MACADAM

State	Thickness of surface	Type of base	Thickness of base	Subgrade treatment	Remarks
	In.		*In.*		
Alabama					Do not use.
Arizona					
Arkansas					
California	1½ and 2	Crusher run stone, gravel or imported material.	Average 6		
Colorado					
Connecticut	2½	Crushed stone	7	Gravel sub-base where needed.	
Delaware					
District of Columbia					
Florida					None constructed recent years.
Georgia	3	Top soil sand clay, pebble soil	8 (stabilized)		Little used today.
Idaho					Not used.
Illinois	6	Earth subgrade	None	Receives bituminous prime coat.	
Indiana					See Table 5.
Iowa					
Kansas					None constructed recently.
Kentucky					
Louisiana					
Maine	3	Crushed stone.	7, 5, 7	12 to 24 in. gravelly sub-base.	
Maryland	3	Crushed stone, filled with clean screenings.	5	2 in. screenings stabilized	Special care in filling base voids.
Massachusetts	2½	Crushed stone, sand filled	3½ to 4½	6 to 12 in. gravel.	
Michigan					None built.
Minnesota					Not laid.
Mississippi					None.
Missouri	1 and 2½	Water bound macadam	7½ and 8	1½ in. limestone screenings	Shoulders are oiled.
Montana	1 to 1½	Crushed aggregates	8-24 loose	Selected soils	2 lift heavy surface treat.
Nebraska					
Nevada					
New Hampshire	3	Crushed stone.	4	Stabilized with gravel.	
New Jersey	3	Macadam	4	None.	
New Mexico					See Table 6.
New York	3	A pen. macadam base over sand filled macadam.	3 to 4 and 3 to 4 respectively	6 to 12 in. gravelly sub-base.	
North Carolina					Do not use.
North Dakota					
Ohio	3	Water bound macadam or old pavement	7	1¼ in. granular insulation course.	
Oklahoma					
Oregon	¾-1¼-3	Crushed rock or gravel	6 to 18	None.	
Pennsylvania	3	Napped or commercial stone	6 or 8 or 10	Bad subgrade removed or stabilized—base thickness increased.	
Rhode Island	2½	Water bound macadam	5½	Drainage	Extra foundation where needed.
South Carolina					
South Dakota					
Tennessee					
Texas					
Utah					
Vermont	3	Gravel or stone	12 to 24	Broken stone base course on sub-base.	
Virginia					
Washington	2½ to 3	Crushed rock or selected sand gravel with rock top.	12 to 20	Sealing with layer fine granular material.	
West Virginia	3	Stone or slag	8 (2 courses)	Extra base course where needed—also stone under drains.	
Wisconsin					None built.
Wyoming					Not used.

TABLE 4
THICKNESS OF BASE AND SURFACE FOR COLD-LAID BITUMINOUS CONCRETE

State	Thickness of surface	Type of base	Thickness of base	Subgrade treatment	Remarks
	In.		*In*		
Alabama	1½ to 2	Clay gravel, top soil, sand clay, chert.	8	As much as 10 in. topping over A-7 soils.	This is coming resurfacing type.
Arizona	......	......	......	......	......
Arkansas	......	......	......	......	......
California	See Table 6	......	......	......	See Table 6.
Colorado	......	......	......	......	......
Connecticut	2	Stone	variable	Usually employed resurfacing over old pavements.	
Delaware	2	Macadam or portland cement concrete.	8	......	Surface placed in two courses.
District of Columbia	......	......	......	......	......
Florida	1½ or 3	Lime rock or portland cement concrete.	6 or 8	30 lb. bearing value, 3 in. depth laid in two courses.	
Georgia	2 binder, 1½ top	Pebble soil, gravel, stone or p. c. concrete.	6 to 8	Where needed—also 5 and 6 in. sand bituminous mix.	
Idaho	......	......	......	......	See Table 6.
Illinois	2	On old or new portland cement concrete.	6		Prime coat usually omitted.
Indiana	1½ to 2	Water bound macadam or stabilized aggregate.	6	......	Plant mix open graded aggregate type.
Iowa	2	Soil-aggregate or rolled stone	5	All fills placed 6 in. layers top 6 in. sheepsfooted to 95 percent Proctor.	
Kansas	......	......	......	......	County use only, but state plans use.
Kentucky	......	......	......	......	......
Louisiana	......	......	......	......	......
Maine	2	Bituminous concrete	3	12 to 24 in. gravel—also used over 8-6-8 in. P. C. C.	
Maryland	2 (average)	Old road or p. c. concrete	8	1¼ to 1½ in. binder course, ½ in. top plus dressing.	
Massachusetts	2¼	Hot penetration macadam	4	6 to 12 in. gravel.	
Michigan	......	......	......	......	None built.
Minnesota	2	Over old portland cement concrete.	......	......	Very little used.
Mississippi	......	......	......	......	......
Missouri	......	......	......	......	......
Montana	......	......	......	......	......
Nebraska	......	......	......	......	......
Nevada	2½	Graded, crushed or uncrushed gravel.	4-8 coarser grading in deep section.	Thickness base varied. A plant mix similar to dense road-mix.	
New Hampshire	3	Broken stone or crushed screened gravel.	4	Stabilized with gravel	Liquefier type surface.
New Jersey	Type a—1 over 2 pen. macadam. Type b—½ to 1 top over 1½ to 2 binder.	Macadam or p. c. concrete	4 macadam, 6 p. c. concrete	None—1.65 gal. per yd. used in 2 in. pen. course.	
New Mexico	......	......	......	......	......
New York	2	P. c. concrete, penetration, macadam or old pavements.	8 plain, 7 reinforced p. c. concrete; or 8 in. macadam over 6 to 12 in. bank gravel; macadam 2 courses top course 4 in. penetration macadam.		

TABLE 4—Continued

State	Thickness of surface	Type of base	Thickness of base	Subgrade treatment	Remarks
	In.		*In.*		
North Carolina	¾ to 1½	Over old pavements	...	...	Used for resurfacing.
North Dakota	...	...	...	...	...
Ohio	2 to 2½	Old pavements or hot mix bituminous concrete.	7	1¼ in. granular insulation course.	Hot mix used in widening work.
Oklahoma	1½	Gravel macadam, p. c. concrete.	6 or more		
Oregon	...	...	...	...	
Pennsylvania	2 and more	Napped stone or commerical stone.	6 or 8 or 10	Remove or stabilize bad subgrade—increase base.	...
Rhode Island	2	Gravel	6	Extra thickness where needed—good drainage.	
South Carolina	...	...	...	...	...
South Dakota	...	...	...	...	See Table 6.
Tennessee	...	...	...	...	...
Texas	1 or more	Pavements of all types	6 min.	Stabilized where needed with selected soils or oil.	
Utah					
Vermont	...	...	...	...	...
Virginia	1½ binder, ¾ top	Plain p. c. concrete or W. B. macadam.	Concrete 8 W. B. macadam 10-9-10	Where needed using 6 to 10 in. selected material.	None.
Washington	1½ to 2½ min.	Old pavements	Variable	This type used almost entirely over old brick, p. c. c., asphalt.	
West Virginia	1 to 1½	Stone, slag or portland cement concrete.	8	Extra base where needed, stone weeper drains.	
Wisconsin	1	Bituminous base	2 to 4	12 to 24 in. selected material where needed.	
Wyoming	...	...	...	...	Not used.

TABLE 5

THICKNESS OF BASE AND SURFACE FOR HOT-LAID BITUMINOUS CONCRETE

State	Thickness of surface	Type of base	Thickness of base	Subgrade treatment	Remarks
	In.		*In.*		
Alabama	1 to 2 top 3 to 4 binder	Clay gravel, topsoil, sand clay, chert	8	As much as 10 in. over A-7 soils	Selected soil in subgrade.
Arizona					
Arkansas					
California	2	Bituminous concrete	7-5-7 thickened edge.	Selected borrow material	Also used over old pavements.
Colorado					
Connecticut					
Delaware					
District of Columbia					
Florida	1½ or 3	Limerock or portland cement concrete	6 to 8	30 lb. subgrade material.	
Georgia	2 binder 1½ top	Pebble soil, gravel, stone or portland cement concrete.	6 to 8	Where needed	Not much used.
Idaho	2	Alternate design 4 in. bituminous concrete on 4 in. rock or gravel or 8 to 12 in. rock or gravel. A-5 to A-7 soils not permitted; Compaction to AASHO Spec. M-57.			
Illinois	2 (or 3 sheet)	New or old portland cement concrete	6		Prime coat usually omitted.
Indiana	1½	Combination of pen. macadam, W. B. macadam, & coarse stone, in thicknesses 3¼, 4¼, 4; 3, 4, 4; and 3, 3¼, 2½ respectively. In competition with 9-7-9, 9-6-9, 8-5-8 portland cement concrete.			
Iowa					
Kansas	1½ to 2	P. c. concrete	7	Shaped and rolled	City work.
Kentucky	New specifications call for all bituminous concrete pavement in competition with portland cement concrete inch for inch. Two layers coarse mix, top layer dense.				
Louisiana					
Maine	2	Bituminous concrete	3	12 to 24 in. gravel	Also used over 8-6-8 in. portland cement concrete.
Maryland	2 to 3	Primed, macadam, old pavements or p. c. concrete.	6 to 8		Surface laid in 2 courses.
Massachusetts	2¼	Hot penetration macadam	4	6 to 12 in. gravel.	
Michigan	3½-2½-3½	Gravel	6 to 8	Sand sub-base over bad soils	Base built year before surfacing.
Minnesota	2 to 2½	Portland cement concrete			City construction only.
Mississippi	1½	Bituminous concrete (black base)	2½	Selected sand clay 6 to 12 in. Uses high pen. AC as stability permits.	
Missouri	1¾ or more	Over old portland cement concrete	6		Used largely for resurfacing.
Montana					
Nebraska					
Nevada					
New Hampshire					No new construction.
New Jersey	2 to 3	Gravel or portland cement concrete	6	3 in. laid in two courses 1½ in. binder, 1½ in. top.	
New Mexico					
New York	2 (topeka)	P. c. concrete, pen. macadam, or old pavements.	8 plain, 7 reinforced portland cement concrete; or 8 in. macadam over 6 to 12 in. bank run gravel, macadam laid 2 courses top being 4 in. pen. macadam.		
North Carolina	¾ to 1½				Used for resurfacing, See Table 6.
North Dakota					
Ohio	2 to 2½	Old pavements or new hot mix bituminous concrete.	7	1¼ in. granular insulation course.	
Oklahoma					
Oregon	5	Crushed gravel or rock (See Table 6)	8 to 12	None—Surface 1 in. coarse texture on 4 in. dense binder.	

TABLE 5—Continued

State	Thickness of surface	Type of base	Thickness of base	Subgrade treatment	Remarks
	In.		*In.*		
Pennsylvania	2 and more	Stone and portland cement concrete	6 or 8 or 10	Remove or stabilize, bad subgrade—increase base thickness.	
Rhode Island	3	Portland cement concrete	7	Extra foundation where needed, good drainage.	
South Carolina	1½	Sand clay, top soil, stabilized soil	5 to 8	Base increased over bad soil—heavy s. t. types and thin road mix.	
South Dakota	......	......	......	......	......
Tennessee	......	......	......	......	......
Texas	2 or more	Both flexible and rigid types	6 or more	Stabilized where needed with selected soils or oil.	
Utah	2	P. c. concrete or asphaltic concrete	6 in. p.c. concrete; or 4 in. black base on 6 in. gravel. Blended and consolidated per AASHO spec. Max. dens.		
Vermont	......	......	......	......	None.
Virginia	1½ binder 1 top	Plain p. c. concrete	8 or 10	Where needed	Sheet asphalt type.
Washington	1½ to 5	Old pavements, new bases, or selected material.	Variable	If new pavement—sealing course of granular material.	
West Virginia	......	......	......	......	......
Wisconsin	3	Portland cement concrete	6 to 8		
Wyoming	......	......	......	......	Not used.

TABLE 6
Thickness of Base and Surface for Miscellaneous Types (Specially Used by States)

State	Thickness of surface	Type of base	Thickness of base	Subgrade treatment	Remarks
	In.		*In.*		
Alabama	⅝ to ⅞	Clay gravel, top soil, sand clay, chert	8	As much as 10 in. over A-7 soils—combination s. t. and 50 lb. plant mix top.	
Arizona					
Arkansas	50 lb. to 60 lb. stone	Stabilized soil various types	6		Heavy surface treatment.
California	2½ to 3	Crusher run rock or gravel base	3½ to 6	Where needed. A variety of cold laid plant mix.	
Colorado					
Connecticut					Heavy surface treatment.
Delaware	1	Traffic bound slag, gravel or stabilized soil.	8		
District of Columbia					
Florida	¾	Sand clay, lime rock, soil cement	6 to 8	30 lb. bearing value material. Heavy surface treatment.	
Georgia	1½	Top soil, sand clay, clay gravel, or stone.	6 to 10	Where needed. Combination s. t. and 50 lb. plant mix top.	
Idaho	2½	Crushed gravel or rock			Plant mix dense graded aggregate.
Illinois					
Indiana	¾	Penetration macadam, water bound macadam.	8½ to 11½	Drainage with open joint tile—rock asphalt seal courses.	
Iowa	½ to ¾	Soil aggregate or rolled stone	5	All fills in 6 in. layers, sheepfooted top 6 in. layer, heavy s. t. type.	
Kansas	less than one inch	Stabilized soil	4 to 10	Fills compacted, selected soils where needed—surface treatment type.	
Kentucky				None.	Heavy surface treatment.
Louisiana	1	Gravel	6		S. t. and premix gravel types.
Maine	2	Gravel	12 to 30		
Maryland					
Massachusetts					
Michigan					
Minnesota	¾ to 1¾	Stabilized gravel	See Table 8	See Table 8	Grading gravel ¾ in.—200 mesh.
Mississippi	2	Sand asphalt base	3	Selected sand clay soil	This is a sand mixture.
Missouri	Armor coat	Clay bound aggregates, W. B. macadam, bituminous soil Stab.	5 to 6	0 to 4 in. stabilization. Used as base for later surfacing.	
Montana					
Nebraska	2 to 3	Stabilized soil	2 to 5 (3 average)	Also experimenting with 4-5 in.; stabilized soil as a surface.	
Nevada					
New Hampshire					
New Jersey					Rock asphalt type.
New Mexico	¾ to 1	Old portland cement concrete or other pavement.	6 to 10		
New York					
North Carolina	1 to 5	Sand asphalt, both hot and cold laid. Hot one course 3 to 5 in.	laid in 2 courses	3 to 3½-in. binder, 1 to 1½-in. top; cold laid	
North Dakota	½ to ¾	Stabilized gravel	4 to 6	Standard compaction sheepsfoot roller.	
Ohio	2 to 3	Old pavements or pre-mix base course.	6 to 9	Bituminous mixtures of less accurate controlled proportioning.	
Oklahoma	1	Gravel macadam	6 or more	4 in. crushed rock sub-base—asph. conc. type.	Double surface treatment.
Oregon	2	P. c. concrete	6		Sheet asphalt surface.
Pennsylvania	2½ to 3	Portland cement concrete	8 or 9		

TABLE 6—Continued

State	Thickness of surface	Type of base	Thickness of base	Subgrade treatment	Remarks
	In.		*In.*		
Rhode Island	2 to 3	W. B. macadam or p. c. concrete	6 to 7	Extra foundation where needed	Variations of plant mix types.
South Carolina					
South Dakota	2	Crushed rock or gravel	4 or more	Rolled to optimum	Cold laid plant mix type.
Tennessee					
Texas					
Utah	2½	Gravel	12 to 24	Materials blended, consolidated AASHO spec for density & moisture content.	
Vermont					
Virginia	¾ approximate	Soil—gravel—sand clay	6 in. sand clay, 14-9-14 others	As needed	S. t. also see Table 1.
Washington	¾	Crushed rock or selected sand gravel with rock top.	12 to 20	Sealing course with granular material—s. t. used a year prior to s. course.	
West Virginia	¾ and ¾	Stone or slag	8 (2 courses)	Extra base where needed—¾ in. leveling course followed later by top.	
Wisconsin					
Wyoming	½				Light surface treatments.

electrical resistivity instrument," and the procedure is a type of geophysical study. The equipment can be set up and readings taken at one foot intervals down to 10 ft. in about 20 min. According to the report the procedure is very successful and permits discovery of deposits which are not available by surface examination and which are difficult and expensive to find by the usual test pit method.

One state in referring to failures of road-mix surfaces some years ago notes that the combination of 6-in. base and no subgrade treatment led to uncertain results, while by improving subgrades according to soil studies and increasing base thickness to 8 in. the greatly increased traffic of present day is carried without failures. The question of improving subgrades by adding granular material has often deterred engineers because of fancied expense. In most parts of the country such material is on the contrary not expensive, and Table 9 is inserted to show just what the various depths do cost.

Numerous studies have indicated that for 10 or 15 cents per sq. yd., the subgrade resistance often can be brought up from 10 lb. under adverse conditions of moisture, to 50 lb. after treatment.

Several states mention the use of an insulation course over the subgrade prior to surfacing. The writer first noticed this procedure some years ago in Ohio. It involves placing from 1 to 2 in. of screenings over the subgrade prior to placing pavement. The value of this layer is not as widely appreciated as should be the case. In the construction of macadam and gravel bases, it is a well known fact that in certain soils a loss of metal is encountered due to the intrusion of the soil into the aggregate layer. Furthermore, obtaining suitable density in the base course is retarded because there is not sufficient resistance in the subgrade against which to roll. By placing this insulation course, a solid subgrade is

TABLE 7 (ARIZONA)

BASE COURSE THICKNESS REQUIRED FOR VARIOUS SUBGRADES AND PROPERTIES OF BASE COURSE MATERIALS

	−40 mesh lineal shrinkage	Centrifuge moisture equivalent	Plasticity index	Material retained on No. 3 sieve	Material passing No. 200 sieve	Thickness base course required
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*In.*
Subgrade	−3	−18	−6	10+	−20	0 to 6
Subgrade	−5	....	−12	10+	−30	6 to 9
Subgrade	−7	....	−15	....	−40	9 to 12
Subgrade	−9	....	−20	....	−45	12 to 15
Subgrade	9+	....	20+	....	45+	15+[2]
Subgrade						100% Passing
Aggregate Base Course	−4	−18	−6	[1]	−20	1 in. Sieve
Select Material	−4	−18	−6	[1]	−20	......
Imported Borrow	−4	−18	−10	....	....	......

[1] Amount of material retained on No. 3 varies according to the amount available. Desirable to hold between 25 percent and 50 percent if economically feasible.

[2] Subgrades of this type should not be used in fills in new construction.

N. B. This table taken from paper by W. G. O'Harra, Chemist, Arizona Highway Department, presented at 1939 Arizona Roads and Streets Conference.

TABLE 8 (MINNESOTA)

MINNESOTA STABILIZED GRAVEL BASE DESIGN PRACTICE TO BE SURFACED WITH THREE QUARTER INCH BITUMINOUS MAT AT THE TIME OF CONSTRUCTION WITH THE ADDITION OF A WEARING SURFACE OF ONE INCH OR MORE IN THICKNESS AFTER THE STABILIZED GRAVEL BASE HAS BEEN UNDER TRAFFIC FOR ONE YEAR OR MORE.

Subgrade soil	Stabilized gravel base average thickness	Subgrade treatment
	In.	
Sand and Loamy Sand	2	Stabilize with binder-soil where loose.
Glacial till Sandy loam & better clay loams	4	Old roads:—correct frost boils and heaves by excavation and back-fill with sand or gravel or other selected local soil.
Heavier clay loams and light clays	6 (Have built some 9 to 12)	New grading projects:—provided upper 1 to 2 ft. of roadbed be of selected soil, best available locally on the job.
Loessial silt	6 to 9	New grading projects:—provided upper 1 to 2 ft. of roadbed be of selected soil, best available locally on the job.
Lacustrine clay (highly plastic—gumbo type)	6 to 12	Generally little treatment of sub-grade except to eliminate poor top-soils in forested regions.

established much as would be the case of putting down a layer of plank, so that when the next layer of aggregate or paving mixture is applied there is little or no deformation and rolling quickly produces a dense consolidated course. It is the writer's firm belief, based on observation of this procedure, that 1½ in. of screenings on a clay soil is equivalent to 3 in. of crushed stone without the use of screenings, and the inclusion of an insulation course as a requirement in the construction of new stone and gravel foundations is urged as desirable and economical construction where screenings are cheaply available.

TABLE 9

Depth of granular material added over subgrade	Cost per square yard when selected granular material ranges in cost from $0 25 to $2.00 per cubic yard				
	$0.25 cu. yd.	$0.50 cu. yd.	$1.00 cu. yd.	$1.50 cu. yd.	$2.00 cu. yd.
In.					
2	$0.02	$0.03	$0.06	$0.08	$0.11
3	.02	.04	.08	.13	.17
4	.03	.06	.11	.17	.22
5	.03	.07	.14	.21	.28
6	.04	.08	.17	.25	.33
12	.08	.17	.33	.50	.67
18	.13	.25	.50	.75	1.00

INFLUENCE OF TRAFFIC ON DESIGN

The effect of changing traffic has not yet fully been taken into account by designers. Ten years ago flexible type surfaces, particularly those of rather thin character, which had been constructed by traffic-bound methods on rural highways, were showing signs of extensive failure. Surface treatments and even penetration macadam surfaces were showing increasing costs of maintenance. This maintenance took two principal forms,—one, the repair of pot-holes where the surface was breaking down, and the other edge failure and settlement. Practically all passenger vehicles at that time were equipped with cord tires, while the majority of trucks had either solid tires or else cord tires which approached them in behavior. Impact was a decided factor because when a vehicle so equipped dropped into a depression there was little give to the tire.

This condition has completely changed and it is safe to say that the impact effect under modern tires is practically negligible. The reason is that even though a vehicle passes over a high spot in the pavement and a drop is experienced, the contact area of the balloon tire with the pavement is immediately enlarged. Recent studies on airplane tires indicate this fact to a marked degree. It explains the fact that with the general adoption of the balloon tire many old thin surfaces which were on the verge of failure in 1928 and 1929 were thereafter salvaged under simple maintenance methods and have been improving steadily ever since.

The present load per square inch under the largest truck is probably less than that under the wheels of a two-horse wagon of 20 years ago. This factor has not yet been taken into full account in pavement design, and it is noted here in order to bring out the fact that it is the *loading per square inch* and the *character of the margin of tire contact* which properly should be taken into consideration, rather than simply the total wheel load in designing flexible types of pavement. This factor is taken into consideration by the writer in the formula suggested for determination of pavement thickness.

EFFECT OF WIDTH

The effect of width of pavement is far more important than is generally realized. Much of the failure which occurred in the late twenties was due to concentration of loads at the outer edge of the pavement. While the better ditch construction today has increased the uniformity of subgrade completely across the roadway width, nevertheless the edge of any pavement is still its weak spot and the intrusion of water beneath this edge under particularly adverse conditions of ice and snow may lead to lowered subgrade resistance. By increasing pavement width as will permit considerable lateral movement, the likelihood of any areas being over-stressed is largely eliminated.

Inasmuch as this ties up with the studies in regard to safety, it is recommended that two-lane pavement widths be a minimum of 22 ft., and for old pavements of lesser width that the berms be given such treatment as will make them practically homogeneous with the pavement itself. It is believed that the trend for two-lane pavements is toward 24 ft. as the minimum and that all experience indicates that pavements of that width can be constructed of such thickness that for a given volume of material it is better design to have this width in a thinner section than a 20 ft. width and a thicker section.

INFLUENCE OF IMPROVED EQUIPMENT

The effect of equipment applies in several ways to present day design, the first one in regard to preparation of the road cross-section. One does not have to go back very far to remember when the flow line in a highway ditch was often inadequate due to the difficulty of readily removing rock and ledge points with equipment then available. Frequent pockets would be encountered in ditches which led water to the subgrade with resultant failure of the pavement due to loss of subgrade support. This one item has been changed to such a degree through the use of power equipment that the water table under modern highways has been lowered to provide more nearly uniform subgrade support throughout the year.

Another point regarding equipment is cheap haulage. The radius of economical haul from any given source of aggregates has been greatly extended, so that it is possible to employ materials for foundation construction to take care of modern traffic needs at costs which are little more than one-half to one-third of what they were ten years ago. This coupled with easy construction of wide roadbeds and lowered water table makes for economical construction of sound foundations.

Likewise for surface courses of all types, cheap haulage has permitted mobilization of materials in storage and stockpile where they are ready with favorable weather conditions for rapid completion of the construction project in a short period. There is practically no limit to the construction rate of bituminous surface types, inasmuch as they may be used immediately after placement. Several States indicate that with cheaper hauls the type of surface has been changed. Two trends appear,—(1) that with construction of solid subgrades, heavy surface treatments are often adequate where formerly greater pavement thickness was employed, (2) that plant mixtures are becoming almost as economical as road-mixes in many areas, especially under adverse climatic conditions. Hot plant mixes are being hauled as much as 50 miles.

A complete study of the influence of equipment was presented at the Twelfth National Asphalt Conference held in Los Angeles in February, 1939, under the general chairmanship of Mr. J. L. Harrison of the Public Roads Administration. Even for those who have been constantly associated with the highway field, it is nothing short of amazing to look back and see how rapidly equipment has been improved and how greatly costs have been lowered, so that types which would not have been economical so recently as ten years ago are now invading the low cost field. A study of this report is recommended.

The improved design of bituminous mixing plants is especially notable, both respecting capacity and cost of output. The average cost of bituminous concrete has been reduced over 50 percent since 1920 and 25 percent since 1930. Some plants now turn out well over 1,000 tons per eight hour day. The development of alloy steels which permit the construction of plants having little or no maintenance and the development of the oil burners for drying have radically altered the position of plant mixtures in the paving field. A new type of "shock heat" dryer is shortly to come on the market which promises to still further extend the trend toward plant mixing of aggregates formerly placed as road mixtures.

However, with all this development in better and cheaper plants, the extension of use of bituminous mixtures is so rapid that the road-mixing types continue to gain, especially through the western and southwestern areas where adverse weather conditions are less severe. The selection of type is being made more and more as a result of study of local behavior rather than to build a type because someone else had done so. Road-mixes have a definite field of use and are particularly adapted to county and township work where tractor-grader equipment is available.

Probably in no aspect of equipment change has there been a greater improvement than in producing the final surface. One of the difficulties of flexible type construction 10 or 15 years ago was in obtaining a smooth riding surface. Old specifications are clearly evident of this fact, wherein tolerances were permitted of from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. variation in 10 ft. The mechanical spreaders and more recently the combination mechanical spreaders and tampers have revolutionized this end of the work, and there is no reason today why tolerances for pavement smoothness should not be as close for flexible types of construction as for any other type. Plant mixes easily can be laid to a tolerance of $\frac{1}{8}$ in. in 10 ft. and many surfaces are being constructed under even stricter control. No plant-mix work now should be permitted (except in certain city work or small rural jobs) other than with mechanical means of spreading.

INFLUENCE OF AGGREGATE AVAILABILITY

Flexible types are different from all others in that there are a number of surfaces from which selection may be made. However in such choice, attention should be given to the availability of local aggregates, and the limitation of the manipulative process. These factors often are overlooked.

By local aggregates is meant not merely wayside products but the materials which are the output of commercial pits and quarries. Stone and gravel vary in different sections of the country in the sizes obtained from the most economical methods of reduction. Cognizance should be taken of this fact, and specifications should be written to best use the complete plant output. Such procedure is immediately reflected in cost. As an example, in Oregon where rock is plentiful, stone bases are the natural order. In Massachusetts where hard rock is found, the penetration type of construction is a logical procedure. Where finely textured surfaces are required the employment of the penetration type as base with a thin plant-mix top is economical and employs the full quarry output. In the South the limerock and other indigenous aggregates are clearly indicated. The point to be emphasized is that design should take into account the commercial side of the picture, and that the closest cooperation should prevail between the commercial producer and the public engineer to work out the most satisfactory combinations.

THICKNESS

Closely tied in with the economical use of aggregates are the thicknesses of base and surface courses which are often governed by the character of manipulative processes. Thus in penetration macadam 2½- and 3-in. depth is best because stone can be prepared efficiently in these sizes and bituminous cement can be forced into the voids in a satisfactory manner. Bituminous concrete can be consolidated in layers up to 4 in. for coarse mixes, and to better advantage in 2- to 3-in. layers for finer mixtures. Road-mixes can be thoroughly mixed, spread and rolled in depths up to 3 in., while surface treatments can be handled best in depths less than 1 in.

Base thickness is being more and more determined by balancing cost of increased depth against cost of raising subgrade support. Usually the base thickness will be determined by the maximum amount capable of being constructed in one layer, as it is usually cheaper to increase subgrade support than to build two or more layers of base. For example, 4½-in. waterbound macadam base is an economical depth to construct in one layer and for this type such thickness is usually sufficient. It is deep enough to use commercially available stone to advantage, and to be closely keyed so that

TABLE 10

THICKNESS AND QUANTITIES FOR TYPICAL TYPES BITUMINOUS PAVEMENTS

Type	Thickness	Weight of aggregate per square yard[1]				Bituminous material per square yard	
		Coarse aggregate	Fine aggregate	Sand	Filler	Primer	Seal
	In.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Gal.*	*Gal.*
Light surface treatment	¼ to ½		25				0.25
Heavy surface treatment	½ or more		30 to 60			0 5	0.3
Light road-mix seal	½ to 1		50 or more			0 2	0 8
Road-mix, macadam—aggregate type	2	174	18			0.4	1.1 mix and seal
Road-mix, dense—graded type	2½	237 total	all sizes including 200	mesh		2.0 to 2.4 total	
Penetration macadam surface	2½	217	35			Total 2.4	
Penetration macadam base	3	260	25			Total 1.65	
Bituminous concrete surface	2	126		65	11	Total 1.7	
Bituminous concrete base	3	204		84		Total 2.1	
Topeka type	2		59	114	20	Total 2.1	
Sheet asphalt	Binder course	100		36		Total 0 85	
	Top course			115	23	Total 1 9	

[1] Weight aggregate based on specific gravity of 2.65.

no weak areas develop. If greater support is required it will be better usually to incorporate additional aggregate with the subgrade soil to produce mechanical stabilization and the needed support. Table 10 shows typical thickness and quantities required for various types of surface in common use.

CONCLUSIONS

1. The most important development in design of "flexible pavements" is the increasing attention to subgrade; viz., the actual design of the subgrade as a part of the pavement structure having definite minimum support values.

2. The development of the balloon tire has so reduced load concentrations that even though traffic volumes have greatly increased, the damaging effects of impact formerly experienced have practically disappeared.

3. The development of power equipment with attendant low cost of operation has greatly extended radius of economical haul of selected aggregates, and their manipulation. Surface types formerly in the high cost class are now competing in the low cost field, while the quality of all types is markedly improved.

4. In design of mixtures more attention is given to some form of stability measurement. The trend toward coarser type plant mixtures is to be noted, and that such mixtures are less critical to design in respect to stability due to the structural strength of the aggregate itself. This trend evidences itself in the newer designs which call for *thin* dense mix top and *thicker* coarse mix binder courses.

5. There is need for some simple field method of determination of subgrade support values, and correlation with a laboratory test.

6. There is need for complete study of stress distribution as related to density and stability of mixtures.

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