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D. M. BEACH, *Editor*

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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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REPORTS SUBMITTED TO INTERNATIONAL ROAD CONGRESS BY REPORTERS FOR THE UNITED STATES

THE EIGHTH CONGRESS of the Permanent International Association of Road Congresses convened at The Hague, Netherlands, on Monday, June 20, 1938 and closed on Saturday, June 25, 1938. Papers written by reporters for the United States dealt with the following subjects in the agenda of the Congress

FIRST SECTION (CONSTRUCTION AND MAINTENANCE)

First topic:
- Progress accomplished, since the Congress at Munich, in the use of—
  - a. Cement on road surfaces.
  - b. Brick surfaces.

Second topic:
- Progress accomplished, since the Congress at Munich, in the preparation and use on roads of—
  - a. Tar.
  - b. Asphalt.
  - c. Emulsions.

SECOND SECTION (TRAFFIC, IMPROVEMENT, AND ADMINISTRATION)

Third topic:
- Accidents on the road.
  - a. Bases of statistics and their unification.
  - b. Determination of causes of accidents, and means for diminishing them.

Fourth topic:
- Segregation, on the route, of the different means of transportation: Roads (one and two lanes), bicycle tracks, footpaths, parking spaces and exit roads, crossings and crossroads.
  - a. Study of the circumstances under which these should be recommended or advised against.
  - b. Application to automobile routes.

FIRST AND SECOND SECTIONS (COMBINED)

Fifth topic:
- Study and standard of quality of a road surface from the viewpoint of—
  - a. Its slipperiness or ruggedness, and its resistance to skidding.
  - b. Its property of reflecting or absorbing light (under artificial lighting).

Sixth topic:
- Study of road subsoils:
  - a. Determination of properties of subsoils, testing methods, equipment.
  - b. Influence of these properties on road construction (base and surface) and on road maintenance.

Reports submitted to the Congress by reporters for the United States will be published in PUBLIC ROADS. Papers dealing with the first and second topics are presented in this issue. The July issue will contain papers dealing with the third and fourth topics, and the August issue will contain papers dealing with the fifth and sixth topics.

PROGRESS IN THE USE OF CEMENT IN ROAD SURFACES

Reported by V. L. GLOVER, Engineer of Materials, Division of Highways, Illinois Department of Public Works and Buildings; Principal Reporter

I. CONCRETE PAVEMENT

Introduction.—The advancement in concrete pavement technique, as a rule, is gradual. New ideas, whether they pertain to design of pavements, materials, construction methods, or equipment, frequently must pass through an extended period of development before they become generally accepted. In the following are included only those which appear promising or have gained general acceptance during the last few years.

Subgrade.—More attention than ever before is being given to the selection and compaction of soils to prevent subsidence of fill material under pavement slabs. In some instances, unsatisfactory subgrade materials are removed and replaced with satisfactory materials. Compaction at the optimum moisture content of the soil by the "Proctor Method" [1] is rapidly gaining favor. The sheepsfoot roller is rapidly becoming the accepted type of mechanical equipment for use in compacting embankments.

Where subgrade soils change volume appreciably from absorbed moisture, it has been found that detrimental distortion of the pavement can be prevented by controlling the moisture content and density of the soil ahead of the paving. The moisture content and density desired are approximately equal to the optimum moisture content and maximum density as obtained by the Proctor Method and may be determined by swell tests on soil pats for any soil on a specified project.

Mechanical equipment for cutting and shaping the subgrade has been improved and is coming into increasing use. Machines have been developed which can cut to a depth of from 3 to 5 inches and move the excavated material by belt conveyors to the shoulders. In some instances the conveyors are designed to permit the loading of excavated material directly into trucks.

Side forms.—Because of the increased weight of finishing and subgrade equipment operating on the side forms, there has been a decided tendency toward the use of heavier forms. The prevailing practice requires a minimum base width of 8 inches for forms which are 8 inches or more in height, and there is a tendency to specify a base width at least equal to the height of the form. Power-driven machines known as form graders, designed to cut a true subgrade on which to set the forms and so give them better and more uniform support, are in common use, and mechanical

[1] Engineering News-Record, August 31 and September 7, 21, and 28, 1933.

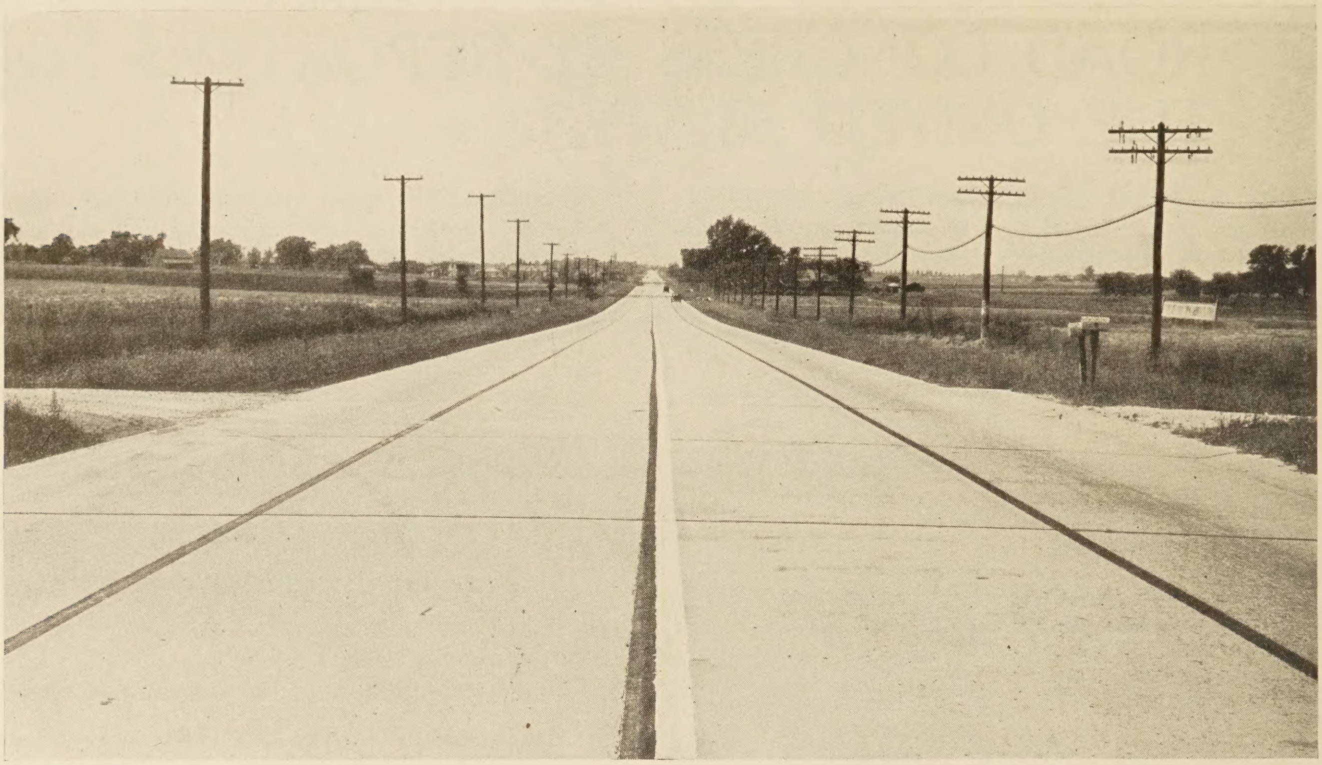


FIGURE 1.—TYPICAL 4-LANE CONCRETE PAVEMENT.

equipment for tamping soil under the forms has been successfully employed.

Pavement cross section.—The thickened-edge pavement design is generally used. The increase in thickness of the edges is usually accomplished in a uniform slope from the center thickness to the edge thickness in the outer 2 to 4 feet of the cross section. Occasionally the edges are of a uniform thickness over the outer 1 or 2 feet of the cross section and the edge thickness is reduced in a uniform slope to meet the center thickness at from 3 to 4 feet from the edges.

There is a marked tendency toward the selection of a pavement design for any given project on the basis of traffic requirements, taking into consideration the volume and weight of traffic loads and the condition of the subgrade. Where, in the past, only one standard pavement design was used, regardless of frequency and weight of wheel loads, two or more standard designs are often employed to suit the different traffic and subgrade conditions encountered. For normal heavily traveled rural highways common practice supplies a section 9 inches thick at the edges and 6 inches thick at the center, for heavy-duty pavements 10 inches at the edges and 7 inches at the center. Where the subgrade has high supporting value and traffic is fairly heavy 8 inches at the edges and 5½ inches at the center may be used, but in no case are sections less than 7 inches at the edges and 5 inches at the center permitted.

Of the methods available for computing stresses to determine the required cross section for given traffic loads and subgrade conditions, the mathematical analysis developed by Dr. H. M. Westergaard, Dean of the Graduate School of Engineering, Harvard University,[2] is undoubtedly the most adaptable to the variable conditions encountered. With proper selections of constants, and taking into account that wheel loads are dynamic forces, stresses may be reliably calculated by this method, which, however, like others available, does not apply directly to the calculation of stresses in thickened-edge designs.

By comparing section moduli of the most heavily stressed section of the pavement corners of thickened-edge designs with those of the corners of pavements of uniform thickness, an approximately "equivalent uniform thickness" may be determined for corners of any thickened-edge design, and Dr. Westergaard's method may then be applied. Similar procedure cannot be followed in the case of an unbroken edge of a thickened-edge pavement. Dr. Westergaard's method applies directly to the design of the interior thickness. In pavements where adjacent corners are mutually supported by dowels or other devices, and where increased edge thickness is obtained in the outer 2 feet, a fairly balanced design is obtained, as far as load stresses are concerned, when the center thickness is about two-thirds of the edge thickness.

An empirical method of determining the "equivalent uniform thickness" of corners of thickened-edge designs was developed by Frank T. Sheets, Consulting Engineer, Portland Cement Association,[3] who also suggests empirical formulas for design.

A pavement design balanced as to load stresses alone is strictly sufficient only in case of very short slabs. Recent investigation [4] indicates that the value of the thickened edge from the standpoint of load stresses may be entirely nullified in long slabs by increased warping stresses, and that warping stresses become unimportant only in a very short slab length, possibly as short as 10 feet. Whether these facts will affect materially the trend in pavement design remains to be seen.

[2] PUBLIC ROADS, Vol. 7, No. 2, April 1926; and Vol. 14, No. 10, December 1933.

[3] Concrete Road Design, Simplified and Correlated with Traffic (3d Edition), published by the Portland Cement Association, Chicago, Ill.

[4] PUBLIC ROADS, Vol. 16, No. 10, December 1935.

FIGURE 2.—PLANT FOR PROPORTIONING SEPARATED SIZES OF COARSE AGGREGATE.

The width of traffic lanes is being increased from 9 feet to as much as 12 feet because of the increase in speed of motor vehicles and the increase in width of the larger units. This additional width of lane may be expected to increase the capacity and add to the safety of the highways.

Roadways of four or more lanes (see fig. 1) are often used, depending upon the volume of traffic. Division of the traffic streams by a medial zone is becoming more and more frequent where four or more traffic lanes are required. The width of the medial zone varies from a few feet to a maximum of 40 feet, depending upon the cost and ease of acquiring the right-of-way, construction costs, and the location and character of the highway. On special roads known as parkways, designed mainly for recreational use, greater widths are used, ranging up to 200 feet.

Materials.—Rigid adherence to high standards has materially raised the general level of the quality of aggregates furnished for concrete. The same is true of improvement in the uniformity of gradation, which has been advanced particularly by the practice of shipping to the construction site coarse aggregates in two or more sizes and recombining them during the process of proportioning. (See fig. 2.) This practice, by reason of the fact that the relation between the amounts of the different sizes may be changed when occasion demands, provides also added opportunity for adjustment of the concrete mixture to obtain the most satisfactory results.

The use of bulk cement has increased and satisfactory methods of handling and batching it have been developed. Its use is in general preferred because of reduced cost and because of the fact that the size of the batch is readily adjusted to the full capacity of the mixer without added labor, as would be necessary in weighing out fractional sacks where sacked cement is used.

There is a growing tendency to demand cements manufactured under restricted specifications to suit certain needs. Much uncertainty exists in regard to the necessity of controlling the composition of portland cement to improve durability, but it is the opinion of many that this property has been overlooked to some degree in the desire to produce high strength. The effect of varying, through wide limits, the composition of cement has been investigated by several agencies, especially with reference to the effect on the resistance of concrete to freezing and thawing. However, no satisfactory answer to this problem has as yet been obtained. There is some inclination to limit the amount of tri-calcium aluminate in an effort to improve durability.

Entirely distinct from disintegration due to frost action is a type of failure which takes the form of abnormal expansion of the concrete and which sometimes does not develop until after several years of service. When this expansion is restrained, multiple cracking followed by ravelling and ultimate disintegration results. There is evidence indicating that this type of failure is due to so-called "delayed unsoundness," probably caused by hard-burned free lime or magnesia in the cement, the effect of which is not revealed in the standard soundness test. To guard against this type of failure, portland cement manufacturers have recently adopted an "autoclave" test in which the constancy of volume of a standard bar of neat cement is observed in an atmosphere of steam at 420° F. for 3 hours.

Proportions.—Because of the high strength of modern portland cements, a much higher concrete strength is now obtainable with a given cement content and water-cement ratio than was formerly possible. As, to insure maximum durability, it is necessary to hold the water-cement ratio within certain limits dependent upon exposure conditions, the application of the water-cement ratio to the design of mixtures is, under some conditions, limited. For instance, under the severe winter conditions of the northern part of the United States it is not considered good practice to use a water-cement ratio by volume exceeding 0.8 even though the strength of the resulting concrete may exceed the design requirements. For this reason the proportion of cement in concrete paving mixtures employed in the northern part of the country is seldom less than 6 sacks per cubic yard and is frequently higher. In the South, where favorable climatic conditions obtain, the cement content is frequently as low as 5.5 sacks per cubic yard and sometimes lower.

Transverse joints.—Early in 1934 the United States Bureau of Public Roads required that expansion and contraction joints should be used in all concrete pavements involving the expenditure of Federal funds. This has stimulated the general use of transverse joints. Previous to that time, many States omitted joints entirely or placed them at long intervals.

The Federal Bureau requires that expansion joints not less than three-fourths inch wide be placed at intervals not exceeding 100 feet in length. In practice the spacing ranges from 40 to 100 feet. The Bureau also requires that contraction joints be placed between the expansion joints so that the transverse joint spacing shall not exceed 30 feet. In practice the transverse joint interval ranges from 10 to 30 feet, generally from 20 to 30 feet. Such spacings are intended to form slab lengths sufficiently short to reduce transverse cracking materially. Only the shortest spacings, however, may be expected to relieve restraint against temperature warping at all points.[4]

Types of joints and joint materials are manifold. The most common types of fillers for expansion joints used previous to 1933 were premolded bituminous felt and poured bituminous materials. Bituminous fillers have the fault of extruding during expansion of the pavement and causing a rough riding surface. Lacking resiliency, they also fail to return to the widening joint when the pavement contracts and so permit infiltration of inert material into the joints which renders them thereafter inoperative for expansion purposes.

Recently various types of nonextruding joint fillers have been used. Among these are cork, rubber, wood or cane fiber, and granular materials such as sawdust and cottonseed hulls. These fillers eliminate the bumps due to extruded material, but they are dependent upon a proper sealing material to prevent infiltration of water and inert material. A recent development is the air-cushion joint which is provided with a seal of thin sheet copper at the top and ends of the joint. These, however, have not been in use for a sufficient length of time to determine their merits definitely. It is recognized that the behavior of the various filler materials cannot be dissociated from the slab lengths with which they are used. Fillers that act poorly with long slabs perform much better when used with short slabs because of smaller movements at the joint.

[4] Public Roads, Vol. 16, No. 10, December 1935.

The contraction joints used are generally of the weakened plane or the dummy types. The weakened-plane type is ordinarily formed by inserting a deformed or straight metal plate in the concrete for the full or part depth of the slab, causing the slab to crack. In some designs the metal plate is provided with a copper seal to prevent the infiltration of water and dirt. The dummy contraction joint usually consists of a groove 1½ to 3 inches in depth formed in the surface of the pavement. The groove is filled with either poured or premolded bituminous filler.

At present it is believed that adequate provision for crack control and proper load transfer across joints will add to the service life of pavements and reduce maintenance costs, and it may be expected that this problem will receive serious study in the future.

Longitudinal joints.—The use of longitudinal joints at lane-width intervals has now become universal in the United States. Their use prevents practically all longitudinal cracking and reduces curling of the slabs. The usual practices employed in the formation of longitudinal joints are: (1) The deep cutting of the surface of the pavement to induce the formation of a crack; or (2) the insertion of deformed metal plates. Tie bars, generally ½-inch rods extending about 1 foot into the pavement at each side of the joint at longitudinal intervals of 2½ feet, serve to hold the sections together and insure load transfer across the joints. In some of the States of the United States each lane is now being built as an independent slab with both edges thickened.

Load transmission-devices.—That a free edge in a pavement is structurally weak has been shown by theoretical analysis, investigation, and experience. Some means of strengthening the edges of slabs at transverse joints is therefore necessary in order to obtain a pavement of balanced design. This is necessary at contraction as well as expansion joints. In some instances this has been accomplished by the use of special reinforcement along the joints, or by thickening the ends of the slabs at the joints in the same manner as the outside edges are thickened. These methods have not in all instances been entirely successful and have never been used extensively in the United States. Load transfer devices, however, which provide mutual support between adjacent slab ends have come into general use during the last few years.

The most common load-transfer device is the dowel bar. These are usually of ¾-inch diameter, 24 inches long, and spaced from 12 to 15 inches along the joints. One-half the length of each dowel is painted and oiled to provide for slippage and a metal cap is placed around the end to form a space in which the dowel slips during movement of the pavement. Other shapes such as T-bars, angles, channels, flat plates, and pipes, have been used in place of dowel bars for expansion joints, because of their greater bearing area and greater stiffness for the same weight of metal. Recently a short dowel bar with close fitting metal sleeve which provides additional bearing area on the concrete has been developed and used quite extensively with apparently good results. There are also many load-transfer devices on the market today. Some are designed as an integral part of the joint, and others can be used with any joint filler.

Recent investigation[5] seems to indicate that doweled transverse joints are effective in relieving stresses caused by expansion, contraction, and warping, but

[5] Public Roads, vol. 17, No. 8, October 1936.

that they are not as effective as might be desired in relieving load stresses near the joint edge. Further investigation and tests are under way in many States which, together with observations of installations in service, should supply data on which definite conclusions can be based.

Reinforcing.—While there have been no recent outstanding developments in the use of reinforcing steel in concrete pavements, there is an increasing tendency toward the use of moderate amounts of distributed reinforcement; and there is a pronounced feeling that the possibilities of steel reinforcement have not been sufficiently explored. As used in the United States, the reinforcement is not designed to prevent either tensile or flexural cracking. The common practice employs a single layer of well-distributed reinforcement consisting of comparatively small members closely spaced to prevent the opening or widening of cracks. Large members, widely spaced, are not as effective for this purpose. The average usage employs from 50 to 55 pounds of steel per 100 square feet and places it 2 inches below the pavement surface, with members spaced not more than 12 inches apart longitudinally and traversely.

Vibration.—In the placing of structural concrete there has been recently a rapid increase in the use of high-frequency mechanical vibration as an aid toward the production of stronger, denser, and more economical concrete than can be obtained by ordinary hand-placing methods. The progress in applying the same principle in the placing of pavement concrete has been slower, possibly because of the difficulty of designing vibratory equipment suitable for the purpose.

The United States Bureau of Public Roads and several States, by constructing experimental sections of pavement with vibratory equipment, have contributed most of the information that is available on the subject. Preliminary investigations, in which the proportions of materials, consistency of the mixture, and quality of the resulting concrete were given a thorough study, have been followed by investigations on regular contract sections to study the practicability of the method for general admission under specifications for concrete pavement construction. The results obtained show, in general, considerable advantage of the vibratory methods over the conventional methods.

It has been fairly well established that concrete, unworkable by conventional means of placing, follows the same laws as concrete of consistencies employed with conventional finishing methods, when it is made plastic by vibration during the process of placing. In other words, vibration imparts no new property to the concrete and the water-cement and voids-cement ratio laws still hold good.

From the standpoint of economy the advantages of vibration are established without doubt. Dry and harsh mixtures of from ½ to 1-inch slump, formed either by reducing the water-cement ratio or by using additional aggregate above that used with conventional methods, have been satisfactorily placed by use of the vibratory method. In either case it has been necessary to reduce the proportion of fine to coarse aggregate in order to obtain mixtures suitable for use with the vibratory equipment. The increase in strength, obtained at no increase in cost of materials by lowering the water-cement ratio, has amounted to about 10 percent.[6] Reduction in the cost of the concrete, by saving from 10 to 15 percent of the cement, has been obtained without sacrifice in strength by increasing the amounts of the aggregates and maintaining the water-cement ratio employed with the conventional method. In addition, the vibrated concrete has been found to be more dense, less absorptive, and less honeycombed than that placed by conventional methods.

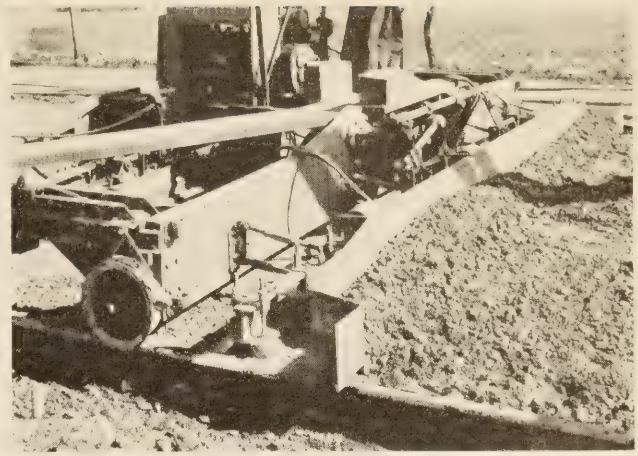


FIGURE 3.—FINISHING MACHINE WITH VIBRATORS MOUNTED ON THE FRONT SCREED.

The vibratory equipment used on regular contract sections has proved entirely practical. No mechanical difficulty of any consequence has been encountered. No increase in construction personnel has been necessary, because the additional labor required to spread the concrete has been offset by the elimination of the necessity of spading adjacent to the forms. No additional equipment has been necessary. The concrete has been consolidated satisfactorily around the transverse joints without damaging them, and the rate of progress has been at least as satisfactory as when conventional equipment and methods were used.

The principles of both surface and internal vibration have been applied to placing concrete pavements, although up to the present time the former perhaps has been most used. The frequency of vibration in most instances is 3,600 impulses per minute or slightly more.

Surface vibration has been accomplished by mounting vibrator units on the front screed of the finishing machine (see fig. 3) or by mounting them on a pan between the screeds and independent of the screeds. Both methods have given very good results. Another method adapts the principle of internal vibration by mounting vibrator units on a pipe suspended in the concrete ahead of the finishing machine. By still another, the vibratory action is applied through a shaft, with protruding pins, which is made to travel on the forms ahead of the finishing machine. These two latter methods are relatively untried at the present time. Other methods, such as an arrangement by which the concrete is vibrated as it passes through the throat of a hopper from which it is spread on the subgrade, are in the development stage.

It is felt that the maximum advantages that may be had through the use of vibration have not yet been obtained. It should be possible to place and finish still drier and harsher mixtures and obtain concrete of still greater density and durability. To achieve this end it will be necessary to redesign other units of the production equipment to handle the material. This

(Continued on page 71)

[6] PUBLIC ROADS, Vol. 18, No. 2, April 1937.

DEVELOPMENTS IN BRICK PAVEMENTS IN THE UNITED STATES

Reported by JOHN JASTER, Jr., Director, Ohio State Highway Department, Principal Reporter; GEORGE F. SCHLESINGER, Engineer Director, National Paving Brick Association; JOHN S. CRANDELL, Professor of Highway Engineering, University of Illinois; and ROY L. PHILLIPS, City Engineer, Meadville, Pa.[1]

INTRODUCTION

THE brick pavement structure as constructed in the United States, consists essentially of the three following component parts. The surface course is composed of rectangular vitrified clay units assembled in regular pattern with the joints or interstices completely filled and sealed, binding the units together. The bed or cushion course, is a thin layer of granular material on which the paving brick units are laid and embedded and which will permit slight adjustments necessitated by irregularities in the foundation or by permissible variations in the depths of the brick. The base course or foundation, supports the bed and surface and distributes traffic loads to the subgrade.

PAVING BRICK UNIT

Manufacture.—Paving brick are formed by what is known as the "stiff-mud" process of clay products manufacture. The shale or clay after being ground very fine is thoroughly mixed with water to the proper consistency. A powerful auger then forces the stiff mixture through a die on to a moving belt in the form of a column. This column is carried to the cutter where taut wires automatically cut it into brick units. In so-called vertical fiber paving brick the width and length are determined by the dimensions of the die and the depth by the spacing of the wires on the cutter. In the wire-cut-lug type the depth is the shorter dimension of the die and the lugs are formed by an eccentric motion given to the cutting wires. In this type the smooth or die side of the brick is in the surface of the pavement. When the brick are re-pressed before burning the surface is also smooth.

Formerly the re-pressed and the wire-cut-lug types were in general use and their preference was in a large degree based on their having side lugs considered essential for the proper filling and sealing of the joints. However, the manufacture of brick having a wire-cut wearing surface with lugs on the side and ends is now commercially practical and this type, known as vertical fiber lug, is now the most popular single variety in use in the United States. Regardless of the type of vitrified paving unit that may result from future developments it will undoubtedly have a roughened or deformed wearing surface of nonskid character.

De-aired brick.—Most paving brick plants are equipped with machinery for evacuating the air from the mixed clay or shale during the process of manufacture. De-airing with proper methods will produce a brick of greater strength and density and improved regularity of shape. Glassy structure causing brittleness must be guarded against and accurate control in manufacture is necessary in order to obtain the full advantages of the process. The Research Bureau of the National Paving Brick Association at the Ohio State University Experimental Station at Columbus, Ohio, has made observations on the internal structure of paving bricks manufactured with various degrees of vacuum and methods of forming with a view to the further perfecting of plant practices. In some cases authorities have specified that the paving brick be de-aired although usually the physical requirements govern with no mention of the method of manufacture. In the brick to be used for paving the first tube of the new Lincoln Tunnel under the Hudson River in New York City, a maximum of 18 percent rattler loss for 3 by 4 by 8½-inch de-aired brick is the requirement.

Standard types and sizes.—Since 1921 the Division of Simplified Practice of the United States Bureau of Standards, through a committee composed of representatives of engineering and technical societies, has annually recommended a standard list of sizes and varieties of paving brick. The current recognized list is given in table 1.

TABLE 1.—*Standard list of sizes and varieties of paving brick*

Variety	Size			1936 shipments
	Depth	Width	Length	
	Inches	*Inches*	*Inches*	*Percent*
Repressed Lug	4	3½	8½	7.1
Vertical fiber lug	2½	4	8½	12.8
Do	3	4	8½	51.3
Do	3½	4	8½	9.3
Total				80.5

It will be noted that the list does not contain lugless varieties which at one time were in general use in the western part of the United States. The proportion of vertical fiber lug brick shipped in 1936 (73.4 percent) is the greatest for any type since standardization was initiated.

Specifications.—Practically all standard specifications for the physical qualities of paving brick used in the United States are identical with, or in essential details are based on those of the American Society for Testing Materials.[2] The requirements in regard to the abrasive loss in the rattler test are sometimes varied (usually downward from the A. S. T. M. requirements) to apply to the quality of brick available in a particular locality. The standard specification for paving brick of the A. S. T. M. was revised in 1937. The most notable innovation in the new specification is the additional requirement to the rattler test limiting the number of broken pieces weighing 1 pound or more.

Some specifications, notably those of the Highway Department of the State of Ohio which is a large user of paving brick, had in recent years added a test for flexural strength. An investigation indicated that there was close coordination between broken brick in the rattler and low flexural strength. It is believed that a broken brick limitation will be more determinate than the flexural test in that it will detect brick that have minute cracks on only one surface. In addition it is considered a criterion of toughness. This is the first time that the rattler test, which was devised in the United States, has been modified, although it is realized that its application by stages is a part of paving brick testing in Holland.

[1] The following information was submitted by the reporters listed and organized into one report by the principal reporter. Information on Manufacture, Specifications, Construction Methods, Fillers, and Base Courses was furnished by Mr. Schlesinger. The section on Bed Courses was written by Professor Crandell. Mr. Phillips submitted the information on Municipal Use.

[2] American Society of Testing Materials Designation C7—37 T.

CONSTRUCTION METHODS

While the type and quality of the paving brick unit is a matter of fundamental importance, its method of utilization is at least of equal moment. Brick in the pavement are surrounded and supported by a number of other materials of construction. The excellence of the pavement structure as a whole is the objective of design and construction requirements. Most of the researches and developments concern improvements in what may be termed "auxiliary materials" and the manner in which they are used.

Bed course.—For many years the sand cushion has been used throughout the world as the standard type of bed course on which to lay paving brick. In 1920 a new type was tried at Syracuse, N. Y. It consisted of a mixture of light refined tar and clean, sharp sand in the proportion of 7 percent coal tar and 93 percent sand by weight. These materials were mixed together and laid cold. The pavement has been examined from time to time since then and it is in excellent condition today, showing no signs of movement of the cushion.

Since that time this bituminous-bound type of cushion or mastic bed has found favor in many parts of the United States, and is now the standard in several States and cities. The specifications for mastic bed of the American Public Works Association (formerly the American Society of Municipal Engineers[3]) are typical of those in most general use. In most cases a liquid asphalt has been substituted for coal tar since the asphaltic product is cheaper. If the correct proportion of asphalt is used the results seem to be as good as those that are obtained with coal tar, but too often the contractor has been allowed to reduce the amount of asphalt to as low as 3½ percent, because he has claimed that it is difficult to work with a mixture as "fat" as was originally called for. This is sheer nonsense, and the cushions laid with the leaner mixes soon show signs of deterioration and eventual failure.

Water-gas tar has been used as a binder to some extent, but the results have not been generally satisfactory, as evidenced by the Chestnut Street pavement, Philadelphia, Pa. Some of the cut-back coal tar products have not given good results either, and their use is not recommended. Asphaltic emulsions are not satisfactory. Best results have been obtained with light, refined straight-run coal tars, as well as those asphaltic cut-backs which do not cure too rapidly.

The sand used for bituminous cushions is important. It should be clean and sharp. A rounded sand, such as is often to be found in river bottoms, or along swift running streams, is, in general, unsatisfactory, because the resulting cushion is not stable. It tends to be rolled up into the joints when the power-roller passes over the brick. A sharp sand resists this tendency, and the cushion made with it stays where it is deposited.

More recently experiment has been made with rock asphalt as a cushion course. A lean rock asphalt has been tried, containing about 3 percent of asphalt. It seems to have some points of superiority, such as ease of handling, and a tendency to set up and resist movement under the wearing surface. It is too early, however, to present a full report on this as the sections observed in this country have been in use less than 2 years.

In the early practice the bedding course or cushion varied in thickness to accommodate irregularities in the roughly finished base. This frequently resulted in shifting of the cushion with consequent effect on the brick surface. Present design calls for a much thinner bed with a uniform thickness not greater than three-fourth inch, which is possible because of a correspondingly smooth base-course surface requirement.

Fillers.—The surface-removal method of bituminous filler application introduced several years ago has now become practically universal practice in the United States. Immediately prior to the application of the filler, the brick are treated with a separating agent of lime and water, or calcium chloride, laundry starch, and water. These agents are sprayed on the surface of the brick in place in the pavement in such way as to coat the exposed surface of the brick without penetrating the joints. When the separating coating has been thus applied the filler is poured directly into the brick joints and the surplus scraped off the top so as to leave the surface of the pavement clean and the joints full.

Investigations reported to the Highway Research Board [4] in 1933 and 1934 indicated that the coefficient of friction, both rolling and sliding, on "a vertical fiber brick road, free of asphalt filler" was relatively high. Observations made on the same pavement during the second and third years after completion indicated a measurable reduction in friction. According to these reports, this was caused by the asphalt progressively exuding from the joints in hot weather and covering a considerable percentage of the surface.

A prominent part of the work of the Research Bureau of the National Paving Brick Association has been concerned with the development of paving brick joint fillers that will not exude in hot weather. Consideration has been given to cement grouts, bituminized cement grouts, plasticized sulphurs, and bituminous fillers. Among the bituminous fillers, comparisons have been made between asphalts from different base crudes, asphalts of different softening points and penetrations, asphalt mastics, and straight pitches and pitch mastics. In the laboratory the properties and behaviors of the fillers were observed and interpreted in terms of practicability. Special emphasis was given to a test wherein the exuding or receding tendencies of the bituminous fillers were observed by subjecting filled brick panels (about 1 square yard in area) to prolonged periods of simulated summer temperatures. From these tests a number of fillers were selected as worthy of actual pavement trial.

In cooperation with the Ohio Department of Highways and the United States Bureau of Public Roads, a project was planned and completed (November 1935) in which the entire length of 1¼ miles of new brick pavement on route 31 in Hocking County, Ohio, was allotted to a test of fillers. Of these fillers 13 are in sections exceeding 300 feet in length and 8 in sections somewhat shorter. During construction, observations were made to determine the practicability of application, including the surface removal of the fillers. While this pavement has been in service but little more than 2 years, the weather experienced has been exceptionally severe. During the winters there have been prolonged periods of subzero weather. The summers, of exceptional warmth, included periods during which temperatures exceeded 100° F.

The Ohio Department of Highways, basing its selection on satisfactory behavior in the test road to date has

[3] American Society of Municipal Engineers, Standard Specification, adopted October 1935.

[4] Proceedings of the Highway Research Board, December 1933, p. 169 and December 1934, p. 131.

designated four of the fillers for more extended use and further trial in brick pavement projects. In 1937 these 4 fillers were optional requirements on 12 projects. They can be described in general terms as follows:

1. A "blended" asphalt, 65 percent midcontinent base and 35 percent asphaltic base; penetration at 25° C., 23 to 32; softening point 101°–110° C.
2. A blended asphalt similar to the above, with 20 to 30 percent finely divided mineral content; penetration at 25° C., 17 to 26; softening point 107°–116° C.
3. A special coal-tar pitch; penetration at 25° C., 35 to 65; softening point 60°–75° C.
4. A plasticized sulphur-asphalt mixture, with sulphur content 38 to 42 percent; penetration at 25° C., 28–34; softening point 65°–75° C.

Typical 3-Lane Brick Pavement on U S 30 in Ohio.

With the removal of the excess mat on top, a more thorough inspection of the pavement is possible. One consequence has been the requiring of end lugs instead of beveled ends (bulged). These lugs on each end are non-meshing, so as to provide for free flow of filler, and function equally well when the brick are turned.

Base courses.—The requirements for foundations or base courses vary according to conditions of climate, subsoil, and traffic loads. In the southern section of the United States, vitrified brick surface courses are successfully used on such foundations as natural sand, gravel, crushed stone, slag, shell, and Florida lime rock. Brick pavements have, of course, given excellent service on bases of waterbound and bituminous macadam, of bituminous concrete, and of portland-cement concrete.

Concrete is the material commonly used as a foundation course for city streets and heavy-traffic pavements. With proper subgrade conditions most engineers prefer a relatively lean concrete for the base. It will be less affected by temperature changes and, because of its lower tensile strength, the cracks that form are more numerous but narrower. The section of the base, separated by such narrow cracks, are displaced relatively one to another with greater difficulty than if the cracks were wider as would be the case if the concrete were stronger; and hence are less likely to affect the surface course. Reinforcing with steel mesh or bar mats, usually in lieu of a richer concrete, is an increasing practice. Expansion joints in the base course are a cause of disturbance of the brick surface and are not recommended. With plain concrete, transverse weakened plane or construction joints are used to a considerable extent. As in concrete pavements, dowelled longitudinal joints should separate the base into sections of 1-lane width. With integral curbs, which perform the same function, thickened edges are not required.

In connection with the discussion of joints in concrete bases it is apropos to mention that the monolithic type of brick pavement shows some signs of revival. In this design the brick are laid, without cushion, directly on the green concrete base and filled with cement grout. In an experimental brick pavement on route No. 43 in Carroll County, Ohio, constructed in 1933, a section of monolithic pavement was included. The construction included a longitudinal center joint and 1-inch transverse expansion joints at intervals varying from 50 to 100 feet. A smooth surface was formed and the section is now in perfect condition. Further projects of this design are contemplated. It would seem certain, however, that even if the monolithic type should again receive favor, the present standard brick pavement with cushion and flexible filler, which has proved its merits, will continue to be the preferred type for general use, particularly for municipal streets and resurfacing.

Longitudinal laying.—In December 1936 the Ohio Department of Highways completed with Federal aid the construction of a section of brick pavement on route 31 (located a short distance from the filler test road previously mentioned) in which the brick were laid longitudinally—that is with the 8½-inch dimension parallel with the curbs. Longitudinal laying was not a complete innovation as it had been used previously for car-track areas, parking strips, on grades, and, to a limited extent, in normal installations. However, this project was the first of its kind using modern construction methods. Contemplated advantages included smoother riding, reduction in traffic noise, spanning of base cracks lengthwise, a reduction in breaking of brick for transverse closures, economy in labor of laying because of unlimited length of rows, and the elimination of special wedge-shaped sections on curves. The project, completed in 1936, was 1.35 miles long, 20 feet wide over-all, had a concrete base, with 9-inch integral curbs, and used 3-inch vertical-fiber lug brick and standard asphalt filler.

An extension of this project for 1.5 miles using nonexuding filler was under construction in September 1937. The specifications for the first project did not permit "batting" but it was necessary at infrequent intervals to cut brick at transition points. Also because brick were respaced or shifted on the cushion, the resulting surface contour was not as smooth as expected. On the second project, batting will be permitted at one curb and it is believed that the appearance of the pavement will not be noticeably affected, and that economy in laying and a smoother surface will result.

Continuous longitudinal joints would be of evident disadvantage if traffic were predominantly steel-tired. However, this type of traffic is practically nonexistent in the United States. The future performance of these projects in service will determine whether the apparent advantages of longitudinal laying are sufficient to justify a change in present standard practice.

Reinforced brick pavement.—Reinforced brick masonry in which steel rods are embedded in the mortar joints has been used to a considerable extent in recent years in pavement construction. This is particularly true in California where it is considered desirable because of earthquake conditions. In June 1931 a reinforced brick

(*Continued on page 72*)

PROGRESS IN THE PREPARATION AND USE ON ROADS OF TAR, ASPHALT, AND EMULSIONS

By E. F. KELLEY, Chief, Division of Tests, United States Bureau of Public Roads, Principal Reporter

INTRODUCTION

NO REPORT on this subject has been made by the United States to the Permanent International Association of Road Congresses since the Congress of Washington. Therefore this report will not be limited in scope to the progress that has been made since the Congress of Munich but will be extended to include the more important developments that have taken place since 1930.

In order to avoid the possibility of misunderstanding it seems necessary in this report, as in that of 1930, to define the accepted meaning in the United States of some of the terms relating to the materials that are the subject of discussion. This is necessary because certain terms do not have the same meaning in the United States that they have in other countries.

As used in the United States and in this report the significance of the terms that appear to require definition are as follows:

Bitumen is that portion of tar, petroleum, asphalt, or asphaltic material, that is completely soluble in carbon disulphide.

The adjective "bituminous" means "containing bitumen." Thus, tars, asphalts, and asphaltic products are all bituminous materials. Therefore the terms "bituminous mixture," "bituminous treatment," "bituminous construction" are general ones and indicate only that the use of either tar or asphaltic material is involved.

Tar is a bituminous product which yields pitch when partially evaporated or fractionally distilled and is produced by the destructive distillation of organic materials such as coal, petroleum, wood, lignite, and peat. The tars used in the United States for road purposes are manufactured almost entirely from coal tar and water-gas tar. A very limited amount of wood tar has been used experimentally.

Asphalt is a solid and semisolid cementitious material, ranging in color from black to dark brown, in which the predominating constituent is bitumen. Asphalts may be those which occur in nature or those produced by refining petroleum.

Since asphalt is defined as a solid or semisolid material it is necessary to differentiate between it and those materials that contain asphalt but are liquid in character. Prior to 1930 the term "road oil" was applied rather indiscriminately to liquid asphaltic materials used for road purposes with a great deal of resultant confusion. Since then the use of that term has been discouraged and the liquid products are now designated as "liquid asphaltic road materials."

Cut-back asphalts are liquid materials produced by fluxing solid or semisolid asphalts with volatile petroleum distillates.

The liquid asphaltic road materials are divided into three general classes depending on the degree of hardening or cementitiousness that is desired and the rapidity with which it is developed. These classes are designated as slow-curing, medium-curing, and rapid-curing. The slow-curing materials are intended to harden very slowly after use and to develop only relatively low cementing values. The medium- and rapid-curing materials are cut-back asphalts and, in contrast to the slow-curing materials, are intended to harden at a relatively rapid rate and, through loss of the volatile solvents, to leave in place a residue of semisolid asphalt. The solvents used in the manufacture of cut-back asphalts are of the kerosene type for medium-curing materials and of the gasoline or naphtha types for the rapid-curing materials.

USAGE OF BITUMINOUS ROAD MATERIALS

The past few years have seen a great increase in the use of bituminous road materials in the United States, particularly in the use of the liquid products.

In 1929 the total consumption of asphaltic road materials was 2,656,000 tons of which the slow-curing liquid products and cut-back asphalts accounted for only 35 percent. In 1936 these liquid materials constituted 63 percent of a total consumption of 3,807,000 tons.[1]

With respect to road tars it is estimated that the annual consumption during this same period increased from more than 100,000,000 gallons to more than 150,000,000 gallons.[2]

Tar emulsions are not used in the United States and no reliable figures are available concerning the consumption of asphaltic emulsions in 1929 or 1930. However, their use at that time was relatively small, while in 1936 the estimated consumption was 56,000,000 gallons.[1]

SPECIFICATIONS

No changes of importance have been made in the specifications commonly used for the semisolid asphalts known as asphalt cements or paving asphalts. However, the increased use of liquid bituminous materials has resulted in the development of a number of new and more adequate specifications for these products.

In 1932 the United States Bureau of Public Roads cooperated with the Asphalt Institute, representing the asphalt producers, in formulating a group of specifications for liquid asphaltic road materials of the slow-curing, medium-curing, and rapid-curing types. The requirements of these specifications are given in table 1. These specifications were recommended to the State highway departments for adoption and, while the States as a whole have not seen fit to adopt them in their entirety, they have had a marked influence on the specifications now in use. In 1933 the requirements of the recommended specifications for the medium-curing and rapid-curing cut-back asphalts were approved for inclusion in the specifications of the Federal Government.

The improvement and standardization of specifications for tar have been aided considerably by the adoption in 1937, by the American Association of State Highway Officials, of the Standard Specifications for Tar for Use in Road Construction, as given in table 2. These specifications have been adopted in whole or in part by several States and their adoption, possibly with slight modifications, is now being considered by the American Society for Testing Materials and the Federal Government. The important improvement in these specifications, as compared with preceding ones,

[1] Figures given are from published statistics of the United States Bureau of Mines.
[2] Unofficial estimates; no official figures available.

TABLE 1.—*Specifications for liquid asphaltic road materials recommended in 1932 by the U. S. Bureau of Public Roads and the Asphalt Institute*

Test requirements [1]	Grades [2]												
	SC-1	SC-2	SC-3	SC-4	MC-1	MC-2	MC-3	MC-4	MC-5	RC-1	RC-2	RC-3	RC-4
Water and sediment, percent	2.0−	2.0−	2.0−	2.0−									
Flash point, °F	150+	200+	200+	250+		150+	150+	150+	150+	80+	80+	80+	80+
Viscosity, Saybolt-Furol, seconds:													
At 77° F	20–150				40–150								
At 122° F		200–320								80–160	200–400		
At 140° F			150–300	350–550		150–250	300–500	500–800				275–400	700–1,400
At 180° F									170–280				
Total distillate, percent by volume:													
To 374° F										5+			
To 437° F		2−	2−	2−	10−	2−	2−	1−	1−	12+	10+	3+	0.5+
To 600° F		15−	10−	8−	25+	10–20	8–20	16−	14−	25+	20+	14+	7+
To 680° F	50−	25−	20−	18−	50−	27−	25−	25−	20−	40−	35−	30−	25−
Float of residue, 122° F., seconds	50−	25+	25+	25+									
Penetration of residue, 100 g, 5 seconds, 77° F					70–300	100–300	100–300	100–300	100–300	60–120	60–120	60–120	60–120
Ductility of residue, 77° F., cm					60+	60+	60+	60+	60+	60+	60+	60+	60+
Solubility of residue in CS_2, percent	99.0+	99.0+	99.0+	99.0+	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+
TYPICAL USES [3]													
Dust layer	X												
Primer					X								
Surface treatments										X			
Mixed-in-place construction:													
Dense-graded aggregate [4]		X	[5] X			X							
Dense-graded aggregate [6]											X	[5] X	
Open-graded aggregate [7]												X	
Plant-mixed construction:													
Dense-graded aggregate [4]			X	X			X						
Dense-graded aggregate [6]								X	X		X	X	
Open-graded aggregate [7]												X	X

[1] Methods of test are those of the American Association of State Highway Officials.
[2] + indicates that the value shown is the minimum allowable; − indicates that the value shown is the maximum allowable.
[3] For the guidance of the user and not a part of the specification.
[4] Maximum size not over 1 inch. Fairly uniform grading from coarse to fine with appreciable percentage passing No. 200 sieve.
[5] Under favorable conditions only.
[6] Maximum size not over 1 inch. Fairly uniform grading from coarse to fine with little or no material passing No. 200 sieve.
[7] Maximum size not over 1½ inches. Little or no material passing No. 4 sieve.

is in the establishment of 12 numbered grades through which the consistency increases from minimum to maximum in a logical manner. That this is true is not readily apparent except when the consistencies of the different grades are measured at a single temperature and expressed in terms of absolute viscosity. The consistency requirements of these specifications are based on absolute viscosity as measured with a capillary rise viscosimeter that has been developed recently (*1*).[3] However, since few laboratories are now equipped with instruments for the measurement of absolute viscosity, the consistency requirements of the specifications are still expressed in terms of specific viscosity, Engler, and the float test.

Much interest is being shown in the proposal to specify viscosity requirements in terms of absolute units, both for tars and for asphaltic materials, and a number of highway laboratories are investigating its possibilities.

Three distinct types of emulsified asphalt are in use in the United States. These types may be classified as follows:

1. Quick-breaking emulsions for penetrations (or grouting) where there is no manipulation of the aggregate after it has been coated.
2. Medium-breaking emulsions for mixing with clean, coarse aggregate.
3. Slow-breaking emulsions for use in densely graded mixtures containing stone dust, sand, or other fine mineral aggregate. Emulsions for soil-stabilization belong to this general class.

[3] Italic figures in parentheses refer to the bibliography, p. 70.

The American Association of State Highway Officials has adopted standard specifications for five grades of emulsified asphalt, the requirements of which are given in table 3. Specification M–51 covers a quick-breaking emulsion suitable for penetration macadam and for surface treatments. Specifications M–47 and M–48 are for medium-breaking emulsions for coarse aggregate mixtures of the plant-mixed and mixed-in-place types, respectively. Specifications M–49 and M–50 are for heavy emulsions to be used in summer and winter, respectively, in the preparation of bituminous concrete for repair work. The American Society for Testing Materials had adopted tentative standard specifications for four grades of emulsified asphalt practically identical with the first four grades shown in table 3.

Several of the tests used to measure the desired qualities of emulsified asphalts are of quite recent origin and merit brief mention.

The demulsibility test is for the purpose of insuring that the emulsion will break at the desired rate. In this test an electrolyte ($CaCl_2$) in weak solution is added to 100 grams of emulsified asphalt and the percentage of the asphalt that is coalesced by contact with the electrolyte is determined. For quick-breaking emulsions a high percentage of coalescence in a weak solution of $CaCl_2$ is required, and for slower-breaking emulsions a low percentage of coalescence in a more concentrated solution.

The settlement test is a sedimentation test to determine if the distribution of the asphalt in the liquid phase will remain reasonably uniform over an extended period of time. Five hundred milliliters of emulsion are placed in a stoppered glass cylinder 5 centimeters

TABLE 2.—*American Association of State Highway Officials Standard specification for tar for use in road construction. Specification M–52; adopted 1937*

Test requirements [1]	Grades [2]													
	RT-1	RT-2	RT-3	RT-4	RT-5	RT-6	RT-7	RT-8	RT-9	RT-10	RT-11	RT-12	RTCB-5	RTCB-6
Consistency:														
Specific viscosity, Engler, at 40° C	5–8	8–13	13–22	22–35										
Specific viscosity, Engler, at 50° C					17–26	26–40							17–26	26–40
Float test at 32° C							50–80	80–120	120–200					
Float test at 50° C										75–100	100–150	150–220		
Specific gravity at 25° C./25° C	1.08+	1.08+	1.09+	1.09+	1.10+	1.10+	1.12+	1.14+	1.14+	1.15+	1.16+	1.16+	1.09+	1.09+
Total bitumen, percent by weight	88+	88+	88+	88+	83+	83+	78+	78+	78+	75+	75+	75+	80+	80+
Water, percent by volume	2.0−	2.0−	2.0−	2.0−	1.5−	1.5−	1.0−	.0	.0	.0	.0	.0	1.0−	1.0−
Total distillates, percent by weight:														
To 170° C	7.0−	7.0−	7.0−	5.0−	5.0−	5.0−	3.0−	1.0−	1.0−	1.0−	1.0−	1.0−	[3] 1.0–8.0	[3] 1.0–8.0
To 200° C													5.0+	5.0+
To 235° C													8.0–18.0	8.0–18.0
To 270° C	35.0−	35.0−	30.0−	30.0−	25.0−	25.0−	20.0−	15.0−	15.0−	10.0−	10.0−	10.0−		
To 300° C	45.0−	45.0−	40.0−	40.0−	35.0−	35.0−	30.0−	25.0−	25.0−	20.0−	20.0−	20.0−	35.0−	35.0−
Softening point of residue, ° C	35–60	35–60	35–60	35–60	35–65	35–65	35–65	35–65	35–65	40–70	40–70	40–70	40–70	40–70
Typical uses and suggested temperatures for application.[4]	Prime coat; 60° to 125° F.		Prime coat and surface treatment; 80° to 150° F.		Surface treatment and road mix: 80° to 150° F.		Surface treatment, road mix, premix and seal coat; 150° to 225° F.			Surface treatment premix, seal coat, penetration and crack filler; 175° to 250° F.			Surface treatment road mix and premix when low temperature application and quick setting are desired; 60° to 120° F.	

[1] Methods of test are those of the American Association of State Highway Officials.
[2] + indicates that value shown is the minimum allowable; − indicates that value shown is the maximum allowable.
[3] This requirement was revised in 1938 to 2.0–8.0.
[4] For the guidance of the user and not a part of the specification.

TABLE 3.—*American Association of State Highway Official standard specifications for emulsified asphalt, adopted 1937*

Test requirements [1]	Specification No.[2]				
	M–47	M–48	M–51	M–49	M–50
Viscosity, Saybolt-Furol, 60 ml at 77° F., seconds	100+	20–100	20–100		
Residue by distillation, percent by weight	60–65	55–60	55–60	65+	65+.
Settlement, 5 days, percent	5−	5−	3−		
Demulsibility, percent by weight:					
50 ml of 0.1 N $CaCl_2$	[3] 30−	[3] 30−			
35 ml of 0.02 N $CaCl_2$			60+		
Sieve test, percent by weight	0.10−	0.10−	0.10−	0.10−	0.10−.
Miscibility with water, no appreciable coagulation in 2 hours	([4])	([4])		([4])	([4]).
Coating test—thorough coating and no appreciable separation of emulsion	([4])	([4])		([4])	([4]).
Freezing test—homogeneous after 3 cycles					([4]).
Residue from distillation:					
Penetration, 100 g, 5 seconds, 77° F	100–200	100–200	100–200	100–200	125–225.
Specific gravity at 77° F	1.00+	1.00+	1.00+	1.00+	1.00+.
Ductility at 77° F., cm	40+	40+	40+	40+	40+.
Solubility in carbon disulphide, percent	95+	95+	95+	95+	95+.
Ash, percent	2.0−	2.0−	2.0−	2.0−	2.0−
Specified uses	Open-graded course aggregate plant mixtures.	Open-graded course aggregate mixed-in-place construction.	Penetration macadam and surface treatment.	Bituminous concrete mixtures for repair work, summer use.	Bituminous concrete mixtures for repair work, winter use.

[1] Methods of test are those of the American Association of State Highway Officials.
[2] + indicates that the value shown is the minimum allowable; − indicates that the value shown is the maximum allowable.
[3] Specifications M–47 and M–48 were revised in 1938 by the addition of the following footnote applicable to the demulsibility test:
The limit shown is for general use. In case it is desired to specify more restrictive requirements based on prevailing climatic conditions, the following limits are suggested: For hot, dry climates, 0–5 percent; for mild climates, 5–30 percent; for cool, damp climates, 20–45 percent.
[4] Required.

in diameter and allowed to stand for 5 days. At the end of that time the top 10 percent and the bottom 10 percent of the emulsion in the cylinder are removed and a determination made of the numerical difference between the percentages of asphalt in each.

In the sieve test the emulsion is passed through a No. 20 sieve, previously wetted with a 2 percent solution of sodium oleate, and is washed through the sieve with the oleate solution. The residue on the sieve is weighed to determine the amount of coagulated asphalt in the emulsion

The test for miscibility with water is merely to insure that the emulsion can be diluted with water prior to use. The emulsion is mixed with distilled water to determine if coagulation takes place. The test is not applicable to quick-setting emulsions.

In the coating test the emulsion is mixed for 3 minutes with a standard reference stone ranging in size from one-fourth to three-fourths inch. The test is to determine if the emulsion will coat the stone thoroughly and if the mixing operation will cause appreciable separation of the asphalt from the water of the emulsion.

The freezing test, applicable only to emulsions for use in cold weather, is to determine if the emulsion can be subjected to low temperatures without detriment. The emulsion is subjected to alternate cycles of freezing and thawing to determine if it will remain homogeneous.

The other tests listed in table 3 are the same as those applied to other asphaltic materials and require no description.

The slow-breaking mixing emulsions are being used to a considerable extent in densely graded bituminous mixtures but, as yet, there are no standard specifications for them. In general, the requirements for these materials are similar to those for emulsions of the medium-breaking type except for demulsibility and the addition of a mixing test to determine if the emulsion can be mixed successfully with fine-grained material. The test for demulsibility is the same as that for medium-breaking emulsions but the amount of breakdown is usually limited to a maximum of about 2 percent. In the mixing test that is frequently used, the emulsion is mixed with portland cement and water, the amount of breakdown permitted being limited to a low percentage.

Emulsified asphalt for soil stabilization is a special grade differing from the others in that it must be capable of being mixed with large quantities of extremely fine soil materials of the clay size and it should dry rapidly after being mixed. The mixing test with portland cement and a dehydration test are frequently used for this grade of emulsion to insure that it will have the desired properties. Aside from the dehydration test, which measures the rate at which the emulsion loses water, the requirements for stabilization of emulsions are much the same as for slow-breaking mixing emulsions except that a harder grade of asphalt (50 to 100 penetration) is generally used.

The foregoing discussion of emulsified asphalts has related entirely to emulsions of asphalt in water. In addition to the extensive use of these, there has been a limited use in the United States of so-called inverted emulsions or emulsions of water in asphalt. However, their use has not been widespread and no effort has been made, as yet, to effect any standardization of requirements designed to insure their satisfactory quality.

In addition to the developments in specifications for the bituminous materials themselves, an important change has taken place in specification requirements for the coarse mineral aggregates with which they are used. This has been the rather general adoption of the Los Angeles abrasion test to replace the Page toughness test and the Deval abrasion test that have been standard for many years.

The latter two tests have a number of defects among which the following are worthy of note. The Page toughness test is made on samples taken from ledge rock and therefore is not applicable to crushed slag or gravel. The Deval abrasion test, as applied to stone, is also made on samples from ledge rock and therefore it has been necessary to modify the test method when it is used for gravel or crushed slag and it has also been necessary to specify different maximum losses for these materials than have been specified for stone. Finally, and most important, the results of these tests are not in good agreement with the observed performance of the aggregates as used in road surfaces. The Los Angeles abrasion test is not subject to the criticism that has been directed at the Page toughness test and the Deval abrasion test. It is applicable alike to crushed stone, crushed or rounded gravel, or crushed slag, and these materials may be tested after being crushed and screened to the sizes that are to be used. Moreover, there is a good correlation between test results and the breakage and crushing of the coarse aggregates that takes place under construction rollers and under traffic.

TYPES OF CONSTRUCTION

Hot-mixed pavements.—The principal types of hot-mixed and hot-laid bituminous pavements used in the United States are coarse-aggregate asphaltic concrete, fine-aggregate asphaltic concrete, and sheet asphalt. It is unnecessary to describe them in detail here since this has been done in the report of 1930 and in other literature. No essential changes have been made in recent years in the design and construction of these types, except in the increased use of improved construction equipment. The new equipment will be described later.

In addition to these standard types that are mixed hot and laid hot, a number of proprietary mixtures have been developed that are designed to be laid cold. These differ from the standard mixtures primarily in the kind of asphaltic materials, or the combinations of them, that are used and in the special procedures that are employed in their preparation.

The heavier grades of tar (RT–8 to RT–12, table 2) are also used to a limited extent in dense graded pavements that are mixed hot and laid, either hot or cold, in two courses. The principal difference between those designed to be laid hot and those designed to be laid cold is that the former have greater density and greater initial stability due to the use of finer aggregates and heavier tar cement.

Bituminous macadam.—The construction of bituminous penetration macadam with asphalt cement or tar does not require description or comment since no significant changes in practice have taken place since the date of the last report.

Cut-back asphalts are being used to a limited extent in penetration macadam and are particularly useful for work in cold weather. Materials of the RC–4 grade (see table 1) or even more viscous grades are used for this purpose. When cut-back asphalts are used it is desirable to use a coarse crushed aggregate of somewhat smaller size than is employed customarily when hot materials are used.

The use of emulsified asphalt for bituminuous macadam construction has increased materially, and when it is used some changes in the standard construction procedure are required. In hot penetration construction the voids between the pieces of coarse stone are left open in order that the bituminous material may penetrate before it cools. When emulsified asphalt is used it is necessary to choke the voids with clean stone chips prior to the first application of bituminous material. This necessary modification of hot penetration practice was first used in Great Britain and Continental Europe. The subsequent application of keystone is usually followed by two light applications of emulsion, each covered with stone chips and rolled, and these in turn are followed by a light seal coat of emulsion that is covered with sand. In general, a somewhat smaller quantity of bituminous material is used for a given thickness of macadam constructed with emulsified asphalt than is usually considered necessary when asphalt cement or tar is used.

Low-cost surfaces.—The term "low-cost" as applied to roads and road surfaces has come into general use in the United States in recent years and its meaning is frequently misunderstood. Such roads and road surfaces are "low-cost" or not, depending entirely on one's conception of what constitutes a low cost. Actually they cost an appreciable sum per mile and an enormous sum in the aggregate. They are not inexpensive but merely less expensive than the higher types of pavement such as sheet asphalt, asphaltic concrete, or portland-cement concrete. But these low-cost surfaces, if constructed on adequate bases, are capable of carrying a large volume of motor-vehicle traffic, including an appreciable percentage of heavy trucks. Their use has made possible the construction of much greater mileages of surfaced roads, on the primary highway systems in sparsely populated areas, and on the secondary highway systems in more thickly populated areas, than otherwise would have been possible.

Low-cost bituminous surfaces, as used in the United States, may be divided into three general classes as follows:

1. Surface treatments.
2. Open-graded or coarse-aggregate surfaces.
3. Dense-graded surfaces.

The open-graded and dense-graded surfacing mixtures may be either mixed in place on the road, premixed in a traveling mixing plant, or premixed in a stationary mixing plant.

It is in these types of bituminous road surfaces that the greatest progress has been made since the Congress of 1930. In these types of construction the greatest amounts of liquid bituminous materials are used and the increased consumption of these products in recent years is an index of the extent to which the low-cost surfaces are being utilized. However, it should be noted that some of the road surfaces of this class are not resistant to the mutilative effect of steel-tired wheels and the hoofs of animals. The United States is fortunate in having very little highway traffic of this character.

Surface treatments or carpet coats are used on water-bound macadam, sand-clay, sand-clay-gravel, or other stable bases and on old bituminous surfaces. Widely varying materials are used and there is a considerable variation in construction procedures. However, disregarding minor refinements, the general practice is to prime the base with bituminous material and, after this has penetrated and dried, a heavier bituminous material is applied. This is covered immediately with clean coarse aggregate, generally having a maximum size of 1 inch or less, and this is rolled. Another coat of bituminous material is then applied and this is covered with stone chips and rolled. It is considered good practice to seal the resulting surface with another light application of bituminous material which is covered with chips and rolled. The seal may be applied at the time of construction or application may be delayed for several months. The net result is a carpet or mat having a thickness of about three-fourths inch and composed of bituminous binder and open-graded aggregate. The one thing common to all surface treatments is that the bituminous material is applied by means of a pressure distributor.

For prime coat, the lighter grades of tar or medium-curing cut-back asphalt are used, the grade selected being dependent on the density of the surface to be primed. The prime coat is sometimes omitted, particularly when surface treating old bituminous pavements or when using emulsified asphalt.

The bituminous materials applied after the prime coat are usually of heavier grades and may be hot asphalt cement, rapid-curing cut-back asphalt, tar or quick-breaking emulsified asphalt. The grade of material selected is dependent to a certain extent on weather conditions, the lighter grades being used in the spring and fall and those of higher viscosity in the summer. In connection with the growing tendency to use the heaviest grades of material that are suitable for the type of construction, attention should be called to the fact that the typical uses of the various grades of liquid asphaltic road materials, shown in table 1, are not entirely in accord with current practice. Great quantities of rapid-curing cut-back asphalt are used in surface treatment work and the RC–1 grade has been used extensively but there has also been a considerable use of the more viscous grades, even including RC–4.

The open-graded or coarse-aggregate surfaces are, as the name implies, composed of bituminous material and clean coarse aggregate free from dust. This type of surface is known by a variety of names, the most common of which is "retread treatment." It is used extensively, particularly for surfacing old gravel or macadam roads and for resurfacing old pavements that are worn or that have excessively high crowns which require flattening. The open-graded surfaces are used to the greatest extent in the eastern part of the United States.

As in the case of surface treatments and other types of bituminous construction, the details of construction vary somewhat in different States. In general, the procedure for road-mix or mixed-in-place construction is about as follows. After the base or old pavement surface has been prepared by removing loose dust, it may or may not, depending on its character, be given a prime treatment with light tar or cut-back asphalt. The coarse aggregate is then spread over the surface to the required depth and bituminous material is applied with a pressure distributor. The materials are then mixed with disk harrows, blade graders, or other simple mixing equipment, after which the mixture is spread and rolled. This is followed by an application of bituminous material and chips to choke the voids in the base mix and this, after being rolled, is given a seal coat of bituminous material, covered with chips or sand, and rolled.

It is frequently desirable to premix the coarse aggregate and bituminous material, either in a portable mixer at the site of the work or in a stationary mixing plant convenient to the supply of aggregate, rather than to mix it in place on the road. In such cases the details of construction, after the base mixture has been spread, are the same as for mixed-in-place work.

The thickness of open-graded surface courses varies from about 1¼ to 2½ inches and the size of the coarse aggregate used is dependent on this thickness. Typical requirements for size of aggregates are those of the American Association of State Highway Officials, shown in table 4. The size designations (34B, 3A Modified, etc.) given at the tops of the columns in table 4 are standard size designations of the Simplified Practice Recommendations for sizes of coarse aggregates for use in highway construction. In table 4 the same aggregate is specified for the key or choke stone and for the seal or cover stone. A size intermediate between that of the coarse aggregate and the cover stone is sometimes specified for the choke stone.

Rapid-curing cut-back asphalt, tar, and emulsified asphalt are all used in open-graded road-mixed or plant-mixed surface courses. In plant mixes it is advantageous to use heavier, less volatile grades of asphalt cutbacks and tars than are used in road mixes since these do not require as much aeration before the mixture is ready for compaction. Cut-back asphalt

TABLE 4.—*American Association of State Highway Officials proposed standard specification for crushed stone, crushed slag and crushed gravel for open-graded bituminous road-mix surface course. Size requirements for aggregates* [1]

Sieve size (square openings)	Coarse aggregate			Choke and seal
	34 B	3A modified	45 B	5B modified
	Percent	*Percent*	*Percent*	*Percent*
2-inch	100			
1½-inch	90–100	100		
1-inch		90–100	100	
¾-inch	30–65	40–75	90–100	
½-inch		5–20		100
⅜-inch	0–10		20–55	90–100
No. 4	0–5	0–5	0–10	10–30
No. 8			0–5	0–8

[1] Figures given are percentages passing the various sieves, by weight.

of grade RC–3 (table 1) is commonly used for road mixes in warm weather, RC–2 for road mixes in cold weather, and RC–4 for plant mixes. The tars used range in grade from RT–6 to RT–9 (table 2). When emulsified asphalts are used, those of the medium-breaking or slow-breaking types are used for mixing with the coarse aggregate and quick-breaking emulsion for the subsequent applications.

The dense-graded surfaces of the low-cost type were first developed and used extensively in the States of the Pacific Coast and they are still used to the greatest extent in the western half of the United States. They were utilized first to eliminate dust and reduce the loss of road metal from untreated fine-crushed rock and gravel surfaces and in the early stages of their development the slow-curing liquid asphaltic materials were used exclusively. Since then the use of asphalt cutbacks of the medium- and rapid-curing types has been found to be advantageous and now all three types of liquid asphaltic materials are used. Emulsified asphalts of the slow-breaking type are also being used but not in such great quantities as the other materials. As this type of construction has become standardized more attention has been given to the grading of the mineral aggregate and to the character of the fine mineral material which, if of unsatisfactory quality, is likely to cause failure.

The dense-graded surfacing mixtures of the low-cost type are mixed in place on the road, or mixed in traveling mixers or in stationary mixing plants. When mixed in place on the road the operations are much the same as in the case of the open-graded mixtures except that a great deal more manipulation is required. If rain happens to fall when mixing is in progress, the mixing operations may be extended greatly due to the necessity of reducing the moisture content to a low percentage. When the traveling mixing plant is used the graded aggregate, which is placed along the road in a windrow of proper size, is picked up and mixed by the machine and deposited behind it ready for spreading and compaction. As compared with road mixing, the traveling mixer is advantageous in permitting a better control of the proportioning of materials, in securing a more uniform mixture, and in eliminating much of the delay and expense caused by rain. The stationary mixing plant has all the advantages of the traveling mixer and, in addition, permits a much more accurate control of the proportioning of materials. Both types of mixers have the common advantage of permitting the use of asphaltic materials of greater viscosity.

Upon completion of the mixing operation the dense-graded mix is spread and compacted to a thickness of from 1½ to 3 inches. Compaction was formerly effected entirely by traffic accompanied by blading of the surface, but there is a growing tendency to supplement this by compaction with rollers. It is also the preferred practice to seal the compacted surface with a light application of bituminous material which is covered with chips or sand.

Typical requirements for grading of the aggregates are those of the American Association of State Highway Officials, shown in table 5. These grading requirements are supplemented by other requirements designed to prevent failures of the type that have taken place in the past. Failures in dense-graded surfaces of the low-cost type have been attributed to two principal causes: Lack of adhesion, in the presence of water, between the aggregate and the bituminous materials which are of relatively low viscosity; and the tendency of the fine-grained filler material to swell and become plastic when wet. In the proposed specifications of the American Association of State Highway Officials it is required that the aggregate, when mixed with the bituminous material that is to be used, shall be resistant to the action of water; that the portion of the aggregate passing the No. 40 sieve shall not have a plasticity index greater than 6; and that the bituminous mixture shall not swell unduly when subjected to the standard test for swelling.

TABLE 5.—*American Association of State Highway Officials proposed standard specification for crushed stone, crushed slag and crushed gravel for dense-graded bituminous road- and plant-mix surface course. Size requirements for aggregates* [1]

Sieve size (square openings)	Mix	Seal	Sieve size (square openings)	Mix	Seal
	Percent	*Percent*		*Percent*	*Percent*
1-inch	100		No. 4	45–65	
¾-inch	85–100		No. 10	30–50	0–5
½-inch		100	No. 200 [2]	5–10	0–2
⅜-inch		90–100			

[1] Figures given are percentages passing the various sieves, by weight.
[2] A smaller percentage passing the No. 200 sieve may be specified by the engineer.

There is no standard practice with respect to the liquid asphaltic materials used in dense-graded, low-cost surfaces. Slow-curing materials and medium- and rapid-curing cut-back asphalts are all used extensively, although at present there is probably a considerably greater use of the slow-curing products and the medium-curing cutbacks than of the rapid-curing materials. The consumption of cut-back products for this type of construction is increasing rapidly since they have a decided advantage over the slow-curing materials in that they result in mixtures that are tougher and more resistant to the action of water and the abrasion of traffic. When asphalt cutbacks are used it is necessary to select the type with respect to the available mineral aggregate since the rapid-curing materials cannot be mixed successfully with aggregates containing a high percentage of material passing the No. 200 sieve. Five percent passing the No. 200 sieve is usually considered the maximum amount of fine material if rapid-curing cutbacks are used and if greater amounts of the fine material are present it is necessary to employ the medium-curing products.

In addition to the extensive use of dense-graded road surfaces containing liquid asphaltic materials, there is a more restricted use in the eastern States of the same general type of construction in which the graded aggregate is mixed with tar.

Stabilized bases.—A major development, since the Congress of 1930, has been in the design and construction, with soil materials (gravel, sand, silt, and clay), of the so-called stabilized bases that are suitable for bituminous surfacing. The use of soils in highway construction is the subject of another report to the Congress and therefore a detailed discussion of this topic is not appropriate here. However, it is necessary to mention stabilized bases since bituminous materials are being used in their construction in an ever increasing amount.

Given a supply of granular materials of suitable grading and fine soil binder of satisfactory quality, it is possible to proportion these materials for base-course construction so that satisfactory performance in service will be assured. But when the granular materials available are insufficient in quantity or of inadequate grading, or the soil binder is of unsatisfactory quality, it is necessary to overcome these defects by some means and bituminous materials have proven effective.

Emulsified asphalt of the slow-breaking type has been used more extensively in base stabilization than the other bituminous materials but tar and slow-curing, medium-curing, and rapid-curing liquid asphalts have also been used with success. However, bituminous base stabilization must still be considered as largely in the experimental stage.

In this type of construction the usual practice is to pulverize the soil material that is to be stabilized, add bituminous material in one or more applications, and mix it on the road. On account of the large amount of fine-grained soil and the relatively small amount of bituminous material used, it has been found that a uniform mixture can be obtained only by adding considerable quantities of water to the mix. This is necessary even with emulsified asphalt. The mixing is done with harrows and blades and the resultant mixture has the appearance and consistency of soft mud. It is spread, permitted to dry to a moisture content that will permit compaction, and is then compacted with sheepsfoot rollers or multiple-wheel rollers with pneumatic tires. Rollers of this type are preferred since they produce the kneading action, so essential to thorough compaction, that cannot be secured with ordinary road rollers.

In addition to the road-mix method that has been described, mixing is also done with traveling mixers of the same type as those used in the preparation of surfacing mixtures.

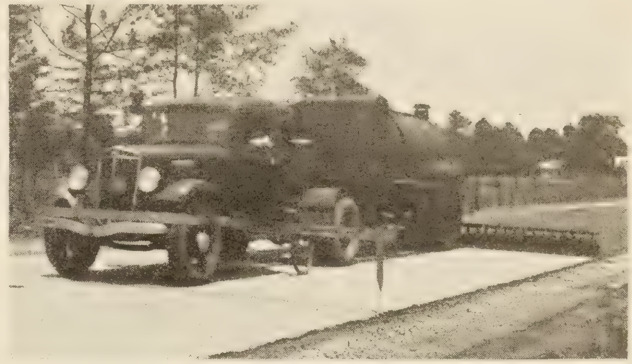
In the road-mix method, the bituminous materials are always applied with pressure distributors except when a machine known as a sub-oiler, designed especially for the purpose, is used. This machine introduces the liquid bituminous material into the pulverized soil by means of pipe lines attached to scarifier teeth.

The stabilized soil layer thus produced is generally too friable to withstand the action of traffic and it is customary to protect it with a bituminous surface, usually one of the low-cost types.

CONSTRUCTION EQUIPMENT

A major development in connection with bituminous road construction in the United States has been the improvement of old types of construction equipment and the development of many new types. The introduction of new machines designed for special purposes has resulted in better and more economical construction and has had an important influence on present practices.

General improvements, common to a number of types of equipment, have been the substitution of pneumatic tires for steel or solid-rubber tires, the adoption of Diesel-type power units where practicable, a change from mechanically operated controls to those designed for compressed-air or hydraulic operation, and a general increase in capacity of all equipment.



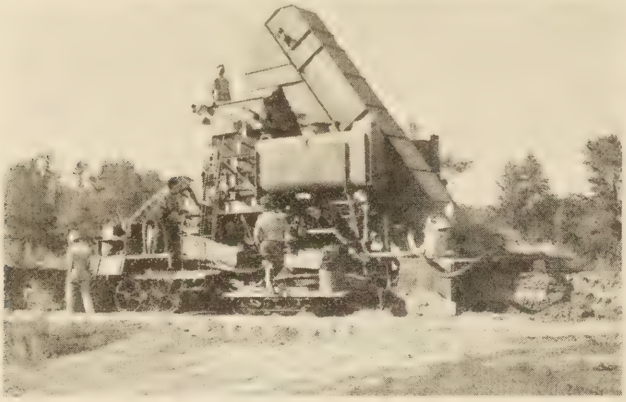
Bituminous Distributor with Full-Width Spray Bar and Tachometer Actuated by an Auxiliary Wheel.

Asphalt plants.—Stationary plants for the manufacture of hot asphaltic paving mixtures have been greatly improved both from the standpoint of design and that of control of operations. The operation of the modern plant is largely automatic, a recent improvement being temperature control of the aggregates in the drier by means of a pyrometer that regulates the burners. This insures delivery of the aggregate to the hot elevators at a more constant temperature with a resultant improvement in the uniformity of the mixing operation. The automatic feeding of aggregates to the drier is becoming common practice. In the past the asphalt heaters used at asphalt plants have usually been of the oil-burning type but an electric heater has been developed that can be used to advantage where the cost of electric power is low. The new electric heater is automatic and will control the temperature of a tank of asphalt within narrow limits, thus reducing the danger of damaging the material by overheating.

Automatic plant control has brought about a great improvement in the quality of the product and has also contributed materially to increased production which has resulted in a lowering of costs.

Asphalt heaters and distributors.—Bituminous road materials are usually shipped in railroad tank cars having a capacity ranging from 6,500 to 10,000 gallons and these cars are equipped with coils for the purpose of heating the material when necessary. The low-pressure steam heaters formerly used are gradually being discarded in favor of high-pressure steam heaters that are more efficient and more easily portable. With this equipment it is possible to raise the temperature of the material in a 10,000-gallon tank car as much as 50° F. in one hour. The shipment from the refineries of heated materials in insulated tank cars and the use of the improved heaters has greatly reduced the time required to transfer material from the tank car to the distributor.

Pressure distributors for the application of bituminous materials are employed in all types of bituminous construction that do not involve plant mixing. The sizes most commonly used have capacities ranging from 600 to 1,500 gallons. The general design of distributors has not changed greatly but refinements in design have increased the ease and efficiency with which materials are handled. More uniform distribution is made possible by increased capacity of pumps and by better heating and circulating systems. Accuracy in the rate of distribution is aided by tachometers,



Traveling Mixing Plant that Picks up the Mineral Aggregate from a Windrow, Mixes it with Bituminous Material, and Deposits the Finished Mixture Behind the Machine.

actuated by an auxiliary wheel, or by other forms of governors that synchronize the speed of the pump and the speed of the truck. Another improvement is a new spray-bar that eliminates dripping as soon as the flow is stopped. This is accomplished by applying suction from the pump or by cut-off valves for each nozzle.

Portable mixing and spreading equipment.—For mixed-in-place construction the greatest use is made of such simple equipment as spring-tooth harrows, disk harrows, and blade machines. An improvement in the disk harrow has been made by mounting the disks in a frame carried on rubber-tired wheels. This permits the disks to be lifted clear of the ground and is advantageous in turning the equipment. The grader machine with a single blade and the multiple-blade machine are both used extensively in road-mixing operations. The multiple-blade machines have four or more blades set in pairs for mixing and for striking off. An improvement in this equipment is obtained by setting the blade assembly in a chassis mounted on rubber-tired wheels, with provision for quickly raising and lowering the blades.

Several types of traveling mixing machines are now available and their use is increasing rapidly. In one type, one or more pug-mill shafts are installed at the front of the machine and, as it moves forward, mixing of the aggregate and bituminous material, previously distributed on the road, is effected in one passage. In another type the aggregate, previously placed in a windrow on the road, is picked up and elevated to a continuous mixer. There the bituminous material is added and mixed, and the finished mixture is then deposited on the road in the rear of the machine.

For the types of construction in which the aggregate is placed in windrows along the road, it is desirable that the windrow be of uniform cross-section and that it contain the required amount of material. A useful device for this purpose is dragged by a tractor over the roughly formed windrow, bringing it to uniform section by means of adjustable tail gates and moving excess material forward.

Brooms and broom drags.—For cleaning road surfaces prior to bituminous construction, better and speedier rotary brooms have been developed and these, combined with motor-driven blowers, make it possible to clean a surface more effectively and economically than can be done with hand brooms.

For spreading small-size aggregate in macadam construction or in surface-treatment work, or for mixing and spreading small quantities of bituminous material

A Broom Drag.

and small-size aggregate, the broom drag has been found very useful in effecting uniform distribution and smoothness of surface. These drags are fairly large and contain several rows of stiff-fiber or wire brooms.

Aggregate spreaders.—Mechanical spreaders, that insure uniformity of distribution of aggregate, are practically always used in the construction of penetration macadam and surface treatments and they are also used in some types of road-mix construction. These are of various types and forms. In one type the aggregate is spread directly from the rear of a dump truck by spreader devices built into the tail gate or attached to it. A second type includes hoppers of various forms, either pulled by a truck or self-propelled, that may be adjusted to spread a layer of aggregate in any amount desired. A third, and rather novel type, consists of two small wheels on an axle that carries, and is geared to, a revolving circular steel plate. This device is attached to the rear of a dump truck loaded with aggregate. As the truck moves forward the aggregate is permitted to fall through the tail gate of the truck onto the revolving plate which sprays it over the road surface. This type is designed for relatively light applications of aggregate in surface treatment.

A Sheepsfoot or Tamping Roller Which Is Very Effective in Compacting Bituminous-Stabilized Bases that Contain a High Percentage of Fine-Grained Material.

Rollers.—For the compaction of bituminous-stabilized bases and bituminous mats the ordinary construction rollers having wide, smooth steel wheels are not generally satisfactory and three special types of rollers, none of which is self-propelled, are used for this purpose. One of these is the sheepsfoot or tamping roller which is not new but which has not been used extensively until recent years. This roller consists of a hollow metal drum, which may be filled with water, and which is studded on its outer surface with metal projections.

These studs are about 6 inches long, of small diameter and end in flat heads somewhat larger than the shanks. These rollers are very effective in obtaining uniform compaction throughout the entire depth of layers of fine-grained soil materials.

A second type is a multiple-disk roller in which 10 or more heavy metal disks, about 3 feet in diameter and 2 inches thick, are mounted a few inches apart on a single axle. The third type is the multiple-wheel pneumatic-tired roller. This is a trailer having either one or two axles, on each of which are mounted, at close spacing, as many as 5 truck wheels equipped with large pneumatic tires. The trailer body may be loaded with any desired weight. This roller is very effective in producing the kneading action that is necessary in compacting bituminous-stabilized bases and dense-graded bituminous surfaces.

A valuable improvement has been made in the conventional tandem and three-wheel rollers that are used so extensively in bituminous pavement construction. This is the addition of an auxiliary roller on a third axle. In the case of the tandem machine the auxiliary roller is of about the same size as the forward roller and is placed in front of it. In the three-wheel machine the auxiliary roller is of considerably smaller diameter than the main rollers and may be placed either between the front and rear axle or behind the rear axle. The auxiliary roller is adjustable as to height and is very effective in eliminating surface irregularities and in producing smoother pavements.

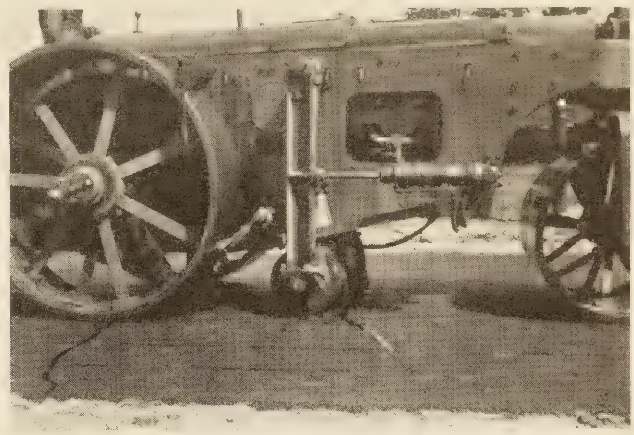
Finishing equipment.—One of the important developments in the construction of plant-mixed bituminous surfaces has been the introduction of mechanical equipment for spreading and leveling the mixture preparatory to rolling. These finishers are of three principal types: The first type is supported on side forms of wood or steel; the second provides its own forms, being supported on long skids or runners that carry the machine over slight depressions and minimize the effect of these irregularities in the base; and the third is carried on rollers of moderate diameter.

The bituminous mixture may be deposited on the road from a hopper that is a part of the finishing machine or it may be dumped from trucks and shoveled into place by hand. One type of hopper contains a horizontal shaft equipped with blades that agitate the mix, thus breaking up lumps and preventing segregation. The mix then flows through the bottom of the hopper and falls in front of the screeds that spread it to a uniform thickness.

Finishing machines are almost always power driven and many of them have an attachment for heating the screed so that the mixture will not cool too much during the spreading process. Some machines have two or three screeds and in the latter case the middle screed is equipped with teeth that rake and loosen the mixture prior to the passage of the last screed. The selection of the type of finisher most suitable for the work depends somewhat on the character of the bituminous mixture but it is becoming common practice to specify the use of some type of mechanical finishing equipment, particularly for the higher types of pavement such as sheet asphalt and asphaltic concrete.

LABORATORY RESEARCH AND FIELD INVESTIGATIONS

The asphaltic road materials used in the United States are produced largely from petroleum that is obtained from a great number of sources and refined by a variety of processes. Petroleum from the different sources varies greatly in character and crude oil from the same source may yield asphaltic materials of widely different character, depending on the method of refining. The cracking processes, designed to increase the yield of gasoline, are used extensively and these produce asphaltic residues that are not always of satisfactory quality.



Three-Wheel Road Roller With Auxiliary Adjustable Roller.

Early in the period that has seen such a great increase in the consumption of liquid asphaltic materials, failures of the lower-cost and lower-type surfaces in which they are used aroused interest in their quality. This interest has been extended, with good reason, to asphalt cements that, in the previous period, had not been the object of serious suspicion. With respect to road tars a new problem has been introduced by the greatly increased production of heavy water-gas tars from heavy carbureting oils of what are known as the "residuum" type. These have largely replaced the light water-gas tars formerly produced.

Experience has shown that one of the most important properties of a bituminous road material is its durability or resistance to weathering, and it is recognized that there are no existing specification requirements that insure this property. As a result a number of agencies have concerned themselves with research work designed to develop some test for predetermining the durability of bituminous materials. These studies have included the exposure of test samples to atmospheric weathering in the open and to the action of heat, light, water, and freezing temperatures in the laboratory and the attempt to correlate the results with the behavior of roads in service. Several reports of work that has been done are listed in the bibliography (*2*).

The dissatisfaction with asphaltic materials that have been injured in refining, either by overheating or by being subjected to cracking processes has resulted in the development of the Oliensis spot test (*3*) and the test for xylene equivalent (*4*). The Oliensis spot test is not claimed to be a test of quality. It is merely an arbitrary measure of heterogeneity and serves to identify those materials that, through cracking or overheating, have been rendered sufficiently heterogeneous to react to the test. A number of State highway departments that have had trouble with cracked materials are using this test to exclude them. The xylene equivalent is a modification of the Oliensis test designed to give a quantitative measure of the degree of heterogeneity.

The cracking of sheet asphalt and asphaltic concrete pavements is a problem that is engaging the attention of a number of investigators. Studies have been and are being made of the characteristics of these paving mixtures at low temperatures, as disclosed by tests for toughness, shearing strength, compressive strength, tensile strength, and modulus of rupture and modulus of elasticity in flexure. Also the hardness and ductility of asphalts extracted from existing pavements are being correlated with the prevalence of cracking. Recent reports of investigations of this character are listed in the bibliography (*5*).

Since hardening of the asphalt in a paving mixture has been found to reduce the resistance to cracking, considerable attention is being given to studies of the changes that take place in the asphalt during the operations of mixing and placing (*6*). It has been found that both the time of mixing and the temperature of the materials have important effects on the hardening and decrease in ductility that occur and that different asphalts are affected to different degrees. Such investigations, which involve the extraction and recovery of asphalt from paving mixtures, have been aided greatly by the recovery methods of Abson and Bussow (*7*).

Numerous studies are being made of the resistance, in bituminous mixtures, of the stripping of the bituminous films from the mineral aggregate in the presence of water. In the field of base stabilization with bituminous materials the studies of Winterkorn (*8*) in surface chemistry are being continued.

Numerous field investigations, involving the construction and observation of experimental roads, are being conducted. Included in these are numerous investigations of the stabilization of base courses with bituminous materials. Also studies are being made of the use, in asphaltic concrete pavements, of softer asphalts than are generally considered suitable. A great deal of publicity has been given to the use, in the United States, of cotton fabric for the reinforcement of bituminous road surfaces. Several hundred miles of experimental roads have been built in which surface treatments, and similar types of light bituminous surfacing, have been reinforced with coarsely woven cotton fabric. However, these experimental roads have not been in service long enough to demonstrate the merits of the reinforcement.

SUMMARY

1. Since the Congress of 1930 the use of bituminous road materials in the United States has increased greatly. This increased consumption is accounted for entirely by the increased use of liquid products in bituminous road surfaces of the low-cost type and in the construction of bases for these surfaces.

2. The low-cost types of bituminous surfaces are: Surface treatments, open-graded surfaces, and dense-graded surfaces. Great progress has been made in the development and improvement of these types.

3. Liquid asphaltic products, tars, and emulsified asphalts are all used successfully in the low-cost types of surfaces.

4. Many of the improvements that have been made are the direct result of the development of numerous new types of construction equipment.

5. Important progress has been made in the design and construction, with soil type materials, of bituminous stabilized base courses suitable for low-cost bituminous surfaces. To a great extent the use of bituminous products in stabilizing soil materials for base course construction is still in the experimental stage. However, emulsified asphalt has been used with notable success, as well as tar, slow-curing liquid asphalt, and cutback asphalt.

6. The quality of bituminous road materials, particularly with respect to their durability, is not assured by existing specifications. Information on this question is being sought in a number of different investigations.

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(*Continued from page 57*)

applies particularly to the mixing and distributing units which in their present form cannot handle concrete of much lower slump than 1 inch. This phase of the problem will unquestionably receive attention in the near future.

Curing.—For the curing of concrete pavements, cotton mattresses, composed of cotton "bats" covered with cotton cloth, have recently been employed to a considerable extent.[7] This type of covering material, in addition to performing the usual function of a curing medium by protecting the surface against loss of moisture and supplying needed moisture to the surface, has the ability to insulate the concrete against extreme changes in temperature during the curing period. Field experiments are now being conducted in various parts of the United States for the purpose of determining the practicability of this type of mattress or mat in the actual construction process.

Additional equipment and construction methods.—There has been no marked recent change in the type of equipment used in handling and transporting materials from the proportioning plant to the mixer. Locomotive or caterpillar cranes are used in moving the materials from freight cars to overhead proportioning bins. Trucks hauling from one to five batches, including cement, transport the materials to the mixer. Industrial narrow-gage railroads are now employed only where trucking is impracticable, such as over sandy subgrades.

Dual-drum mixers have been developed, whereby the batches are mixed in one drum for about half of the mixing period and then transferred to the other for the remainder of the period. With this equipment it has been found possible to increase production about one-third over that of a single-drum mixer. Occasionally, where conditions are favorable, two mixers have been operated at the same location. In some States of the United States, the hauling of materials over the subgrade ahead of the mixer and the operation of the mixer on the subgrade are not permitted, except where such procedure is unavoidable.

Recently a power-driven longitudinal float has been developed, which is operated back of the finishing machine, taking the place of the hand-operated longitudinal float. It is claimed that a more nearly perfect crown and surface can be produced with it.

Internal vibrators of the spud type have come into use for consolidating concrete around joints and adjacent to the forms.

II. CEMENT-BOUND MACADAM

After having fallen into disuse, the construction of cement-bound macadam has again returned to use mainly as a means of employing large numbers of otherwise unemployed men.

In 1933 the Portland Cement Association undertook a laboratory and field investigation to determine the requirements for coarse aggregate and grout in this work, and to study construction methods. A suitable test for fluidity of grout, the "flow cone" test, was developed, and the necessary properties of grout for various sizes of coarse aggregate were determined. Both gravel and crushed stone coarse aggregate were used successfully and depths up to 10.6 inches were effectively penetrated with grout, without resorting to any special method to facilitate the flow. Compaction of gravel coarse aggregate before grouting was found impracticable, and compaction of crushed stone reduced the grout consumption. Satisfactory results were obtained with hand tamping.

The tests showed that compaction after grouting, when properly timed, increased the strength of the slab by reducing voids left by escaping water. Heavy rollers, however, forced some of the coarse aggregate into the subgrade, which had been softened by water from the grout, and caused irregularities in the surface which were difficult to remove. Compaction by hand tamping gave slightly lower strengths, but loss of material into the subgrade was eliminated. Compaction by vibration also gave good results, but the available equipment was not practical.

Employing the information thus made available, appreciable quantities of cement-bound macadam have since been laid, largely as a measure of work relief for the unemployed. One development in the field has been the successful use of broken brick and concrete from old pavements as a part of the coarse aggregate.

[7] Public Roads, Vol. 14, No. 5, July 1933; and Vol. 15, No. 9, November 1934.

III. CEMENT-HARDENED EARTH ROADS

With the objective of developing a material suitable for low-cost, all-weather, secondary road surfaces, as well as methods of construction, rather extensive laboratory and field experimentation with soil-cement mixtures has been carried on during the last few years. As a general rule, this work has beeen done by the Portland Cement Association in cooperation with various States and the United States Bureau of Public Roads.

While this type of construction is by no means out of the experimental stage, definite principles governing soil-cement mixtures have been established and experience has shown that laboratory work must precede the field work in order that any degree of success may be assured.

Each field job has simplified the application of laboratory results with attendant economies of construction. The surfaces constructed are capable of withstanding a considerable amount of traffic. The projects constructed to date have gone through one winter without structural disintegration.

(*Continued from page 60*)

pavement slab was installed in the driveway entrance to the plant of a paving-brick company in Illinois. Brick were placed in a "basket weave" manner with three brick constituting a unit. Reinforcement, consisting of ⅜-inch round deformed bars was placed at 8¾-inch centers both ways, 1 inch from the bottom, and all joints were filled with 1 : 2 cement mortar. Two weeks after the slab was completed an excavation was made under one side creating a clear span of 5 feet. It is estimated that during the past 6 years 25,000,000 paving brick have been trucked over the pavement which shows no sign of distress over the excavation.

Encouraged by the success of this experiment, additional test installations are now being planned in Ohio and Illinois. Instead of using standard paving brick in basket weave pattern, large vitrified units 3½ by 8 by 8-inches have been manufactured. They will be laid by hand in checkerboard pattern, properly spaced, and reinforcing rods will be placed in two directions in the cement-grouted joints.

MUNICIPAL USE

Vitrified brick are widely used as a paving material by municipalities in the United States. Engineers generally regard it as a superior type of surface for streets carrying heavy and destructive traffic, and it is frequently used for all types of streets in districts close to brick plants.

Many kinds of bases are used in cities but as in rural road practice, concrete is most popular over the entire country. Mixes vary but cities seldom use a mix richer than 1 part cement, 2½ parts fine aggregate, and 5 parts course aggregate while the leaner proportioning known as the 1 : 3 : 6 mix is more widely used at present. A few cities use a 1 : 2 : 4 mix. Depths vary from 5 to as much as 10 inches, the popular average being 6 inches. There seems to be little, other than individual preference, to account for the wide variation in practice.

Beds or cushions used in municipal practice are also similar to those used on rural highways. However, in addition to the mastic beds, many cities are still successfully using plain sand.

In municipal work a 3-inch depth brick is generally used and a wire cut surface is exposed to traffic to avoid slipperiness. The rather complete motorization of all services in American cities with the resulting elimination of the horse has largely done away with the hillside brick although some are still used.

The type filler in most general use in cities is a so-called hard asphalt with low penetration and a high melting point. Use of the softer asphalts has resulted in a substantial loss of the filler from the joints in hot weather and slipperiness caused by the adherence of the filler material to the wearing surface of the brick. Use of the hard asphalts does not entirely cure this trouble and materials of the experimental types previously mentioned are being tried for city as well as rural use.

In recent years many old brick pavements in cities have been relaid, either on the old bases or on new foundations, which results in appearance and service value approaching those obtainable with entirely new construction. As the removing and cleaning of the old brick before relaying is entirely a labor item, the cost varies with the wages paid. The cost of cleaning is also dependent upon the type of filler used in the original construction, varying between the extremes of plain sand and rich cement grout. In most of the old pavements the brick were laid on edge. When relaid they are frequently laid flat, according to present-day practice, and there is a gain in surface area. This fact affects the percentage of salvage measured by the area covered by the relaid brick. In some cases this has actually resulted in a salvage greater than 100 percent and a surplus of brick which were used for additional paving. However, the average proportion of salvaged brick is about 80 percent. Owing to the increase in manufacturing costs since the brick pavements were originally constructed years ago, the relay value of the brick is in many cases materially greater than the original cost.

STATE MOTOR-FUEL TAX RECEIPTS, 1937

(Compiled for calendar year from reports of State authorities)

State	Tax rate per gallon		Date of rate change	Receipts from taxation of motor fuel			Other receipts in connection with motor-fuel tax					Net total receipts
	On Jan. 1	On Dec. 31		Gross receipts	Refunds paid	Net receipts	Distributors' and dealers' licenses [1]	Inspection fees [2]	Fines and penalties	Miscellaneous receipts [3]	Total	
	Cents	*Cents*		*1,000 Dollars*	*1,000 Dollars*	*1,000 Dollars*	*1,000 Dollars*	*1,000 Dollars*	*1,000 Dollars*	*1,000 Dollars*	*1,000 Dollars*	*1,000 Dollars*
Alabama	6	6		13,295		13,295		55			55	13,350
Arizona	5	5		5,059	734	4,325	(*)		8		8	4,333
Arkansas	6½	6½		9,877		9,877		85			85	9,962
California	3	3		51,486	4,872	46,614	10				10	46,624
Colorado	4	4		8,659	1,228	7,431						7,431
Connecticut	3	3		9,640	195	9,445	51				51	9,496
Delaware	4	4		2,173	142	2,031	3				3	2,034
Florida	7	7		22,023		22,023	49	394			443	22,466
Georgia	6	6		19,550		19,550						19,550
Idaho	5	5		4,532	497	4,035				2	2	4,037
Illinois	3	3		38,907	3,071	35,836		428	2		430	36,266
Indiana	4	4		24,699	1,712	22,987	(*)	509		1	510	23,497
Iowa	3	3		14,836	1,813	13,023	1	23			24	13,047
Kansas	3	3		10,083		10,083	6	104		43	153	10,236
Kentucky	5	5		12,671		12,671						12,671
Louisiana	7	7		15,923		15,923		75	2	(4)	77	16,000
Maine	4	4		5,755	205	5,550						5,550
Maryland	4	4		10,587	730	9,857						9,857
Massachusetts	3	3		20,712	876	19,836						19,836
Michigan	3	3		30,774	1,349	29,425	4			1	5	29,430
Minnesota	3	4	Apr 23	17,594	2,301	15,293	1	199			200	15,493
Mississippi	6	6		10,801	579	10,222				(5)		10,222
Missouri	2	2		11,675	593	11,082		124	11		135	11,217
Montana	5	5		5,424	843	4,581						4,581
Nebraska	5	5	(6)	11,157	232	10,925		105			105	11,030
Nevada	4	4		1,248	71	1,177	(*)					1,177
New Hampshire	4	4		3,385	99	3,286						3,286
New Jersey	3	3		23,584	2,019	21,565	26			2	28	21,593
New Mexico	5	5		4,447	444	4,003	19				19	4,022
New York	3	4	May 10	63,569	1,728	61,841	63			11	74	61,915
North Carolina	6	6		22,950	521	22,429		958		6	964	23,393
North Dakota	3	3		3,453	580	2,873	1	61			62	2,935
Ohio	4	4		[7] 48,639	2,101	46,538	(*)					46,538
Oklahoma	4	4		15,050	1,282	13,768			4		4	13,772
Oregon	5	5		11,161	1,362	9,799				2	2	9,801
Pennsylvania	4	4		55,715	4	55,711			4	5	9	55,720
Rhode Island	2	3	Apr. 22	3,322	232	3,090	4				4	3,094
South Carolina	6	6		11,160	259	10,901		234			234	11,135
South Dakota	4	4		4,380	309	4,071		84			84	4,155
Tennessee	7	7		17,914		17,914		1,024			1,024	18,938
Texas	4	4		47,895	6,224	41,671				7	7	41,678
Utah	4	4		3,421		3,421	2		1		3	3,424
Vermont	4	4		2,323		2,323						2,323
Virginia	5	5		17,112	998	16,114	(*)		7	1	8	16,122
Washington	5	5		16,558	1,290	15,268	2			12	14	15,282
West Virginia	4	5	Apr. 1	8,695	207	8,488	8				8	8,496
Wisconsin	4	4		21,032	1,495	19,537		214			214	19,751
Wyoming	4	4		2,498		2,498	2				2	2,500
District of Columbia	2	2		2,737	13	2,724	8				8	2,732
Total	Weighted average rate 3.91 cents			800,140	43,210	756,930	260	4,676	39	93	5,068	761,998

[1] Stars (*) indicate amounts less than $500.
[2] Fees for inspection of motor-vehicle fuel. Wherever possible fees for inspection of kerosene and other non-motor-vehicle fuels have been eliminated.
[3] Includes fees for motor-fuel carrier permits, refund or exemption permits, interest on deposits, and miscellaneous unclassified receipts.
[4] Receipts from tax on lubricating oil, $570,000, not included in this table.
[5] Special taxes of 3 cents per gallon in Hancock County and 2 cents per gallon in Harrison County are imposed for sea-wall protection. The receipts from these taxes, $151,000, in 1937, are not included in this table.
[6] Tax was 5 cents Jan. 1 to Feb. 28; 4 cents Mar. 1 to 24; 5 cents Mar. 25 to Dec. 31.
[7] Ohio imposes a 3-cent tax on motor-vehicle fuel and a 1-cent tax on all liquid fuels. The receipts from the 1-cent tax applicable to non-motor-vehicle fuels (kerosene, fuel oil, etc.) were $662,000. These receipts have been eliminated from the total given, which represents a 4-cent tax on motor-vehicle fuel.

MOTOR-FUEL CONSUMPTION, 1937

(Compiled for calendar year from reports of State authorities)

State	Tax rate per gallon: On Jan. 1	Tax rate per gallon: On Dec. 31	Date of rate change	Motor-fuel consumption as reported by States: Gross amount reported [1]	Amount exempted from payment of tax [2]	Gross amount Assessed for taxation	Amount Subject to refund of entire tax	Net amount taxed [3]: Total	Net amount taxed: At full rate [4]	At reduced rates: Rate per gallon	At reduced rates: Amount	Analysis of motor-fuel usage [5]: Net total Consumption in State	Allowance for evaporation and other losses [6]	Federal and other public use [7]	Nonhighway use [5]	Highway use: 1937	Highway use: 1936 [9]	Highway use: Percentage change
	Cents	Cents		1,000 gallons	1,000 gallons	1,000 gallons	1,000 gallons	1,000 gallons	1,000 gallons	Cents	1,000 gallons	1,000 gallons	1,000 gallons	1,000 gallons	1,000 gallons	1,000 gallons	1,000 gallons	
Alabama	6	6		222, 121		222, 121		222, 121	222, 121			228, 954	*3, 382	*3, 451	*11, 448	210, 673	188, 931	11. 5
Arizona	5	5		104, 312	5, 786	98, 526	12, 130	86, 396	86, 396			104, 312	995	4, 791	12, 130	86, 396	78, 304	10. 3
Arkansas	6½	6½		164, 146	6, 059	158, 087		158, 087	142, 383	(10)	15, 704	164, 146	1, 535	4, 524	*8, 207	149, 880	140, 566	6. 6
California	3	3		1, 762, 039	38, 379	1, 723, 660	162, 402	1, 561, 258	1, 561, 258			1, 762, 039	8, 414	29, 965	162, 402	1, 561, 258	1, 464, 072	6. 6
Colorado	4	4		225, 498	10, 333	215, 165	30, 364	184, 801	184, 801			225, 498	4, 615	9, 555	26, 527	184, 801	172, 046	7. 4
Connecticut	3	3		326, 907	6, 883	320, 024	6, 496	313, 528	313, 528			326, 907	3, 228	1, 341	8, 810	313, 528	287, 242	9. 2
Delaware	4	4		54, 849	1, 041	53, 808	2, 930	50, 878	50, 878			55, 123	274	1, 041	2, 930	50, 878	47, 677	6. 7
Florida	7	7		329, 646	13, 001	316, 645		316, 645	316, 645			329, 646	2, 777	7, 747	*16, 482	302, 640	273, 070	10. 8
Georgia	6	6		331, 760	6, 491	325, 269		325, 269	325, 269			331, 760	2, 704	3, 787	*16, 588	308, 681	283, 475	8. 9
Idaho	5	5		95, 087	4, 350	90, 737	9, 911	80, 826	80, 571	2½	[11] 255	95, 087		3, 859	10, 658	80, 570	74, 700	7. 9
Illinois	3	3		1, 293, 364		1, 293, 364	101, 785	1, 191, 579	1, 191, 579			1, 346, 128	*20, 098	*6, 271	101, 785	1, 217, 974	1, 143, 272	6. 5
Indiana	4	4		634, 136	21, 150	612, 986	42, 800	570, 186	570, 186			634, 136	*18, 958	2, 192	42, 800	570, 186	520, 103	9. 6
Iowa	3	3		495, 896		495, 896	66, 306	429, 590	429, 590			520, 940	*15, 337	*9, 845	66, 168	429, 590	410, 306	4. 7
Kansas	3	3		460, 768	127, 270	333, 498		333, 498	333, 498			470, 171	*9, 403	*2, 720	124, 550	333, 498	316, 438	5. 4
Kentucky	5	5		251, 850		251, 850		251, 850	251, 850			258, 195	*3, 188	*3, 157	*12, 910	238, 940	216, 502	10. 4
Louisiana	7	7		238, 695	5, 554	233, 141	2	233, 139	226, 297	(12)	6, 842	238, 695	[12] 160	5, 396	*11, 935	221, 204	201, 392	9. 8
Maine	4	4		145, 443	960	144, 483		144, 483	137, 649	1	[13] 6, 834	146, 903	*1, 460	960	6, 834	137, 649	127, 306	8. 1
Maryland	4	4		270, 188	4, 329	265, 859	17, 731	248, 128	246, 036	3	[14] 2, 092	270, 188		4, 329	17, 731	248, 128	226, 128	9. 7
Massachusetts	3	3		696, 473	3, 723	692, 750	28, 189	664, 561	664, 561			696, 473		3, 861	28, 051	664, 561	625, 629	6. 2
Michigan	3	3		1, 110, 604	91, 040	1, 019, 564	44, 777	974, 787	974, 422	1½	[15] 365	1, 110, 604	31, 533	11, 764	94, 368	972, 939	868, 947	12. 0
Minnesota	3	4	Apr. 23	514, 112	19, 568	494, 544	61, 401	433, 143	433, 143			514, 112	15, 291	3, 346	62, 332	433, 143	404, 065	7. 2
Mississippi	6	6		186, 839	8, 111	178, 728		178, 728	167, 175		[16] 11, 553	186, 839	3, 626	4, 485	11, 553	167, 175	151, 879	10. 1
Missouri	2	2		590, 669		590, 669	24, 055	566, 614	566, 614			612, 936	*18, 268	*3, 999	24, 055	566, 614	548, 168	3. 4
Montana	5	5		113, 800	6, 162	107, 638	16, 655	90, 983	90, 983			113, 800	2, 153	4, 009	16, 655	90, 983	90, 459	. 6
Nebraska	5	5	(17)	231, 360	8, 891	222, 469	19	222, 450	222, 450			231, 360	7, 086	1, 809	*23, 136	199, 329	200, 064	−. 4
Nevada	4	4		33, 781	1, 811	31, 970	1, 767	30, 203	30, 203			33, 781		1, 495	2, 083	30, 203	28, 052	7. 7
New Hampshire	4	4		85, 295		85, 295	2, 488	82, 807	82, 807			87, 325	*862	*1, 168	2, 488	82, 807	78, 608	5. 3
New Jersey	3	3		797, 055	3, 136	793, 919	67, 273	726, 646	726, 646			797, 055		12, 671	22, 743	761, 641	696, 746	9. 3
New Mexico	5	5		95, 251	6, 568	88, 683	8, 883	79, 800	79, 800			95, 251	1, 583	4, 985	8, 883	79, 800	69, 445	14. 9
New York	3	4	May 10	1, 815, 563	61, 029	1, 754, 534	51, 913	1, 702, 621	1, 702, 621			1, 815, 563		56, 447	56, 495	1, 702, 621	1, 613, 016	5. 6
North Carolina	6	6		391, 816	8, 070	383, 746		383, 746	373, 317	1	[16] 10, 429	391, 816	3, 799	*3, 650	11, 050	373, 317	335, 097	11. 4
North Dakota	3	3		117, 943	1, 532	116, 411	27, 764	88, 647	88, 647			117, 943		1, 532	27, 764	88, 647	79, 570	11. 4
Ohio [18]	4	4		1, 308, 748	74, 266	1, 234, 482	12, 442	1, 222, 040	1, 167, 989	1	[19] 54, 051	1, 308, 748	38, 180	5, 617	96, 962	1, 167, 989	1, 076, 854	8. 5
Oklahoma	4	4		386, 580	11, 092	375, 488	31, 461	344, 027	344, 027			386, 580	7, 629	3, 463	31, 461	344, 027	330, 992	3. 9
Oregon	5	5		226, 445	4, 611	221, 834	25, 157	196, 677	195, 874	1	[20] 803	226, 445		6, 487	23, 831	196, 127	186, 193	5. 3
Pennsylvania	4	4		1, 417, 478	7, 288	1, 410, 190		1, 410, 190	1, 410, 190			1, 417, 478		7, 288	*56, 699	1, 353, 491	1, 225, 894	10. 4
Rhode Island	2	3	Apr. 22	122, 334	826	121, 508	2, 979	118, 529	118, 529			122, 334		1, 260	2, 430	118, 644	114, 057	4. 0
South Carolina	6	6		187, 024		187, 024	4, 313	182, 711	182, 711			187, 024		4, 313	*9, 351	173, 360	152, 959	13. 3
South Dakota	4	4		116, 797	6, 917	109, 880	2, 145	107, 735	97, 347	(21)	10, 388	116, 797	4, 672	2, 245	12, 533	97, 347	96, 750	. 6
Tennessee	7	7		265, 142	14, 345	250, 797		250, 797	250, 797			265, 142	2, 528	11, 817	*13, 257	237, 540	239, 348	−. 8
Texas	4	4		1, 217, 241	23, 086	1, 194, 155	152, 692	1, 041, 463	1, 041, 463			1, 217, 241	12, 070	21, 981	141, 727	1, 041, 463	958, 958	8. 6
Utah	4	4		91, 110	5, 368	85, 742		85, 742	85, 742			91, 110	2, 648	2, 720	*10, 022	75, 720	69, 013	9. 7
Vermont	4	4		65, 797	1, 917	63, 880		63, 880	63, 880			66, 442	*645	1, 917	*1, 993	61, 887	55, 880	10. 7
Virginia	5	5		342, 626		342, 626	19, 959	322, 667	322, 667			350, 228	*1, 722	*5, 880	19, 959	322, 667	298, 888	8. 0
Washington	5	5		336, 280	5, 397	330, 883	25, 801	305, 082	305, 082			336, 280		5, 397	25, 801	305, 082	288, 560	5. 7
West Virginia	4	5	Apr. 1	196, 236		196, 236	4, 157	192, 079	192, 079			198, 128		*2, 198	3, 851	192, 079	174, 930	9. 8
Wisconsin	4	4		540, 545	16, 760	523, 785	39, 470	484, 315	484, 315			540, 545	13, 430	3, 386	39, 414	484, 315	452, 709	7. 0
Wyoming	4	4		64, 027	1, 935	62, 092		62, 092	62, 092			64, 027		1, 935	*7, 043	55, 049	50, 569	8. 9
District of Columbia	2	2		137, 301	5, 559	131, 742	662	131, 080	131, 080			137, 301	318	5, 241	662	131, 080	121, 625	7. 8
Total	Weighted average rate 3.91 cents.			21, 208, 977	650, 594	20, 558, 383	1, 109, 279	19, 449, 104	19, 329, 788		119, 316	21, 345, 536	264, 571	313, 297	1, 549, 547	19, 218, 121	17, 855, 454	7. 6

[1] Export sales and other amounts not representing consumption in State have been eliminated as far as possible. Exemptions and refunds in a few States include small amounts of such deductible items not reported separately. In cases where States failed to report amounts exempted from taxation the gross amount taxed is shown in this column.

[2] Includes allowances for evaporation and other losses, Federal use, other public use, and nonhighway use, where initial exemptions rather than refunds are made.

[3] In the following States percentage allowances are made to distributors for expense of tax collection: Georgia, 1 percent beginning Apr. 1, 1937; Illinois, not more than 2 percent; Nebraska, ½ to 1 percent; Nevada, 2 percent; New York, 1 percent; North Dakota, 1½ percent; Pennsylvania, 2 percent. In tabulating the net amount taxed these allowances have not been deducted.

[4] In States where rate changed during the year the gallons taxed at different rates were as follows: Minnesota, 110,343,000 at 3 cents, 322,800,000 at 4 cents; Nebraska, 202,938,000 at 5 cents, 19,512,000 at 4 cents; New York, 519,817,000 at 3 cents, 1,182,804,000 at 4 cents; Rhode Island, 31,331,000 at 2 cents, 87,198,000 at 3 cents; West Virginia, 41,070,000 at 4 cents, 151,009,000 at 5 cents.

[5] In these columns available data have been used to determine approximately the amount of highway use and other uses in all States. The approximate methods used are described in notes 6 to 9.

[6] In the case of States indicated by stars allowances for evaporation, spillage, and other losses have been estimated on the basis of the percentages allowed by law and other available data. Where no data are given there is no percentage allowance, although actual proved losses are generally deducted from the taxable amount.

[7] Includes amounts exempted or subject to refund because of sale to the Federal Government. In the case of States indicated by stars Federal use has been estimated on the basis of the number of Federal vehicles and other available data. Amounts exempted or subject to refund for State, county, and municipal use also included, as follows: Colorado, 6,192,000 gallons; Delaware, 607,000; Florida, 431,000; Iowa (estimate), 7,640,000, Michigan, 7,186,000; New Jersey, 9,535,000; New York, 45,537,000; Oregon, 1,876,000; Rhode Island, 434,000; Tennessee, 4,480,000; Texas, 10,100,000; West Virginia, 263,000. For other States no information was given. Totals as follows: Federal use, 219,016,000; other public use, 94,281,000.

[8] Includes amounts exempted, subject to refund, or taxed for nonhighway use. In the case of States indicated by stars (*) no exemptions or refunds are made for nonhighway use. Amounts have been estimated, as percentages of total consumption, by comparison with data on nonhighway use in adjacent States.

[9] 1936 data revised to conform with 1937 analysis. Differences between amounts in this column and corresponding amounts in table Motor Fuel Consumption, 1936, previously issued, are due to adjustment of refund data to approximate month of purchase, estimate of nonhighway use in nonrefund States, and minor adjustments.

[10] Within 300 feet of border, tax is reduced to that of adjacent State. Gallons taxed at 2 cents, 3,106,000; at 4 cents, 12,598,000.

[11] Motor fuel used in aviation.

[12] Includes 3,000 gallons of inferior grade of gasoline taxed at 6 cents; and 6,839,000 gallons taxed at 2 cents, representing evaporation or loss allowance under the 5-cent tax not allowed under the additional 2-cent tax, which is administered under a separate law. Additional loss allowance of 160,000 gallons was fully exempted from taxation.

[13] 3 cents per gallon refunded on nonhighway uses.

[14] 1 cent per gallon refunded on motor fuel used in vehicles licensed to operate exclusively in cities.

[15] 1½ cents per gallon refunded on motor fuel used in interstate aviation.

[16] 5 cents per gallon refunded on nonhighway uses.

[17] Tax was 5 cents Jan. 1 to Feb. 28; 4 cents Mar. 1 to 24; 5 cents Mar. 25 to Dec. 31.

[18] Amounts given do not include 68,390,000 gallons of liquid fuel (kerosene, fuel oil, etc.) taxed at 1 cent per gallon but not subject to the 3-cent tax on motor-vehicle fuel.

[19] 3 cents per gallon refunded on motor fuel used for nonhighway purposes.

[20] 4 cents per gallon refunded on motor fuel used in aviation.

[21] Refunds on nonhighway use were made at 2 cents per gallon Jan. 1 to June 30; and at 3 cents July 1 to Dec. 31. Full refund of 4 cents on all claims paid after Dec. 31, 1937.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF MAY 31, 1938

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 1,253,020	$ 616,510	65.3	$ 5,480,902	$ 2,736,705	270.9	$ 3,084,950	$ 1,540,670	75.4	$ 5,556,443
Arizona	2,393,808	1,672,609	109.3	1,773,871	1,150,634	95.1	318,038	173,827	17.1	1,909,171
Arkansas	3,090,778	3,061,971	187.4	1,091,511	1,083,185	73.5	60,246	58,838	7.7	4,327,715
California	7,134,798	3,864,782	154.8	9,212,545	4,841,754	165.7	4,354,315	2,310,481	100.6	2,701,226
Colorado	3,179,438	1,741,332	124.9	2,413,756	1,324,514	79.3	486,120	260,476	9.6	3,333,875
Connecticut	817,358	406,276	9.3	445,750	212,589	3.1	1,384,690	676,415	14.4	1,506,510
Delaware	534,818	263,575	21.0	377,568	188,529	4.7	530,055	250,440	17.5	1,399,843
Florida	1,054,653	524,469	29.0	2,451,442	1,225,721	51.8	1,027,760	513,880	18.2	3,822,610
Georgia	2,377,634	1,149,465	126.7	6,582,343	3,291,172	317.0	2,786,540	1,393,270	146.6	5,969,864
Idaho	2,723,739	1,587,662	211.8	1,119,310	667,278	77.1	1,282,306	760,707	59.6	1,496,429
Illinois	11,678,019	5,700,751	342.2	8,450,689	4,147,773	171.5	4,563,700	2,281,850	116.9	4,007,173
Indiana	6,185,861	3,036,230	149.6	3,873,841	1,936,920	103.7	3,720,719	1,854,010	80.5	2,923,627
Iowa	7,134,059	3,365,417	234.2	6,057,640	2,804,456	177.7	1,981,400	815,542	70.6	2,309,328
Kansas	4,671,980	2,306,728	262.8	3,642,858	1,821,330	94.8	4,556,719	2,234,710	747.4	4,251,501
Kentucky	2,780,677	1,378,557	68.4	4,874,632	2,437,316	164.3	3,476,112	1,725,314	112.4	2,443,135
Louisiana	582,530	286,501	15.0	6,378,335	1,381,335	39.5	7,092,858	1,615,531	51.7	2,720,809
Maine	1,958,287	961,207	54.8	2,270,096	1,132,113	51.7	1,339,570	669,784	25.6	607,963
Maryland	1,048,330	524,145	15.0	1,696,594	846,534	27.4	1,315,360	628,127	12.8	2,114,449
Massachusetts	4,417,322	2,208,609	20.3	2,523,521	1,261,760	8.3	446,240	221,820	2.8	3,127,964
Michigan	7,094,121	3,338,946	173.8	6,427,415	3,108,612	130.8	444,850	221,800	9.8	3,849,406
Minnesota	6,625,480	3,272,065	341.5	4,362,993	2,170,147	194.1	1,450,898	714,347	54.5	3,949,874
Mississippi	3,127,801	1,548,263	157.8	5,291,290	2,603,840	230.5	3,476,270	997,935	144.6	3,680,064
Missouri	9,109,675	4,435,132	468.2	5,029,894	2,485,285	155.7	3,826,287	1,607,972	148.5	4,095,850
Montana	3,716,751	2,078,017	277.7	2,416,103	1,358,675	116.9	280,841	157,972	8.7	4,458,935
Nebraska	2,660,483	1,315,014	276.4	5,754,277	2,864,967	507.6	4,172,366	1,394,241	223.3	3,148,696
Nevada	2,491,341	2,051,622	132.5	911,844	790,273	75.3	566,129	490,934	23.3	1,791,000
New Hampshire	358,791	176,896	6.5	991,407	492,095	16.9	457,371	226,501	9.7	1,150,804
New Jersey	2,055,958	933,456	20.3	2,762,676	1,380,133	19.9	129,000	64,500		2,776,553
New Mexico	4,412,241	2,708,439	292.7	1,555,908	1,048,835	84.2	1,191,506	726,693	154.9	1,467,892
New York	14,167,589	6,394,190	250.7	13,800,694	6,819,950	235.4	3,715,748	1,820,424	62.6	5,117,185
North Carolina	5,222,986	2,607,430	387.0	6,459,353	3,038,072	262.0	1,287,860	632,710	98.3	3,784,614
North Dakota	1,114,612	1,036,055	186.5	2,505,131	2,426,901	155.2	493,650	445,458	56.0	3,836,905
Ohio	4,510,308	2,175,379	58.8	9,151,132	4,545,120	101.6	1,922,760	961,340	17.4	8,947,494
Oklahoma	3,728,885	1,940,482	186.7	3,744,831	1,939,510	136.6	3,072,895	1,617,593	143.7	4,088,441
Oregon	4,190,974	2,451,357	135.3	2,089,962	1,231,075	101.8	605,330	369,320	19.1	2,529,698
Pennsylvania	13,148,101	6,491,718	179.2	7,376,241	3,675,331	117.0	2,252,002	1,122,664	39.9	6,862,430
Rhode Island	923,039	443,128	8.1	1,184,060	592,030	16.7	111,197	55,598	1.1	1,223,518
South Carolina	3,762,555	1,590,753	260.9	5,504,881	2,348,743	247.9	1,135,704	518,986	58.2	2,069,431
South Dakota	2,223,721	1,257,452	228.5	3,045,772	1,687,300	276.6	1,818,710	1,013,580	123.4	3,619,406
Tennessee	1,989,348	990,687	71.3	4,853,574	2,426,287	145.1	1,058,200	444,060	40.1	5,299,764
Texas	14,755,214	7,286,292	967.8	11,153,440	5,530,407	626.4	4,851,647	2,314,721	288.1	9,207,058
Utah	1,429,642	999,693	136.8	939,560	672,620	52.7	835,970	592,804	86.0	1,750,068
Vermont	1,159,310	551,784	31.6	1,598,151	698,154	41.1	433,509	207,145	9.7	461,814
Virginia	4,432,577	2,168,083	172.4	4,717,748	2,357,287	151.4	2,285,526	1,142,763	81.7	1,703,944
Washington	2,363,913	1,229,813	76.0	4,022,187	2,111,524	54.2	1,418,729	728,000	37.2	1,381,197
West Virginia	1,494,901	760,504	42.7	1,575,227	1,045,523	46.7	854,187	543,102	23.5	2,701,952
Wisconsin	8,349,032	4,063,619	278.8	5,468,484	2,529,577	117.4	2,070,557	879,843	74.6	2,959,848
Wyoming	2,302,288	1,748,262	300.7	1,477,642	904,462	150.1	998,775	613,282	115.6	938,327
District of Columbia										
Hawaii	845,057	412,657	13.3	727,000	360,215	13.2	765,270	375,695	12.7	1,289,017
Puerto Rico				1,075,539	535,790	20.3	60,920	30,360	.2	668,225
TOTALS	199,283,803	103,113,984	8,322.3	198,691,620	100,270,358	6,578.4	91,852,362	43,018,035	3,853.9	157,339,045

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF MAY 31, 1938

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 16,100	$ 16,100	1			$ 228,501	$ 228,427	4			$ 336,850	$ 336,850	4		6	$ 1,420,242
Arizona						4,718	4,718									625,495
Arkansas						251,180	250,023	6			28,459	28,459	1			1,480,287
California						1,234,430	1,233,855	2	4		144,157	144,157	1			2,322,197
Colorado	1,880	1,880			1	26,240	26,240	1			4,491	4,491			2	1,257,311
Connecticut																844,490
Delaware											56,000	56,000			15	437,750
Florida						10,616	10,616									1,395,181
Georgia						18,346	18,346									2,399,041
Idaho						100,167	99,994	1								722,876
Illinois						728,175	728,175	3	2		595,600	595,600	7		1	3,900,368
Indiana	165,790	165,790	2			671,090	566,813	4	5		549,060	466,600	2		86	1,379,293
Iowa	172,088	163,900	3	3	1	976,983	923,800	12	1	4	125,876	117,200	1		16	1,568,746
Kansas	6,290	6,290			3	471,660	471,660	10		3	436,095	436,095	6		3	1,665,048
Kentucky						145,000	145,000	1			167,924	167,924	1		31	1,501,121
Louisiana						23,648	23,648				122,838	122,830	2			1,430,593
Maine						140,057	140,057		1		117,610	117,610	2	1	1	433,536
Maryland						7,800	7,800				664,000	56,130	1			962,903
Massachusetts						70,420	70,420		1							1,999,051
Michigan						476,972	476,972	3			667,820	667,820	7	1	45	2,140,393
Minnesota	174,236	174,236	1		5	608,748	608,748	2	4	12	98,650	98,650		2		1,775,066
Mississippi						252,700	252,700	3								1,331,451
Missouri						236,070	236,070	4			149,140	149,140	2			2,640,043
Montana						258,180	253,298	3			404,026	404,026	3			667,147
Nebraska						210,137	210,137	10			147,756	147,756	3			1,406,517
Nevada	35,109	35,109		1		91,561	91,561		2		52,574	52,574	1			314,506
New Hampshire						65,482	65,175		1							428,575
New Jersey						210,005	204,779	2	1							1,765,478
New Mexico						122,441	122,441	4								729,050
New York						1,415,251	1,414,100	5	4	2	553,946	546,746	3	1		4,809,083
North Carolina						135,400	135,400		1		420,550	420,550	4			1,931,624
North Dakota						534,046	534,046	1	1							1,045,175
Ohio						32,120	32,120									4,197,048
Oklahoma						17,343	17,343									2,264,166
Oregon	178,890	178,890	3			293,683	293,683	1	1		32,021	31,372		1		650,276
Pennsylvania						181,628	166,422	1			100,000	100,000	1			5,466,113
Rhode Island						223,897	223,897	1								269,853
South Carolina						38,473	16,137		1		324,844	324,844	2	1	2	1,148,121
South Dakota	43,770	43,770			13	124,438	124,438	1	1	1	73,505	73,505	1		6	1,126,744
Tennessee						14,381	14,381									1,877,652
Texas	19,700	19,700	1			77,133	76,200	4			94,940	94,605	1			5,208,363
Utah	71,000	71,000	2		2	105,073	105,073	2			6,860	6,860			4	461,055
Vermont	12,028	12,027			4	213,108	208,108	6	1	1	26,450	22,170		1		251,445
Virginia	80,710	80,710	2	3		230,395	230,395	12	1		106,720	106,720		1	3	1,458,915
Washington	80,215	80,215	1	1		232,133	230,033	2	2		268,368	268,368	4		3	939,956
West Virginia						139,175	138,155	1			267,660	267,660	3			918,283
Wisconsin						875,054	874,880	7			163,203	136,907	2			1,461,722
Wyoming						144,884	144,884		2		14,460	14,460			6	517,386
District of Columbia	168,320	168,320		1												325,431
Hawaii											197,540	197,540	3	1		296,210
Puerto Rico						61,900	61,550	2			102,621	101,740	1			567,010
TOTALS	1,226,126	1,217,937	16	9	29	12,730,842	12,512,718	121	37	23	7,622,614	6,883,959	69	10	230	78,135,386

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF MAY 31, 1938

STATE	Completed During Current Fiscal Year: Estimated Total Cost	Completed: Federal Aid	Completed: Miles	Under Construction: Estimated Total Cost	Under Construction: Federal Aid	Under Construction: Miles	Approved for Construction: Estimated Total Cost	Approved: Federal Aid	Approved: Miles	Balance of Funds Available for Programmed Projects
Alabama				$ 209,700	$ 104,850	11.9	$ 219,500	$ 109,650	11.9	$ 838,472
Arizona	$ 33,909	$ 23,138	2.4	204,974	117,189	11.4	157,793	107,507	14.7	475,353
Arkansas				13,126	6,563					857,545
California	105,952	61,502	30.2	454,226	261,987	30.1	299,350	173,746	31.5	1,421,463
Colorado				394,396	218,488	19.3				703,080
Connecticut							12,960	6,465	.2	311,813
Delaware										246,875
Florida				20,122	10,061					664,791
Georgia	6,000	3,000	1.8	232,598	116,299	20.2	350,580	175,060	52.1	983,267
Idaho	233,905	114,838	33.7	310,743	144,404	17.6	52,683	26,341	4.2	336,190
Illinois	36,000	18,000	3.3	804,632	402,316	57.6	1,373,900	684,250	108.6	962,249
Indiana				216,800	73,150	22.6	1,015,633	449,003	100.6	720,285
Iowa										1,298,449
Kansas	19,510	9,755	24.0	49,234	24,617	.9	131,450	65,725	6.7	1,231,364
Kentucky	246,502	122,573	105.1	532,214	148,425	50.6	630,565	179,286	66.3	479,393
Louisiana				21,670	10,835		117,099	54,696	11.1	658,605
Maine	58,904	29,140	4.1	311,636	155,818	20.0	120,800	60,400	7.6	197,048
Maryland				6,264	3,132					409,344
Massachusetts				5,300	2,650					696,530
Michigan				23,362	11,681					1,523,858
Minnesota				265,714	130,950	6.4	141,164	50,477	39.1	1,198,153
Mississippi										888,927
Missouri	954,315	458,965	242.3	275,810	136,605	39.1	231,700	96,235	16.9	838,759
Montana				13,983	7,865					1,027,170
Nebraska	40,394	20,197	1.1	276,210	138,105	42.6	378,686	189,343	51.5	696,463
Nevada	177,826	153,860	26.5	190,948	165,308	15.5	82,224	67,423	18.7	257,920
New Hampshire				101,176	50,152	1.7	61,884	30,904	1.5	165,819
New Jersey							42,310	17,500	.1	655,273
New Mexico				426,365	260,037	27.5	115,029	70,156	3.2	476,579
New York	119,825	58,962	12.8	2,212,860	1,106,430	145.7	188,800	94,400	5.5	1,212,981
North Carolina	132,350	66,062	33.1	618,940	309,470	76.5	169,000	78,980	13.4	729,045
North Dakota							31,450	16,844	5.5	770,408
Ohio				184,400	92,200	3.8				1,739,441
Oklahoma				16,888	8,986		199,160	95,932	26.0	1,079,997
Oregon	111,890	62,115	33.8	84,422	50,532	10.7	420,020	245,120	45.6	470,390
Pennsylvania	33,202	16,601	4.9	607,217	292,506	38.6	1,038,548	498,128	72.3	1,337,983
Rhode Island	25,162	10,355	.3	118,988	59,494	3.6	89,590	44,795	2.6	132,231
South Carolina				408,398	169,862	40.4	336,290	143,354	41.1	365,464
South Dakota				11,300	6,250					816,436
Tennessee				184,806	92,403	7.8	71,520	35,760	4.8	931,327
Texas	22,300	11,150	9.7	491,768	240,645	102.8	1,450,918	658,772	200.2	2,238,503
Utah	16,812	11,750	2.1	220,770	134,610	21.9	191,065	91,205	13.7	334,151
Vermont	76,012	37,335	4.3	200,056	87,853	11.6				121,687
Virginia	40,210	20,105	10.2	319,168	157,369	42.2	320,460	160,230	7.2	581,945
Washington	117,776	61,874	18.0	244,960	128,778	15.4	265,697	139,800	22.9	461,391
West Virginia				208,000	104,000	16.5	82,300	41,150	4.5	404,524
Wisconsin	30,710	15,250	6.7	225,510	106,945	1.7	411,331	176,651	22.6	928,632
Wyoming	75,809	46,849	7.2	363,920	224,860	39.1	14,500	8,960	4.7	351,373
District of Columbia										
Hawaii							54,010	27,005	2.4	219,870
Puerto Rico				217,720	108,860	11.3	31,930	15,865	2.4	122,150
TOTALS	2,715,275	1,433,376	617.6	12,301,294	6,183,540	984.6	10,901,899	5,187,118	1,043.9	36,570,966

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