Experience with Flexible Pavements in Maryland

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This report is concerned principally with the historical development of the design and construction of flexible pavements in Maryland and with the structural adequacy of pavements built according to the provisions of the method of design currently in use.

This method utilizes CBR values of the subgrade soil as a basis of determining the thickness of subbase material necessary as an interfacial layer on the subgrade beneath either of two standard sections. One of the standard sections is for traffic of 2,000 vehicles or more per day and consists of 10 inches of macadam base and 3½ inches of asphaltic concrete; the other is for traffic less than 2,000 vehicles per day and consists of 8 inches of macadam base and 2 inches of asphaltic concrete.

The service behavior of the majority of pavements built in the state during the past several years using the method has been satisfactory.

DESIGN

THE design method followed in connection with flexible pavements in Maryland is not unique, but rather has been developed by evolution and investigation of current research. It makes use of the CBR test as a means of determining the overall thickness of pavement.

In common with many states, Maryland built many miles of flexible pavement during the early days of its State Roads Commission. Due to the availability of suitable aggregate over a large portion of the state, these early pavements were constructed of 5 inches of waterbound macadam, highly crowned. This of course was a section based on judgment, and one can hardly say that any rational design entered into the picture. They were good roads for their day, however, and pictures of early macadam road building in Maryland have found their way into highway texts and Public Roads murals.

With the increase in the intensity of traffic, and weight of motor trucks, it became apparent that a heavier section, and one whose surface was more resistant to abrasion and ravelling was needed. Again based on judgment, a section of 8 inches total thickness came into use. This consisted of the same 5-inch layer of waterbound macadam, with a 3-inch layer of bituminous penetration macadam placed on top. The surface of the penetration macadam was double sealed. This section came to be regarded as the standard for flexible-type construction, and was used until the late 1930's. During this period Maryland, along with many other states, began making detailed soil investigations and reports for each project. This work was under the direction of the Materials Division and is referred to in more detail later in this paper. After the advent of the detailed soil investigations, the practice of placing selected granular subbase material beneath the standard section, where conditions indicated it necessary, was adopted.

The World War II years, closely following the period previously mentioned, brought practically all highway construction to a halt, particularly after the military access road program was completed. However, research in flexible pavement design was greatly accelerated during this period.

In common, with the engineers of most highway departments, Maryland used this slack period to look into its practices in many fields, and the field of flexible pavement design and construction was realized to be one needing close attention. The work of the Corps of Engineers, the Bureau of Public Roads, the Civil Aeronautics Administration, the Bureau of Yards and Docks, and others, was carefully considered. It seemed reasonable to begin the basic study by an evaluation of some of the same fundamentals which most other states have considered. These fundamental elements are load, area of contact, distribution, and bearing capacity of the subgrade. Review of the development literature in this field led us to consider the following assumptions: (1) elliptical contact areas of single and dual tires; (2) a 1:1 distribution of the load to the subgrade material; (3) an equivalent uniform pressure equal to half the maximum bearing capacity

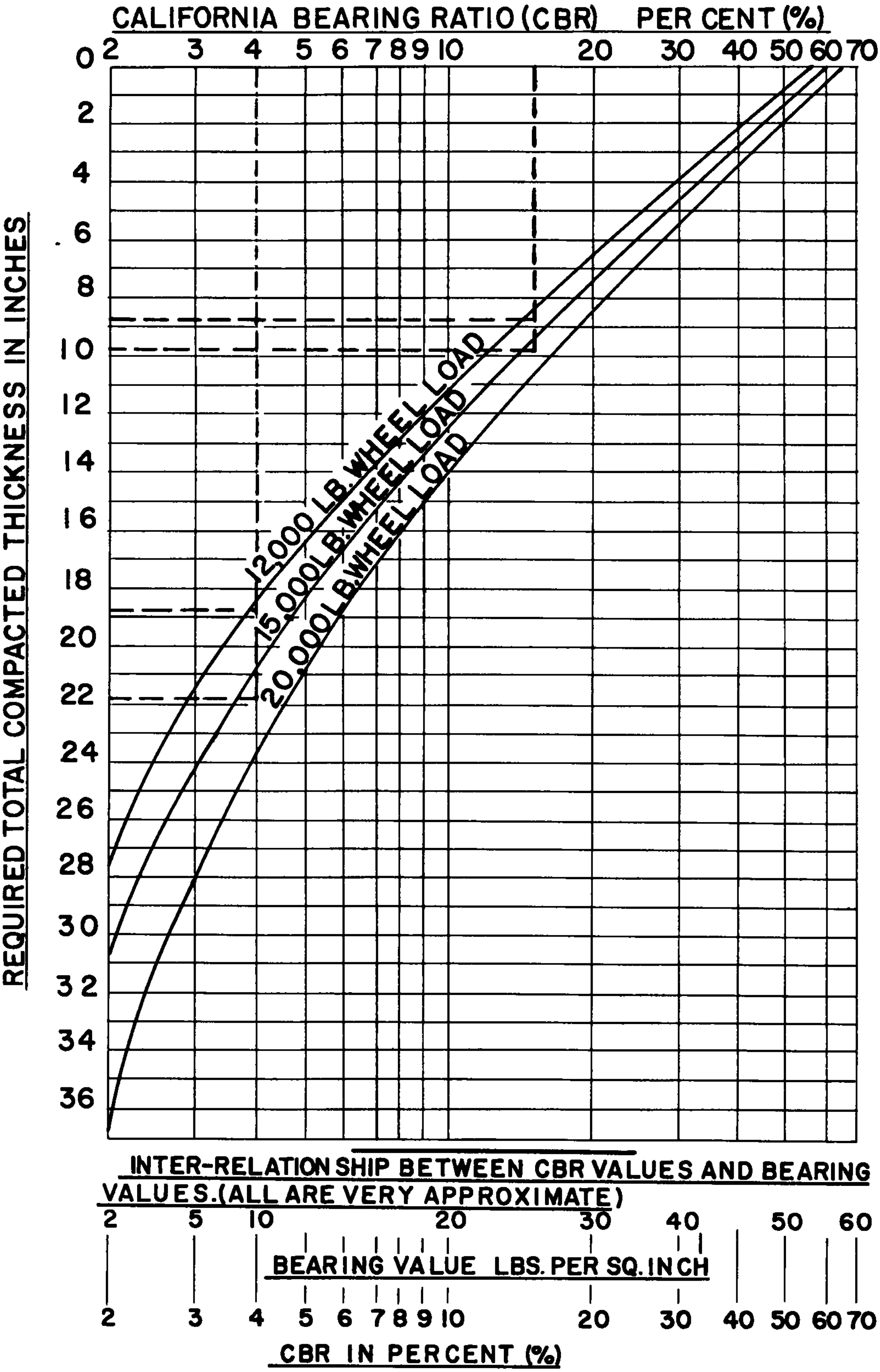

Figure 1. Flexible pavement - design chart.

TABLE 1

DEFLECTION DATA SUMMARY

22, 400-Pound Rear Axle Load (Deflection Values in . 001 Inches)

Route Number	Time of test 1955	Wheel Path[a]	Deflection No. Tests	Deflection Mean	Deflection Standard Deviation[b]	Remarks
US 40 W	Spring	OWP	269	32	15	
		IWP	276	22	10	
		BWP	545	27	-	
	Fall	OWP	276	25	-	
		IWP	278	18	-	
		BWP	554	21	-	
US 240	Spring	OWP	148	44	18	
		IWP	148	37	15	
		BWP	296	40	-	
	Fall	OWP	159	32	-	
		IWP	158	28	-	
		BWP	317	30	-	
US 40 E	Spring	OWP	138	70	28	Stage construction
		IWP	138	67	24	Surface treatment only.
		BWP	276	69	-	
	Fall	OWP	138	26	-	AC surface course placed in
		IWP	136	25	-	late summer and fall of 1955.
		BWP	274	25	-	

Note: Deflection values are for outer lane only.

[a] OWP - Outer wheel path.
IWP - Inner wheel path.
BWP - Both wheel paths combined.

[b] 68 percent of test values fall within ± one standard deviation of the mean.

of the subgrade; and (4) the maximum bearing capacities of various subgrade materials.

It was definitely realized that heavy axle load was going to be one of the major points of consideration in Maryland. About 15 years ago legislation was enacted in Maryland which allowed the gross weight of a single axle to go up to 22, 400 pounds. Subsequent legislation has provided another class of carriers to be included in the category of "Dump Service Registration." This legislation provides for a gross weight of not more than 40, 000 pounds for two-axle vehicles, nor more than 65, 000 pounds for three- or more axle vehicles. These registrations are issued to dump trucks hauling loose material in bulk. Vehicles so registered may be operated within a radius of not more than 40 miles of the point of pick up. Considering the many quarries and sources of bank run gravel, etc., within the state, and the allowable 40-mile radius, it can be seen that a very considerable portion of the state highway system can be subjected to the loads from this class of registration. According to the Traffic Division of the Commission the rear axles of many of these dump trucks carry a load between 28, 000 and 31, 000 pounds. In addition to the consideration of axle loads, Maryland's geographical position places it along the heavy trucking routes of the Eastern Seaboard region and the high volume of truck traffic must necessarily be a prime consideration in the selection of the flexible

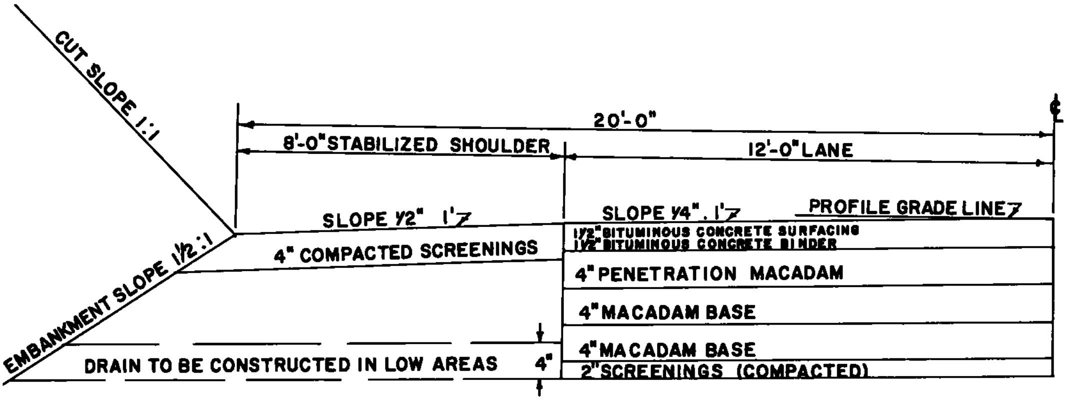

Figure 2. Partial typical section of improvement. US 40, west of Frederick toward Hagerstown.

section for any route. It has been noted that some research studies have been made concerning the number of load repetitions required to produce failure in flexible pavements of various depths. However, no rational basis has been found for relating these two factors. Consequently, Maryland's considerations along this line are still pretty much a matter of practical judgment.

The effect of impact loads on flexible pavement is also a subject which commands no uniform thought. While it has been observed that maximum pavement deflections usually occur at low speed, it nevertheless seems reasonable to include at least a small allowance for impact effect. The Maryland Roads Commission selected a value of 10 percent of the static load. This factor applied to the axle loads previously noted gives wheel loads of 12,300 pounds for ordinary carriers and 16,500 pounds for the dump truck classification, considering 30,000 pounds as an average rear axle load in this category.

Although frost penetration varies appreciably throughout the state, severe winters can cause a penetration of such depth that it must be considered a significant factor in the design of pavements. Frost conditions in the central and western regions are sometimes quite severe. An average annual penetration of 24 inches occurs in the western portion of the state, with a maximum of 36 inches occurring in this region during severe winters. A report published some years ago, moreover, indicates that the remaining portions of Maryland may be subject to maximum depths of frost penetration varying between 18 and 35 inches.

The development of pavement thickness formulas based on the first three of the assumptions mentioned earlier have been published previously. The formulas used were presented in a paper entitled "The Problem of Flexible Pavement Design," by A. T. Goldbeck, published in the Crushed Stone Journal, June, 1948.

A formula for the thickness of flexible structure necessary to support a load on dual

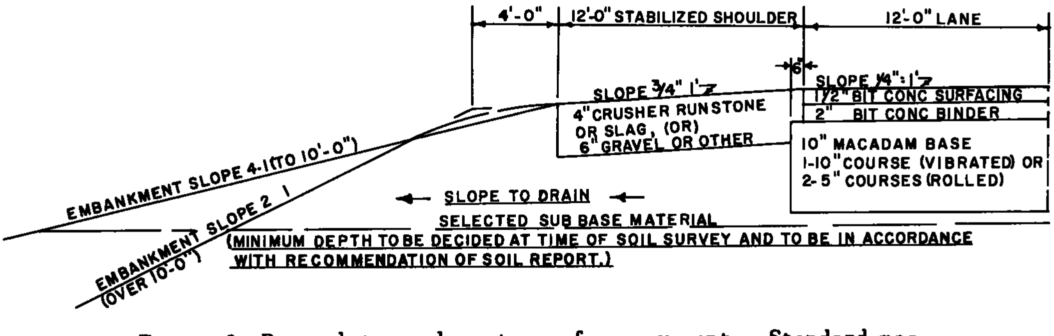

Figure 3. Partial typical section of improvement. Standard macadam section for traffic counts of 2,000 or more vehicles per day.

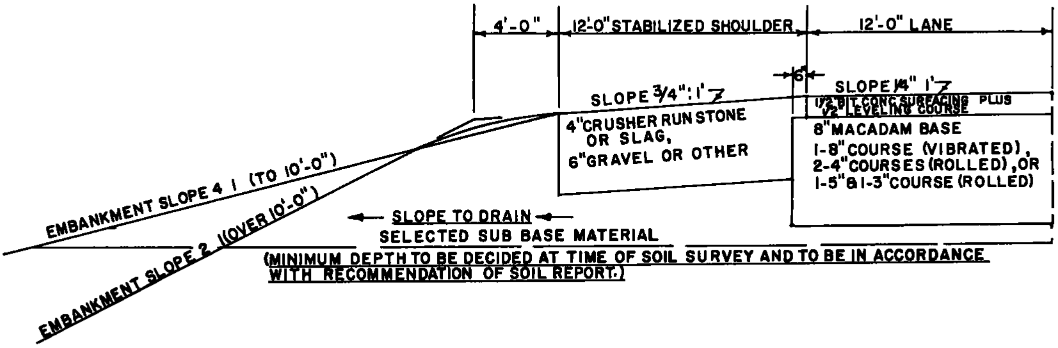

Figure 4. Partial typical section of improvement. Standard macadam section for traffic counts up to 2,000 vehicles per day.

tires is given in this article as follows:

$$T = \sqrt{\left(\frac{B}{2\pi}\right)^2 + C} - \frac{B}{2\pi}$$

Where $B = 2S + \pi (L_1 + L_2)$

$$C = \frac{Pk}{M\pi} - \frac{2SL_1}{\pi} - L_1 L_2$$

where A = area of equivalent uniform subgrade pressure

P = wheel load

U = equivalent uniform pressure over area A

M = maximum subgrade pressure and also the bearing value of the subgrade

S = center to center spacing of dual tires

L_1 = half major axis of tire contact area

L_2 = half minor axis of tire contact area

$k = \frac{M}{U}$ assumed to be = 2

or assuming $k = 2$, and $L_1 = 2L_2$

$$B = 2S + 3\pi L_2$$

$$C = \frac{2P}{M\pi} - \frac{4SL_2}{\pi} - 2L_2^2$$

Many subgrade bearing values were thus investigated, but for purposes of illustration the example here is limited to one very low value, namely 10 psi. Using this value for the 12,300-pound wheel load, an overall structure thickness of about 19 inches is indicated. If the bearing value of the subbase is assumed as 25 psi., the combined thickness of the base and surfacing layers would be indicated as about 10 inches. Considering the heavier wheel load of 16,500 pounds and using appropriately larger tires, for the same bearing values previously mentioned, an overall thickness of about 22 inches is indicated, and a combined base and surfacing course thickness of about the same, or 10 inches.

After a thorough study of the problem, the conclusion was reached that insofar as total thicknesses were concerned, the CBR curves as originally developed from the work done in California would suit the present purpose admirably. (See Figure 1) We did not feel satisfied, however, with the depth of macadam base and asphaltic concrete surface indicated by these curves for the very heavy loads to which our highway system is subjected. Naturally we had a reason for this concern. Our experience over a long period indicated that the former generally used section of 5-inch waterbound and 3-inch penetration macadam had not been entirely satisfactory under heavy traffic, even though, in many cases, the subgrade conditions were good. Practically all of our heavily used macadam roads had required rehabilitation through the years, and many of them cored

Figure 5.

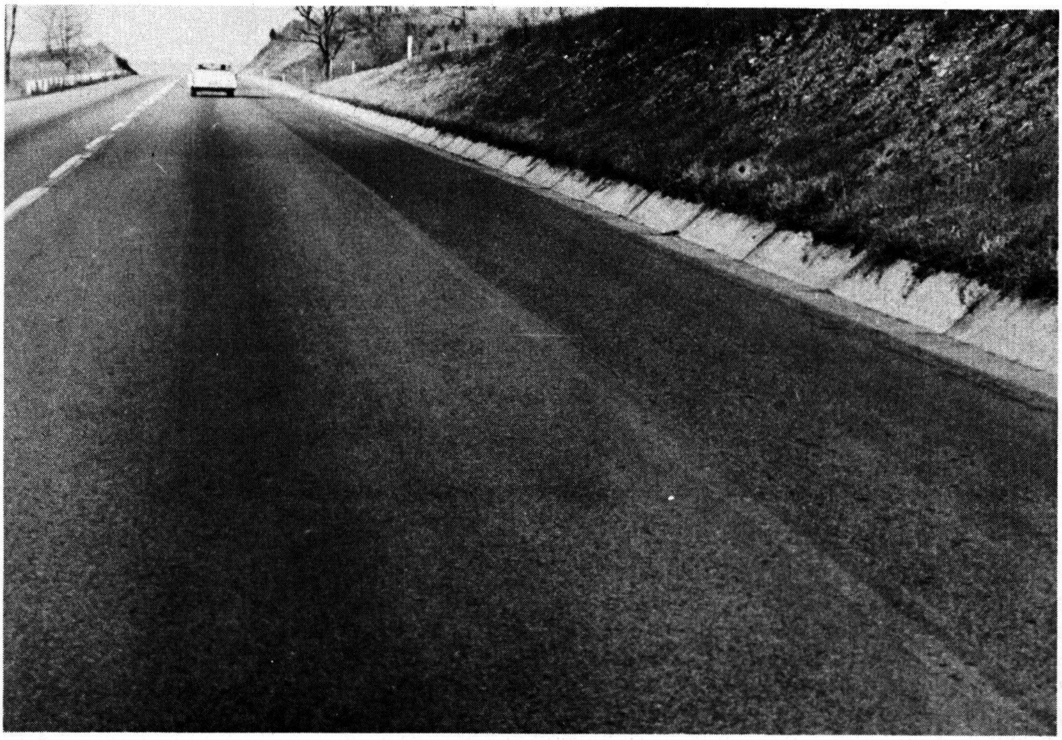

Figure 6.

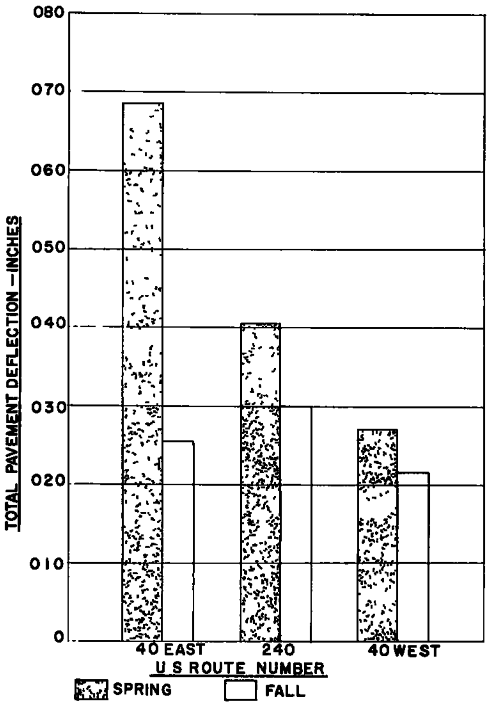

Figure 7. Comparison of mean deflections observed on the various pavements in the spring with those of the fall. (1955)

for investigation have shown combined thicknesses of original macadam, and rehabilitation courses of 12 inches and more.

The first high type flexible pavement project scheduled in the post war period was along US 40 west of Frederick, Maryland in the western portion of the state. This is a route subjected to heavy trucking, the possibility of the operation of dump truck vehicles is present, and frost conditions can be quite severe. After a thorough consideration of the detailed investigation noted earlier, a very substantial section was selected for the pavement on this route. The load bearing components as shown in Figure 2 were as follows: two 4 inch layers of waterbound macadam, one 4 inch layer of penetration macadam and 3 inches of asphaltic concrete, placed in two courses. The two courses of asphaltic concrete consisted of 1½ inch binder and 1½ inch surfacing. The pavement along this section of US 40 has been very closely observed during the 10 years which it has been in service. Later in this paper we will comment in detail concerning the performance and the maintenance costs of this pavement. In general its performance has been so good that we considered it reasonable to use this design as a guide for later flexible pavements.

Several years after the completion of the US 40 project noted above, the state embarked on its first post war accelerated highway building program. At present it is engaged in an even larger construction and reconstruction program which covers a 12 year period that began January 1, 1954. The conclusion was reached that it would be advantageous to develop standard sections for flexible pavements, for cases where our economic studies indicated that this type should be built. We knew, however, it would be necessary in many cases to supplement such standard sections with selected subbase material, the thickness of which would be determined by our materials division from their studies of the prevailing soils. The use of a standard section supplemented by varying thicknesses of subbase has been described in one of the Highway Research Board publications dealing with flexible pavements as an inverted method of design. All of the data gathered during the slack period of World War II, and our experience with the US 40 pavement was carefully considered.

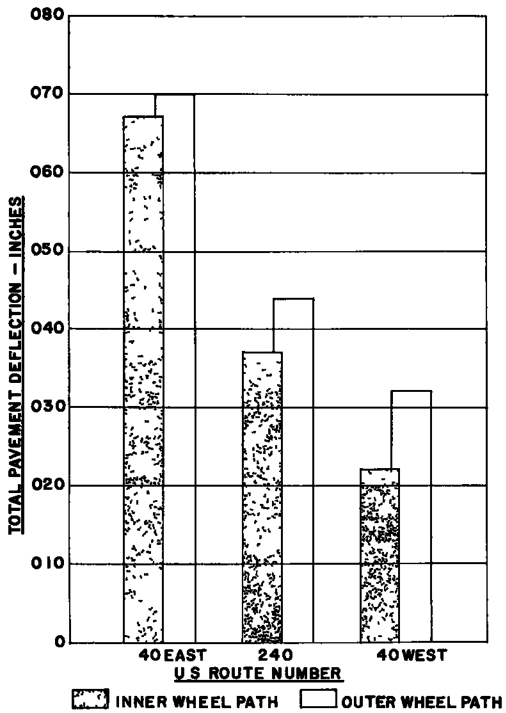

Figure 8. Mean deflections observed on various pavements in the spring of 1955.

After additional study and evaluation participated in by engineers of our districts, and the construction, maintenance, materials, and design divisions, we selected the following two standard sections:

(a) For highways carrying 2,000 or more vehicles per day, a 10 inch macadam base course plus 3½ inches of asphaltic concrete surfacing placed in two courses, a 2 inch binder and a 1½ inch surfacing course. (See Figure 3)

(b) For highways carrying less than 2,000 vehicles per day, an 8 inch macadam base course, plus 2 inches of asphaltic concrete placed in two courses, a leveling course of an average thickness of ½ inch and a 1½ inch surfacing course. (See Figure 4)

It is pertinent to elaborate a bit on the detailed soil survey and analysis which has been mentioned previously. Borings are made at an average spacing of 300 feet center to center on the right, left and/or centerline of the project. In cut sections they are carried to a minimum depth of 3 feet below subgrade. In all areas they are made to a minimum depth of 3 feet below the original ground surface. In fills at least one boring is carried to a depth below the original surface equal to the height of fill. Borings closer than 300 feet center to center are made if nonuniform conditions prevail. Boring equipment includes hand augers, gasoline powered augers, and jeep mounted drills. Additional field data pertaining to rock conditions, water conditions, and swamp comditions are recorded. Complete gradations by sieve and hydrometer methods are determined in the laboratory. The following tests are also run as a routine procedure: field moisture equivalent, liquid limit, plastic limit, shrinkage limit, and Proctor compaction. Californing Bearing Ratio Tests are conducted on selected samples on all representative soil types encountered on the project. The report from the materials division to the design division outlines in detail the results of the soil survey and analysis and recommends the thickness of subbase in conformity with the CBR values of the subgrade soils encountered.

The present design procedure has now been followed for approximately the last six years. While this period is relatively short for a long range evaluation, we feel that we have been obtaining very good results. In the section of this paper dealing with the performance of flexible pavements, we will discuss this point in more detail. Also in the section dealing with construction, we will comment on the possibility of introducing additional types of construction for flexible bases.

CONSTRUCTION

We do not intend, nor consider it pertinent, to give any long and detailed descriptions of complete sequences of flexible pavement construction. We will limit ourselves to a few comments on macadam construction.

Considered from the historical standpoint, we have already mentioned that Maryland built a considerable mileage of macadam roads in the early years of this century, and that for their day they were excellent, enduring the rigorous weather conditions of all portions of the state. Our advisory engineer, who experience spans the period 1910 to the present, has shed some interesting light on this early period. Crowns were high, the pavement slope being ½ inch per foot for grades up to about 5 percent, and ¾ inch per foot for grades over 5 percent. Overall roadbed widths were 24 feet, the travelled way being usually 12 feet to 14 feet, except in the Baltimore or Washington area, where 16 feet was used. The rolling, choking, and watering operations were very similar to these same operations, if resorted to today. Of course, in those days, much use was made of hand labor, which cannot be afforded to the same extent today. It is interesting to note that a road finished after November 1 was not accepted from the contractor until the following construction season; also that a base was well compacted and acceptable if it gave satisfactory metallic "ring" when the Chief Engineer drove over it in a horse drawn, metal tired conveyance; and any "mud intrusion" which showed up through the courses was required to be removed by the contractor and replaced with new base construction.

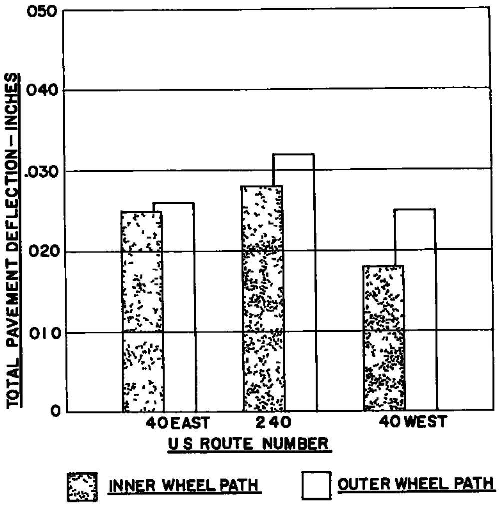

Figure 9. Mean deflections observed on the various pavements in the fall of 1955.

Today, pavements of the flexible type are built when indicated to be justified by detailed economic analyses, including first cost, salvage value, maintenance, interest, etc. Traffic forecast for a period twenty years hence, gives a determination as to which of the two standard sections should be used. The detailed soil borings, laboratory analysis, and report and recommendations from the Materials Division determine the need for selected subbase material, and the depth to which it should be placed. The preliminary field investigation is made as soon as the preliminary grade line has been set. This field investigation and the office conference which follows, is an important phase of the preconstruction period. Representatives of the Design and Materials Divisions participate. Preliminary location of subdrainage, grade line with respect to water table.and other pertinent field conditions, optimum locations for surface drainage structures, etc., are set at this phase of development.

Considerable use is made of a 2 inch compacted layer of stone screenings between the subgrade or subbase and the macadam base course. This is the usual insulation layer, and is always used where the subbase material consists of bank-run gravel. However, where a crusher run stone or crusher run slag type of subbase is used, the stone screenings course is not considered to be necessary.

The use of subgrade drains (so called shoulder drains) is most important to this type of construction. The state installs them at 100 foot intervals, except in sumps where a total of 10 or 12 are placed 25 feet apart.

The traditional construction methods of loose spreading, rolling, choking, and watering still may be followed, according to our latest specifications. A maximum compacted thickness of 5 inches may be placed by this method. Recently we have allowed the use of vibratory compactors in the construction of macadam bases. A minimum of 5 inches compacted thickness, up to a maximum of 10 inches compacted thickness may be placed in one course by this method.

After the compaction and dry choking by either the rolling or vibratory method is accomplished, watering and additional applications of screenings follow until a well finished surface is produced. This is evident by the absence of voids, and the absence of an excess of loose screenings in any spots. Deviations exceeding ½ inch from the true transverse template must be corrected. Likewise, longitudinal deviations greater than ½ inch in 10 feet must be corrected.

Regardless of what type of compaction is used, we are convinced that a construction crew and inspectors with a real interest in the finished product, are absolutely necessary to produce top quality work. Also, hand forking, picking, and casting are just as essential to obtain the best results today, as was the case in the early days of road construction.

Although this type of flexible pavement construction has been standard for about 5 years or so, we do not consider that its continued use is mandatory, and that we cannot change some of its components if conditions warrant. For instance, some of our flexible pavements have been built using stage construction methods. The macadam base of a project recently built in this manner was surface treated and a great deal of damage resulted from the penetration of water through this temporary surface into the underlying base. We are now considering the use of an alternate type of section in the event a project is to be built by stage construction methods. The upper layer will consist of 3 inches of bituminous penetration macadam with a double seal treatment as the temporary wearing surface.

We are also much interested in the plant-mixed, dense-graded aggregate base which several of our neighboring states have used to such good advantage. Our latest specifications include this type of base construction. Briefly, it consists of coarse aggregate, fine aggregate, calcium chloride and water, plant-mixed, mechanically spread, and compacted with rubber tire rollers. Although we have not built any roads of this type as yet, we plan to let a few pilot jobs in the near future. If the prices seem to be favorable and the product satisfactory, we will most likely use more and more of it as time goes on. It is quite possible that it will supplant our present standard sections, at least in certain areas of the state, where material supply conditions are favorable.

PERFORMANCE

In evaluating the performance of various flexible pavements to determine if our standard sections are reasonable, we have rather carefully considered many roads built throughout the state since the early 30's. Although it is only since the World War II period that flexible pavements in Maryland have been designed for heavy duty service, we felt that it would be helpful and necessary to observe many examples of our earlier construction. We have obtained very good service from the older roads, but in almost every case maintenance operations have been necessary which resulted in a significant increase in their total thickness. This in effect is the equivalent of stage construction, a process to which, as we all know, the flexible type of construction is particularly well adapted. Generally speaking the 5 inch macadam base and 3 inch penetration macadam surfacing did not prove to be a sufficiently thick section to withstand heavy trucking service, even though built on good subgrades. We have in mind one example of a major route over mountainous terrain in the western portion of the state. Although the total volume of traffic is not unusually high, the percentage of trucks is a good bit above the average found in most parts of the state. Rutting of the pavement has been pronounced, and before long it will be in need of resurfacing. We have found that on relatively heavily travelled roads of the above type, rehabilitation was necessary after a period of service of perhaps six years. We have cored a number of highways of this type throughout the state. Some of them were built in the 30's and some in an even earlier period. In many cases we have found 12 inches of substantial road metal, consisting of various combinations of waterbound macadam, penetration macadam, cold mixes, and hot mixes. Our evaluation of the performance of these roads has been limited to the history of their behavior and the study of cores taken from them.

As noted earlier, our experience and observation of the behavior of older pavements let us to select the rather substantial section for US 40 west of Frederick. The behavior of this road has been observed diligently, as we considered it a pilot job which might lead us into some standardized sections. It has now been in service for close to 10 years and its performance has been excellent. There are only two localized areas where any roughness has developed and this is quite minor. Like many states, we did not always break our maintenance costs down into the separate items of surfacing, shoulders, ditches, etc. However, since June, 1949 we have kept itemized records of maintenance costs. The records show that, for this Route 40, about 16.5 miles long, the average annual surface maintenance cost per mile for the four-year period from June 30, 1949 to June 30, 1953 was $58.00. This amounts to about 7/10 of a cent per square yard per annum. The selection of the standard sections which have been described earlier in this paper was based, in part, on these observations. (See Figures 5 and 6)

Within the past year we were fortunate in being able to arrange, in cooperation with the Bureau of Public Roads, for the conduct of two series of deflection tests on several of our modern designed flexible pavements. The first series of tests was made early in the spring and the second in November.

Three pavements were selected for the tests in the vicinity of Frederick, Maryland: the ten year old project to the west on US 40; a 16 mile section of the New Washington National Pike pavement, US 240, to the south toward Washington; and a portion of the new pavement on the Baltimore National Pike extending eastward toward Baltimore, 12 miles in length. The total traffic on US 40, both east and west of Frederick, totals about 6,000 to 8,500 vehicles per day. That along US 240 south of Frederick totals some 5,000 vehicles per day, but will most likely increase greatly as the route is completed to the Washington, D. C. area. Commercial vehicles account for about 20 to 30 percent of the total traffic.

In the tests the deflection of the pavement was measured at selected points under an 11,200 pound moving wheel load with the Benkelman beam device. (1) This device records the vertical movement of the pavement surface midway between the dual tires of a loaded truck wheel as the load approaches and leaves a given point. Two of the beam devices were used simultaneously to measure the deflection under both sets of rear wheels, with the center of the outer dual wheel positioned approximately 18 inches from the pavement edge. About 20 locations were tested per mile.

The initial series of tests was made at a time when the condition of the subgrade was considered to be adverse, and the second series at a time when the condition was considered to be more favorable. The results of the tests are presented in Table 1 and are shown graphically in Figures 7, 8, and 9. They may be summarized as follows:

1. On a basis of all the tests, both wheel paths combined, the deflection of the pavement in the spring period was 26, 35, and 169 percent greater than in the fall for the US 40 West, US 240 and US 40 East projects respectively. (See Figure 7) The values of 26 percent and 35 percent represent what we believe to be a more or less typical decrease in the indicated ability of a pavement of this type to support load in the spring as compared to the fall. (2) It should be noted here that the US 40 East project was built by stage construction methods. When the spring deflection measurements were made, only a surface treatment had been placed on the macadam base. This, no doubt, accounts for the high deflections found at this time. Prior to making the fall tests, the final asphaltic concrete surfacing had been placed, and the deflection values were considerably less.

2. For the tests made in the spring period, the average deflection in the outer wheel path was about 4 percent greater than in the inner wheel path for the US 40 East pavement, 19 percent for the US 240 pavement and 45 percent for the US 40 West pavement. (See Figure 8) Comparable values for the series of tests performed in the fall period are 4 percent, 14 percent and 39 percent respectively. (See Figure 9)

3. As shown in Figure 9, little difference in the mean deflection of the three pavements was found in the outer wheel path for the fall period of testing. In the inner wheel path there was not much difference in these values for the US 40 East and US 240 pavements; that in the inner wheel path of the US 40 West pavement was, however, considerably less, for which we have no explanation.

4. That considerable variability exists in the indicated load supporting capacity of the three pavements is shown by results of a statistical analysis of the spring deflection data. (See Table 1) For example, while the mean deflection of the US 40 West pavement in the outer wheel path was 0.032 inch, 68 percent of the total of 269 measurements ranged from 0.017 to 0.047 inch. These values for the US 240 pavement are 0.044 inch, and 0.026 to 0.062 inch; for the US 40 East pavement they are 0.070 inch, and 0.042 to 0.098 inch.

The WASHO Road Test report contains an analysis of deflections correlated with satisfactory and unsatisfactory pavement performance. The conclusion of this analysis is that 0.045 inch deflection is satisfactory for warm weather periods, and 0.030 inch is satisfactory for cold weather. The report states that these values do not necessarily apply to other pavements, or to pavements of greater age.

The mean deflection on one of the new roads, US 240, agrees quite well with these values, while the mean value for the older project, US 40 west of Frederick, is considerably smaller.

We believe that the results of the deflection tests indicate in a general way that pavements being built using our selected design method will perform satisfactorily. However, the variability in indicated load supporting capacity as shown by statistical analysis of the deflection data is such that we do not feel that any reduction in the pavement structure would be justified. Apparently some factor of safety is necessary to ensure satisfactory performance of such flexible pavements as we have built, or are building in Maryland.

It is anticipated that we will continue our studies of the performance of pavements in service in Maryland, and that, as more data are accumulated, we will be in a better position to decide on the merits of the approach to this problem.

ACKNOWLEDGEMENT

The assistance of Stuart Williams, Highway Physical Research Engineer, Bureau of Public Roads, in the conduct of the deflection tests, and the analysis of the data is gratefully appreciated.

References

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2. Public Report of the Highway Research Board Committee on "Load Carrying Capacity of Roads as Affected by Frost Action."