fine aggregates in projects using questionable cements only, and of all cements in projects using questionable fine aggregates only. The resulting mileages were small and the projects scattered, therefore no conclusions were drawn.

SUPPLEMENTAL FIELD OBSERVATIONS

Upon study of the last elimination, it was revealed that a number of these questionable materials were used on relatively short mileages. Therefore, it was decided to investigate the service records of these materials over a longer period. A list of projects constructed in the years 1930 to 1935, inclusive, in which these questionable materials were used, was obtained from testing laboratory records. In making up this list an attempt was made, insofar as possible, to select those projects in which some given questionable material had been used along with other materials that were not questionable. (For example, where questionable fine aggregate "X" had been used along with non-questionable cement "Y" and non-questionable coarse aggregate "Z".) Unfortunately a number of the questionable materials were not used from 1930 to 1935. In fact, a number of them were materials which had been obtained from recently opened deposits.

The committee inspected the jobs on this list and took such data as would enable them to obtain ratings for surface and progressive scale. These data were not averaged with previous data on these materials but were used as supplementary evidence only.

DEPARTMENT OF MAINTENANCE

W. H. ROOT, *Chairman*

SOME OBSERVATIONS ON RESURFACING PORTLAND CEMENT CONCRETE PAVEMENTS WITH BITUMINOUS MIXTURES

BY WAYNE R. WOOLLEY, *Materials Engineer*
Public Roads Administration

SYNOPSIS

In order to secure information to indicate the most desirable construction practices for resurfacing old portland cement concrete pavements with bituminous concrete, regular inspections over a three-year period were made of a number of previously constructed bituminous resurfacing projects on which pertinent construction data were available.

Bituminous resurfacing of old concrete provides a waterproof roof over the subgrade and forms a smooth riding surface which reduces impact on the concrete base. By these means the load-carrying capacity of the old surface is preserved and perhaps increased.

The practices which seem to be giving the best service for the money expended are these:

Old concrete pavements in the area of the study having reasonably satisfactory grades and alignments may be economically resurfaced with about a two-inch thickness of relatively rich dense graded bituminous concrete laid in two layers. The most economical time to apply a bituminous surface is when it is anticipated that, as an annual average, 1 to 1.7 percent of the area would need to be patched with concrete if the road were to be maintained as a concrete pavement. Very little patching immediately prior to resurfacing is justified. Removal of fat bituminous patches and the use of a light tack coat is considered good practice.

The resurfacing of pavements subject to pumping cannot be depended upon to stop pumping permanently. Covering pumping concrete with a layer of dense graded granular material prior to resurfacing has been effective in stopping

pumping. Forcing a rather hard bituminous material into the voids under pumping pavements is believed to be a good investment, particularly if the pavement is to be resurfaced.

Resurfaces placed, as outlined above on the basis of service rendered to date, may be estimated to have a life of ten or fifteen years with a very low maintenance cost.

During the late world war, many hundreds of miles—perhaps thousands of miles of old concrete pavements were resurfaced with some sort of bituminous materials. A number of technical articles have been published telling how this engineer and that State resurfaced old pavements, but very little data based on service behavior have been published. This paper presents data obtained from three years' observation of the service behavior of 22 bituminous resurfacing projects of various types, thicknesses and ages. Also, a less detailed study has been made of a large mileage of bituminous resurfacing projects in Illinois, Indiana, Michigan and Kentucky.

In the spring of 1944, eight bituminous resurfacing projects were selected in Illinois, seven in Indiana and seven in Michigan. These projects had been resurfaced at dates ranging from 1934 to 1944 inclusive. The thickness of the resurfacing varied from 1 in. to 4 in. The types of bituminous mixes used on the various projects were:

Cold mix, dense gradation.......	1 project
Cold mix, open gradation	4 projects
Binder and Kentucky rock asphalt surface	7 projects
Hot asphaltic concrete..........	10 projects

In each case, the history of the old concrete pavement was known and the data concerning the bituminous resurfacing were obtained. Inspections have been made on each of these projects during the last three years in order to determine not only the present condition, but also, to attempt to chart the rate of deterioration. A typical data sheet such as was filled out for each of the 22 projects is appended. Because of the large number of variables affecting these selected projects, the personal opinion of the observer is necessarily a factor in evaluating the effect of some of the variables.

PURPOSE OF RESURFACING

The primary purpose of placing a bituminous resurfacing is generally to preserve the concrete as a base. A resurfacing forms a waterproof roof over the road that tends to delay disintegration of the concrete and to keep surface water from the subgrade. The resurfacing also forms a smooth riding surface which the travelling public likes. The smooth surface reduces impact and thus has the effect of increasing the load-supporting capacity of the pavement. It is doubtful that the bituminous resurfacing has any appreciable effect in increasing the load-carrying capacity through spreading the load over a larger area. The fact that thicknesses varying from 1½ in. to 4 in. all had about the same amount of base failures is an indication that thickness in itself is not important. These observations are somewhat similar to those made in a report by Illinois on the Bates Experimental Road nearly 25 years ago. The following statement is quoted from the Illinois Report: "Asphaltic concrete surfaces apparently do not add materially to the strength of the base, but by lessening impact at small broken corners, they give considerably increased resistance to progressive destruction."

CONDITIONS OF OLD PAVEMENTS THAT JUSTIFY RESURFACING

Pavements having grades, alignment and widths good enough to use another ten years or more are generally worth resurfacing. At what stage of deterioration such pavements should be resurfaced is a problem requiring some individual judgement, but the following discussion should be helpful.

The maintenance departments charged with the responsibility of keeping surfaces in a satisfactory condition often have to decide whether a section of pavement should be maintained by means of concrete patches or by resurfacing. Cost analyses, illustrated as follows, are necessary to determine the most economical method. Assuming a contract price of $1.00 per square yard for a bituminous surface in place, a ten-year average service life, and a ten-year maintenance cost of 10 cents per square yard, a total ten-year cost of

$1.10 per square yard is computed. One-tenth of this amount, or 11 cents per square yard, would be the annual cost.

For purposes of comparison, it is necessary to estimate the cost of maintaining the old concrete pavement without resurfacing. In 1945 the average unit price of several concrete patching contracts was $6.00 per square yard. If 1.7 percent of the concrete pavement needs to be patched each year in order to maintain it satisfactorily and the cost of making a patch is $6.00 per square yard, then the annual cost of patching based on the total area of pavement is 1.7 percent of $6.00 or 10 cents per sq. yd. To this figure should be added the normal annual cost of maintaining a concrete surface which may be taken as 1 cent per sq. yd. This makes a total of 11 cents per sq. yd. as the annual cost of maintaining a concrete pavement that requires replacement of 1.7 percent of the area each year with concrete patches. As this cost is the same as the estimated annual cost of resurfacing, it follows that in this case, resurfacing becomes a more economical method of maintenance than patching with concrete when the annual amount of patching exceeds 1.7 percent of the total area.

Somewhat different percentages of patching may, of course, be obtained by making different assumptions. For example, the life of a bituminous resurfacing was assumed to be 10 years, whereas, road life studies made by the Public Roads Administration indicate a probable service life of 15 years for this type of pavement. By substituting 15 years for 10 years as the life of a bituminous resurfacing and a 15-yr. maintenance cost of 20 cents per sq. yd., it may be calculated that resurfacing should be placed when the annual amount of concrete patching is estimated to be slightly greater than one percent. Actually 15 years is a more accurate estimate of the life of a resurfacing than is 10 years. However, most bituminous concrete surfaces, particularly in rural areas where the traffic is moderate, will need a seal coat after about ten years. Seal coats are an economical method of maintenance, but on heavy traffic roads there is a tendency for seal coat aggregate to be thrown off the surface by traffic leaving an excess of bitumen and a surface lacking in non-skid properties. In order to maintain a high-type, smooth riding, non-skid surface, a new layer of plant-mixed bituminous concrete is preferable to a seal coat. A life of 10 years, therefore, was assumed because this is the approximate average age at the time a bituminous concrete surface is likely to need some overall maintenance to protect it against excessive drying and ravelling at the cracks.

In the case of a surface having a reasonably satisfactory grade and alignment but inadequate width, the case for resurfacing is not so clear. Roughly, the cost of widening from 18 ft. to 22 ft. and resurfacing in the area of study is about $28,000 per mile. Allowing two resurfacings in 20 years, a 20-yr. construction cost of $40,000 is computed which is about the cost of a new 22-ft. concrete pavement constructed on the existing grade and alignment.

The discussion so far has been based on the assumption that the old concrete pavement was not subject to pumping. Bituminous resurfacing of pumping concrete pavements has not been entirely successful. Of six pavements known to have been subject to pumping prior to resurfacing, all have shown some pumping within three years' time after resurfacing. One project in Illinois, resurfaced with a rich dense graded bituminous concrete 3 in. thick has developed pumping at only one crack after two years' service. One in Michigan resurfaced with a similar mix of a thickness varying from 2 in. to 4 in. has developed slight pumping at only a couple of cracks through the 2-in. thickness portion and no pumping at all through the thicker resurfacing after three years' service. The resurfaces on which considerable pumping have developed, have all been less than 3 in. thick. It appears therefore that bituminous resurfacing less than 3 in. thick will not be effective in correcting pumping. Those 3 in. or more in thickness have been fairly effective in preventing pumping for three years but there are signs that pumping will develop in time even with these thicker surfaces. Resurfacing pumping pavements is not recommended unless some remedial action is taken to stop the pumping.

The only resurfacing operation which has been observed to prevent pumping action is to cover the old concrete with about four or more inches of well compacted dense graded granular material. If stabilized gravel is used, the clay content and plasticity index must be kept low. In 1942 Illinois resurfaced an old concrete pavement by placing 3 to 5 in. of granular material and 2½ in. of bituminous surface over an old pumping concrete pavement. This has been completely effective in stopping pumping. Practically no transverse cracks have appeared through the resurface. There are two other more recent examples in Illinois where a layer of traffic-bound crushed stone between the old concrete and the bituminous surface is performing satisfactorily. California reports that a layer of crusher-run stone generally 6 in. thick has prevented rocking slabs from causing cracks in the overlying bituminous surface for three years.[1]

Another method of treatment, which may not be completely effective but which is being used, is to fill the voids under a pumping concrete pavement with a rather hard grade of bituminous material. This may be done economically prior to resurfacing by using a bituminous distributor to pump the material through holes drilled in the concrete.

Of some interest, perhaps, is a section of bituminous resurfacing containing expanded metal reinforcement placed by the State of Michigan in 1937. The old concrete pavement was laid in 1924 on 4 in. of bank-run gravel over unstable muck. By the fall of 1937 the pavement was cracked into slabs less than 10 ft. long and these slabs were rocking so badly that it was feared it would not be possible to maintain the concrete surface during the following winter. Because of the unstable material under the pavement and because of the pronounced rocking of the concrete slabs, it was decided to place expanded metal reinforcement weighing 5.2 lb. per sq. yd. in portions of the bituminous resurfacing. The total thickness of the bituminous resurfacing varied from about 3 to 7 in. The binder was a mixture of powdered asphalt and flux designed to result in an asphalt having a penetration in the neighborhood of 70.

Early reports indicated that cracks were much farther apart in the portion containing reinforcement than where reinforcement had been omitted. When the author first inspected the project in 1944, it appeared that all of the cracks in the old pavement were visible in the bituminous resurfacing in both the reinforced and unreinforced portions. Due to the unstable underlying material there has been some distortion of the surface and it appeared that this distortion was more pronounced on the unreinforced portion. Perhaps the steel has helped maintain the proper cross-section of the pavement, but after seven years' service, it has had no effect in preventing cracks. During an inspection made in 1946, when this resurfacing was nine years old, all sections looked to be in about the same condition—which was poor. Although Michigan has placed several hundred miles of bituminous resurfacing since placing the original reinforced resurfacing, they have not used any reinforcement since that time.

[1] From an article by Earl Withycombe, Assistant Construction Engineer of California summarized in the July 1946 issue of *Roads and Streets*.

TREATMENT OF BASE PRIOR TO RESURFACING

Bituminous patches fat enough to bleed up into the resurface should be removed. There is nothing to be gained by removing patches of bituminous mixtures not rich enough to bleed into the new resurface. Old patches are likely to be at least as stable as new material placed in the same hole. Hardened crack filler in and on top of cracks causes no damage to the resurface and need not be removed. In fact it may be that this crack filler is heated sufficiently by the resurfacing material to form a fairly good seal of the crack in the concrete, so that it may actually be beneficial to leave it in place.

Expansion joints which have not become filled with incompressible material should be cleaned out for a couple of inches from the top and back-filled with a fine graded bituminous mixture. This tends to lock the joint against further closure and to prevent a bump in the resurface due to subsequent closure of the expansion joint.

Some projects have been extensively patched with concrete prior to resurfacing and others, even though badly broken, have not been patched at all. In spite of the absence of patching, surface failures have been very rare except where caused by pumping pavements. On pavements subject to pumping, surface failures have occurred in three to five years' time on most projects whether or not they had been patched prior to resurfacing.

Patching old concrete with concrete is expensive. No one knows which places to patch and which do not need patching. Base failures on resurfacing projects have been almost negligible, except where caused by pumping, whether or not prior patching was done. It seems that the most economical procedure is to place the resurfacing without patching the old concrete. The cost of repairing the few depressions that occur in the resurfacing, will be much less than the cost of patching the old concrete prior to resurfacing. An exception to this statement is that blow-ups in the old concrete should be patched with concrete. Otherwise, these places will tend to expand and cause bumps in the resurfacing.

Many engineers have stated that it is their practice to replace rocking slabs in surfaces subject to pumping prior to placing a resurfacing course. Wherever pumping has occurred enough to remove a portion of the subgrade, rocking slabs, or slabs subject to vertical movement under load, are sure to be the result. Replacing all such slabs would result in an entirely new pavement in the pumping area. This is obviously impractical and besides, would not correct the subgrade condition that causes pumping. What is generally done is to replace only a few short slabs which move the most. The practice is not commended because many sections of concrete are left in place which rock under loads and which will continue to be subject to this movement even after the bituminous resurfacing is in place. Under such circumstances, the re-occurrence of pumping is likely to be just a matter of a few years' time.

Figure 1. The old concrete was a 9–7–9–in. plain concrete pavement without transverse joints, built 1930–33. Rather serious pumping began to develop about 1941. In 1943, the concrete was widened from 18 to 22.5 ft using a 6–in. depth of black base. In 1944, a 2–in. layer of hot binder and $\frac{5}{8}$ in. of Kentucky rock asphalt was placed. The left hand photograph was taken March 26, 1945 and the right hand one was taken April 3, 1946. Both photographs show stains on the surface caused by muddy water being forced up through the cracks. Although this pumping has not yet seriously damaged the resurfacing, it is probable that damage will occur in a few years.

In resurfacing operations a tack coat of

0.05 to 0.1 gal. per sq. yd. should be applied. Otherwise, the material will shove under the roller until some bituminous material on the concrete is encountered which stops the movement and may build up a bump in the resur-

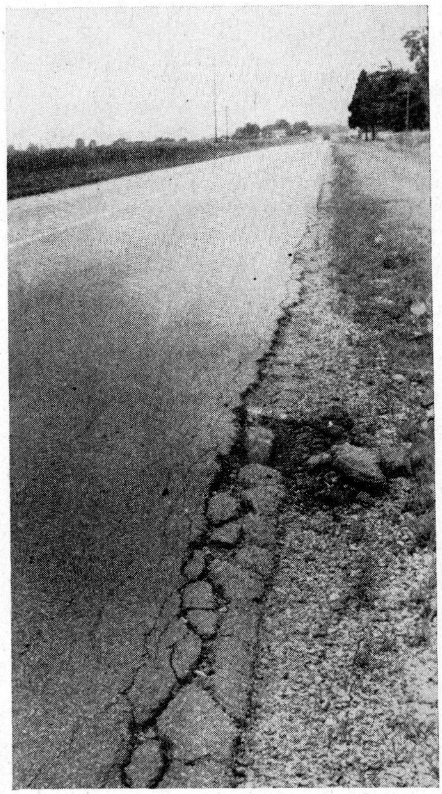

Figure 2. The edge ravelling illustrated in this photograph appears to be due to the resurface overhanging the edge of the concrete. Apparently wheel loads running on the edge of the unsupported bituminous resurface acted as a cantilever to cause a crack some distance from the edge of the concrete. Cracking similar to this has occurred on several projects, but no such cracking has been found unless the resurfacing extends beyond the edge of the concrete.

face. Light grades of rapid curing cutback or a quick-breaking emulsion make satisfactory tack coats. If the work is done under traffic, the emulsion is preferred because it breaks and sets more rapidly than does a cutback.

TYPE OF MIX

Hot-mixed asphaltic concrete appears to be the most durable type studied. The open graded types tend to dry out, become brittle and ravel at an earlier date than the denser mixes. The surface of the one cold dense mix project studied is in excellent condition now but it was necessary to apply a seal coat at the age of 3 yr. It seems probable that such mixes may be expected to result in higher maintenance cost than would be expected for hot mixes. Kentucky rock asphalt surfacing laid on both hot and cold binders has a service record inferior to bituminous concrete sur-

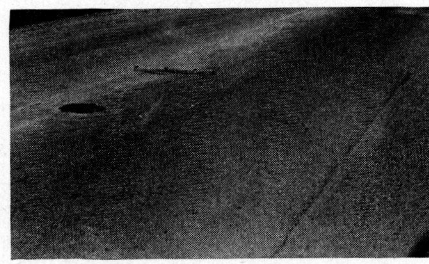

Figure 3. A Base Failure Associated with Pumping. The resurfacing is bituminous concrete 2 in. thick.

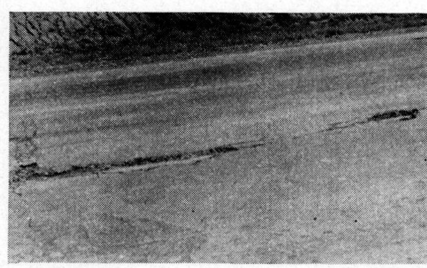

Figure 4. Binder, $1\frac{1}{2}$ in. and Rock Asphalt, $\frac{1}{2}$ in. Laid in 1938. Picture taken March 26, 1945 to show ravelling at longitudinal crack due probably to stripping of the asphalt off the aggregate. Such stripping occurs more quickly in somewhat open mixes such as this, than in denser mixes.

facing. Rock asphalt does furnish a rather pleasing uniformly black surface having excellent non-skid properties. However, it does not appear to be as effective as bituminous concrete in keeping water away from the base.

Illinois has very good surface maintenance costs on two of their older resurfacing projects involving three types of mixes. It appears that the data shown below tend to rate the various mixes in their proper order.

Total—10-yr surface maintenance cost on 2-in. bituminous concrete—\$.12 per sq yd

Total—8-yr surface maintenance cost on 2-in. open graded cold mix—$.21 per sq yd

½-in. Kentucky rock asphalt on 1½-in. open binder was reconstructed at the end of 8 years.

The maintenance costs on the first two types listed include one seal coat.

Each of the States studied has had successful performance from bituminous concrete resurfacing, even though the mixing formula is somewhat different. The mix which seems to be giving the best service is as follows:

	percent
Passing ½-in.—ret. on No. 10	50 –55
Passing No. 10—ret. on 200	34 –39
Passing 200	5
Bitumen	5½– 6

This mix is extremely dense, often resulting in a mix weighing 110 lb. per sq. yd. per inch of thickness. As much as 98 percent of theoretical density is obtained in the finished surface. Penetration grades of asphalt ranging from 60–70 to 85–100 have been used. No difference due to penetration of the original asphalt can be observed from service behavior inspections. There is a tendency, however, for the richer mixtures to have fewer cracks showing and for cracks once formed to at least partially reseal themselves under traffic. On two of the bituminous concrete projects inspected, there were practically no cracks visible at the age of three years. The mix on both of these projects appeared to be rather rich and it has been the general experience in the area of the study that rich mixes resist cracking much better than lean mixes.

On two projects involving more than two lanes, the outside lanes were black and dense in appearance, whereas, the inside lanes looked open and had a much lighter color. As bituminous resurfaces are commonly laid a lane at a time, it would seem desirable to lay a slightly richer mix on the inside lanes than on the outside lanes. Unfortunately, it is generally not practical to do this because the contractor shifts from lane to lane too often.

The same line of reasoning would lead to a richer mix being used on a medium or light traffic road than on a surface subject to heavy traffic. This principle has been recognized for many years, but not often followed in the area studied.

THICKNESS OF RESURFACING

As previously mentioned, the thicknesses of resurfacing on the projects studied varied from 1 to 4 in., design thickness. Actually, holes dug through the resurfacing disclosed thicknesses of from ½ in. to 7 in. These variations in thickness resulted from small bumps or settlements in the old concrete.

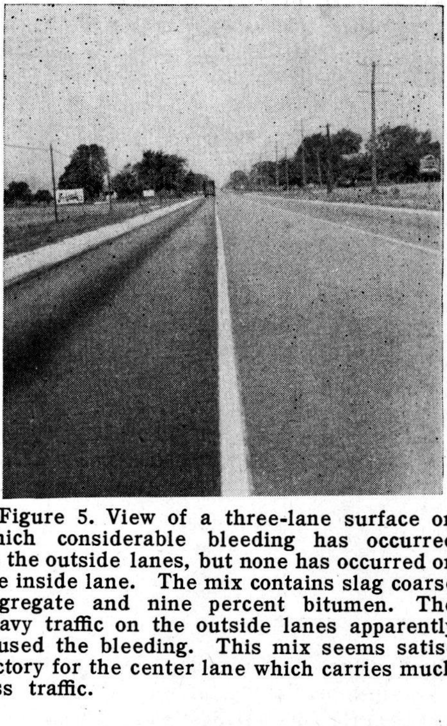

Figure 5. View of a three-lane surface on which considerable bleeding has occurred on the outside lanes, but none has occurred on the inside lane. The mix contains slag coarse aggregate and nine percent bitumen. The heavy traffic on the outside lanes apparently caused the bleeding. This mix seems satisfactory for the center lane which carries much less traffic.

There is no general agreement on the most economical thickness of bituminous resurfacing. It is easy to inspect projects of various thicknesses and determine which are in the best condition but assigning the reason for the condition is a problem subject to considerable personal opinion. With the idea of shedding some light on the behavior of various thicknesses of resurfacings, the cracks visible through the resurface were counted on most of the inspections made. Table 1 shows the average interval between cracks.

The figures shown in some cases represent only one count on one project and in other cases represent the average of as many as five different projects. These data may not be conclusive because in some instances, the crack interval is a function of variables other than thickness of the resurface. However, crack counts were not made on several projects, where it was thought that such things as extremely unstable subgrade or reinforced concrete base had affected the crack interval.

These data seem to show that the thicker the resurfacing the longer will be the time required for cracks in the old concrete to appear. It is indicated, however, that the effect of the thicker resurfacings is merely to delay the appearance of cracks by perhaps three years.

Probably surfaces as thin as 1 in. will fail more quickly than thicker surfaces because the thinner surfaces do not have enough stability to stay in place after the bond between the concrete and bituminous surface has been broken. Frequent checks made by removing small areas of resurfacing revealed that in most instances a film of water has collected between the concrete base and the bituminous material and that the bond between the surfaces has been destroyed in less than three years. It is necessary therefore that the resurfacing have enough stability and thickness to remain in place even though not bonded to the concrete. A stable mixture 2 in. or more thick appears to meet these requirements. In some instances a thickness of 1½ in. has been satisfactory. Thin road mixed surface treatments are not recommended because sometimes they do not stay in place and the surface is usually rough. Bituminous resurfacings which are not thick enough to allow the removal of irregularities in the base fail to fulfill what should be one of the primary functions of resurfacing.

CRACK INTERVAL IN RESURFACING IN LINEAR FEET

Age in years	Thickness of Resurfacing in Inches				
	1	2	2½	3½	4
1			100	Nearly crack free	Nearly crack free
2	35	56	40	Nearly crack free	103
3	33	45	40		63
4	30	30	31		
5			37		
6				25	
7				25	
8				21	

For most cases it is believed a 2-in. thickness is sufficient to waterproof the base and to remove surface irregularities and thus fulfill the two primary purposes of resurfacing. It may be that surfaces thicker than 2 in. have some advantages, but inspections of roads in service do not show positive improvement due to thicker surfaces. In the case of pumping pavements, thicker surfaces probably delay the re-occurrence of pumping, but thicker bituminous resurfacing is not believed to be the most economical way of preventing pumping.

Coarser binder courses may be placed if desired but because of the larger size aggregate, it will probably be necessary to lay a minimum thickness of 1½ in. of binder plus the surface course. The mix described previously under TYPE OF MIX may be laid in two 1-in. layers. Two layers are desirable in order to obtain the maximum degree of smoothness.

The conclusions presented in this paper are based upon observed service behavior of the resurfacing jobs studied and upon information obtained from the various State Highway Departments.

TYPICAL DATA SHEET

State.. .Michigan ....
Project No.. ..*FA 70 D*........
Date Resurfaced....*1941*.....
Location....*U.S. 16 from 12-mile road to 0.6 mile west of Novi*.. . . . ..
Description of old pavement at time of resurfacing ...(a) *Cross-section 8-in. uniform and 10-in. uniform*..... ..(b) Date Constructed....*20 ft. in 1925 and 10 ft. in 1932*....... (c) Condition *Cracked and scaled*..................... .. ..
Type of Subgrade.. .*Variable but no pumping ever observed*.... ......
Traffic....*In 1940—9,200*........
Length Resurfaced... *2.75 miles*........
Details of resurfacing:
(a) Type of widening... *Concrete widened from 20 to 30 ft. 1932. No widening at time of resurfacing.*
(b) Treatment of old base... *No patching done. Base primed.*
(c) Type of thickness of resurface....*220 lbs. per square yard of dense graded bituminous concrete surface course laid in two one-inch courses. Crushed stone aggregate.*

Condition of resurface on

July 18, 1944: *Crack interval on eastbound lane, 60 feet which is probably more than crack interval in old pavement. About four bumps per* *mile tha appear to be caused by closing of expansion joints in old concrete. Center joint cracked but crack is tightly closed. Transverse cracks appear to have been sealed last year. No ravelling or distortion of surface. No signs of failure other than bumps over joints.*

May 23, 1945: *Crack interval on west mile of eastbound lane is now 44 feet. Some cracks have resealed themselves over a portion of the width. Cracks have not been poured during last year. A few are beginning to ravel. It does not appear that any maintenance has been performed on the surface during the past year. No new blow-ups observed. Holes dug at edge indicate thickness at edge to be slightly less than two inches. Bituminous concrete not stuck to concrete at crack—nor at edge where there is no crack. Longitudinal cracking in middle of outside lane, showing up in east mile.*

June 27, 1946: *Crack interval on west mile of eastbound lanes 41 feet. Now six bumps in west mile of eastbound lane due either to blow-ups or expansion joints. Center lane appears much drier than outside lanes, probably because of less traffic on inside lane. Longitudinal cracks eight or ten inches from edge beginning to appear due to bituminous resurfacing overhanging edge of concrete. Cracks have not been sealed but a small amount of patching of ravelled cracks has been done.*

EFFECT OF EXPERIMENTAL SUBGRADE TREATMENTS ON PAVEMENT FAULTING AND PUMPING

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AND

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State Highway Commission of Indiana

SYNOPSIS

This report of a study of the effect of various subgrade treatments on the performance of a heavily traveled, concrete pavement constructed on plastic, silty-clay soils was conducted as a co-operative investigation by the State Highway Commission of Indiana and the Joint Highway Research Project of Purdue University.

One of the many problems in the design of concrete pavements is the selection of the proper base or subgrade to aid the pavement in withstanding the volume and weight of modern traffic. With this in mind, the State Highway Commission of Indiana, during the construction of U.S. Highway No. 30 in 1937, installed seven test sections with differently treated subgrades. Many structural failures have developed on this highway. A study of these failures offers a means of evaluating the effects of the various subgrade treatments on the pavement performance by comparison with the untreated portions. Aerial strip maps were used as one means of evaluating pavement performance.

The performance data indicate that six of the subgrade treatments improved the concrete pavement performance. Granular base courses contributed the most, the result of their use being a pavement of nearly as good a riding quality today as at the time of construction nine years ago. The mixing of bituminous materials with the fine-grained subgrade soil improved the pavement performance but not as effectively as did the granular base courses. No significant difference was readily apparent in the pavement performance on the bituminous treated sections, although all three treatments improved the performance in comparison with untreated sections.

With the increase in volume and weight of highway traffic during the past few years, many States have encountered serious problems in connection with structural failures on high-type pavements. The extrusion of fine-grained subgrade materials from beneath concrete pavements by pumping action is a major cause of a large portion of the failures. It is