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Bulletin 123

Bituminous Resurfacing

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Bituminous Resurfacing

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Rejuvenating Highway Pavement

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The paper describes the resurfacing with a flexible pavement of the Roy Junction - Muck Creek section of Primary State Highway 5, located 6 miles south of Tacoma, Washington, on the route to Mount Rainier National Park that was originally paved in August 1914 with a 16-foot-wide portland-cement-concrete pavement. This section, 5.46 miles in length, was widened to 22 feet in 1940, using a 3-inch-depth asphaltic-concrete-base mixture as a widening medium and the widened roadway was resurfaced with an average thickness of 2½ inches of asphaltic concrete material.

A description of the type of soil underlying the pavement is given and the condition of the old pavement before resurfacing. Figures show typical sections before and after resurfacing and after 14 years of service.

The typical grading of the base, leveling and wearing surface mixtures is outlined along with the type and character of the mineral aggregates used and the grade and source of asphalt cement. A brief description of the methods and types of equipment used in construction of the resurfacing is given, also the length of time and the cost to construct the project.

A table indicating the cost to maintain this section of highway per year per mile is presented, also the average daily traffic for each year. Slides showing the crack patterns that have developed during the 14 years of this pavement's life are shown with an analysis of the cause of each type.

The paper is concluded with an attempted evaluation of this resurfacing work, pointing out the weaknesses that have developed and how possible correction can and has been made in this type of construction.

● THE problem of providing adequate highway surfaces in the face of ever increasing traffic volumes and inadequate funds is one the Washington State Highway Department has shared with the other 47 states of the union since the advent of the motorized vehicle.

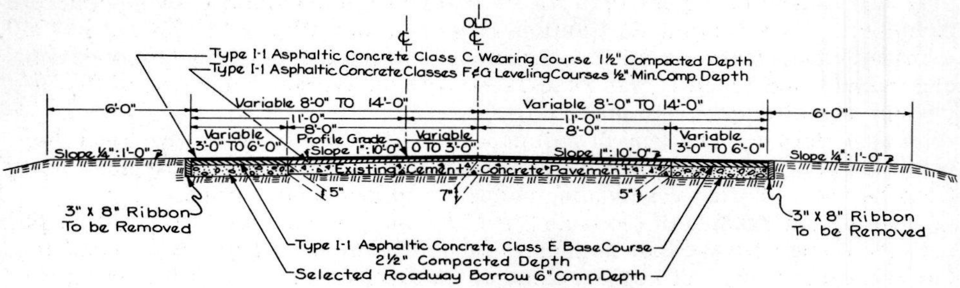
A part of Primary State Highway 5, located 6 miles south of Tacoma, Washington, and known as the Roy junction to Muck Creek section, was judged to be in critical need of widening and improvement of the riding surface when the biennial construction budget of 1939-40 was made. This was due to the increased traffic by reason of the expansion of population of the second largest city in Washington and spread of home building in all directions, increased use of trucks to haul logs and rough lumber to Tacoma mills from forests and small mills south of Tacoma, and growing popularity of Mount Rainier National Park as a recreational center for motorists from Seattle-Tacoma vicinities.

The glacial deposit of sand and gravel which underlies this section of highway, up to 50 feet deep, provides an excellent free-draining foundation, and conditions would be ideal if it were not for a highly plastic, silty, black-colored soil that covers the gravel from 4 to 8 inches in depth. It is this soil that, due partly to ignorance and partly to carelessness on the part of the inspectors, was allowed to become mixed in some areas with the base aggregate for the widened areas and that later caused trouble, as will be shown in this paper.

A flexible type of widening and resurfacing material over the rigid portland-cement-concrete pavement was determined early in 1940 to be an adequate method of rejuvenating this section of 16-foot wide pavement, which is 5.46 miles long and was constructed in August 1914 on an existing gravel road. The old pavement had a slab thickness of 5-7-5 inches and was not subsealed, due to the fact this technique was untried and unknown in Washington in 1940.

A typical cross-section of this project, as shown in Figure 1, consisted of 3 feet of widening on each side of the old pavement with a 2½-inch asphalt-concrete base, after which a leveling course with a minimum thickness of ½ inch over high points, or an average thickness of 1 inch was placed over the old 16-foot roadway. The depth of leveling mix on the new base course varied from ½ to ¾ inch. A wearing surfacing of 1½-

inch uniform thickness was constructed to complete the resurfaced roadway. In areas where depths of more than 2 inches of leveling course were required to produce a uniform grade line, leveling mix was spread by motor-patrol blade to prelevel the depressions in the old cement concrete pavement. The shoulders on each side of the pavement were excavated to a width of 5 feet and depth of 6 inches below grade line of the finished subgrade. This area was then filled and compacted with selected gravel roadway borrow upon which to lay the asphalt concrete base mixture. One exception to the above cross-



ROADWAY SECTION
16' MIN. 28' MAX. TYPE I-1 ASPHALTIC CONCRETE PAVEMENT

Figure 1.

section was a ¾-mile area where, due to limited right of way, the widening was all constructed on the east side of the roadway.

Figure 2 shows the old pavement as it appeared in March 1940, or nearly 26 years after it was constructed. Note the transverse cracks and the indications of pumping movement of the slabs at the expansion joints by the light patches near the center line. Figure 3, taken in September 1940, illustrates the resurfaced pavement at the same location as Figure 2, while Figure 4 was taken in October 1954, showing the conditions of this pavement 14 years later. These three views were taken at the north end of the project at the same location.

Figure 5 reveals the condition of the old pavement at approximately the center of the project and although some of the corners of the slabs are broken and the expansion joints

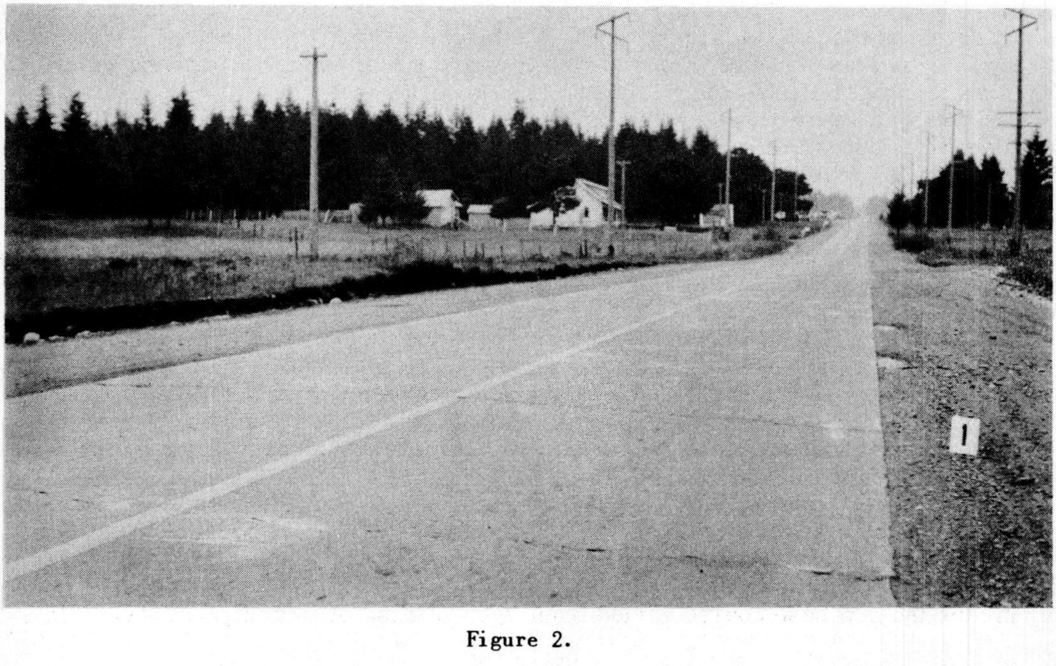


Figure 2.

Figure 3.

are chipped, the 26-year old pavement is in fair condition at this point.

Figure 6 exhibits the completed resurfacing work in September 1940, showing the rather granular texture of the wearing surface. Figure 7 discloses this same area in October 1954, or 14 years later.

The contract for the widening and resurfacing work on this section was awarded in April 1940 to two Tacoma contracting firms, Paine & Gallucci and Woodworth & Cornell, working as partners. Woodworth & Cornell constructed the asphalt-concrete portion of the work. The mixtures were produced by a standard four-bin batching type plant with a 2,000-lb. capacity mixer, located along the waterfront in Tacoma. The mixtures were hauled by truck an average distance of 15 miles to the job. A Jaeger self-propelled, mechanical spreading machine was used to spread all mixtures, except the base and spot

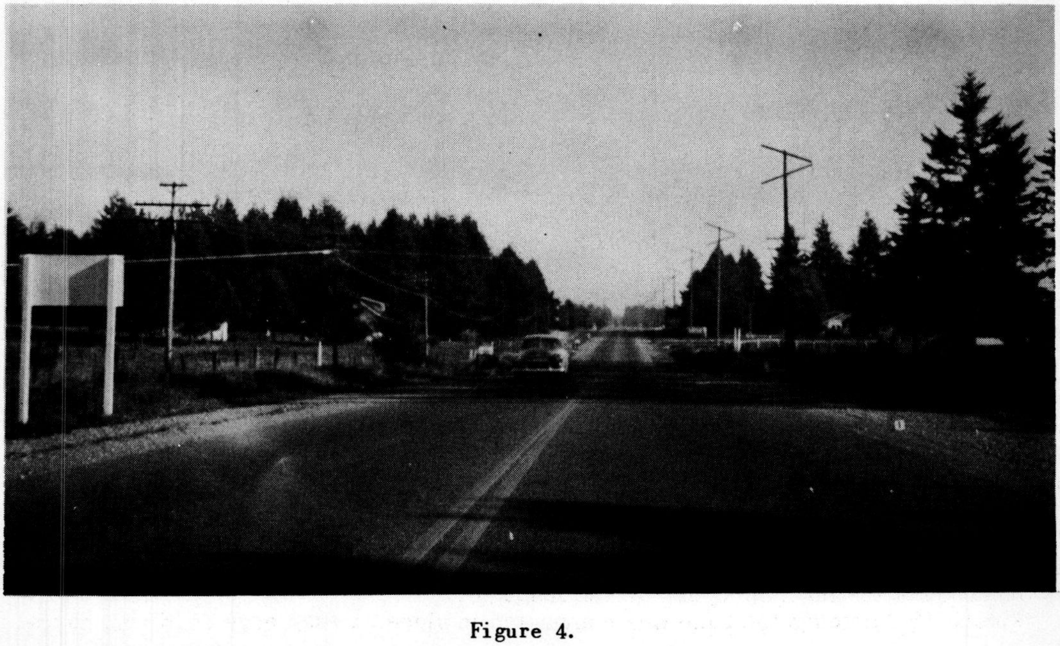


Figure 4.

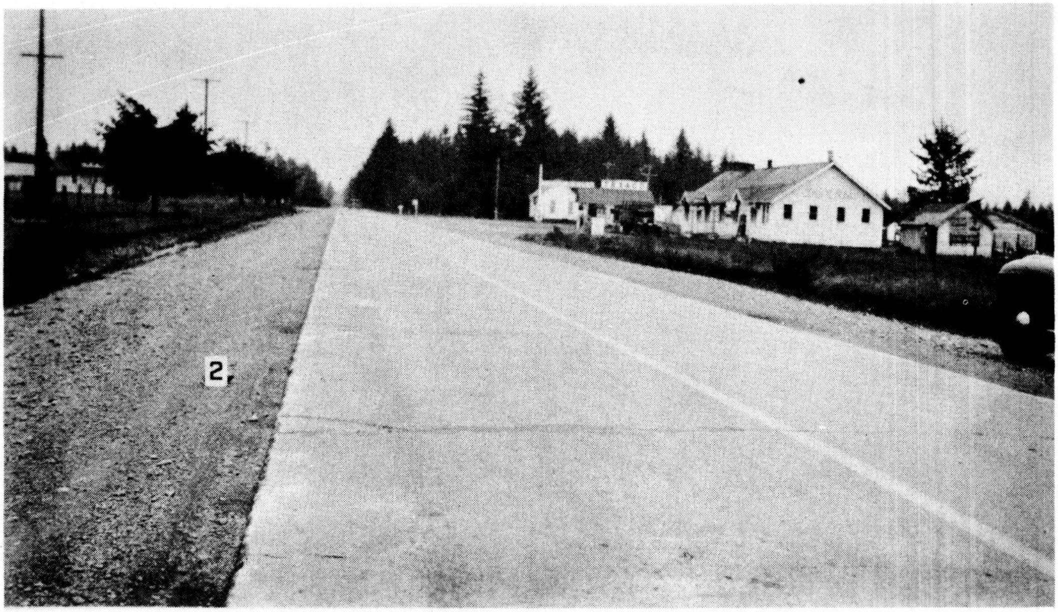


Figure 5.

Figure 6.

leveling materials. These were placed with a heavy motor-patrol blade. The pavement was rolled with one 10-ton, three-wheel and one 8-ton tandem roller. Figure 8 shows the spreading machine working on leveling mix and the three-wheel roller can be seen in the background.

Figure 9 demonstrates a straightedge equipped with an adjustable carpenter's level for obtaining the thickness of mat on the old pavement for correct crown. Marks indicating the thickness of the mat were placed on the pavement each 25 feet of length for the information of the machine operator and inspector.

Figure 10 discloses the base mix compacted in place on each edge of the old pavement. Note the 3-by-8-inch wood form laid on edge at each side of the roadway. These forms were removed after the asphalt concrete was completed and before the shoulder material was placed. Present-day construction does not require forms of any type, since it has been found the mechanical self-propelled machines do not require side forms for grade or alignment.

Representative composite screen gradings of the three classes of mixtures used on this project are shown in Table 1. Note the grading of material is expressed on a passing-and-retained basis rather than a total passing. The mixtures were within the limits of the 1935 standard specifications of the department. There was no difficulty experienced in adjusting the feed of the aggregates at the plant to meet the specification in grading.

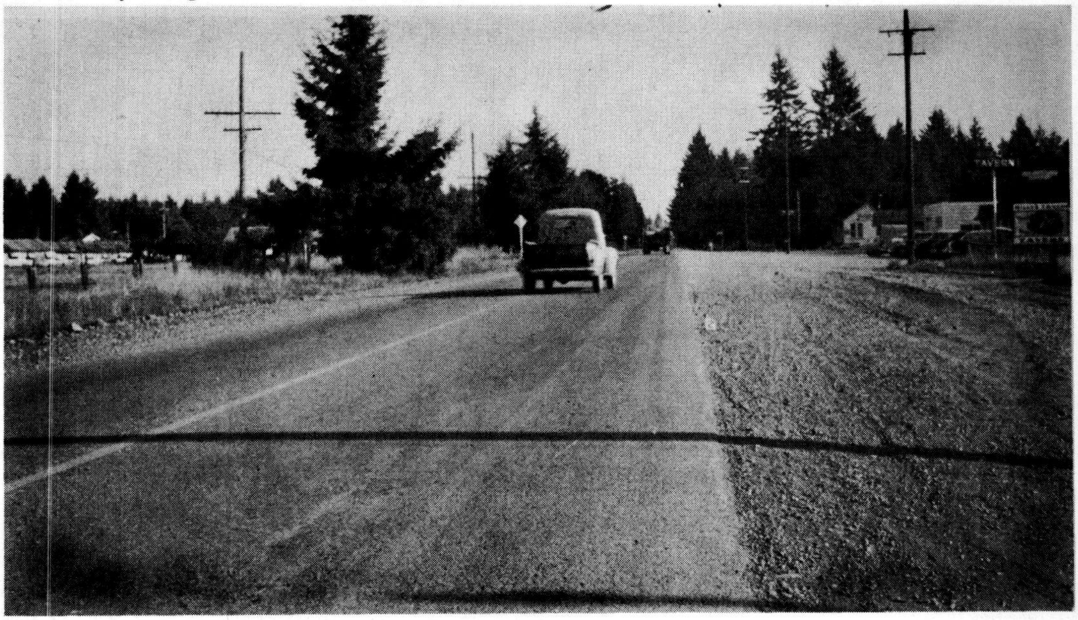


Figure 7.

Figure 8.

Figure 9.

The aggregate was an excellent 100-percent crushed gravel shipped to the asphalt plant in barges from a gravel plant located at Steilacoom, Washington, that primarily produced aggregates for cement concrete use. The large, oversize gravel pieces were crushed to produce the asphalt concrete. This gravel is considered as a high-quality aggregate and is used as a standard material in the department's material testing laboratory. The blending or muck sand used to mix with the pass No. 10 mesh sieve of the crushed, ⅝-inch-to-0 gravel was obtained from the Hylebos Hill pit owned by the contractor and located 3 miles from the asphalt plant. This material is composed of sharp,

Figure 10.

clean particles and has a good grading for a blending sand. The limestone dust used only in the wearing-surface mix at the rate of 2 percent was obtained from commercial sources in Seattle. The asphalt cement was supplied by the Standard Oil Company and was 61-70 penetration grade, meeting the department's specification in all respects.

A total of 13,845 tons of asphaltic concrete was used in the project, of which 6,650 tons was wearing surface, 3,895 tons was leveling mix, and 3,300 tons base mixture. The unit cost of the asphalt concrete was $6 per ton for all classes of mixture, or a total cost of $83,070. There was a total of 69,595 sq. yd., including intersections, in the contract. The unit cost per square yard was $1.19 for the asphalt concrete resurfacing. The total cost of the contract paid the contractor on the final estimate for all items of work was $106,989.45.

TABLE 1

Size of Round Opening Screens	Weaving Surface Mix Class C	Leveling Mix Class F	Base Mix Class E
Pass 2" ret. 1¼"			8.0
Pass 1¼" ret. 1"			8.0
Pass 1" ret. ¾"			10.0
Pass ¾" ret. ½"			14.0
Pass ⅝" ret. ½"	6.0	5.5	-
Pass ½" ret. ¼"	46.0	41.0	19.0
Pass ¼" ret. No. 10 sieve	27.0	20.0	14.0
Pass No. 10 sieve ret. No. 40 sieve	4.0	6.5	7.0
Pass No. 40 sieve ret. No. 80 sieve	7.5	13.0	10.0
Pass No. 80 sieve ret. No. 200 sieve	6.0	10.0	8.0
Pass No. 200 sieve	3.5	4.0	2.0
Total	100.0	100.0	100.0
Percent asphalt cement	4.9-5.0	4.5-5.0	4.6-5.0

The resurfacing portion of the project was started on April 22, 1940, and completed on June 24, or an elapsed time of 64 calendar days. The contractor required 37 working days to complete the work. Much of the delay was due to unfavorable weather conditions during April and May.

The cost per mile per year to maintain the traveled or paved area of the section and the average daily traffic since 1940 are shown in Table 2. During the last two years of World War II and the two years following, the cost to maintain the pavement surface only was not segregated from the costs to maintain shoulders, ditches, and other items of maintenance work. The maintenance costs are shown for the fiscal year ending March 31, while the ADT shown is computed on a calendar year basis. It is to be noted that traffic counts on this section were not recorded during the war years and not until 1947. It is estimated that 10 to 15 percent of the traffic using the northbound lane was logging trucks with maximum loads of 40.5 tons or more.

The cracks that have developed in the wearing surface of the pavement fall into two

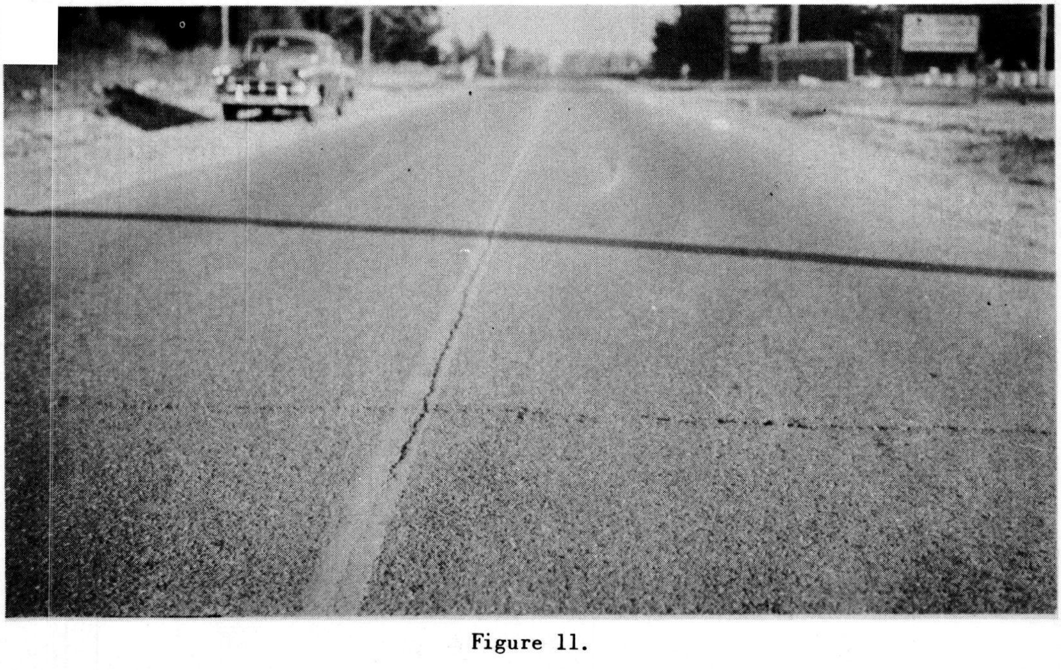


Figure 11.

TABLE 2

Year	Cost to maintain pavement surface only per mile computed to closest dollar	Average daily traffic
1941	1	2940
1942	19	-
1943	6	-
1947	-	3206
1948	96	3391
1949	36	2671
1950	63	2890
1951	43	3414
1952	68	3109
1953	122	3209
1954	90	-

general classes that are common in this type of construction. The first class is where a relatively thin flexible pavement is placed over a rigid pavement or base and the expansion joint pattern in the rigid base reflects through to the new surface after a few years. The second class of crack pattern is where the nonrigid base under the widened area is lacking in thickness or contains plastic material which causes the pavement to yield under traffic during wet weather or during the early spring thawing period.

Figures 11 and 12 illustrate the first type of crack pattern that developed in this pavement to a minor extent the second year after it was laid. The second type of crack pattern in Figures 13 and 14 indicates the foundation under the asphalt concrete pavement has yielded and caused the surface to form an irregular crack pattern, sometimes called alligator cracks. There are cases where this type crack will form due to lack of compaction of the widened area, and the area, under traffic, will compact and subside causing the cracks to form. However, cracks caused from lack of compaction will usually heal up in following years and will not recur when the base material is unyielding. The cracks over the old concrete pavement are less noticeable during the summer and early fall months before cool weather causes the old pavement to contract. To date little patching has been done on this asphalt-concrete resurfacing, and the cracks have never been poured with a crack-filling material. However, such areas as shown in Figures 13 and 14 will need attention in the next year, since they are becoming progressively wider and allowing more water to reach the base or foundation.

From experience gained by study and observation of the wearing ability and value to the tax-paying highway user of the Roy junction to Muck Creek project and many other sections resurfaced before and after this work, certain criteria have been established and must be satisfied before such work is budgeted. The tests are as follows:

1. Does the old rigid-type pavement to be resurfaced have fair to good alignment,

Figure 12.

Figure 13.

so that if it were resurfaced with or without widening of the traveled surface and shoulders, the resurfaced pavement will have capacity to carry the anticipated traffic during the next 10 to 15 years? It is apparent that if the horizontal and vertical curves existing in the old roadway are so sharp that the section will have to be reconstructed to present day standard within a few years in order to carry traffic, the mere act of smoothing and widening the highway would be a wasteful expenditure of funds.

2. Does the old pavement have sufficient foundation as observed by an inspection? If the old pavement has many areas that are unstable, causing excessive patching, it is obvious that a flexible resurfacing would have a short useful life and should be reballasted

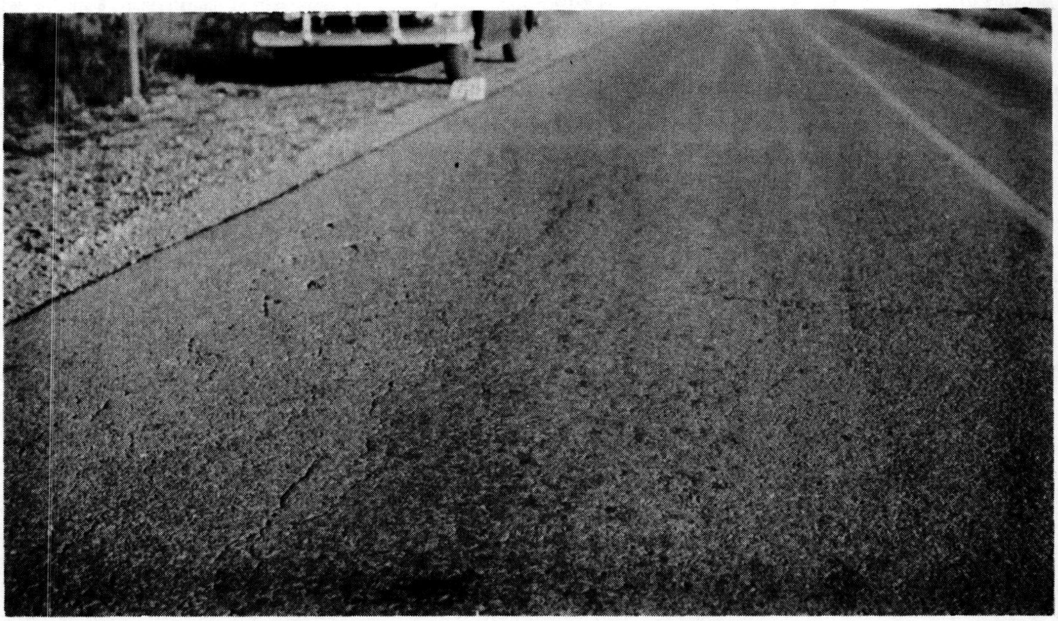


Figure 14.

or an unyielding foundation constructed before any type resurfacing is attempted. However, if the old pavement is rough from settlement and has only minor foundation deficiencies, the logical procedure is to correct these areas by removal and replacing with suitable base material and the whole section resurfaced with a two-course asphalt-concrete mat.

3. The present or anticipated traffic on any section must be such that the expenditure of funds is warranted.

It has been observed from the inspection of many sections resurfaced with a flexible pavement that pavements with overlay thickness of a minimum of $2\frac{1}{2}$ to 3 inches suffer less from expansion-joint cracks eventually showing through than do pavements having thinner overlays. Also, where an old pavement is to be widened and resurfaced with asphalt concrete, it is mandatory to get the most-thorough compaction possible of the base material under the widened asphaltic concrete. Other observations are that when an old pavement is resurfaced, it is profitable to remove the old shoulder material to an elevation slightly below the bottom of the old pavement, so that all impounded water under the pavement will be drained.

The engineers of this department have been surprised to find large quantities of water under old pavements, even when the underlying soil has been sandy in character. The excavated shoulder area should then be replaced with a granular, free-draining aggregate. It has been found that when old rigid pavements are found to have slabs rocking or moving under traffic, it is good insurance from future maintenance to subseal these pavements with a low-penetration, air-blown asphalt to seal the joints from beneath and fill in depressions under the slabs. The rule observed by the Washington highway department on whether or not a rigid pavement needs undersealing before resurfacing depends on the observed pumping action of the slabs. Where no action is noted, subsealing is usually omitted.

In conclusion, it is the opinion of the author that the scope and evaluations of Highway Research Board Project Committee on Salvaging Old Pavements by Resurfacing will develop methods and techniques that will be invaluable to all highway organizations. The evaluation of the work completed to date in Washington descloses that this type of work on old pavements, when and if the section satisfies the criteria noted above: (1) receives favorable comment from the tax-paying public, especially the truckers; (2) reduces maintenance costs from 50 to 75 percent; and (3) speeds up traffic on sections of highway that formerly were bottlenecks. To evaluate this saving in dollars would be difficult and subject to controversy, but the conserving in tire wear, mechanical repair to springs, etc., and the reduction in vibration resulting from the resurfacing of a rough pavement with a nonskid, smooth-riding surface must play an important part in making this type of work popular with the traveling public.

Conditioning an Existing Concrete Pavement For Bituminous Resurfacing

FRED W. KIMBLE, Flexible Pavements Engineer
Ohio Department of Highways

● FOR more than a decade Ohio has found it necessary to salvage many existing pavements by resurfacing or by widening and resurfacing with hot-mix asphaltic-concrete in order that its highway system be kept open to accommodate the ever-increasing volume of traffic. Pavements that have been so salvaged are of many types, being principally bituminous surface treated, brick wearing course with either flexible or rigid base, and portland-cement concrete.

In this type of work varying degrees of preparation of the existing pavement have been practiced. Such preparation as has been practiced, being influenced by either the thinking of the designer or the length of time between the decision to salvage and the completed work is desired. However, considerable thought has been given to the best way to resurface old portland-cement-concrete pavements to prevent the reflection of transverse and longitudinal joints and cracks, stop pumping, and stabilize moving slabs.

Such approaches as bituminous surface treatments, compacted granular courses, thickened resurfacings and subsealing with both heavy tars and low-penetration asphaltic cement, have been tried with varying degrees of success. A compacted granular course over the existing pavement or subsealing, or a combination of both, have probably given the best results where no removal and replacement have been done.

As more experience was gained, it was found that the piling on of thickened courses of resurfacing would not correct conditions of bad or weakened pavements. This has been demonstrated where existing pavements with cracked, broken, and pumping slabs were resurfaced with as much as 5 inches of compacted, hot-mixed asphaltic concrete. In some cases, in less than a year, the cracks and joints reflected through and the rocking slabs continued to pump. These pavements being salvaged had been laid on earth subgrade and the subgrade soils were clay or clayey materials.

Money for rebuilding highways has not been available to meet the demands of increasing traffic volume. This lack of money has also influenced salvage programs, and pavements have not always been salvaged at the point just before rapid disintegration sets in. Consequently, those pavements being salvaged show marked or extreme distress before those persons responsible feel that such salvage work can justifiably be programmed.

Under such conditions of operation, it becomes apparent that preparation of the pavements being salvaged for resurfacing is necessary to assure a reasonable service life of the resurfacings. In locations where there is a large volume of heavy truck traffic, some preparation is necessary, or the seriously distressed areas soon reflect through the resurfacing. Regardless of the location of the pavement and the character of the traffic, where an old portland-cement-concrete pavement reaches a certain stage of disintegration, preparation for resurfacing appears to be a justifiable and economic procedure.

During the years of 1942-43, the Ohio Department of Highways constructed a new portland-cement-concrete pavement on US 42, between the towns of Ashland and West Salem. This new pavement was built parallel to the existing pavement, forming the north-bound lanes of a divided highway. The plans provided that the new lanes be built 24 feet wide with a 9-7-7-9 section, transverse joints be spaced at 60 feet, alternate joints being expansion and contraction. Reinforcing was included, with dowels at transverse joints and tie bars along the longitudinal joint.

Due to conditions then existing, resulting from a state of war, the contractor was unable to obtain reinforcing mesh as required by the plan under the priority rating assigned to the project. Because of this reason, the pavement was built without reinforcing mesh and the section was deepened to 9-8-8-9. The transverse-joint spacing was rearranged to intervals of 20 feet, with expansion joints at intervals of 120 feet. Of the resulting five contraction joints between expansion joints, four were built without dowels and one with dowels. Dowels were used in this manner because they had been supplied for the original joint spacing and none further could be obtained. The longitudinal joint remained as originally planned. The holding devices on hand placed the dowels ½ inch below the horizontal transverse centerline of the slab, but this was not considered to be critical or detrimental to the slab. Side forms 8 inches deep were used with 1-inch hardwood lifts.

This pavement was placed on earth subgrade, which was built under a specification requiring a minimum of 95 percent of standard Proctor density for soils having a maxi-

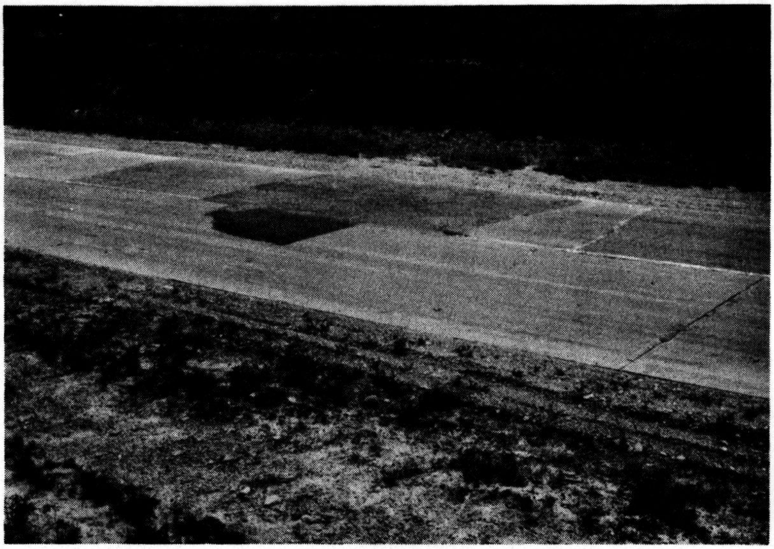


Figure 1. Condition of old pavement prior to resurfacing. Foreground is passing lane.

Figure 2. Condition of old pavement prior to resurfacing. Foreground example of extensive bituminous patching. Background example of numerous corner breaks.

mum dry weight of 95 to 120 pcf. and 90 percent for soils having a maximum dry weight in excess of 120 pcf.

By the fall of 1949, this pavement was requiring more than ordinary maintenance, and it was programmed for resurfacing in 1950. A plan was prepared and a contract was let early in 1950 for the work. The resurfacing was for a minimum of 1¾ inches of leveling course and 1¼ inches of surface course. Both courses were of the same mix and involved a ¾-inch aggregate maximum. The plan provided for the removal and replacement of 600 sq. yd. of the existing pavement and the installation of 300 linear feet of porous backfilled underdrains. The total project was 4.521 miles long.

Before the resurfacing work could start in the spring of 1950, the condition of the pavement became steadily worse, because of alternate periods of frost and extremely

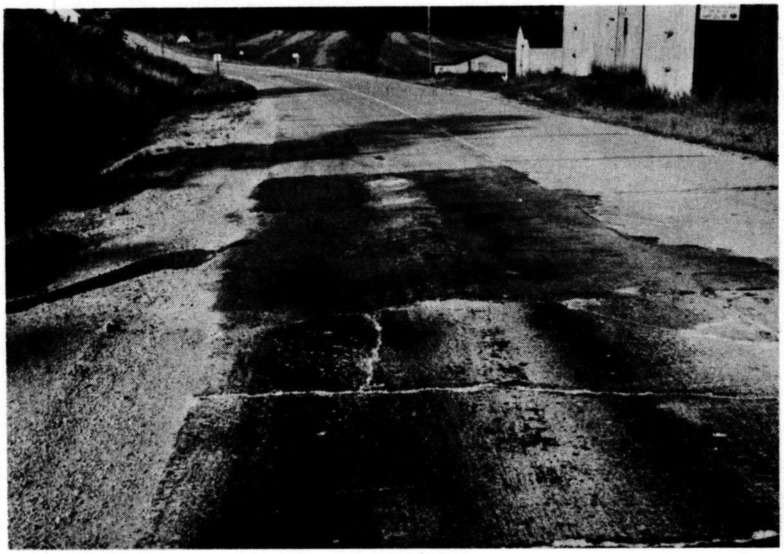


Figure 3. Condition of old pavement prior to resurfacing. View shows faulted and pumping slabs and extensive bituminous patching.

Figure 4. Condition of old pavement prior to resurfacing. View shows a pumping joint that has broken through an extensive bituminous patch.

wet weather. When the spring finally came, with settled weather, a survey of the pavement indicated that the pavement corrective measures set up by the plan were not adequate to take care of the condition. Negotiations were started with the contractor to perform the additional corrective work necessary to bring the old pavement to a satisfactory condition for resurfacing under an extra-work contract. The contractor was unwilling, at the unit prices bid under his contract, to perform the additional corrective work.

Since the unit prices he was asking for the additional work were so high, the department decided to do the additional corrective work with maintenance forces.

This project was an excellent opportunity to determine the value of old pavement preparation before resurfacing. The preparation work consisted of removing the badly broken areas of pavement, excavating the wet subgrade, and replacing with granular subbase

Figure 5. View showing old concrete removed preparatory to patching. This is a minimum width removal of 4 feet.

Figure 6. View showing a large size plain concrere patch on left. Right side partially patched. Surface of patches were float finished and were not edged.

material, installing drains, and then placing pavement patches of either plain portland-cement concrete or of the flexible type. Before any work started, an accurate condition survey of the pavement was made and recorded on a condition survey form (see Figure 9 for an example). The survey noted all faulted joints and extent of the faulting, patches, cracks and breaks in the slabs, pumping joints, and other conditions considered to have an influence on the resurfacing. Figures 1 through 4 illustrate the condition of removal areas at the time of the condition survey.

Pavement marked for removal was broken into small pieces with a gravity hammer. The edges of the removal areas were trimmed, where necessary, with pneumatic drills and chisels. The minimum size of removal area was 4 feet by 4 feet. The edges of all patches were parallel and at right angles to the centerline of the pavement. This prac-

Figure 7. Typical condition of the resurfaced pavement December 1, 1954.

Figure 8. Typical condition of the resurfaced pavement December 1, 1954.

tice necessitated the removal of some sound pavement in areas of triangular corner breaks. It was felt that if small triangular patches were placed, however, they would soon be rocking under the traffic load. Figure 5 illustrates a minimum width of removal.

Wet subgrade soil, under the removal areas, was removed to the affected depth. The subgrade in the areas was then shaped and compacted. Where the areas of removal would allow, rollers were used, and small areas and the subgrade around the edges of all patches were compacted with pneumatic tamps, which were heavy pneumatic pavement breakers equipped with 10-by-10-inch tamping heads.

Granular subbase material, a local bank-run gravel, was placed on the prepared subgrade. Compaction was accomplished in the same manner as for the subgrade. The subbase material had enough fines for compaction, yet was free draining. The porous backfilled underdrains were next installed from subgrade elevation, with enough fall to

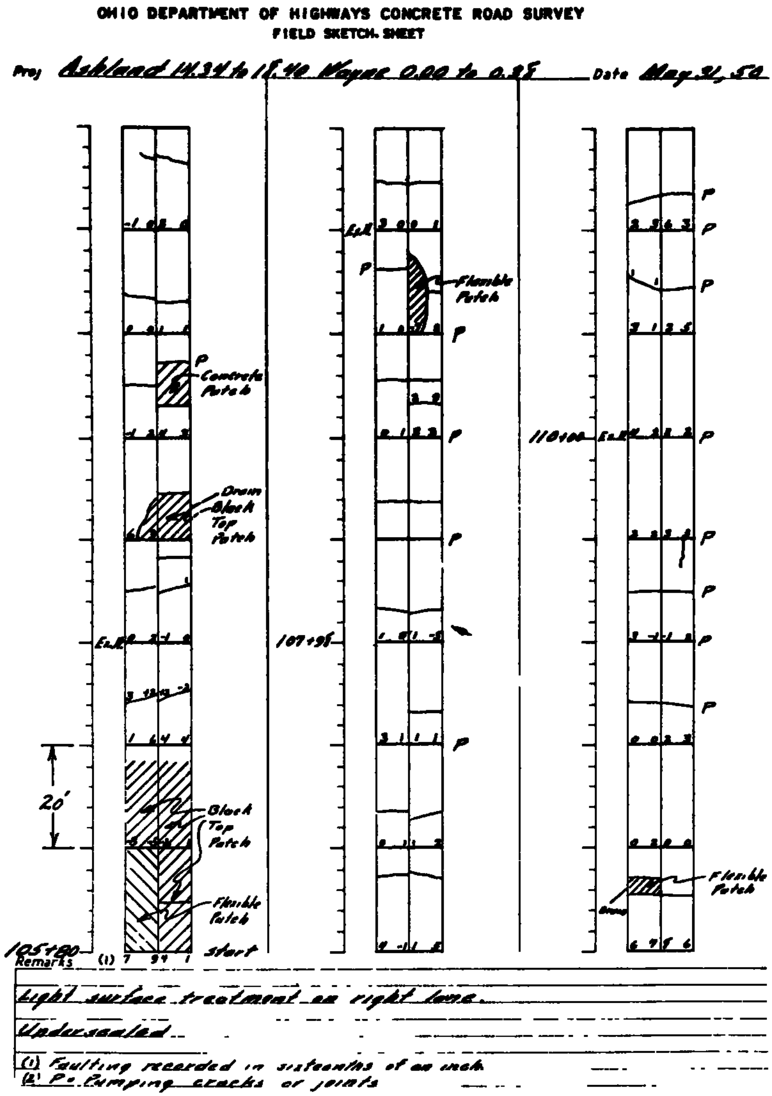


Figure 9.

drain through the berm to either the side ditch or through the slope of the fill. Some of the drains were installed without tile, however, the same size of filter material (Ohio No. 6 size $^3/_8$ to $^1/_8$ inch) was used in both cases.

The plain-cement-concrete patches were all placed 9 inches thick, except in the minimum-sized areas. The thickness in the 4-by-4-foot areas was increased to 12 inches. The edges of this size patch were undercut about 3 inches. It was believed that this treatment of the small patches would better enable them to resist moving under the traffic load. Figure 6 illustrates some of these patches. The surface of the patches was given a float finish and no edging was done.

The flexible patches were made up of a 5-inch course of dry-bound macadam and a

3-inch course of bituminized macadam. The dry-bound macadam was made from Ohio No. 12 size limestone (3½ to 1½ inches) and filled with limestone screenings. The bituminized macadam was plant mixed using MC-5 and Ohio No. 46 size limestone (¾ to

TABLE 1

CONDITION SURVEY
MAY 23, 1951
ASHLAND 14.34 to 18.40 WAYNE 0.00 to 0.38
T-35 RESURFACING OF CONCRETE PAVEMENT

Station		Right of Left	Type of Patch	Remarks
From	To			
106+52	106+72	R	Flex.	Slight depression that enables one to locate patch area. Some cracks in patch area.
106+83	106+93	R	Conc.	No surface evidence of patch.
108+58	108+71	R	Flex.	Slight opening at centerline over patch.
109+06	109+09	L	"	No surface evidence of patch.
109+80		R		4 to 5 area depressed as much as 1/2" over old crack.
110+65	110+78	R	Flex.	No surface evidence of patch.
111+58	111+63	R	"	" " " " " Drain running.
114+87		R		No surface evidence of loose area of concrete.
115+35	115+38	L	Flex.	" " " " patch.
127+70	128+35	L	"	" " " " "
129+00	129+80	L	"	" " " " "
130+10	130+30	L	"	" " " " "
131+50	131+70	L	"	" " " " "
132+00	132+17	L	"	" " " " "
132+30	132+82	R	"	" " " " " Drain running.
132+50	132+75	L	"	" " " " "
133+23	133+50	R	"	" " " " "
133+57		R		Drain running.
133+90	134+00	L	Flex.	No surface evidence of patch.
136+58	136+78	R	"	" " " " "
136+69	136+85	L	"	" " " " "
137+97	138+09	R	"	" " " " "
138+37	138+57	R	"	" " " " "
138+53	138+62	L	"	" " " " "
139+48	139+68	R	"	" " " " "
141+69	141+79	R	"	" " " " "
143+50	143+70	R	Conc.	" " " " "
144+66	145+15	R	Flex.	" " " " " Drain dry.
145+62		R		Drain running.
148+35				Pumping joint. Faulting at centerline.
150+54	150+70	R	Flex.	No surface evidence of patch. Drain running.
154+35	154+49	R	"	" " " " " " "
154+75	154+81	R	"	" " " " "
154+84		R		Drain dry.
158+96	159+00	L	Flex.	No surface evidence of patch.
161+58	161+70	R	Conc.	" " " " "
164+36	164+50	R	"	" " " " "
164+70		L		Drain missing.
164+81	164+83	L	Flex.	No surface evidence of patch.
165+06	165+11	R	"	" " " " "

⅜ inch). The compaction of these courses was accomplished the same as for the subgrade and subbase material.

The total area of the pavement removed was 3,342 sq. yd. Of this amount, 666 sq. yd. was removed and replaced under the contract using plain portland-cement-concrete patches. The remainder was removed and replaced with maintenance forces and was divided into 1,073 sq. yd. of flexible patches and 1,603 sq. yd. of plain portland-cement-concrete patches. The total area of all the patches was 5 percent of the total area of the pavement.

After the corrective work was accomplished, the resurfacing was placed at the rate of about 90 tons per hour. Three rollers, one three-wheeled, 10-ton finishing and two 8-to-12 ton tandem rollers, were necessary to get satisfactory density in the resurfacing courses. The project was completed in the latter part of June 1950.

Annual condition surveys have been made each May since the project was completed. The pavement and drains were carefully checked and a record made (see Table 1). The pavement was last examined on December 1, 1954. Figures 7 and 8 illustrate the present general condition of the pavement.

From the experience gained with this project, it is believed that the importance of conditioning an old portland-cement-concrete pavement before resurfacing has been well demonstrated. The resurfacing is now 4½ years old and is in good condition. This length of service is almost two thirds of the life of the original pavement. Traffic during this time has steadily increased and is now probably 25 percent greater than when the pavement was originally built. With a moderate amount of maintenance, this resurfacing should last at least 4½ years more. By the end of that time the economic worth of such pavement preparation before resurfacing can be determined with accuracy.

Condition Surveys of Bituminous Resurfacings Over Concrete Pavements

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ALEXANDER J. BONE, Associate Professor
Joint Highway Research Project, Massachusetts Institute of Technology

This paper describes a technique for making and analyzing condition surveys of bituminous resurfacings over concrete pavements. Successive surveys provide a basis for evaluating the performance of different resurfacing types.

Survey sections include about 1,000 feet of typical pavement. The location and extent of all defects are measured in the field and recorded directly on forms prepared for that purpose. All cracks are classified by width and by their most likely cause, which can usually be determined quite accurately by observation or by inspection of construction and maintenance records.

Indices are computed from the field data and are used to compare the performance of the different resurfacings. They are computed for the incidence of cracking over transverse and longitudinal joints, over joints between concrete and adjacent bituminous shoulders, at construction joints in the resurfacing, and over cracks and other defects in the underlying concrete.

The survey method differs from those applicable to concrete pavements or to bituminous surfaces on flexible bases. Defects may be caused by deterioration of either the concrete or the bituminous resurfacing, or by the dissimilar properties of the two materials. The method has been developed and refined through 2 years of data collecting and has been successfully used on repeated surveys of 25 test sections totaling over 6 miles in length.

●THE condition survey has long been recognized as a useful tool for evaluating pavement performance in the field. It may be used to determine the present condition of a pavement, as is often done for sufficiency-rating purposes, or to determine the rate and nature of deterioration. The latter requires repeating surveys at regular intervals.

In making studies of bituminous resurfacings over concrete pavements, the need for condition surveys soon became obvious. While the occurrence of reflection cracking (cracking of the resurfacing immediately over joints, edges, and cracks in the underlying pavement) was readily recognized, little was generally known regarding its extent, cause, and rate of growth. The condition survey described in this paper has been designed to collect quantitative data on these factors. In addition, it is used to compare various types of resurfacings.

CONDITION CHARACTERISTICS TO BE MEASURED

The first step in setting up a survey is to determine what is to be measured. In evaluating resurfacings, the following condition characteristics are important:

Cracking

Cracking is the first serious defect that develops in resurfacings. Most of it is reflection cracking caused by the joints in the underlying concrete. Since reflection cracking is the primary objective of the study, it is desirable to have as much detail as possible about cracks. Location, size, and shape should be determined. Cracks also vary in appearance. Some tend to spall along the edges. Others tend to heal due to the kneading action of traffic. It is necessary to know whether the cracks have been sealed, and to note the presence of any excess sealing material on the adjacent surface. Information should also be recorded as to whether cracks are filled with dirt and sand.

Texture of Surface

Surface texture is an important clue to performance of the pavement. Uneven or wavy surfaces are indications of instability. The extent of any wavy surface should be noted, along with some quantitative indication of the axis, amplitude, and period of the waves.

It should be noted whether the surface is open or dense, rough or smooth. Surface texture will vary with the aggregate gradation and asphalt content of the mixes, as well as with construction procedures such as finishing and rolling. Surface texture often changes with age and may be a clue to densification by traffic or to scaling. Nonuniformities should be especially noted.

Local Defects

Local defects should be described fully to facilitate explanation of their occurrence and an appraisal of their influence on pavement performance. They include such items as localized areas of wear, ravelling, patches, shoving or unevenness, and fat spots

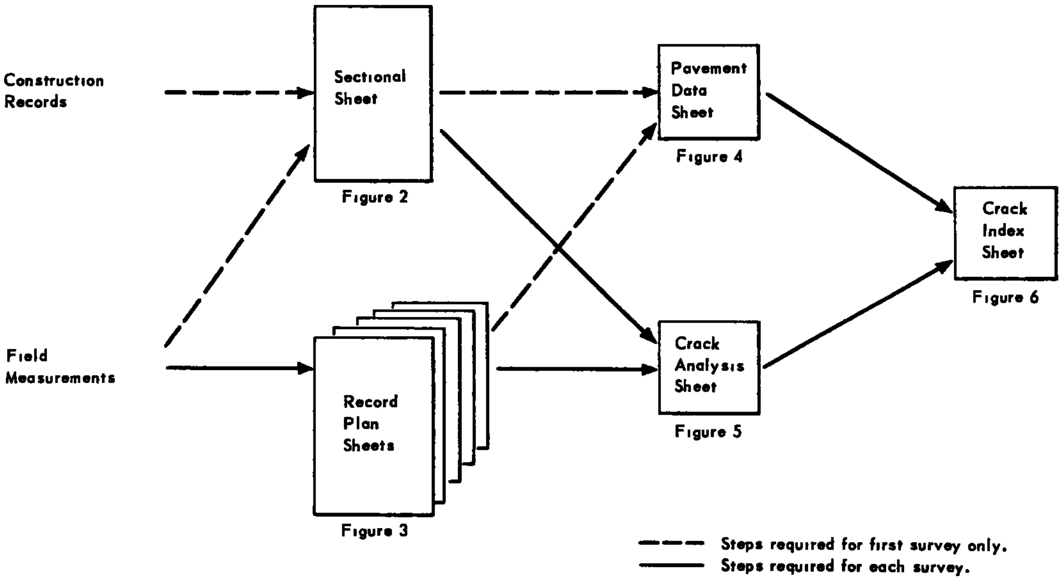


Figure 1. Data flow diagram for survey data of one section.

caused either by an excess of bitumen in the pavement or by oil drippings. Crawler tracks, accident scars, and other evidences of vehicle damage should also be recorded.

Special Conditions

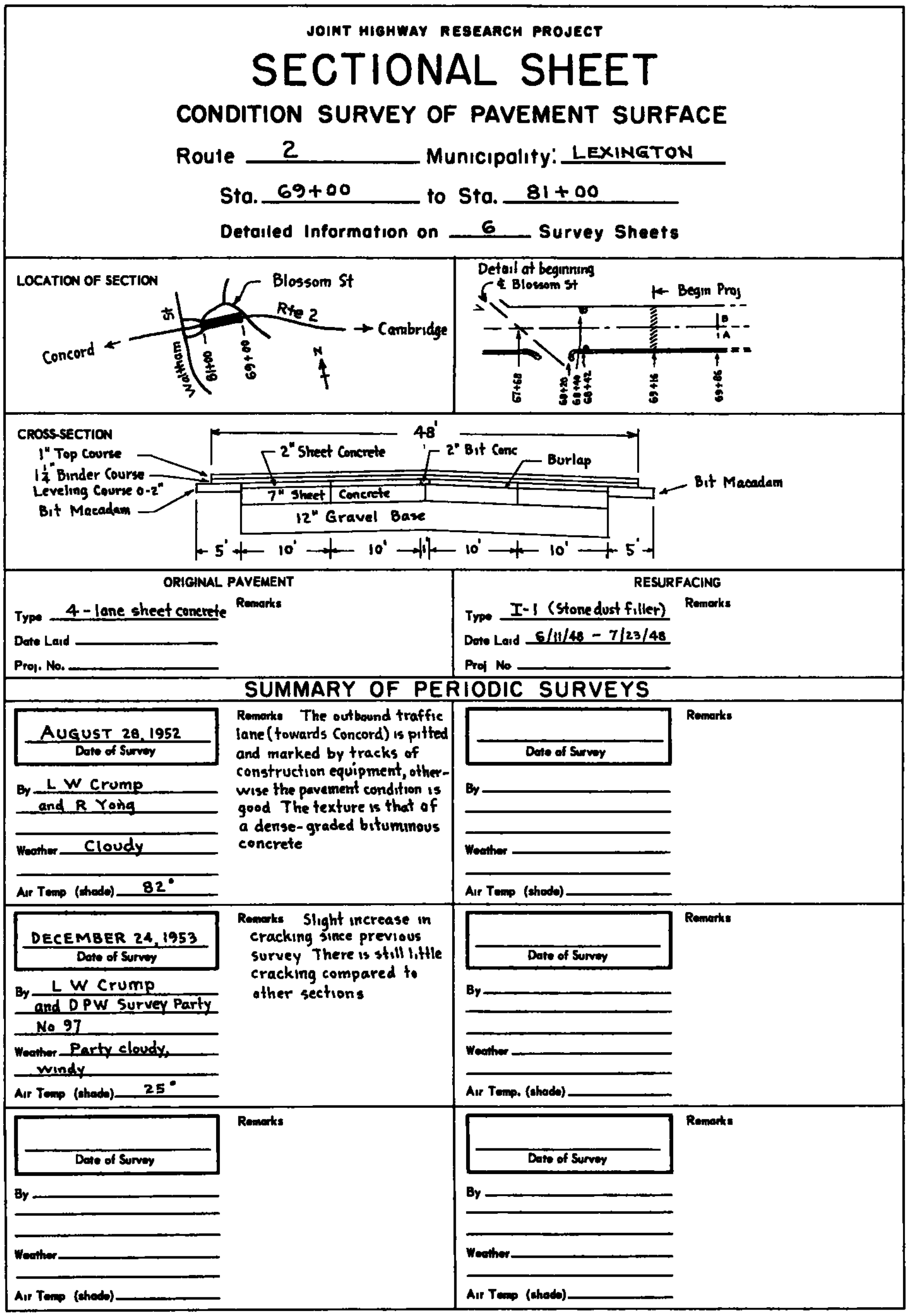
Any special conditions that might affect performance should be reported. Three types which should be looked for are unusual subgrade conditions, drainage conditions, and traffic patterns. The latter might include lateral placement of vehicles, unusual speeds, heavy truck traffic, presence of bus stops, stop signs, traffic signals, or truck turning areas. Traffic patterns at intersections should be noted if they are unusual.

Miscellaneous

Other factors that have a bearing on pavement performance should also be noted. It is better to have too much detail than too little. Extraneous data can be eliminated in the analysis, but missing data is seldom available at a later date.

OBTAINING AND RECORDING SURVEY DATA

Before laying out the survey procedure for resurfacings, a review was made of survey techniques developed for concrete pavements and for bituminous pavements on flexible bases. Most of these measure the size and seriousness of defects. In evaluating the defects in resurfacings, it is necessary to relate them to features in the underlying concrete. For this reason, a further classification, "cause," was established. The cause relates the defects to the joints, edges, and cracks in the concrete which are responsible for them.



JOINT HIGHWAY RESEARCH PROJECT

SECTIONAL SHEET

CONDITION SURVEY OF PAVEMENT SURFACE

Route 2 Municipality: LEXINGTON

Sta. 69+00 to Sta. 81+00

Detailed Information on 6 Survey Sheets

LOCATION OF SECTION

Detail at beginning

CROSS-SECTION

ORIGINAL PAVEMENT		RESURFACING	
Type 4-lane sheet concrete	Remarks	Type I-1 (Stone dust filler)	Remarks
Date Laid		Date Laid 6/11/48 - 7/23/48	
Proj. No.		Proj No	

SUMMARY OF PERIODIC SURVEYS

AUGUST 28, 1952 Date of Survey By L W Crump and R Yong Weather Cloudy Air Temp (shade) 82°	Remarks The outbound traffic lane (towards Concord) is pitted and marked by tracks of construction equipment, otherwise the pavement condition is good. The texture is that of a dense-graded bituminous concrete	Date of Survey By Weather Air Temp (shade)	Remarks
DECEMBER 24, 1953 Date of Survey By L W Crump and D PW Survey Party No 97 Weather Party cloudy, windy Air Temp (shade) 25°	Remarks Slight increase in cracking since previous survey. There is still little cracking compared to other sections	Date of Survey By Weather Air Temp. (shade)	Remarks
Date of Survey By Weather Air Temp (shade)	Remarks	Date of Survey By Weather Air Temp (shade)	Remarks

Figure 2. Typical sectional sheet for condition survey of bituminous resurfacing.

Possible Techniques

Four possible techniques of making the survey were considered. Each was evaluated as to reliability in measuring the condition characteristics desired and as to ease and economy of operation. The four methods were aerial photography, ground photography, visual observation with results plotted to scale on plan sheets, and visual observation with data recorded as field notes. Neither type of photography will show up cracks in bituminous pavement in their natural state. Painting the cracks to emphasize them is feasible only where the road can be closed to traffic, for any tracking of the fresh paint by vehicle tires would result in hopeless confusion. Since visual inspection of surrounding conditions is necessary to adequately describe many of the defects, there appeared to be no advantage in collecting part of the data by photographic means.

Having decided upon visual observation as the survey technique, consideration was given to the best way of recording the data in the field simply, yet in the desired detail. The method adopted is to plot the defects to scale on grid-plan record sheets. The data is subsequently analyzed systematically to determine overall trends. Figure 1 shows the relation of the various sheets used in the fieldwork and in the analysis. Figures 2 to 6 show the actual forms used.

Selection of Survey Sections

In determining the length of highway which may be properly represented by a sample section, the following factors must be considered: (1) type of original pavement and condition at time of resurfacing; (2) type of resurfacing, date laid, and construction conditions; (3) subgrade and drainage conditions; and (4) geometric design, traffic volumes, wheel loads, etc.

The entire roadway should be inspected to determine the limits of areas within which the above factors are consistent. Once these areas are established, sample sections can be selected in each at a location which appears to be representative and which is convenient for the field work.

The sample of highway adopted as a survey section is usually 1,000 feet long. This has been found to be an adequate sample size from which to evaluate reflection cracking.

Collecting Basic Data on the Section

Before making the surveys, all available construction records should be reviewed to secure basic pavement data. This information is recorded on the sectional sheet (Figure 2) and provides a basis for classifying and evaluating the data collected in the field survey. Basic data include the section location, dates of construction and resurfacing, subgrade and drainage characteristics, traffic data, and all details of pavement design.

Field Procedure

The field procedure consists of systematically locating and recording the defects. A temporary grid, corresponding to the grid on the record sheets (Figure 3), is established on the pavement with two intersecting tapes. Defects are plotted to scale and identified by appropriate symbols shown on the record sheets. The width of cracks is measured visually in units of 0.01 foot and recorded on the sheets with a letter code.[1] While this is only approximate, the meandering alinement of the cracks makes more precise determinations impossible. The step-by-step procedure, together with details of the personnel and equipment required, is given in Appendix A.

Description of the Record Sheet

On the record sheet there are three identical grids, which are used for successive surveys of the same area. This type of sheet has proved more satisfactory than one having a single grid on which the various surveys are superimposed. On the sheets shown, each grid corresponds to 200 feet of highway. Thus, several sheets are needed for each section. The scale is 25 feet to the inch, which is satisfactory for moderate amounts of deterioration. Larger-scale sheets should be used for badly deteriorated pavements.

[1] The crack width code described has been used for several years by the authors. Convenience justifies its continuance in their organization, but they recommend that any future classifications be based on tenths of inches, not hundredths of feet.

Different colors can be used to advantage. The form has lettering and border in black and the grids in light blue. The field data are recorded in black pencil lines over the

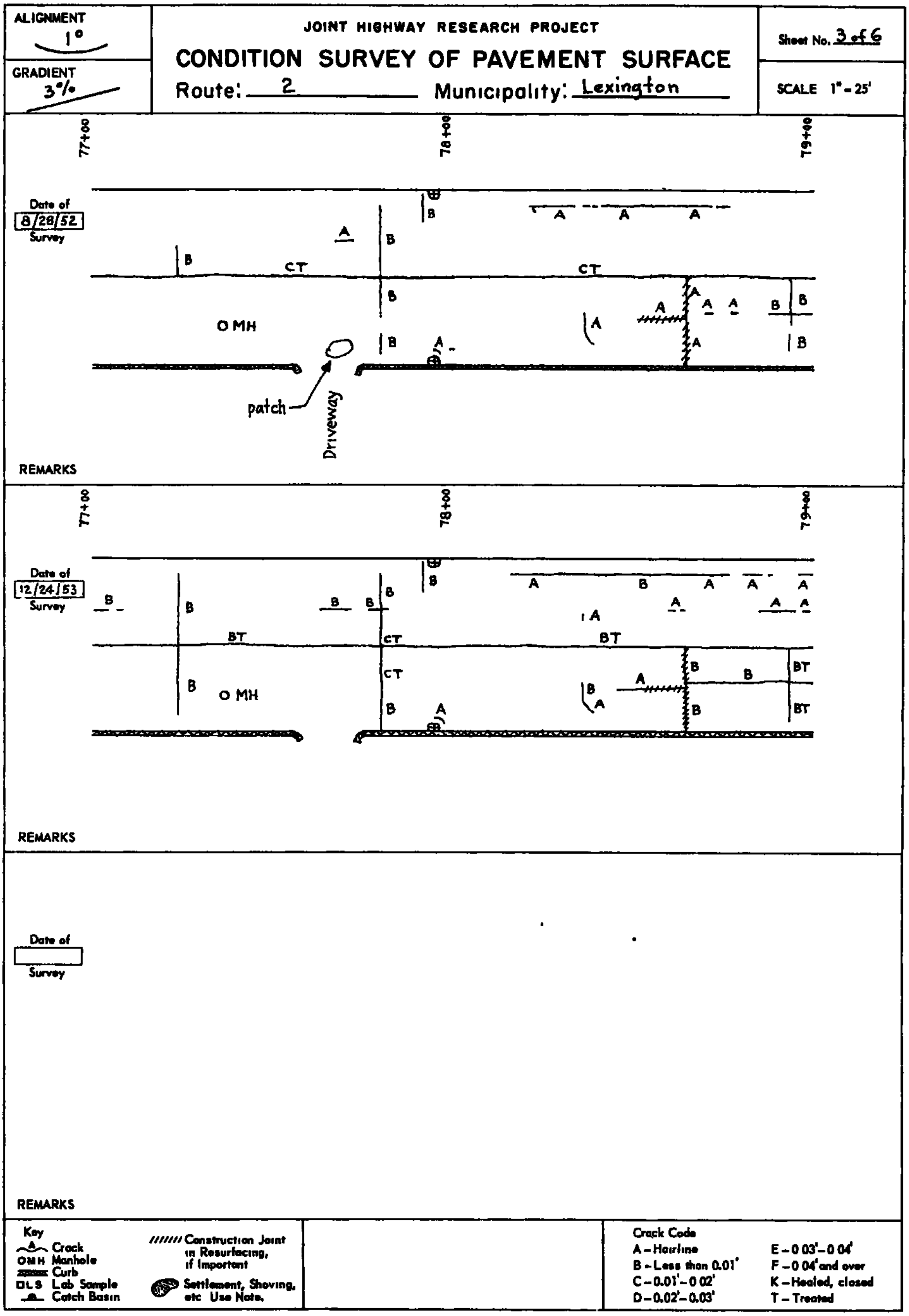


Figure 3. Typical record plan sheet for condition survey of bituminous resurfacing.

blue grid, thus, avoiding confusion between grid lines and cracks. As an aid in classifying and analyzing cracks, a third color may be used to delineate the outlines of the underlying concrete slabs.

JOINT HIGHWAY RESEARCH PROJECT

M. I. T. – Mass. D.P.W.

CONDITION SURVEY OF BITUMINOUS PAVEMENT SURFACE

PAVEMENT DATA SHEET

Section	
11	
5.5	[illegible]

Route 2 Town Lexington

Sta. 69 + 00 to 81 + 00

MEASUREMENTS OF THE SECTION

1.	Length of section at ℄, in ft.		1,200
2.	Width of resurfacing, in ft		48
3.	Area of total resurfacing, in sq. ft.		
	length x width	57,600	
	other areas		
		–	
		–	
	Total area (sq. ft.)		57,600
4.	Area of resurfaced concrete, in sq. ft.		
	length x width	48,000	
	other areas		
		–	
	Total concrete area (sq. ft.)		48,000
5.	Number of standard slabs*, Line No. 4 Total / 570		842

NUMBER AND LENGTH OF TRANSVERSE JOINTS

6.	Number of transverse joints, 10 ft. wide	84
7.	Number of joint ends adjacent to bituminous shoulder (or lane)	42
8.	Total length of transverse joint, in ft.	840

LENGTH OF LONGITUDINAL JOINT, IN FT., BETWEEN

9.	adjacent slabs	3,600
10.	slab and bituminous shoulder	2,400
11	slab and bituminous center lane	—
12.	Total length of longitudinal joint, in ft	6,000

* Standard slabs are 10 ft. by 57 ft.

E T. 12/54

Figure 4. Typical pavement data sheet.

ANALYSIS OF THE SURVEY

Computation of Crack Indices

Nearly all the defects discovered in the pavements for which this survey was designed are cracks of various types. To insure a uniform, systematic grouping system for cracks, a standard "Crack Analysis Sheet" has been designed. This is shown in Figure 5 and each item is described in detail in Appendix C. One sheet is used for each survey of each section. The cracks are classified by cause, and each cause group further subdivided by width. There are nine cause classifications and six width classifications, giving a total of 54 groups. Usually all of these do not apply to any one pavement section. The actual grouping process consists of systematically going through the record sheets and summing the lengths of cracks in each of the 54 groups. The sums are determined graphically by plotting the lengths of the cracks in each group consecutively along the edge of a strip of paper.

The Pavement Data Sheet (Figure 4) lists basic information about the resurfacing and the underlying concrete pavement in a survey section. A detailed description of this sheet is given in Appendix B. Data are obtained from the sectional sheet and from record plan sheets as a part of the first survey of each section. Much of it can be inferred from the crack patterns.

The data on the analysis sheets is used in conjunction with that on the pavement data sheet to compute a series of indices, which have been developed to facilitate comparisons of various surveys. These indices are recorded on the standard Crack Index Sheet (Figure 6), one of which is used to summarize each survey. Detailed definitions of the indices are given in Appendix D.

JOINT HIGHWAY RESEARCH PROJECT

M.I.T. - Mass D.P.W.

CONDITION SURVEY OF BITUMINOUS PAVEMENT SURFACE

CRACK ANALYSIS SHEET

Section	11
	A.A.G. / [illegible]
Survey Number	3

Route 2 Town Lexington

Sta. 69+00 to 81+00

Date of Survey Dec 24, 1953

GENERAL CRACK DATA

13. Number of transverse joints, 10 ft. wide, with some kind of crack over them 83
14. Number of transverse crack extensions over bituminous shoulder (or lane) 29

LENGTH OF CRACKS, IN FT.

Type → / Width ↓	Transverse					Longitudinal					Misc.	Total
	Over transverse joints	Not over joint, but over concrete	Extensions over bituminous shoulder (or lane)	In construction joint in resurfacing	Total	Over joint between adjacent slabs	Over joint between slab and shoulder	Over joint between slab and bituminous center lane	In construction joint in resurfacing	Total	All cracks not listed otherwise	All cracks
	15	16	17	18	19	20	21	22	23	24	25	26
A	52	10	11	19	92	310	163		–	473	20	585
B	513	–	50	2	565	273	859		–	1132	–	1697
C	213	–	–	–	213	–	–		–	–	–	213
D	10	–	–	–	10	–	–		–	–	–	10
E	–	–	–	–	–	–	–		–	–	–	–
F	–	–	–	–	–	–	–		–	–	–	–
Total	783	10	61	21	880	583	1022		–	1605	20	2505

E.T. 12/54

Figure 5. Typical crack analysis sheet.

11
Section
g.S	E
3
Survey Number

CRACKS OVER INTERIOR OF SLABS

Linear feet per slab. (Transverse cracks only)	0.1

CRACKS IN CONSTRUCTION JOINTS IN RESURFACING

Feet per 1000 sq. ft.	
Transverse	0.36
Longitudinal	0

EXTENSIONS OVER BITUMINOUS SHOULDER (or LANE)

LENGTH	Average length of transverse crack extension	2.1
FREQUENCY.	Number of crack extensions / Number of joint ends adjacent to bituminous shoulder (or lane)	0.7

JOINT HIGHWAY RESEARCH PROJECT

M.I.T.-Mass. D.P.W.

CONDITION SURVEY OF BITUMINOUS PAVEMENT SURFACE

CRACK INDEX SHEET

Route 2 Town Lexington

Sta. 69+00 to 81+00

Date of Survey Dec 24, 1953

CRACKS OVER JOINTS

Width	TRANSVERSE	LONGITUDINAL: Percent of Length cracked			
	Percent of length of transverse joint cracked	Of longitudinal joint between adjacent slabs	Of longitudinal joint between slab and adjacent bituminous shoulder	Of longitudinal joint between slab and adjacent bituminous center lane	Of total longitudinal joint
A	6	9	7		8
B	61	8	36		19
C	25	–	–		–
D	1	–	–		–
E	–	–	–		–
F	–	–	–		–
Total	94	17	43		27

E.T 12/54

Figure 6. Typical crack index sheet.

In general, each index compares the amount of cracking of a certain type with a measure of the features of the underlying pavement to which this cracking is related. Cracking over joints is expressed by the percentage ratio between the length of crack and the length of joint, as for example, "percent of length cracked of transverse joint." Cracking over the concrete, but not at joints, is expressed as the average length of crack per unit area of concrete. Cracking of the construction joints in the resurfacing is expressed by the ratio of length of crack to area of resurfacing. Such cracking is not related to the concrete but is purely a phenomenon of the resurfacing itself.

It was found that many transverse-reflection cracks extended into the resurfacing over the bituminous shoulder adjacent to the old concrete pavement instead of ending at the edge of the concrete as might be expected. Crack extensions were also found over bituminous center lanes used in "dual" type pavement.[2] Many of these crack extensions were 2 or 3 feet long, some as much as 6 feet, running to the edge of the resurfacing. Indices were set up to measure their frequency of occurrence and average length.

In the Massachusetts pavements for which these surveys were designed, only expansion joints are used in the transverse direction. There are no contraction joints and no warping joints. In pavements having more than one type of transverse joint, the cracks over each type should be analyzed separately.

Comparison of Periodic Surveys

Data from periodic surveys of the same section can be compared by means of the indices and, also, by a direct comparison of defects plotted from successive surveys on the field record sheets. The indices for various types of cracking, being ratios with a fixed denominator, can be tabulated or plotted for comparative purposes.

The successive record of various sections taken thus far shows a definite progression of reflection cracking in the early years. Different types of cracking develop at different rates, but all types tend to increase with each additional climatic cycle. For instance, by the third year many pavements have cracks over more than 75 percent of the length of transverse joint. A few reach 95 to 100 percent in 3 or 4 years. Successive surveys then show progressive growth of crack width after each annual temperature cycle, rather than an increase in length of cracking.

Surveys made in different seasons show a cyclical change in crack width following the annual temperature cycle. Cracks are widest in the winter and early spring. In certain sections, they close during the summer and narrow cracks tend to "heal," especially in the wheel tracks. The indices of total cracking and the indices of width distribution both show these trends. In comparing the crack widths, allowances must be made for unusual annual cycles and for wide temperature variations between days on which surveys were made.

The most-significant results shown by the surveys made to date is that resurfacings laid in the fall usually do not crack until their second winter. Those laid in the spring and summer almost always begin to crack during the first winter. The amount of cracking present in late-season resurfacings after 2 years is about the same as that present in early-season resurfacings after only a year. This conclusion is derived primarily from surveys of experimental pavements but is further borne out by less-formal observation of many other resurfacing projects.

Comparison of Different Surface Types

The performance of different types of resurfacing materials can be compared by their indices. Comparisons of present condition can be made directly. These would show the relative susceptibility of the various materials to different types of cracking. The crack width comparisons are especially valuable in this respect. Cracks in some mixes tend to ravel faster than in others, and this is reflected in the apparent width at the surface.

The best comparison of performance is made by relating the crack indices for the pavements at the same age. Since the climatic cycle tends to be fairly repetitive each

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[2] Dual type pavements have two lanes of concrete separated by one or two lanes of bituminous macadam. Many of these are used in Massachusetts.

year, valid comparisons can be made among pavements laid in different years. Unusual extremes in the annual climatic cycle and wide variations in temperature on the day of survey must of course be considered in making the comparisons. Different types of resurfacing mixes have been found to show somewhat different rates of crack development.

EVALUATION OF THE SURVEY TECHNIQUE

Sample Size

The 1,000-foot survey section adopted as a sample of pavement has been found adequate. Comparisons were made between two such samples of each of several different pavements. The indices derived for each of the two samples agreed closely, indicating that one sample adequately represents a given pavement.

Precision of Data

There are sources of error inherent in any process of measuring and computing. In the survey technique described in this paper, the two-most-important sources are the field measurement and recording and the process of graphical addition.

The locations and lengths of defects are recorded to the nearest foot. This is sufficient to give reasonable precision to the computed indices, and yet is consistent with reasonable field progress. Small errors in the alinement of the transverse tape are negligible. Factors such as uphill taping, vertical irregularities, and determination of the exact end of fine cracks can be ignored. Small irregularities in the alinement of cracks also disappear. It must be pointed out, however, that very-short cracks tend to be plotted too long.

For the indices which are expressed as percentages, the following rules for precision are recommended: (1) Indices greater than one percent shall be expressed to the nearest whole percent. (2) Indices less than one percent shall be expressed to one significant figure. This precision is consistent with that of the original data.

The data-recording process in the field and the graphical addition in the analysis are both susceptible to personal errors. In the first of these, the chance of error is minimized by preliminary marking of the defects followed by subsequent recording of the data, which provides double coverage. In the second, error is minimized by careful duplicate checking until the computers become familiar with the process. The correlation between independent totals is usually quite close with experienced personnel.

The Need for Engineering Judgment

The survey and its resulting indices alone show certain factual quantitative data relative to the deterioration of resurfacings. Considerable judgment is needed to interpret some of the results. The width indications are one example of this. The experienced engineer can evaluate the seriousness of various width cracks by their surface appearance. But to base conclusions on the coded indices, he must be familiar with what a "B" crack looks like. As another example, the edges of the white lines used to delineate traffic lanes show a coarseness which closely resembles the ravelled edges of cracks. Often it is impossible to distinguish a crack located adjacent to the painted lines. For this reason, much care must be used in interpreting the "percent of length cracked of longitudinal joint between adjacent slabs," since the centerline marking often occurs directly over the center joint between slabs.

CONCLUSION

The condition survey outlined in this paper can be a useful research tool if used with reasonable care and skill. The sample size adopted is adequate to give a reasonable precision to the data. The individual defects have been grouped and arranged in such form that they can be analyzed in any degree of detail desired. While judgment is required in interpreting any such collection of information, the method described for analyzing the data facilitates the closer examination of certain parts of it. It records conditions as they appear at the time of survey and reduces the otherwise incomprehensible mass of data to simple figures which can be interpreted meaningfully.

ACKNOWLEDGEMENTS

The condition surveys are part of a study of reflection cracking being conducted by the Joint Highway Research Project, established at the Massachusetts Institute of Technology by a grant from the Massachusetts Department of Public Works for research in the field of highway engineering. The maintenance and survey divisions of the Department of Public Works are cooperating in making the surveys.

The authors wish to express their sincere appreciation to R. E. Pyne and J. McCarthy, assistant maintenance engineers; the district survey supervisors; and others who have helped to set up and carry out these surveys. V. J. Roggeveen, professor; S. M. Breuning, research assistant; E. Tons, research engineer, all of the Joint Highway Research Project staff, have contributed many helpful suggestions.

Appendix A

FIELD PROCEDURE

Personnel

The field survey requires four men, one of whom should be an engineer. The organization used by the Joint Highway Research Project includes one of their engineers and a regular survey party of the Massachusetts Department of Public Works. The engineer directs the operation and takes notes. Two men handle the transverse tape. The remaining man marks defects with lumber crayon to facilitate recording. He also directs traffic.

Equipment

The following equipment is used in the field: one 100-foot cloth tape; several 50-foot cloth tapes; two pins or weights for securing the 100-foot tape; portable "Men Working" signs, or other suitable protection devices; strips of cloth to be used as tape handles; light truck or other conveyance; clipboard, data sheets, lumber crayon, etc.

Cloth tapes are used in preference to metallic or steel tapes so that they will break if caught on vehicles, thus avoiding the danger of the user's being dragged into the path of traffic.

Preliminary Preparation of Survey Forms

When a section of pavement is being surveyed for the first time, the only preliminary preparation necessary is to establish the limits of the section and to tie them in to an established system of stationing, if there is one. For succeeding surveys the road edge and permanent features, such as intersections, curbs, manholes, catchbasins, driveways, culverts, and highway boundary monuments, should be drawn on the sheets before the field survey begins. Enough information should be included so that locations on the road can be established easily. Each sheet should have at least one distance reference, since taping with cloth tapes can accumulate considerable error unless checked frequently.

Detailed Procedure

The first step in the field procedure is to locate the point of beginning and to reestablish the stationing from the references. The next step is to locate defects on the pavement by systematic visual inspection. Convenient areas are panels 100 feet long by one-half the width of the roadway, bounded by even station marks and the centerline and edge of the pavement. Inconspicuous defects and the boundaries of defective areas should be emphasized with lumber crayon.

A temporary grid is established on the panel by using the two tapes at right angles to each other. The 100-foot tape is stretched along the centerline (along the median curb on divided highways), between even station marks, the zero end being placed at the lower numbered station. The 50-foot tape is stretched across half of the roadway, with the zero end at the centerline. Defects are thus located by station-plus and offset from the centerline. On two-lane roads the 100-foot tape is placed on one side and the entire width of the pavement is surveyed in one pass.

The 100-foot tape remains in place for some time, and it has been found expedient to secure it with nails, pins, or weights. The 50-foot tape is moved along as the data are recorded. It is held by two men and runs from one man's hand, under his instep, across the road, under the other man's instep, and up to his hand. Strips of cloth are attached to the ends for handles. These must be weak enough so that they will break if the tape should be suddenly carried away by the traffic, which is freely passing over it.

The defects are plotted to scale on the record sheets as the recorder comes to them. This is the slowest function, and necessarily sets the pace for the entire procedure. The chainmen can be of great assistance by calling out locations to the recorder. Experienced chainmen can also determine the width of cracks and the descriptions of the various other defects. With a trained, cooperative four- or five-man crew, all functions proceed simultaneously and continuously, interrupted only by an unusually heavy barrage of traffic.

Appendix B

DESCRIPTION OF THE PAVEMENT DATA SHEET

Numbers refer to item numbers on the form.

Measurements of the Section

1. Length of the section at centerline, in feet.
2. Width of resurfacing, in feet. Any variations in width should be noted.
3. Area of total resurfacing, in square feet. Other areas include all areas not enclosed in the rectangle bounded by the length and width. The boundaries of the section should be rigidly defined.
4. Area of resurfaced concrete, in square feet. This area includes only that part of the resurfacing which is actually underlain by the original concrete slabs.
5. Number of standard slabs. A standard slab, in Massachusetts, is 10 feet wide and 57 feet long. The number of standard slabs is equal to the area of resurfaced concrete divided by 570 sq. ft.

Number and Length of Transverse Joints

6. Number of transverse joints 10 feet wide. The usual width of the slabs encountered in old concrete pavements in Massachusetts is 10 feet. Equivalent 10-foot joints should be used if slabs of odd width are encountered.
7. Number of joint ends adjacent to bituminous shoulder (or lane). This includes joint ends adjacent to either shoulders or bituminous center lanes of "dual" type pavements. This figure represents the number of potential locations of transverse crack extensions over bituminous material.
8. Total length of transverse joint, in feet.

Length of Longitudinal Joint in Feet

9. Length of longitudinal joint between adjacent slabs.
10. Length of longitudinal joint between slab and bituminous shoulder.
11. Length of longitudinal joint between slab and adjacent bituminous center lane. Many pavements in Massachusetts are of the "dual" type, having two lanes of concrete pavements separated by one or two center lanes of bituminous macadam.
12. Total length of longitudinal joint. The sum of Items 9, 10, and 11.

Appendix C

DESCRIPTION OF CRACK ANALYSIS SHEET

Numbers refer to item number on the form.

General Crack Data

13. Number of transverse joints 10 feet wide having some kind of crack over them. This is a very rough index of transverse reflection cracking which can be determined from a quick inspection of the record sheets. It can be found without the usual process of graphical addition.

14. Number of transverse crack extensions over bituminous shoulder (or lane). This figure is a count of the number of crack extensions without regard to either length or width. See Item 17.

Length of Cracks, in Feet

15. Length of transverse cracks over transverse joints. For each width class the length of crack is found by graphical addition.

16. Length of transverse cracks not over joints, but over concrete. This includes all transverse cracks lying over the original concrete. Cracks oriented 45 degrees or less from the transverse direction are considered transverse.

17. Length of transverse crack extensions over bituminous shoulder (or lane). An "extension over bituminous shoulder (or lane)" occurs when a crack extends across the junction between a concrete slab and an adjacent bituminous strip. The extension is only that part over the adjacent strip, the part over concrete being included in a previous category. Cracks over bituminous bases which are not extensions of cracks over concrete are not included. In this item, "bituminous" includes any base which is not cement concrete.

18. Length of transverse cracks in construction joint in resurfacing. This includes only cracks in construction joints where two runs of the paver butt together. Usually this jointing can only be identified in the top course of the resurfacing.

19. Total linear feet of transverse cracks. This is the sum of Items 15, 16, 17, and 18.

20. Length of longitudinal cracks over joints between adjacent slabs.

21. Length of longitudinal cracks over joints between slab and shoulder. This group includes all cracks occurring over the outside edges of slabs.

22. Length of longitudinal cracks over joints between slab and bituminous center lane. This group is used only for resurfacings of original pavements of the "dual" type. The condition represented by this item is similar to that at slab edges adjacent to bituminous shoulders.

23. Length of longitudinal cracks in construction joint in resurfacing. This group includes all cracks in construction joints between adjacent runs of the paver. Usually it is necessarily limited to construction joints in the top course.

24. Total length of longitudinal cracks. This is the total of Items 20, 21, 22, and 23.

25. Miscellaneous - All cracks not listed otherwise. This group includes cracks around manholes, over pipes, over settled areas, cracks over concrete that are oriented more than 45 degrees from the transverse direction, and any other cracks not previously included.

26. Total length of all cracks. This is the sum of Items 19, 24, and 25.

Appendix D

CRACK INDEX SHEET
DESCRIPTIONS AND FORMULAS FOR THE INDICES

Item numbers refer to items on Pavement Data Sheet and on the Crack Analysis Sheet.

Cracking Over Interior of Slabs

The index is expressed as "linear feet per slab." It is computed by dividing the total of Item 16 by Item 5. Since Item 16 includes only transverse cracks, only these are shown by the index.

This index is a measure of reflection cracking over transverse cracks in the concrete. A direct correlation cannot be made by length since the length of cracks in the underlying concrete is difficult to determine in resurfaced pavements. This index is highest where slabs are badly broken due to poor foundation conditions.

Cracking of Construction Joints in Resurfacing

There are two indices, one for transverse construction joints and one for longitudinal joints. The first is found by:

$$\frac{\text{Item 18}}{\text{Item 3}} \times 1000$$

and the second by:

$$\frac{\text{Item 23}}{\text{Item 3}} \times 1000$$

The cracking shown by these figures is primarily a function of the care used in laying the resurfacing material and the conditions prevailing when this was done.

Extensions Over Bituminous Shoulder (or Lane)

Two indices are used to measure the occurrence of this phenomenon. The first gives the average length of the extensions (Item 17 total divided by Item 14), and the second the frequency of occurrence, expressed as the ratio of extended crack ends to the number of locations where crack extensions potentially could occur (Item 14 divided by Item 7

Cracking Over Joints

Each of the indices below is computed for each width of crack. The index for the total is the sum of the indices for the various widths.

Percent of length of transverse joint cracked. This is computed by dividing the figure in each width class of Item 15 by Item 8 and converting to percent.

Percent of length cracked of longitudinal joint between adjacent slabs. This is computed by dividing the figures in Item 20 by Item 9 and converting to percent.

Percent of length cracked of longitudinal joint between slab and adjacent bituminous shoulder. This is computed by dividing the figures in Item 21 by Item 10 and converting to percent.

Percent of length cracked of longitudinal joint between slab and adjacent bituminous center lane. This is computed by dividing the figures in Item 22 by Item 11 and converting to percent.

Percent of length cracked of total longitudinal joint. This is computed by dividing the sum of the figures in Items 20, 21, and 22 by Item 12 and converting to percent. It is not the sum of the three previous indices.

Current Practices and Research on Controlling Reflection Cracking

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Reflection cracking has become an increasingly important problem as the mileage of bituminous resurfacings over concrete pavements has grown. As yet no wholly satisfactory technique of crack control has been developed.

The methods proposed for controlling reflection cracking are reviewed and discussed. In general they fall into two broad categories: prevention and sealing. Prevention involves eliminating the forces which cause cracking or modifying the resurfacing in the vicinity of joints to enable it to withstand these forces. None of the proposed methods of elimination are in general use, but many have been incorporated in test roads both in this country and abroad. Some have proved to be unworkable; others are being tested but are still too new to provide definite conclusions. Several proposed techniques have yet to be tried or need further development before their worth can be determined.

The sealing of reflection cracks is difficult because of their narrow width and irregular shape. They require techniques and materials differing from those developed for sealing joints in cement concrete pavements. Surveys of technical literature, correspondence, and questionnaires to highway agencies reveal that current practices are far from satisfactory. Most treatments are not effective in keeping out water and dirt and preventing further deterioration. Some research on improved sealing techniques is underway, but much has yet to be learned and applied.

●ONE of the most-widely used ways to prolong the useable life of concrete pavements is to resurface them with a layer of bituminous concrete. This restores the smoothness and improves the riding quality. It also improves the structural strength by adding several inches to the thickness of the pavement. This practice has grown in use since World War II, as part of a general program to catch up with deferred maintenance, and to strengthen pavements to meet the current demands of more and heavier traffic. Resurfacing is also adaptable to widening of pavements and salvaging old pavement on reconstruction projects.

One of the characteristics of these resurfacings which demands repeated maintenance is its tendency to form reflection cracks. These cracks develop directly over the joints and cracks in the underlying slabs, reflecting their pattern into the new surface. There is obviously a connection between the cracks and the underlying joints, and it has been found that cracking can result from either of two causes, differential vertical movements between adjacent slabs or the repeated opeining and closing of the joints due to the thermal expansion and contraction of the concrete (5). While both causes are often present, the horizontal opening and closing is the more difficult to control. Subsealing and mudjacking have been successfully used to restore the support needed to prevent critical differential vertical movements. The techniques for controlling horizontal movements, however, are not so well known and many of them are still experimental. This paper deals primarily with methods of reducing the effects of horizontal movements.

The subject matter for this paper is drawn from published and unpublished reports, from the authors' experience, and from replies received to a questionnaire on sealing methods sent to state highway departments. Where applicable, references are made to the bibliography at the end of the paper.

METHODS OF CRACK CONTROL

There are two approaches to the control of reflection cracking. The first is to attempt to prevent the formation of these cracks by some modification of the current resurfacing practice, and the second is to minimize the harmful effects of the cracks by effectively sealing them after they have formed. Each of these phases will be presented separately.

In discussing crack control methods it should be kept in mind that any method to be of practical application must not only successfully eliminate the undesirable features of cracks, but it also should not: (1) lessen the strength, stability or service life of the resurfacing, (2) add excessively to the cost, (3) unduly delay construction progress, or (4) require special skills or techniques which cannot be handled by the usual labor force.

Reduction of Slab Movement at Joints

One method of reducing cracking is to fill the expansion joints in the concrete with incompressible material so that the movement of the slabs is reduced to an amount which the resurfacing can absorb without cracking. Such a process eliminates the expansion space which was provided in the original design and will cause compression in the slabs when they expand with temperature rise. While some compression can be taken by the slabs, not all of the movement can be eliminated without danger of blow-ups or compression failures. For this reason, it would not be advisable to fill too many consecutive joints. In one state where joints 60 feet apart were plugged with grout blow-ups occurred at about every fifth joint.

In practice, it is difficult to thoroughly clean out the old filler material and to completely plug the joints. The presence of dowel bars in the joints restricts the depth to which they can be cleaned out by mechanical means. Hand methods, used on the Revere Test Road in Massachusetts, proved very inefficient (6).

The experimental joints plugged with cement grout and with soil mix on the Revere Test Road proved ineffective in eliminating very much of the movement and in preventing reflection cracking (7).

Breaking Concrete Slabs into Small Pieces

Breaking the slabs into small pieces will reduce the amount of movement taking place at the joints. The pavement then becomes a series of small slabs, each of which induces its small amount of movement into the crack surrounding it. In this way, the local movement taking place at any one crack or joint can be kept well below that amount which the resurfacing can absorb without cracking. One state reports success with breaking slabs into pieces having a maximum dimension of about 2 feet. It is likely that others have also used this method.

The process appears expensive and time-consuming, especially where the slabs are reinforced. The structural integrity of the concrete is, of course, destroyed, and unless the subbase is firm there is danger of vertical movement between fragments.

Increasing Thickness of Resurfacing

Increasing the thickness of the resurfacing adds to its crack resistance, or at least delays the appearance of reflection cracking at the surface. It has been noted that where resurfacings were thickened to introduce superelevation at curves reflection cracks begin at the thin edge and sometimes die out as the resurfacing becomes thicker. After 2 years of service the section of the Revere Test Road resurfaced with three inches of mix shows substantially less cracking than the 2½-inch-thick section (7). More time will be needed to establish whether this difference will be permanent.

It is not known what thickness of resurfacing would be required to prevent cracking. Undoubtedly it is greater than the 2½ to 4 inches currently being used, since 3-inch resurfacings have been found to crack over more than 90 percent of the length of transverse joints in only four years (4). The cost will increase roughly in proportion to the added thickness. A further limitation to increasing the thickness in certain locations is the amount by which the original grade can be raised.

Increasing the Stretchability of the Mix

Another method of reducing the incidence of reflection cracking is to introduce into the mix some additive which will give it the ductility necessary to absorb the joint movement without cracking. Tests have shown that the ductility of a typical bituminous concrete mix would have to be increased about five times to accommodate the stretch imposed by slabs 57 feet long such as are found in Massachusetts (5). The authors are not aware of any additive which will impart this property to a bituminous mix and question whether this much ductility can be attained without reducing the stability below acceptable limits. The addition of various types of rubber to bituminous concrete can significantly increase the ductility of the mix (19), but so far there is no indication that the increase is sufficient to prevent reflection cracking. Catalytically-blown asphalt has been used in combination with regular asphalt in an attempt to increase the stretchability of the mix (6, 7). It was thought that this mix would be more ductile at low temperatures and more resistant to cracking than the regular mix. However, the reverse proved to be true. After 14 months of service it was found that 40 percent of the transverse joints in the catalytically-blown asphalt blend section were cracked through, whereas only 14 percent of these joints were cracked in the regular Type I section. An emulsified rubber-asphalt section after the same period had only three percent of transverse joints cracked.

One disadvantage of using an additive is that, as a practical matter, it must be added to the production for the entire job, whereas it is usually only needed over small areas on each side of joints. These small areas usually comprise only a small percent of the total surface, but the cost of the additive will apply to the whole mix. Any difficulties encountered in incorporating the additive will also add to the cost.

Use of Welded Wire Fabric Reinforcing

Another possible way of eliminating cracking is to distribute the stretch imposed at the joints in some manner so that the stretch occurring at any one point in the resurfacing does not exceed the amount that the material can absorb. A number of installations of various types of wire mesh reinforcing have been made to test the effectiveness of this material. On some test roads the reinforcing has been placed over the entire pavement; in others strips have been placed only over joints. In some cases the reinforcement has been placed on the cement concrete; in others it has been placed between layers of bituminous concrete. The first installation of welded wire in a bituminous resurfacing over concrete was laid in 1946 in Texas. On this project the resurfacing was continuously reinforced with a 6 by 12-9/9 fabric.[1] Since 1946 at least 12 similar reinforcing projects have been built. Most of them have utilized a 3 by 6-10/10 fabric, which is the size currently recommended by the Wire Reinforcement Institute. Other sizes which have been used are 4 by 4-10/10, 6 by 6-10/10, 3 by 6-8/8 (12, 13, 14).

Reports available on the earlier projects indicate that the reinforcing was effective in reducing cracking in some of them. No systematic follow-up of performance appears to have been made on these projects and quantitative comparisons with unreinforced control sections are not available. Many of the projects are of recent construction and cannot be evaluated as yet (12).

Reinforcing with Strips of Mesh over Joints

Strips of wire mesh have been used to reinforce resurfacings in the area over expansion joints. The various installations cover a wide range of sizes, shapes, and weights of mesh. Expanded metal has been used on several test roads in England (9), and on the Millbury Test Road in Massachusetts (8). It is reported that the British tests reduced the amount of cracking in the first few years of pavement life, but the effects in later years must await the passage of more time. The two-foot, eight-inch strips of mesh used in the Millbury experiment were too small. Cracks developed at the edge of the strip, indicating that a definite transfer of stretch did take place. It is not known how much was actually distributed in the reinforced portion of the mix.

[1] The size of welded wire fabric is expressed by four dimensions. In order, these are the spacing of the longitudinal wires (in inches), the spacing of the transverse wires, the gage (United States Steel Wire Gage) of the longitudinal wires, and the gage of the transverse wires.

The Revere Test Road in Massachusetts included four different types of mesh over the joints. These were chicken wire (in strips 4 feet wide), a 2-by-2-inch light mesh (in strips 4 feet wide), a 6-by-6-inch heavy mesh (in strips 7 feet wide), and chainlink fencing (in strips 5 feet wide). After 14 months, the chicken wire and 6-by-6-inch mesh showed less cracking than at unreinforced control joints. The 2-by-2-inch mesh showed more cracking, but all of it occurred at the edge of the mesh, not over the joint. The strips of this material were evidently not large enough to distribute the stretch sufficiently to prevent cracking, the same condition as was found in the Millbury tests. The chainlink fence proved to be too stiff for use in bituminous concrete, and induced map cracking in the surface.

Distribution of Stretch by Breaking Bond

Another possible way of distributing movement at joints is to break the bond between the resurfacing and concrete for some distance on each side of a joint (20). A limited test of the use of metal plates to reduce bond was included in the Revere Test Road. Where 26-gage plates (3 feet wide) were placed across joints, some distribution of the stretch occurred in the area over the plate during the first year. However, cracks have developed over the edge of the plates, indicating that all of the stretch was not distributed. Heavier (11-gage) plates proved too stiff and soon caused breakup of the pavement over them.

The feasibility of thin metal plates of sufficient size to allow distribution of all the stretch is yet to be proven. The reduction of bond that is beneficial for the control of reflection cracking has the disadvantage that it renders the resurfacing more subject to shoving under horizontal braking or accelerating forces.

The Revere tests also included a limited test of common building paper as a bond-breaking medium, which did not prove effective.

Use of Base Course Between Concrete and Resurfacing

The practice of breaking bond by placing a layer of crushed stone or gravel over the old concrete before resurfacing has been used in a number of states and abroad (22). The layer is usually about 4 inches thick. Thicker courses have been used where the subgrade was poor and the concrete badly broken. The thickness of layer required has not been fully established.

The limited data available to the authors indicate that this method does reduce reflection cracking.

The addition of 4 inches or more of granualr material under the resurfacing inherently raises the final grade of the pavement. This is usually not feasible in urban areas, where the effect on curbs, sidewalks, and abutting property must be considered. In rural areas, however, this method of treatment shows good promise of being effective.

Combination of Methods

It is possible that a combination of two or more of the methods above might be more effective than any one of them alone. For example, reinforcing might be effective in a rubber-asphalt mix but not effective in standard mixes. The combination of light plates with mesh reinforcing might also be effective.

SEALING OF CRACKS

Sealing of reflection cracks has not proved uniformly satisfactory. Most of the materials and techniques currently used are those which have been developed for joints in cement concrete or for cracks in bituminous pavements on flexible bases.

While reflection cracks are similar to the cracks over flexible bases, the continuous movement in the crack due to the expansion and contraction of the concrete is an additional condition that must be overcome. Laboratory tests indicate that many materials satisfactory for sealing joints and random cracks are not capable of meeting the special conditions imposed by reflection cracks (13).

During the past year, a questionnaire was sent to most highway departments request-ing information regarding the materials and pouring techniques used, and the performance of their current sealing materials. Replies were received from 34 states, the District of Columbia, and one turnpike commission. This survey revealed that most of the states use some form of asphalt cement sealer, although several are also experimenting with other types. Cutbacks of the RC and MC types are commonly used for very fine cracks. Other sealers used are rubber-asphalt compounds, tar, emulsions, catalytically-blown asphalts, and sand-asphalt mixes (for wide cracks). Two states reported that they do not make a practice of sealing reflection cracks.

The usual practice is to seal cracks in the late fall when the surface is cold and the cracks are open. When pouring, an effort is made to put the sealing material into the crack without overflow or spillage. This is difficult to accomplish where cracks are narrow and crooked. Where overflow does occur the excess material is often dusted with sand, screenings, limestone dust, cement, lime, or sawdust. The last is preferred by four states because it is highly absorbant and does not result in any appreciable buildup on the surface.

Several states specify blowing out of cracks with a compressed air jet before sealing; a few are experimenting with grooving the cracks to straighten and widen them before pouring.

The asphalt kettle and hand pouring pot are the most common types of equipment for sealing cracks. Often special nozzles or attachments are used to control more closely the flow of material into fine cracks.

Although some of the states appear satisfied with their results, others, particularly those with large mileages of resurfacing, are not and are seeking better methods. Rubber-asphalt compounds and catalytically-blown asphalt are reported better than low penetration asphalt cement in some instances, but experience with them is said to be insufficient to prove whether their higher cost is justified.

Typical of the dissatisfaction with current methods is the following comment: "The problem of sealing cracks in asphaltic concrete surfaces which are a reflection of cracks in old concrete pavements appears to be universal. We have not at this time developed either techniques or equipment which in our opinion are entirely satisfactory. We have used various types of material and methods of pouring, none of which have produced outstanding results."

Research in Sealing of Cracks

Considerable research in sealing materials and methods is currently underway. Several manufacturers of sealers are developing new types and working to improve the properties of existing types. Equipment manufacturers are developing new kettles, crack cleaning and cutting equipment, and pumps. Thinner nozzles and the extrusion of a sealer under pressure are typical examples of new techniques. Various highway departments are cooperating in making performance tests of new products and new methods.

Sawing Grooves in Resurfacing over Joints

One of the principle difficulties in sealing cracks arises from their narrow width and crooked alinement. One method of overcoming this is to saw a groove in the resurfacing over joints in the underlying pavement before the cracks appear. This procedure is similar to the construction of sawed contraction joints in concrete. The groove should be wide enough to fill easily and large enough to contain a sufficient volume of sealing material to keep the crack continuously sealed whether open or closed.

Sawing a groove into the bituminous concrete is neater and generally more satisfactory than forming one in the mix before it sets. Sawed joints have been constructed on a test pavement in Walpole, Mass.,[2] but no conclusive results are as yet available. More tests are desirable to determine the optimum dimensions for the groove and the proper age of mix for easiest sawing.

Controlled reflection cracks may be created by placing a folded sheet of heavy paper

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[2] Constructed by the Joint Highway Research Project, Massachusetts Institute of Technology, and the Massachusetts Department of Public Works.

on the concrete so that the fold will extend upward into the mix. This device has been used with some success in sheet asphalt mixes. It usually causes a straight crack to form, but does not provide an adequate reservoir for sealing material.

Burlap Overlays

Some highway departments have experimented on lightly traveled roads with burlap overlays over cracks. The pavement adjoining a crack is swabbed with asphaltic material, burlap is placed on it, and it is then treated with a further coating of asphalt. It is not known how successful or long lasting this method has proved to be.

SUMMARY

This report has reviewed methods proposed for controlling the reflection cracking of bituminous resurfacing placed over old concrete pavements.

The following methods are described and commented upon: (1) elimination of joint movement by filling the joints with incompressible material; (2) breaking the concrete into small pieces with a drop ball before resurfacing; (3) increasing the thickness of the resurfacing; (4) addition of materials to the bituminous mix to increase its ductility; (5) use of mesh reinforcing in the mix over the joints in underlying pavement; (6) use of light metal plates between the concrete and the resurfacing; (7) use of granular layer placed between the concrete and resurfacing; (8) sawing grooves in the resurfacing over the joints in the concrete to form a weakened plane; (9) use of burlap layers in bituminous resurfacing over joints; and (10) sealing methods and materials for maintaining reflection cracks.

RECOMMENDATIONS

As a result of the review the following recommendations are made:

1. Research should be intensified on methods of making bituminous concrete mixes more stretchable at low temperatures and on preventing the loss of this characteristic with age. This might be accomplished by the use of additives or by changes in the refining processes of asphalt.

2. Further investigation should be made of the use of mesh reinforcing and of thin metal plates as a means for distributing stretch in the resurfacing so that the unit movement at any point will not be large enough to cause cracking.

3. Combinations of methods employing reinforcing, plates, special mixes, etc. should also be investigated.

4. More performance information should be obtained on the effectiveness of base course layers between resurfacing and concrete. Of particular interest is the thickness of courses and the types of materials used.

5. More development work should be done on sealing materials and on sealing methods for cracks in bituminous surfaces.

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Some HRB Publications Relating to Bituminous Materials And Flexible Pavements

BULLETIN 105: BITUMINOUS-PAVING MIXTURES: FUNDAMENTALS FOR DESIGN (1955) 45 pp. $.75

Discusses fundamentals governing design of bituminous paving mixtures. Essential properties required are defined and procedures are discussed for designing to meet these requirements. Effects of variations in characteristics and gradations of aggregates and the effects of variation in bitumen content and characteristics of bitumen on the physical properties of mixtures are discussed at length.

BULLETIN 109: UNGRADED AGGREGATES IN BITUMINOUS MIXES (1955) 49 pp. $.75

The authors develop a mortar theory as a means for utilizing ungraded local aggregates in bituminous mixtures for low-cost, secondary roads.

BULLETIN 114: DESIGN AND TESTING OF FLEXIBLE PAVEMENT (1955) 88 pp. $1.6

Four papers are included in this publication: Wheel-Load-Stress Computations Related to Flexible Pavement Design; Design, Construction and Evaluation of Heavy-Duty Runways; Flexible-Pavement Design with Cone Device; Pavement Deflections and Fatigue Failures.

BULLETIN 118: EFFECTS OF CHLORINATION AND MICROORGANISMS AND CONSTITUENTS OF ASPHALTS (1956) 48 pp. $.90

The three papers in this bulletin are: Effect of Chlorination on Oxidizability of Road Asphalts; Constitution and Characterization of Paving Asphalts; Action of Microorganisms on Petroleum Asphalt Fractions.

BULLETIN 123: BITUMINOUS RESURFACING (1956) 39 pp. $.75

SPECIAL REPORT 18: THE WASHO ROAD TEST, PART I: DESIGN, CONSTRUCTION AND TESTING PROCEDURES (1954) 121 pp. $2.25

This report includes a comprehensive description of the project, methods of test operation and instrumentation procedures. It summarizes all data in construction controls and related operations. The purpose of this project is to determine the relative effects of various weights on bituminous-type pavements of varying thicknesses.

SPECIAL REPORT 22: THE WASHO ROAD TEST, PART 2: TEST DATA, ANALYSES FINDINGS (1955) 212 pp. $3.60

This report includes summaries and analyses of the data taken in the test, discussion of the various relationships shown, and tabulation of the findings.

RESEARCH REPORT 7-B: SYMPOSIUM ON ASPHALT PAVING MIXTURES (1949) 115 pp. $1.80

The papers contained in this symposium are: Selection of Test Equipment; Laboratory Study of Asphalt Paving Mixtures; Asphalt Stability Test Section; Correlations of Laboratory and Field Data; Detailed Test Procedures for Design and Field Control of Asphalt Paving Mixtures; The Practical Application of the Design Method of Asphaltic Mixtures to Pavement; Design of Asphalt Mixes as Related to Other Features of Flexible Pavement Design.

RESEARCH REPORT 16-B: DESIGN OF FLEXIBLE PAVEMENTS (1954) 77 pp. $1.05

Includes the following papers: Triaxial Tests in Analysis of Flexible Pavements; Flexible Pavement Design as Revised for Heavy Traffic; Flexible-Pavement Design by the Group-Index Method; Modified CBR Flexible-Pavement Design; Designing Flexible-Pavements (Virginia); Flexible-Pavement Design Correlated with Road Performance. Five Discussions are also included.

CURRENT ROAD PROBLEMS 8-R (REVISED): THICKNESS OF FLEXIBLE PAVEMENTS (1949) 49 pp. $.45

This publication is devoted largely to empirical methods of design which are considered the most reliable for present practice.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government designated by the President of the United States, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.