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Widening and Resurfacing with Bituminous Concrete

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Widening and Resurfacing with Bituminous Concrete

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Wire Mesh Reinforcement in Bituminous Resurfacing

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The problem of what to do about reflection cracks occurring in bituminous resurfacing blankets placed over old Portland cement concrete pavements has been a subject of much concern and paving engineers have long been seeking a satisfactory solution.

A number of methods have been used in an attempt to prevent or retard this type of cracking. Subsealing or mudjacking of the old concrete slabs has been tried, but has not eliminated the trouble. In many cases the old concrete has been covered with a cushion course of granular material of substantial thickness before placing the new surfacing. In other instances, the thickness of the new surfacing has been increased in an attempt to eliminate or minimize this cracking.

A more recent and promising method involves the use of some form of wire mesh, laid directly on the existing concrete surface and covered by a bituminous surfacing.

This paper describes an experimental project in which the California Division of Highways in 1954 placed several test sections for the purpose of comparing the relative merits of various types of wire mesh.

An old existing concrete pavement subjected to heavy truck traffic on highway US 40 and constructed in 1935 was selected for the test site. The pavement was badly cracked, had undergone extensive patching and was to be covered with a 4 inch contact blanket of plant mixed surfacing.

A total of eight experimental sections were placed, incorporating four types of expanded metal mesh, two types of so-called bituminous road mesh and two types of welded wire fabric.

The various experimental sections were separated by control sections containing no wire mesh thus permitting a direct and close comparison between reinforced and nonreinforced sections. Cost comparisons indicate the welded wire mesh to be the least expensive of the various types of reinforcement used.

The final answer as to the economical justification for placing wire mesh will depend upon the amount of retardation of cracking or prolonged life of the surfacing with the various types of reinforcement when compared to the control sections.

● THE problem of what to do about reflection cracks occurring in bituminous resurfacing blankets placed over old P. C. C. pavements has been a subject of much concern and paving engineers have long been seeking a satisfactory solution. These cracks not only present an unsightly appearance, but often develop subsequent spalling which presents a difficult maintenance problem. The cracks may appear at any time from a month up to a few years after construction depending upon the condition of the underlying concrete pavement. Vertical movement of the slabs, commonly referred to as rocking slabs, is the most common cause. Other contributing factors are the type and volume of traffic, particularly heavy truck traffic, the thickness of the new blanket and probably to a lesser degree, at least in California, the temperature differential of the seasons. Figure 1 shows typical reflection cracking of a thin bituminous blanket placed over old concrete pavement on one of our main roads. This picture bears out the fact that reflection cracking is not entirely due to horizontal movements caused by temperature changes in the underlying concrete, as evidenced by the absence of cracking in the lighter traveled passing lane. In this case it is obviously caused by vertical movements of the slabs under heavy traffic.

A number of methods have been used in an attempt to prevent or at least retard reflection cracking. Subsealing or mudjacking of the old concrete pavement slabs prior to blanketing has been tried and although this process greatly reduced the amount or intensity of cracking, it has not completely eliminated the trouble.

In many cases particularly when the old concrete pavement is badly faulted or broken and structurally inadequate to carry the traffic loads, a blanket of granular material 4-to-8 inches in thickness is placed and covered with 3-to-4 inches of new surfacing. However, existing curbs and gutters or structures and the additional cost of raising shoulders very often discourage such a substantial increase in thickness.

In other instances, the thickness of the new asphaltic surfacing has been increased in an attempt to eliminate or minimize this cracking. Even the so-called open graded mixes of the macadam type possessing somewhat more flexibility than dense graded mixes have been tried but still have not completely solved the problem.

From the varying degree of success obtained by any of the above-mentioned methods it appears that prevention of the vertical movement of slabs caused by the passage of heavy trucks is the most important step towards eliminating or delaying the appearance of reflection cracks. In recent years it has been the standard practice of the California Division of Highways to subseal with asphalt before blanketing any concrete pavements showing signs of movement or pumping of the slabs.

It is of interest to note that bituminous blankets placed over many miles of old broken concrete pavements which were built in the early 20's without expansion or contraction joints (but which during the years of service have developed random cracks) are usually free from reflection cracking. This is also true of the pavements covered with the granular cushion courses.

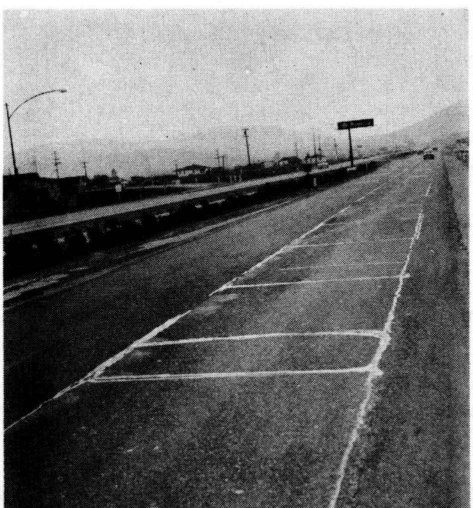


Figure 1. Typical reflection cracking. Both lanes resurfaced June 1954, with 1-inch thick bituminous mix. Note absence of cracks in passing lane at left. Cracks began to appear after 1 month. US 40 near Fairfield.

One of the more recent and promising proposals for eliminating or minimizing the number of reflection cracks is the use of some type of wire mesh reinforcing laid directly on the concrete slab or placed between the leveling and surfacing courses of the bituminous blanket. Although the first attempt to use such material was apparently made in Michigan in 1937, it was not until after the last World War that the use of some form of wire mesh became more widespread. In 1946 the State of Texas placed two projects involving the use of so-called wire fabric and reports from Texas engineers indicate that this method apparently reduced crack formation. Since that date numerous experimental installations of welded wire fabric have been placed in various states and reports in general indicate favorable results in suppression of reflection cracking.

Another form of wire mesh is expanded metal sheets of small diamond size mesh which are used to cover only individual joints and cracks in the existing concrete pavement. This method of treatment was developed in England, where a number of test sections were placed in 1951. Reports received in 1953 indicate that this application shows a definite promise of delaying or materially reducing the amount of cracking.

It might be well to outline briefly the types of wire mesh that have been used in the various trial installations both in the United States and England.

The two primary types of wire mesh are known as expanded metal mesh and welded wire fabric. The expanded metal mesh is produced by feeding stock sheets into a machine

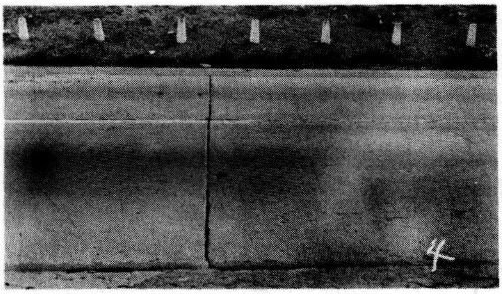


Figure 2. District X-Sol-7-G, condition of old concrete pavement. Note hole for subsealing.

Figure 3. Random cracks.

which cuts and expands the solid sheet into a diamond shaped mesh. The diamonds vary in size from ¼-by 1-inch to 6-by 12-inches and the gauge of metal can also be varied. The sheets with the smaller sized diamonds are usually cut into 4- by 8-foot size and are used in building construction for open partitions, door panels, shelving, etc. The larger sized diamond mesh is used for reinforcement in concrete construction work and may be secured in sheets as large as 12- by 16-feet. The small diamond mesh sheets are normally produced with the long dimension of the diamond parallel to the long axis of the sheet, whereas the large diamond mesh is produced with the long dimension of the diamond at right angles to the long dimension of the sheet. Welded wire fabric is produced by spot welding wires to form rectangles. These sheets may have openings of 3- by 6-inches or 6- by 6-inches or any other dimension desired by the consumer. The gauge of the wire may also be varied, and rolls containing up to 300 feet in length are available. However, the majority of the installations have been laid using sheets 11 feet -6 inches wide by 8-feet long.

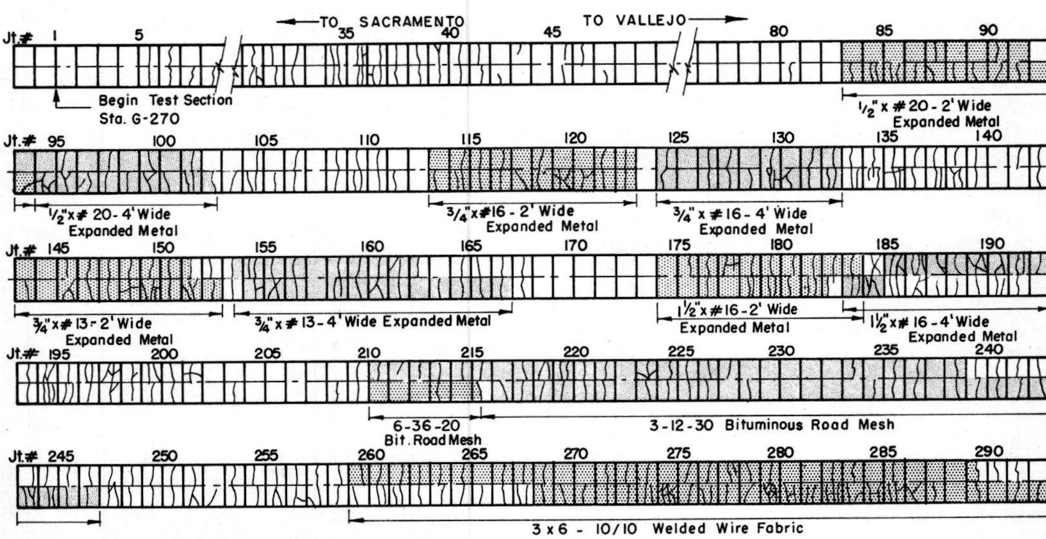


Figure 4. Layout of test section-X-Sol-7-G.

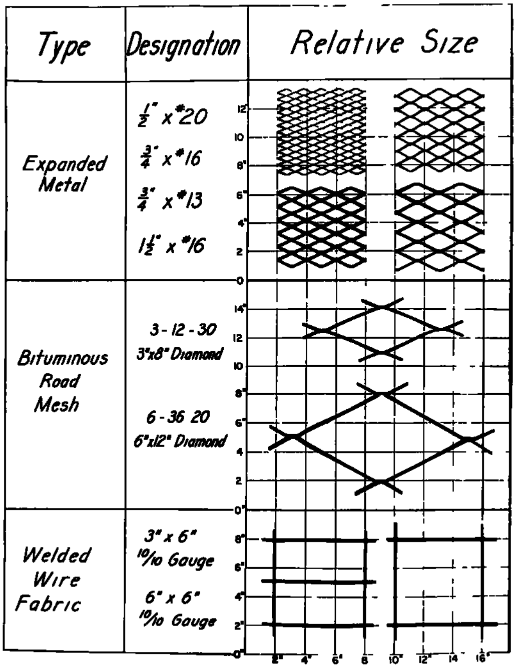


Figure 5.

This paper describes three experimental projects which were installed by the California Division of Highways in three different highway districts using various types of wire reinforcement. The report describes primarily the installation and problems encountered in the major installation in District X where eight different types of wire mesh were used. The other two installations, in Districts V and VI are of a minor nature and mentioned briefly, in this report, involved the use of welded wire fabric only. The project in District VI used wire fabric in rolls each containing 200 feet which were placed in 6 foot, 12 foot, and 18 foot widths. The wire fabric installation in District V was covered with bituminous pavement varying in thickness from 2½ inches to 8 inches and thus should provide some information on the relation between reflection cracking and thickness of plant mixed surfacing. In all cases the wire mesh was placed directly upon the old concrete pavement.

ROAD X-SOL-7-G

The test section is located near the town of Vallejo on highway US 40, the main arterial between Sacramento and San Francisco, a heavily traveled four lane highway. The average daily traffic count is about 20,000 vehicles with about 15 percent consisting of heavy truck traffic.

This installation, involving a number of different types of wire mesh, was completed in June 1954 under Contract 55-10TC2. It is a rather complete test section in that all of the recommended types of wire mesh were placed under similar construction conditions and in areas where the existing pavement was of the same general nature in respect to amount and severity of cracking. The test sections involved the westbound travel and passing lanes only.

The existing 20 foot wide concrete pavement, constructed in 1935, had been mudjacked and later subsealed with asphalt and some bituminous patches had been placed by the maintenance department in past years.

As the old pavement showed signs of vertical movement, the contract provided for subsealing the existing slabs again with hot asphalt. Before resurfacing, the traveled way was widened with cement treated base to provide a standard 24 foot, cross-section with full paved shoulders. This widening resulted in a 2-foot shift of centerline. The resurfacing consisted of 3 inches of plant mixed surfacing, ½-inch maximum size aggregate, placed in two layers and topped with 1 inch of open graded mix, ½-inch maximum size aggregate. 85-100 penetration paving grade asphalt was used as the bituminous binder.

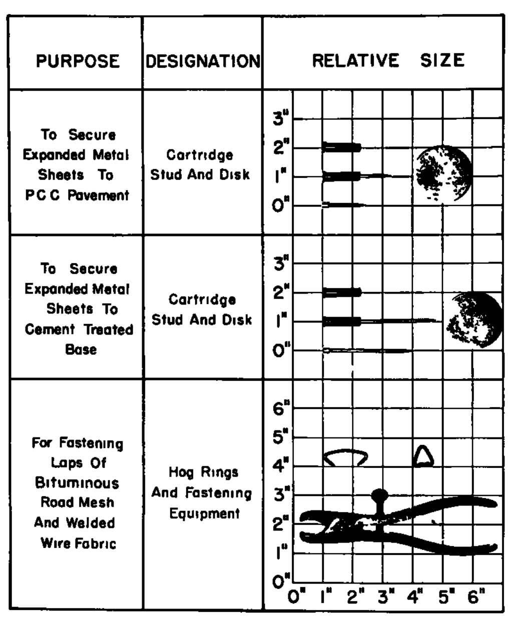


Figure 6.

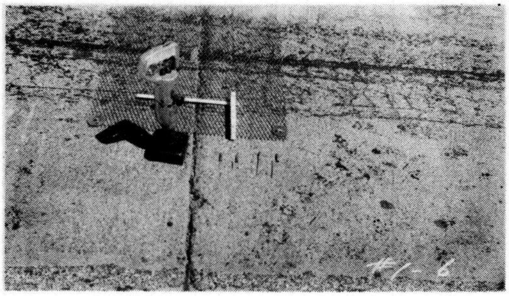


Figure 7. Stud driver used in fastening sheets to P.C.C. pavement.

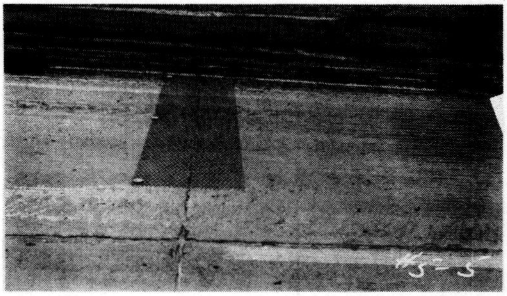


Figure 8. 2-foot wide sheet fastened along leading edge. Paver approaches from left.

The grading of the bituminous mix conformed to the specifications shown below:

	Percent Passing	
Sieve Size	Dense Graded	Open Graded
½ inch	95-100	100
⅜ inch	75-90	90-100
No. 4	50-70	35-50
No. 8	35-50	15-32
No. 16	-	0-15
No. 30	15-30	-
No. 200	4-7	0-3

A careful crack survey of the existing P. C. C. pavement was made and the location of the various test sections laid out. Alternate control sections without reinforcement but showing similar cracking were provided so as to permit ready comparison with each test section. Figures 2 and 3 are typical of the condition of the old concrete pavement and Figure 4 shows the general layout of the test sections.

The following forms of wire mesh were used in the test sections:

Type	Mesh Size
Expanded metal	½ inch by No. 20
	¾ inch by No. 16
	¾ inch by No. 13
	1½ inches by No. 16
Bituminous Road Mesh	3-12-30 (3- by 8-inch diamonds)
	6-36-20 (6- by 12-inch diamonds)
Welded Wire Fabric	3- by 6-inch -10/10 gauge
	6- by 6-inch -10/10 gauge

Figure 5 illustrates the comparative sizes of the various types of metal used.

Expanded Metal

The expanded metal was delivered to

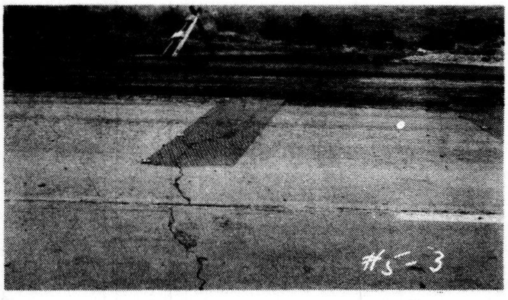


Figure 9. 2-foot wide sheet placed over random crack.

Figure 10. Typical expanded metal test section just prior to paving. Short section of longitudinal joint covered.

the job site in 2 and 4 foot wide strips by 8 feet long. As the expanded metal is rather expensive the two and four foot wide sheets were being tried in order to determine the most economical size which would prevent crack formation. The 8 foot long sheets were satisfactory for the passing lane as 8 feet of old concrete pavement remained due to a shift of the centerline. For the 12 foot wide travel-lane some sheets were cut in half and an 8 foot and 4 foot long sheet used, allowing an overlap of about 3 inches. All joints such as expansion and contraction joints and random cracks of the slabs were covered with the metal. Short sections of the longitudinal joints between the old concrete and new cement treated base were also covered with 2 foot and 4 foot wide sections of the metal, (see Figure 10).

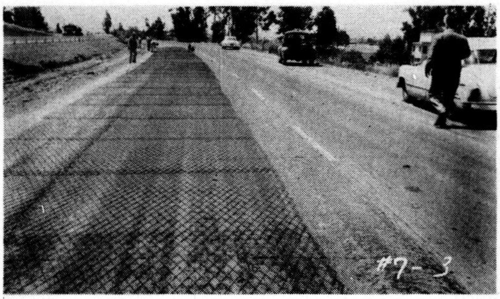


Figure 11. Test section with 3- by 8-inch diamond mesh. New centerline will be at inner edge of wire. On left, sheets cover 4 feet of cement treated base.

The variation in the random crack patterns, encountered mainly in the travel lane, required a great deal of fitting and cutting of the sheets. In a number of cases, a random crack could not be entirely covered with a 2- by 8-foot sheet and required the use of 4- by 8-foot sheets.

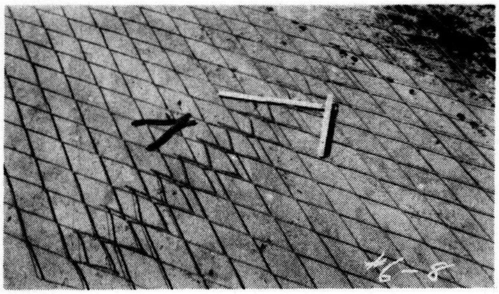


Figure 12. Lapping of sheets. Wires are tied with hog rings about every fifth diamond.

The sheets were securely fastened to the old pavement by means of a standard stud driver, (see Figure 7). In this operation a stamping disc, 2 inches in diameter was laid on the metal mesh, taking care to center the disc approximately in the center of the diamond. The operator, after loading the gun with the correct stud and cartridge, placed the gun over the disc and fired the charge. The stud penetrated the disc and concrete, and pulled the mesh into tight contact with the pavement. After a few trials it was decided that a stud having an over-all length of $1\frac{15}{32}$ inches was best suited. A heavy charge cartridge No. 832 was used in order to secure the required penetration. Satisfactory anchorage was obtained in the cement treated base by using a stud having an over-all length of $2\frac{31}{32}$ inches and a light No. 232 powder charge, (see Figure 6).

The $\frac{1}{2}$ inch by No. 20, 2-foot wide sheets were placed first to determine proper stud spacing. The 8-foot long sheet was fastened at both the leading and trailing edges with about 5 studs and also at a number of spots on either side of the joint.

On passage of the paver over the sheets it was noted that a definite vertical bow appeared in the sheet immediately after the paver treads moved onto the leading edge. It was not possible to determine if the sheet returned to its original shape after the paver moved past. There were no indications of distress caused by failure of the studs to hold the wire in place, as far as longitudinal movement was concerned.

Immediately after the first roller pass, transverse cracking appeared in the mix over the expanded metal sheets. This cracking became more severe on the final roller pass, although the metal was tight against the pavement as determined from

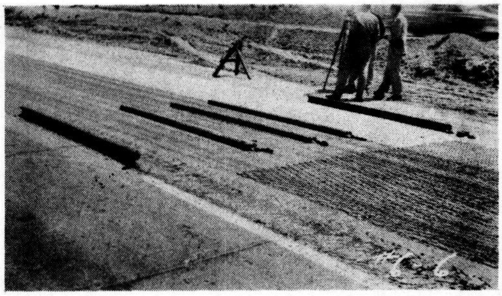
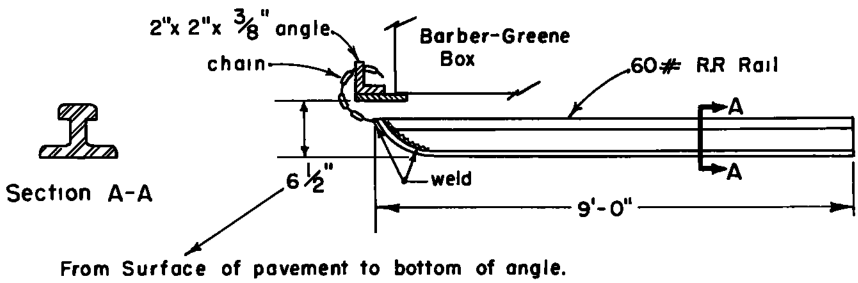


Figure 13. Sleds used to hold down road mesh and welded wire fabric.

OUTER SLEDS

Two used on outside of tracks



1. Total weight of outer R.R. sleds 180 # per sled.
2. Total weight of inside sleds = 198 # per sled.

INSIDE SLEDS

Three used between the tracks

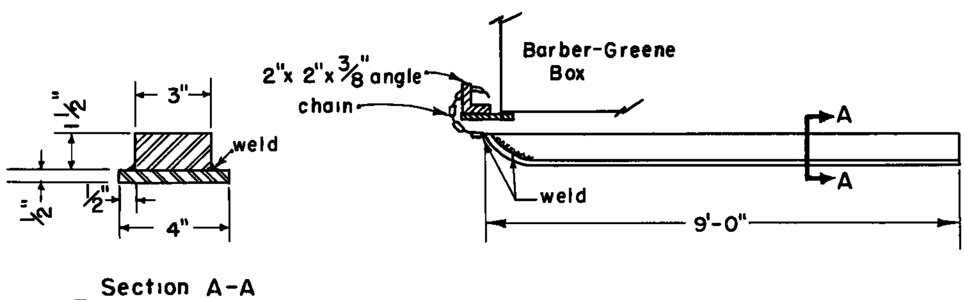


Figure 14. Wire mesh test sections. Details of sleds. X-Sol-7-G, June, 1954.

the protruding edge of the sheet. On a number of sheets a very definite bump was present, mainly at the leading edge. Generally cracks appeared over both the leading and trailing edges and in a number of cases there also were three or four transverse cracks spaced about 5 inches apart. However, the next morning after approximately fifteen hours of traffic most of the cracks had healed, although the leading and trailing edge cracks were still noticeable.

It was then decided to fasten the sheets only at the leading edge and to determine the least number of studs necessary to hold the sheet in place. Various numbers of studs were used including the absolute minimum for an 8- foot long sheet, one at each corner and one in the center of the leading edge, (see Figure 8). This proved to be satisfactory and resulted in a considerable saving as each stud in place costs about $.25.

Stud driving operations proved quite successful in the passing lane, with very few failures due to shattering or excessive penetration. Some difficulties were encountered in the travel lane where the concrete appeared to exhibit marked variations in degree of hardness. In numerous instances the stud would penetrate only one-half of its normal

Figure 15. Close-up of paving operations. Note sled attachment on left.

Figure 16. Position of mesh after placing leveling course.

distance, or would bend or shatter the concrete, or the charge would drive the stud completely through the disc necessitating the driving of additional studs.

There was no difficulty in the paving operations in any of the expanded metal sections. None of the sheets, including those fastened at the leading edge with only three studs, were torn loose by either truck or paver movement. It was noted that some longitudinal movement on a large number of sheets occurred under the traction stresses of the paver. This movement was in the same direction as the forward movement of the paver and was about $\frac{1}{4}$ inch to 1 inch for the $\frac{3}{4}$-inch diamonds and 1 inch to $1\frac{1}{2}$ inches for the $1\frac{1}{2}$ inch diamonds. This movement undoubtedly was caused by the forward shifting of the entire sheet, until the studs which were fired in the center of the diamond encountered the edge of the metal.

The rather severe cracking following rolling as noticed in the beginning, where both leading and trailing edges were fastened, was not noted where only the leading edge was fastened. Paving and rolling operations were normal and very little cracking, following rolling, was noted.

The best size of diamond from the construction viewpoint, appears to be either the $\frac{3}{4}$ inch by No. 16 or the $\frac{3}{4}$ inch by No. 13. The lighter stocks were harder to handle and more difficult to fasten securely. The $\frac{3}{4}$ inch by No. 13 in both 2 and 4 foot wide sheets was easiest to lay and showed the least movement under paver traction forces. However, the $1\frac{1}{2}$ inch by No. 16 can be laid and if it retards the cracking as efficiently as the $\frac{3}{4}$ inch by No. 13 then the lighter metal would be the most advantageous from an initial cost standpoint.

Bituminous Road Mesh

The bituminous road mesh was delivered to the job in sheets measuring 11 feet -6 inches in width and 8 feet in length. The sheets (3- by 8-inch diamond) were laid along the median strip at various locations in the 600 foot test section and placed continuously on the pavement as needed. Due to widening of the pavement, as mentioned before, the wire mesh extended 4 feet over the cement treated base in the passing lane. Only 20 sheets of the large, 6- by 12-inch diamond mesh were placed.

The leading edge of the first sheet was

Figure 17. Paving over 3- by 8-inch mesh.

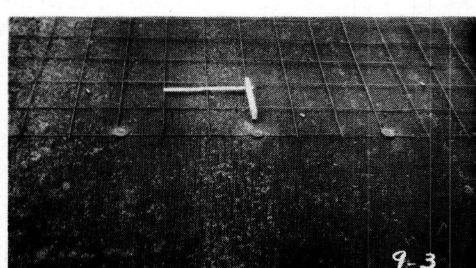


Figure 18. Fastening leading edge of first sheet.

securely fastened to the pavement by means of the stud driver, at about 1 foot intervals. All succeeding sheets were lapped one diamond, taking care that the sheets in place always overlapped the sheet being laid. The next operation was the fastening of the individual sheets to each other. This was done by two men, using medium sized hog rings and a hog ring clipper, (see Figure 6). About four to five rings were used at each lap, the wires being ties along the length of the diamond. The first diamond on each edge of the sheet was always fastened as well as two or three diamonds in between. The hog rings, when crimped into lock position, do not rigidly clamp the wires together and the rings could be freely moved in a longitudinal direction. Vertical movement, however, is restricted to a large extent. The 3-12-30 mesh laid very flat against the pavement and very little curl or raised areas were noted along the entire 600 foot section.

In order to pave over the large sheets it was necessary to provide sleds which forced the sheet to remain flat during movement of the paver. These sleds were fastened to the front of the paving machine and dragged over the sheets just in front of the auger feed. Figure 13 shows the sleds just before being attached to the paver. A total of five sleds were used, each 9 feet long. The sleds used on the outside of the Barber-Greene tracks consisted of regular 60 lb. railroad rails. The three sleds placed between the tracks were especially constructed from heavy bar stock to a total height of 2 inches in order to fit under the paving machine. See Figure 14 for details of sleds.

No particular difficulty was encountered with paving over the bituminous road mesh, except on a curve when due to the uneven traction of the paving machine a slight shifting of the mesh occurred and in one instance some of the wire for a distance of about 30 feet lifted suddenly out of the leveling course and had to be removed. After proper coordination of the truck driver and paving machine operator no further trouble was encountered. Occasional transverse cracks formed almost at once following the paver and in some cases after the first roller pass. Most of these cracks appeared at the laps of the sheets but were ironed out in the final rolling. However, the few that remained on opening the level course to traffic, had healed after overnight traffic. Some of the leveling course mixture was removed, after the rolling, in order to determine the location of the wire. The mesh in all cases was within ¼ inch of the concrete pavement.

Welded Wire Fabric

This material was delivered to the job in sheets measuring 11 feet- 6 inches wide and 8 feet long. Laying operations were the same as previously described for the bituminous road mesh. The fabric was laid so that for the 3- by 6-inch mesh the 3 inch spaced wires were transverse to the direction of travel and the longitudinal wires were uppermost. The 6- by 6-inch mesh was placed so that the longitudinal wires were also in the uppermost position. The first sheet was securely fastened to the pavement at about 1 foot intervals. Each sheet was overlapped 6 inches and tied on the longitudinal wires only with hog rings. These sheets, having a 1 inch projection of wire, seemed easier to lap than the bituminous road mesh and had less tendency to catch. Generally, the wire laid quite flat, although in some areas the sheets were raised from 3 to 4 inches due to warping of the wire above the pavement prior to paving operations. While laying this first section of welded wire fabric it was believed that the movement of the wire ahead of the paver would begin to accumulate enough forward longitudinal movement to cause buckling of the sheets. Therefore, as an experiment, it was decided to secure the leading edge of a sheet about every 150 feet. The overlapping sheet at this point was left free. The idea here was to take up all longitudinal forward movement of the previously laid sheets at this free joint. Close observations during paving operations did not disclose any marked movement of the sheets and any such small movement as occurred was taken up at the individual laps. We, therefore, concluded that this precaution would not be necessary in any future operations.

There were no difficulties in laying the mix over the section and the sleds appeared to iron down the mesh in an excellent manner. Cracking of the mix was very similar to that encountered with the bituminous road mesh. There were occasional transverse cracks, mainly at the laps, which appeared immediately after the mix was laid. Most

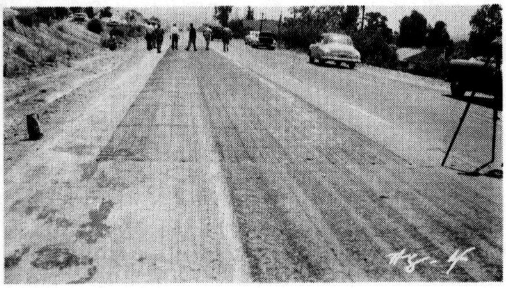


Figure 19. Laying 3- by 6-inch wire fabric. Left edge covers 4 feet of cement treated base.

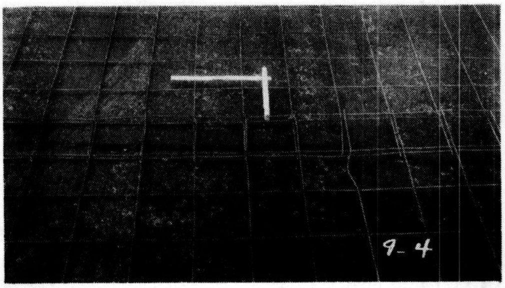


Figure 20. Lap of sheets. Longitudinal wires tied with hog rings every fifth to seventh square.

of these tended to iron out after the final roller pass and the remaining ones had healed after overnight traffic. Removal of the mix in numerous locations along the two 600 foot sections indicated that the fabric was about ½ to ¾ inches above the concrete pavement. The surface course was placed without any difficulties and no cracks of any kind were noticed.

Crack Survey

Three detailed surveys have been made of the job since its completion in June 1954. The first, in January 1955, revealed a few fine short transverse cracks in the nonreinforced control sections and none in any of the wire mesh sections. The second survey in May 1955, after eleven months of traffic, did not show any material change and no crack over 6 feet long. The latest survey, made in December 1955 revealed slightly more transverse cracking in the control sections, two cracks extending over the entire width of 20 feet of the old pavement. No transverse cracks of any kind were visible in the wire mesh sections. Therefore, as of this date no conclusions can be drawn except that so far there is no difference in the relative abilities of the various types of wire mesh to prevent or retard reflection cracking.

At this later survey, however, considerable longitudinal edge cracking was noticed in both the travel lane and passing lane. This cracking extended along the joint between the old concrete pavement and the newly laid widening strip of cement treated base. As none of the longitudinal edge along the travel lane was covered with wire mesh this cracking is irrelevant as far as the wire mesh is concerned. However, in the passing lane which is underlain only with an 8 foot width of old P. C. C. due to a shifting of centerline, the 8 feet long expanded metal sheets placed over the joints were laid to the edge of the old pavement only. The bituminous wire mesh and welded wire fabric, however, extended the full width of the new pavement and covered 4 feet of the new cement treated base. It was noted that no longitudinal cracking occurred over the joining edge which was covered with the bituminous road mesh or welded wire fabric. The total length of the project is 8, 320 feet. Of this distance, 6, 540 feet or 78. 6 percent consisted of the nonreinforced edge and 1, 780 feet or 21. 4 percent is covered with metal. Approximately 1, 200 feet comprising 18. 3 percent of the nonreinforced edge section has developed longitudinal cracking. It appears that up to this time the bituminous road mesh and welded wire fabric has definitely prevented longitudinal cracking.

Cost Analysis

It is difficult to present an accurate cost analysis where a number of relatively short test sections are involved. The installation of the various types of wire mesh was not part of the original contract and was performed under "extra work" and, therefore, no bid prices are available. However, an attempt has been made to present a cost comparison based on our observations during construction and cost figures supplied by the resident engineer. Labor costs, transportation and unloading costs and the price paid for construction and installation and of the sleds all tend to reflect somewhat higher prices due to the short test sections. The final analysis is based on the cost of mesh per square yard of pavement. This method was selected as the only way that a true cost comparison could be made between the small diamond sheets which covered the individual joints and cracks only, and the wire mesh which covered the entire pavement.

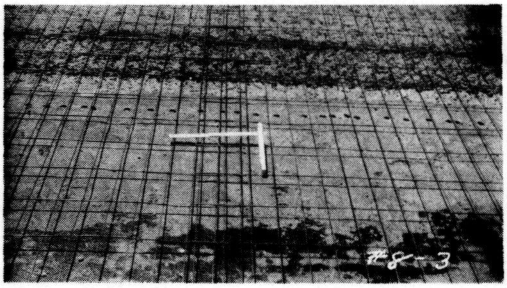


Figure 21. Lap in 3- by 6-inch mesh.

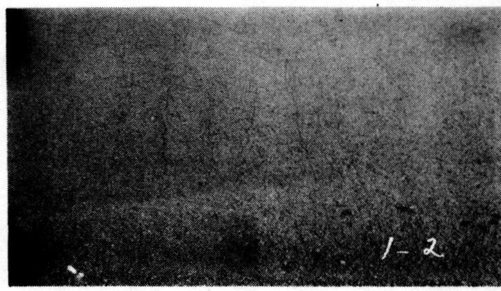


Figure 22. Typical transverse cracking of leveling course following first roller pass. Cracks were closed by traffic within 24 hours.

Three tables showing analyses for different conditions are presented. Table 1 shows the actual cost of the metal reinforcing on this job calculated on the basis of square yards of pavement covered. The 6- by 6-inch welded wire fabric appears the least expensive with the large diamond bituminous road mesh only slightly higher in cost. As the handling and installation of these two types of metals are similar, the final cost depends primarily upon the original price of the metal. The cost of the expanded metal per square yard of pavement is noticeably higher and is greatly influenced by the number of random cracks and the cost of fastening.

A direct cost comparison between the small diamond expanded metal sheets and the mesh which covers the entire pavement is difficult to make. On a pavement exhibiting little random cracking and where only the expansion and contraction joints would be covered, the cost of the expanded metal would be greatly reduced. A relative comparison may be obtained by assuming various conditions of the concrete pavement as shown in Table 2. In Case I the joints only are to be covered whereas Case II assumes the coverage of at least one random crack per 15 foot slab. The cost figures are based on the actual installation costs as shown in Table 1. The first assumed condition indicates that the 2 foot wide expanded metal sheets are less expensive than mesh which covers the entire slab. In the second assumed condition where one additional crack per slab is to be covered, the cost of the expanded metal is exactly doubled and exceeds the cost of the bituminous road mesh and welded wire fabric. The cost of the 4 foot wide sheets, of course, is considerably higher. As badly cracked concrete pavements very often have more than one random crack per slab it would appear from this analysis that the cost of covering these cracks with expanded metal sheets of either 2 foot or 4 foot widths would be prohibitive. On the other hand, the cost of the other two types of wire mesh which cover the entire pavement remains the same regardless of the number of random cracks.

In Table 3 a cost comparison, for the same specific conditions of the pavement as shown in Table 2, has been calculated in terms of cost per mile for a 24 foot width of pavement. For further comparison the cost of adding an increasing thickness of plant mixed surfacing is included at the bottom of the table. The cost of P. M. S. is based on average bid prices current in California. Roughly, the cost of either the large diamond bituminous road mesh or the 6- by 6-inch welded wire fabric is equal to the cost of 1½ inch thickness of plant mixed surfacing.

As stated, the cost comparisons presented are approximate only. There is little doubt that large scale installations of any of the wire mesh types described, together with experience gained by contractors, should show an appreciable reduction in cost.

TABLE 1

COST ANALYSIS FOR WIRE INSTALLATIONS ON CONTRACT 55-10TC2, X-Sol-7-G

Type of Metal		Expanded Metal		Expanded Metal		Expanded Metal		Expanded Metal		Bituminous Road Mesh		Welded Wire Fabric	
Size		1/2"x#20	1/2"x#20	3/4"x#16	3/4"x#16	3/4"x#13	3/4"x#13	1-1/2"x#16	1-1/2"x#16	3-12-30	6-36-20*	3"x6"	6"x6"
Width or Width and Length		2'	4'	2'	4'	2'	4'	2'	4'	11'-6"x8'	11'-6"x8'	11'-6"x8'	11'-5"x8'
Materials Costs													
Metal Sheets	$	128	256	143	286	203	406	115	230	860	489	665	478
Delivery and Unloading	$	26	26	26	26	26	26	26	26	52	52	52	52
Studs	$	46	46	46	46	46	46	46	46	3	3	3	3
Cartridges	$	24	24	24	24	24	24	24	24	2	2	2	2
Discs	$	6	6	6	6	6	6	6	6	(Included in cost of cartridges)			
Tie Supplies (Hog rings)	$	-	-	-	-	-	-	-	-	3	3	3	3
Sled Installation on Paver	$	-	-	-	-	-	-	-	-	40	40	40	40
Total Material Costs	$	230	358	345	388	305	508	217	332	950	589	765	578
Labor Costs		24	24	24	24	24	24	24	24	79	79	79	79
Grand Total	$	254	382	269	412	329	532	241	356	1039	668	844	657
Total Sq Yds of Pvt in Section		444	444	444	444	444	444	444	444	1701	1701	1701	1701
Cost/Sq Yd of Pvt Surface	$	0.57	0.86	0.61	0.93	0.74	1.20	0.54	0.80	0.61	0.39	0.49	0.38

*Only 20 sheets of 6-36-20 Bituminous Road Mesh were laid. The noted cost figures are theoretical values for laying an area equivalent to the 3-12-30 Bituminous Road Mesh and welded wire fabric sections

TABLE 2

COST OF VARIOUS TYPES OF WIRE REINFORCING BASED ON ONE SQUARE YARD OF PAVEMENT SURFACE COVERAGE

			Case I Joints only				Case II Joints plus one Transverse Crack Per Slab			
			Cost prorated per 180 sq.ft. of pavement Assumed that concrete is 12' wide with 15' joint spacing				Cost prorated per 180 sq.ft. of pavement Assumed that concrete is 12' wide with 15' joints and 1 transverse crack per slab			
Type	Designation	Width of Expanded Metal	Metal Cost	Installation Cost (4 Studs per 12' Sheet)	Cost Per Slab 15' long x 12' wide	Cost of Mesh per sq.yd. of Pavement	Metal Cost	Installation Cost (4 Studs Per 12' Sheet)	Cost Per Slab 15' long x 12' wide	Cost of Mesh per sq.yd. of Pavement
Expanded Metal	1/2"x#20	2'	$ 3.66	$ 1.52	$ 5.18	$ 0.26	$ 7.32	$ 3.04	$ 10.36	$ 0.52
		4'	7.32	1.52	8.84	0.44	14.64	3.04	17.68	0.88
Expanded Metal	3/4"x#16	2'	4.09	1.52	5.61	0.28	8.18	3.04	11.22	0.56
		4'	8.18	1.52	9.70	0.49	16.36	3.04	19.40	0.98
Expanded Metal	3/4"x#13	2'	5.79	1.52	7.31	0.36	11.58	3.04	14.62	0.72
		4'	11.58	1.52	13.10	0.65	23.16	3.04	26.20	1.30
Expanded Metal	1-1/2"x#16	2'	3.29	1.52	4.81	0.24	6.58	3.04	9.62	0.48
		4'	6.58	1.52	8.10	0.40	13.16	3.04	16.20	0.80
Bituminous Road Mesh	3-12-30 (3"x8" diamonds)		10.23	1.97	12.20	0.61	10.23	1.97	12.20	0.61
Bituminous Road Mesh	6-36-20 (6"x12" diamonds)		5.77	1.97	7.74	0.39	5.77	1.97	7.74	0.39
Welded Wire Fabric	3x6-10/10		7.91	1.97	9.88	0.49	7.91	1.97	9.88	0.49
Welded Wire Fabric	6x6-10/10		5.69	1.97	7.66	0.38	5.69	1.97	7.66	0.38

VI-KER-138-A, B

Figure 23. Position of fabric after completion of leveling course.

This installation involved the use of welded wire fabric, and was placed in May 1954 under Contract 55-6VC1. The job consisted of resurfacing 13 miles of old concrete pavement with 3 inches of plant mixed surfacing using 85-100 penetration grade paving asphalt. The old concrete pavement was very badly broken and had been extensively patched. Figure 25 shows a typical view of the old pavement.

The test sections involving the wire mesh consisted of a number of short sections varying in length from 100 feet to 500 feet and with varying width of wire fabric as shown in Figure 24.

The wire fabric used was 6- by 6-inch x $^{10}/_{10}$ gauge wire which was delivered to the job in 200 foot rolls 6 feet wide. Three different methods were used in placing the wire directly on the concrete prior to laying the leveling course, which was laid by means of spreader box and blade.

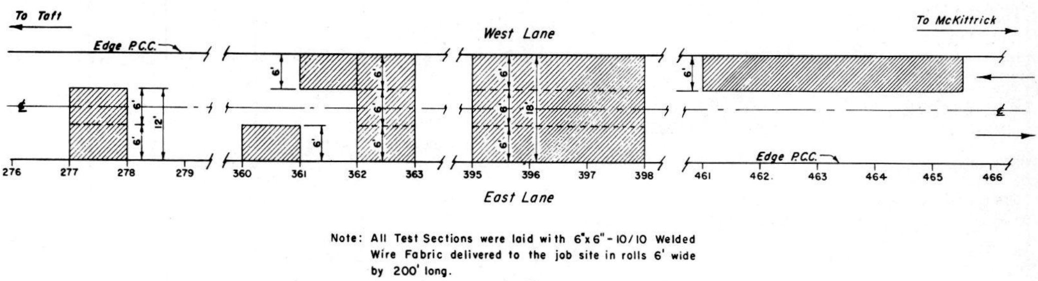


Figure 24. Wire mesh test sections. VI - Kern - 138 - A, B.

1. An entire roll was laid on the pavement and unrolled with the longitudinal wires uppermost. The leading edge was then tacked down with 1½ inch wire staples driven into the cracks. This method of fastening was not very successful. Only about ½ inch of penetration could be secured and many of the staples bent over. They also were easily forced out by movement of trucks over the wire.

2. A roll was cut into 16 foot lengths which were then overlapped one square and interlocked by bending over the cut ends of the mesh. A portion of this section was also stapled while the remainder was not fastened.

3. The roll was unrolled on the pavement and the leading edge was stapled to the pavement or fastened to the previously laid wire. The other end of the roll was placed between two 2- by 6-inch planks which were fastened together. A chain was attached to the planks and tied to a truck, which applied tension to the sheet during paving operations.

No material change was made in the spreader box, except to round the leading corners of the bottom plates. The trucks were backed over the wire mesh and hooked to the spreader box. All truck movements were at very slow speed especially during any turning movements on and off the mesh. After the windrow was laid a winged blade of 10 foot width was used to spread the mix. Two passes of the blade completed the spreading operations of the leveling course. The surface course was spread in the conventional manner with a Barber-Greene Paving Machine.

Of the three methods tried it appeared that the one involving the use of a tension device was the most satisfactory. This method also has been reported as giving good results on a recent large scale installation in Texas, involving the use of 300 foot rolls of 6- by 6-inch -$^{10}/_{10}$ welded wire mesh.

A survey made in December 1955 after 1½ years of traffic did not disclose any evidence of transverse cracking in the test sections nor adjacent control sections. However,

TABLE 3

COST PER MILE OF VARIOUS TYPES OF WIRE MESH FOR SPECIFIC CONDITION OF EXISTING CONCRETE PAVEMENT

Type	Designation	Width of Expanded Metal	Original Concrete Condition (12' Lane with 15' Joint Spacing)	
			Jts. Only No Cracks Cost/Mile for 24' Pvt. Width.	Jts. + 1 Transverse Crack Per Slab. Cost/Mile for 24' Pvt. Width
Expanded Metal	1/2" x #20	2'	$ 3,660	$ 7,320
		4'	6,196	12,392
Expanded Metal	3/4" x #16	2'	3,942	7,884
		4'	6,900	13,800
Expanded Metal	3/4" x #13	2'	5,068	10,136
		4'	9,152	18,304
Expanded Metal	1-1/2" x #16	2'	3,380	6,760
		4'	5,632	11,264
Bituminous Road Mesh	3-12-30 (3"x8" Diamonds)	-	8,588	8,588
Bituminous Road Mesh	6-36-20 (6"x12" Diamonds)	-	5,492	5,492
Welded Wire Fabric	3"x6"-10/10	-	6,900	6,900
Welded Wire Fabric	6"x6"-10/10	-	5,350	5,350

Cost/Mile of 1" of added thickness of P.M.S. for 24' Pavement = $ 3,878

Cost/Mile of 1½" of added thickness of P.M.S. for 24' Pavement = 5,817

Cost/Mile of 2" of added thickness of P.M.S. for 24' Pavement = 7,756

(Based on average cost price of $5.10 per ton in place)

there were signs of longitudinal cracking in some of the control sections, but none in the wire sections.

V-SB-2-D, C

This test section was laid in March 1955, on Contract 54-5VC12. On a portion of this contract a short section of the old existing P. C. C. pavement was covered with 8 inches of cement treated base and 4 inches of plant mixed surfacing. The adjacent pavement on either end was left in its existing condition, thereby requiring the construction of two tapered transitions involving a varying thickness of plant mixed surfac-

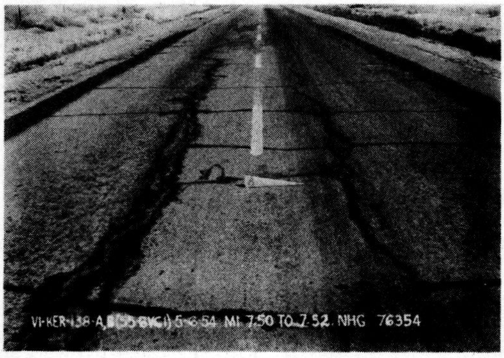


Figure 25. General view of pavement prior to blanketing.

Figure 27. Spreading leveling course.

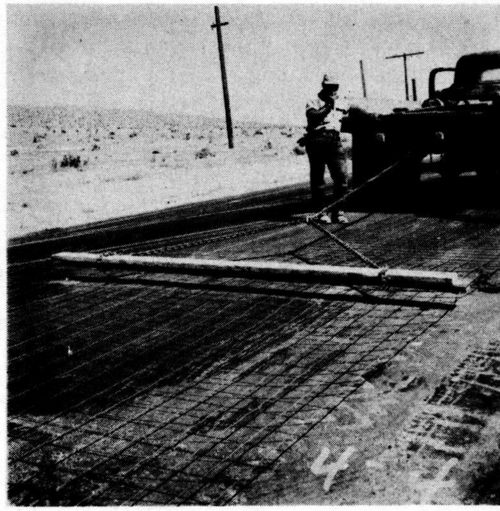


Figure 26. Method of applying tension to wire.

ing as shown in Figure 28.

A number of sheets of 6- by 6-inch - 10/10 gauge welded wire fabric were placed in both lanes of one of the transitions while the other was allowed to remain as a control. This trial section, although small, should provide some information on the relation between reflection cracking and thickness of plant mixed surfacing over the wire fabric. An attempt was made to secure the minimum thickness of plant mixed surfacing at one end of the tapered section by laying the wire up to the "feathering" point for the leveling course. This resulted in a minimum

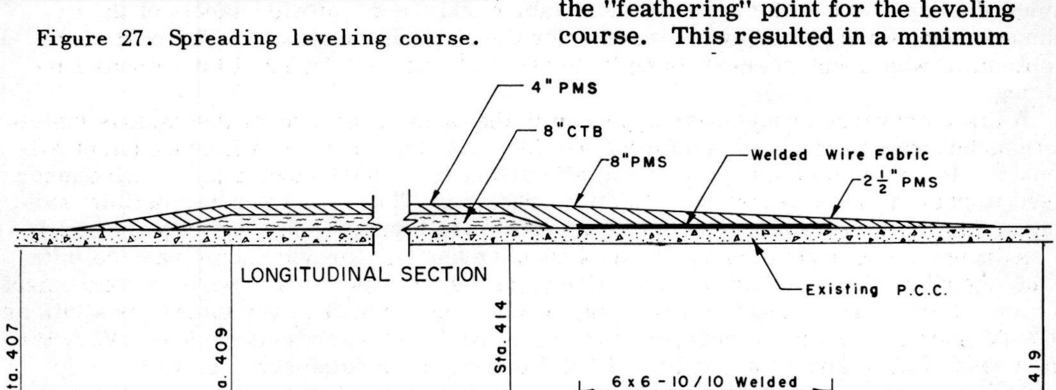


Figure 28. Welded wire fabric test section V - SB - 2 - D,C.

thickness of 2½ inches of surface course over the wire mesh.

The sheets were laid directly on the existing P. C. C. pavement and lapped one square and then tied with hog rings every fifth or sixth square. The leading edge of the first sheet was secured to the existing P. C. C. pavement by means of a stud driver in order to prevent the spreader box from catching. A light asphalt emulsion tack coat was placed after the wire was laid. However, the amount used was not sufficient to coat the wire and little protection from rusting may be expected.

The leveling course was laid with a spreader box and a blade. No difficulties were encountered, however, the equipment including trucks should be carefully handled while on the fabric. The surface course was laid in the conventional way with a Barber-Greene Paving Machine.

A survey was made in December 1955 after nine months of service. The tapered control section, containing no wire mesh, showed transverse cracking at the thin end over the first two joints. The other tapered section, containing the wire mesh, exhibited transverse cracking at all joints from the beginning of the taper to the start of the wire mesh where the pavement was about 2½ inches thick. No cracking was noticed in the wire section.

SUMMARY AND CONCLUSIONS

The three types of wire mesh used and described in this report can be laid and paved over by conventional construction equipment without undue difficulty. The expanded metal placed over joints and cracks only, required no modification of equipment. The bituminous road mesh and welded wire fabric required some type of hold-down device in order to press the wire flat against the old pavement and prevent the tracks of the paving machine from catching in the mesh. On pavements that are badly cracked or extensively patched it would appear that the use of wire mesh which covers the entire pavement would be more feasible and economical than the use of individual sheets placed locally over the joints and cracks only. Care should be taken in transporting and handling these sheets. The flatter the sheets, the less difficulty will be encountered with springiness and resulting cracking of the mix after placing. Any twisted or kinked sheets should be discarded. When paving on curves the paving machine operator should carefully control the traction of the paver so as to avoid shifting of the wire mesh.

The cost analysis indicates that the welded wire fabric is the least expensive of the various types of metal used. The large diamond bituminous road mesh can be considered competitive with the welded wire fabric and the 2 foot wide sheets of the expanded metal when placed over expansion or contraction joints only. The cost of the continuous wire reinforcement is equal to about 1½ inch thickness of bituminous surfacing.

A few transverse cracks have appeared in the control sections of the various installations but none in the wire reinforced sections. At this date there is insufficient evidence to form an opinion regarding the effectiveness of the various types of wire mesh used in preventing or retarding reflection cracking. There is, however, definite evidence that the wire reinforcement has prevented the formation of longitudinal cracks.

Although these experimental sections should eventually provide some very definite data regarding the beneficial effects, if any, of the various types of wire reinforcement to prevent or retard reflection cracking, it would appear that in any future installations thought should be given to incorporating one or two other variations such as: Vary the thickness of surfacing from perhaps 2 to 4 inches in the reinforced sections and in certain control sections increase the thickness of the bituminous mix so that the price per square yard of the nonreinforced portion is equivalent to that of the wire reinforced section. There is evidence that an increase in thickness of bituminous surfacing may not entirely prevent reflection cracking but the magnitude or severity of such cracking may be greatly delayed and reduced. This is demonstrated to some extent by the pavement represented by Figure 1 where a 1 inch blanket began to show reflection cracking after 30 days when compared to the District X job where the 4 inches of bituminous surfacing in the control sections has shown practically no reflection cracking so far. Traffic is similar in both cases. Another variation might be to place, prior to resuring, a cushion course of granular material varying perhaps in thickness from 4 inches to 6 inches over the old pavement and compare the cost and effectiveness with the wire reinforced sections. One other alternative might be to add rubber in various proportions to the bituminous mixture as a possible method of reducing reflection cracking.

ACKNOWLEDGMENTS

The work described herein was performed under the general direction of F. N. Hveem, Materials and Research Engineer, California Division of Highways. Excellent cooperation was extended by the Resident Engineers of the three test sections, L. E. Daniel of District X, N. H. Green, District VI, and C. L. Bunce of District V.

The writer wishes to especially acknowledge the efforts of John Skog who took care of most of the detailed work and assisted the resident engineers during the placing of the various wire test sections.

Discussion

EDWARD M. HOWARD, Field Engineer, Wire Reinforcement Institute—The presentation made by Mr. Zube of the California Highway Department at the recent Highway Research Board meeting was most interesting. His report of their experiences and results are quite similar to those which we have met with in corresponding construction in the central and eastern part of the United States with one exception. That exception is equivalent cost when comparing the cost of wire fabric with additional thickness of asphaltic concrete overlay.

Mr. Zube was quite explicit in stating that their costs were on a strictly research project and that for any comparison that point should be borne in mind. His statement was that the cost of mesh was equivalent to about an inch and one-half of additional thickness of overlay.

As was pointed out by J. W. Horn of Massachusetts Institute of Technology during the question period, the cost encountered on construction in the eastern part of the United States was equivalent to about three-quarters of an inch of asphaltic concrete overlay. Just half of the cost referred to by Mr. Zube.

This difference is accounted for by the fact that Mr. Zube's construction was strictly a carefully controlled research project, whereas the other comparison was to actual construction on a commercial scale.

My comment is offered to clear up any misunderstanding that might exist as to comparative costs, as there was no record made of the questions from the floor during the question period, nor of the answers given.

ERNEST ZUBE, Closure— Mr. Howard stated that during the discussion period J. W. Horn of the Massachusetts Institute of Technology pointed out that in the eastern part of the United States the cost of the welded wire fabric is equal to about ¾ inch of asphaltic concrete overlay against our cost of about 1½ inch of surfacing. Howard believes that such differences may be assigned to the experimental nature of our project.

Although the cost of our project may be a trifle high due to its experimental nature, I believe the main difference in the cost comparisons between eastern and western states lies in the price of the asphaltic concrete itself. The wire mesh is undoubtedly less expensive in the East than in the West. However, the price per ton of asphaltic concrete in the East is considerably higher than in the West.

As an example, using prices found in the paper entitled, "Welded Wire Fabric Reinforcement in Bituminous Resurfacing," by N. C. Smith of the District of Columbia, we noted an average bid price of $8.52 per ton of surfacing in place as against the California price of $5.10 per ton.

Using the California prices from Table 3 of $3,878 per mile per inch of surfacing and the cost of the 6- by 6-inch wire as $5,350 per mile we obtain

$$\frac{\$5,350}{\$3,878} = 1.4 \text{ inch thickness of surfacing equivalent to cost of 6-by-6 inch wire.}$$

Now, assuming that the cost of bituminous surfacing in the West was equivalent to that quoted by Smith, we arrive at

$$\frac{\$8.52}{\$5.10} \times 3,878 = \$6,500 \text{ cost per mile for 1 inch thickness of surfacing}$$

and using our cost of installation for the 6- by 6-inch wire fabric we arrive at

$$\frac{\$5,350}{\$6,500} = 0.8 \text{ inch thickness of surfacing or about the same equivalent thickness as quoted by Horn.}$$

Therefore, it would appear that the difference in equivalent thickness is primarily due to the cost per ton of the bituminous surfacing in the eastern and western parts of the United States.

Pavement Widening and Resurfacing in Idaho

L. F. ERICKSON, Materials Engineer, and
PHILLIP A. MARSH, Assistant Materials Engineer
Idaho Department of Highways

●DURING World War II construction of Idaho highways was at a standstill and maintenance was greatly curtailed. As a result, at the close of the war, many miles of high type pavement both asphaltic and portland-cement concrete, structurally inadequate and too narrow, were in need of immediate reconstruction.

Reconstruction to the desired standards could not be accomplished as rapidly as road conditions required and need to take immediate action to accommodate traffic and reduce maintenance costs prompted the Idaho Department of Highways to initiate a program of widening and resurfacing.

DESIGN

The majority of the pavements which were resurfaced were constructed in the late twenties and early thirties generally 18 feet wide and with shoulders three to four feet wide. These pavements were resurfaced to 24 foot width, with three to six foot shoulders. Additional right-of-way was purchased for these projects only when absolutely essential, and shoulder widths were therefore sometimes limited by the existing right-of-way widths.

A condition survey was made of most projects to determine the thickness and quality of pavement and existing base, shoulder material, and the type of subgrade soil. The condition of the existing roadway was carefully noted. Samples of existing base and shoulder gravel were submitted to the Materials Laboratory for determination of quality. Subgrade soil samples were tested and evaluated for total ballast thickness requirements using the same criteria as for construction of new highways with comparable traffic. In a few instances where no failures had occurred and the road appeared structurally adequate, no subgrade soils samples were taken.

Nearly all of these projects had earth shoulders with the base and pavement placed in a trench section. The earth shoulders were removed to subgrade elevation and reconstructed, using clean, permeable crushed gravel base. Idaho discontinued the use of the "trench" section during the mid-thirties and has since constructed all base and subbase courses full width.

Roads paved with asphaltic concrete and structurally adequate but requiring widening and minor correction of the riding profile, were treated as in the typical section of Figure 1. The earth removed from the shoulder was used to widen the roadbed. Crushed gravel base and plant mixed bituminous stabilized base in courses not exceeding 3 inches compacted was placed to form a base for pavement widening. A tack coat was applied to the surface and edges of the existing pavement at a maximum rate of 0.15 gal. per sq. yd. with an RC-0 asphalt further fluxed with 25 percent naphtha. The plant mix pavement was constructed 3½ inches in thickness in two courses. The bituminous plant mix consisted of a ¾-inch maximum crushed gravel and SC-6 liquid asphalt, or 120-150 or 200-300 penetration asphalt cement.

Roads paved with asphaltic concrete which were structurally inadequate, were widened and reinforced as shown in Figure 2. The earth shoulders were removed to a depth equal to the thickness of the existing base or subbase and backfilled with compacted crushed gravel base. Additional base was then placed full width of the roadway over the newly constructed shoulders and the old pavement. A prime coat of MC-1 was applied at approximately 0.30 gal. per sq. yd. and plant mix surfacing was applied in a single 2½-inch course.

Portland-cement concrete pavements that were structurally adequate were widened and resurfaced as shown in Figure 3. Subsealing of slabs or cleaning of cracks was not required. Scaled areas were patched with bituminous surfacing before paving. The existing concrete pavement was tacked at a maximum rate of 0.15 gal. per sq. yd. with RC-0 further fluxed with 25 percent naphtha. The 3½-inch plant mix surfacing was laid over the existing pavement and widening in two courses.

Badly broken portland-cement concrete was resurfaced as shown in Figure 4. Shoulders were removed and replaced with crushed base; additional base was placed full width over the concrete pavement and shoulders and resurfaced with a single 2½-inch course of bituminous surfacing.

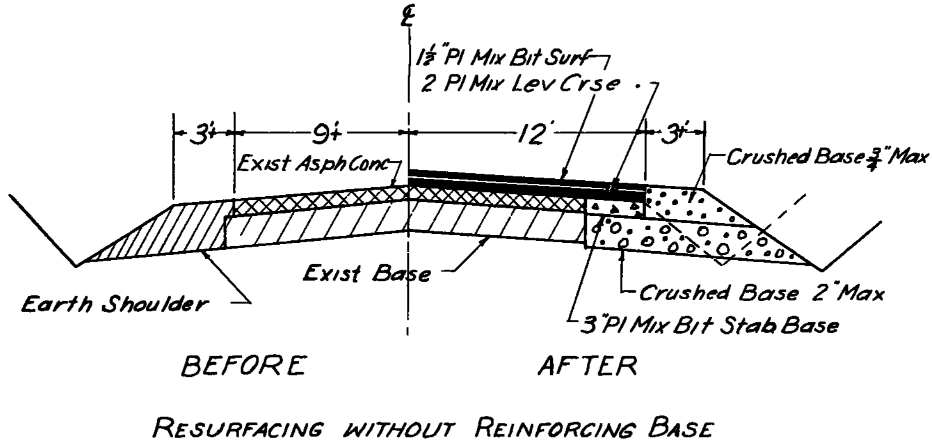


Figure 1. Widening and resurfacing asphaltic concrete pavement.

All of the resurfacing projects were given a seal coat not sooner than ten days after laying the pavement. The seal coat consisted of MC-5 or RC-5 liquid asphalt applied at the rate of 0.25 to 0.30 gal. per sq. yd. with ½-inch to No. 10-mesh cover coat material applied at approximately 30 lb. per sq. yd.

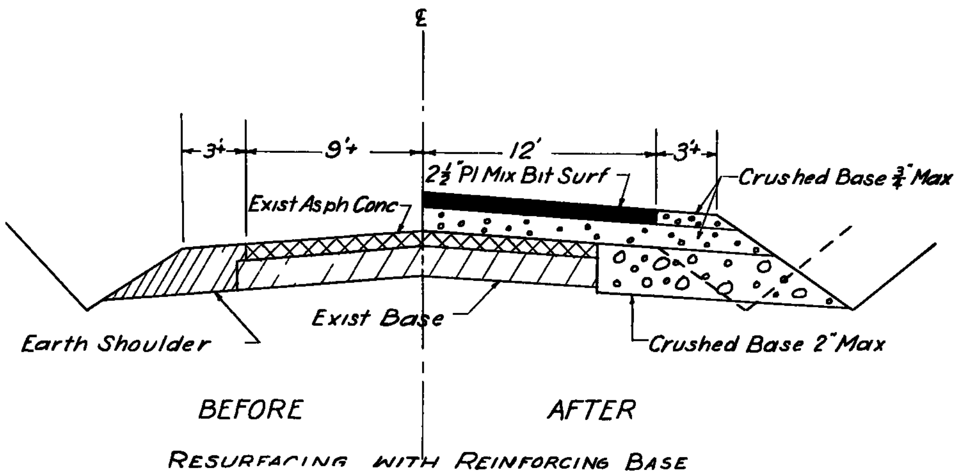


Figure 2. Widening and resurfacing asphaltic concrete pavement.

CONSTRUCTION

The earth shoulders were removed with a motor patrol and the excavated material bladed outward to widen slopes and fill the existing ditch, or carried ahead to widen embankments. Safety of the traveling public dictated that no trench be left open at night and therefore the specifications required all open trenches to be completely backfilled and compacted by sundown each day. Courses of crushed base for widening were deposited on the existing pavement by trucks dumping into an adjustable orifice type windrow placing device. This windrow of base was then bladed into the trench by motor patrol, leveled off with a special attachment bolted on the blade, and compacted.

Crushed base for the widening and the bituminous stabilized base was compacted with a pneumatic tired truck roller and a steel wheel roller. The specifications for the truck roller provided for a truck of three-ton minimum capacity loaded with five tons of ballast. The truck was equipped with dual tires on the rear wheels, each tire having a width of contact with the pavement of not less than 7½ inches.

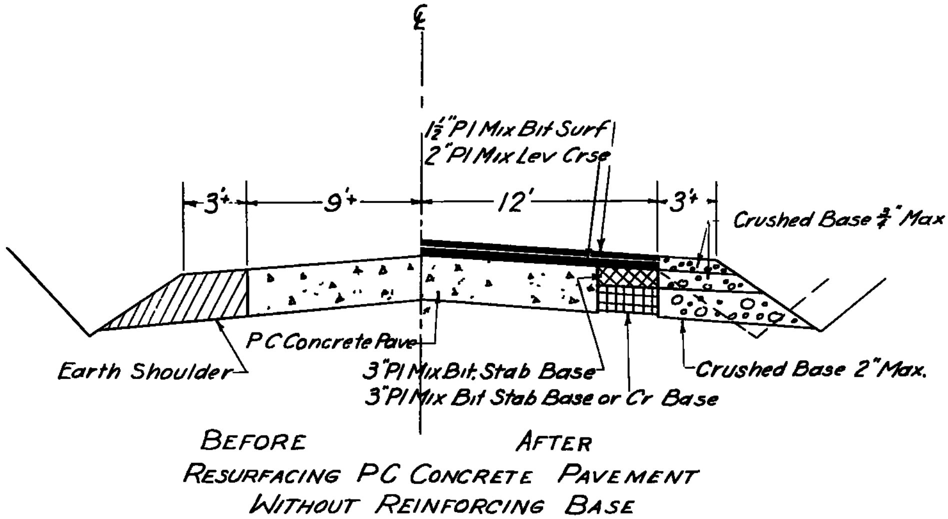


Figure 3. Widening and resurfacing portland-cement concrete pavement.

The bituminous stabilized base was placed in the same manner with sufficient material used so that ¼-inch to ⅜-inch was left above the existing pavement after truck compaction to permit the full weight of the steel roller to be borne by the widened section. Pavements were thoroughly cleaned, all old unstable patches removed, and other failed areas patched with plant mix before applying the tack coat. Where the existing pavement was rough or badly warped, a leveling course of plant mix was laid

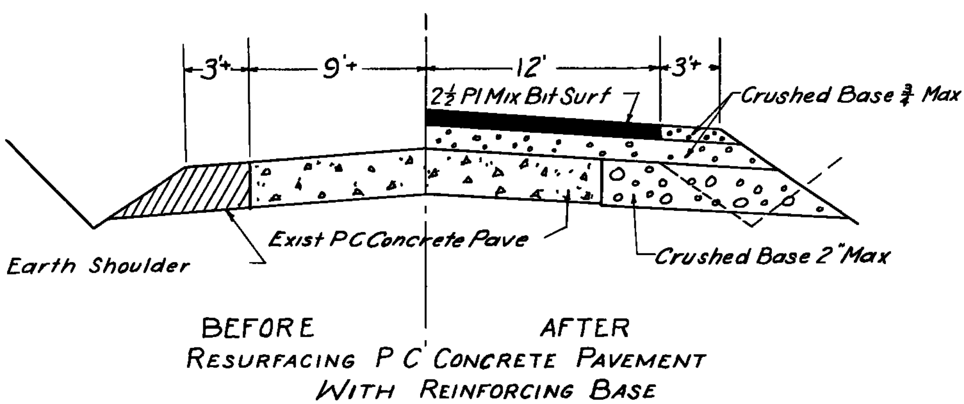


Figure 4. Widening and resurfacing portland-cement concrete pavement.

with a motor patrol. The plant mix level course and surface course were then placed by the conventional pavers.

One rough asphaltic concrete pavement which had been planed and sealed a year previous to resurfacing had failures develop immediately after planing. The following spring it was decided that the project had to be resurfaced that summer. This project was given an additional course of ¾-inch base as shown in Figure 2. No detour was available and the usual prime coat was considered inadequate to carry the heavy traffic

TABLE 1

PERFORMANCE OF RESURFACED PAVEMENTS

Project	Year Constructed	Type Resurfacing Figure No.	Miles Length	Additional Base Overlay	Traffic Count A. D. T. 1954	Performance: Pavement Cracks: Transverse	Long on Centerline	Long Edge	Compaction of Widening	Subgrade or Base Failure	Riding Qualities
SA 17(4)	1946	3	5.289	None	2250	Yes[1]	Mod[2]	Mod	None	None	Good
SA 161(2)	1946	1	8.804	None	4168	Yes	---	Mod	None	None	Fair
Misc 1458	1946	1	0.800	None	3854	Yes	---	Mod	None	None	Good
Sa 253(1)	1947	3	5.577	None	5670	Yes	Yes	Yes	Yes	Yes	Poor
"	"	4	0.39	4-inch	"	Yes	Yes	Yes	Minor[3]	Yes	Poor
SA 253(2)	1948	1	10.804	None	5180	Yes	---	Yes	None	None	Good
"	"	2	3.695	4-inch	"	Yes	Yes	Mod	None	None	Good
"	"	3	4.754	None	"	Yes	---	Yes	Yes	None	Poor
F 23(10)	1948	2	5.112	6-inch	2498	Mod	---	None	None	None	Good
F 27(3)	1948	1	2.84	None	4900	Yes	---	Yes	None	Minor	Good
SA 64(6)	1949	1	8.364	None	1106	Mod	---	---	None	None	Good
SA 253(3)	1949	2	16.88	4-inch	4940	Yes	---	Mod to Minor	None	Minor	Good
SA 17(5)	1949	1	6.861	None	2250	Yes	Mod	Yes	None	None	Good
SA 275	1949	1	6.101	None	3140	Yes	---	None	None	None	Good
SA 9(18)	1950	3	4.22	None	3015	Yes	Yes	Yes	None	None	Good
"	"	4	1.31	6-in. +	"	None	None	None	None	None	Good
SA 4114	1951	1	5.97	None	2169	Minor	---	None	None	None	Good
"	"	1[4]	2.83	None	"	Minor	---	None	None	None	Good
SA 3281	1951	4	4.546	4-inch	6433	Yes	Mod	Yes	Mod	Mod	Good

[1] Yes—Predominant characteristic nearly 100 percent.
[2] Mod—Occasional occurrence but not predominant. Less than 20 percent.
[3] Minor—Infrequent or rare occurrence.
[4] 3-inch Bituminous Stabilized plant mix overlay plus 2-inch Bituminous Plantmix resurfacing.

(5,000 v.p.d.) during paving operations. A two-course surface treatment was therefore substituted for the prime coat. This consisted of applying 0.30 gallon of MC-2 per square yard and immediately covering with 30 lb. per sq. yd. of ¾-inch surfacing to secure an inverted penetration. After curing five days a second similar application was made, except that MC-3 liquid asphalt was used. Paving was started in late September and completed during early November. This surface treatment aided materially in providing a dust free surface for the heavy traffic volume.

PERFORMANCE

These resurfaced projects have benefited the state materially by providing smooth and structurally sound roads of reasonably adequate width at low cost. The cost ranged from $12,000 to $33,000 per mile. These projects are still being used and many will continue in service for an additional five to ten years. The lone exception is a resurfacing of portland-cement concrete pavement which should have been subsealed to stabilize rocking slabs, and overlaid by a gravel base of at least six inches in thickness. Table 1 lists these projects and gives information regarding performance.

The resurfacing and widening of asphaltic concrete pavements without base reinforcement appears successful, but surface transverse cracks in the old pavement appear to be reflecting. (see Figure 5). Some longitudinal edge cracking has occurred,

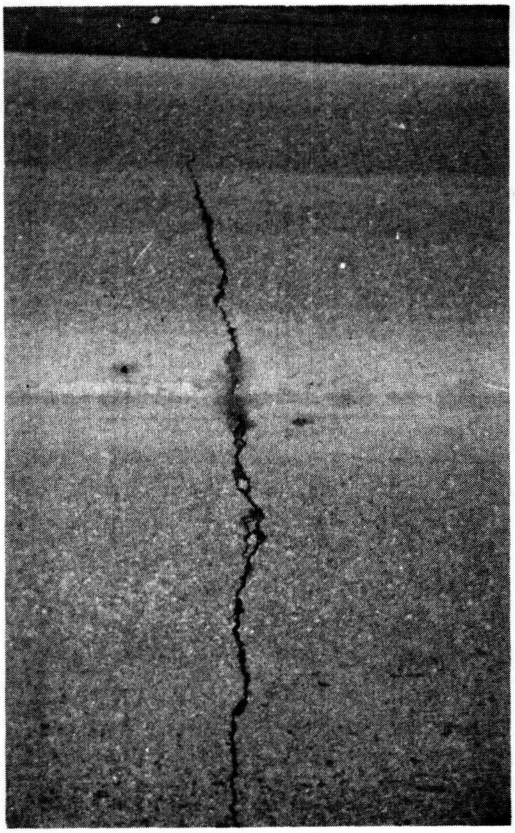


Figure 5. Reflected transverse crack in resurfaced asphaltic concrete pavement.

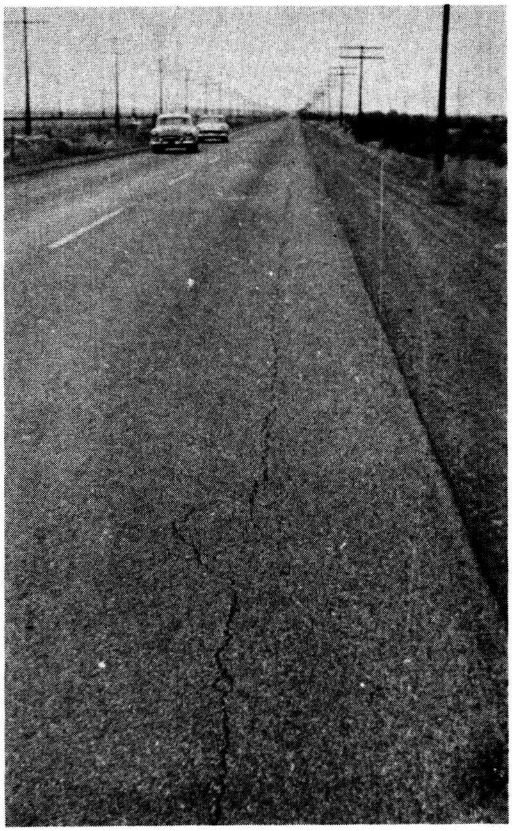


Figure 6. Longitudinal crack over old asphaltic concrete pavement edge.

although apparently only after about five years. Heavy trucks are observed to drive with the outer wheels near the pave-

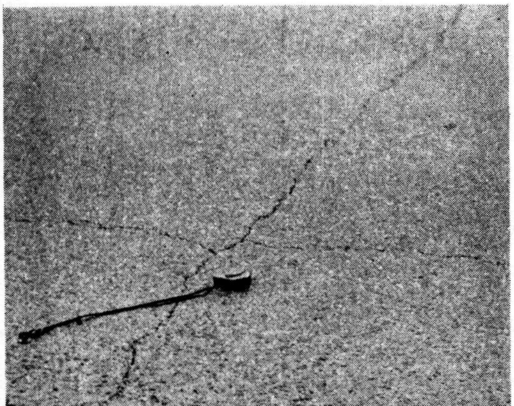


Figure 7. Longitudinal and transverse cracking over asphaltic concrete pavement.

Figure 8. Reflected joints in resurfacing of portland-cement concrete pavement, no base added.

ment edge, and where base widening apparently was not compacted sufficiently, a longitudinal crack reflecting the old pavement edge occurs. (see Figures 6 and 7). However, these pavements still exhibit good to excellent riding qualities.

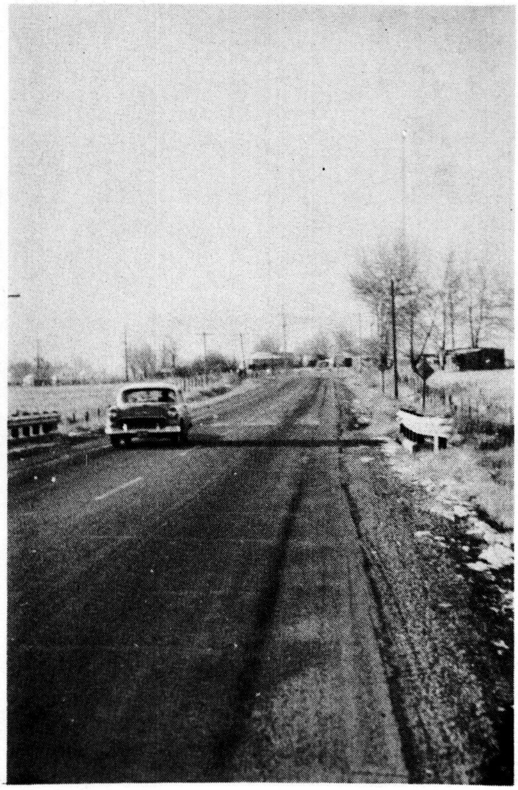


Figure 9. Traffic compaction of widened section, portland-cement concrete pavement, no base added over old pavement.

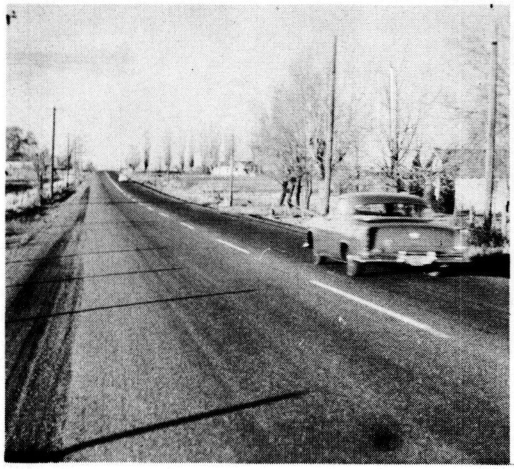


Figure 10. Resurfaced portland-cement concrete pavement with six inches of base added, in perfect condition seven years later.

The resurfacing of asphaltic concrete pavements with base reinforcement has given excellent service. Some longitudinal cracking over the old pavement edge, and some transverse cracking has occurred, although much less than where no base was added. The transverse cracking appears to be a reflection of cracks existing before resurfacing, since cracks were known to exist even though no definite location survey was made.

The resurfacing of portland-cement concrete pavements without the addition of base overlying the old pavement results in reflection of nearly all dummy and expansion joints and other cracks. (see Figure 8). The edge of the concrete pavement also reflects through the new pavement by the appearance of longitudinal cracks. Where compaction apparently was lacking in the base beneath the widened section, traffic compacted the pavement with the result that a groove was formed. (see Figure 9). The riding qualities of these pavements are generally fair but one pavement is definitely poor. All transverse and edge cracks have had to be sealed.

Our first resurfacing project was accomplished using six inches of bituminous stabilized base course for widening and is still one of our better pavements, both from overall appearance and riding quality. The next project had the stabilized base for widening reduced to three inches with the remainder consisting of compacted crushed gravel. This is our poorest pavement considering edge compaction and riding qualities. It is our opinion however, that the subgrade soils of these projects differed sufficiently to cause part of this difference in performance. The pavement on the silty soil probably continued to pump and the slabs to rock. The pavement constructed over sand or sand-silt soils which are generally free draining shows little distress.

One pavement with a layer of crushed gravel base three inches thick laid over the old pavement reflects dummy and expansion joints. The reflection has not become serious and does not impair the riding quality. The base used, however, has a plasticity index of about three, and exhibits the familiar alligator or hexagonal crack pattern immediately over the concrete pavement. Our experience indicates this much plasticity can be detrimental more often than not.

A pavement constructed in 1951, with a 6-inch base overlaying a portland-cement concrete pavement is still in excellent condition and does nor reflect cracks, joints or the edge of the old pavement. Adjacent sections without the crushed gravel base exhibit reflection cracking of the usual type. (see Figures 10 and 11).

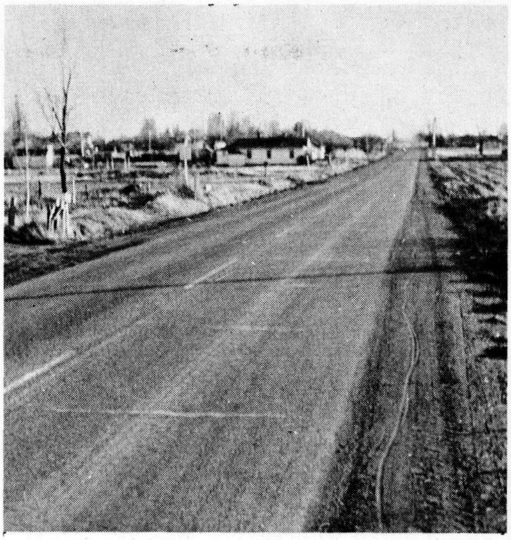


Figure 11. Resurfaced portland-cement concrete pavement with no added base.

RECOMMENDATIONS

It is recommended that the added base and stabilized base be compacted equal in density to the existing base and pavement. This should reduce grooving and possibly reflections of the old pavement edge. The use of bituminous stabilized base a distance of one foot or more outside the finished pavement would possibly help reduce pavement edge reflection cracks by increasing edge support. Also in line with our present practice, paving the shoulder full width to the same thickness, and with the same material as the pavement would help to an even greater extent. The value of paved shoulders was proven on part of the pavement in the WASHO road test.

Stabilizing of the crushed gravel base widening with portland cement to eliminate compaction of the aggregate by traffic would in our opinion be the best treatment. Stabilization of the widened base should be for the full depth.

Portland-cement concrete pavements should have all rocking and loose slabs mudjacked to prevent movement. It is our observation that a minimum of six inches of crushed gravel base over the old pavement is required if reflection cracks are to be eliminated. A uniformity of section full width is of major importance to riding qualities.

Highway Rehabilitation by Resurfacing

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Old and bumpy pavements, both asphalt and concrete, can in many instances be rehabilitated to serve present traffic needs by means of a one-layer, two-layer, or multiple-layer resurfacing of asphalt concrete. In the case asphalt pavements, some city streets have been rehabilitated with a one-layer resurfacing of an average thickness of as little as ¾ inch. Even broken and rocking concrete pavements have been successfully and economically rehabilitated by means of a two-layer resurfacing of an average thickness of 2¼ inches.

● PRIOR to World War II, our main highways were designed in accordance with the comparatively light traffic then existing. The tremendous increase in highway traffic, both as to volume and size of wheel loads during the period of World War II and thereafter was entirely unanticipated. Also during the war period, our roads and highways, in common with those of the various states, suffered because of lack of maintenance.

The increase in traffic during the postwar years has been phenomenal. This means that prewar design standards, while they were adequate then, are no longer so. For example, a typical prewar pavement section design for primary highways was 4 to 6 inches of waterbound macadam base plus a 2½ inch penetration asphalt surfacing. Shortly after the end of World War II, the design standards were upgraded to 8 inches waterbound macadam base plus 2½ inches of asphalt concrete surfacing. Even this has proved barely sufficient in some cases, so that today, for primary highways, a subbase course in addition to the regular base course is often necessary.

The damages caused to highways by the war-time traffic was the result of overloading as well as lack of adequate maintenance. Inadequate maintenance was due to a shortage of manpower as well as of supplies and equipment to do the job. As is well known, these items were in critical supply and were subject to a rigid system of priorities.

With the end of hostilities it was apparent that a sort of accelerated depreciation had set in, and a program of rehabilitating war-torn highways became imperative.

In Hawaii, because of its relatively lower initial cost as compared with portland cement, asphalt is used almost exclusively for highway surfacing. Except for short sections at bus stops, acceleration and deceleration lanes, etc., practically all our concrete highways were built more than 25 years ago. These incidentally were reinforced, at a time when other states were building their concrete highway without reinforcement.

Prior to World War II, asphalt surfacing was either 2½ inch penetration macadam for so-called permanent improvements, or 1 inch surface treatment for temporary surfacing. Both types ravelled and potholed badly under the heavy war-time traffic, especially in the areas where rainfall was moderate to heavy. Since then, asphalt concrete has become the standard type of surfacing for new construction wherever available at reasonable cost.

In the rehabilitation program, which was started during the latter part of 1945, the greatest mileage was surfaced with asphalt concrete. It has proved to be generally satisfactory under all climate conditions and under the heaviest traffic. On the other hand, other pavement types such as surface treatment has proved inadequate for heavily travelled primary highways.

THE REHABILITATION PROGRAM

In rehabilitation as opposed to reconstruction, the objective is to restore the surface with a minimum of work done to the substructure, such as scarifying and recompacting the base and subbase courses.

A field survey showed that the rough riding quality of the roads to be rehabilitated was due mostly to badly ravelled surfacing and in only a minor way to base failure.

Accordingly, the greater part of the rehabilitation program consisted essentially of adding a new surfacing layer (or layers) over the old and rough surface. Base thickness was left intact. The only increase in the overall thickness of the pavement structure (base and surfacing) was that due to the new surfacing. This added increase in thickness, on the average, did not amount to more than 1½ to 2¼ inches or so at the most. Some city streets were rehabilitated by the City and County of Honolulu by means of a one-layer resurfacing of an average overall thickness of ¾ inch. The small added thickness appears to have greatly increased the load carrying capacity of the rehabilitated pavement, although the total overall thickness of base and pavement was in many cases less than the new standards of design. Apparently a small added thickness of asphalt concrete is more effective in increasing the load capacity than an equal thickness of base, which generally consisted of water-bound macadam. Another reason may be the increase in subgrade strength as a result of the added compaction over the years by traffic wheel loads. Such increase in subgrade strength with time has been observed by others. (1)

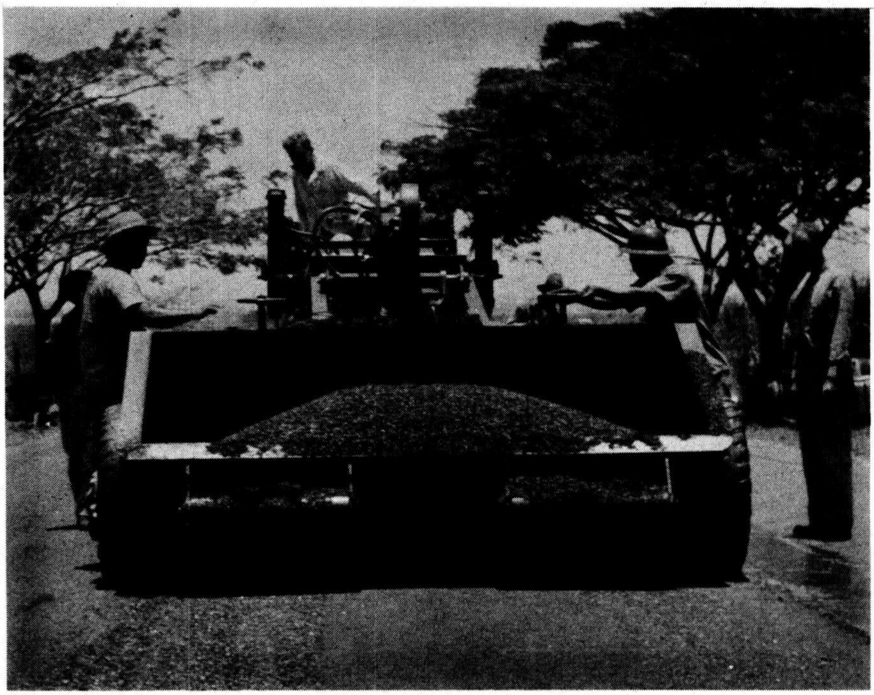

Figure 1.

In general, pavement widths were left unchanged. In cases where the pavement was rehabilitated to a greater width, the widening was accomplished by adding a trench section, usually two feet wide along one or both edges of the pavement.

The first step in the resurfacing operation was to spot patch chuck holes and rebuild or otherwise reinforce the base where it had failed. Next a tack coat of emulsified asphalt was applied at the rate of about 0.10 to .15 gal. per sq. yd. depending on the condition of the surface. Before the tack coat was applied, the surface was swept clean of dirt and other fine loose material by brooming and by means of a compressed air jet. This lessened the chances of the tack coat peeling off and with it the resurfacing.

On some projects the resurfacing was laid down in one layer. On most projects, it was laid in two layers and on two projects, in multiple layers.

Over the years the original grade had become distorted and wavy. One objective in resurfacing was to achieve a more even grade line by filling in the valleys and skimming the resurfacing material just above the top of the hills. In practice, the above operation proved more difficult than it sounds. A single layer resurfacing, although it was a vast improvement over the rough and ravelled pavement, left much to be desired in the way of a smooth grade line. For example, a single layer resurfacing will smooth out the longer undulations of the profile but tends to leave a series of shorter undulations in place of the longer ones. A second layer will smooth out most of these remaining short undulations so that a two-layer resurfacing job, in general, results in a much smoother riding surface than a single-layer resurfacing.

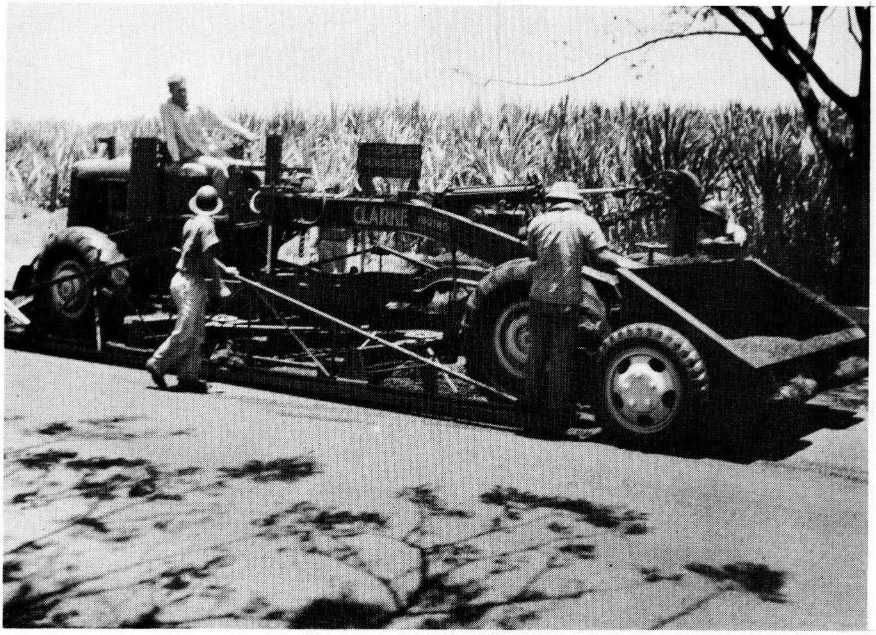

Figure 2.

Figure 3.

In general, however, the smoothest riding surfacing can be achieved if the resurfacing is laid down in multiple-layers. This multiple-layer method is specially adapted for resurfacing those roads with surface undulations that are deep as well as long. It has been previously described in "Construction Methods" for July, 1947, p. 102-104.

In ordinary two-layer resurfacing, a motor grader was sometimes used to spread the first layer or leveling course. The use of a motor grader is advantageous if a relatively thick first layer is to be laid. In multiple-layer resurfacing on the other hand, the individual layers are laid down as thin as possible. The theory is that each successive layer corrects the undulations and unevenness of the previous layer until the best possible riding qualities are attained. In order to do an effective job of leveling out the small undulations, the wheel base of the leveling machine must be long compared to the wave length of the undulations. A motor grader with a long wheel base is generally available on highway construction projects. But the single blade of a motor grader is inadequate for multiple-layer leveling. The type of leveler used in our work was devised by Jess Kopp, at the time a contractor's construction superintendent. It consists of a series of screeds suspended from the frame of an Austin-Western Road Grader. Figures 1, 2, and 3 show front, side and rear views of the Kopp leveler.

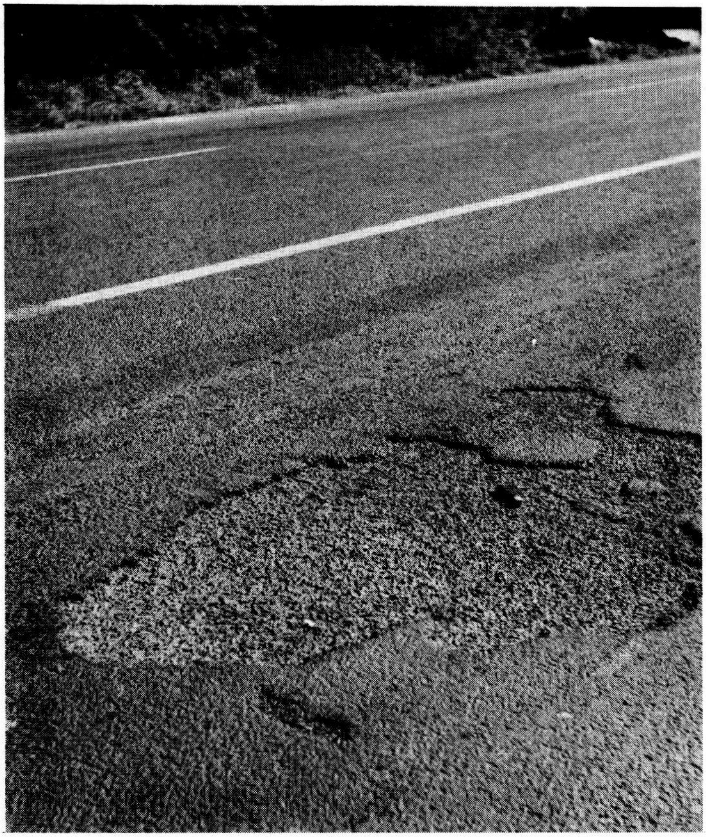

Figure 4.

The use of a series of screeds in lieu of a single blade results in better control, since each screed is adjustable and any overflow or imperfections left by a forward screed can be corrected by a rear or following screed.

The Kopp leveler is not currently in use on any Territorial project. However, it is in constant use by the City and County of Honolulu in its resurfacing work. It is also the writer's understanding that it is being used by the Grifith Co. in work in California, particularly the Los Angeles area.

One other innovation developed here in Hawaii is worth mentioning and that is the use of emulsified asphalt in hot paving mixes in lieu of paving grade asphalt. Ordinarily a product such as emulsified asphalt is used only in cold mixes. The use of emulsified asphalt in hot mixes came about because of economic reasons. Until very recently, all paving asphalt was shipped to Hawaii from the west coast in barrels. On the other hand, emulsified asphalt could be shipped at low bulk rates in tankers. The rapid rise of labor rates during the last decade raised the cost of handling barreled asphalt to the point where emulsified asphalt could compete on almost even terms, even though it contained only 55 to 60 percent asphalt.

Today, paving grade asphalt is manufactured locally from selected crudes shipped from California, so that the economic factors just mentioned no longer apply. However, it is conceivable that the same economic situation regarding bulk versus barrel handling may arise in other out-of-the-way places.

One change that must be made in using emulsified asphalt in hot mixes is to heat the aggregate much hotter than when using paving grade asphalt. The higher temperature is necessary to insure sufficient heat to evaporate all the water in the emulsified product and still maintain a high enough temperature in the mix. This initially high aggregate temperature does not appear to have affected the cementing qualities of the asphalt adversely. The most frequent complaint from the field in regard to this type of mix was that it set up too slowly, that it remained soft for a week or more somewhat like a cut-back mix. The trouble was traced to the use of an emulsion made from high penetration asphalt (150-200). The substitution of an emulsion made from a lower penetration asphalt (85-100) resulted in sufficient improvement in setting up time so that the product came to be quite generally acceptable, especially by the City and County of Honolulu, which agency used it extensively in resurfacing many of the streets of Honolulu. The advantage of hot-mixing of course, was that the product was stable under wheel-loads from the start and did not need a curing period as in the case of the usual cold mixes.

Our experience has been that asphalt pavements can be successfully rehabilitated even with a single thin layer of asphalt concrete without too much trouble with the latter peeling off. However, the same does not hold true for concrete pavements or surface treatment. The latter lacks "body" and much trouble has been experienced with "peeling off" (see Figure 4).

In rehabilitating concrete pavements, we have found it to be generally impractical and uneconomical to remove broken or rocking slabs. Doing so amounts to reconstruction rather than rehabilitation. However, if the rocking slabs were large, they were broken up into smaller units by dropping a heavy steel ball from a crane. Undersealing as practiced by Ohio was not done in any of our work involving concrete pavements. (2)

In the case of concrete pavements, there is a greater chance of the resurfacing layer pulling away from the old surface. Hence the resurfacing must be thick enough so that it will have enough stability in itself to stay in place, after the bond between it and the old concrete surfacing has been broken (3). A 1½ inch leveling course followed a ¾ inch surfacing course, a total thickness of 2¾ inches or so, was generally sufficient to rehabilitate our old concrete pavements. This thickness was not enough to prevent the cracks in the underlying concrete from eventually showing up at the surface. However, the rehabilitated pavements have retained their good riding qualities.

The thickness of leveling and surfacing courses over old asphalt pavements for two-layer rehabilitation have been about the same as above.

The views and opinions expressed in the above are the author's own and do not necessarily reflect those of the Territorial Highway Department.

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Progress of Reflection Cracking in Bituminous Concrete Resurfacings

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During 1949 to 1952, a large mileage of Portland cement concrete pavements in Massachusetts was resurfaced. This was done with the standard state specification bituminous mix (Class I) as well as with mix modified by various types or rubber additives.

Periodic condition surveys have been conducted on twenty-five 1,000 foot samples of this pavement since their resurfacing to evaluate their relative performance. Data are summarized quantitatively by a method described in a previous paper. Results are classified percentagewise by width and type of crack and are presented graphically to show the progress of cracking with time.

From this analysis it is concluded that about 90 percent of the possible potential reflection cracking will take place by the time 5 or 6 years have elapsed. This appears to be true whether or not additives were added to the mix.

● THE life of concrete pavements is often prolonged by resurfacing with a layer of bituminous concrete. This serves to restore smoothness, increases structural strength, and makes it possible to widen a narrow pavement easily and effectively.

A common defect in the resurfacing is the appearance after a short time of reflection cracks in a new bituminous surface. These develop directly over the joints and cracks of the pavement below. It is believed that this cracking is caused primarily by three phenomena: (a) the differential vertical movements between adjacent slabs that occur during load transfer causing a shearing action in the bituminous surface, (b) permanent displacement of adjacent slabs due to differential settlement, and (c) the continuous restless movement of the underlying slabs due to temperature changes, causing opening and closing of the joints and a consequent pulling of the resurfacing above. Vertical movements have been measured on highways in Massachusetts, and even in pavements where no pumping whatsoever occurs have been found to be as much as 0.07 inches during early morning hours. The width of reflection cracks has been found to vary by 0.1 to 0.2 inches during the four seasons.

For several years the staff of the Joint Highway Research Project of the Massachusetts Institute of Technology and the Massachusetts Department of Public Works have been studying reflection cracking, its causes, and possible means of prevention or treatment. This work has already been reported on on several Highway Research Board papers and Project reports (see references).

As part of the research, detailed condition surveys have been made annually on several miles of resurfaced highways. These have served to give an understanding of the progress of reflection cracking and the variations in the rate of cracking that might be found in different resurfacings. Sufficient data have now been accumulated to make an analysis possible.

THE TEST SECTIONS AND METHOD OF SURVEY

The reflection cracking described in this paper occurred in bituminous concrete resurfacings laid from 1948 to 1951 on parts of Massachusetts Route 2 (the Concord Turnpike) and Route 28 (Figure 1). The former road was originally constructed in 1935 as a four-lane portland-cement concrete highway on new location (Figure 2-A). The latter was built in 1930-1932 as a three-lane highway, on the same location as an older road. The outer lanes were portland-cement concrete, the middle lane consisted of either bituminous macadam in some locations or portland-cement concrete in others (Figure 2-B). The slabs were 57-feet long and 10-feet wide with bar reinforcement and dowels at the expansion joints. No contraction joints were used.

Traffic on both routes is heavy. By the late 1940's the slabs were for the most part still structurally sound, and there was no evidence of pumping. This appears to be due to the Massachusetts practice of placing gravel bases under all pavements as a frost preventive measure. Concrete surfaces were spalled primarily because of extensive use of chlorides for snow and ice control. When driven over some thumping was noticeable at joints due to settlement of the slabs and faulted joints. The original 10-foot lanes had become too narrow for modern traffic. To remedy these defects resurfacing was resorted to, constructed wider than the original pavement.

Standard Massachusetts Type I bituminous concrete was used, modified in several cases by rubber additives.

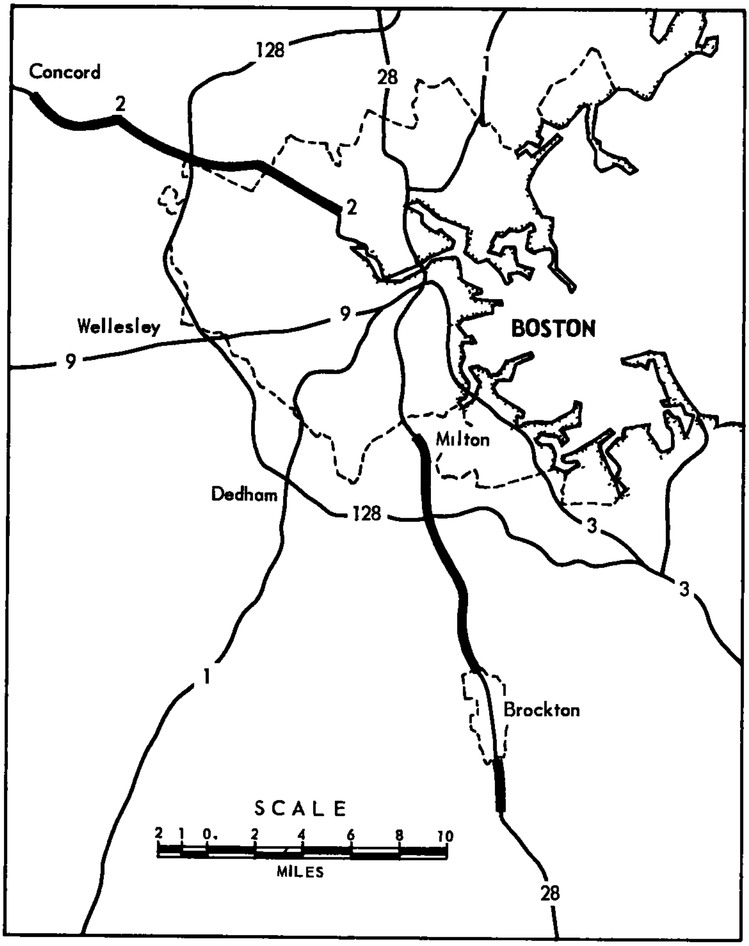

Figure 1. Location of test sections, Mass. Routes 2 and 28.

Resurfacings surveyed were:

Route 2

Type I, 2½-inches thick
Type I, 2½-inches thick, with emulsified rubber asphalt additive

Route 28

Type I, 3-inches thick
Type I, 2½-inches thick with natural rubber crumbs added
Type I, 2½-inches thick with GRS rubber added

Specifications for Type I and for additives are given in Table 1.

All pavements were hot mix, spread and finished with Adnun or Barber-Greene paving machines, with the customary rolling afterward. No difficulties or unusual conditions were reported to have occurred during placement.

Condition Surveys

Condition surveys were first made in the fall of 1952. Resurfacings were then from one to three years old. Condition surveys were not made prior to construction, as the research project did not exist before 1951. Detailed construction records and photographs are available, however. The locations of joints in the underlying pavement was self-evident from the pattern of reflection cracking and the known spacing of joints (Figures 3 to 6).

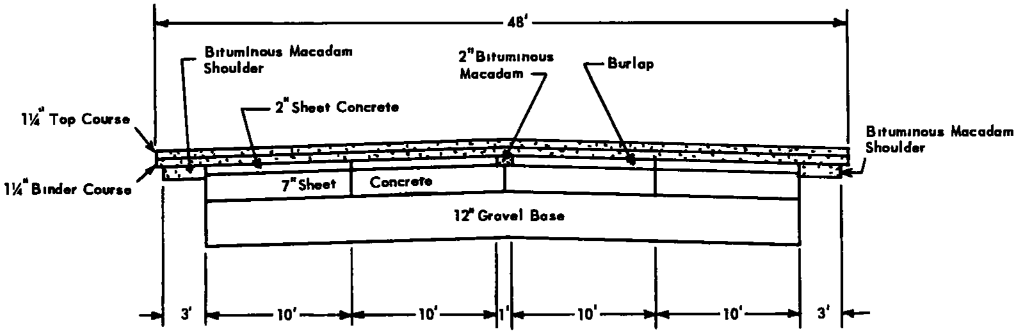

Figure 2A. A typical cross-section of Route 2 sections.

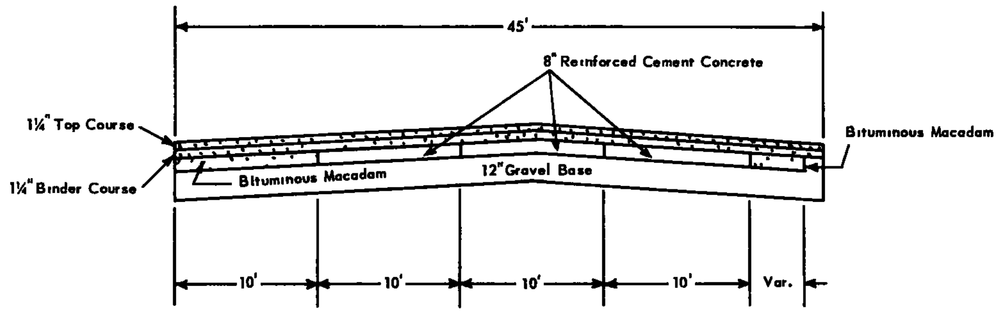

Figure 2B. A typical cross-section of Route 28 sections.

The 25 sections chosen for survey were from 425 to 1,685 feet long with 17 of them over 1,000 feet in length. They were selected to be as representative as possible of the 750- to 1,200- foot lengths of each pavement type in which they were located. Condition survey sections totalled 25,230 feet, chosen from 88,550 feet of pavement, or about a 28 percent sample.

Resurfacing Used	Number of Survey Sections	Total Length of Survey Sections	Percent of Total Resurfacing	Route No.
Type I plus ERA, 2½- in. thick	8	8,267	26	2
Type I plus GRS, 2½- in. thick	4	4,075	40	28
Type I plus Nat. Rub. 2½- in. thick	4	3,980	41	28
Type I 2½- in. thick	6	5,909	28	28
Type I 3- in. thick	3	3,000	19	2

Condition surveys were repeated at annual intervals. After the first year they were

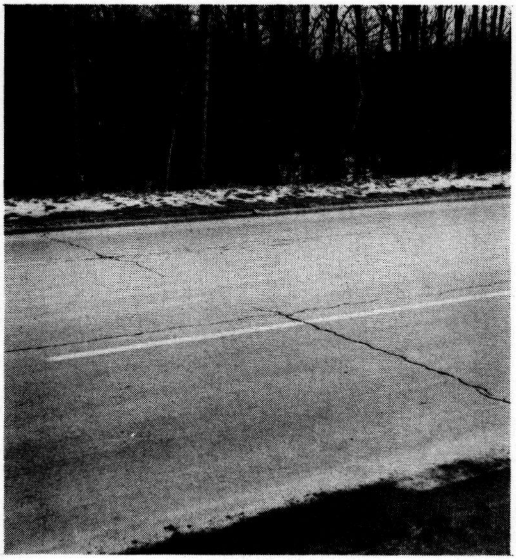

Figure 3. Typical reflection cracking pattern.

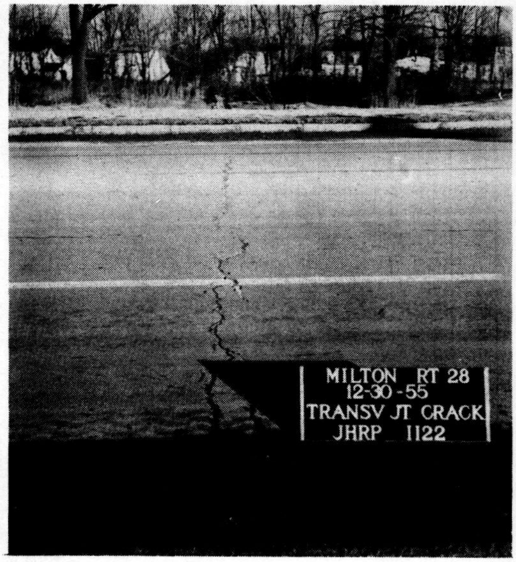

Figure 4. Transverse joint crack.

conducted as late in the fall as possible when the weather was cold and the cracks were wide open. This procedure assured that very narrow cracks would not be missed.

It is planned to make another survey several years hence to evaluate any gradual deterioration of the pavement which may take place in areas over the interior of slabs. As for reflection cracking, however, the results of the surveys to date are such that final conclusions can be drawn from them.

Method of Survey

The method of survey has been described in detail in a previous paper (9). Briefly, the location and length of all cracks was determined by a surveying field

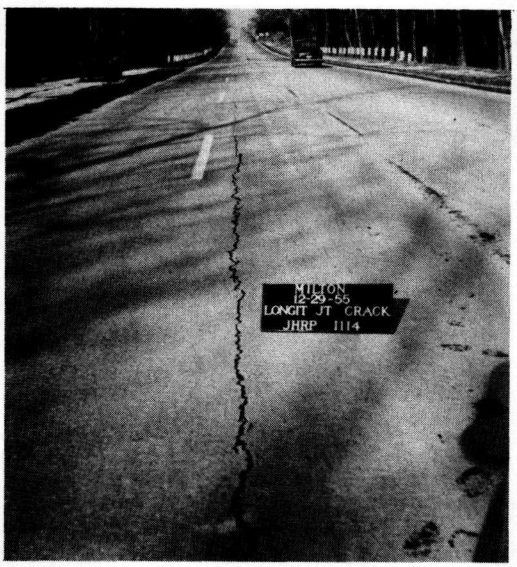

Figure 5. Longitudinal joint crack.

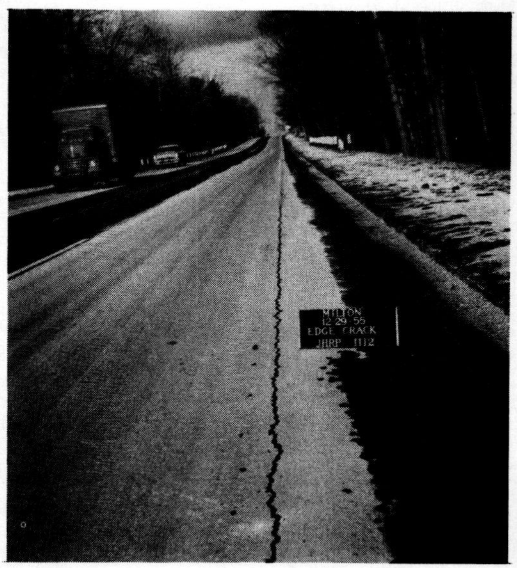

Figure 6. Longitudinal edge crack.

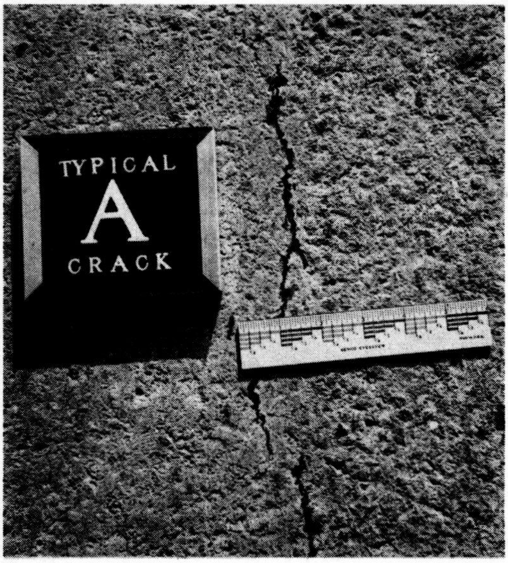

Figure 7. "A" crack-hairline.

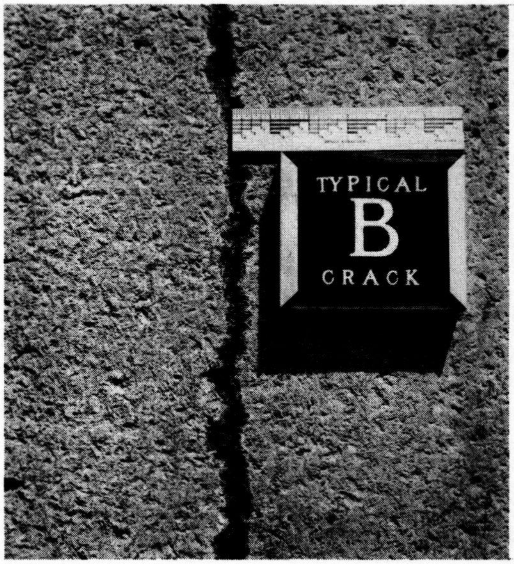

Figure 8. "B" crack-narrow-less than 1/8 inch.

crew. They were classified by width, as follows:

Symbol	Width
A	Hairline
B	Below 0. 01 feet, or about $\frac{1}{8}$ inch or less
C	Between 0. 01 and 0. 02 feet or about $\frac{1}{8}$ to $\frac{1}{4}$ inches
D	Between 0. 02 and 0. 03 feet or about $\frac{1}{4}$ to $\frac{3}{8}$ inches

Photographs of typical cracks are shown in Figures 7 to 10. All cracks were plotted accurately on field sheets devised for the purpose (Figure 11).

For each survey section the length of each crack of each width was scaled from the field sheets and totalled, after being further classified as transverse, longitudinal over slab edges, transverse crack extensions, etc. Total lengths were then compared with

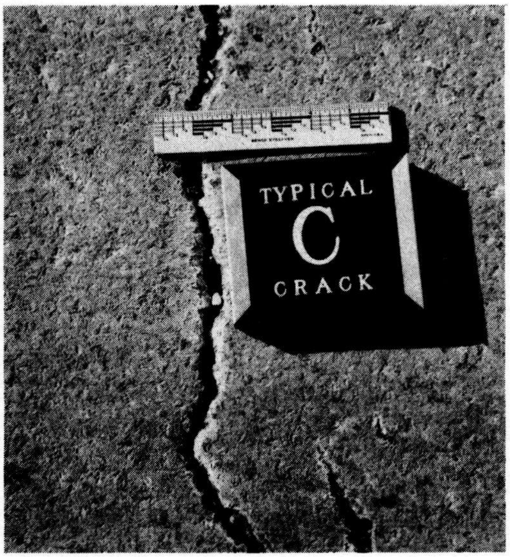

Figure 9. "C" crack-medium 1/8 to 1/4 inch.

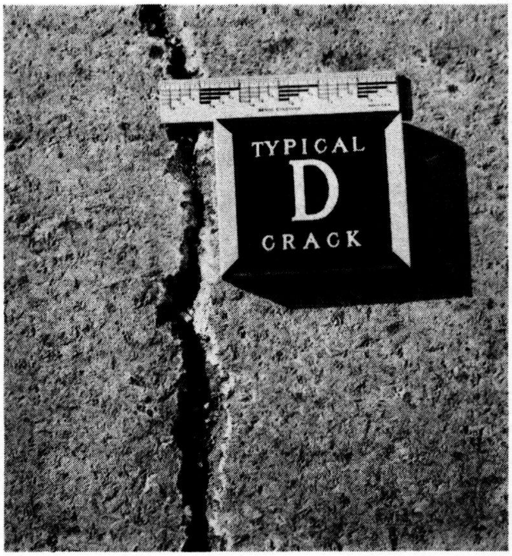

Figure 10. "D" crack-wide: 1/4 to 3/8 inch.

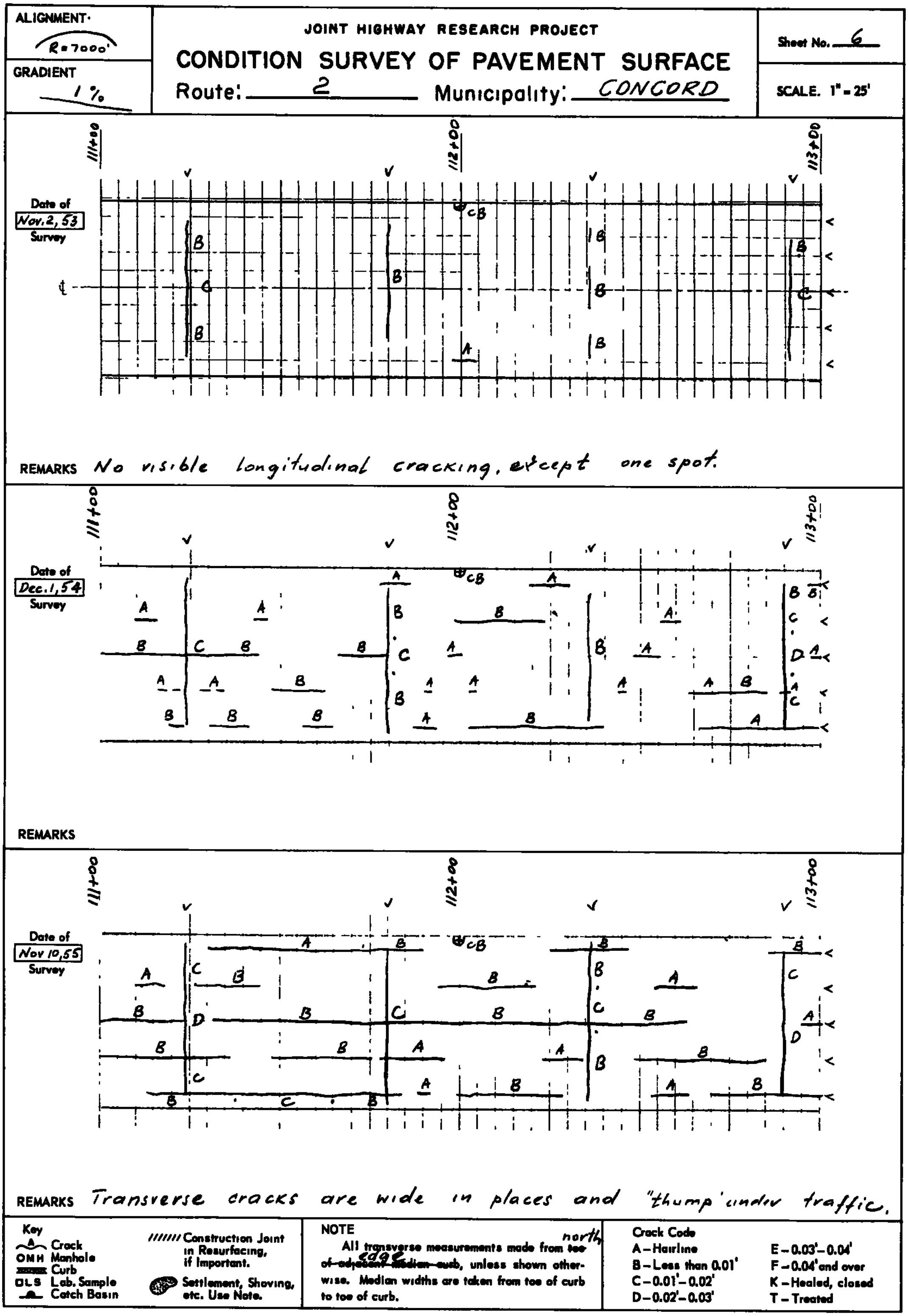

Figure 11. A typical condition survey field sheet.

TABLE 1

RESURFACING MATERIALS

Massachusetts Type I Bituminous Concrete:
Specifications for Mix:
Asphalt Cement: Penetration Grade 85-100 and 100-120 (at 77 F, 100 g five seconds)

Square Opening		Percent by Weight			
		Binder Course		Top Course	
Passing	Retained	Minimum	Maximum	Minimum	Maximum
1 inch		100			
1 inch	¾ inch	0	10		
¾ inch	½ inch	35	65		
½ inch				100	
½ inch	#4	10	25	20	60
#4	#10	5	15	10	35
#10		15	30	30	45
#10	#20	2	10	4	15
#20	#40	2	8	4	16
#40	#80	2	10	6	20
#80	#200	1	6	5	16
#200		1	6	4	9
Bit. (Sol in CS_2)		4	6	5	8

RUBBER ADDITIVES

Emulsified Rubber Asphalt - Had five percent (of the weight of final asphalt content) of rubber latex added. This compound was mixed with heated aggregate.

CRS Synthetic Rubber - Powder 100 percent passing 20 mesh sieve. It was cooked into the asphalt in the amount of 7½ percent by weight at 225 F. The material was then mixed with heated aggregate.

Natural Rubber Crumbs - Crumbs added directly into the pug-mill in the amount of approximately 7½ percent to the top course and 5¾ percent to the binder course. Percentages are based on asphalt weight.

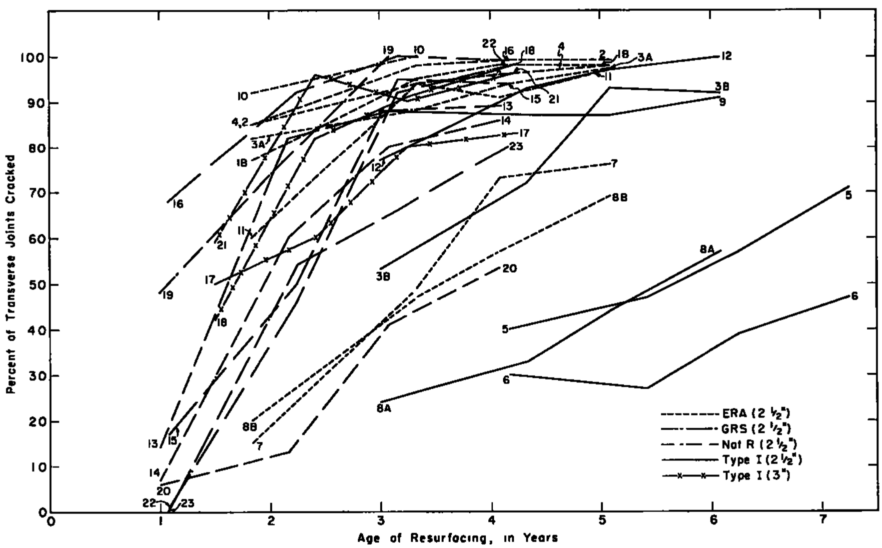

Figure 12. Transverse joint cracking by sections.

the total lengths of each type of underlying joint. These comparisons were expressed in percentage form. Data are summarized in Tables 2 and 3; these represent the condensation of 125-pages of field sheets.

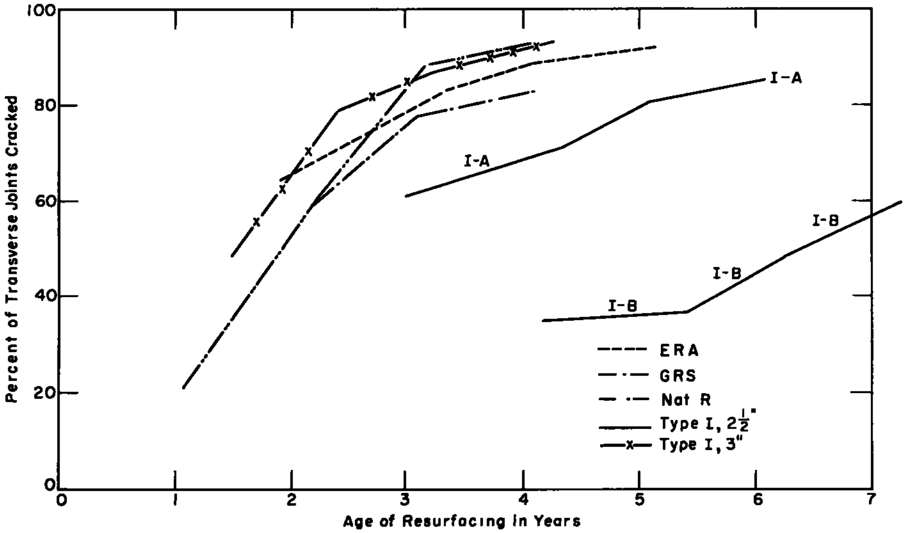

Figure 13. Transverse joint cracking, average curves.

TABLE 2

PERCENT OF TRANSVERSE AND LONGITUDINAL JOINTS CRACKED

Section Number	Resurfacing Material	AGE OF RESURFACING IN YEARS											
		2			3			4			5		
		Transverse Joints	Longitudinal Joints	Transverse plus Longitudinal Joints	Transverse Joints	Longitudinal Joints	Transverse plus Longitudinal Joints	Transverse Joints	Longitudinal Joints	Transverse plus Longitudinal Joints	Transverse Joints	Longitudinal Joints	Transverse plus Longitudinal Joints
1-B	ERA	77	0	16	95	40	51	98	56	66	98	71	76
2	ERA	85	9	25	98	56	64	99	71	77	98	76	80
3-A	ERA	82	10	24	88	34	45	94	45	55	98	57	65
4	ERA	85	4	20	94	51	59	96	72	79	98	74	79
7	ERA	15	6	8	49	13	20	73	28	37	76	39	46
8-B	ERA	20	-	-	47	27	31	57	30	36	69	40	46
10	ERA	92	5	22	100	24	39	100	36	49	100	66	73
11	ERA	60	7	17	94	16	31	91	20	34	97	42	52
13	GRS	82	-	-	88	-	-	89	-	-	-	-	-
14	GRS	60	-	-	80	-	-	86	-	-	-	-	-
19	GRS	78	25	36	100	47	58	100	58	63	-	-	-
20	GRS	13	3	5	41	8	15	54	11	20	-	-	-
15	Nat. Rub.	50	-	-	95	-	-	94	-	-	-	-	-
16	Nat. Rub.	92	-	-	100	-	-	99	-	-	-	-	-
22	Nat. Rub.	46	7	16	92	6	24	98	15	32	-	-	-
23	Nat. Rub.	54	6	16	66	6	19	80	6	22	-	-	-
3-B	Type I 2½ in.	-	-	-	53	22	29	72	43	49	93	43	55
8-A	Type I 2½ in.	-	-	-	24	34	32	33	43	41	44	40	40
9	Type I 2½ in.	-	-	-	88	16	29	87	26	38	87	35	45
12	Type I 2½ in.	-	-	-	77	23	33	93	33	44	97	48	57
5	Type I 2½ in.	-	-	-	-	-	-	40	34	35	47	32	35
6	Type I 2½ in.	-	-	-	-	-	-	30	20	22	27	56	51
17	Type I 3 in.	60	-	-	80	-	-	83	-	-	-	-	-
18	Type I 3 in.	82	5	21	91	13	29	99	24	39	-	-	-
21	Type I 3 in.	96	6	24	90	17	31	96	23	38	-	-	-

TABLE 3

PERCENT OF JOINT AND EDGE CRACKING

Section Number	Resurfacing Material	AGE OF RESURFACING IN YEARS: 2			3			4			5		
		Longitudinal Edges	Longitudinal Joints plus Edges	Longitudinal plus Transverse Joints plus Edges	Longitudinal Edges	Longitudinal Joints plus Edges	Longitudinal plus Transverse Joints plus Edges	Longitudinal Edges	Longitudinal Joints plus Edges	Longitudinal plus Transverse Joints plus Edges	Longitudinal Edges	Longitudinal Joints plus Edges	Longitudinal plus Transverse Joints plus Edges
1-B	ERA	-	0	16	-	40	51	-	56	65	-	71	76
2	ERA	-	9	25	-	56	64	-	71	77	-	76	81
3-A	ERA	-	10	24	-	34	45	-	45	55	-	57	65
4	ERA	60	26	34	75	61	64	80	75	77	88	80	81
7	ERA	84	37	34	92	44	45	99	57	59	97	62	64
8-B	ERA	83	-	-	88	51	51	94	56	56	95	62	64
10	ERA	13	8	19	57	37	45	62	47	53	82	74	76
11	ERA	29	15	21	43	27	35	59	36	42	67	52	58
13	GRS	9	9	17	24	24	30	39	39	44	-	-	-
14	GRS	5	5	9	17	17	22	25	26	31	-	-	-
19	GRS	9	17	24	13	30	38	14	36	44	-	-	-
20	GRS	3	3	4	5	7	11	7	9	15	-	-	-
15	Nat. Rub.	6	6	10	26	26	31	39	38	43	-	-	-
16	Nat Rub.	7	7	14	41	42	46	49	49	54	-	-	-
22	Nat. Rub.	9	8	12	11	8	18	25	21	29	-	-	-
23	Nat. Rub	0	3	9	1	4	11	3	4	13	-	-	-
3-B	Type I 2½ in	-	-	-	27	24	28	23	34	39	25	35	43
8-A	Type I 2½ in.	-	-	-	34	34	33	38	41	40	43	41	41
9	Type I 2½ in.	-	-	-	40	25	33	44	34	40	52	42	48
12	Type I 2½ in.	-	-	-	36	28	34	43	37	44	57	52	57
5	Type I 2½ in.	-	-	-	-	-	-	0	20	23	1	20	23
6	Type I 2½ in.	-	-	-	-	-	-	14	17	19	21	42	41
17	Type I 3 in	0	0	4	0	0	6	5	6	12	-	-	-
18	Type I 3 in	2	4	13	10	12	21	17	21	30	-	-	-
21	Type I 3 in.	31	18	27	52	35	41	54	39	46	-	-	-

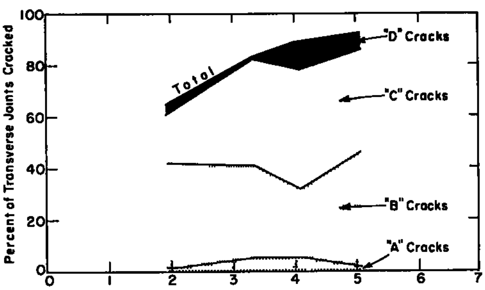

Figure 14. Transverse joint cracking, emulsified rubber asphalt sections. Average of eight sections.

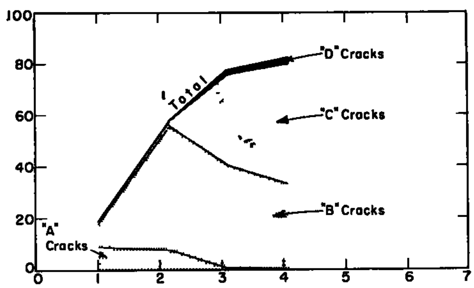

Figure 15. Transverse joint cracking, GRS rubber sections. Average of four sections.

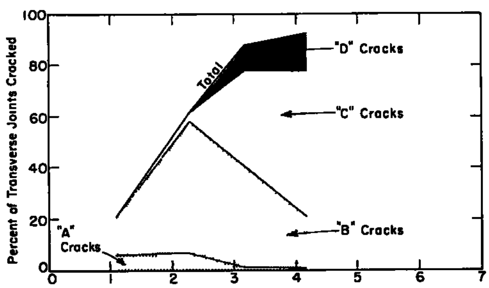

Figure 16. Transverse joint cracking, natural rubber crumb sections. Average of four sections.

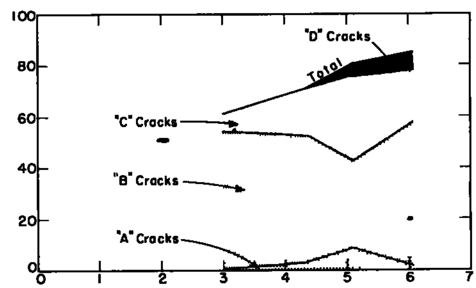

Figure 17A. Transverse joint cracking, Type I, Group A, 2½-inch sections. Average of three sections.

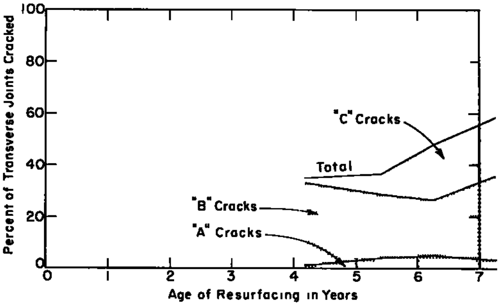

Figure 17B. Transverse joint cracking, Type I, Group B, 2½-inch sections. Average of two sections.

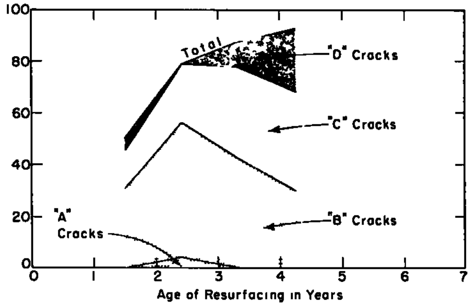

Figure 18. Transverse joint cracking, Type I, 3-inch sections. Average of three sections.

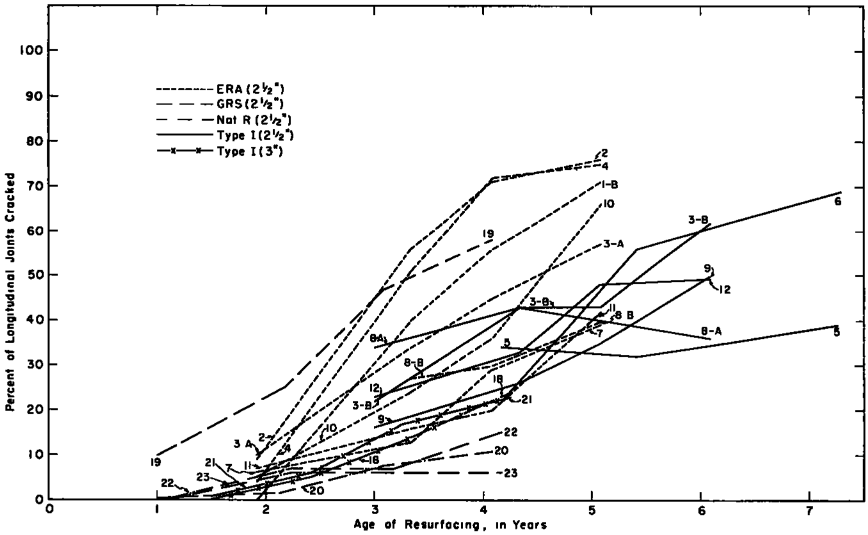

Figure 19. Longitudinal joint cracking by sections.

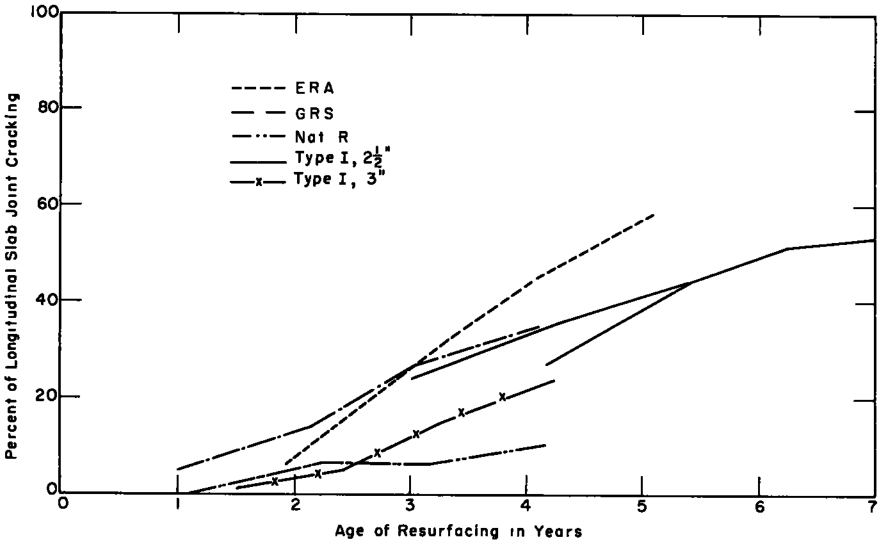

Figure 20. Longitudinal joint cracking between adjacent slabs only, all cracks average curves.

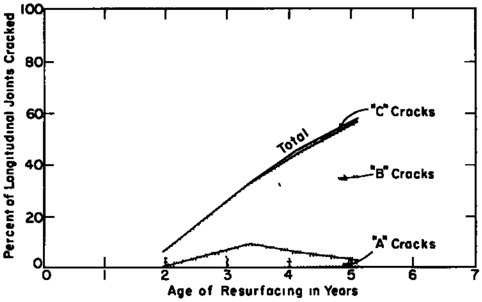

Figure 21. Longitudinal joint cracking, emulsified rubber asphalt sections. Average of eight sections.

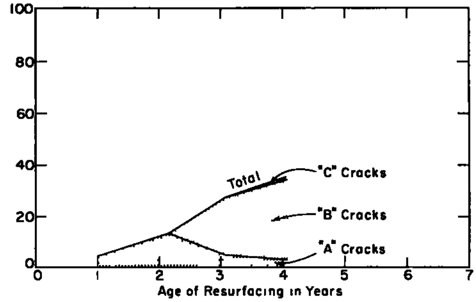

Figure 22. Longitudinal joint cracking, GRS rubber sections. Average of two sections.

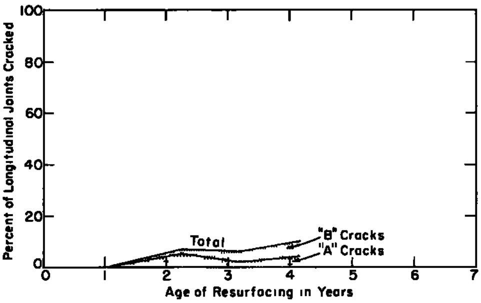

Figure 23. Longitudinal joint cracking, natural rubber crumb sections. Average of two sections.

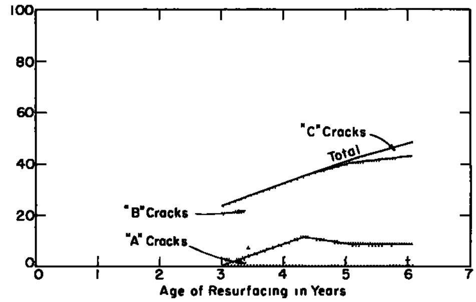

Figure 24A. Longitudinal joint cracking, Type I, Group A, 2½-inch sections. Average of four sections.

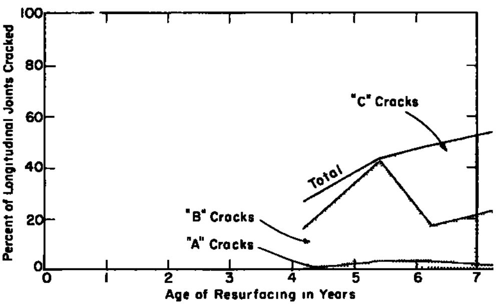

Figure 24B. Longitudinal joint cracking, Type I, Group B, 2½-inch sections. Average of two sections.

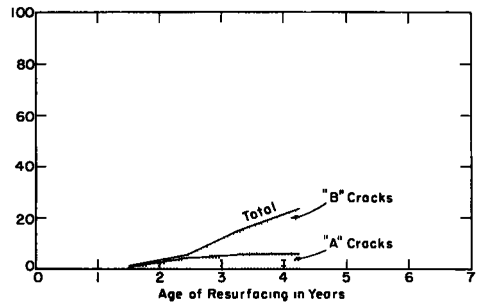

Figure 25. Longitudinal joint cracking, Type I, Group C, 3-inch sections. Average of two sections.

GRAPHICAL PRESENTATION OF DATA

The computed percentages of cracking have been plotted against time in years in a number of ways:

Transverse Cracking

(a) Transverse cracking over joints for each separate survey section (Figure 12).

(b) Average transverse cracking over joints for the combined sections of each resurfacing material (Figure 13).

(c) Average transverse cracking by width of crack (A, B, C, and D) plotted cumulatively for the combined sections of each resurfacing material (Figures 14, 15, 16, 17-A, 17-B, and 18).

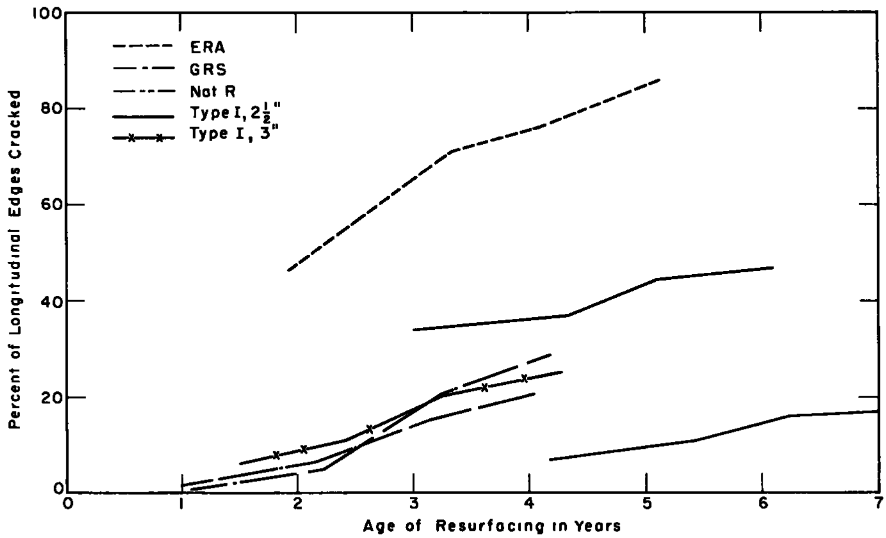

Figure 26. Longitudinal edge cracking. Average curves.

Longitudinal Cracking

(d) Longitudinal cracking over joints between adjacent slabs for each separate survey section (Figure 19).

(e) Average longitudinal cracking over joints between adjacent slabs for the combined sections of each resurfacing material (Figure 20).

(f) Average longitudinal cracking over joints between adjacent slabs by width of crack (A, B, C, and D) plotted cumulatively for the combined sections of each resurfacing material (Figures 21, 22, 23, 24-A, 24-B, and 25).

(g) Average longitudinal cracking over slab edges for the combined sections of each resurfacing material (Figure 26).

(h) Average longitudinal cracking over joints between adjacent slabs and over slab edges for the combined sections of each resurfacing material (Figure 27).

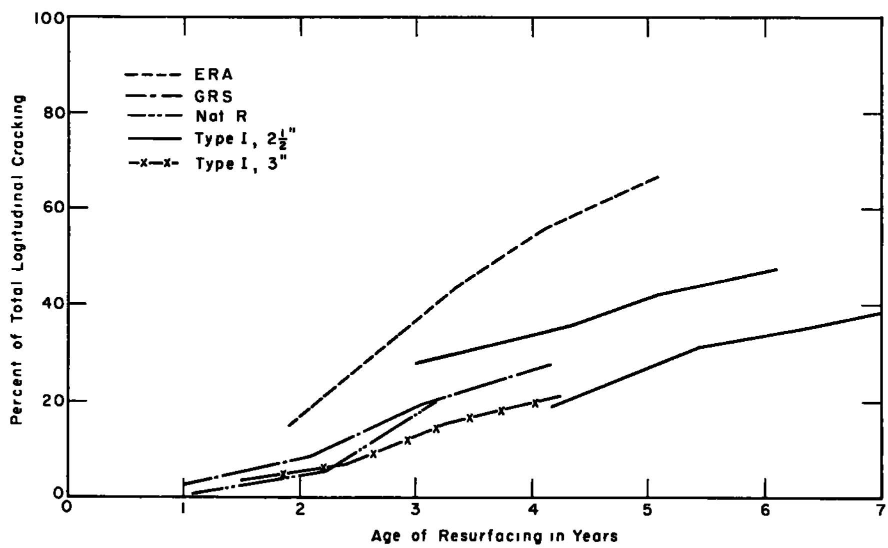

Figure 27. Total longitudinal cracking. Average curves.

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On page 43, the captions of Figures 28 and 29 have been transposed. The upper drawing actually is Figure 28; the lower, Figure 29.

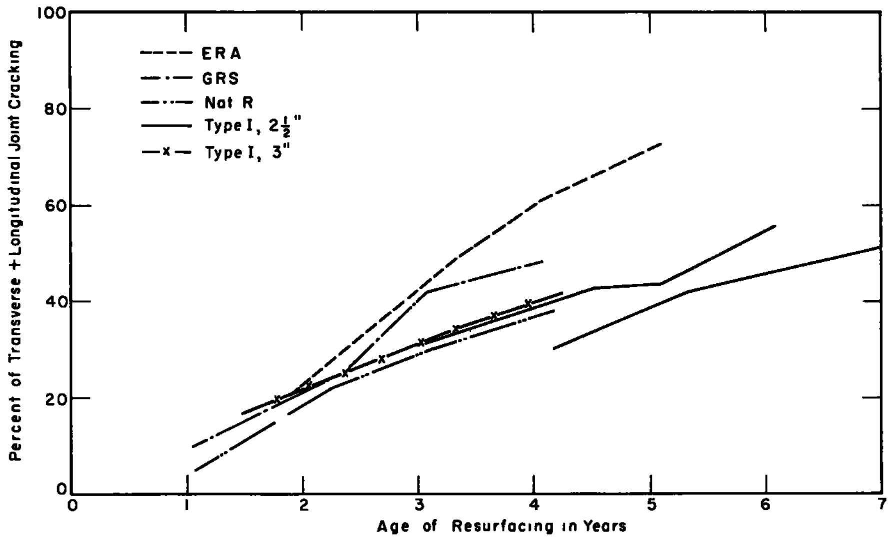

Figure 29. Total cracking, transverse joints + longitudinal joints + edges average curves.

Transverse Plus Longitudinal Cracking

(i) Average total longitudinal and transverse cracking over joints between adjacent slabs for the combined sections of each resurfacing material (no slab edge cracks included) (Figure 28).

(j) Average total longitudinal and transverse cracking both over joints between adjacent slabs and over slab edges for the combined sections of each resurfacing material (Figure 29).

DISCUSSION OF RESULTS

Transverse Cracking

The extent of cracking over transverse joints is plotted against age for each section individually in Figure 12. There is a wide variation in the resulting curves. Most of

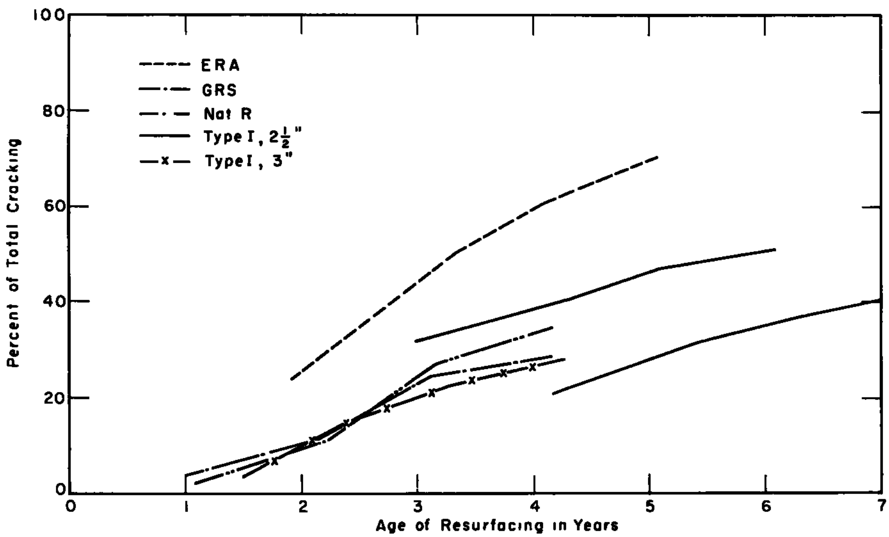

Figure 28. Total transverse + longitudinal joint cracking (no edges included) average curves.

them, however, fall within a well defined band. The majority of sections were 80 percent reflection cracked within two years, nearly all were cracked that much in three years, and many were approaching 100 percent by the end of five years. No striking difference in trend was found among surfacings with or without rubber additives, except that three sections of regular Type I mix showed a slower rate of crack development. The better performance of these Type I sections might be due to superior subgrade although this is not obvious from field observation or noted in the construction records. Possibly the mix had some unusual characteristics which caused it to be more crack resistant.

The trends for each type of resurfacing are grouped in Figure 13. The comparison again emphasized the slower rate of cracking in the Type I mixes.

The percentage of transverse cracking by width of crack is shown plotted cumulatively for each type of mix in Figures 14 through 18. In these comparisons the Type I sections 2½ inches thick were separated into two groups because of their differences in age. Group A was three to six years old during the period of condition surveys, and Group B was four to seven years old. The Type I mixes 3-inches thick were one to four years old.

The percentage of "A" cracks is small for all types of materials and decreases with age as "A" cracks widen to "B" class. Also "B" cracks tend to change to "C", and some "C" cracks to "D", especially as the total cracking approaches 100 percent. Some types of surfaces appear to be developing wide cracks more rapidly than others, but the differences are not marked.

Longitudinal Cracking

The percentages of longitudinal cracking with time over the total of joints and slab edges are shown graphically for each section individually in Figure 19. The results are quite variable, but the general trend is an increase of cracking with age. The rate of increase is less than that observed for transverse cracks. After four years most of the sections had cracked less than 50 percent, the median being about 35 percent.

The percentage of cracking at different ages over longitudinal joints (between adjacent slabs) is plotted by groups of sections of each type of resurfacing in Figure 20. The trends show a faster rate of cracking for two of the mixes with rubber additive than for regular Type I. The natural rubber, however, shows a very slow rate of longitudinal crack development. This trend is the opposite of that found for the same material over transverse joints. This inconsistency may be traceable to some unknown characteristic of the underlying pavement which restricts movement at longitudinal joints.

Widening with age of cracks over longitudinal joints is shown for each type of resurfacing in Figures 21 through 25. Widths are much less than for transverse cracks. In the first four or five years relatively few "C" cracks developed and no "D" widths.

The trends in cracking over edges (Figure 26) were similar to those for cracking over longitudinal joints, except that the ERA rubber additive mix developed a much higher rate of cracking than did the other types. This edge cracking may have been caused by unusual edge settlement in the sections surveyed. A similar trend is found when joint and edge cracking are combined (Figure 27).

Transverse and Longitudinal Cracking

Transverse and longitudinal joint cracking trends are combined in Figure 28. In general the performances of the regular Type I sections appear to be somewhat better than those with rubber additives.

Transverse Crack Extensions

Five sections on Route 28 had 10-foot bituminous macadam asphalt center lanes under the resurfacing. Transverse reflection cracking extended entirely across this lane at 24 percent of the joints in the adjacent concrete. At the other 76 percent of the joints crack extensions averaged 50 percent of the center width.

Surface Condition Other Than Over Joints and Edges

The surface condition of the bituminous concrete in areas between joints and edges is generally good. No significant difference was detected between sections with or without additives.

CONCLUSIONS

1. For bituminous resurfacings over concrete pavements, as constructed in Massachusetts, either with normal Type I mix or with 4 to 6 percent rubber additives, transverse cracking usually develops over 80 percent of total joint length after four years have elapsed, and approaches 90 percent in most cases at the end of six years.

2. For the same resurfacings total longitudinal cracking over joints between concrete slabs amounts to about 40 percent of joint length after four years, or about one-half the extent of transverse joint cracking.

3. The width of transverse cracks gradually increases with time until, for most of the surfaces under observation, over 50 percent of the cracked length is class "C" or "D" width after a few years; i.e., between ⅛- and ½-inches wide.

4. The majority of longitudinal cracks over joints and edges are of "B" width, i.e., ⅛-inch or less.

5. In the resurfacings surveyed no important differences in length and width of reflection cracking were found between regular Type I mixes and those with the added types and amounts of rubber.

6. Considerable variation occurred in rate and width of cracking between sections resurfaced with similar materials. The condition survey sections were chosen to be as nearly comparable as possible by surface inspection. However, results of four years of surveys suggest that certain variable factors are present which cannot be effectively evaluated.

ACKNOWLEDGMENTS

The research described in this paper was part of the 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.

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On the M.I.T. staff Professor A.J. Bone and L.W. Crump, Research Engineer, started the research described in this paper. S.M. Breuning and K. Weiner, Research Assistants, contributed many helpful suggestions.

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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.