

Five-Year Performance of Welded Wire Fabric in Bituminous Resurfacing

EGONS TONS, Assistant Professor of Transportation Engineering, and
ALEXANDER J. BONE, Associate Professor of Transportation Engineering, M. I. T.; and
VINCENT J. ROGGEVEEN, Associate Professor of Civil Engineering and Transportation, Stanford University

The primary objective of this paper is to report on placement and performance of reinforced bituminous concrete resurfacing over old portland cement concrete roadway.

In 1955 two sections of road (in Massachusetts) totaling three miles in length were resurfaced with a 3-in. bituminous concrete reinforced with various styles of welded wire fabric. The main purpose of this reinforcement was to prevent reflection cracks caused by underlying slab movements.

In one of the test roads the resurfacing was reinforced with strips placed above the slab joints only, whereas the other had various styles of continuous reinforcement extending into the shoulders. Altogether 25 test sections were installed with comparable unreinforced control sections.

The method of placing the reinforcement was simple and did not cause much difficulties.

After five years under traffic and weathering all reinforced test sections had lower cracking indexes than comparable controls. The best performance was by 3 x 6, $\frac{10}{10}$ welded wire fabric placed in continuous rolls where transverse cracking was about one-eighth of that found in the control, and longitudinal cracking was negligible.

THE CAUSES of reflection cracking have been described and discussed in numerous publications and it is evident that the amount of cracking will depend on many different factors. In this paper the emphasis is on reflection cracking as it has been observed in Massachusetts.

STRAINS IN RESURFACING CAUSED BY UNDERLYING SLAB MOVEMENTS

Many miles of old portland cement concrete slabs which have been covered with a 2- to 3-in. bituminous resurfacing, are about 8 in. thick, 10 ft wide and 57 ft long. They have been placed on a 12-in. gravel base with about 0.13 percent of longitudinal reinforcement. These roads were constructed in the thirties using only expansion joints with four 1-in. load transfer dowels for each 10-ft joint.

Horizontal Joint Opening

The amount of horizontal joint opening was studied in several Massachusetts locations over a period of years. The measurements show that about 80 percent of the transverse expansion joints open 0.05 in. or more during a one-year cycle. The largest joint opening measured was 0.18 in. with a maximum daily variation of about 0.04 in. Laboratory strain tests have shown that a 4-in. long bituminous concrete

specimen can be strained about 0.04 to 0.05 in. before it breaks (12). A comparison between this obtained strain for the Massachusetts mix and the measured joint opening on a road indicates that due to horizontal strains alone at least 80 percent of the resurfaced transverse joints will have reflection cracks above them within a relatively short period.

Vertical Differential Movements

To estimate the vertical differential movements of the slabs numerous field measurements were made using a truck and a deflection gage. The maximum relative deflection at a joint was 0.09 in. with about 50 percent of the measurements being 0.005 in. or less. Thus, it appears that the vertical joint deflections are relatively small compared to the horizontal movements. Laboratory measurements indicate that a crack might not appear in the surfacings if such low deflections are applied without any strains due to horizontal slab contraction. These studies further show that the differential vertical movement due to traffic load causes a flexural distortion in the resurfacing rather than shear deformation (11).

Combined Effects

Although field observations and laboratory measurements show that the main reason for reflection cracking in Massachusetts is the horizontal joint opening or tensional stress, it often can be the combined effects of both horizontal joint opening and vertical deflection movements which cause the cracking. Damaging axial and flexural tension in the resurfacing at a joint affect not only the immediate area above the joint, but also extend some distance on each side. Once a crack has appeared it has a tendency to deteriorate and widen.

PURPOSE OF STUDY

The main objective of this study was to test on the road the effectiveness of various welded wire fabric types as a reinforcement in bituminous concrete resurfacing against reflection cracking (in Massachusetts). The second purpose was to compare the field behavior of welded wire fabric reinforcement with data obtained from tests in the laboratory.

PREVIOUS INSTALLATIONS OF WELDED WIRE FABRIC REINFORCEMENT

The Walpole and Raynham Test Roads described in this paper were built in 1955. Before that, numerous experimental wire fabric installations had been placed in service and various results were obtained with the oldest dating back as far as 1945. These field installations were placed without any engineering calculations or experience, regardless of whether the wire fabric reinforcement was used for airports, highways, city streets, etc. The main emphasis in these experiments was on transverse joint reinforcement using both strip and continuous welded wire fabric.

TEST ROADS IN MASSACHUSETTS

The planning and execution of a test road involves cooperation and interest by numerous agencies. The interest of the Commonwealth of Massachusetts in reflection crack prevention was the principal reason for making road tests in Massachusetts. The personnel of the state-supported Joint Highway Research Project of the Massachusetts Institute of Technology and the Department of Public Works had been working on the reflection cracking problem for several years and had accumulated a considerable amount of data which were useful in planning actual welded wire fabric reinforcement test installations. Another reason for having the test roads in Massachusetts was the climatic conditions which are quite severe and to a degree typical of the northern states.

PLANNING SCOPE OF PROJECT

Planning and building a field test calls for consideration of many variables. Only those who have participated in an actual execution of a test road can fully appreciate the complexity of such an undertaking. The condition of the old portland cement concrete roadway and the types and sizes of wire fabric reinforcement to be used in the resurfacing were the two major variables. Although the type and size of reinforcement could be selected, the condition of the old roadway was much more difficult to control.

Desired Variables and Length of Test Road

During the preliminary planning it was assumed that the test road itself would be uniform for all test sections. Therefore, the major variables were reduced to the type of wire fabric and its placement. The following major factors were discussed and considered: (a) wire size, (b) transverse wire spacing, (c) longitudinal wire spacing, (d) strip reinforcement versus continuous reinforcement, (e) position of the wire fabric in the resurfacing, and (f) ways of holding the wire fabric down.

If all these variables were to be included in this research the total number of test sections would have exceeded 10,000. As this was a practical impossibility a small number of tests were agreed on which are described later in this paper.

Number of Transverse Joints Needed to Obtain Meaningful Data

To compare two types of wire fabric the test conditions have to be similar. This is often not possible where a large number of test sections is involved. The slight variations in a test road of appreciable length can affect the results and prohibit a direct comparison between a section at one end of the test with that at the other. Therefore, it was decided that control sections would be placed between the test sections and the performance of the various wire fabrics would be compared directly with the adjacent controls. To decide on the minimum number of test joints, condition survey data from numerous field installations over the past five years were studied. It was found that at least 12 transverse joints would be necessary to keep a 5-yr cracking index within 10 percent, between two adjacent 12-joint test sections, 95 percent of the time. It was also anticipated that some joints would have to be eliminated due to construction faults and inherent irregularities in the portland cement concrete base. Therefore, the final number specified was 16 to 20 joints for each test and control section.

Practical Limitations

The amount of road surface available as well as budgetary limitations finally led to choice of 25 sections, excluding controls.

After the number of test sections was decided on a special committee (consisting of wire fabric manufacturers and the staff of the Joint Highway Research Project at Massachusetts Institute of Technology) listed the types of wire fabric that were to be used. The practical limitations favored the use of standard size wire fabrics rather than special fabrications. An attempt was made to incorporate various wire sizes in tests with the 10-gage wire dominating because it is easy to install in a 3-in. resurfacing.

Types of Wire Fabric Chosen

Besides the common spacings (4 by 4 in., 6 by 3 in., and 3 by 6 in.) for the 10-gage wire, other dimensions and wire sizes were also used. The largest wire was 6 gage because the committee felt that anything stiffer than that would not be compatible with the relatively thin flexible overlay. The smallest wire was 14 gage. One section of the test road in which continuous reinforcement was planned contained wire fabric in rolls. In those installations the longitudinal wire was 10 gage or thinner because it is too difficult to flatten out a roll when stiffer wire was present.

Size of Mats and Types of Reinforcement Chosen

As mentioned before, the most critical points where cracking is usually more severe

are the transverse joints. Therefore, attempts have been made in the past to place a strip of reinforcement right above the joints to prevent a reflection crack. To protect the longitudinal joints from crack appearance, similar strip reinforcement would be necessary also in these locations. This led to the conclusion that three major types of reinforcement should be tried: (a) strip reinforcement over transverse joints only, (b) strip reinforcement over longitudinal joints, and (c) a continuous reinforcement which covers the whole portland cement concrete roadway and extends a short distance beyond the longitudinal edges of the slabs. Small test installations in the past using strip reinforcement have indicated that the strip width of 3 to 4 ft is not always enough to curb reflection cracking (3, 4). If the strip is narrow there is a tendency to get a crack at the edge of the reinforcement. Therefore, about 7-ft wide reinforcement was adapted for the transverse joints. A few installations using 5- and 10-ft wide strip reinforcement were also tried.

The continuous reinforcement had most of the fabric in rolls. The length of the roll was 57 ft or the same length as the underlying slabs. This was chosen to have the lapping of the rolls far away from the joints at the center of the slabs.

In three test sections a continuous sheet of reinforcement was planned using 18-ft long wire fabric.

TEST ROAD SPECIFICATIONS

After deciding on the number of test sections and the types of wire fabric to be used a search for a test road was undertaken which would fit the following requirements:

1. The test section should contain at least two adjacent lanes of old portland cement concrete.
2. The horizontal curves in the test road should not be less than 600-ft radius and the grades should be less than 2 percent.
3. The test road should have a uniform subgrade.
4. The underlying concrete slabs should not have longitudinal reinforcement failure.
5. The slabs should exhibit similar crack frequency characteristics.
6. Control sections of identical length should be spaced in between the test section and at least 12 transverse joints or 120 ft of joint should be usable in each test.
7. The test sections should carry similar traffic.

FINAL SELECTION OF TEST SITES

To place the 25 test sections with appropriate controls, about three miles of two-lane road were required. As it was not possible to find such a length of road under uniform conditions in one location, two separate test roads were selected. In this paper they are referred to as Raynham and Walpole Test Roads. At the Raynham Test Road, strip reinforcement was used and at the Walpole Test Road continuous wire fabric reinforcement (see Figs. 1 and 2 for wire fabric styles and sizes).

Raynham Test Road

The Raynham Test Road consisted of a three-lane reinforced cement concrete pavement 8 in. thick, placed on a 12-in. gravel base. It had bituminous macadam shoulders 3 to 5 ft wide, on each side.

The original portland cement concrete was in a good condition structurally. The majority of the 57-ft slabs had but one transverse crack with a very small percentage having two or more. The surface was scaled in places and many bituminous skin patches had been placed. The joints were about 1 in. wide and had worn considerably causing traffic to thump, but there was no evidence of major settlements.

The Raynham installations consisted of two types of strip reinforcement tests: (a) reinforcing of transverse joints with welded wire fabric sheets, and (b) reinforcing of longitudinal joints with wire fabric sheets (Table 1).

Walpole Test Road

The Walpole Test Road was a two-lane reinforced concrete pavement 8 in. thick,

placed on a 12-in. gravel base. It had bituminous macadam shoulders 3 ft wide on each side. The concrete lanes were 10 ft wide, the slabs averaged 57 ft in length. The resurfacing extended over both shoulders.

The original concrete was in fair structural condition, although the slabs averaged two to three transverse cracks each. The surface was scaled and contained a few bituminous skin patches. The rough-riding transverse joints were about 1 in. wide but did not show appreciable settlement.

The Walpole installation consisted of two types of continuous reinforcing tests: (a) continuous reinforcing of entire slabs using wire fabric sheets, and (b) continuous reinforcing using 57-ft long rolls (Table 2).

Comparison of Raynham and Walpole Sites

Even though the two test roads are quite similar as far as the underlying portland cement concrete is concerned there are some differences that should be pointed out. One is the amount of transverse cracking. Whereas in Raynham only one or two transverse cracks were found on each slab, Walpole had two or three cracks per slab. This was one of the reasons why a continuous reinforcement was chosen for the Walpole Test road. On the other hand, it must be emphasized that intermediate cracking between joints affects the amount of horizontal joint opening and closing. Therefore this should be kept in mind when making comparisons between Raynham and Walpole results.

The amount of traffic on both sites was medium heavy but in Raynham it was distributed over three lanes whereas in Walpole, due to the relatively narrow width, the traffic is concentrated in one lane in each direction.

PRELIMINARY WORK ON TEST SITES

Before the actual surfacing was started repairs were made to old road surface. The transverse joints still contained bituminous sealer and they were untouched. In some cases, where scaling of the slabs was extensive, new patches were applied. Some work was also performed on the shoulders and new side drains were installed where necessary.

TRANSPORTING AND DISTRIBUTING WIRE FABRIC REINFORCEMENT

The wire fabric reinforcement was received from the manufacturers already cut to size. In Raynham the fabric was carried to the site on a flat-bed truck and distributed beside the test sections of roadway. It was then placed over the joints immediately

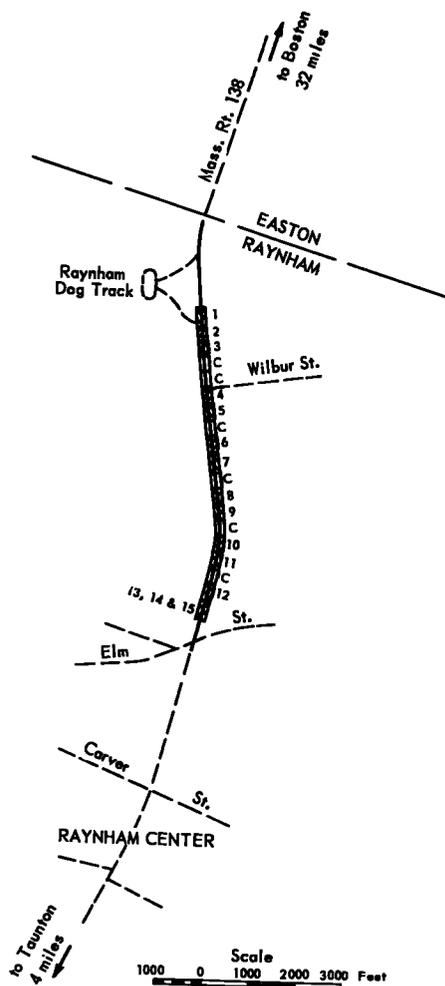


Figure 1. Location map of test road, Raynham, Mass. Numbers indicate test sections, C indicates control sections.

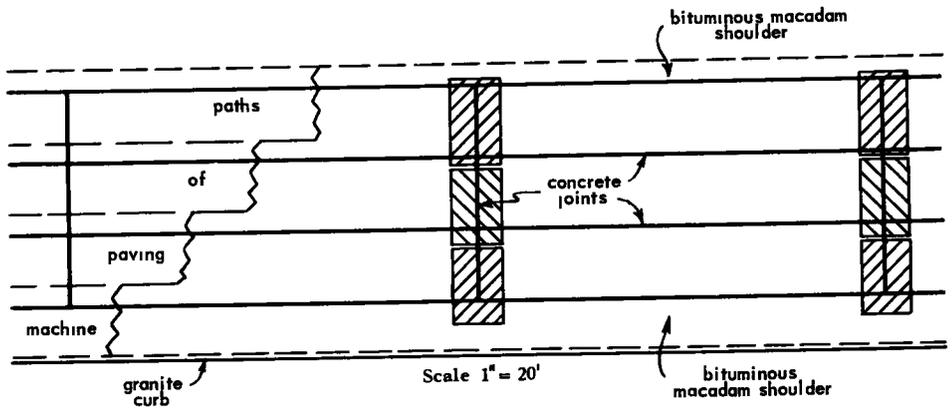


Figure 2. Placement of fabric on road. Transverse joint reinforcing with sheet fabric.

TABLE 1
WELDED WIRE FABRIC (SHEET REINFORCING) USED AT RAYNHAM TEST SITE

Test No.	Total Sheets	Fabric Style	Spacing of Wire in Inches		Gage of Wire		Outside Dimensions of Sheets in Place	
			Transverse Dimension	Longitudinal Dimension	Transverse Wire	Longitudinal Wire	Transverse Dimension	Longitudinal Dimension
(a) Transverse Concrete Joints								
1	18	3×6 10/6	3	6	6	10	11	6'6"
2	18	6×6 10/10	6	6	10	10	11'	5'
3	18	6×6 10/10	6	6	10	10	11'	6'6"
4	18	3×6 10/6	3	6	6	10	11'	5'
5	18	6×3 10/10	6	3	10	10	11'	6'6"
6	18	3×6 10/10	3	6	10	10	11'	7'6"
7	18	4×8 10/6	4	8	6	10	11'	6'6"
8	18	4×4 10/10	4	4	10	10	11'	6'6"
10	18	6×6 8/8	6	6	8	8	11'	7'6"
11	18	12×6 8/6	12	6	6	8	11'	7'6"
12	36	12×6 8/6	12	6	6	8	5'6"	10'
(b) Longitudinal Concrete Joints								
Test No.	Total Sheets	Fabric Style	Spacing of Wire in Inches		Gage of Wire		Outside Dimensions of Sheets in Place	
			Transverse Dimension	Longitudinal Dimension	Transverse Wire	Longitudinal Wire	Transverse Dimension	Longitudinal Dimension
13	24	4×4 10/10	4	4	10	10	5'	12'
14	24	6×3 10/10	6	3	10	10	5'	12'
15	24	6×6 8/8	6	6	8	8	5'	12'

TABLE 2
WELDED WIRE FABRIC (CONTINUOUS REINFORCING) USED
AT WALPOLE TEST SITE

Test No.	Total Sheets	Fabric Style	Spacing of Wire in Inches		Gage of Wire		Outside Dimensions of Sheets in Place	
			Transverse Dimension	Longitudinal Dimension	Transverse Wire	Longitudinal Wire	Transverse Dimension	Longitudinal Dimension
(a) Sheet Fabric								
16	96	6×12 8/6	6	12	6	8	6'	18'
	32	6×12 8/6	6	12	6	8	5'	18'
17	96	6×6 8/8	6	6	8	8	6'	18'
	32	6×6 8/8	6	6	8	8	5'	18'
18	96	3×6 10/6	3	6	6	10	6'	18'
	32	3×6 10/6	3	6	6	10	5'	18'
(b) Roll Fabric								
Test No.	Total Rolls	Fabric Style	Spacing of Wire in Inches		Gage of Wire		Outside Dimensions of Rolls in Place	
			Transverse Dimension	Longitudinal Dimension	Transverse Wire	Longitudinal Wire	Transverse Dimension	Longitudinal Dimension
19	30	6×3 10/10 ⁽¹⁾	6	3	6	10	6'	57'
	10	6×3 10/10	6	3	6	10	5'	57'
20	30	3×6 10/10	3	6	10	10	6'	57'
	10	3×6 10/10	3	6	10	10	5'	57'
21	30	4×4 10/10	4	4	10	10	6'	57'
	10	4×4 10/10	4	4	10	10	5'	57'
23	30	6×3 10/10	6	3	10	10	6'	57'
	10	6×3 10/10	6	3	10	10	5'	57'
24	30	3×6 10/10 ⁽¹⁾	3	6	10	10	6'	57'
	10	3×6 10/10 ⁽¹⁾	3	6	10	10	5'	57'
25	Test 25 placed with total resurfacing thickness increased from normal 3" to 3 1/2", without reinforcing.							
26	30	3×3 12/12 ⁽²⁾	3	3	12	12	6'	57'
	10	3×3 12/12 ⁽²⁾	3	3	12	12	5'	57'
27	30	2×2 14/14 ⁽²⁾	2	2	14	14	6'	57'
	10	2×2 14/14 ⁽²⁾	2	2	14	14	5'	57'

Note (1) - Placed with Transverse wire on top

Note (2) - Galvanized wire

front of the trucks delivering the mix to the paving machine. Similarly, the Walpole reinforcement was transported to the site and distributed along the roadside.

PLACING OF REINFORCEMENT

In both Raynham and Walpole tests the wire fabric was placed directly on the portland cement concrete with longitudinal wires up. There were a few installations where the transverse wires were up (Tables 1 and 2).

In Raynham the wire fabric strips were nailed to the pavement using metal clips and a Remington stud driver (Fig. 10). About four to six clips were placed along the side of the fabric nearest the paver thus preventing the wire reinforcement from being caught in the machine. The transverse sheets of fabric were laid with little effort. Occasionally where the crown of the road was lowered by reducing the usual 1³/₄-in. thickness of the binder, an additional one or two studs and clips were used. No sleds or other hold-down devices were needed. The tracks of the Barber-Greene finisher did not cause any disturbance of the fabric except where an attempt was made to pave over strips which had not been fastened down.

On the Walpole Test Road the rolls were first flattened out to their full length of about 57 ft (Figs. 12 and 13). The ends were overlapped in the middle of the concrete slabs by about 1¹/₂ of the transverse wire spacing. However, the curl of the rolls, when rolled out, caused the lap to have a tendency to rise up off the concrete. This was remedied by increasing the overlap to 18 in. and fastening both ends of the rolled out fabric together with hog rings. Thus a lane of smooth reinforcement was obtained.

In the three sections where continuous sheet reinforcement was laid, the sheets were overlapped about 1¹/₂ of the transverse spacing and tied together with hog rings. One or two rings were also occasionally used to fasten the longitudinal edges of adjacent sheets together whenever they showed a tendency to curl (see Figs. 1 to 14 for laying plans and operations).

PLACING BINDER COURSE ON TOP OF FABRIC

Massachusetts Type I binder course mix with 7/8-in. maximum size aggregate was used to cover the fabric with a 1³/₄-in. layer. Specifications for this mix are given in the Appendix. For both test roads a Barber-Greene finisher was used. The work was done under contract and, therefore, the test installations were actually laid with the same equipment and construction techniques as on the usual resurfacing job.

On the Walpole Test Road the fabric was held down by a sled made of railroad rails and attached to the Barber-Greene paving machine (Fig. 14). This sled was dragged ahead by the front frame of the finisher with the individual rails trailing behind and riding directly over the fabric for their length. One rail of the sled was always kept on the edge of the fabric to prevent it from curling up.

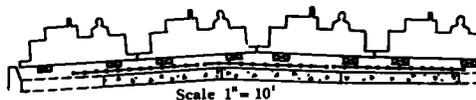


Figure 3. Cross-section showing positions of paving machine passing over fabric

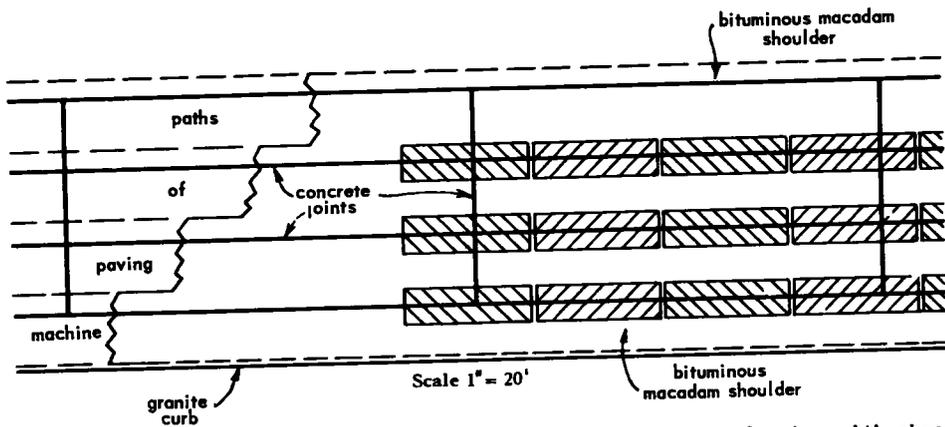


Figure 4. Placement of fabric on road. Longitudinal joint reinforcing with sheet fabric.

During the paving operations traffic was restricted to one side of the road. As soon as the binder course was completed in one lane, traffic was switched to the other side while the remaining bare area was covered with fabric and paved.

AREAS WHERE CAUTION IS ADVISABLE

During the paving operations in Raynham very few difficulties were encountered in placing the binder course over welded wire fabric reinforcement and 96 percent of placement was completed without any incident. In the Walpole Test Road several small difficulties developed with the continuous reinforcement. In the continuous roll section sometimes a wave was created by the paving machine as it moved forward. This wave usually extended itself at the next lap at the middle of the slab but sometimes it curled up and became caught in the machine. In some locations where the binder course happened to be quite thin due to surface irregularities of the old portland cement concrete, the screed caused a relatively high frictional force and pushed a localized wave of the fabric ahead of it. This resulted in distortions of the reinforcement and cracking in the binder behind the finisher. Some wire sections had to be cut out for this reason. There were also a few difficulties due to the curl of the rolls which sometimes caused it to rise under the binder immediately behind the paver at the lap joints. Under roller the binder either cracked or became springy over the lap, and the ends of the rolls tended to protrude through the mix. This was remedied to a great extent by increasing the length of the lap. There were instances where the mix had been spilled on the pavement before the reinforcement was laid, thus creating a high spot and causing the paver to catch the fabric as it passed over it.

In the Walpole Test Road the top course was not placed immediately after the binder application and the binder course was subjected to considerable traffic use. As a result after about 24 hours a few springy spots developed in some sections, each about

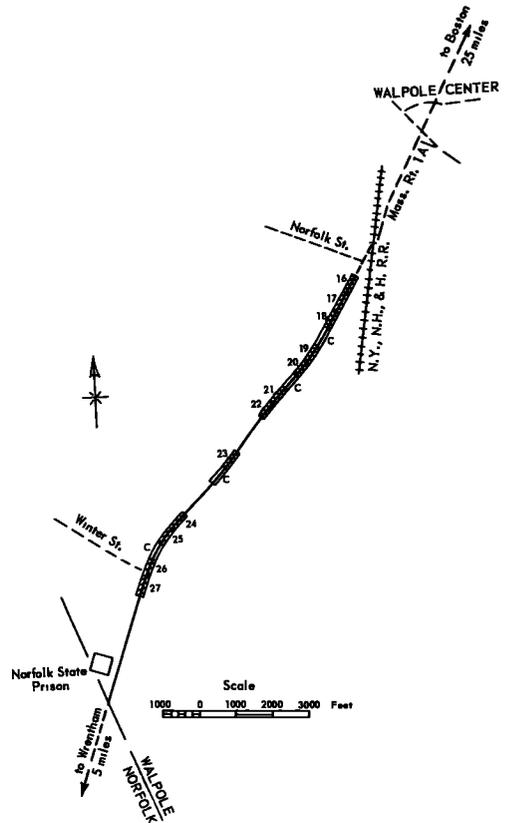


Figure 5. Location map of test road, Walpole, Mass. Numbers indicate test sections, C indicates control sections.

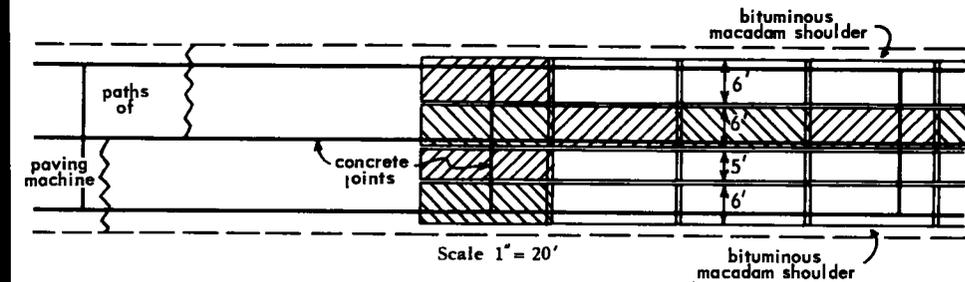


Figure 6. Placement of fabric on road. Continuous reinforcing with sheet fabric.

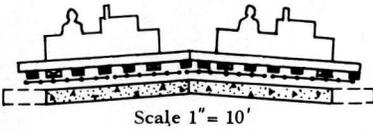


Figure 7. Cross-section showing positions of paving machine passing over fabric.

12 to 18 in. in diameter. The areas in which this developed were over fabric which had curled up in the mix where the bituminous concrete binder course was relatively thin. In these springy spots the binder was removed, the wire cut out and the area patched before the top mix was placed. These defects have not shown up in the top surface so far.

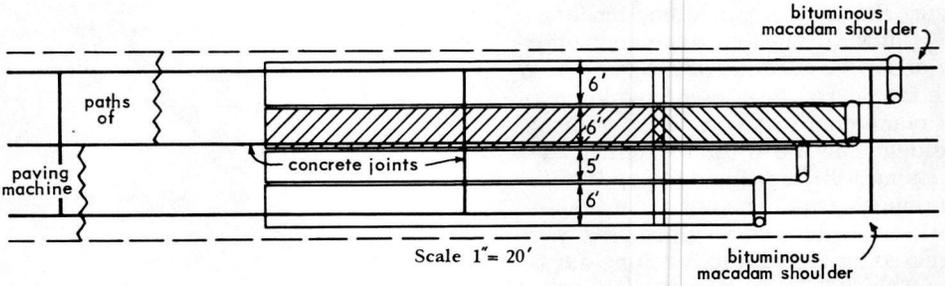


Figure 8. Placement of fabric on road. Continuous reinforcing with roll fabric.

PLACING TOP COURSE

The mix used to cover the binder course was Massachusetts Type I top mix, 1 1/4 in thick. This was laid by a Barber-Greene finisher without any special precautions or provisions being required. The mix specifications are given in the Appendix.

CONDITION SURVEYS AND INSPECTION

The paving operations on the Raynham test site began on September 28, 1955, and were completed on October 18, 1955. The



Figure 9. Typical installation of transverse reinforcing over joint.



Figure 10. Remington stud driver used to hold down fabric sheets.



Figure 11. Typical installation of longitudinal reinforcing over joint.



Figure 12. Placing continuous sheet reinforcing.



Figure 13. Placing continuous roll reinforcing.

Walpole test was started on October 26 and completed on November 17, 1955.

The first inspection of the test roads was made in the fall of 1955. From that time on two major condition surveys were made each year: the first one during the winter months, preferably January or February, and the second one during the summer months. The surveys were done according to an established method by plotting the crack lengths and widths on forms specially prepared for this purpose. These records were then analyzed and the various types of cracks classified according to the width and type.

Several additional inspections were made using photographic and visual methods. The development of defects and cracking in the various sections has been recorded from survey data and is presented in subsequent paragraphs.

CRACK DEVELOPMENT WITH TIME

It has been observed during the past 10 years that under Massachusetts conditions reflection crack development in a Type I mix is usually delayed for about a year after placing the resurfacing (8). This holds true also for the Raynham and Walpole Test pads. Only few cracks were observed on the Walpole Test Road during the winter of 1956 and the first cracks were observed on the Raynham test in September 1956. The initial large-scale condition survey in February 1957, revealed considerable cracking because the winter was severe and the crack development was unusual as compared to past experience. During this second winter more than 50 percent of the transverse joints in the control sections had cracks, whereas other test sections showed lower percentages or none at all.

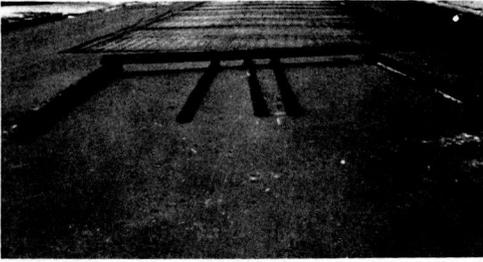


Figure 14. Sled used on Barber-Greene paver for holding down continuous reinforcing.

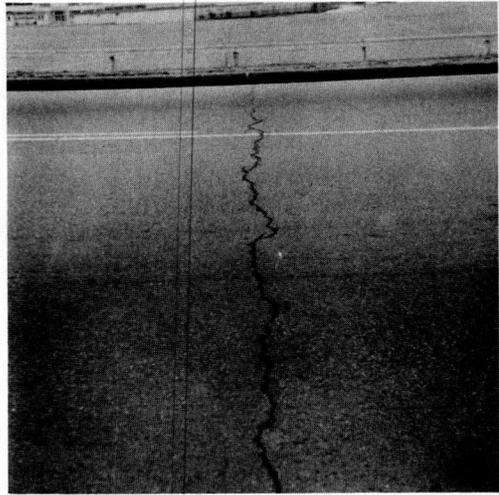


Figure 15. One of the cracks in non-reinforced section.



Figure 16. Crack above joint in reinforced section, Raynham.

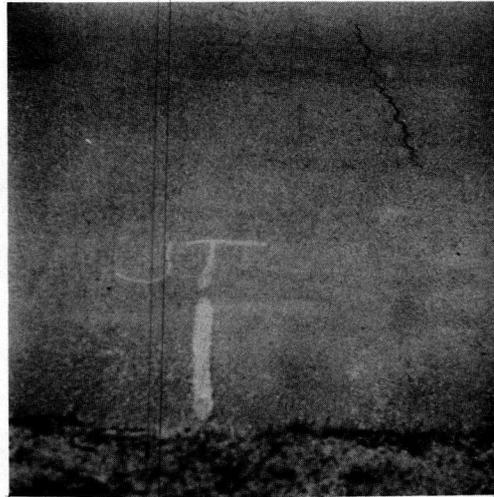


Figure 17. Crack at edge of reinforcement, Raynham.

FIVE-YEAR FIELD RESULTS

All sections have been subjected to five years of traffic and weathering. Data compiled from winter and summer surveys indicate that the differences between the amount of cracks during the warm period and the cold period are not great except for the crack width. Some small cracks tend to close up during the summer especially during the first years. In this report comparisons between the various test sections will be made on basis of winter surveys when the cracks are at their widest opening.

Raynham—Transverse Joint Strip Reinforcement

The width of the strip reinforcement in Raynham varied between 5 and 10 ft. The 5-ft wide strips are herein called narrow, the 6½- to 7½-ft strips are called medium wide and the 10-ft strips are designated as wide. The percentage of total reflection cracking above the transverse joints is given in Figure 19. This figure contains six

separate bar graphs which were necessary to compare each of the reinforced test sections with its adjoining control section. It can be seen that the amount of cracking both in the test sections as well as in the controls increased with time, with the control sections developing cracks at a faster rate than the test sections. Because the width of the cracks varied from one area to another, the distinction between "wide cracks" and "narrow cracks" was set at $\frac{1}{8}$ in. The cracks wider than $\frac{1}{8}$ in. are represented by the shadowed part of the bar, whereas narrow cracks have not been shaded. This dividing point at the $\frac{1}{8}$ -in. width was selected because usually cracks that are $\frac{1}{8}$ in. and less in width are not sealed in maintenance operations. During the actual field surveys the narrow cracks were subdivided into two categories: (a) hair cracks and (b) cracks of about $\frac{1}{8}$ -in. width. The wide cracks had several other recorded sub-classifications. The records of these are available, but for the sake of simplicity and brevity, the detailed data have not been included in this paper.

In the case of the strip reinforcement the cracks that are found appear in two distinct places: (a) immediately above the old joint and (b) at the edge of the reinforcement strip. In practically all cases the cracks appeared either above the joint or at the edge and very seldom in both places. In those few instances where two parallel cracks had appeared the lengths of the cracks were counted as one, and only the crack width was increased in the classification. In this manner the total percentage of cracking cannot exceed 100 percent.

Figure 20 shows a division between the amount of edge cracks and cracks right over the joint. Here again, the hatched area designates wide cracks, whereas the blank part of the bar denotes the narrow cracks. The arrangement of the bar graphs is slightly different in Figure 20 than in Figure 19, showing for each test section the development or increase in cracking with time. The control sections are not included in this comparison because they contain only one kind of crack; that is, only those immediately above the joint.

Wainham—Strip Reinforcement over Longitudinal Joints

As given in Table 1, three test sections were established using 5-ft wide strip reinforcement over the longitudinal joints only. The relative comparisons between the control and the three tests are given in Table 3. The percentages are based on about 240 ft longitudinal joint for each test section.

Walpole—Continuous Reinforcement Sections

As given in Table 2, the Walpole test sections were constructed using continuous reinforcement not only over the whole area of the portland cement concrete slabs but also extending over each side onto the shoulders (Figs. 6, 8, and 12).

The cracking percentages for the transverse joints are shown in Figure 21. Three of the test sections contained wire fabric in sheets, whereas the rest of the test had the reinforcement in rolls of approximately the same length as the slabs. In Figure 21 the various test sections are compared with the adjacent control sections and, therefore, each section of the bar graphs has to be studied independently. For instance, tests 20 and 21 have an adjoining control section, C-3, which cannot be directly

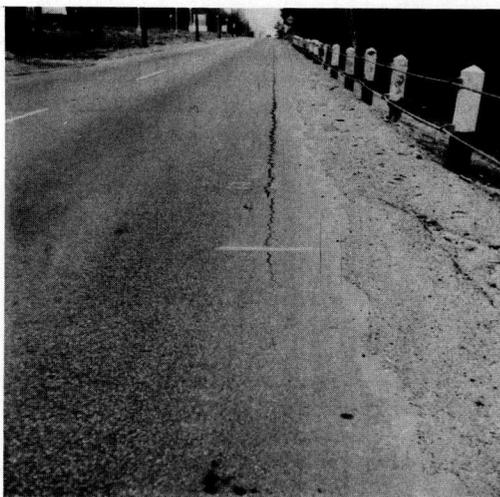


Figure 18. Longitudinal crack narrows down and stops at reinforced section (bottom), Walpole.

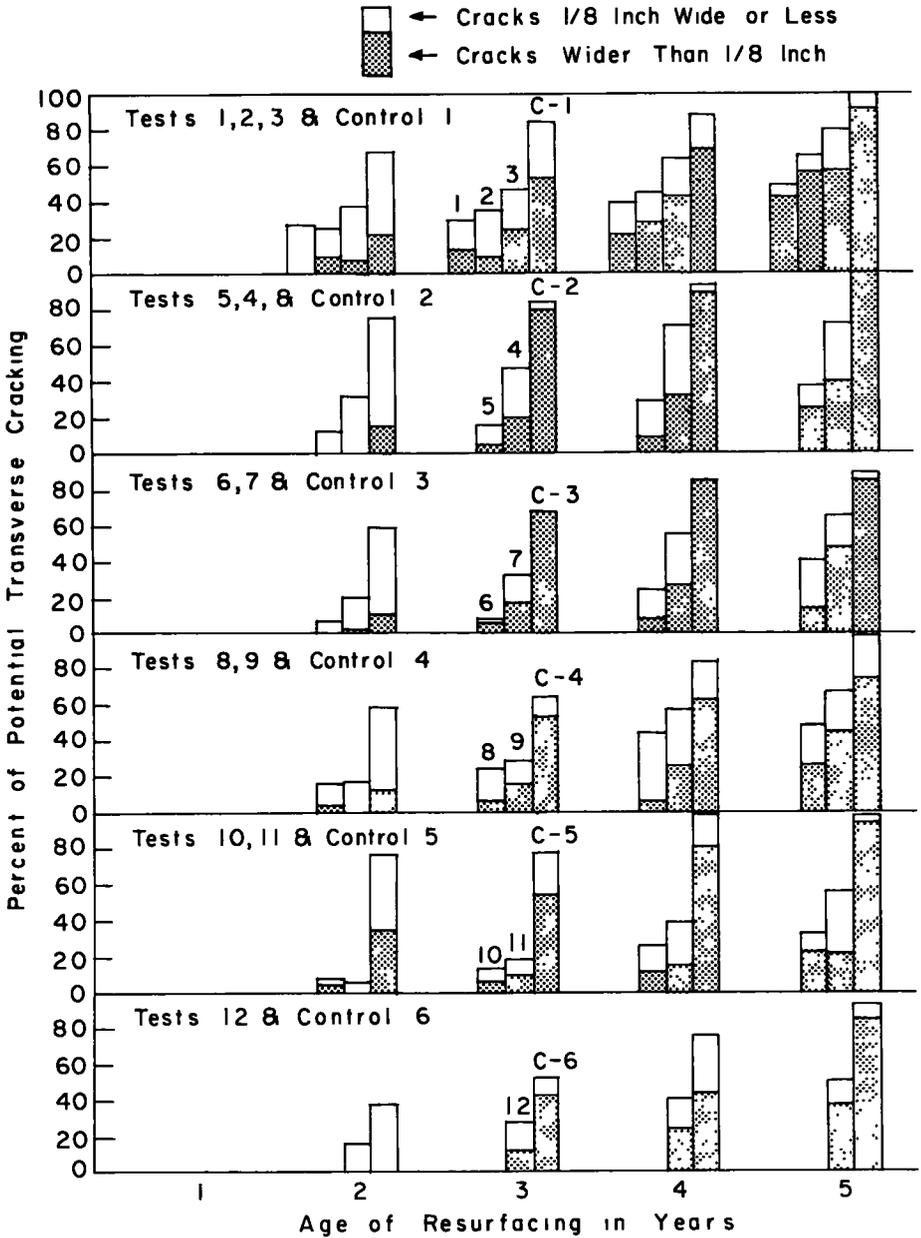


Figure 19. Comparison of transverse crack development for the Raynham Test Road using strip reinforcement.

compared with tests 16 and 17 because the control section adjacent to tests 20 and 21 shows about 70 percent cracking, whereas the control section next to tests 16 and 17 has cracked 100 percent. Again, as in the Raynham test results, the hatched area of the bar graphs denotes the amount of wide cracks, whereas the blank area gives the percentages of narrow cracks.

Figure 22 shows a comparison for cracks along the edges of the pavement between the slab and the shoulder. Comparing Figure 21 with Figure 22 it is apparent that the amount of longitudinal cracking in Walpole is very small as compared to the transverse cracking.

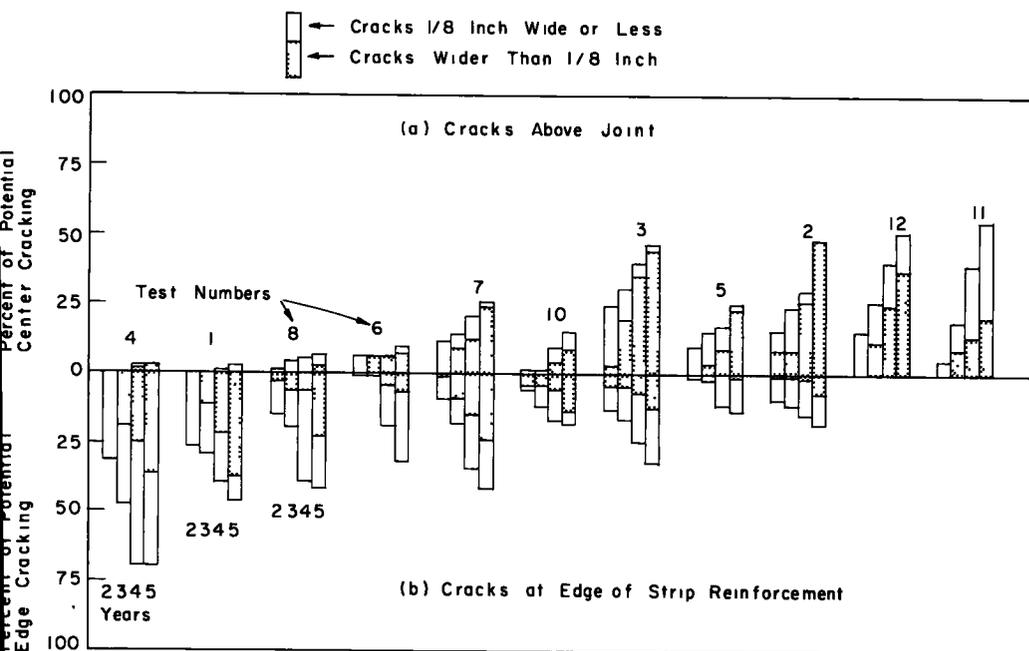


Figure 20. Comparison between the two types of transverse cracking in Raynham: (a) cracks right above the underlying joint and (b) cracks at the edge of the strip reinforcement.

TABLE 3

COMPARISONS OF LONGITUDINAL CRACKING BETWEEN ADJACENT SLABS IN THREE TEST SECTIONS IN RAYNHAM

Test	Fabric Style	Potential Cracking at Various Ages (%)				
		1 Yr	2 Yr	3 Yr	4 Yr	5 Yr
3	4 x 4, $\frac{10}{10}$	0	0	15	21	31
4	6 x 3, $\frac{10}{10}$	0	0	6	6	7
5	6 x 6, $\frac{8}{8}$	0	0	0	0	0
2	none	0	7	14	22	38

Besides cracks immediately above the old joints, there are also a few cracks in areas where the overlap of the wire fabric sheets or rolls occurs. The relative amount of this kind of cracking as compared to the longitudinal and transverse cracks is very small and the length of cracks for 1,000 sq ft, both for wire fabric in sheets and rolls, is given in Tables 4 and 5.

The amount of longitudinal cracking between two adjacent slabs in Walpole has not been shown in any of the comparisons. The reason for this is that many cracks in the center of the road had been caused by the paint stripes and it was virtually impossible to separate these cracks from the joint cracks. It can also be seen from Figure 8 that the butting of two adjacent rolls or sheets occurred about 6 in. on one side of the longitudinal center joint. Observations in cracking pattern indicate that reinforcement at such a short distance from a joint leaves the reinforcement ineffective against longitudinal joint crack appearances. Therefore, due to the closeness of the reinforcement

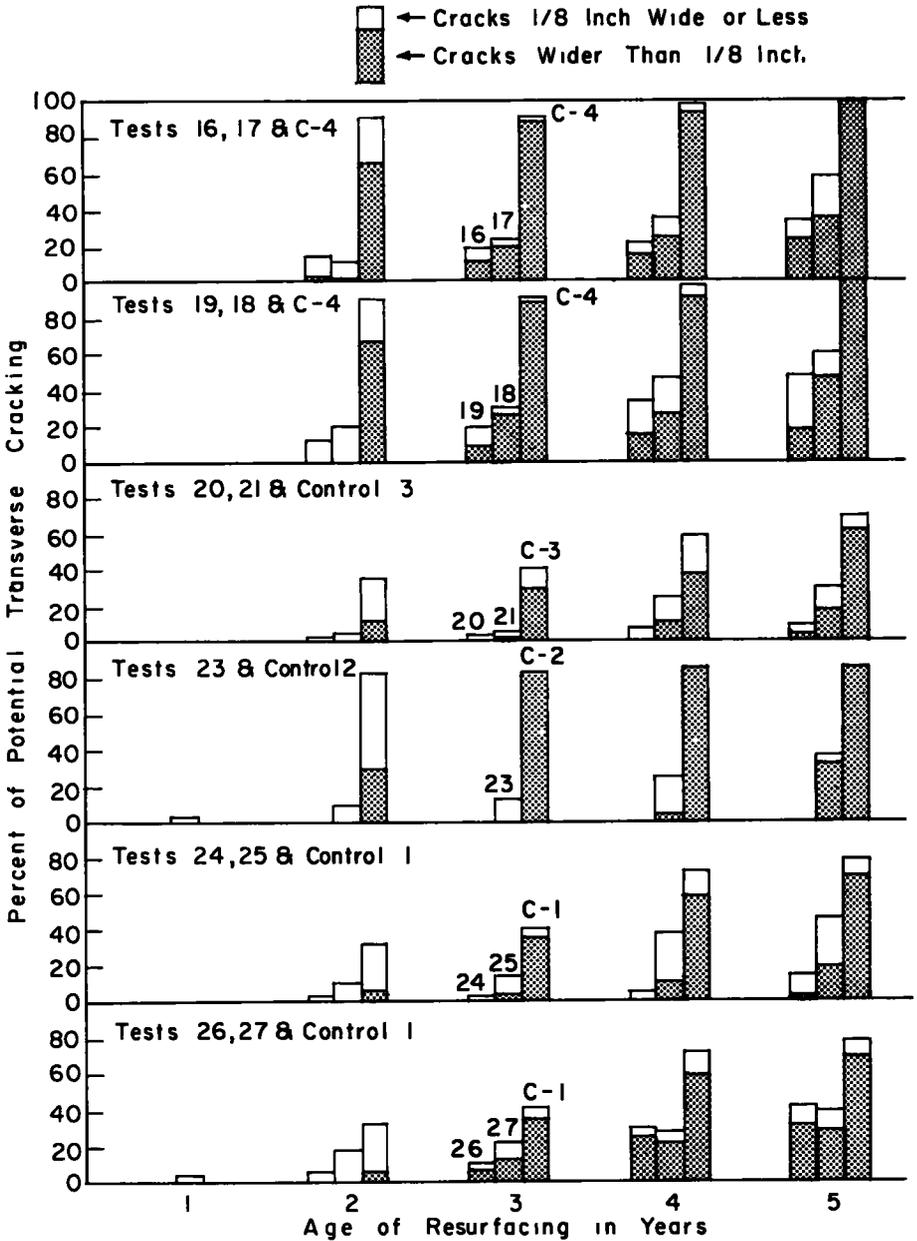


Figure 21. Comparison of transverse crack development for the Walpole Test Road using continuous reinforcement.

butting and the occurrence of paint cracks immediately above the joint, the comparison between the test sections and the control sections in this paper has not been made. The actual observed amount of cracking was similar to the adjacent control sections.

DISCUSSION OF FIELD RESULTS

The main purpose of the two test roads was to compare the effectiveness of various strip reinforcements placed above the transverse joints and continuous reinforcement

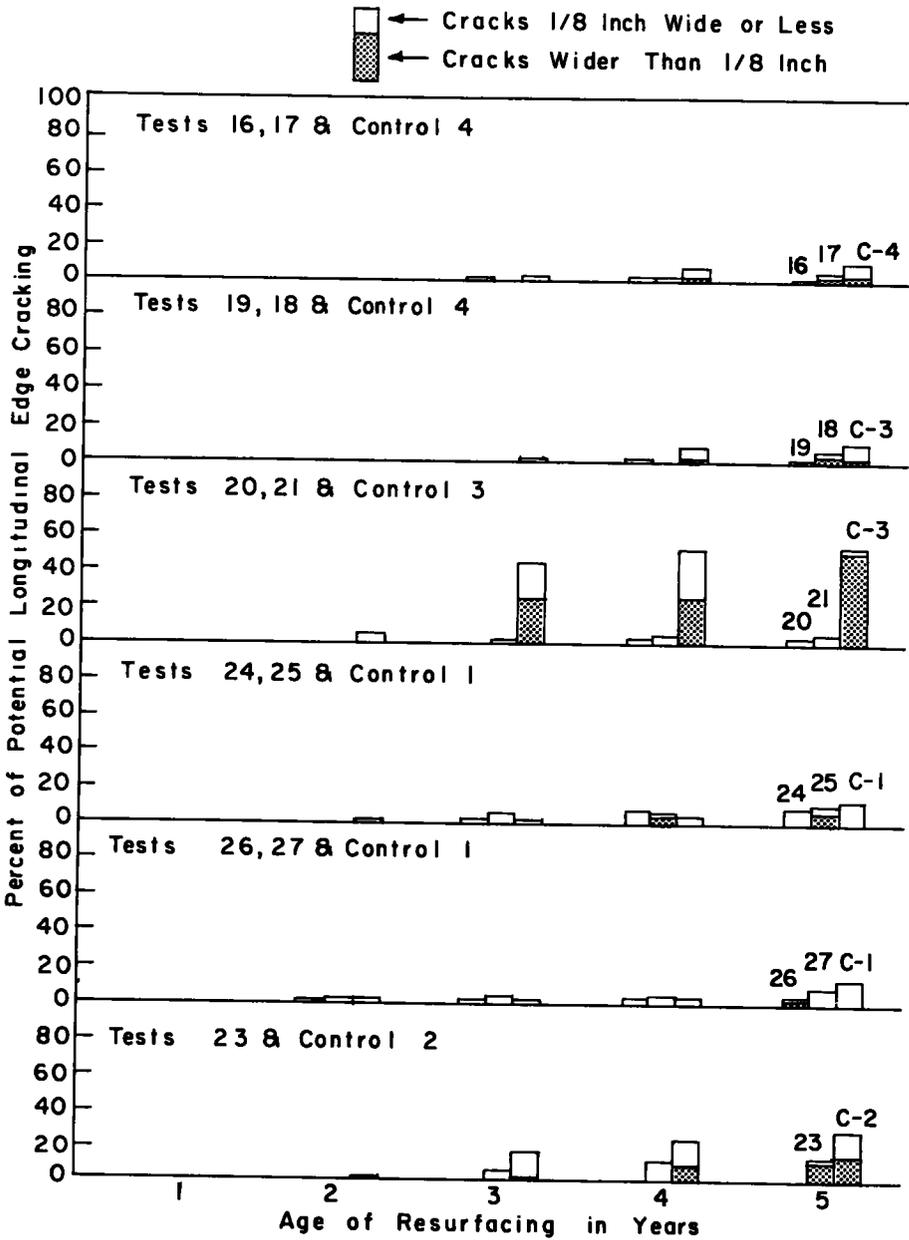


Figure 22. Comparison of longitudinal edge crack development for the Walpole Test Road.

which covers the whole road surface. The types and sizes of the wire fabric used in various sections were selected according to practical considerations and availability of the various wire fabric styles. Following is a discussion of the field performance of the two test roads.

Raynham—Strip Reinforcement

The main emphasis in the Raynham test section was placed on the performance of strip reinforcement over transverse joints because the strains are relatively higher at these

TABLE 4
CRACKING OVER LAPS BETWEEN SHEETS AND ROLLS IN
WALPOLE TEST ROAD

Test	Cracking (ft/1,000 sq ft)				
	1 Yr	2 Yr	3 Yr	4 Yr	5 Yr
16	0	2.4	3.1	3.7	5.1
17	0	1.1	1.4	2.2	2.3
18	0	1.2	2.0	3.1	3.1
19	0	1.4	2.0	3.1	3.9
20	0	0	0	0.3	0.3
21	0	0	0.1	0.8	0.8
23	0	0	0	0	0.1
24	0	0	0	0.2	1.8
26	0	0	0	0	0.2
27	0	0	0	0	0

TABLE 5
RANDOM CRACKING OVER INTERIOR OF SLABS IN WALPOLE TEST ROAD

Test	Cracking (ft/1,000 sq ft)				
	1 Yr	2 Yr	3 Yr	4 Yr	5 Yr
16	0	0.3	0.8	5.1	5.1
17	0	1.8	1.4	3.5	3.1
18	0	0.8	0.8	0.8	0.1
19	0	1.6	1.1	3.3	4.1
20	0	0	0	0.2	0.1
21	0.2	0.4	0.4	1.2	1.1
23	0	0	0.6	1.6	1.1
24	0	0.4	0.6	0.7	1.1
25	0	0	0	0.3	1.1
26	0	0	0.2	0.2	1.1
27	0.7	2.8	4.5	4.9	8.1
C-1	0	0.2	1.1	2.9	4.1
C-2	0	0.4	0.5	1.2	2.1
C-3	0	0	0.2	1.3	1.1
C-4	0	0.2	1.0	3.2	4.1

areas as compared to the longitudinal joints. Figure 19 shows that all test sections and controls had cracks after two years of traffic and exposure to weather. In all cases the cracks increased in width and length with time. The most undesirable cracks are the wide ones because they require continued maintenance. Comparing the amount of wide cracks as well as the total cracking in Figure 19 it is apparent that the control sections in all cases had more of both types of cracking than any of the wire reinforced test sections. Thus, it can be said that any of the wire fabric reinforcement over the transverse joints will help in a degree to prevent reflection cracking. The lowest percentage of reflection cracks was found in test 10 (fabric style—6 x 6, $\frac{8}{16}$) which had about one-third of that in a comparable control section. If the percentage of the wide cracks is defined as the most important, test 6 (fabric style—3 x 6, $\frac{10}{10}$) is the best. In general, tests 5, 6, 8 and 10 are the best performers with total cracking from ab-

one-half to one-third and wide cracks between one-half to one-sixth of that in the controls.

The two types of transverse cracks encountered in Raynham test section are compared in Figure 20. It is apparent that the type of reinforcement plays a great role in the structural behavior of the bituminous concrete and reinforcement combination. Laboratory studies show that the design and placement of the reinforcement for transverse joints is an engineering problem which requires balancing of "strength" to resist the forces of nature and traffic (11). For instance, if the strip reinforcement is made of stiff wire closely spaced and the width of the strip is not adequate, there will be no cracking immediately above the joint but the strongly reinforced section will transfer the strain to the edge of the reinforcement causing a crack there. On the other hand, if the sizes of the wire fabric are small, the spacing between the wires is considerable, and the strip of wire fabric placed above the joint is wide, the likelihood of reflection cracks occurring immediately above the joint is high. Laboratory tests and theoretical studies indicate (10, 11, 17), that the behavior of welded wire fabric in the bituminous concrete is different from that of reinforcement placed in portland cement concrete. When a reinforced bituminous concrete layer is subjected to slow tension the longitudinal wires offer very little bond resistance. The main resistance to the strain of the reinforced overlay is exercised by the transverse wires which undergo a shear movement through the mix. The amount of shear movement depends on stress, temperature of mix, time of loading and other factors. Part of this movement is recoverable elastically, whereas the other part becomes a permanent deformation. The main factors that appear to play a role in deciding whether a crack will appear immediately above the joint or at the edge of the strip reinforcement are as follows:

1. The percentage of the longitudinal steel area affects the amount of strain that is distributed along the longitudinal wire for a given stress. The thinner the longitudinal wires or the less of them per unit area the easier it will be to "stretch" the fabric.
2. The transverse wire length between two longitudinal wires is of great importance. The longer the spacing the more flexible is the reinforcement system and the more likely center cracks can occur. This flexibility is influenced also by the transverse wire diameter.
3. The shear resistance of the transverse wires which is influenced by the transverse wire diameter is another factor that affects the wire fabric reinforcement behavior. The smaller the transverse wire diameter the easier the wire will cut into the mix or undergo shear movement under the given load and more likely allow cracks to develop immediately above the joint.
4. Road tests show that the width of the wire fabric strip reinforcement is important in deciding whether there will be cracking or not and if so where this cracking will occur. For narrow strip reinforcement the likelihood is an edge crack.

It must be remembered, however, that the wire fabric reinforcement alone is not going to determine whether the reinforced joint will have a crack or not. The condition of the underlying slab, especially surface roughness as well as other factors, will play a role in defining where the crack will form—if it does. By outlining the previously-discussed reinforcement factors for each of the Raynham test sections, a fairly consistent explanation of why certain sections had cracks at the edges, whereas the others did not, can be obtained. For instance, test 12 has a relatively low longitudinal wire steel area, the longitudinal wire spacing is 12 in., the transverse wire diameter is relatively large but the spacing is 6 in., and the strips are 10 ft wide which is wide according to the authors' classification. Therefore, it is likely that cracks will develop along the center of the reinforcement or immediately above the joint. On the other hand, test 4 has a high longitudinal steel area, narrow spacing of longitudinal wires, and the strip width is only 5 ft. Therefore, if any cracks would appear they are likely to be at the edge of the strip. This is true for both installations (Fig. 20). Similar comparisons for the other test sections will indicate the same trend. Although it is difficult at this time to assign definite numbers for the aforementioned factors, it is assumed that future research will reach conclusions as to their relative significance. The Raynham Test Road indicates that under Massachusetts conditions and with the

styles of strip reinforcement used, reflection cracking can be considerably reduced but not prevented. The main reason for this is the fact that strip reinforcement needs a balanced design which is difficult to achieve where slabs are of considerable length and the horizontal joint opening and closing is large. This question has been discussed at greater length in a previous publication (11).

In addition to the 11 tests of transverse joints, three areas were covered with strip reinforcement for longitudinal joints only. The cracking index for these three sections are given in Table 3. Because of the relatively short length of these tests any conclusions should be drawn with caution. Test 13 (fabric type 4 x 4, $\frac{10}{10}$) has unusually high crack index which is unexpected and cannot be explained at this time. Test 15 (fabric type 6 x 6, $\frac{8}{8}$) which has the same fabric as test 10, has no cracking.

Walpole—Continuous Reinforcement

The Walpole Test Road contains three test sections with the continuous sheet of reinforcement and seven sections where rolls were used. Figure 21 summarizes the amount of transverse cracking and again it must be emphasized that comparisons can be made only between the tests and the adjacent control sections. Thus tests 20 and 24 should be compared with control 3 rather than with other controls. This calls for a caution when direct comparison between various sections are made.

The basic idea behind the continuous reinforcement is to make the resurfacing independent of the underlying slab movements. In a continuously-reinforced surfacing the possibility of so-called edge cracking (as shown in Raynham) is no longer a problem; and instead of balancing the various forces on both sides of the joint, the design involves optimum reinforcement to obtain the strength necessary to avert any excessive strain in the resurfacing. The results in Figure 21 indicate that the best performance was obtained with 3 x 6, $\frac{10}{10}$ welded wire fabric in rolls. There are two test sections with this type of wire fabric and both of them show good results (tests 20 and 24). The difference between the two is the manner in which the wire was laid: in test 20, the longitudinal wires were on the top of the fabric, whereas in test 24 this was reversed. The total amount of cracking as compared to the control is about one-seventh for test 20 and about one-fifth for test 24. The number of wide cracks in both test sections is low and very few cracks are noticeable driving over these sections. It can be said that after five years, transverse cracking in these two sections is negligible from a maintenance standpoint.

Tests 16, 17 and 18 were reinforced with various types of fabric in sheets and the performance is less impressive than with similar wire fabrics of a continuous type of reinforcement. The possible reason for this is that even though the sheets were tied together by hog rings there actually was never a continuous-type reinforcement in such an arrangement. In several cases the laps of the joints were very close to the old portland cement concrete joints thus causing a plane of weakness near the joint. In test sections where rolls were used the longitudinal wires in all cases had to be gage 10 or higher (thinner) because of the difficulty in flattening the rolls on the road. As a consequence no heavier gage than 10 was used on a test section. Test 26 had 3 x 3 $\frac{13}{12}$ wire fabric style in rolls and test 27 was 2 x 2, $\frac{14}{14}$ wire fabric. Both sections were difficult to place mainly because of the narrow wire spacing and the $\frac{7}{8}$ -in. aggregate used in the binder course. Test 25 contained no wire but the thickness was increased to 3 $\frac{3}{4}$ in. instead of the conventional 3 in. so that the cost would equal that of wire fabric. The transverse cracking in this section has reached 50 percent but is still low compared to the adjacent control.

The percentages of longitudinal cracking between the edge of the slab and the shoulder on each side are given in Figure 19. As can be seen, the relative number of cracks found is small compared to the previously discussed transverse cracking. Even the control sections (except for control 3) have low cracking index. The reinforcement in the bituminous concrete overlay was extended over already existing bituminous concrete shoulders. Therefore, the amount of settlement so far has been very small which might account for the relatively low cracking indexes. There were a few instances where drainage was placed along the edge of the old pavement prior

o resurfacing. The disturbed and then compacted soil and gravel support has settled about $\frac{1}{4}$ to $\frac{1}{2}$ in. in these locations and edge cracking has taken place. These areas, however, had to be eliminated from the test compilations as they could not be compared with test sections where such disturbances were not present. The high percentage of cracks in control 3 is not explainable from data available.

In summary it can be said that several types of wire fabrics are capable of restricting the longitudinal edge reflection crack development for at least five years.

Table 4 summarizes the number of cracks which have developed at the wire fabric strips. Similarly, a few cracks that have developed over the interior of the slabs are given in Table 5. The highest occurrence of these two types of cracks is found in tests 16, 17 and 18 where the sheet type of reinforcement was used. The length of the crack for each area, however, is very small and of little importance.

Raynham Compared to Walpole Tests

The comparison between the two has to be made with some caution because of the relative differences between the test roads and also due to slight differentials in the cracking indexes of the control sections. If a "rough" comparison is assumed to be valid, all but two of the wire tests have performed better than the best control. In an over-all comparison a continuous type of reinforcement has performed better than the strip type of reinforcement with 3 x 6, $\frac{10}{10}$ wire fabric in continuous rolls showing the most outstanding performance. The ability of the 3 x 6, $\frac{10}{10}$ welded wire fabric to resist formation of cracks above transverse joints is also clearly indicated by the performance of tests 1, 4 and 6 in Raynham. Although they have cracks at the edges of the reinforcement, center cracking is below ten percent; that is, comparable to the 3 x 6, $\frac{10}{10}$ sections in Walpole.

CONCLUSIONS

When comparing these results, the variations in the condition of each test section as well as in the physical environment of the test sites over the 5-yr period must be kept in mind. Observations and measurements indicate the following:

1. It is easy to place the types and styles of welded wire fabric used in Raynham and Walpole tests in 3 in. of bituminous resurfacing when the fabric is placed directly on the surface of the old concrete pavement.
2. All types and styles of fabric used had the effect of reducing the amount of reflection cracking to less than that in control sections.
3. Where cracks did appear at reinforced transverse joints, they were of smaller average width than those in the comparable control sections.
4. The most outstanding resistance to reflection cracking was shown by 3 x 6, $\frac{10}{10}$ continuous welded wire fabric reinforcement in rolls (test 20). For example:
 - (a) Only nine percent of the total length of potential transverse reflection cracks appeared. This is nearly one-eighth that in the comparable control section.
 - (b) Only four percent of the cracks are wide (more than $\frac{1}{8}$ in.), which is about one-fifteenth of the wide cracks found in the control section.
 - (c) Only about two percent of possible longitudinal edge cracking occurred with only narrow cracks present.
5. In the strip reinforcement test a strip of 6 x 6, $\frac{8}{8}$ welded wire fabric 7.5 ft wide proved the best. Total cracking was only one-third (33 percent) of that in the control. Test 6 using 3 x 6, $\frac{10}{10}$ fabric showed the lowest percentage of wide cracks; that is, about one-seventh that of the control.
6. The performance of welded wire strip reinforcement is evidently influenced by the longitudinal steel area, longitudinal wire spacing, transverse wire diameter, and width of the strip reinforcement. Strip reinforcement requires a balanced design (not too strong and not too weak) where relatively large horizontal joint openings are expected (about 0.1 in. or more).
7. While the choice of width of welded wire fabric reinforcement strips is a function of several factors, under the conditions tested 6- to 8-ft wide reinforcement for

transverse joints and about 5 ft for longitudinal joints appears satisfactory.

8. The amount of longitudinal edge cracking was small in the Walpole Test Road in all reinforced sections.

9. If settlement of the resurfacing over a shoulder is more than about $\frac{1}{4}$ in., longitudinal cracks will occur between the slab and the shoulder even with reinforcement.

10. The $\frac{3}{4}$ -in. thick resurfacing in test 25, costing the same as a continuously-reinforced surfacing 3 in. thick, had a transverse crack incidence five times greater than in test 20 where 3 x 6, $\frac{10}{10}$ welded wire fabric reinforcement was used in the 3-in thickness.

11. Field observations show that $\frac{7}{8}$ -in. maximum size aggregate appears to be the upper size limit if the reinforcement opening is 2 x 2 in. In other words, the minimum fabric wire spacing in the map should be at least twice and preferably three times the maximum dimension of the aggregate used in the mix.

RECOMMENDATIONS

The work described in this paper has been aimed at systematic gathering of data concerning welded wire fabric reinforcement in bituminous concrete resurfacings so that meaningful conclusions could be reached. This should be continued in order to find solutions for varied situations:

1. The amount of horizontal and vertical joint movements should be measured and data compiled in each state.

2. In areas where the conditions are similar to Massachusetts large installations using the best types of continuous reinforcement should be undertaken.

3. Strip reinforcement should be tried in areas where the maximum horizontal joint movement is not as great as in Massachusetts and where the main purpose is to reinforce against shear and flexure at the joints.

4. Some samples removed from the test road showed evidence of rusting of the wire fabric. Although this does not appear to have influenced the performance of the reinforcement, ways of protecting the steel should be investigated, such as sandwiching it between layers of bituminous concrete.

5. Improvements in methods of laying fabric including the development of equipment for this purpose should be studied.

6. Theoretical studies of welded wire fabric reinforcement in a viscoelastic material (bituminous concrete) should be pursued.

7. Laboratory studies to prove theories and to accumulate knowledge on the importance of factors like longitudinal wire cross-sectional area, spacing, transverse wire size and strip width should be continued.

8. Rheological studies of various types of bituminous concrete reinforced with welded wire fabric should be continued in the laboratory.

ACKNOWLEDGMENTS

The cooperation and help of many organizations and individuals was necessary to make the first phase of the project a success.

The Committee on Welded Wire Fabric Reinforcement Research of the American Iron and Steel Institute sponsored the research.

The Massachusetts Department of Public Works incurred considerable extra expense in planning and constructing the test roads used for the experiment. It bore the full cost of fabric placement. In addition, it provided field personnel for the necessary condition surveys and extra resident engineer staff during construction. Considerable time was spent by the supervisory staff of the Maintenance Division at Department headquarters, Nashua Street, and by the staff of District 6, Taunton.

The Wire Reinforcing Institute, British Road Research Laboratory, and many other organizations familiar with the use of welded wire fabric in resurfacing projects contributed valuable technical advice and assistance.

The Pittsburgh Steel Products Company, American Steel and Wire Division of United States Steel Corporation, and Wickwire Spencer Steel Division of The Colorado Fuel

and Iron Corporation manufactured the fabric, much of which was in small lots of special styles.

The Remington Arms Company furnished a stud driver and donated the supplies used with it.

The Norfolk Construction Company and Thomas Brothers Corporation were the construction contractors.

The staff members of the Joint Highway Research Project all gave invaluable assistance to the work. Especially appreciated are the efforts of J. W. Horn, who was active in planning and construction of the test roads.

REFERENCES

- Bone, A. J., and Roggeveen, V. J., "A Survey of the Use of Rubber in Asphalt Paving." MIT Joint Highway Research Project Research Report 4 (Sept. 1951).
- Bone, A. J., Crump, L. W., and Roggeveen, V. J., "Control of Reflection Cracking in Bituminous Resurfacing Over Old Cement-Concrete Pavements." HRB Proc., Vol. 33 (1954).
- Bone, A. J. and Crump, L. W., "Revere Resurfacing Project - Progress Report No. 1 - An Experiment in Control of Reflection Cracking in Bituminous Surfaces Over Concrete Pavement." MIT, Joint Highway Research Project Research Report 8 (June 1954).
- Crump, L. W., and Bone, A. J., "An Experiment in Use of Expanded Metal Reinforcing to Control Reflection Cracking in Bituminous Surfaces Over Concrete." MIT, Joint Highway Research Project Research Report 11 (June 1955).
- Crump, L. W., and Bone, A. J., "A Review of Current Practices and Research on Controlling Reflection Cracking." HRB Bull. 123 (1956).
- Crump, L. W., and Bone, A. J., "Condition Surveys of Bituminous Resurfacing Over Concrete Pavements." HRB Bull. 123 (1956).
- Horn, J. W., Roggeveen, V. J., and Bone, A. J., "Welded Wire Fabric in Bituminous Resurfacing - Progress Report No. 1 - An Experiment in the Use of Welded Wire Fabric Reinforcing to Control Reflection Cracking in Bituminous Resurfacing Over Concrete." MIT, Joint Highway Research Project Research Report 17 (Nov. 1955).
- Roggeveen, V. J., and Tons, E., "Progress of Reflection Cracking in Bituminous Concrete Resurfacings." HRB Bull. 131 (1956).
- Tons, E., and Bone, A. J., "Westboro Subsealing Experiment." MIT, Joint Highway Research Project Research Report 21 (Dec. 1956).
- Bicher, G. A., Harris, R. L., and Roggeveen, V. J., "A Laboratory Study of Welded Wire Fabric Reinforcement in Bituminous Concrete Resurfacing." AAPT Proc., Vol. 26 (1957).
- Tons, E., and Korkosky, E. M., "A Study of Welded Wire Fabric Strip Reinforcement in Bituminous Concrete Resurfacings." Presented at Annual Meeting, AAPT, Memphis, Tenn. (Jan. 1959).
- Bowers, L. L., "Influence of Temperature and Admixtures on Tensile Strength of Bituminous Concrete Mixes." M.S. Thesis, MIT (1953).
- Blakeslee, R. W., "Correlation of Joint Width and Temperature Changes in Concrete Pavements." B.S. Thesis, MIT (1954).
- Horn, J. W., "The Experimental Use of Welded Wire Fabric Reinforcing in Bituminous Concrete Resurfacing." M.S. Thesis MIT (1956).
- Cyros, K. L., "A Method of Measuring Temperatures of Concrete Pavement Slabs." B.S. Thesis, MIT (May 1956).
- Bicher, G. A., and Harris, R. L., "An Experimental Investigation of the Action of Welded Wire Fabric in Bituminous Concrete Overlays as Related to Its Use in Control of Reflection Cracking." M.S. Thesis, MIT (Sept. 1956).
- Foley, J. V., and Waggener, J. G., "The Behavior of Welded Wire Fabric Reinforcement in Bituminous Concrete." M.S. Thesis, MIT (Sept. 1957).

18. Milligan, R. I., "A Method for Testing Reinforced Bituminous Concrete." B.S. Thesis, MIT (May 1958).
19. Comerford, J. M., "An Experimental Investigation of Plain and Reinforced Bituminous Concrete in Shear." B.S. Thesis, MIT (May 1959).
20. Davis, M. M., "A Field Study of Methods of Preventing Reflection Cracks in Bituminous Resurfacing of Concrete Pavements: Part I, Theory and Installation." Ontario Joint Highway Research Program, Report No. 12 (1960).
21. Payne, H. F., Bransford, T. L., and Gartner, W., Jr., "Cracking of Asphaltic Concrete Adjacent to Traffic Stripes." HRB Proc., Vol. 38 (1959).
22. Boring, J. E., and Myers, B., "Investigation of Longitudinal Cracking Reflected Through Asphaltic Concrete Resurfacing." HRB Proc., Vol. 38 (1959).
23. Roberts, S. E., "Cracks in Asphalt Resurfacing Affected by Cracks in Rigid Bases." HRB Proc., Vol. 33 (1954).
24. Erickson, L. F., and Marsh, P. A., "Pavement Widening and Resurfacing in Idaho." HRB Bull. 131 (1956).
25. Hirashima, K. B., "Highway Rehabilitation by Resurfacing." HRB Bull. 131 (1956).
26. Stackhouse, J. L., "Rejuvenating Highway Pavement." HRB Bull. 123 (1956).
27. Howard, E. M., "Welded Wire Fabric Reinforcement in Asphaltic Concrete." Amer. Road Builders' Assoc., Tech. Bull. 226 (1957).
28. Wakefield, F. G., "The Practical and Laboratory Use of Wire Fabric in Bituminous Resurfacing at Willow Run Airport." Amer. Road Builders' Assoc., Tech. Bull. 215 (1956).
29. Smith, N. G., "Resumé of Results of Welded Wire Fabric in Bituminous Surfaces." Amer. Road Builders' Assoc., Tech. Bull. 215 (1956).
30. Swanberg, J. H., "Experimental Installation of Welded Wire Fabric in Bituminous Pavements." Amer. Road Builders' Assoc., Tech. Bull. No. 207 (1954).
31. Zube, E., "Wire Mesh Reinforcement in Bituminous Resurfacing." HRB Bull. 131 (1956).

Appendix

SPECIFICATIONS FOR MASSACHUSETTS TYPE I BITUMINOUS CONCRETE MIX

Material	Standard Sieves		Percent by Weight			
	Passing	Retained	Standard Bottom Course		Standard Top Course	
			Min	Max	Min	Max
Coarse aggregate ^a	-	7/8"	-	0	-	-
	7/8"	1/2"	30	50 ¹	-	0
	1/2"	No. 4	15	30	25	40 ¹
	No. 4	No. 10	5	15	15	25
Fine aggregate	No. 10	No. 20	2	8	4	12
and	No. 20	No. 40	4	10	6	16
mineral	No. 40	No. 80	4	10	6	16
filler	No. 80	No. 200	2	6	4	10
	No. 200	-	1	4	4	6
Bitumen (sol in CS ₂)			4 1/2	5 1/2	6	7
Total				100		100
Total fine agg. and min. filler			20	30	35	45

^aNot more than 1/5 of the 7/8- to 1/2-in. fraction in the bottom course shall be retained on a 3/4-in. sieve. Not more than 1/4 of the 1/2 in. to No. 4 fraction in the top course or dense mix shall be retained on a 3/8-in. sieve.