R-365

CONTINUOUSLY REINFORCED BITUMINOUS RESURFACING
Detroit Industrial Expressway (I 94), West of Ypsilanti

Onto L. Lindy

Cooperative Project with the Office of Design
and the Office of Construction
With the Approval of the Bureau of Public Roads

Research Laboratory Division
Office of Testing and Research
Research Project 54 D-20(3)
Report No. 365

Michigan State Highway Department
John C. Mackie, Commissioner
Lansing, January 1962

Synopsis

In 1955, Michigan installed two test sections of continuously reinforced bituminous concrete resurfacing over widened portland cement concrete on the Detroit Industrial Expressway west of Ypsilanti. Two control sections of non-reinforced resurfacing of similar lengths were placed at the same time. The welded wire mesh was laid in flat sheets directly on the base concrete surface, and then binder and wearing surface overlay courses were added.

Riding quality has been measured periodically with the Michigan roughometer and complete condition survey mapping has recorded development of reflection cracking and other deterioration.

After more than five years of service, the reinforced sections do not differ significantly from the non-reinforced sections in either surface condition or riding quality. Extraordinary corrosion and fragmentation of the reinforcement was found both in potholes and at locations where the surface appeared to be in good condition, when the overlay was excavated.

CONTINUOUSLY REINFORCED BITUMINOUS RESURFACING
Detroit Industrial Expressway (I 94), West of Ypsilanti

In 1955, the Michigan State Highway Department installed test sections of bituminous concrete resurfacing containing welded wire mesh continuous reinforcement over widened portland cement concrete pavement on the Detroit Industrial Expressway at the intersection with US 112.* The objective was study of structural behavior and service life of bituminous concrete resurfacing as modified by techniques other than variation of mix design.

The specifications, design and layout, and construction of the pavement were carried out by the Offices of Design and Construction, with final approval of the Bureau of Public Roads. The Wire Reinforcement Institute advised the Department on various aspects of design and construction, and its representative, E. M. Howard, Field Engineer, was present at the site throughout the construction period. The Research Laboratory Division was responsible for observations during construction and for the subsequent program studies. No previous reports have been published on this study, and because of performance evidence which may be accepted as conclusive in the terms of the specific objectives involved, this report terminates the project.

Michigan's research background in reinforced bituminous resurfacing goes back to a 1937 installation of 7000 ft of continuously reinforced bituminous concrete over severely deteriorated 1927 rigid pavement on M 21 southwest of Grand Rapids. This project is frequently cited in the literature as the nation's first significant experiment of its type. Because of the limited scope of Michigan's research organization at the time and the extraordinary traffic and load conditions ensuing during World War II, observations on M 21 were somewhat inconclusive, although performance seemed promising.

The next major installation in Michigan was the reinforced bituminous resurfacing of various pavements at Willow Run Airport in the summer of 1955, by the Airport's owner, the University of Michigan.

---

* Effective 1-1-62, existing US 112 will be known as US 12, and existing US 12 (Detroit Industrial Expressway) will be known as I 94.

By 1955, when the Expressway test project was proposed and approved, the Department was placing considerable emphasis on overlay construction for rehabilitation of older concrete pavements. At about the same time, the subject of crack control on bituminous resurfacing by means of reinforcement was stimulating considerable interest elsewhere; projects with this research orientation were being undertaken in California, Minnesota, Ohio, Texas, Indiana, New Jersey, Illinois, the District of Columbia, and in England.

The Michigan project was specifically restricted in several respects. Only one reinforcement type was used--3 x 6-10/10 welded wire mesh fabric. It was installed as continuous reinforcement and not limited to strip reinforcement over particular joints and cracks, as was the case in some experiments elsewhere. The reinforcement was applied directly to the cleaned and widened pavement, without elaborate patching or resealing of deteriorated joints, cracks, or rough slab surfaces. Although the two reinforced test sections had adjacent non-reinforced control sections of about the same lengths for comparison purposes, only one basic design cross-section was used--placement of reinforcement directly on the base concrete with two bituminous overlay courses above. Thus while the Michigan project appears to be one of the longest field installations of this design type, it is also more limited than some projects where several reinforcement types were placed in several cross-sections.

Although reports have been published on construction and early service life of some of the other projects, this report is one of the first to cover at least five years of in-service study. The major factors examined here are the relative effectiveness of reinforcement in crack control in this particular cross-section, as determined by periodic inspections and condition surveys, and in maintaining good riding quality as determined by periodic measurements with the Department's roughometer. The claim that reinforcement distributes effective loads with particular efficiency in bituminous resurfacing has not been investigated here, and probably cannot be determined conclusively without complete field instrumentation and detailed electronic data-recording of deflection and other variables.

CONSTRUCTION

The portland cement concrete pavement to be resurfaced was Project 81-7, C8, constructed in 1943 under wartime specifications permitting omission of reinforcing steel and load transfer bars. Expansion joints were spaced at 120 ft, with weakened plane joints at 20-ft intervals. As part of the Detroit Industrial Expressway (I 94 - US 12), the project carried heavy commercial and passenger traffic continuously from its completion. By 1955, it had severe transverse cracking, with faulting of cracks and joints (Fig. 1). Roughness in accumulated inches per mile by integrator count is shown for the old pavement in Table 1. It should be noted that with 175 in. per mi as the normal margin between "average" and "poor" riding quality, the sections which became the four test areas were in very poor condition. The averages were 258 in. per mi where reinforced bituminous concrete was to be placed, and 261 for the non-reinforced, with a total roughness range from 208 to 351 in. per mi.

Figure 1. Typical appearance of original 1943 concrete pavement in July 1955.

Prior to the placing of resurfacing, the old pavement was widened from 22 to 24 ft. This 2-ft concrete base-course widening was added on the traffic lane at the outer pavement edge, reinforced longitudinally with deformed rods but not tied to the old pavement. Both the pavement and widening were of 9-in. uniform thickness.

The resurfacing was placed as Project 81-7, C12R, C13R, C14U, and C15R, in August and September 1955. Four sections of similar lengths were designated for test purposes, with a reinforced section and a corresponding non-reinforced section at either side of the interchange with US 112 (Fig. 2). A daily construction record is given in Table 2.

TABLE 1
ROUGHNESS OF BASE PAVEMENT AND BITUMINOUS RESURFACING*
(Figures underlined for 1943 base pavement)

Location	Survey Date	Roughness, Accumulated Inches Per Mile				Average All Tracks
		Passing Lane		Traffic Lane		
		Wheel Track 1[b]	Wheel Track 2[b]	Wheel Track 3[b]	Wheel Track 4[b]	
Section 1[a]	July 1955	264	248	218	216	236
Reinforced	Sept 1955	159	156	150	145	152
(3299 ft)	Oct 1956	168	168	175	161	168
	May 1961	215	198	220	237	218
Section 2[a]	July 1955	261	268	261	253	261
Non-Reinforced	Sept 1955	132	140	133	125	132
(3394 ft)	Oct 1956	153	145	150	137	146
	May 1961	190	194	198	198	195
Section 3	July 1955	208	204	334	377	281
Reinforced	Sept 1955	110	138	152	129	132
(4505 ft)	Oct 1956	120	148	168	136	143
	May 1961	168	154	204	187	178
Section 4	July 1955	195	192	308	351	262
Non-Reinforced	Sept 1955	117	106	123	143	122
(3110 ft)	Oct 1956	128	120	151	153	138
	May 1961	176	174	211	205	192

* Riding quality classifications: "good" (0-130 in. per mile), "average" (131-174), "poor" (175 or more).

(a) Sections 1 and 2 carried two-way traffic from September 1955 to October 1956.

(b) Wheel tracks numbered from median shoulder to outer shoulder.

The work was done under standard specifications calling for a binder course of 190 lb per sq yd (about 2 in. thick) and a surface course of 130 lb per sq yd (slightly over 1 in. thick). The binder mix consisted of 69.5 percent 9A stone, 26.0 percent 3BC sand, with 4.5 percent of 60-70 pen. asphalt cement, conforming to Department specifications as follows:

9A Stone		3BC Sand		
Sieve	Percent Passing	Sieve No. Passing	Sieve No. Retained	Percent
1-1/4 in.	100	4	0	100
3/4 in.	45-65	4	10	0-15
3/8 in.	0-25	10	40	15-35
No. 4	0-10	40	80	30-60
		80	200	15-35
		200	0	0-5

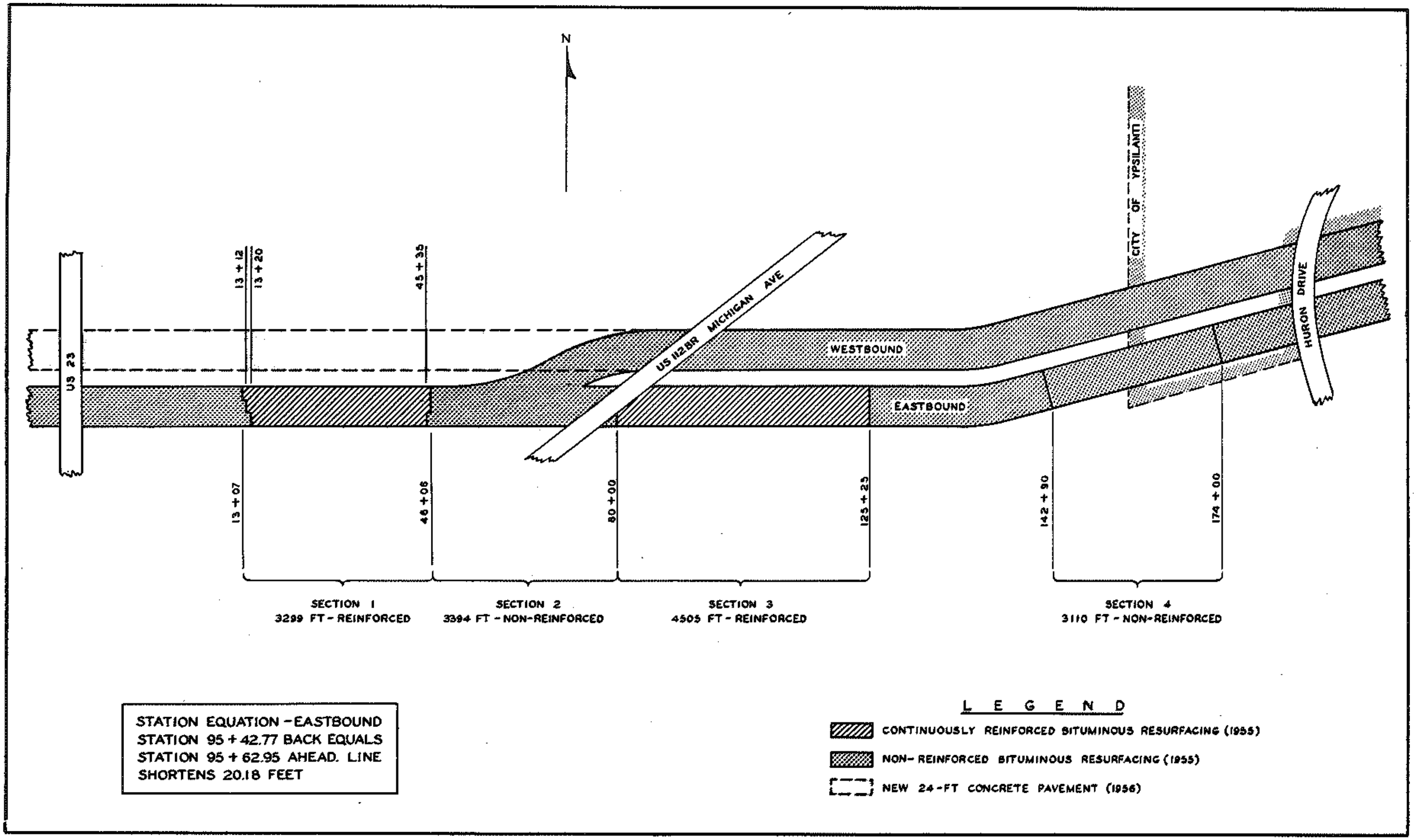
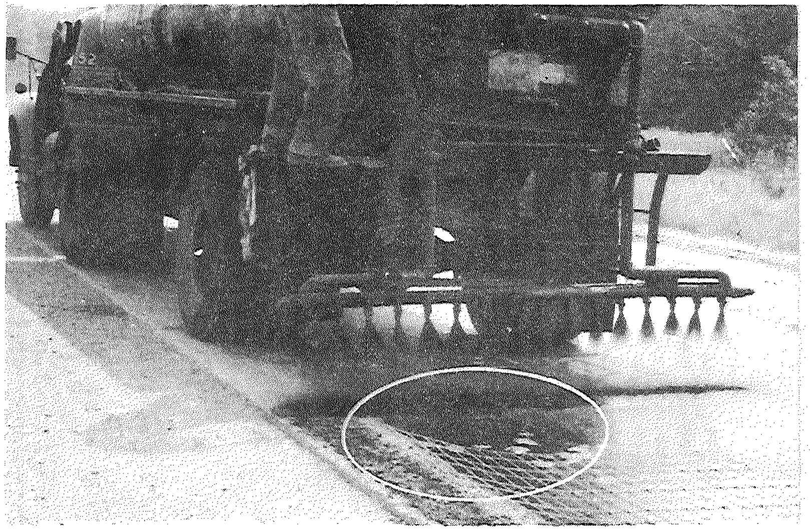
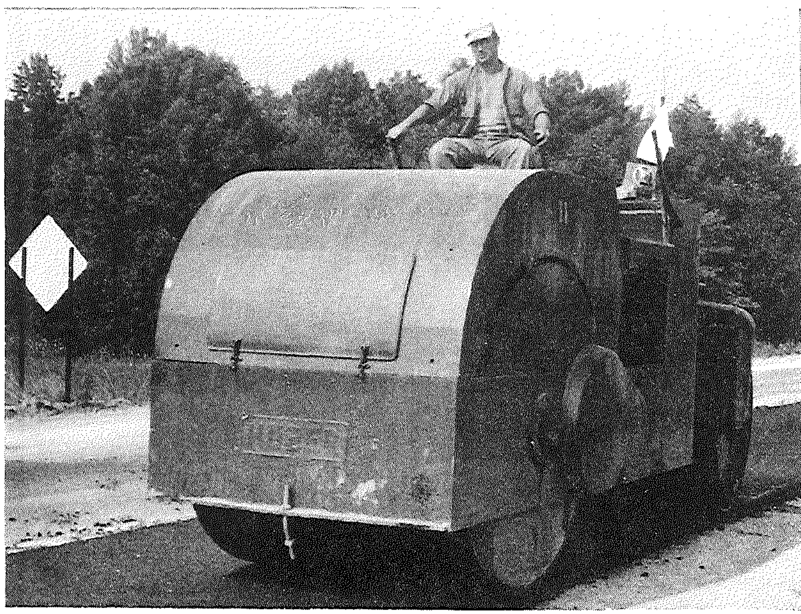


Figure 2. Plan view of resurfacing test sections on I 94.



Spraying on asphalt emulsion bond coat; note curling on long edge of sheet.

Spreader placing 8-ft binder course over reinforcing sheet.



Rolling the binder course with 16,520-lb Huber.

Figure 3. Stages in placing reinforced resurfacing.

Table 2 indicates ten construction days for placement of 7,804 lin ft of reinforcement and 16,960 lin ft of binder course, and seven days for 17,400 lin ft of wearing course. These gross figures for overall eastbound roadway construction include the four test sections. The "deviation" column indicates variations from specified quantities of bituminous concrete from a maximum surplus of 18.3 lb per sq yd to a maximum shortage of 10.0 lb per sq yd for the binder course, and from a surplus of 17.5 to a shortage of 13.7 in the wearing course.

Construction operations are shown in Fig. 3, and a cross-section view in Fig. 4.

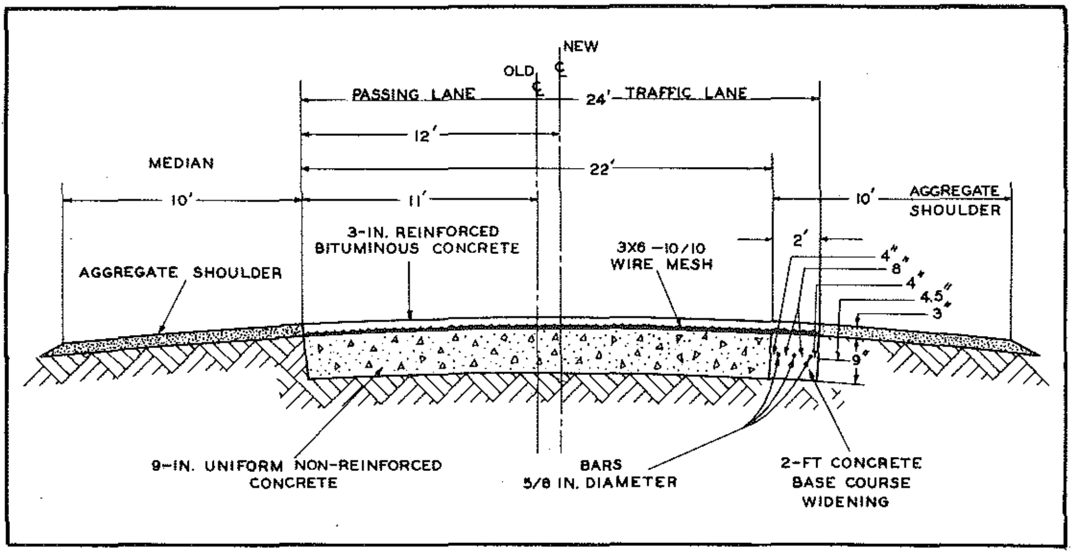


Figure 4. Typical cross-section of continuously reinforced resurfacing (Sections 1 and 3). Non-reinforced resurfacing (Section 2 and 4) had cross-section identical with exception of mesh.

In all four sections, the old concrete was given a bond coat of 0.15 gal of AE-2 per sq yd per standard specifications. Prior to spraying on this bond coat, the concrete was cleaned. The old pavement joints and cracks were not resealed, however, and no deteriorated sections were replaced. In Sections 1 and 3, 3 x 6-10/10 welded wire mesh reinforcement was placed directly on the coated concrete. Although it was intended that the mesh sheets should all be placed with longitudinal wires up, because of edge curling some sheets were turned over and placed with transverse wires up instead. The mesh was supplied in 7.5- by 15-ft flat sheets, which were lapped one transverse wire spacing (6 in.) at the leading edge. In Section 1, at the start of construction, 3/4-in. hog rings were used to tie the lapped sheets at both outside wires and at three

TABLE 2
DAILY CONSTRUCTION RECORD
(Stationing underlined for reinforced sections)

Course	Date	Station to Station	Pass*	Bituminous Concrete Yield: Tons	Sq Yd	Yield,** lb/sq yd	Deviation, lb/sq yd
BINDER COURSE	8-1-55	11+70 to 13+12 13+12 to 26+80 11+70 to 13+07 13+07 to 27+70	C C N N	284.6	2,764	206.0	+16.0
	8-2-55	27+70 to 34+45 11+70 to 13+20 13+20 to 26+80	N S S	202.2	1,942	208.2	+18.2
	8-3-55	34+45 to 46+06 46+06 to 46+85 26+80 to 46+06 46+06 to 46+85 26+80 to 45+35 45+35 to 45+60	N N C C S S	443.7	4,556	194.7	+ 4.7
	8-4-55	46+85 to 72+40 46+85 to 72+40 45+60 to 46+85	N S S	626.7	6,824	181.0	- 9.0
	8-18-55	72+40 to 80+00 80+00 to 88+20 72+40 to 80+00 80+00 to 88+70 72+40 to 80+00 80+00 to 88+70	N N C C S S	428.5	4,302	199.2	+ 9.2
	8-19-55	88+20 to 105+15 88+70 to 105+15 Acceleration Lane	N C, S	480.2	5,158	185.6	- 4.4
	8-23-55	105+15 to 125+25 125+25 to 127+00	N, C, S N, C, S	579.2	5,827	198.8	+ 8.8
	8-24-55	127+00 to 139+00	N, C, S	300.8	3,200	188.0	- 2.0
	8-27-55	139+00 to 143+20 139+00 to 149+45	N S	172.7	1,920	180.0	-10.0
	8-29-55	143+20 to 181+50 149+45 to 181+50	N	900.0	9,513	189.2	- 0.8
WEARING COURSE	8-5-55	11+70 to 39+25	N	270.9	3,673	147.5	+17.5
	8-8-55	39+25 to 46+06 46+06 to 71+40 11+70 to 46+06 46+06 to 71+50	N N S S	713.1	12,260	116.3	-13.7
	8-25-55	71+40 to 80+00 80+00 to 125+25 125+25 to 136+90	N N N	569.8	8,733	130.5	+ 0.5
	8-26-55	71+50 to 80+00 80+00 to 125+25 125+25 to 137+00 Acceleration Lane	S S S	608.6	9,400	129.5	- 0.5
	9-7-55	136+90 to 204+35	N	646.3	9,115	141.8	+11.8
	9-8-55	137+00 to 164+40 204+35 to 256+60	S N	720.3	10,620	135.6	+ 5.6
	9-9-55	164+40 to 186+10	S	202.7	2,893	140.1	+10.1

* Binder course placed in reinforced sections in three 8-ft passes: N = north third (median edge), C = center third, S = south third (outer edge). Binder course in non-reinforced sections and all of wearing course places in two 12-ft passes: N = north half (passing lane), S = south half (traffic lane).

** Binder course specification: 190 lb per sq yd; wearing course specification: 130 lb per sq yd.

intermediate points (Fig. 5). It was soon clear, however, that these five ties across the lap prevented free lateral movement of the steel by construction workers for correction of alignment. From then on, the side ties were omitted, and instead three ties were made at intermediate points in the lap.

Because of the sheet dimensions, the bituminous concrete binder course was placed in three separate 8-ft passes in the reinforced sections. Sheets were staggered in these three construction lanes so that no leading edges were transversely adjacent. In the non-reinforced sections, two 12-ft passes were made with the paver for the binder course. Throughout the project, the wearing course was placed in two 12-ft passes.

As construction progressed, difficulty was encountered in keeping sheets flat ahead of and under the paver. Anticipating this and possible entanglement in the paver, a "hold-down sled device" had been fabricated to ride along and depress the sheet wires under the spreader (Fig. 6). The longitudinal members of the sled were turned up or "skied" at both ends to allow for backward and forward movement of the spreader, to which it was attached by chains, just in front of the mix conveyor screw. On many of the similar projects built in other states, these same problems of placing ties for the lapped mesh and preventing buckling also arose during construction. In California and elsewhere, hold-down devices were also used to depress the curling steel. The Michigan sled was only partially effective the first two days, but modifications improved its performance from then on.

The major problem during placement of the reinforcement was buckling of sheets ahead of and behind the paver (Fig. 7). The only solution at 69 locations where the buckling was particularly bad was cutting and removing the warped steel. A typical sequence of these steps is shown in Fig. 8. In both Sections 1 and 3, where buckling occurred across the full sheet width of 7.5 ft, the deformed steel was generally replaced with new mesh; in smaller areas, buckled reinforcement was generally not replaced. The tabulation of removal and replacement of reinforcement in the Appendix shows that of the total area of 78,464 sq ft in Section 1, about 2 percent (1685 sq ft) had reinforcement removed. Reinforcement was replaced in 815 sq ft of this area. By correcting position and adjusting the mats in Section 3, better results were obtained and only 218 sq ft of reinforcement was removed in the total area of 180,120 sq ft (0.2 percent). Reinforcement was not replaced in these 25 areas of Section 3.

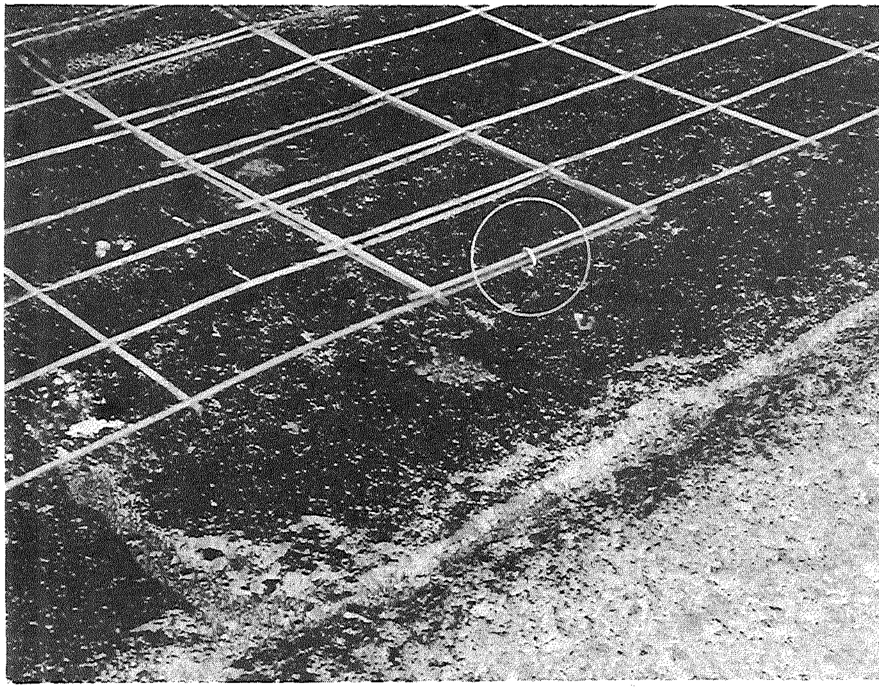


Figure 5. Lapped sheets in place on bond-coated base concrete, showing hog-tie on edge wire as used on first day of placing resurfacing.

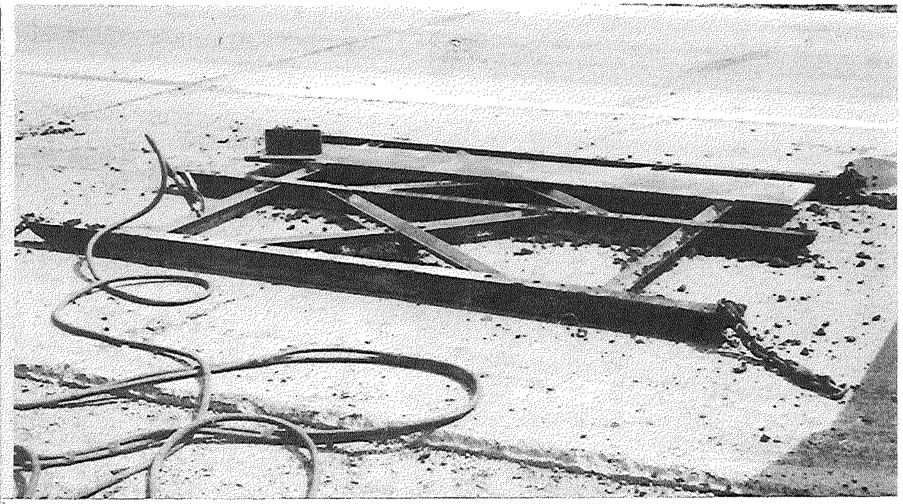


Figure 6. "Hold-down device" used to depress reinforcing sheets under paver.

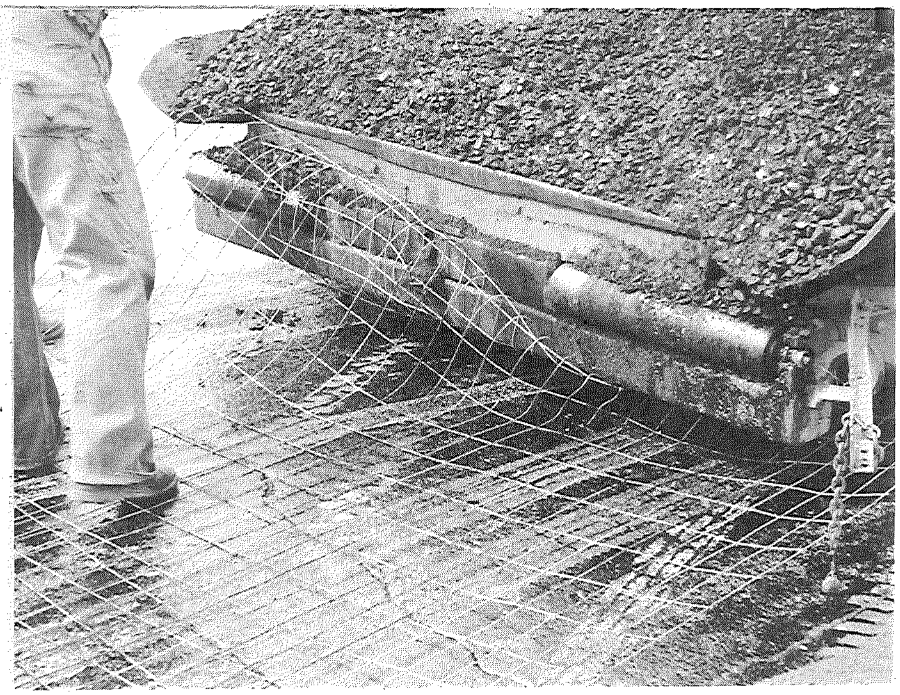


Figure 7. Buckling of reinforcing sheet ahead of paver.

Extreme buckling of reinforcing steel behind the paver, protruding through binder course.

Smaller area of buckled steel.

Wire cutting at edge of an area of buckled steel.

Removal of full width of buckled sheet from binder course.

Installing new full width sheet to replace buckled steel, and replacing bituminous concrete by hand.

Figure 8. Typical sequence of steps in removing and replacing buckled steel.

PERFORMANCE

The literature concerning reinforced bituminous resurfacing indicates several possible disadvantages in installing steel directly on old concrete pavement, without a preliminary leveling or binder course of bituminous material:

1. Normal expansion-contraction pressures in the base concrete pavement, continuing even under a reinforced overlay, plus a tendency of the reinforcement and overlay toward longitudinal stretch or slippage under heavy traffic loads, will cause grinding or abrasion of the mortar surface of the old concrete by the reinforcing steel.

2. Vertical deflection under traffic impact at joints and cracks in the old pavement, also continuing even under a reinforced overlay, will cause digging or "indenting" of the base concrete by the steel, particularly over inadequate foundation soil support.

3. Considering these probabilities for movement of steel placed directly over an old concrete base, any effective bond between the base and the bituminous overlay is liable to interruption. In time, deposits will build up of dust and fragments of portland cement concrete and bituminous concrete and metal shavings from the steel, further interrupting effective bond. In effect, the steel forms a separation course between the overlay and the base.

4. Reinforcement beneath an overlay is less effective in controlling wearing surface cracking than is reinforcement "sandwiched" within an overlay.

5. Reinforcement in the plane between an old concrete base and a bituminous overlay is exposed to moisture entering cracks at the wearing surface and also to seepage from below through cracks and joints in the old base pavement, increasing the likelihood of rusting and fracturing of the steel.

6. A plane of interrupted bond between the old pavement base and the overlay, subject to seepage from above and below, is a likely place for accumulation of moisture during winter months. Thus the overlay undersurface is vulnerable to fracture and breakup through freeze-thaw pressures.

These observations derived from other projects appear to explain some of the deterioration recorded on the Michigan project.

Traffic and Roughness

Table 3 shows the heavy daily traffic load carried by the test sections in 1955 and the increase by 1960. It should be noted that Sections 1 and 2, west of the US 112 interchange, carried the full load of east-west traffic (8200 vehicles daily) for a year after the resurfacing was placed, until a new westbound roadway was opened.

TABLE 3
TRAFFIC AT INTERCHANGE WITH MICHIGAN AVE. (US 112)
(Station 79+16)

Survey Year	West of Interchange*			East of Interchange*		
	Daily Average	Percent Passenger	Percent Commercial	Daily Average	Percent Passenger	Percent Commercial
1955	8,200	84	16	13,000	78	22
1960	17,000	80	20	22,500	75	25

* Sections 1 and 2 west, Sections 3 and 4 east; Traffic Division reports westbound traffic consistently "slightly heavier" than eastbound.

The roughness figures presented in Table 1 show the contrast between riding quality before and just after resurfacing occurred (July and September, 1955), a year after construction when a new westbound roadway relieved Test Sections 1 and 2 of the full two-way traffic load (October 1956), and finally, after more than five years of service performance (May 1961). The inferior riding quality of Test Section 1 in all three roughness surveys, as contrasted to comparable wheel tracks in other sections, may be attributed to inadequacies and alterations of construction procedures in this first-built portion of the resurfacing project and to the especially heavy traffic load during the first year of service. However, the general similarity of the surface roughness statistics for the other reinforced area (Section 3) and the two non-reinforced areas (Sections 2 and 4) is significant in indicating that no marked improvement in riding quality was obtained through installation of continuous reinforcement.

Cracking

During the first six months of service, transverse and longitudinal cracks developed both in reinforced and non-reinforced sections, as shown in the condition survey figures of April 1956. Data from this survey and those of April 1958 and September 1961 are given in Table 4. Survey procedures included specific detailed mapping of the entire project length.

TABLE 4
RESURFACING DETERIORATION

Location	Survey Date	Longitudinal Cracks				Transverse Cracks						Pothole-Alligator Cracks	
		Over Old Centerline		Over Widening Strip		Over Old Transverse Joints		Over Old Transverse Cracks		Over Lapped Mat Edges			
		lin ft	% of Length	lin ft	% of Length	No.	% of Total	No.	% of Total	No.	% of Total	No.	Sq Ft
Section 1*	April 1956	130	4	0	--	152	46	171	41	121	18	9	61
Reinforced	April 1958	304	9	2058	62	209	64	242	58	157	23	9	61
(3299 ft)	September 1961	3245	98	3270	99	211	64	242	58	158	23	9	61
Section 2*	April 1956	1764	52	0	--	284	87	205	56	0	--	0	--
Non-Reinforced	April 1958	1959	58	3386	100	305	94	250	69	0	--	0	--
(3394 ft)	September 1961	3283	97	3386	100	308	94	251	69	0	--	0	--
Section 3	April 1956	0	--	128	3	288	64	199	48	77	8	6	66
Reinforced	April 1958	0	--	898	20	341	76	217	53	100	11	6	66
(4505 ft)	September 1961	1379	31	4178	93	341	76	218	53	100	11	6	66
Section 4	April 1956	36	1	1874	60	233	48	75	16	0	--	0	--
Non-Reinforced	April 1958	36	1	2100	68	299	61	166	35	0	--	0	--
(3110 ft)	September 1961	287	9	3016	97	299	61	166	35	0	--	0	--

* Sections 1 and 2 carried two-way traffic from September 1955 to October 1956.

The old base pavement pattern of transverse and longitudinal joints (Fig. 9), the longitudinal joint formed by the widening strip beneath the resurfacing (Fig. 10), the old transverse cracks, and the staggered and lapped edges of the reinforcing sheets (Fig. 11), all were reflected on the wearing course surface.

The reinforcement seems to have controlled longitudinal cracks over both the old centerline and the widening strip joint for the first few months, losing this effectiveness as service progressed. Cracking failure in reinforced Sections 1 and 3 along 93 and 99 percent of the length of the widening joint, and along 31 and 98 percent of the length of the old centerline joint, is notable in showing no advantage for the reinforced sections.

The ineffectiveness of reinforcement in crack control over old transverse joints and cracks is even more pronounced than along the longitudinal axis, with poor performance data in the initial 1956 survey, and later, progressive deterioration and failure.

In addition to reflection of joint and cracks in the base pavement, cracks developed in the reinforced sections over the lapped edges of the reinforcement itself. It may be noted in Table 4 that transverse cracks have been identified over 23 percent of the lapped transverse edges of

Figure 9. Right-angle reflection cracking in non-reinforced resurfacing, over intersecting transverse and longitudinal joints in the old base concrete pavement, after eight months service (May 1956).

Figure 10. Reflection crack in non-reinforced resurfacing over longitudinal construction joint between old base pavement and 2-ft widening strip (April 1956).

Figure 11. Reflection crack in continuously reinforced resurfacing section, showing staggered pattern of leading edges of adjacent mesh sheets (turn-off lane for US 23 at far edge). (May 1956)

reinforcing sheets in Section 1 and over 11 percent of the laps in Section 3, for a total of 258 individual cracks of this type. These are conservative figures, representing only clear instances of regular straight-line cracks not over old transverse joints or cracks, appearing at the 14.5-ft intervals where sheet laps occurred. If a more precise record were available of specific locations of laps for cut or shortened sheets, these figures would undoubtedly be much higher.

It is interesting that no longitudinal cracks encountered in the surveys could be attributed to reflection over the long edges of the sheets, which of course were not lapped. It should be remembered that many sheets were sharply curled at the long edge at the time of placement during construction.

Potholes and Other Deterioration

One form of deterioration found only in the reinforced test sections, and cited in the literature as occurring on similar projects, is pothole deterioration proceeding from so-called "alligator cracking" on the wearing surface. This cracking appears to originate where loose material has collected in pockets under steel that is curled or rippled within the overlay course. Then, as moisture enters through these surface cracks, a distinctive circular or oval area of springy, unstable bituminous material develops, spreading rapidly under traffic. Vertical and horizontal movement of the curled reinforcement under traffic occurs within this spreading area until the surface cracks widen to allow pothole spalling and breakaway of surface material. The reinforcement curling or rippling can sometimes be traced back to rolling pressure by pavers and other heavy construction equipment while the resurfacing is being placed. In other cases, poor gradation of aggregates or coarse mix density may cause development of these loose pockets or "hollow spots" in the reinforcing courses, as well as permitting infiltration of excessive moisture.

On the Michigan project, these potholes began appearing almost immediately after pavement was opened to traffic, and continued to develop during the five years of service (Table 4). Typical potholes are shown in Fig. 12, and after repair in Fig. 13.

During final inspections in the fall of 1961, bituminous concrete was removed from potholes and at other locations to expose the reinforcement. As was anticipated, wires were fractured and severely rusted in potholes over intersections of transverse and longitudinal joints in the old pavement, indicating infiltration of moisture from below and also through

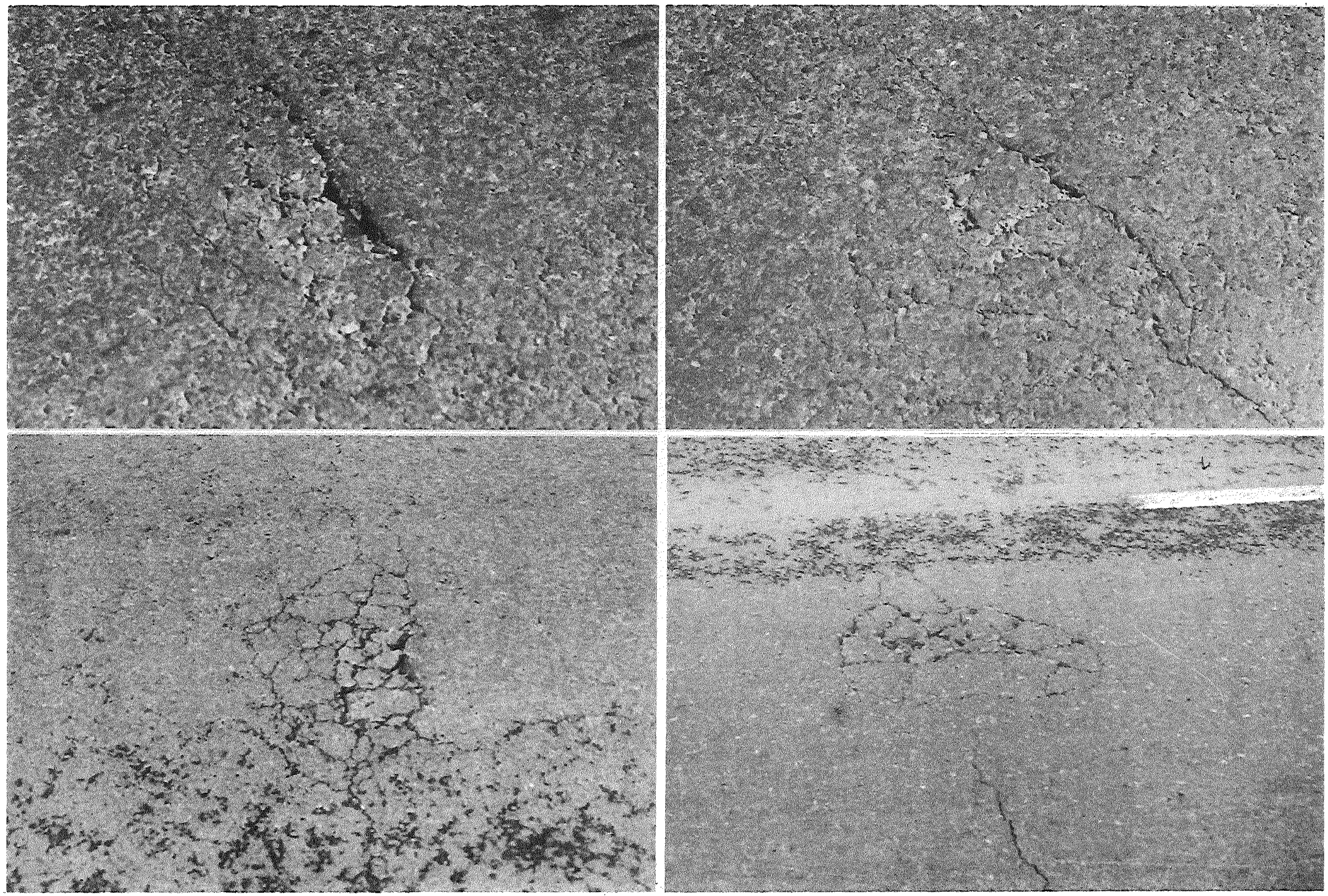


Figure 12. "Alligator" cracking and pothole spalling of bituminous concrete in continuously reinforced test sections (Spring 1956).

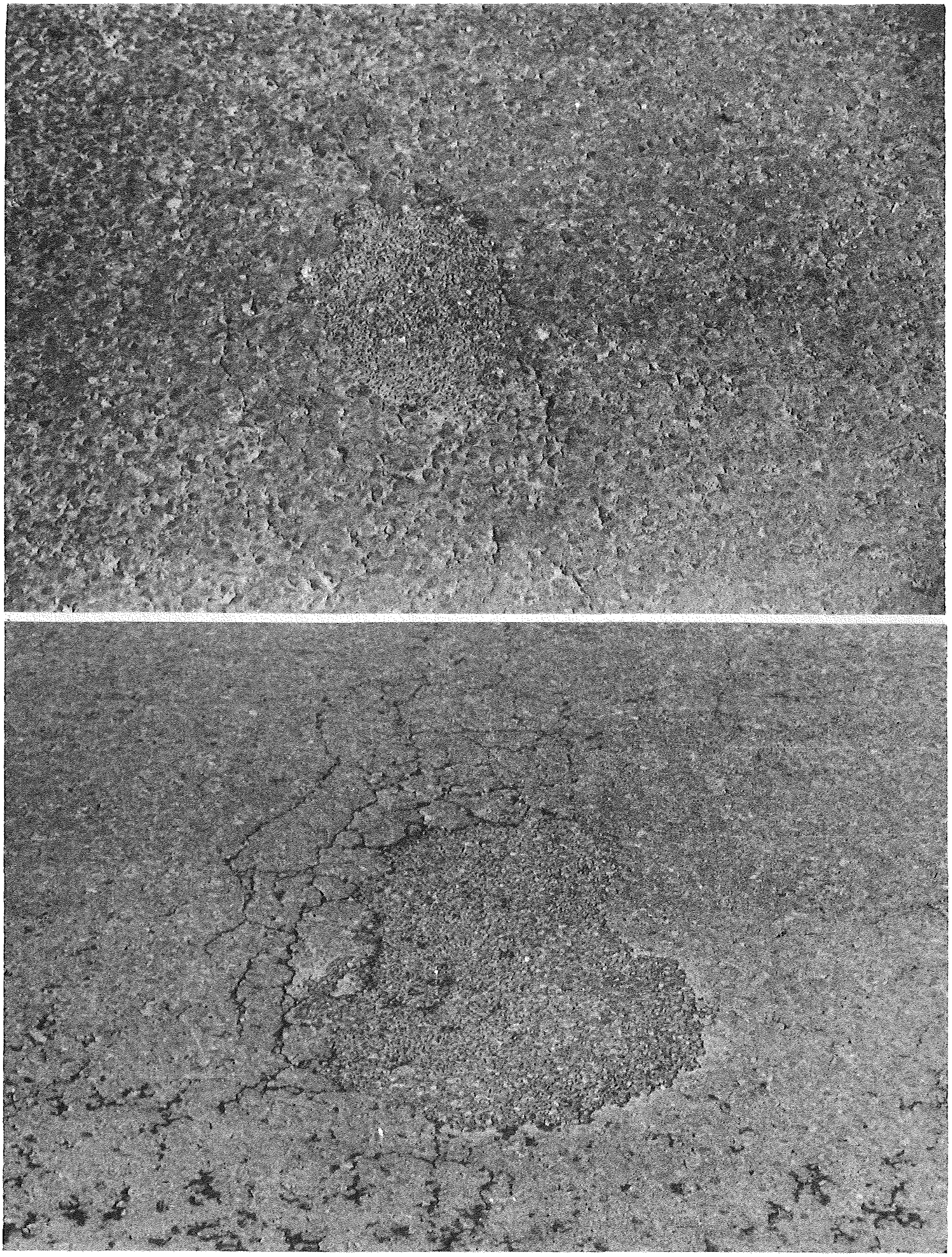
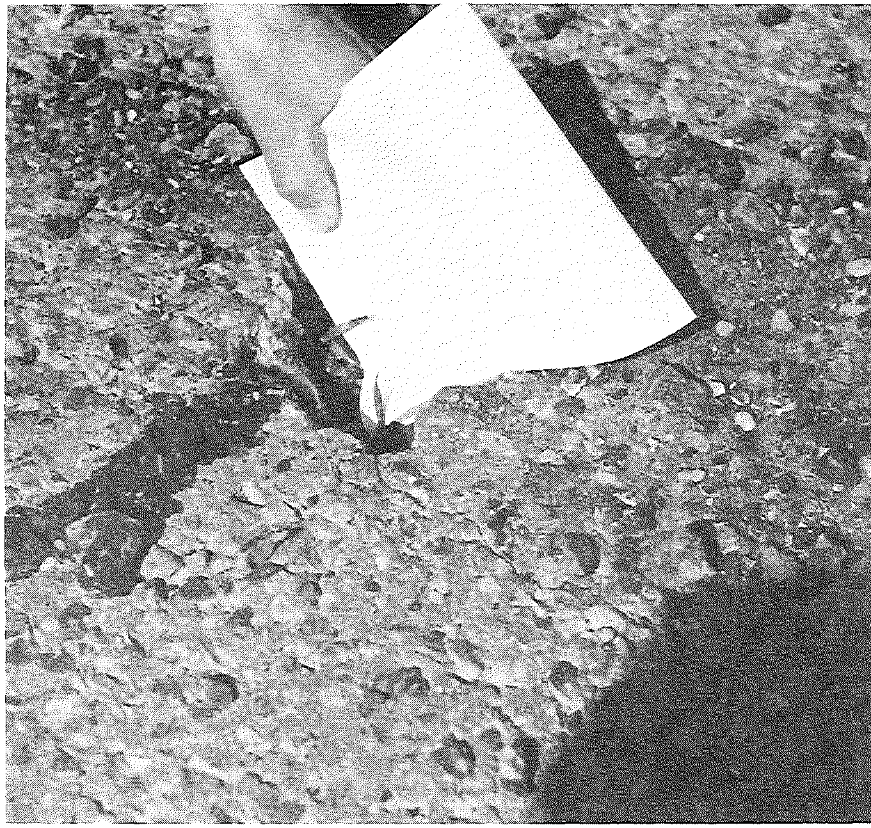


Figure 13. Bituminous concrete patches at potholes and further alligator cracking in reinforced test sections (April 1956).



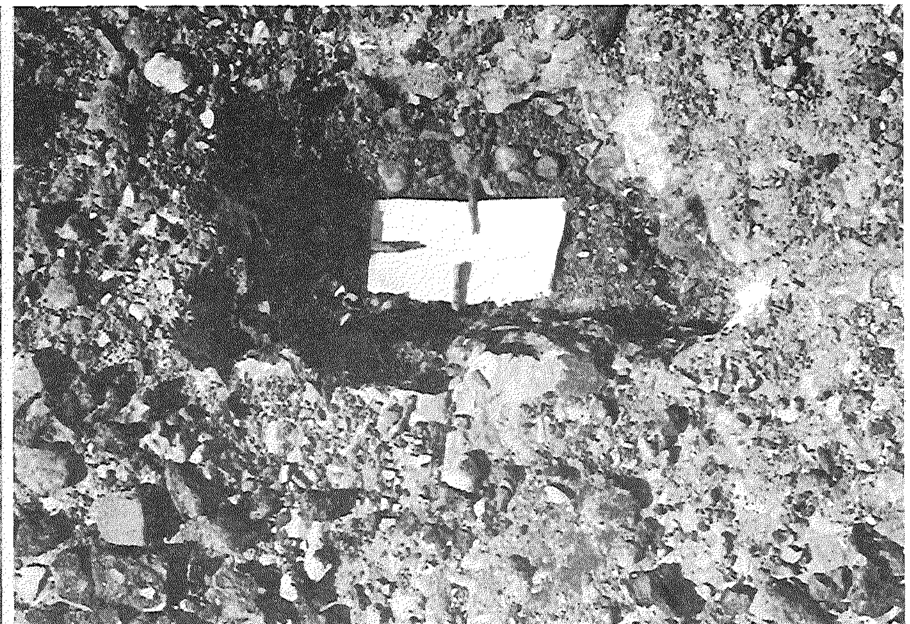


Figure 14. Fractured and rusted steel exposed in potholes located at intersecting transverse and longitudinal reflection cracks (left above), and from beneath sound surface areas (right above and below).

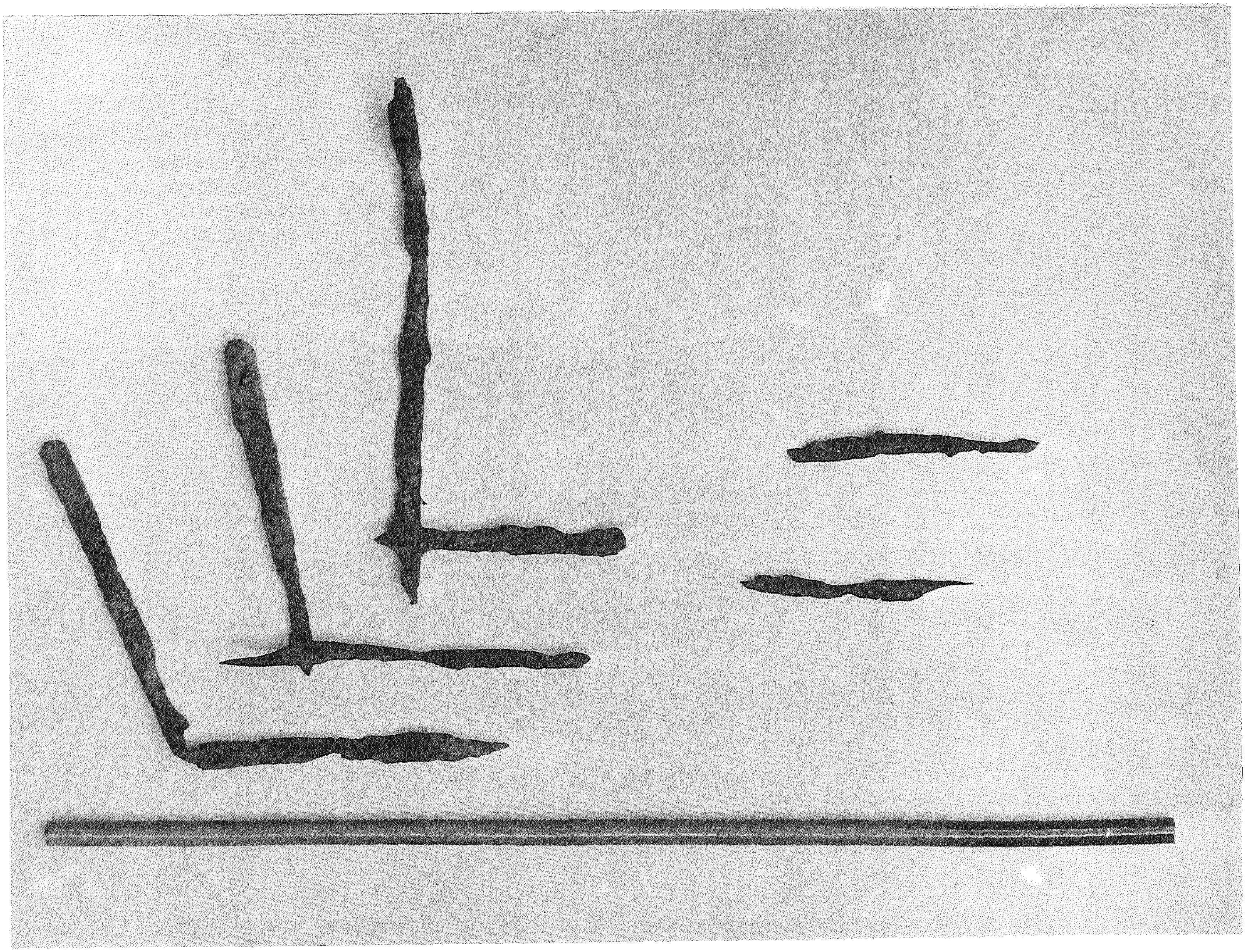


Figure 15. Specimens removed from locations shown in Fig. 14, with sample of new No. 10 gage wire at bottom.

overlying reflection or alligator cracks (Fig. 14). However, steel exposed at other locations, where no surface deterioration had occurred, was similarly deteriorated, suggesting that the sheets had in effect been reduced throughout the overlay to disconnected networks of broken and corroded wire fragments (Fig. 15).

Of all the steel examined, the best-preserved was a lightly rusted short length that had not even been covered during construction, but had been left exposed to the weather at the pavement edge. This exposed wire was actually in better condition than parts of the same sheet that had been covered with bituminous concrete (Fig. 16). The examples illustrated show that steel was notably deteriorated near the welded intersections of transverse and longitudinal wires.

During one inspection, the bituminous concrete at excavated points was moist near the surface, and moisture increased deeper in the overlay at the level of the reinforcement, with larger particles thoroughly saturated. A check on figures for recent rainfall preceding this inspection indicated 0.1 in. precipitation in the preceding 24 hr, and only 0.5 in. in the preceding 72 hr. Since a porous paving material containing even minute cracks will tend to absorb and retain moisture from humid air or rainfall through capillary action, steel in the overlay courses clearly has had sustained and intensive exposure to moisture. Deposition of winter maintenance chemicals and possible year-round retention of traces of these chemicals would accelerate the corrosion. It would seem that any bituminous concrete reinforcement lacking specific treatment for corrosion prevention would be liable to rust and fracture, transforming the integral sheets of steel into random lengths and isolated intersections of wire.

Because of this deterioration of reinforcement and because of performance evidence which may be accepted as conclusive in terms of the research objectives involved, this report terminates the current research project.

CONCLUSIONS

The Michigan experiment with welded wire mesh continuous reinforcement, placed directly on a widened portland cement concrete base and then covered with two-course bituminous concrete resurfacing, indicated that:

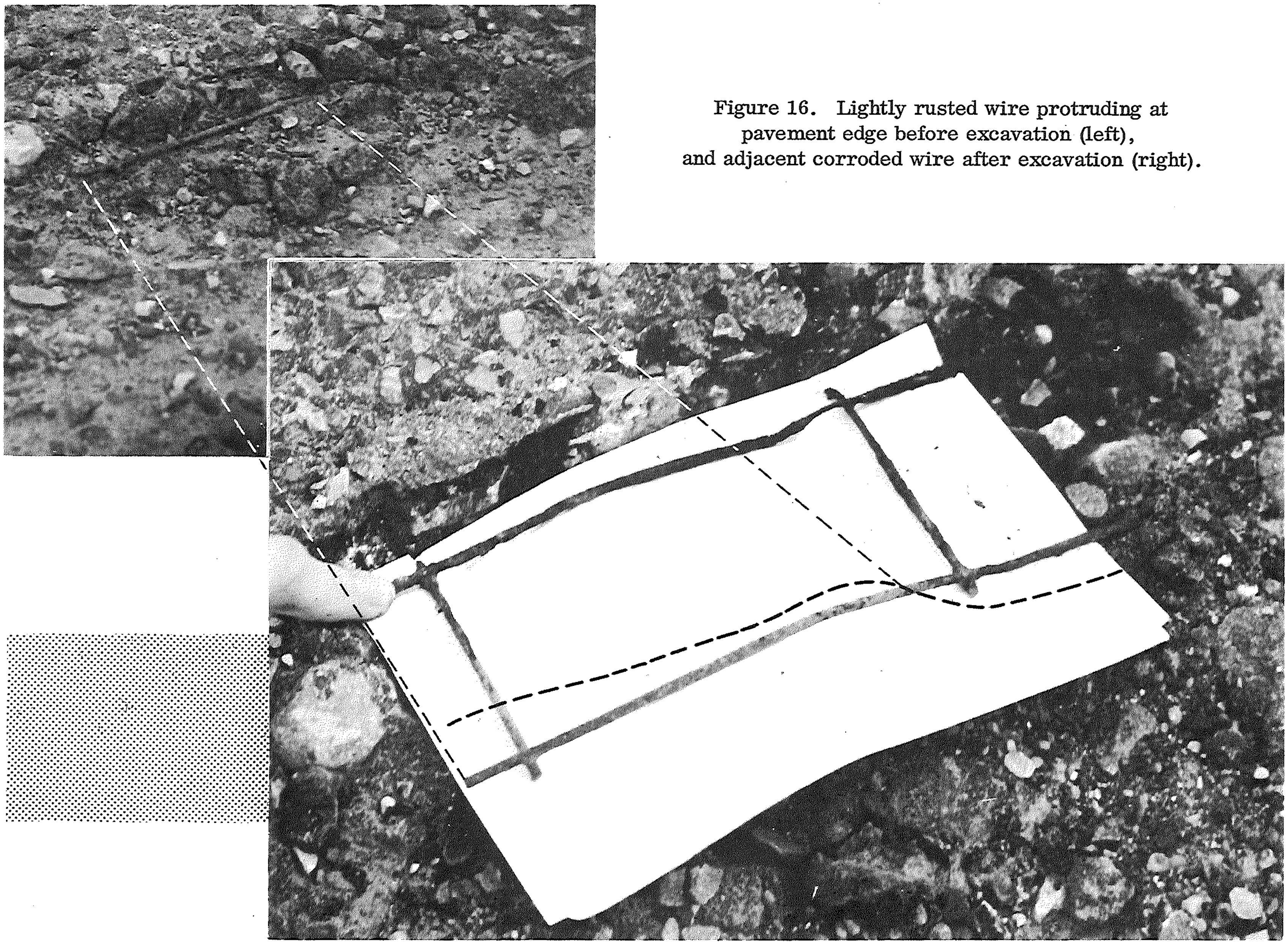


Figure 16. Lightly rusted wire protruding at pavement edge before excavation (left), and adjacent corroded wire after excavation (right).

1. Reinforcement in this cross-section offered no significant advantage in control of transverse or longitudinal reflection cracking.

2. Reinforcement in this cross-section offered no advantages in surface smoothness.

3. As a result of curling or buckling of reinforcing steel within the overlay during construction, potholes developed which are typical of this type of construction.

4. Extensive corrosion and fragmentation of reinforcing steel, a performance factor that has not been mentioned in the literature, was encountered even where the overlay surface was in good condition. In view of the tendency of bituminous concrete to absorb and retain moisture, some protective treatment seems necessary for the reinforcement.

On the basis of other experimental studies, the Wire Reinforcement Institute and state agencies active in this research area now advise against installation of reinforcement directly on the base pavement. Notably successful experiments have been reported in other states, where both crack control and effective load distribution appear to have been achieved by placing a leveling or binder course over the concrete base, then laying reinforcement, and completing the resurfacing with a wearing course, for a "sandwiched" cross-section. In some cases the "sandwiched" reinforcement is placed over a leveling or binder course and then covered with separate binder and surface courses for a three-layer cross-section.

REFERENCES

1. Bone, Alexander, and Crump, Lewis J. "Current Practices and Research on Controlling Reflection Cracking." HRB Bull. 123 (1956), pp. 33-39.

2. Bone, Alexander; Crump, Lewis J.; and Roggeveen, Vincent J. "Control of Reflection Cracking in Bituminous Resurfacing Over Old Cement-Concrete Pavements." HRB Proc., Vol. 33 (1954), pp. 345-54.

3. Brownridge, F. C., and Hartley, J. R. "Wire Mesh in Bituminous Resurfacing of Concrete Pavements in Ontario." Manuscript prepared for 5th Annual Meeting of Canadian Technical Asphalt Assn., Montreal, Nov. 1960.

4. Howard, Edward M. "Welded Wire Fabric Reinforcement in Asphaltic Concrete Overlays." ARBA Tech. Bull. No. 238 (1959).

5. Howard, Edward M. "Welded Wire Fabric Reinforcement of Asphaltic Concrete." ARBA Tech. Bull. No. 226 (1957), pp. 1-11.

6. Smith, Norman G. "Resume of Results of Welded Wire Fabric in Bituminous Surfaces." ARBA Tech. Bull. No. 215 (1956), pp. 10-19.

7. Smith, Norman G. "Welded Wire Fabric Reinforcement in Bituminous Resurfacing." ARBA Tech. Bull. 204 (1954).

8. Smith, Norman G. "Welded Wire Fabric in Bituminous Surfaces." ARBA Tech. Bull. No. 226 (1957), pp. 11-15.

9. Swanberg, John H. "Experimental Installation of Welded Wire Fabric in Bituminous Pavement." ARBA Tech. Bull. 207 (1954).

10. Tons, Egons, and Krokosky, Edward M. "A Study of Welded Wire Fabric Strip Reinforcement in Bituminous Concrete Resurfacings." AAPT Proc., Vol. 29 (1960), pp. 43-80.

11. Wakefield, Floyd G. "The Practical and Laboratory Use of Wire Fabric in Bituminous Resurfacing at Willow Run Airport." ARBA Tech. Bull. No. 215 (1956), pp. 1-9.

12. "Welded Wire Fabric in Asphaltic Concrete Overlay." Better Roads, January 1960, pp. 18-19.

13. "Welded Wire Reinforcement for Asphaltic Concrete Resurfacing Over Concrete Pavement Slabs." Washington, D. C.; Wire Reinforcement Institute (1954).

14. Zube, Ernest. "Wire Mesh Reinforcement in Bituminous Resurfacing." HRB Bull. 131 (1956), pp. 1-18.

APPENDIX

TABLE A
REMOVAL AND REPLACEMENT OF REINFORCEMENT IN TEST SECTION 1
(Station 13+07 to 46+06--3299 lin ft; 78,464 sq ft)

Station	Location*		Removed			Replaced, sq ft
	Pass	Cut Area	Length, ft	Width, ft	Area, sq ft	
13+15	C	Full width	6	7.5	45	45
13+59	N	N edge	6	1.3	8	--
15+12	N	S edge	2	2	4	--
20+45	S	Full width	12	7.5	90	90
21+62	S	N edge	2	4	8	--
22+07	N	Full width	12	7.5	90	90
25+25	S	N edge	4	1	4	--
25+78	S	Full width	1	7.5	7.5	7.5
25+85	N	S edge	1	1	1	--
26+10	S	Center	2	0.8	1.6	--
27+43	S	N edge	60	3	180	--
27+78	N	N edge	2.5	1.7	4.3	--
28+20	N	Full width	2	7.5	15	15
29+06	N	Full width	30	7.5	225	225
29+14	S	N edge	3	1	3	--
29+48	N	S edge	8	0.25	2	--
31+70	N	N edge	10	0.25	2.5	--
32+10	N	Center (N)	0.7	6	4	--
32+70	N	N edge	1	4	4	--
37+64	N	N edge	6	1.3	8	--
37+84	N	Center (S)	4	2	8	--
38+03	S	Full width	11	7.5	82.5	--
38+45	N	S edge	2.7	0.75	2	--
40+27	S	N edge	18	2.5	45	--
40+48	S	Full width	8	7.5	60	60
40+70	S	N edge	8	2.5	20	--
40+90	S	Full width	13	7.5	97.5	--
41+03	S	N edge	7	2.5	17.5	--
41+42	S	N edge	6	2.5	15	--
41+48	S	N edge	7	2.5	17.5	--
41+64	S	N edge	21	2.5	52.5	--
42+03	S	Center	2.5	1.5	3.75	--
42+15	S	N edge	7	3	21	--
42+30	S	Full width	21	7.5	157.5	157.5
42+68	S	N edge	15	3	45	--
42+90	S	Full width	10	7.5	75	--
43+55	C	N edge	10	3	30	--
43+72	S	S edge	8	1.3	10.7	--
43+91	S	S edge	4	1.3	5.2	--
44+35	{ S, C	Full width, S edge }	1.3	10.0	13.0	13.0
44+50	S	S edge	18	2	36	--
44+90	S	N edge	10	3	30	--
45+12	N	N edge	7	3	21	--
45+67	C	Full width	15	7.5	112.5	112.5
				TOTAL	1685.05	815.5

2.1 PERCENT OF TOTAL AREA REMOVED.
48 PERCENT OF REMOVED REINFORCEMENT REPLACED.

* Reinforcing mats (7.5 by 15 ft) placed in three 8-ft passes: N = north third (median edge), C = center third (over old centerline), S = south third (over widening strip to outer edge.

TABLE B
REMOVAL OF REINFORCEMENT IN TEST SECTION 3
(Station 80+00 to 125+25--4505 lin ft; 180,120 sq ft)

Station	Location*		Removed		
	Pass	Cut Area	Length, ft	Width, ft	Area, sq ft
18+18	S	N edge (3 sections)	3	1	3
18+18	S	S edge	5	1	5
82+00	C	N edge	7.5	1.5	11.25
82+95	S	N edge (6 sections)	6	1	6
83+00	S	S edge	1	1	1
83+15	S	N edge	8	1.5	12.0
85+00	C	S edge	3	1	3
85+40	C	S edge	5	0.5	2.5
97+05	C	N edge	9	2	18
100+00	S	N edge	4	1	4
100+00	S	S edge	5	1.5	7.5
100+80	S	N edge	2	1.5	3
102+15	S	S edge	9	1.5	13.5
105+60	S	N edge	7	1.5	10.5
106+80	S	S edge	4	3	12
108+65	S	S edge	7.5	3	22.5
108+70	S	S edge	0.5	3	1.5
111+65	C	S edge	5	0.75	3.85
112+12	S	N edge	3.5	1	3.5
112+15	S	N edge	7.5	2	15
112+35	S	N edge	7.5	1	7.5
112+65	S	N edge	7.5	1.5	11.25
113+25	S	N edge	7.5	2	15.0
113+60	S	N edge	7.5	2	15.0
113+85	S	N edge	7.5	1.5	11.25
				TOTAL	218.60

0.2 PERCENT OF TOTAL AREA REMOVED.

* Reinforcing mats (7.5 by 15 ft) placed in three 8-ft passes: N = north third (median edge), C = center third (over old centerline), S = south third (over widening strip to outer edge.