EXPERIMENTAL STEEL-FIBER-REINFORCED CONCRETE OVERLAY

MICHIGAN HIGHWAY RESEARCH LABORATORY SECTION

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

EXPERIMENTAL STEEL-FIBER-REINFORCED CONCRETE OVERLAY

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An Experimental Project
By the Michigan Department of State Highways
In Cooperation with the Michigan Concrete Pavers Association
And the Federal Highway Administration

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Summary

A jointed fibrous concrete overlay of 3-in. minimum thickness was mixed and placed with a conventional batch plant and slipform paver with only minor alterations in procedure. Fiber contents were 120 and 200 lb per cu yd of concrete. Joint spacings in the overlay were 50 and 100 ft. The fibrous concrete was handled quite well by the construction equipment, with the main problem being formation of small fiber balls in the mix.

The new pavement was opened to heavy traffic after only two days cure at quite cold temperatures. Early performance has been poor in the areas with 120 lb of fibers per cu yd, but considerably better in the 200-lb sections. This is particularly true on the two outside, most southerly, lanes.

Introduction

This report covers construction of an experimental steel-fiber-reinforced concrete overlay on M 102 (Eight Mile Rd) in Detroit. The work in this project is being done as a cooperative effort by the Michigan Department of State Highways, the Michigan Concrete Pavers Association, and the Federal Highway Administration.

Conventional overlays of flexible materials are generally affected by reflective cracking over cracks and joints in the old pavement. Fiber-reinforced concrete has high flexural strength and rigidity that may be capable of successfully bridging over defects in the old pavement, and more effectively distributing loads.

The purpose of this experiment is to evaluate the performance of a fairly thin steel-fiber-reinforced concrete overlay under heavy traffic, in comparison with a conventional bituminous concrete overlay, when both are applied over an old and cracked portland cement concrete pavement. A primary objective was to determine the feasibility of batching, mixing, transporting, placing, and finishing the fiber-reinforced concrete with conventional equipment in an urban construction environment.

This project was proposed by the Michigan Concrete Pavers Association as a test of the fibrous concrete principle under conditions of very heavy traffic to determine whether it was suitable for urban highway reconstruction. The Department agreed with the proposal, and subsequent approval of the FHWA allowed the project to be completed by authorization as an addition to an existing contract.

Scope

Approximately 520 cu yd (5,900 sq yd) of fibrous concrete were placed on a heavily traveled urban roadway, overlaying a 20-ft concrete pavement that was built in 1930, a 12-ft concrete widening lane placed in 1955, and new 6 and 10-ft base course widening. The overlay was designed for 3-in. minimum thickness. Two slab lengths and two different fiber percentages were used.

Preliminary Laboratory Work

Once the site was selected and sources of materials determined, samples of the materials were submitted by MCPA to Prof. C. E. Kesler at the University of Illinois, for trial mixes. A smaller quantity of the materials also was sent to the Department's Research Laboratory for experimentation. These samples included the actual cement to be used, along with sand, 25A slag aggregate, and wire fibers (US Steel 0.010 by 0.022 by 1-in.), liquid water reducer/retarder and air-entraining agent. Preliminary results from Prof. Kesler led to the selection of a mix containing 9 sacks of type 1A cement per cu yd, and a 40/60 slag to sand ratio by volume. The 9-sack mix was selected for high early strength for opening to traffic at relatively early age, and also for high ultimate strength to adequately span the discontinuities in the old pavement. Another benefit of the higher cement and mortar content is to provide a more workable mix at the paver.

Table 1 shows the results of two 1 cu ft lab mixes made from the limited materials supplied. The strength values shown are the average of two test specimens each, cured under polyethylene until time of test. Decreased strength values at greater age, as shown for Mix B, are not unusual for tests with such a few specimens.

Based upon information supplied by Prof. Kesler, and on the limited work indicated above, the mix design for the project was set up as shown in Table 2. Normal adjustments for moisture in the aggregates and air entraining agent additions to insure a 2 to 3-in. slump and air content of 5 to 8 percent would be made at the plant.

Calculations indicated that flexural strength should be in the range of 800 to 900 psi at time of opening to traffic, and it appeared that the mix specified should be capable of developing such strength in two days if the weather was reasonably warm during cure.

Photographs were taken from the curb, at approximately 10-ft intervals, to record the condition of the existing pavement prior to placement of the overlay.

TABLE 1
RESULTS OF LABORATORY MIXES PREPARED
FROM PROJECT MATERIALS

	Mix A	Mix B
Cement, sack/cu yd	9.0	9.0
Steel fibers, lb/cu yd	200	120
Stone/sand, by vol	40-60	40-60
Pozzolith 100 XR, oz/sack	3	3
MBVR, oz/sack	1/4	1/4
Slump, in.	2-1/2	3
Air content, percent	5.6	5.5
Flexure strength, psi		
1 day	650	650
2 day	930	950
7 day	1,010	910
Compressive strength, psi		
1 day	3,290	3,510
7 day	5,600	5,500

TABLE 2
FIBROUS CONCRETE OVERLAY MIX DESIGN

MATERIALS

Portland Cement	- Peerless, Detroit, Type 1A
Fine agg., 2NS	- Pit No. 63-55
Coarse agg., 25A	- Blast furnace slag

MIX DESIGN (lb/cu yd)

Cement (9.0 sacks)	846	846
Fine agg. (dry wt)	1,494	1,539
Coarse agg. (dry wt)	873	900
Total water*	395	379
Steel fibers	200	120
Net W/C ratio	0.38	0.36
Pozzolith 100 XR (Oct. 7)	27 oz	27 oz
Pozzolith 200N (Oct. 9)	36 oz	36 oz
Daravair (1 oz/sack) as needed for 5 to 8 percent air		

* Includes water of absorption of aggregates which amounts to 72.6 and 75.9 lb for the two mixes. Adjust mix water for 2 to 3-in. slump at the paver.

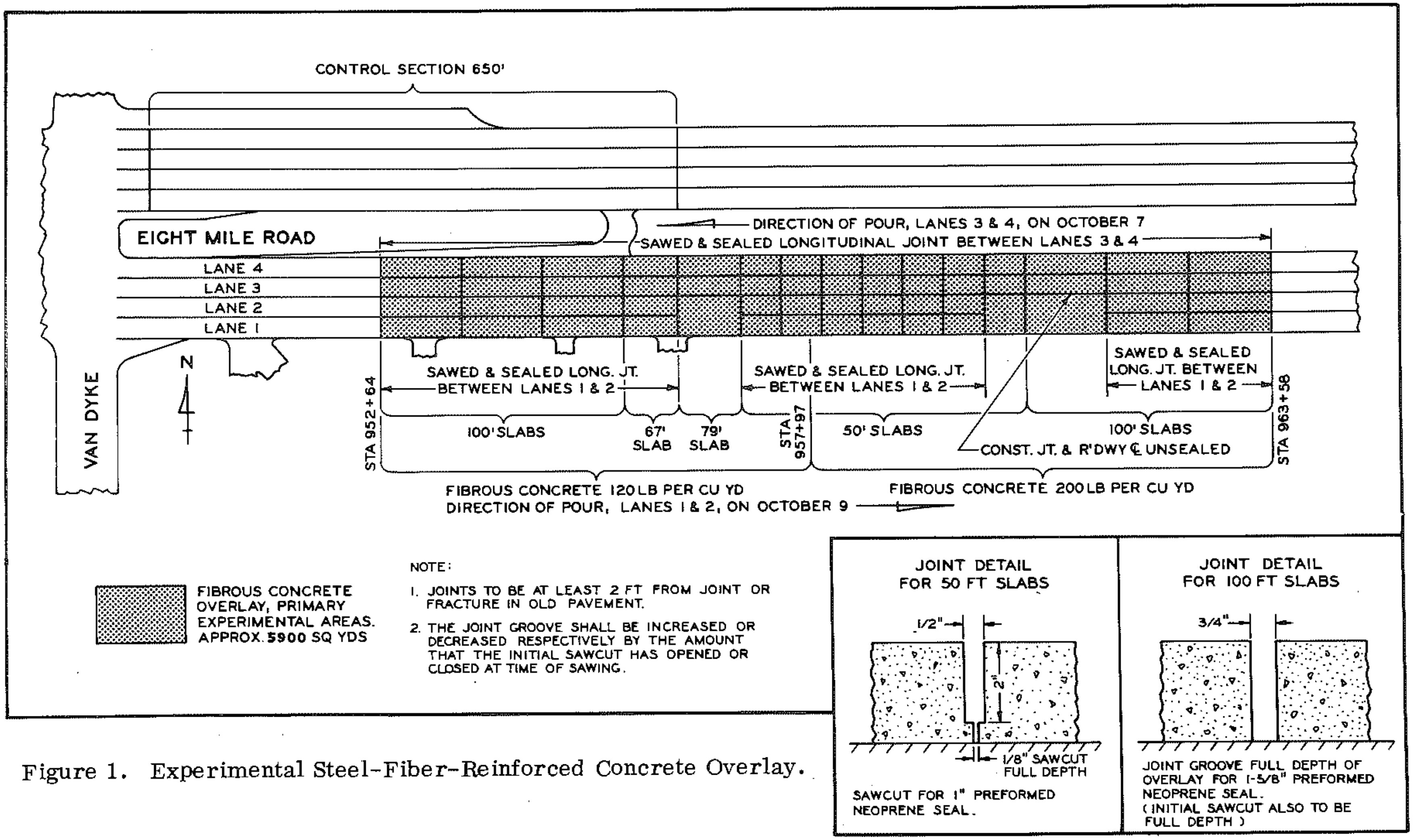


Figure 1. Experimental Steel-Fiber-Reinforced Concrete Overlay.

Experimental Details

The experimental overlay was placed October 7 and 9, 1972 on eastbound Eight Mile Rd, just east of VanDyke. New concrete base course widening had been placed for a width of 10 ft on the median side and 6 ft on the outside. The overlay is four lanes, 48-ft wide, with normal slab lengths of 50, and 100 ft. Two slabs were made about 67 and 79 ft long because of manhole covers in the roadway. Fiber contents were 120 and 200 lb per cu yd. Figure 1 shows a sketch of the installation and the arrangement of the variables. Concrete placed on October 7 contained a water reducer/ retarder but that placed on October 9 contained only a straight water reducer.

Batching and mixing of the fibrous concrete, were done by standard equipment at the contractor's nearby central mix plant. Batch size was 6 cu yd. No specially designed machinery was available for use in handling the steel fibers which were delivered to the site in 40-lb cardboard boxes.

The plant was in use for other purposes until the day that paving was scheduled to begin, so there was little opportunity for experimentation. Therefore, paving was delayed for a day to work out some early difficulties in batching. The main problem that occurred in the batching operation was the formation of clumps of fibers. An initial attempt was made to use a modified agitator truck to break up clumps prior to placing the fibers on conveyors for charging the mixer. It was found that clumps reformed quickly at any constriction through which the fibers were forced to pass, and therefore the truck was abandoned.

The method finally used to handle the fibers was mainly manual. Boxes of fibers were dumped by hand into an end loader. The loader then transported the fibers to a table and hopper assembly that was built over a conveyor belt. Workmen then raked the fibers into the hopper, and worked them through a wire mesh screen onto the belt, as shown in Figure 2.

There were some additional problems at the mixer entrance, since this particular plant had a drum with an opening somewhat smaller than desirable for this type of work. The end result was that there were some small balls of fiber in the mix when it was delivered to the paver. A mixer with a large opening would be a considerable advantage in work with fibrous reinforcement.

However, in spite of the problems that occurred at the plant, which were to be expected in a venture of this type, the crew managed to average about 40 cu yd per hr the first day, nearly 60 cu yd per hr the second day,

Figure 2. End loader delivers fibers to table and hopper where workmen rake them through the screen.

and at one time prepared the mix at a rate equivalent to about 90 cu yd per hr, for a few loads. It seems evident that the development of specialized bulk handling and screening equipment for the steel fibers (probably vibratory in nature) would pay dividends in both quantity and quality of the fibrous mix produced.

Construction

The existing roadway was prepared for overlay by air blast and power brooms. No special surface preparation was done to assure bond of the overlay. The overlay was intended to be "partially bonded," which requires only a clean surface, preferably sprayed with water ahead of the paving operation. Some portions of the old pavement were sprayed with water, others were left dry.

The mix was deposited on the slab by trucks, and placed by a 24-ft slipform paver (Fig. 3). Some problems were encountered in placement of the mix, as is to be expected on an initial trial of a new product. They are documented here in the hope that future applications may benefit from this experience, and avoid some of these difficulties. The problem areas appear to be mainly operational, and not related basically to the principles of fibrous concrete.

The first load of concrete was quite stiff, as shown in Figure 4. Since the fibers tend to inhibit flow of the mix, and the thickness of overlay was only 3 in., a torn surface resulted when the paver moved forward. The machine was backed over the area, some wetter concrete added, and a suitable finish accomplished. Later deliveries with slump of around 3 in. were placed and finished without problems.

During the first day's work, a machine finisher was used behind the paver, but it was discarded the following day with no apparent loss in effectiveness. The surface was hand floated, and textured with a transverse mechanical broom or rake as shown in Figure 5. (This machine also applied the sprayed white membrane curing compound). Previous experience by others had indicated that burlap drag is unsatisfactory for use with the fibrous reinforcement. The transverse texturing machine did a satisfactory job on the fibrous concrete.

Previous mention has been made of small fiber balls in the mix. Figure 6 shows the appearance of such balls in the surface of the overlay, behind the paver. Apparently such balls absorb moisture and fines from the mix, causing small depressions in the surface that become more obvious with passing time. Some of these balls were removed by workmen during

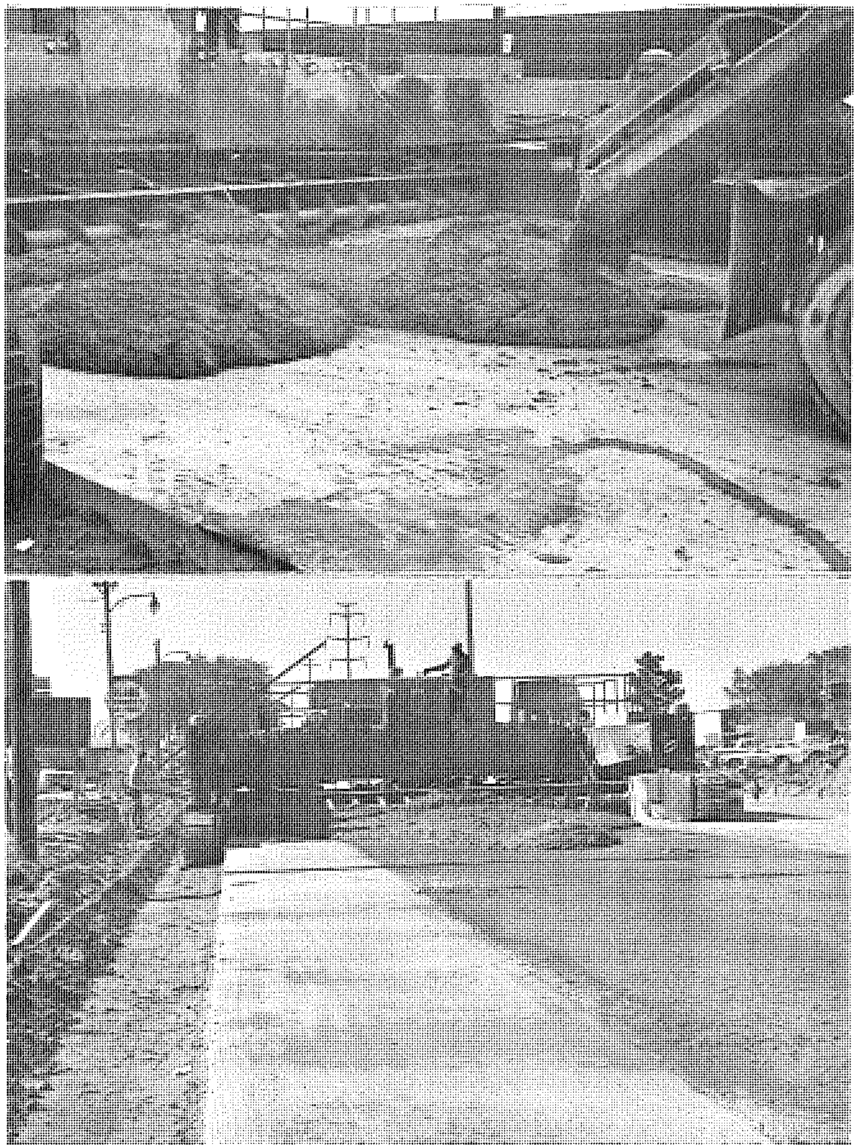


Figure 3. Slipform paver (24-ft) placing fibrous mix; second pass, outside lanes. Note new 6-ft base course widening in foreground, and tracks running on previously placed overlay at the right.

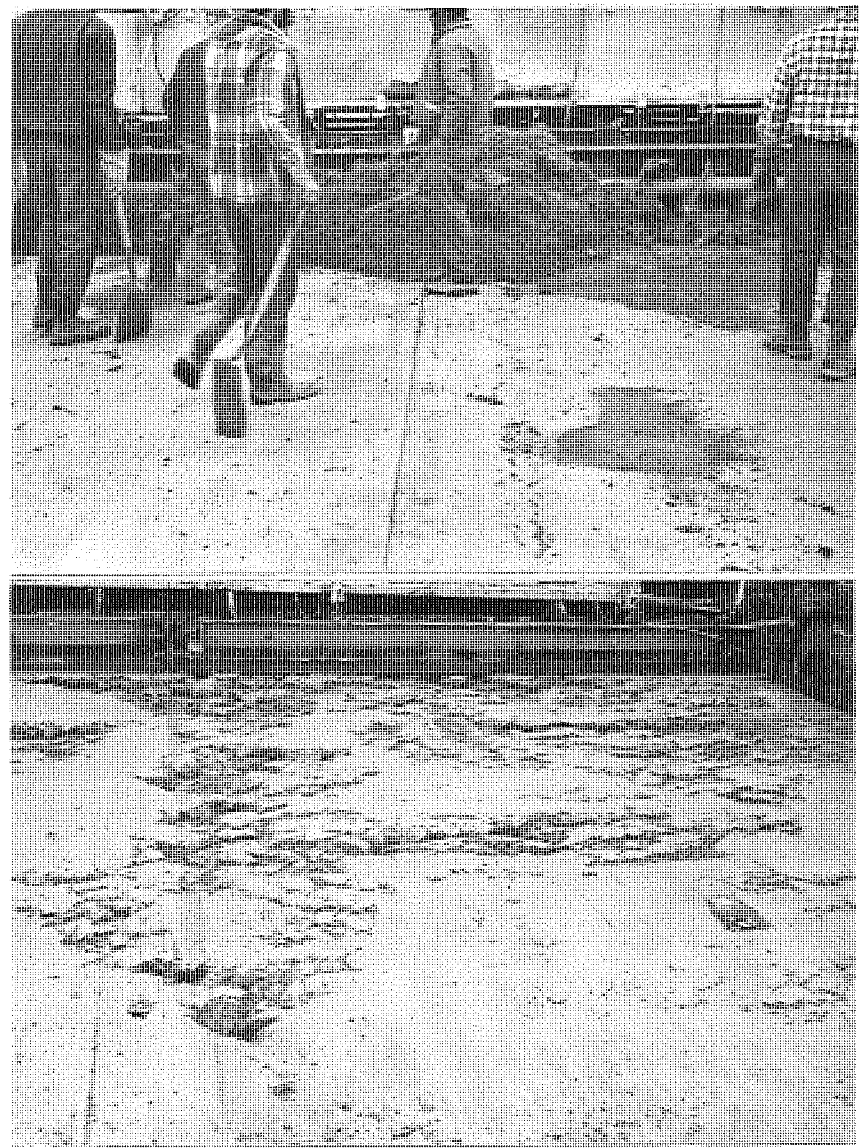


Figure 4. Dry concrete mix (upper) resulted in torn surface behind the paver (lower). A second pass with wetter mix finished the area suitably.

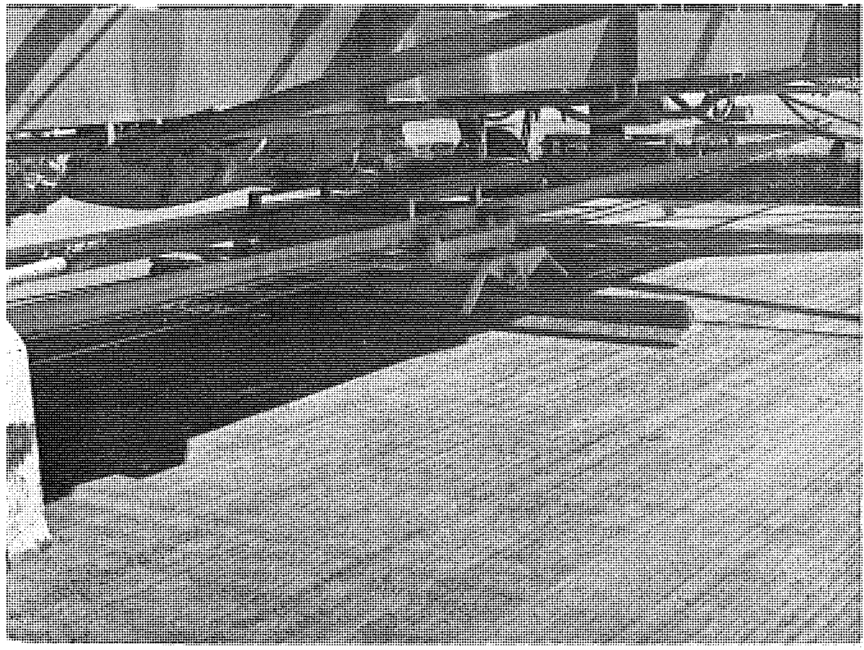
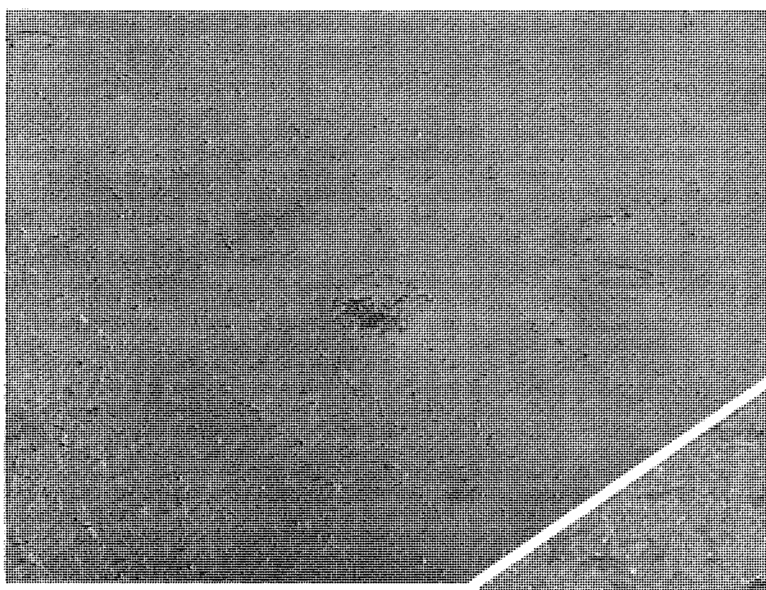


Figure 5. Transverse texturing machine provided satisfactory surface on the fibrous overlay.



Appearance of fiber ball in the fresh concrete. Water absorption by the balled fibers cause surface depressions that become more obvious sometime after finishing.

Appearance of surface failure after three month's service. Loose fibers are visible in water that had collected in the hole.

Figure 6. Fiber balls in the concrete overlay.

the paving operation, but many remain in the pavement, and will cause some problems in the future. Figure 6 also shows the type of early failure that has resulted at a few locations. It would seem that the occurrence of such balls would be minimized by the further development of materials handling equipment at the plant.

Heavy traffic in the construction area required opening the lanes two days after placement. Since construction was done late in the fall, under adverse weather conditions, curing temperatures were considerably lower than desirable. A temperature recorder was placed in a shaded location at the concrete plant to provide a record of the temperatures that occurred in the area during cure. Figure 7 shows the record obtained, and indicates that the temperature dropped below 40 F during the night after placement of the outside lanes on October 9. Heat from the ground and the heat of hydration would keep the pavement at some higher temperature, but the overlay is quite thin and would be expected to be affected to a greater extent by atmospheric conditions than would a thicker slab. It would seem reasonable

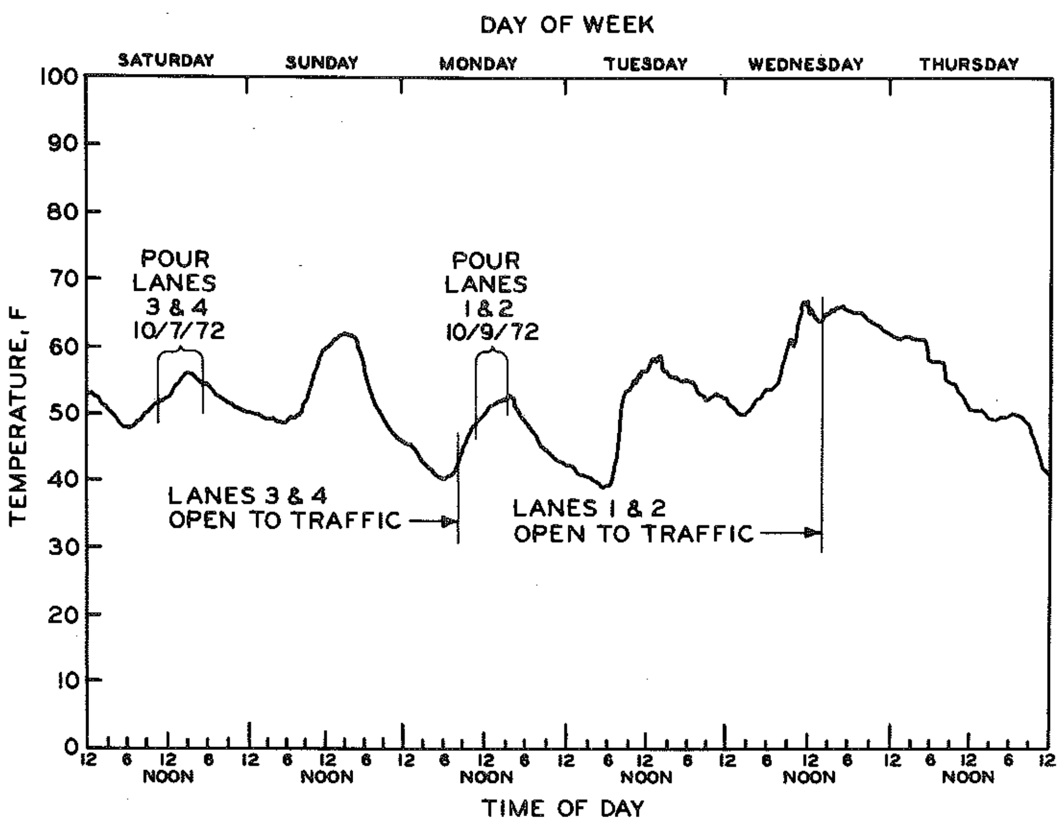


Figure 7. Temperature variation during placement and cure of overlay.

to apply some type of thermal protection to future projects, if such low curing temperatures are encountered, in order to obtain greater early strength gain.

Beams and cylinders were made from the mix at the job site for laboratory determination of strength gain and freeze-thaw durability. Results are shown in Table 3.

TABLE 3

COMPRESSIVE AND FLEXURAL STRENGTHS FOR FIBROUS CONCRETE CURED 1 DAY AT THE SITE.

(The cylinders, 7-day and 14-day beams were cured in plastic bags in the Laboratory until testing. Freeze-thaw beams were moist cured for 14 days and cycled through quick freezing in air and thawing in water (ASTM C 291).)

Date Cast	Fiber Content lb/cu yd	Air, percent	Slump, in.	Compressive Strength,[1] psi		Flexural Strength,[2] psi		Flexural Strength after 336 F-T cycles, psi[3]
				7-day	28-day	7-day	28-day	
10-7-72	200	6.5	2	4,110	5,430	810	1,070	1,000
10-9-72	200	6.0	2-3/4	4,000	5,690	760	950	1,080
Average Strengths				4,060	5,560	790	1,010	1,040
10-7-72	120	9.0	5-1/2	3,700	4,620	700	880	860
10-9-72	120	9.5	3	4,140[4]	5,040	750	860	950
Average Strengths				3,880	4,830	730	870	910

[1] Cylinders, 4 by 8-in., each tabulated value is an average of 3 tests.
[2] Beams, 3 by 4 by 16-in., each tabulated value is an average of 2 tests.
[3] Beams, 3 by 4 by 16-in., each tabulated value is an average of 3 tests.
[4] Average of 2 samples only.

Specimens made October 7 were cured under sheet plastic at the job site two days and then under plastic in the laboratory. The October 9 specimens were cured one day in the field and then in the laboratory.

Comparison of these results with comparable values from Table 1 indicates that the field specimens tested in flexure at seven days developed about 80 percent of the strength indicated for beams prepared and cured in the laboratory. Probably this is due to low temperatures encountered at early age in the field, as well as somewhat higher values for slump and air content, especially in the 120-lb mix.

Flexural results after freeze-thaw testing show that the specimens held up very well. Relative dynamic modulus of elasticity after 336 cycles of freeze-thaw (ASTM C 291-67), was still holding above 96 percent of the original value, which is very good. The fact that some flexural values are higher for the freeze-thaw specimens than for the 14 day beams is undoubtedly due to the additional moist curing applied to the former, as well as the fact that some additional curing can take place during the thaw cycles.

Table 4 shows early strength values measured by construction personnel at the job site, using the standard 6 by 6 by 36-in. beams, loaded at the center. Here again, a lower strength value at greater age is a result not unusual, considering normal variability of such test results, especially with such a few samples to average. Also there is the possibility of variable fiber dispersal and other slight mix variations from batch to batch and within a given batch. Comparison of these results with comparable values from Table 1 shows that the 200-lb mix in the field, tested at two days, was about 80 percent of the laboratory value, while the 120-lb mix at the same time was only slightly above 50 percent. Similar comparisons of seven-day values are roughly 85 and 70 percent, respectively. We would expect the early strength gain in the actual slab to be somewhat faster than in the beams cured at the site because of higher temperatures that are generated in larger masses of concrete. However, since the pavement was opened to traffic after only two days, the beam tests for the 120-lb mix seemed quite low when compared to the projected strength requirements of 800 to 900 psi.

TABLE 4
RESULTS FROM 6 by 6 by 36-in. BEAMS CURED AT
THE JOB SITE AND TESTED IN CENTER-POINT LOADING

Fiber Content	Modulus of Rupture, psi				
	1-day	2-day	3-day	7-day	14-day
200	590	750	800	960	870
	530	680	720	860	780
120	300	550	720	680	750
	270	500	650	610	680

*The lower values (line 2) in each category have been reduced by 10 percent for comparison with flexural values (Table 3) that were the results of 1/3-point loading.

A "feather edge" termination of the overlay was placed by the paver on one end of the job. This was accomplished quite easily and early performance of the thin wedge section seemed to be good; however, it began to break away after a few weeks, since it was not well bonded to the pavement.

At one location, the bituminous fill in a deteriorated pavement joint was not removed, and the upward projection of the joint area resulted in reduction of the overlay to less than 1-in. thickness. Traffic action on the thin section has resulted in a crack, but progressive failure has not occurred as yet. A failure of this type underscores the importance of adequate preparation prior to placement of the mix.

Pavement joints were sawed as previously shown in Figure 1, and sealed with preformed neoprene. Previous installations of fibrous concrete generally have been in continuous slabs of various sizes and, so far as we know, this is the first experiment with jointed fibrous concrete. One previous long-slab installation has developed fractures at various intervals throughout the length. The obvious adverse effects of infiltrated water or incompressible materials intruding between the old and new slabs, require the use of adequate seals at the joints. The full-depth saw cuts shown in the figure were made to allow some expansion space in the overlay. The depth of joint groove required for the seals would leave very little area at the bottom to resist compression, and therefore it was necessary to remove some of this material by sawing. Since weather was quite cool during construction some closure of the joints is to be expected during hot summer weather. Long term performance of the joints will determine whether adequate precautions were taken in design and construction.

Performance

Performance through the first three months of life seems to be adequate in the eastern end of the project where fiber content is 200 lb per cu yd. However, the outside lanes of the 120-lb section have developed some serious problems.

Several reflective cracks have developed over joints and cracks in the old pavement, and closely spaced fractures have developed in some localized areas. The worst deterioration that has developed to date does not appear to be totally the result of the pavement conditions underneath the overlay. Figure 8 shows the most seriously deteriorated section of the roadway, along with a view of the underlying pavement. It appears that the fractured area in the overlay exceeds the dimensions of the deterioration in the old pavement. This would seem to indicate a lack of strength or thickness of the overlay. Apparently the existing crown and grade in lanes 1 and 2 at the western end of the installation were such that the planned minimum thickness was not obtained. It appears that the overlay may be only 1-1/2 to 2 in. thick in several locations. Undoubtedly better curing conditions or longer cure before opening to traffic would have made some improvements

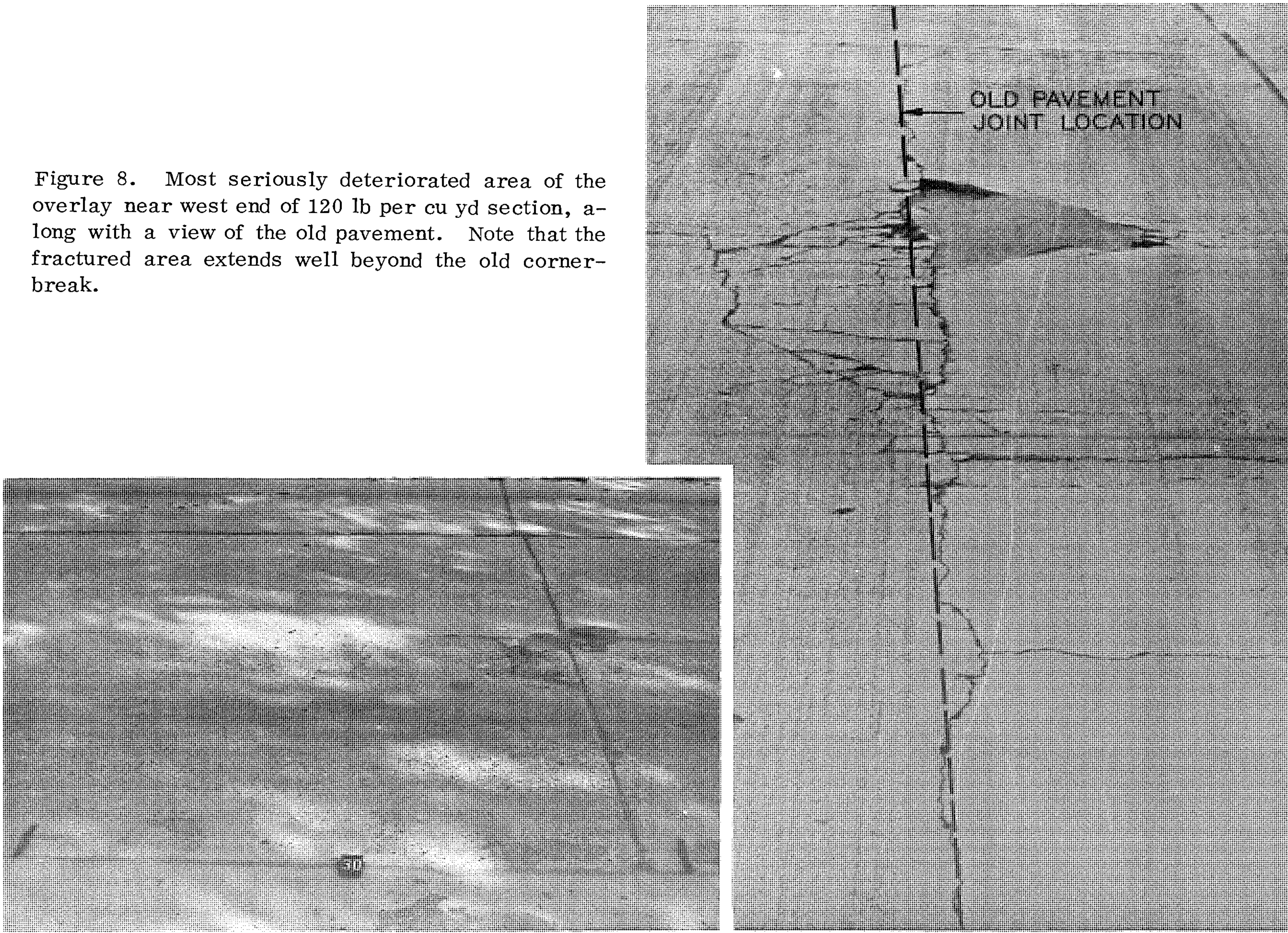


Figure 8. Most seriously deteriorated area of the overlay near west end of 120 lb per cu yd section, along with a view of the old pavement. Note that the fractured area extends well beyond the old cornerbreak.

in the performance of the section, but the reduced thickness would have drastic effects in any case.

The sawed longitudinal joint was left out of one slab in the 120 lb per cu yd section and two slabs in the 200 lb per cu yd section. Reflective cracks developed over the nearby longitudinal joint in the old pavement in the unsawed slab of the 120-lb section. The unsawed slabs of the 200-lb section are still without longitudinal cracking. This follows, in general, the better performance of the 200-lb mix. However, it was noted that the longitudinal joint in the old pavement seemed to be open wider towards the western end of the job where the 120-lb mix was used.

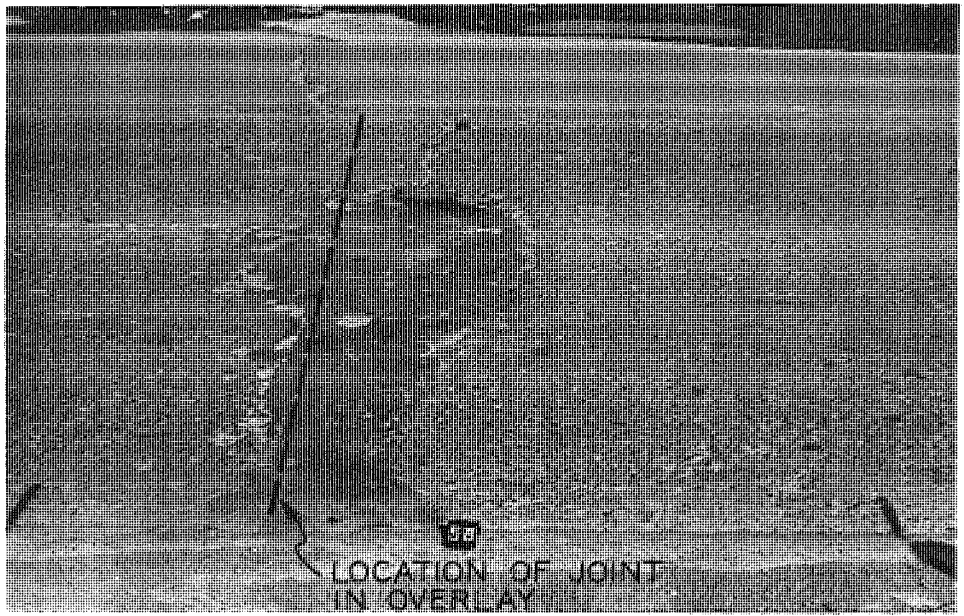
Figure 9 shows an object lesson in the location of joints in an overlay. The crack pattern in the overlay follows the pattern of the bituminous patch. Since this location is within the 120 lb per cu yd section, it may be that a crack pattern would have developed in any case. However, the ability of a given overlay to bridge such an area would be improved by removing the joint to an area with better support.

Conclusions

The preliminary results of this experiment indicate that standard construction equipment is capable of preparing, handling, placing, and finishing fibrous concrete, within certain limitations and with relatively minor modifications for dispensing fibers. Further equipment developments are required for bulk handling of fibers and for adequate dispersal of the fibers in the mix. Formation of clumps or balls is the problem that must be overcome. A concrete plant with a relatively wide-mouth mixing drum would be a distinct advantage in this respect, and vibratory feeders with fine screens would seem to hold promise for improvement of the system.

Fibrous concrete appears to be a new material with considerable potential for further application in the field of heavy construction. However, early performance information clearly indicates that great care is needed to make sure that the minimum required thickness is obtained throughout the entire area. Also, insulation of the overlay seems warranted during cold weather curing, if it is necessary to obtain high-early strengths for opening to traffic in a short time.

Although the 200-lb section has not cracked in the area where the centerline joint was left out, it would seem prudent to provide centerline joints in new overlays placed more than about 16 ft wide. The cost of sawing and sealing such a joint is not large, and seems to be worth the investment in



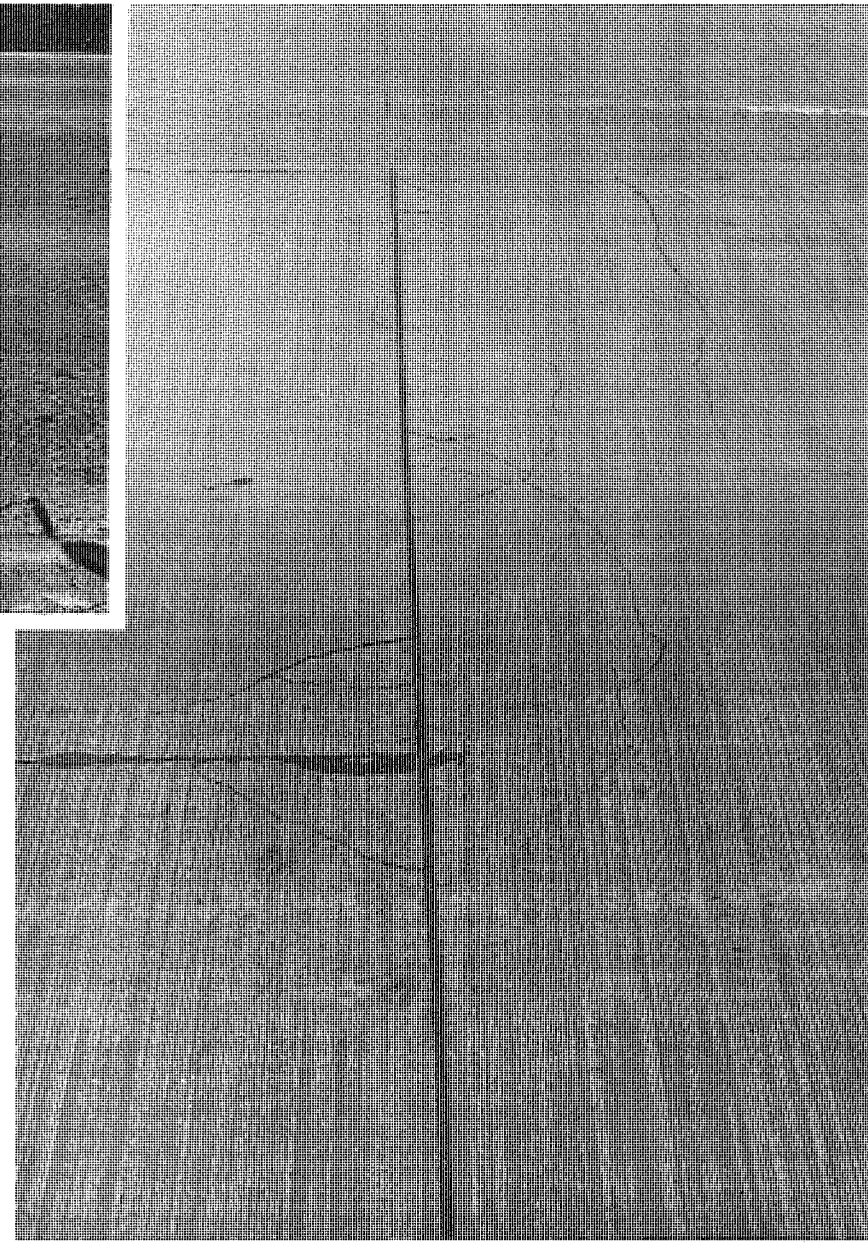


Figure 9. Deterioration of overlay due to location of joint over bituminous patch in old pavement.

order to prevent random longitudinal cracking and the associated problems that go along with such wandering cracks.

Note:

The above comments on performance were based on a condition survey made during January 1973. A subsequent inspection in mid-March revealed the following additional information.

The area shown in Figure 8 has deteriorated still more, and it was determined that the fibrous concrete thickness is only about 1-1/4 in. Also, another area known to be thin (refer to top of page 13), has developed closely spaced cracking similar to that shown in Figure 8.

Areas of such small thickness would be structurally inadequate, even if cured under the best of conditions. However, the thin section has additional adverse effects in this case. Such a thin layer of concrete would be drastically affected by the cold weather conditions that occurred during cure. Heat of hydration would be ineffective in maintaining higher temperatures, because of the high surface-to-volume ratio, and the concrete temperature at early age would have been far too low for reasonable strength gain. This has coupled an inadequate thickness with low strength, and the results are obvious to see.

The poor performance of the 120-lb test section, obviously has been affected by several factors other than the fiber content. Future performance of lanes 3 and 4 in the 120 lb section will provide additional information, since the pavement thickness there appears to be as planned. Therefore the failures mentioned here must not be construed as failures of the 120 lb fiber mix concept as such, and this project should not preclude further experimentation with mixes of similar fiber content.

Research Laboratory personnel will continue to evaluate the installation, and will issue further reports when sufficient data have been accumulated.