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PATCHING OF RIGID PAVEMENTS ON INTERSTATE HIGHWAY USING GLASS FIBER REINFORCEMENT

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SECTION I

INTRODUCTION

To investigate the problems of placement and the performance of glass fiber reinforced pavement patches, the service test described in this report was planned and executed. The object of the tests was to demonstrate the feasibility of using glass fibers for the principal reinforcement of repair patches made to highway pavements subjected to high volume traffic.

This maybe characterized as a pragmatic test of a promising application of short glass fiber reinf orcement in uniform distribution and of random orientation in portland cement concrete. The preliminary test results are qualitative only. No attempt has been made to develope quantitative results.

The test patches were made on a section of Interstate Highway 30 (presently designated I-20), in the western part of Fort Worth, Texas. A total of four patches were made on May 8, 1974. One was made with glass fiber reinforcement, about one percent by volume, substituted for conventional steel reinforced patches. Another was made with a small amount of fiber reinforcement, about 0.2 percent by volume, supplementing conventional steel reinforcement and intended to reduce or eliminate shrinkage cracks. Two additional patches were placed in a conventional fashion, with steel reinforcement, and function as "control patches" for the purpose of performance comparison.

No difficulties were encountered in mixing and placing the glass fiber reinforced concrete. The feasibility of such placement was, therefore, clearly demonstrated.

After 72 hours of curing, the lane with the patches was opened to traffic. Observations were made daily for a period of a week, then once each week through a total period of 60 days. All four patches have performed adequately. One small, lateral crack has developed in the Patch #1, where glass fiber alone was used. All other patches show no discernable distress. Observations will be continued, one per month, for a period of one year or until noticeable differences in performance become obvious.

The authors wish to acknowledge the assistance given by individuals of the Fort Worth District of the Texas Highway Department in making these tests possible. Mr. Jack Green was responsible for the original coordinated planning that was done. Mr. Green died during the week preceeding the placement of the test patches, and we profoundly regret his passing. Mr. Robert Cox, Mr. Luther Renfro, and the excellent repair crew were, in all ways, cooperative and enthusiastic in the accomplishment of the reported work. The participation of Owen-Corning Fiberglas in furnishing the glass fiber used was the direct result of the efforts made by Mr. William Pansius and Mr. Henry March of the Owen-Corning Fiberglas Technical Center at Granville, Ohio.

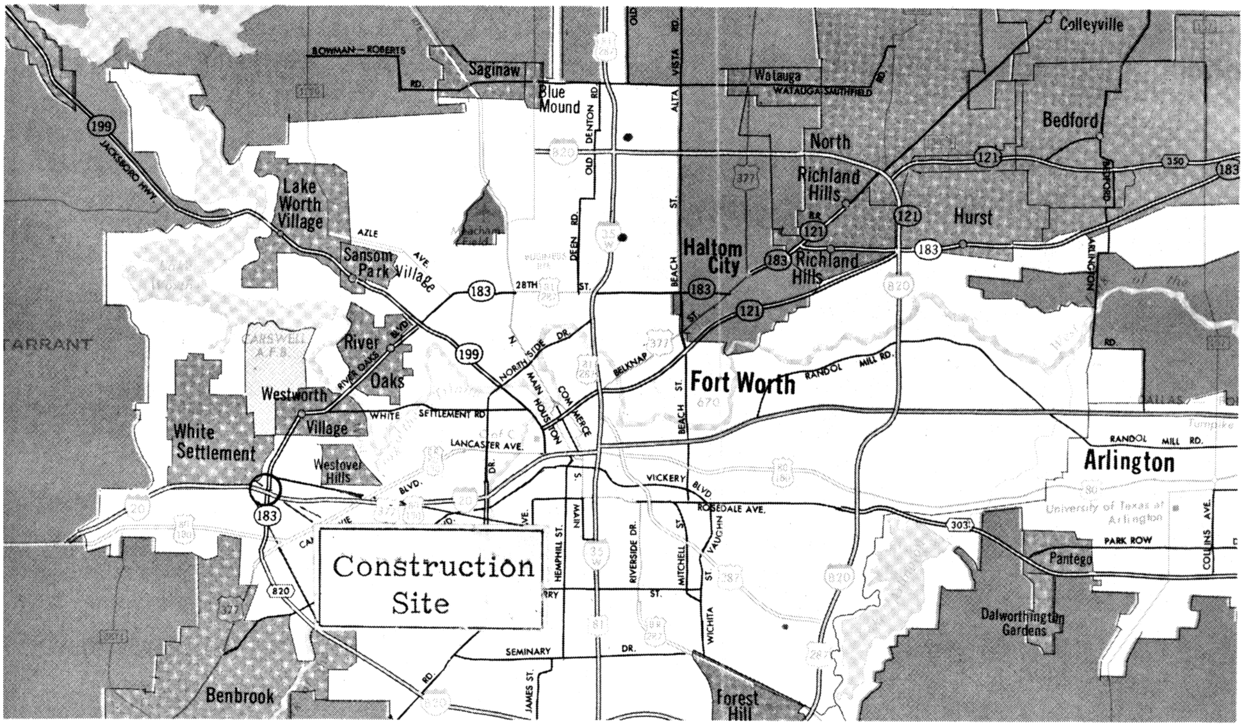

Figure 1: SITE OF GLASS FIBER REINFORCED PAVEMENT PATCHES ON INTERSTATE HIGHWAY 20

SECTION II

BACKGROUND

Investigations were begun early in 1970, at the University of texas at Arlington, of the physical characteristics of various kinds of fibrous materials that might be used as reinforcements for Portland Cement Concrete Mortar. Laboratory tests were made that have shown the superior properties of mortar and concrete matrices reinforced with glass fibers as compared to those reinforced with boron or graphite fibers. The results also indicate that glass fibers perform better as a concrete reinforcement than do steel fibers.[(1)]

Small, short, steel wire fibers have been used by others, for a wide variety of test specimens and in full-scale service tests of pavements, floor slabs and structural members. Difficulties have been experienced in handling, dispersing and placing the steel fibers. There is the tendancy of the steel fibers to form "balls" of tightly interlocked fibers and, because of their sharp, stiff, needle-like characteristics, steel fibers are hazardous to workmen during mixing and placement. For exposed concrete, these hazards could constitute

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(1) Buckley, E. L., Investigations of Alternative Fiber Reinforcement for Portland Cement Mortar and Concrete, Research Report TR-2-72, Construction Research Center, University of Texas At Arlington, Arlington, Texas; November 28, 1972.

a threat to the safety of the public. Never-the-less, the promising potential of fiber reinforced concrete has been fairly well established. Glass fiber, of an alkali-resistant formulation produced by Owen-Corning Fiberglas, is a practical reinforcement material with desirable properties. Like other fibers, surface adsorption of mixing water produces a stiff, unworkable mix at high concentrations of the fibers. Best results in the laboratory are obtained at fiber content of 1.5 to 2.0 percent by volume. In field tests, a fiber content of about 1.0 percent appears to be a reasonable limit until special equipment is developed to provide high energy vibration for compaction during placement. Tests have shown that fibers disperse with relative ease during on-site mixing in a conventional truck-mounted transit mixer. There are no hazards in handling nor in the finished product.

The theoretical equation shown below, and the typical values for the properties of concrete shown in Table 1, can be used to predict performance of glass reinforced concrete.

Using an energy balance approach, based upon the Griffith model of brittle fracture, the critical modulus of rupture for a fiber reinforced mortar or concrete can be predicted by:

$$f_r = \sqrt{\frac{2TE_c}{(1-\mu^2)\pi c} + \frac{(u\ \lambda)^2 \quad Lp}{928(1\ -\mu^2)nc}}$$

where T is the surface energy absorbed in the formation of cracks per unit of crack area,

TABLE 1

TYPICAL PROPERTIES OF CONCRETE

Ultimate Compressive Strength f'_c (psi)	Modulus of Elasticity E (psi x 10^6)	Poissons Ratio μ	Surface Tension T (in lbs/in^2)	Ctitical Half-crack Length c (inches)
2000	2.58	0.20	0.015	0.637
4000	3.64	0.16	0.035	0.641
6000	4.46	0.12	0.042	0.598
8000	5.15	0.11	0.050	0.538

E_c is the elastic modulus of the composite material determined by calculations based upon the "theory of mixtures".

μ is Poissons ratio for the concrete matrix.

c is the half-crack length of the critical crack or flaw

u is the unit bond stress

λ is the aspect ratio or length of the fiber over its effective diameter

L is the length of the fiber

p is the fiber content expressed as a percent of total volume

n is the modular ratio, the Young's modulus of the reinforcement (E_r) over the modulus of the concrete or mortar matrix (E_m).

The validity of the equation has been established by extensive tests,[2] within the following limits:

1) The aspect ratio is limited to values of about 100 for laterally stiff fibers. For glass fibers, aspect ratios up to about 135 (L = 1.5 inches) have been used, and the upper limit may be assumed to be about 2 inches.

2) The volume percentage p is limited by the adsorption characteristics displayed by all fibers which affects workability. Values of p of up to 4 or 5 percent have been used in the laboratory. Fiber content of from 1.0 to 2.0 percent by volume appears to be the practical limit for field applications.

3) Developable bond stress in steel wire fibers may be about 400 psi. Values of u for glass fibers have been approximated at about 200 psi by indirect methods. Work is continuing to change surface chemistry and increase the bond.

4) The modular ratio in the denominator indicates that low modulus materials, like glass, are superior to high modulus fibers. The lower limiting value would be when $E_r = E_m$ or n = 1.

Potential practical application of glass fiber reinforced concrete are numerous. Thin sections, where cover requirements result in disadvantateous placement of steel reinforcing bars, are most attractive. Slab-on-grade foundations for buildings are to be tested at the University of Texas at Arlington during the academic year 1974-75. Architectural panels, and other concrete products are considered to be promising applications. Glass fiber reinforced concrete pipe has been shown feasible by applications tests made in 1972 and 1973.[3]

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(2) Buckley, E. L.; op. cit.
(3) Buckley, E. L.; Unpublished reports of tests made for Can-Tex Industries, a division of HARSCO in 1972 and 1973.

Municipal street pavements have been tested.[4] Rigid highway pavements have characteristics that would appear to encourage the use of glass fiber reinforcement. The test reported here is, perhaps, the first step in developing the use of fibrous concrete as an alternate paving material.

Rigid pavements, serving high traffic volume routes, must perform under a wide range of subgrade support conditions. High wheel loads, a large number of load repetitions, and complex conditions of internal stress combine to result in frequent localized failures that reduce the serviceability index expressed in terms of crack development and degrades ride quality. No fully developed standard for the design of repair patches has been established.

The conventional repairs made by the Texas Highway Department are exemplified by Patch #3 and #4, described in this report and used as the basis of comparison of performance. Failed sections of a pavement slab and its steel reinforcement are removed, excavating to next vertical lines. Steel reinforcing bars, welded in place to the steel reinforcement that was installed in the original construction, are #5 ∅ bars at 6-inch centers longitudinally and #4 ∅ bars at 24-inch centers laterally. The steel is placed at the middle depth of an 8-inch slab.

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(4) Buckley, E. L.; Accelerated Trials of Glass Fiber Reinforced Rigid Pavements, Research Report TR3-74, Construction Research Center, University of Texas at Arlington; Arlington, Texas; April 12, 1974.

Shrinkage cracks, around the perimeter of the patch, are often the first stage in the failure of the patch. Subsequent admission of moisture, pumping, and loss of subgrade support result in loss of serviceability.

Fibrous reinforcement places randomly oriented fibers, uniformly distributed throughout the concrete matrix. Flexural strength can be substantially increased since reinforcement is provided at the extremities of the section. Improvement in ductility and fracture toughness can also be of benefit in avoiding or postponing evidence of initial distess under repetitive vehicular loads.

The apparent advantages that could be gained through the use of glass fiber reinforcement led to the planning, preparation and execution of the service test described in this report.

SECTION III

CONSTRUCTION

The selection of the pavement patch test site was made by Mr. Robert Cox, responsible for maintenance in the Fort Worth District of the Texas Highway Department. The site is in the center lane, eastbound on Interstate Highway 20 (soon to be redesignated as I-30), over a length of about 500 yards, in close proximity to the grade separation at the intersection of I-20 and State Highway 183. This section of Interstate Highway 20 is on the far West side of Fort Worth, Tarrant County, Texas. The four repair patches are located at intervals of from 50 to 100 yards, along the Eastbound lane.

For identification, the patches were numbered #1 through #4, beginning with the patch farthest to the West. The failed concrete was removed by a crew using pneumatically operated jack hammers. An acetylene torch was used to remove all steel bar reinforcement. All patches were carefully excavated to neat, vertical lines, and each hole was thoroughly cleaned. Before concrete placement was begun, new steel was installed with #5 ∅ bars at 6-inch on center in a longitudinal (East-West) direction. Tie bars, #4 ∅, were installed and welded to original steel bars. Concrete was delivered to the site by transit mix trucks. During placement, compaction was gained through the use of Wyco electrically powered vibrators. Thorough vibration was done to prevent voids and to aid in compaction and placement.

Patches were placed in the late morning of May 8, 1974. The slabs were sprayed with a curing component and allowed to cure for 72 hours. No traffic was allowed on the patches until the afternoon of May 11, 1974. Owens-Corning alkali resistant fibers one inch long were placed in the concrete for patches #1 and #2.

Patch #1:

Repair patch #1 was of a volume of 0.9 cubic yards. All steel in the patch section was removed as shown by Figure 2. The patch was made without steel reinforcement as shown by Figure 3. The concrete mix was designed for the proportions shown in Table 2.

The chopped glass fibers, one inch long, were dumped directly from the cardborad shipping container into the hopper of the rotating drum mixer of a ready-mix truck. The truck mixer was then operated at maximum mix speed for three to five minutes. Thorough distribution was achieved, and there was no evidence of any clusters or clumps of glass fibers being formed in the mixture. See Figure 4. The fibrous concrete composite material was readily ejected from the truck-mounted mixer with an apparent slump of about 2 inches. It was placed as shown by Figure 4, internally, and finished without difficulty. See Figure 5.

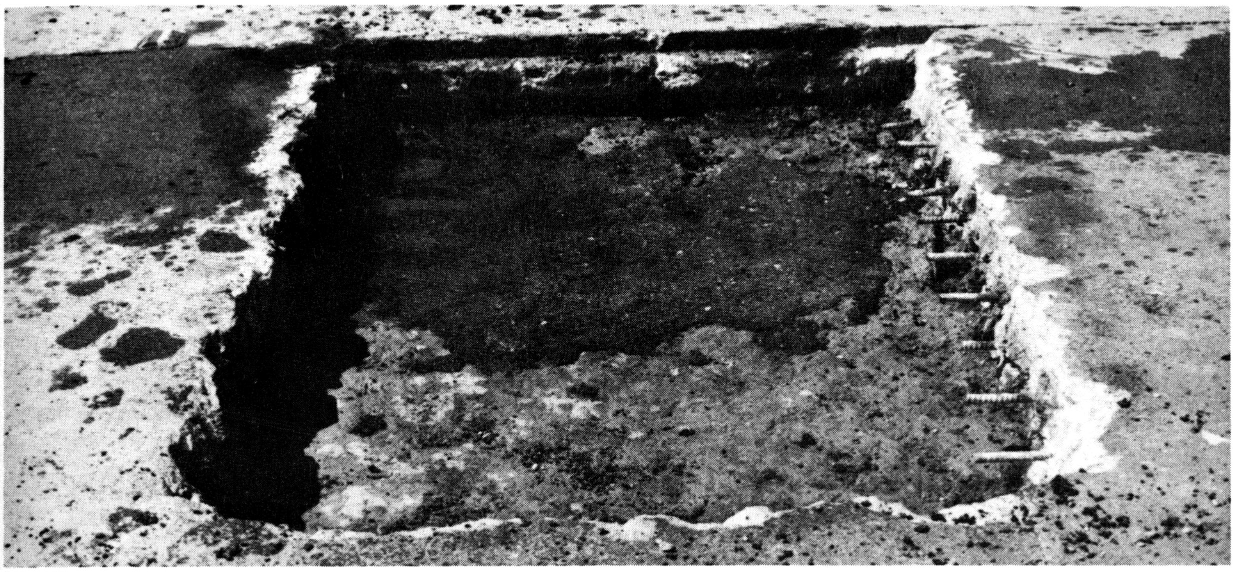

Figure 2: PATCH #1 BEFORE BEING FILLED WITH FIBERGLAS REINFORCED CONCRETE

Figure 3: PLACING FIBER REINFORCED CONCRETE IN PATCH #1

Figure 4: PLACING FIBER REINFORCED CONCRETE IN PATCH #1

TABLE 2

MIX PROPORTIONS FOR PATCH #1

Material	Quantity
Cement	8 bags/cubic yard of concrete (Portland type)
1 inch Fiberglas	slightly less than 0.9% by volume
water	451 pounds/cubic yard
sand	1,454 pounds/cubic yard
1/2" to 3/4" gravel	1,295 pounds/cubic yard

Patch #2:

The approximate concrete requirement, for the second patch to be made with glass fiber reinforcement, was about 0.7 cubic yards. An insufficient amount of glass fibers was available to permit the mixing at a volume content of about 1%. Also, there was less than 0.7 cubic yards remaining in the ready-mix truck. Therefore it was decided to leave the steel reinforcement in place in Patch #2. See Figure 6. It was also decided to place a patch with a mix of high shrinkage potential.

Concrete quantity in the mixer was increased by adding sand (no additional coarse aggregate was available), cement to maintain the eight sack/yd.^{3} proportion, and water to produce a slump of six inches or more. The glass fiber content was estimated to be about 0.2 percent by volume.

Figure 5: FINISHING OF CONCRETE IN PATCH #1

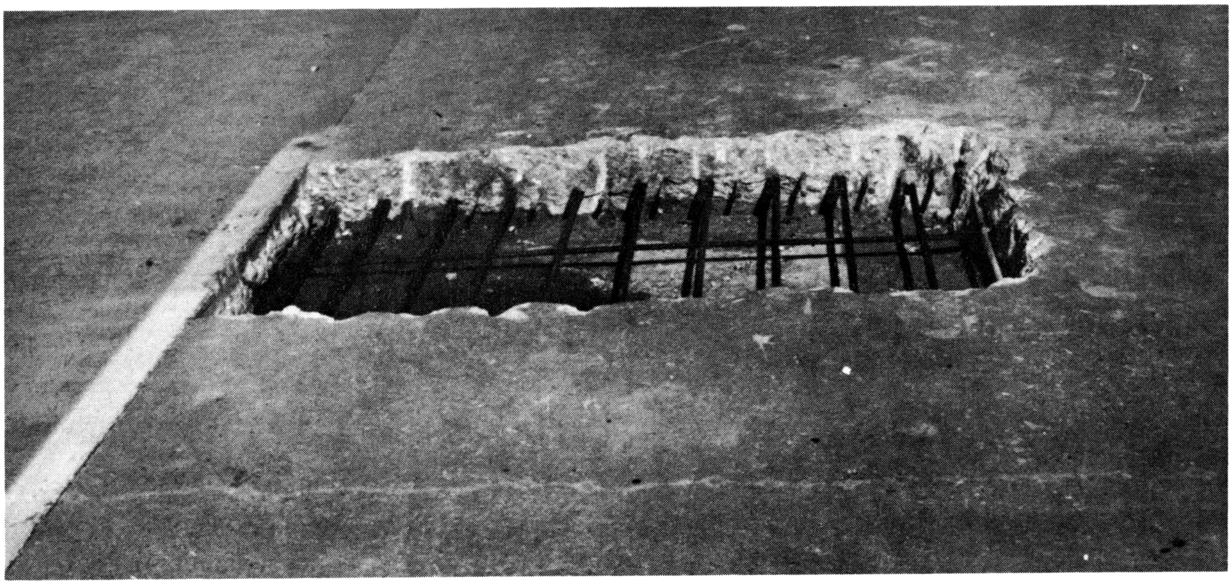

Figure 6: EXCAVATION OF PATCH #2

The idea was to place a concrete patch that would be sure to shrink and produce peripherial cracks if the glass fibers were not present.

Previous application tests made, by the Construction Research Center in the production of concrete pipe for Can-Tex Industries[5], had revealed unique shrinkage resistance of concrete mixes with small volume content of glass fibers. In the manual cutting, patching and plastering process that is involved in producing special reinforced concrete pipe fittings and shapes (tees, elbows, reducers, etc.), the shrinkage of the patch is a serious problem. Such cracks result in a high rejection rate of fittings produced. The glass fiber reinforcement in the concrete used for this manual patch work has produced very favorable results in terms of reduced rejection rate. It has been reported, by the operations branch of the Can-Tex plant in South Beloit, Illinois, that shrinkage cracks have been virtually eliminated, and the rejection rate has been reduced to zero.

The concrete was placed around steel reinforcement (#5 ∅ bars at 6-inch centers longitudinally and #4 ∅ bars at 24-inch centers laterally, as shown by Figure 7 in Patch #2) would normally have resulted in substantial shrinkage cracking about the perimeter of the patch.

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(5) Buckley, E. L.; Unpublished reports, op. cit.

The glass fibers, subsequent observations showed, resist shrinkage and cracking that would normally have occurred in this type of mixture.

Control Patches #3 and #4:

Patch #3 and Patch #4 (see Figures 9 through 12) were each of a volume greater than one cubic yard. The patches were made using concrete mix proportions and placement techniques that are typical of those most frequently used by the Fort Worth District maintenance function of the Texas Highway Department, with the exception that a maximum aggregate size of 3/4-inch was used in lieu of the $1\frac{1}{2}$-inches maximum aggregate size that is normally used.

Curing Period:

Curing compound was sprayed on all patches and barricades, erected for construction, were left in place for 72 hours. Observations made just before the resumption of traffic, with special attention given to Patch #2, show no indication of shrinkage cracks.

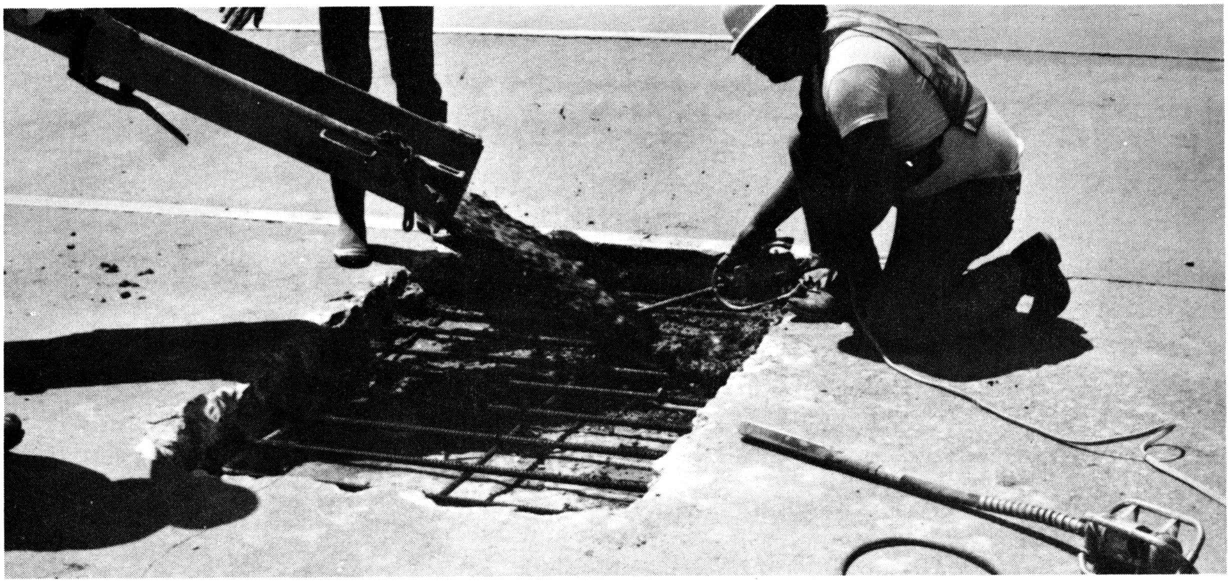

Figure 7: POURING OF PATCH #2

Figure 8: VIBRATING HIGH SLUMP CONCRETE IN PATCH #2

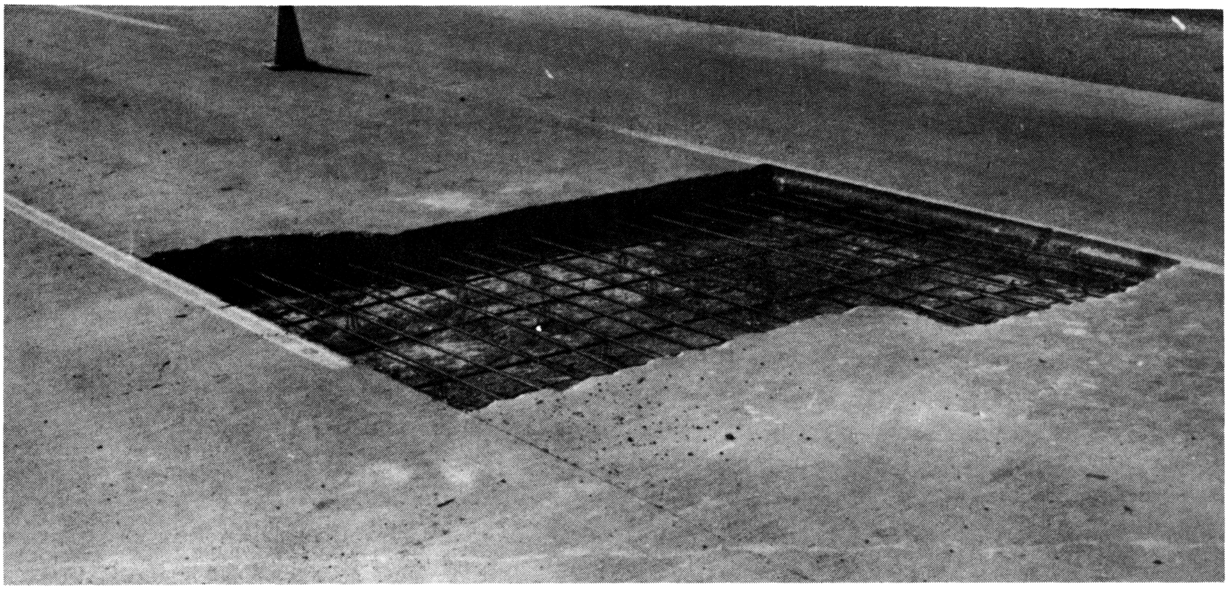

Figure 9: EXCAVATION OF PATCH #3

Figure 10: FINISHING OF PATCH #3

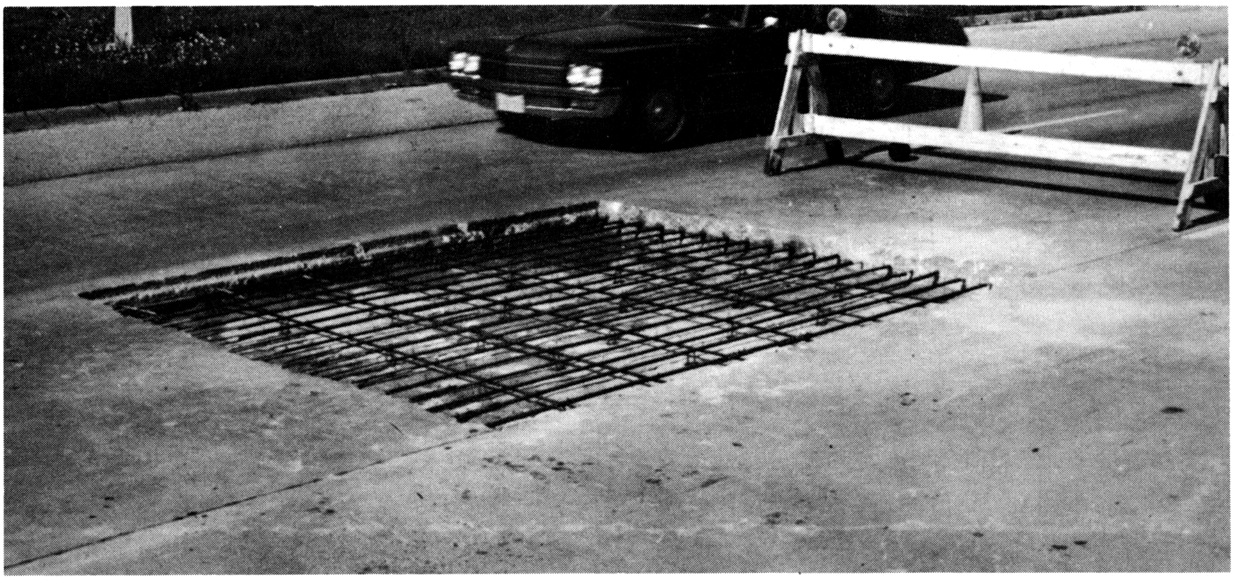

Figure 11: EXCACATION OF PATCH #4

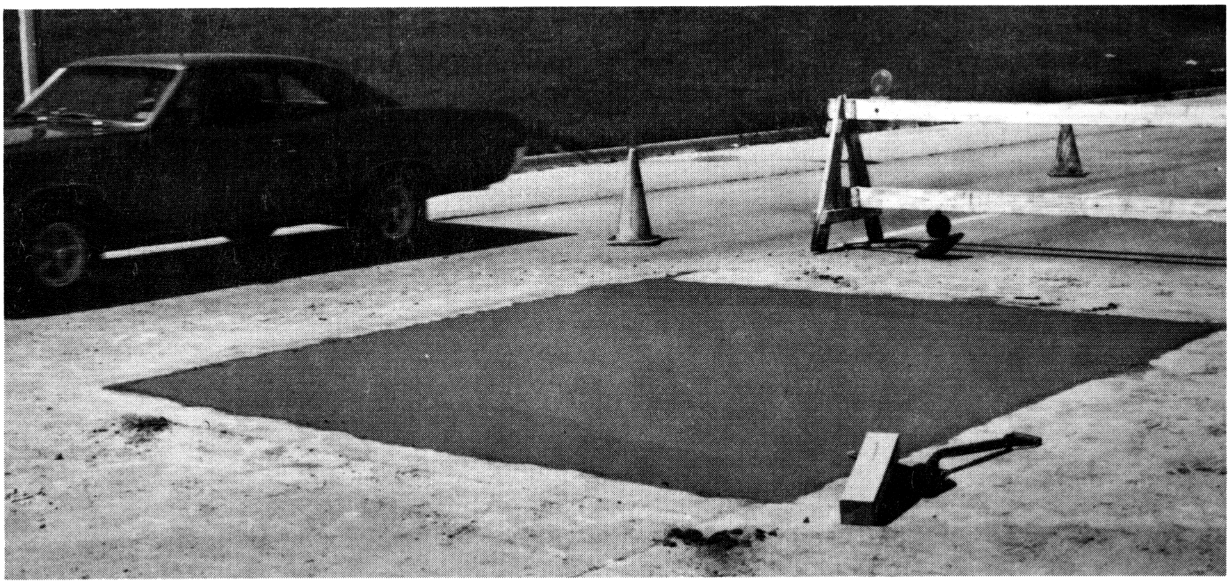

Figure 12: FINISHING OF PATCH #4

Figure 13: CLOSE UP SHOWING ABRASION OF PATCH #2

SECTION IV

OBSERVED PERFORMANCE

Daily observations, made for one week after traffic was allowed to travel upon the repaired center Eastbound lane of I-20, showed no discernible effects. Weekly observations were then made for two months from the date of placement.

After two weeks of traffic, the surface of Patch #2 showed some effects of abrasion. See Figure 13. This is believed to be the result of the floating of highly diluted cement paste to the surface of the high slump, sandy concrete employed in this patch.

Patch #1 was observed to have developed a Class 3 crack, discernible in the photograph, Figure 14, after 56 days of exposure to traffic. The crack runs laterally (from North to South) on the entire railing edge with respect to the direction of traffic flow (e.g.: East edge) of the patch where it joins that portion of the pavement that was undisturbed.

Patches #2 through #4 (Figures 15 through 17) showed no further appreciable changes.

A preliminary evaluation, of the observations made thus far, indicate that the objectives of the test are being met. The feasibility of placement of glass fiber reinforced patches in rigid pavement have been demonstrated. The performance of all patches has shown no significant difference between glass fiber reinforced concrete and steel reinforced patches.

In placing the patches, the glass fiber material reduces the time required since the welding of reinforcement bars in place can be avoided. With current increases in the cost of steel reinforcing bar, the economics of the patching operation also would appear to favor the use of glass fiber.

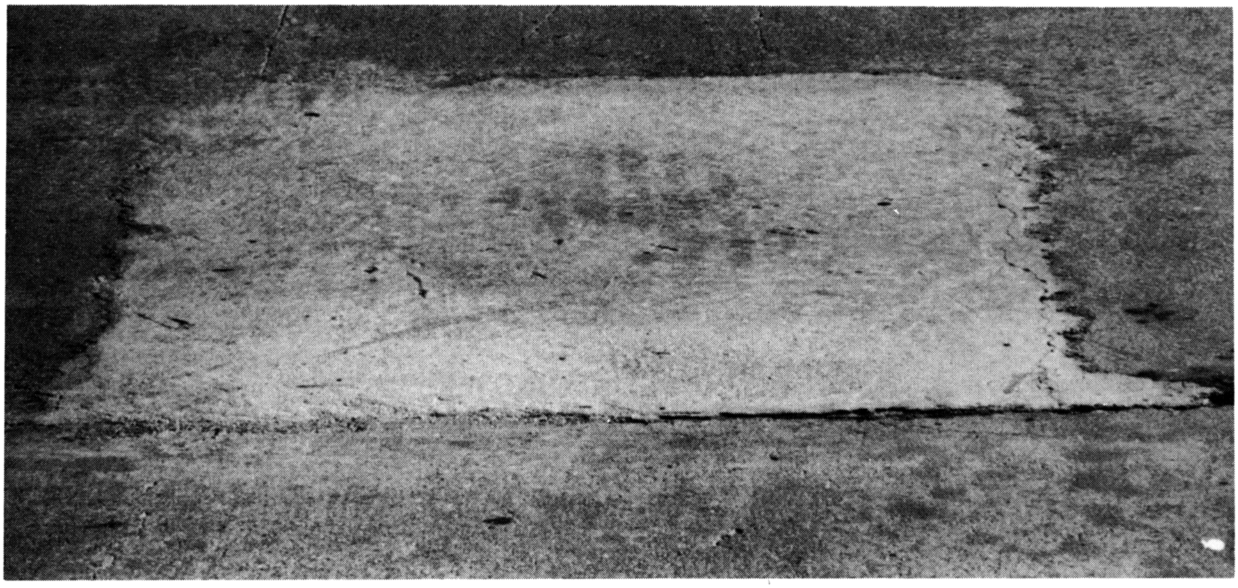

Figure 14: PATCH #1 AFTER 56 DAYS OF TRAFFIC

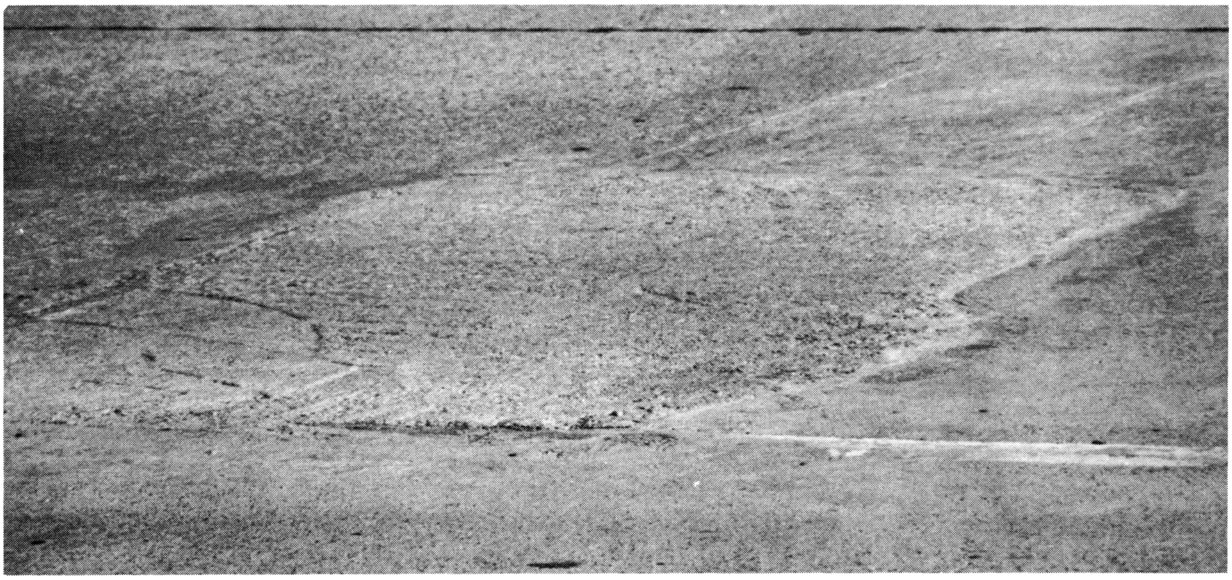

Figure 15: PATCH #2 AFTER 56 DAYS OF TRAFFIC

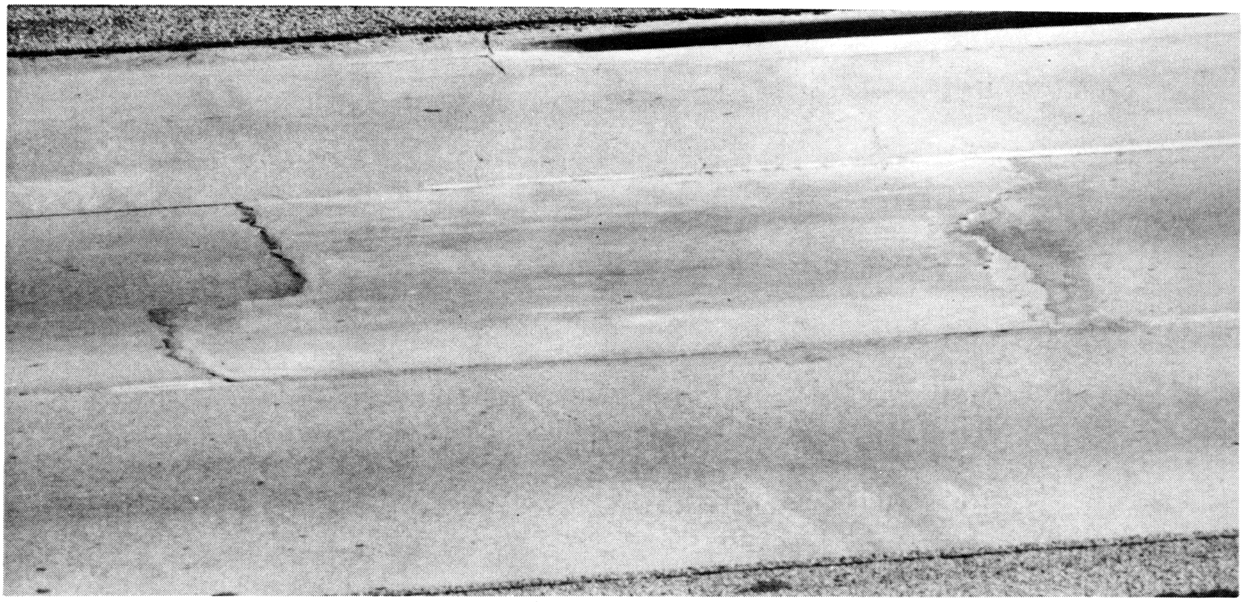

Figure 16: PATCH #3 AFTER 56 DAYS OF TRAFFIC

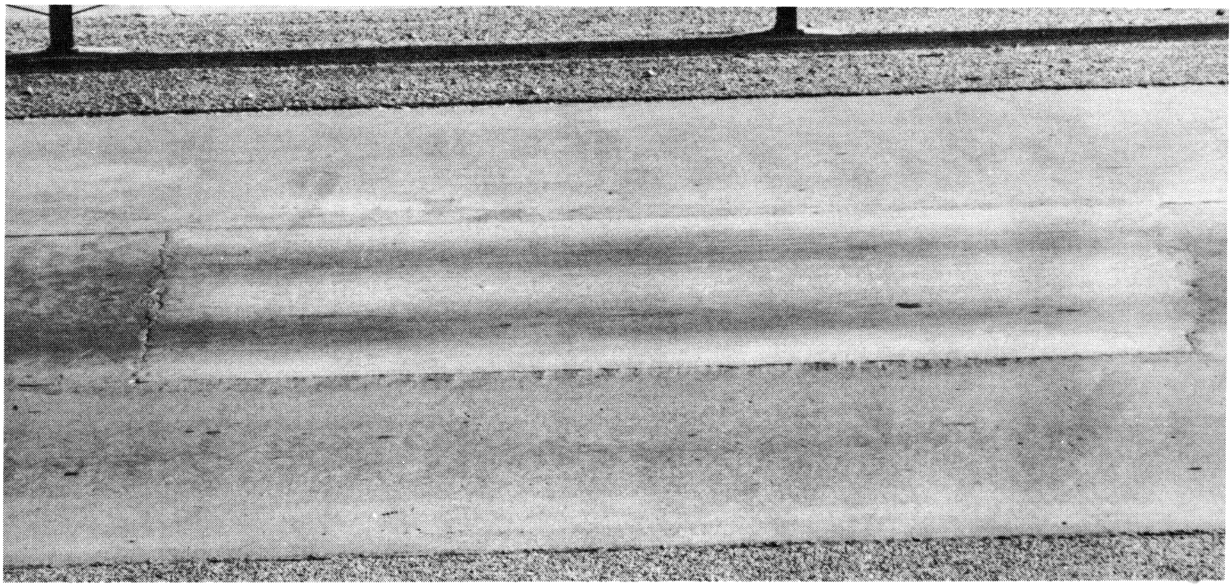

Figure 17: PATCH #4 AFTER 56 DAYS OF TRAFFIC