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FAULTING OF PORTLAND CEMENT CONCRETE PAVEMENTS

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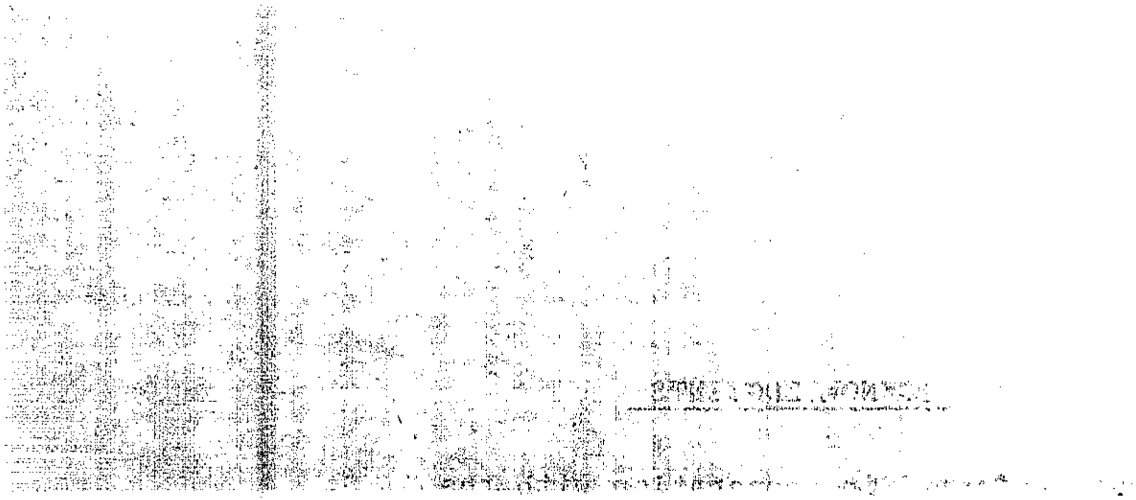

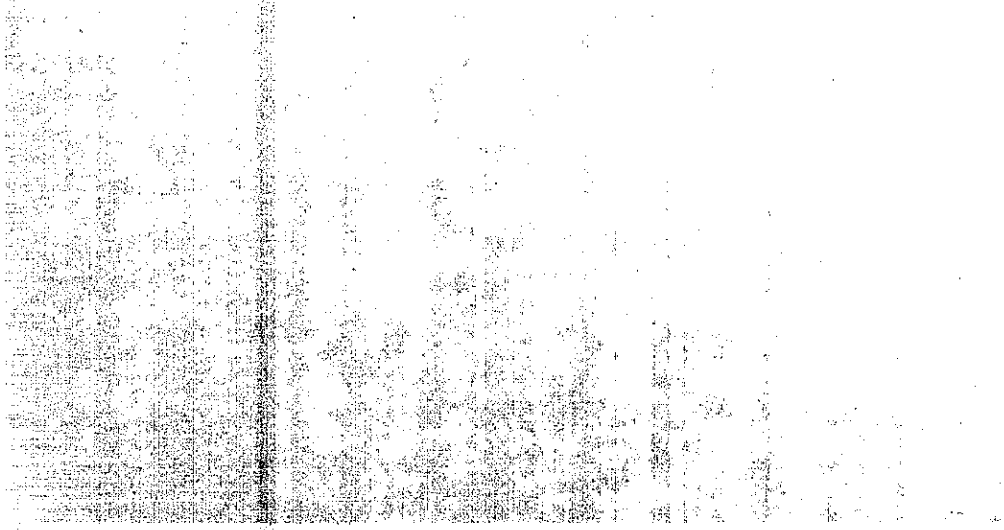

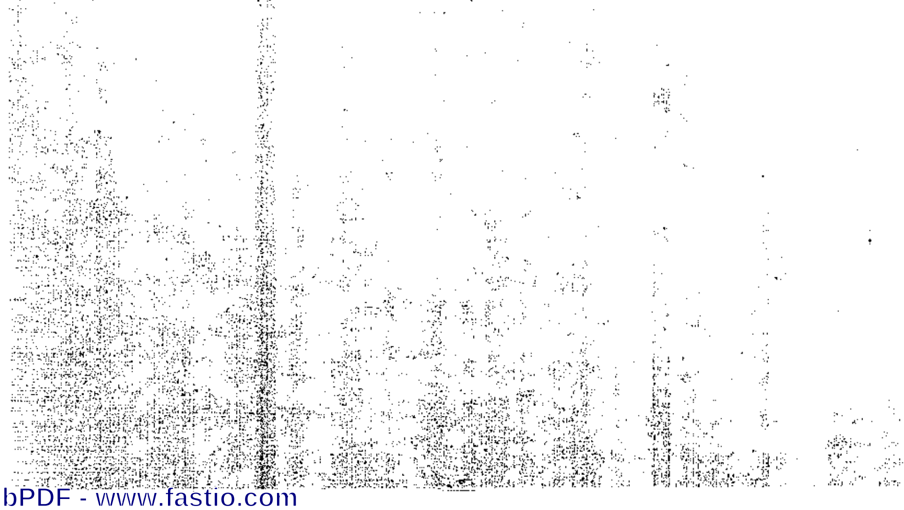

TABLE OF CONTENTS

FAULTING OF PORTLAND CEMENT CONCRETE PAVEMENTS

INTRODUCTION

The term "faulting" refers to the vertical displacement of concrete paving slabs at joints. As faulting progresses, riding quality is adversely affected and cracking of the slabs may follow. Since "ride" is influenced by several factors, including vehicle wheelbase, suspension, and weight, there is some disagreement on the degree of faulting which seriously affects rideability. On a moderately faulted pavement (say .12 to .25-inch), some vehicles may not be affected, but drivers of trucks and a number of the lighter weight cars may feel considerable discomfort.

"Pumping" or "blowing" has long been considered to be associated with faulting. Circa 1946 California adopted cement treated bases (CTB) for use under portland cement concrete pavements. This greatly reduced pumping at joints, but it was not until about 1960 when the CTB was widened one foot on each side of the pavement that edge pumping was virtually eliminated. Very little evidence of pumping is now seen, but some faulting is still occurring. In past years, faulting did not appear to be serious until pavements were about 12 - 15 years of age. More recently, a few projects were found to develop moderate faulting within five years after construction.

A limited statewide faulting survey of PCC pavements constructed since 1960 was made in early 1968. The survey consisted of selecting random locations on each project and measuring the vertical displacement, if any, at approximately ten consecutive joints. These are undowelled joints at either regular 15-foot spacing, or at our present spacing of 13, 19, 18, 12-feet and repeat. Due to traffic conditions in urban areas, measurements were made only on rural highways, although many of the urban freeways were driven and conditions observed.

Pavements in all areas of the state were found to be about equally subject to faulting. Generally, only the outside or truck lane joints are faulted, with the greater magnitude at the outer edge and a lesser amount at the inner edge. There were a few exceptions noted, especially near urban areas where there are three or more lanes in each direction and a heavy concentration of truck traffic in all lanes. It was also noted that faulting was usually less in urban areas. This may be attributable to the fact that better drainage is provided by curbs and gutters and more paved areas, thus decreasing the chance of water getting under the pavement.

Of the projects surveyed, 85 were in the age range of 3 to 8 years. Of these, 12 had some faulting greater than 0.10-inch and four of the projects had some joints faulted 0.15-inch or more. It is reasonable to assume that faulting will continue to increase on these projects. To check on the progression of faulting and the effect of seasonal changes, test sections were established throughout the state. Both new and old pavements were selected in areas that include the coastal, valley, mountain, and desert regions of California, and measurements are being made at 3 - 4 month intervals.

In 1968 and 1969, field investigations were carried out to determine the cause or causes of the faulting observed. The research was done with the cooperation of the Federal Highway Adminstration and assistance in the form of men and specialized equipment from the Portland Cement Association. A report giving more detailed information on the 1968-69 investigation entitled "California Pavement Faulting Study", No. M&R 635167-1, was distributed in January 1970.

To summarize the investigation, a total of 14 openings were made at pavement joints in three different geographical regions - valley, coastal, and mountain. Ten of the joints were faulted in amounts varying from 0.10-inch to 0.30-inch. At each site, a section of concrete three feet wide and approximately three feet on either side of the joint was removed. At each faulted joint, a buildup of granular material was found under the approach* slab and in some cases, under the leave* slab as well, though to a lesser degree. The buildup differential was approximately equal to the amount of the fault. There was no evident settlement or faulting of the cement treated base.

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*Note: "Approach" and "leave" refer to the slabs on either side of transverse joints. If traffic is considered as moving from left to right, the "approach" slab is on the left, and the "leave"slab is on the right.

POSSIBLE SOLUTIONS

As a result of the findings from this investigation, numerous ideas were considered as possible solutions to the faulting problem. Among these were:

1. Continuous reinforcement.

2. Dowelled joints to eliminate curl and promote load transfer.

3. Shorter joint spacing -- possibly 6 - 8 feet. While this would not eliminate curl, it would reduce the distance through which curl acts and provide tighter joints with better interlock.

4. Construct base and pavement monolithically. Possibly the increased thickness, rigidity, and weight would reduce curling tendencies and result in less deflection.

5. Prevent or minimize the entrance of water. This would involve maintaining seals of all joints and cracks.

6. Provide free drainage to the outside for any water which finds its way under the slab. This would reduce the time water is available to erode base or shoulder materials.

7. Provide more erosion resistant base and shoulder materials. Lean concrete or asphalt concrete should serve satisfactorily for base and asphalt concrete for the outside shoulder adjacent to the slab. (The shoulder next to the median is not considered as a contributing factor to the faulting problem.) An alternate to erosion resistant material in the shoulder is a membrane seal along the edge of the slab to prevent erodable materials from finding its way under the slab. Erosion of the CTB is believed to be due, to a large extent, to poor recementing and recompaction of the surface after trimming to grade. Possibly the elimination of the trimming operation would provide sufficiently erosion resistant CTB.

In deciding on a course of action to solve the faulting problem, several factors had to be considered, not the least of which is the effect of any change on the Contractor's operation which would affect production. In recent years, concrete pavement production rates have increased tremendously. With two large mixers and fast charging equipment, a central batch plant can produce approximately 800 cubic yards of concrete per hour, and a slipform paver can place that concrete at a rate of up to 30 feet per minute for conventional pavement 24 feet wide and 0.70-foot thick. The use of bottom dump trucks has increased the speed of concrete delivery so that with this combination, production rates of up to 2 miles of pavement in an 8 to 10 hour day are possible. These rates of production plus some changes in design and construction details are largely responsible for bid prices of pavement being about the same now as they were in 1956. Any change in construction or design which would slow the high speed operation would have a significant adverse effect on bid prices. For example, on a recent project in California, it was found that the use of continuous reinforcement with concrete delivered from the side by belt, production rates were up to 50% lower than those of conventional pavement placing. Although production rates vary with the type and amount of placing equipment being used (and there are records of placing 2 miles per day), there is little doubt that with the equipment and methods being used in California, placing costs are higher when side delivery is required. Preplaced dowels would result in similar increased costs.

Maintaining sealed joints for the life of a pavement is considered impractical with presently available methods and materials. It was decided therefore, that the most practical and economical solution to the faulting problem was to try for an erosion resistant base and to prevent the movement of untreated material from the outer shoulder. Several experimental shoulder sections have been constructed and are now being monitored for performance.

EXPERIMENTAL SHOULDER SECTIONS

(Outside shoulder only)

1. I-880, near Sacramento - Four 1000-ft. sections

   A. Class 2 Permeable Base in lieu of the standard section of Class 2 aggregate base. Shoulder surfaced with 0.25-ft. asphalt concrete (in all sections). The intent here is to reduce erodability and increase drainage of water from under the pavement.

   B. Same as "A", but with a seal of a fairly thick coating of 60-70 pen. asphalt sprayed along slab face and on the extra width of CTB, before placing base.

   C. Class 2 aggregate base with asphalt seal as in "B".

   D. AC placed full depth of the slab and full width of the shoulder (10 ft.).

2. I-5, near Willows in Northern California

   The aggregate base of the shoulder was replaced with permeable AC (very open graded) in a 1000-ft. section. (See Figure 1.)

3. US 99, South of Sacramento - Two 2000-ft. sections

   A. A seal consisting of a fiberglass reinforced plastic strip - 2 ft. wide, placed along the edge of the slab and over the widened CTB in the shoulder. Aggregate base and AC then placed as usual. (See Figure 2.)

   B. Aggregate base replaced with permeable AC. (See Figure 3.)

4. I-205, South of Sacramento - 2000-ft.

   A layered membrane of coal tar and fiberglass - 2 ft. wide, placed along the slab and over the CTB extension as in 3-A.

5. I-80, West of Sacramento - Two 2000-ft. sections.

This was a partial shoulder replacement of a pavement that had been in service about 8 years and had moderate faulting. A 2-ft. wide section of the outer shoulder adjacent to the slab was removed down to the bottom of the slab. Loose material was broomed away, a tack coat of asphalt emulsion applied, then 0.5-ft. permeable AC and 0.25-ft. dense graded AC to complete the shoulder. A 2000-ft. section was replaced in both the eastbound and westbound lanes. The basic objective of this work was to eliminate erodable shoulder material from the areas adjacent to the slab to see if faulting could be arrested. In addition to providing erosion resistance, the permeable AC is expected to provide better drainage which may also help reduce faulting tendencies. Performance of the test sections will be compared to that of adjacent untreated areas. (Reconstruction features are shown in Figure 4.)

With less than 10% of the aggregate passing the No. 4 sieve and using 2% asphalt, there was some difficulty in compacting the permeable AC. After some experience, it was found that cooler mix temperatures and lighter rollers (6-8 tons) provided better results. On the shoulder replacement test section, wheel rolling in the confined area was felt to be sufficient. A steel wheeled roller was used on the dense graded surface course. The cost of the permeable AC under the experimental conditions was 20% to 40% more than the dense graded mix.

Some difficulty was also encountered in placing the membranes. Although an asphalt emulsion was satisfactory as an adhesive for the membranes on flat surfaces, it would not hold them for a sufficient time on vertical surfaces. As a result, it was necessary to hold the membrane against the slab by hand while aggregate base was being placed against it. Finished placement was proven satisfactory, at least for the plastic, by opening up the shoulder about 8 months later for examination. The material was found to be solidly stuck to the concrete and CTB, and had conformed to all irregularities caused by excess concrete left on the edge during pavement construction. (See Figure 5.) The material cost for fiberglass reinforced plastic was about $600 per mile, while the cost of the layered coal tar and fiberglass was about three times as much. The underground life of the plastic is unknown, but if the theory of its use is proven, it would probably be sufficient to at least delay faulting for many years.

The sections with a 60-70 penetration asphalt membrane were also examined about a year after construction. While the asphalt is readily visible, there does not appear to be sufficient thickness to be fully effective as a seal in preventing erosion.

The experimental shoulder sections are being monitored on a seasonal basis. To date, there has been no difference in performance noted between experimental and control sections.

Other possible solutions to prevent erosion of shoulder materials have been considered, but not tried. One is the use of a membrane which could be sprayed on, such as plastic or polyurethane foam. Another is to place a small wedge of AC next to the slag and "wheel roll" with a motor grader. Either of these methods could reduce faulting potential by eliminating the availability of loose material adjacent to the bottom of the slab.

BASE

Although base settlement has long been suspected as a cause of faulting, there was no evidence found during the field investigation of any such settlement. (All pavements opened had cement treated base - CTB.) There was, however, positive evidence of erosion of the base surface under the leave slab. The evidence was in the form of rivulets caused by water movement and might result in some lack of uniform support but would not allow the slab to be depressed (see Figure 6). The top portion of the CTB at many locations has been found to be loosely cemented and readily erodable. While drying of the surface before curing may be responsible for part of the problem, much is felt to be due to the trimming operation used to conform to grading tolerances. Since a high base will result in thin pavement for which a Contractor is penalized, and a low base results in the use of excessive concrete, considerable effort is exerted in obtaining the proper grade. Trimming is usually done about an hour or more after original placement. The surface material, once loosened, is never fully rebonded and so does not form a monolithic erosion resistant base.

To eliminate the need for trimming, a local paving machine manufacturer proposed the idea of placing CTB with a slipform paver. By adding extra cement and water to form a "wet-lean" CTB or "lean concrete base" (LCB), the material could be vibrated internally and placed like concrete to final grade with no rolling or trimming needed. Although he had done this in other countries, little was known of the properties of such material. A laboratory testing program was carried out to determine the advantages and disadvantages of lean concrete base and compare the properties with those of CTB.

Tests were performed using typical CTB aggregates from six sources. The aggregates from these sources had a representative range of characteristics, such as durability, particle shape, and geological origin. The CTB specimens were fabricated following routine procedures and using the cement content necessary to obtain a compressive strength of 750 psi at 7 days. Similar mixing procedures were used for LCB samples, but enough water was added so that the mixture resembled concrete with an approximate 2-inch slump, and using cement contents of 6, 9, and 12%. The moisture content needed to produce the 2-inch slump was considered optimum and other mixes were made using 1.5% less water and 1.5% more water. Aggregate gradings were also varied from the middle of the specification limits to both the fine and coarse sides of the limits. Internal vibration was used in compacting the LCB specimens.

Specimens of both materials were fabricated for comparison of the following properties: compressive strength, flexural strength, shrinkage, and abrasion loss. The following tables show how CTB compares to LCB made with 9% cement, medium grading, and optimum moisture content.

Table 1

Cement and Optimum Moisture Content of CTB and LCB (Percent)

Test No.	Cement Content CTB	Cement Content LCB	Moisture Content CTB	Moisture Content LCB
70-1089	3.5	9.0	8.1	10.8
70-1097	4.5	9.0	8.0	13.7
70-1122	4.0	9.0	7.8	12.5
70-1127	5.5	9.0	8.1	13.5
70-1142	5.5	9.0	6.6	12.9
70-1308	3.2	9.0	6.6	11.6

Table 2

Compressive Strength, PSI

Sample Number	7 days CTB	7 days LCB	28 days CTB	28 days LCB	90 days CTB	90 days LCB
70-1089	842	765	1055	1119	---	---
70-1097	757	544	1152	721	1272	---
70-1122	738	350	541*	689	1304	---
70-1127	812	450	871	692	1131	938
70-1142	772	402	910	597	1412	1081
70-1308	825	640	773	1230	884	1437
Average	791	525	952	841	1201	1152

*Not included in average

Table 3

Flexural Strength, PSI

Sample Number	7 days CTB	7 days LCB	28 days CTB	28 days LCB
70-1089	50	168	89	251
70-1097	184	203	195	380
70-1122	106	56	171	231
70-1127	155	147	207	261
70-1142	154	133	207	246
70-1308	110	175	155	374
Average	126	147	171	290

Table 4

7-day Surface Abrasion Losses, Grams

Test No.	CTB	LCB
70-1089	44.5	3.4
70-1097	16.7	0.5
70-1122	37.8	10.7
70-1127	15.4	5.0
70-1142	11.4	12.3
70-1308	4.0	1.5
Average	21.6	5.6

Table 5

50-day Shrinkage, %

Test No.	CTB	LCB
70-1089	-----	0.032
70-1097	0.111	0.138
70-1122	0.065	0.118
70-1127	0.042	0.053
70-1142	0.029	0.032
70-1308	0.026	0.023
Average	0.055	0.066

Table 6

A SUMMARY OF THE PROPERTIES OF LEAN CONCRETE BASE

	Cement Contents (%)			Moisture Contents (%)			Gradings			Curing Period (Days)		
	6%	9%	12%	Opt. -1.5%	Opt.	Opt. +1.5%	Fine	Medium	Coarse	7	28	90
Compressive Strength	Increases →			Decreases →			Increases →			Increases →		
Flexural Strength	Increases →			Decreases →			Increases →			Increases →		
Abrasion Losses	Decreases →			Increases →			Decreases →			Decreases →		
Shrinkage	Slight decrease →			Increases →			Decreases →			No Measurement		
Workability	Slight increase →			Increases →			Decreases →			No Measurement		

From these laboratory tests, it appears that a lean concrete mixture could be made having properties satisfactory for base. The superior abrasion resistance is a highly desirable property. To approach an equivalent compressive strength, LCB would require approximately double the cement needed for CTB. This increase in cost could be partially offset by the elimination of rolling and trimming equipment normally required. For some contractors, the need for a central mixing plant and slipform paver sooner than necessary for concrete paving might be an added expense.

A few contractors have been contacted regarding a trial of LCB. Probably due to their prior planning and uncertainty, none has expressed interest in changing their method of operation.

Recently it has been noted that a few contractors are changing their CTB placing methods. They have gone to central mixing, whether required or not, and to placing with a slipform paver. Instead of a wet mix and internal vibration, they use the regular dry mix and a vibrating screed behind the paver, followed by rollers. This results in a much harder appearing surface and trimming is seldom if ever necessary. Unfortunately, there is no test method available for measuring abrasion resistance of CTB in place. If the trend to this type of construction continues, our objection to CTB due to trimming may be overcome (see Figure 7).

Other Base Alternatives

Asphalt Concrete

At several locations, PCC pavements have been constructed directly over old AC roadways or over AC on CTB used for detour purposes. Some of these pavements have exhibited very good performance with no apparent abrasion of the base taking place. A further trial of AC base has been planned for the near future. Cost data will be obtained and performance will be compared to that of CTB sections on the same project.

Monolithic Base and Pavement

A proposal now being considered is the construction of base and pavement in one layer, or in effect, no treated base. As mentioned in the first faulting report, the increased thickness and weight of a monolithic slab should reduce curling and deflection. The thickness necessary to provide the desired features is now being studied. Also to be considered, however, is the effect that elimination of the widened CTB would have on pumping of the subgrade.

OTHER EXPERIMENTAL CONSTRUCTION

Continuously reinforced concrete pavement is considered as one solution to the faulting problem. Under another research project, approximately 10 miles of this type of pavement construction has been monitored. A report on construction details and comparative costs will be made at a later date. Other experimental features were incorporated into the same project which might also be useful in preventing faulting.

Short Joint Spacing

Two sections of pavement with short joint spacing were constructed. Joints were skewed (4 ft. in 24 ft. counterclockwise) and sawn at repeat intervals of 8, 11, 7, and 5 feet. The length of the four slabs is about one-half that of our normal spacing. A check before shoulder construction indicated more than 80% of the joints had cracked on at least one side of the centerline joint soon after construction. Performance will be monitored to determine if faulting tendencies are reduced as compared to normal joint construction.

Lean Concrete Base

This base should not be confused with the type previously referred to in this report. On this project, two experimental base sections were constructed with 4-sack concrete made with concrete aggregates. The base turned out to be stronger than anticipated, with a compressive strength of over 3000 psi in less than 28 days. No problems with surface abrasion are anticipated in these sections, and the test section should provide more positive evidence about intrusion of shoulder material if it occurs.

7.5-sack Concrete

While the job control concrete contained 5.5 sacks of cement, two experimental sections were constructed with concrete containing 7.5 sacks per cubic yard. The effect of extra strength concrete on performance characteristics such as curl and deflection, will be studied.

Extra Thick Pavement

These sections were constructed 0.95-ft. in thickness over 0.45-ft. CTB. Although constructed as "no fatigue" sections, it was found that the extra thickness did not present any particular construction difficulties and it, too, should provide some interesting data relative to deflection under load.

SUMMARY

To find solutions to the faulting problem, California has so far concentrated efforts toward preventing erosion and movement of materials of the base and the adjacent portion of the outside shoulder. A number of experimental sections have been constructed and others are being planned. Test sections are being monitored on a regular basis so that conclusions can be drawn as soon as possible. In the meantime, still other possible solutions are being actively considered. It is likely that any implementation will result in an initial increased pavement cost (which can be offset later in decreased maintenance), but if such implementation can be made without adversely affecting paving production, then the increased cost will be much less.

Fig. 1 Permeable asphalt concrete shoulder being placed on I-5

Fig. 2 Fiberglass reinforced plastic placement, US 99

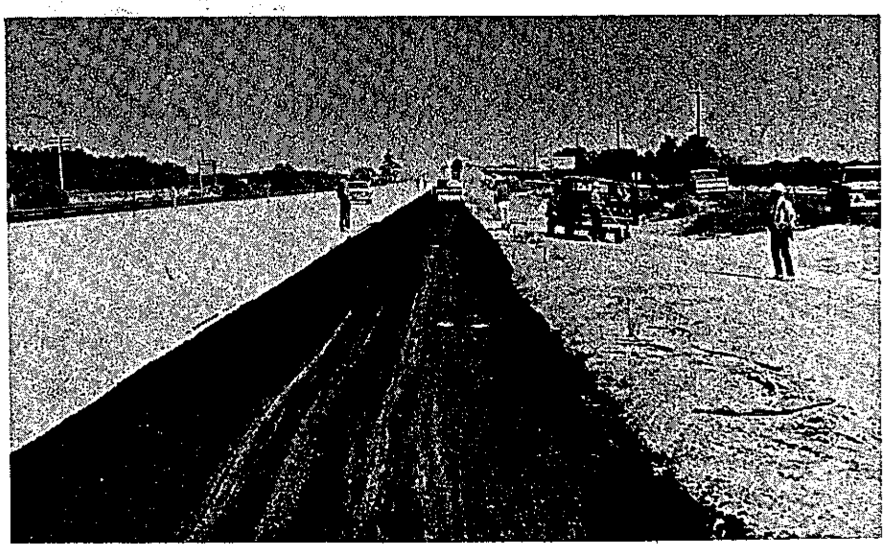

Fig. 3 Rolling of Permeable asphalt concrete, US 99

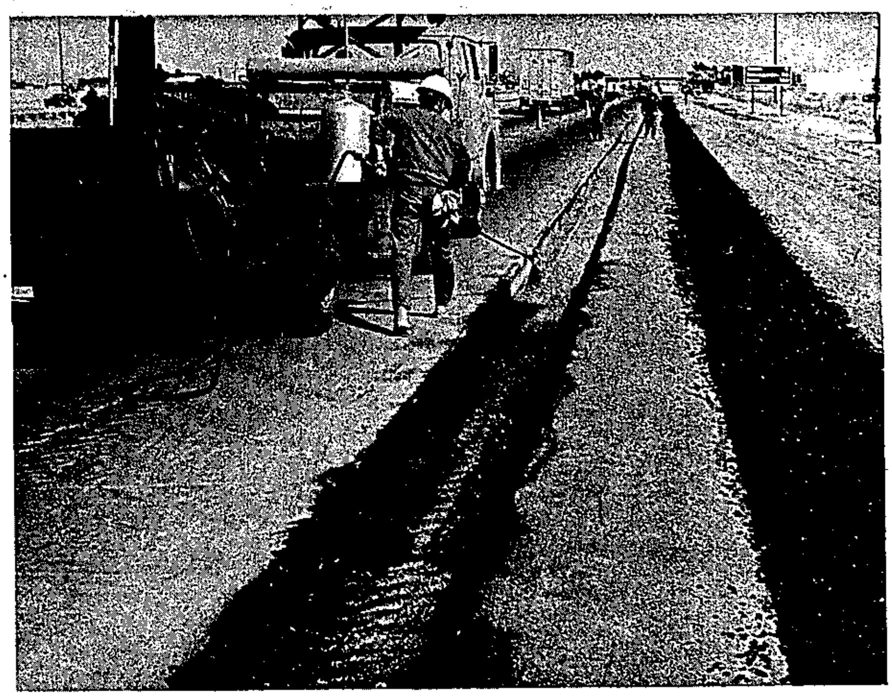

Fig. 4 Partial shoulder replacement - I-80

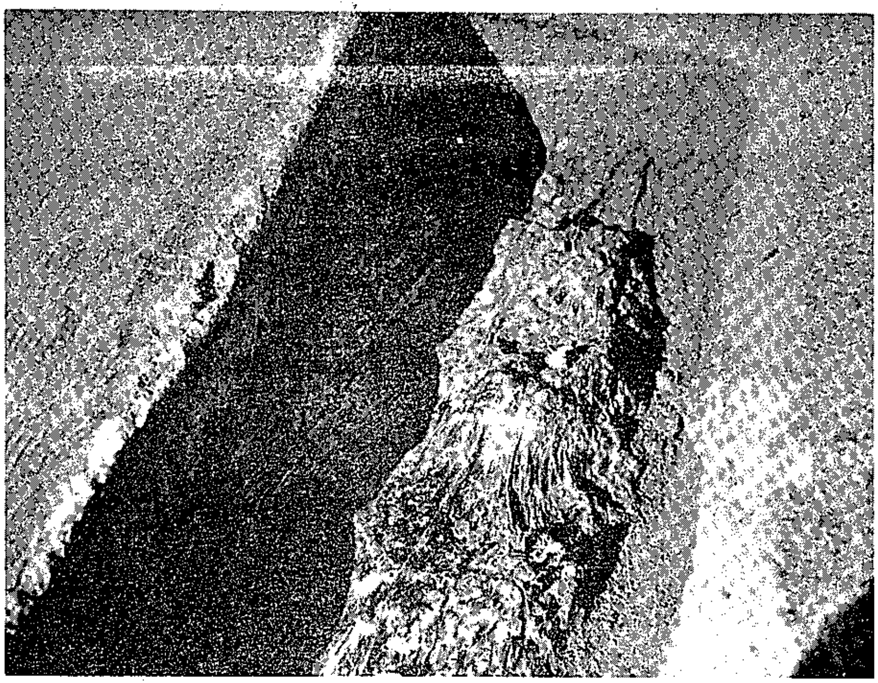

Fig. 5 Shoulder opening showing plastic conforming to irregularities

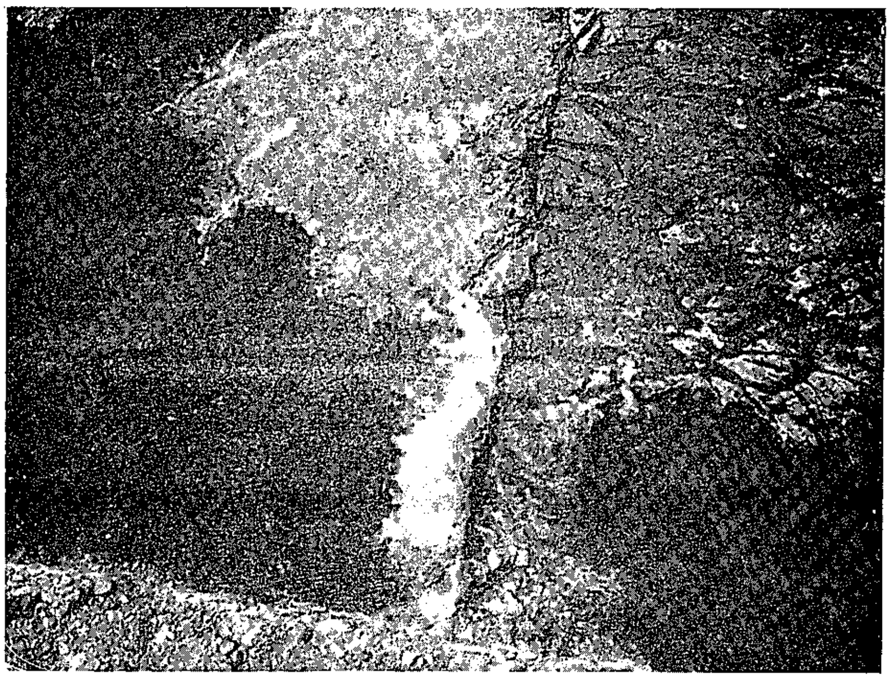

Fig. 6 Channels indicating water movement on cement treated base surface

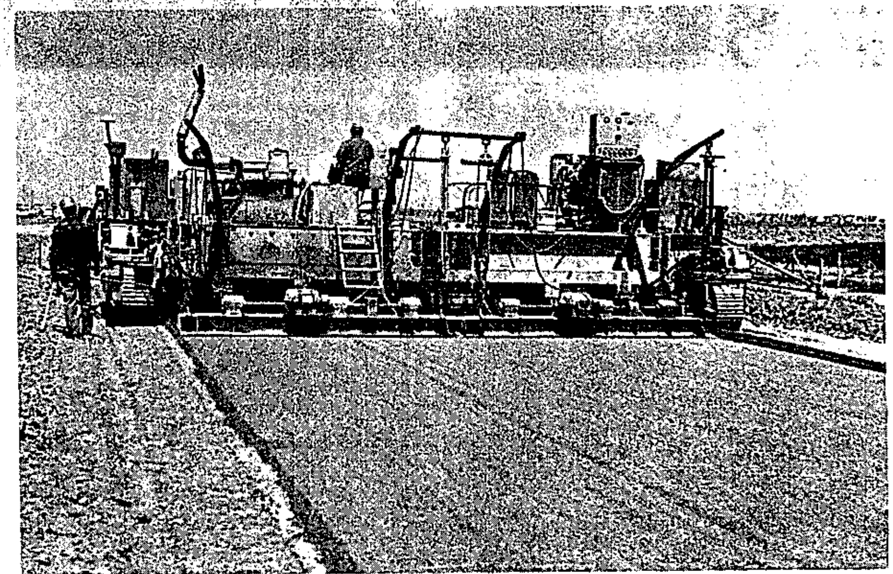

Fig. 7 Placing cement treated base with slipform paver