TREATMENT OF PUMPING PAVEMENTS WITH CEMENT-SLURRY MIXTURES

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SYNOPSIS

This is a report of experimental treatments for correction of pumping pavements on three test sections in Indiana, using a mixture of portland cement and calcium aluminate cement as a filling material. The experimental use of a mechanical pavement jack, in connection with the slurry treatments to correct faulted joints, is also reported. Cost records were maintained on most of this work.

Joint performance was measured by comparisons of the amount of faulting. Measurements of faulting were made before and after the treatment operations, and have been made at regular intervals since that time. One test section was rated numerically as to severity of the pumping condition of each joint.

On one of the sections, pavement slabs which had been treated one year showed an average settlement of less than 0.10 in., as indicated by measurements of faulting. Another section showed an average settlement of only approximately 0.05 in. after six months of service. Pumping was practically eliminated on these treated sections. On a third section, treated joints showed a much better performance after a year of service than the untreated joints in the same traffic lane, as based upon averages of numerical ratings of severity. Expansion joints showed a greater response to treatment than contraction joints.

On two of the sections, the experimental lifting and treating cost $7.50 per joint, one lane in width, while the treating operation cost $4.25 per joint.

It was concluded that the use of cement slurry of this type was practical and that, based upon performance data, joints treated in this manner are giving satisfactory service. Costs were considered to be moderate, and the use of comparatively expensive materials appears to be justified. The use of the pavement jack in re-aligning faulted slabs, when used in connection with the slurry treatment, also is considered to be a practical method of correcting joints which have been damaged by pavement pumping.

One of the major problems confronting maintenance engineers is the correction of pumping pavements. This type of pavement failure is prevalent throughout many areas of the United States, and, with constantly increasing traffic loads, the mileage of damaged highways is rapidly growing.

It is an accepted fact that pavement pumping is caused by a combination of conditions, all of which must be present before the pumping action can occur. These conditions include heavy traffic, susceptible subgrade soil, the presence of water beneath the pavement, and the existence of transverse joints or cracks. The presence of these factors finally brings about a definite type of failure, differing from one location to another only in degree of severity, or in the extent to which this destructive action is allowed to progress. Certain corrective measures are indicated by a range in conditions from minor deflections of the pavement slabs, causing small amounts of water-suspended subgrade material to be ejected, on through the stage in which the leading slab fails to fully recover its position after the load has passed by, and finally to the point where the pavement on both sides of the joint or crack becomes broken and permanently settled. Some of these measures may be intended to prevent pumping or the recurrence of pumping, and some may be used to correct the damage which has already occurred.

Heavy traffic loads have been an important cause of pavement failure for many years (*7*)[1], and a great deal can be done to eliminate this factor by proper regulation and enforcement methods. In the matter of susceptible subgrade soils, much more has been and is

[1] Italisized figures in parentheses refer to the list of references at the end of the paper.

being done. The use of subgrade treatments, including courses of granular materials, has become standard practice in many States, and it is hoped that the problem of pumping may in the future be reduced by this type of construction. Proper maintenance procedures, which include adequate joint and crack pouring operations and complete shoulder and side ditch maintenance, will do much to prevent the accumulation of water on the subgrade. And finally, the present trend away from the use of expansion joints, in many States, may eventually reduce the magnitude of the problem. All of these factors are important in the prevention of original damage by pumping.

After the pavement has been subjected to pumping, other corrective measures are needed. If an appreciable amount of subgrade material has been removed, it is important that the resulting voids be filled with some suitable material, and also that the cracks or joints be completely sealed. It is also desirable that the sealing operation be extended to include any existing space between the pavement slab and the shoulder, since this is a frequent source of infiltration.

The Joint Highway Research Project at Purdue has used several different types of materials in experimental installations during the past few years. In 1942, and again in 1945, several test joints were treated by pumping various mixtures of soil, cement and bituminous materials into the voids beneath pumping slabs (*1*). Missouri (*2*) has done a large amount of work in the use of these materials in the treatment of joints. Bituminous material in the form of low-penetration asphalt cements was also tried. The use of this material originated in Ohio (*3*), and it has since been used by other States.

For the past 18 months, the Project has been installing experimental treatments at pumping joints, using a cement slurry mixture composed of portland cement, calcium aluminate cement, and water. This mixture was developed in the laboratory of the Project (*4*), and was designed to provide a material which could be easily installed, would harden rapidly, and would produce a durable filling material. It is with the use of this material that this report is mostly concerned.

In the early experimental work in Missouri (*2*), it was discovered that the soil-cement mixtures which were used in the treatment of pumping joints should be of a much thinner consistency than the mixture which was commonly used in ordinary mud-jacking, or pavement-lifting operations. In order to insure the complete filling of the thin, wedge-shaped voids beneath the pavement slabs, the slurry was reduced to an almost water-thin consistency. This was also found to be true in the experimental work in Indiana. On the Indiana experiments, this thinner mix, under pressure, tended to flow from open cracks and joints, and along the edges of the pavement, and the lifting action was usually found to be negligible, or, when it occurred, erratic and generally uncontrollable. The same was found to be true with the bituminous material and with the cement slurry. In order to complete the corrective treatment at joints where the pumping has caused a serious mis-alignment of the pavement slabs, a mechanical jack was constructed, which lifts the lower slab accurately into place and supports it until the void has been filled with the treating material. This jack was used in the experimental work which is described in this report.

EXPERIMENTAL WORK

Location of Experimental Work

Several locations were selected to be used as test sections for this work. Some of the earlier work was done by small crews furnished by the State Highway Commission of Indiana, under the direct supervision of a member of the staff of the Joint Highway Research Project of Purdue. Later, as the work became better organized, and some of the first installations had gone through a winter season with good performance, it was decided to increase the scope of the work. From that time on, the work has been done by regular State highway maintenance crews, with a member of the Project staff making preliminary measurements and maintaining a record of the operations.

Test Section I is located on U. S. 52 at the south edge of Lafayette, with Test Section II immediately adjacent, to the south. Test Section III is located on S. R. 57, approximately ten miles north of Evansville. Test Section IIA is a portion of Section II in which only one lane was treated, and on which significant comparisons of performance have been made. Other miscellaneous test installations were made at various locations throughout the State, including U. S. 52 By-Pass north of Lafayette, U. S. 30 near Valparaiso, U. S. 50 near Shoals, S. R. 67 near Bloomfield, U. S. 31 near Columbus, and U. S. 41 south of Vincennes.

Equipment

A Koehring mud-jack, Model No. 10 was used for placing the cement slurry. This machine is a small mud-jack, mounted on two wheels and can be moved by one man. The pumping action is direct, with the nozzle attached beneath the cylinder. There is no

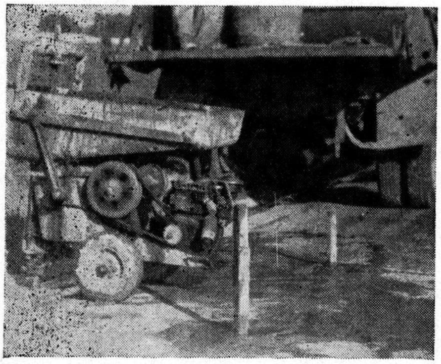

Figure 1. Mud-jack Used on Most of the Experimental Work

mixing attachment on the machine. No experimental work has yet been done by the Project on the use of other types of equipment for the pumping of this material, but it is possible that, due to the thin consistency of the slurry, a simpler type of pump could be used (Fig. 1).

Miscellaneous equipment used in placing the slurry included an air drill, mixing tanks and hand paddles, a water tank mounted on a truck, and a regular patrol truck for handling the cement and other supplies and equipment.

The mechanical pavement jack was constructed at the Joint Highway Research laboratory two years ago. This machine consists primarily of a hydraulic jack of 20 tons capacity, resting on steel beams, which are mounted upon two wheels. A trailer hitch is provided for towing. The device is so constructed that a direct lifting force is applied to the lower slab near the joint, while at the same time the higher slab is restrained from movement. (Figs. 2 and 3)

The jack is fastened to the lower slab by means of a pair of expanding anchors of a new design, which are inserted into two holes. The machine is frequently used with lifting forces of from fifteen to eighteen tons.

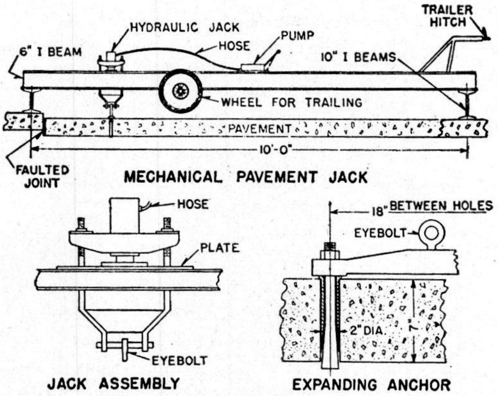

Figure 2. Diagram of Pavement Jack

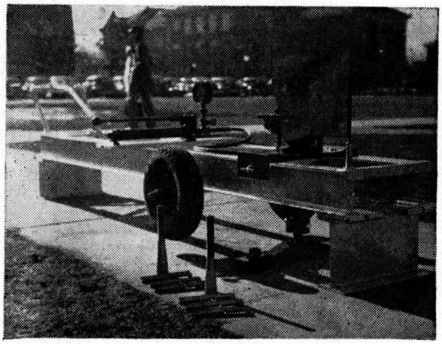

Figure 3. Mechanical Pavement Jack

Measurement of Joint Performance

In a study of joint performance, and in making a comparison of treated and untreated joint performance, it is necessary that some practical method be used to evaluate the performance. It has been found that the amount of faulting is usually an accurate indication of the condition of a pumping joint, and comparative measurements can be used as a measure of performance. Faulting can be described as the amount of vertical mis-alignment of adjacent slabs, and almost always the leading slab, in the direction of traffic, is the lower one. In the few instances that a treated joint showed faulting in the opposite direction, the negative reading was assumed to be zero, since the action of traffic would soon eliminate this condition. In the accompanying tables, the information for the various test sections includes approximately 5,000 measurements of faulting.

Before the treatments were begun on a test section, all of the joints to be treated were measured for faulting, one measurement being taken near the edge of the pavement, and one near the center line. Subsequent readings were recorded immediately after the treatments were completed, and at regular intervals since that time.

Methods of Installation

Field installations of cement slurry, as well as experimental operations with the pavement jack, have been carried on for almost two years. During that time, the methods of procedure were gradually developed. Since large-scale operations were begun by regular State highway maintenance crews, field procedures have been more or less standardized on the various projects.

The pavement is first inspected, and joints which are to be treated are marked with paint. If the pavement jack is to be used, joints which show the greatest amount of faulting are marked for this additional treatment. On some projects, where pumping is present at a large proportion of the joints, all joints are treated.

Holes are drilled in the pavement slab adjacent to the joints by the use of air drills. Two, ¾-in. holes are drilled for placing the slurry, one near the center joint and 1 ft. ahead of the transverse joint, and the second 3 ft. from the pavement edge and 4 ft. ahead of the joint. If the pavement jack is to be used, two holes, 2 in. in diameter and 18 in. apart, are drilled in a line parallel to the joint and 14 in. ahead, near the center of the traffic lane.

A crew of six men operates the mud jack in placing the cement slurry, and in using the mechanical pavement jack on the low joints. The portland cement and the calcium aluminate cement are stored on a dump truck which is moved to each joint as the treating progresses. Except for work on U. S. 31 and U. S. 50, where a larger mud-jack having an attached mixer was used, all mixing has been done by hand, using paddles and a 20-gal. mixing can. Two men can mix the material needed for normal operation. Mixing water is measured in marked containers, and emptied into the mixing can, after which one bag of portland cement is emptied into the can. The required amount of calcium aluminate cement is measured by volume, in a container, and mixed separately with a small, measured amount of water. After the portland cement has been thoroughly mixed and the mud-jack is prepared to receive the next batch of slurry, the calcium aluminate cement slurry is emptied into the larger mixing can and the mixture is throughly stirred, after which it is emptied into the hopper of the mud-jack.

The basic mixture, which was derived from reports of laboratory studies (*4*), was in the following proportions:

94 lb. (1 bag) portland cement
18 lb. calcium aluminate cement
65 lb. water

This mixture, under proper conditions, is of a water-thin consistency when it is placed in the hopper. It should begin to thicken at the end of 10 min., and should reach a stiff consistency in about 15 or 20 min Several factors may cause slight variations in the consistency of the mixture, or in the time of thickening and setting. Small alterations in the amount of mixing water will correct the consistency, and the time of hardening can be delayed or accelerated by slightly decreasing or increasing the amount of calcium aluminate cement. This slurry is easily placed, and maintains a very thin consistency for a sufficient length of time to allow for pumping, after which it hardens rapidly.

After the mixture is placed in the hopper of the mud-jack, it is pumped into the hole nearest the center of the pavement until it is forced out through the transverse joint or center joint, or even at the edge of the pavement. The machine is then moved to the hole near the edge of the pavement, and the pumping continued. If a large leak develops at some point, usually at the joint, when it is apparent that the void beneath the joint has not yet been completely filled, it is possible to stop the leakage by applying moist soil to the surface at the point of escape. It is customary to continue the pumping as long as possible, until it is apparent that most of the additional material is escaping.

Occasionally one, or both, of the slabs are raised slightly by the hydraulic pressure, but care should be used to prevent the high side of the joint from being raised. There have been a few instances where the opposite lane was affected by the lifting action, and the entire center joint was raised. Usually, however, the mixture, being of a thin consistency, flows from numerous leaks, and no lifting takes place. A plug is usually placed in the hole near the center while the other hole is being treated, to help establish sufficient pressure for proper distribution of the slurry. The holes are not permanently plugged, as the cement slurry remaining in the holes makes a satisfactory seal.

When it is decided that a faulted joint is to be re-aligned before the treating material is placed, the pavement jack is used. The expansion anchors are placed in the 2-in. holes, and connected to the cross-bar extending between the two holes. The jack frame is then placed over the lower slab, with one end supported by the higher slab immediately adjacent to the joint, and the lower end supported by the pavement at a point 10 ft. ahead of the joint. The hydraulic jack, which rests upon the frame, is then fastened to the cross-bar, and the entire assembly is tightened. The hydraulic pump is then operated, and the lower slab is lifted into alignment. Usually a pressure of 10 to 12 tons is sufficient, but occasionally pressures as high as 18 tons have been used. This pressure represents the differential lifting force required to re-align the joint, plus a relatively small force which represents the actual weight of the slab. These large forces indicate the resistance offered by the internal structure of the joint, as the damaged load transfer devices come into play in reversed stresses. (Figs. 4 and 5.)

After the slab has been lifted, the cement slurry is placed in the regular manner. The mud-jack equipment is then moved on to the next joint, and the jack is left in place for 15 min., in order that the slurry can harden sufficiently to support the weight of the slab.

Even with the large lifting forces which it is possible to exert, some joints cannot be completely corrected because of the excessive resistance within the structure of the joint, due to the expansion of the concrete. This condition is encountered more frequently in warm weather, when the pavement slabs are expanded.

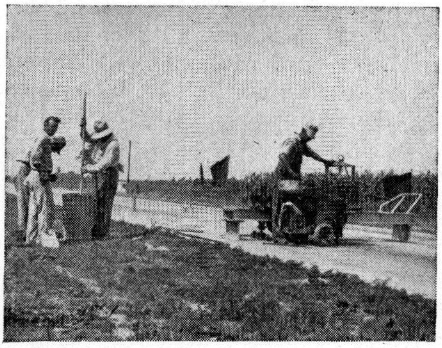

Figure 4. General View of Treatment Operations

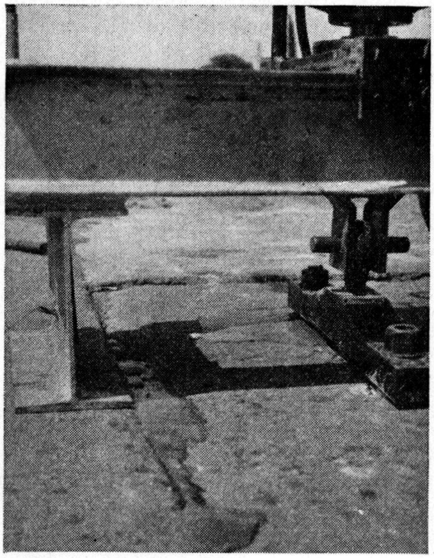

Figure 5. Slurry Flowing from Lifted Joint During Treatment Operation

Test Section I

Test Section I, on U. S. 52 at the south edge of Lafayette, is 3900 ft. long. This road is a dual lane pavement consisting of two, 22-ft. sections, 9–7–9 in. deep, and having doweled expansion joints at 120-ft. intervals. Contraction joints are placed 20 ft. apart. The pavement was constructed in 1942. In 1944, sub-surface drains were placed in the shoulders to help prevent pumping. The road carries a very large volume of transport trucks, and the total daily volume of vehicles is 4000.

This section of pavement had been pumping in both outer lanes for some time, and many of the joints were badly faulted. Several sections of pavement were broken, and a few concrete patches have been placed during the past few years. The road is fairly level, and is situated on the uplands adjacent to the valley wall of a glacial stream.

Treatment was begun on this section on October 22, and was completed on December 26, 1946. The work was done by a regular maintenance crew, using a Koehring mud-jack No. 10. The crew was efficient, but since the men had other responsibilities on another section of highway, the progress on the test section was irregular, and some good working days were lost. In the latter part of the work, the weather was bad, and the progress was hindered considerably. However, even with some bad weather, the subgrade remained relatively dry.

The work on this section consisted of lifting pavement sections adjacent to 122 joints, and placing cement slurry beneath the pavement at 297 joints, including the ones which were lifted. Treatments were confined to the outside lanes. Standard procedures were used and the work progressed reasonably well, but it was felt that much better progress could be made on future work as a result of experience gained on various phases of the operation.

An accurate cost record was maintained for each day. Equipment costs were relatively low, but since the hourly rates were applied to full working time, without regard to the actual time of operation, the resulting costs were probably reasonable. These rental rates were established from actual operating costs of State-owned equipment.

The average cost per treated joint was obtained from the daily records. Since some joints were lifted and some were not, and work was done on both types of treatment simultaneously, exact average costs per joint for each type of treatment were not readily available. However, with complete daily records of both operations and costs, it was possible to compute approximations of average costs. Cost data are given in Table 1.

On Test Section I, the average cost of lifting and treating was $7.27 per joint for one lane, while the cost of treating only was $4.14. The total cost of the treatment, including the lifting operations, and treating all joints was $1089 per mile for one lane. It should be noted that these costs are based upon work which was, to a large extent, experimental, and on a pavement which was badly damaged, and it is probable that similar work on most pumping pavements would cost less than the amounts which are shown.

TABLE 1
COST OF EXPERIMENTAL TREATMENTS
Test Section I—U. S. 52, South of Lafayette

Portland cement	375 bags @	$0.68	$ 255.00
Lumnite cement	65⅓ bags @	3.00	196.00
Mud-jack rental	133½ hrs. @	1.00	133.50
Truck, 1½ yd	149½ hrs. @	0.53	79.24
Truck, 1½ yd	170½ hrs. @	0.64	109.12
Compressor & air drill	31 hrs. @	0.76	23.56
Labor	819 man-hours		815.06
Total cost			$1611.48
Cost of drilling holes			$ 180.44
Cost of lifting and treating			1431.04
			$1611.48
Total number joints lifted and treated or treated only (one lane)	297		
Average cost per joint (one lane)			$5.42
Approx. average cost of lifting and treating per joint			7.27
Approx. average cost of treating per joint			4.14
Total joints lifted and treated	122 @ $7.27 =		$886 94
Total joints treated	175 @ 4.14 =		724.50
Total holes treated	604		
Total length of one lane pavement	7810 ft.		

In general, the results obtained on Test Section I have been very encouraging. Although it is apparent from the information contained in Table 2 that there has been some settlement on the lower sides of the treated joints, the amount has been slight with an average of less than 0.1 in. per joint. After a year of service, a detailed inspection showed that there are a few joints which are pumping slightly at the present time, and two or three which are showing signs of complete failure. However, based upon the prevalence of the pumping before the treatments were made, and upon the general signs of deterioration of adjacent sections, and even of the inside traffic lanes, the treated joints are showing excellent performance. The slabs which were lifted by the pavement jack are, for the most part, remaining in their proper positions, with only minor settlement. Some of the slabs could not be lifted completely into place, and on a few the original correction was negligible.

There are several joints which will probably require additional treatment, or even pavement replacement, after another winter season, but engineers who have watched the performance of the treated joints on this test section are convinced that the treatments have been successful.

TABLE 2
PERFORMANCE
Test Section I—Summary of Faulting Measurements (Treatments in November and December, 1946)

	All Treat. Jts.		Treated Only		Lifted & Treated	
	Out	Center	Out	Center	Out	Center
	in.	*in.*	*in.*	*in.*	*in.*	*in.*
Average Faulting before treatment	0.23	0.27	0.20	0.21	0.29	0.36
Average Faulting after treatment	0.09	0.12	0.12	0.13	0.05	0.11
Average Faulting April, 1947	0.14	0.19	0.17	0.20	0.10	0.18
Average Faulting Nov., 1947	0.15	0.21	0.18	0.20	0.12	0.23
Average Correction at time of treatment	0.14	0.15	0.08	0.08	0.24	0.25
Average Total Settlement, from time of treatment until April, 1947	0.05	0.07	0.05	0.07	0.05	0.07
Average Total Settlement, from time of treatment until Nov., 1947	0.06	0.09	0.06	0.07	0.07	0.12

Test Section II

Test Section II is located on U. S. 52, immediately south of Section I. Work on this section was delayed until April, 1947, and for that reason this portion of the road is considered as a separate test section. Since this pavement had carried heavy traffic through an additional winter season, it was in a somewhat worse condition at the time of treatment than was the pavement on Section I, at the time that it was treated during the previous fall. At the south end of the north bound lane, 2200 ft., were not treated, but are included in the test section for purposes of comparison. The pavement jack was used on 220 of the 478 joints which were treated with cement slurry on this section. This section is approximately 4700 ft. in length.

Work on this section was done in April and May, 1947. There was much rain during this period, and the subgrade was very wet during most of the time. The joints appeared to be in worse condition than when they were inspected during the previous fall. Although the joints were all treated, a few of them were obviously in such an advanced condition of failure that the pavement should have been replaced. Four concrete patches have been placed during the past two months.

TABLE 3
COST OF EXPERIMENTAL TREATMENTS
Test Section II—U. S. 52, 1.5 Miles South of Lafayette

Portland cement	936 bags @	$0.68	$ 636.48
Lumnite cement	155½ bags @	3.00	466.00
Mud-jack, rental	164 hrs. @	1.00	164.00
Truck, 1½ yd. dump rent	200 hrs. @	0.53	106.00
Truck, 1½ yd. dump rent	242 hrs. @	0.64	154.88
Compressor & air drill rent	42 hrs @	0.833	34.99
Labor	1263 man-hours		1205.40
Total cost			$2767.75

Cost of drilling holes	$ 145.87
Cost of lifting and treating	2621.88
	$2767.75
Total number joints lifted and treated or treated only (one lane) 478	
Average cost per joint (one lane)	$5.79
Approx. average cost of lifting and treating per joint	7.55
Approx. average cost of treating, per joint	4.29
Total joints lifted and treated 220 @ $7.55	$1661.00
Total joints treated 258 @ 4.29	1106.82
Total holes treated 1393	
Total length of pavement 9449 ft.	

In general, there have been a few more failures on this section than on Section I, but when the original condition of the joints is considered, the treatments have been successful. Although it is difficult to measure accurately the success or failure of work of this nature, a study of the condition of adjacent sections of pavement indicates that the slurry has prevented much additional pavement damage by pumping. The data giving comparisons in the amounts of faulting, listed in Table 4, show that since the time of treatment, the average amount of settlement is only 0.05 in. Joints at which the pavement sections were lifted are, for the most part, showing good performance, but a few slabs have settled back into place. From the indications which were apparent during the treatments, and from the general appearance of the pavement at this time, it is thought that the wet subgrade decreased the effectiveness of the treatments. The warmer weather near the end of the work also made it impossible to lift some of the low slabs.

Costs for work on this section are listed in Table 3. It will be noted that the average cost per joint is slightly higher than the cost of the work done on Test Section I during the previous fall season. In general, at the time of treatment, the pavement in Test Section II was in even worse condition than that in Section I. From a comparison of Tables 2 and 4, it will be seen that the original amount

TABLE 4
PERFORMANCE—TEST SECTION II
Summary of Faulting Measurements
(Treatments in April and May, 1947)

	All Treated Joints		Treated Only		Lifted & Treated	
	Outside	Center	Outside	Center	Outside	Center
	in.	*in.*	*in.*	*in.*	*in.*	*in.*
Average faulting before treatment	0.26	0.32	0.18	0.20	0.37	0.46
Average faulting after treatment .	0.09	0.19	0.12	0.15	0.05	0.23
Average faulting, Nov., 1947 .	0.12	0.24	0.15	0.18	0.08	0.28
Average correction at time of treatment	0.17	0.13	0.04	0.05	0.32	0.23
Average total settlement from time of treatment to Nov., 1947 .	0.03	0.05	0.03	0 03	0.03	0.05

of faulting was greater on Test Section II, and the total amount of the original correction was greater. These factors would account for an increase in cost of more than the actual increase of $0.28 for the lifted and treated joints, and $0.15 for the treated joints, and a definite decrease in the expected costs may be indicated as the efficiency of the operating crews is improved.

Test Section III

Test Section III is on State Road 57, ten miles north of Evansville. This section is located on the site of a former experimental project to test embankment compactive methods, and, for this reason, contains fill material of uniform quality. The soil consists of a wind-blown silt which has been reworked by water. In Indiana, this type of soil has never been considered particularly susceptible to pumping. The pavement, which was constructed in 1939, is 20 ft. wide, and has a depth of 9–7–9 in. Expansion joints, containing load transfer devices, are located at intervals of 100 ft., with contraction joints 33 ft. apart.

This test section was suggested by the State highway personnel, because the pavement in this section had suddenly begun to pump. For approximately 3000 ft., practically every joint was showing evidences of pumping in the summer of 1946, and many of the joints were pumping severely. Very little faulting was in evidence.

Work on this section consisted of pumping cement slurry beneath many of the joints on the north-bound lane. An attempt was made to treat a given percentage of expansion and contraction joints, without regard to the severity of the pumping condition. However, it developed that the maintenance crew inadvertently treated many of the more severely damaged joints that were originally intended to be left untreated, which for the purpose of comparison, resulted in a preponderence of badly pumping joints in the data for treated joint performance. No lifting was done on this section except for minor amount of lifting which was occasionally obtained from the hydrostatic pressure of the slurry.

Before the installation of the cement slurry was started, each joint on the entire section was examined and a numerical rating of the severity of the pumping was recorded (Table 5). These ratings ranged from "0" for a good, or non-pumping joint, to "5" for a joint which had completely failed. The amount of faulting at the edge and near the center of the pavement was also recorded for each joint in the north-bound lane which was to be included in the test, as well as on the south-bound lane, which was not to receive treatment.

The cement slurry treatment was started on July 23, 1946, and completed in three days. Approximately one-third of the joints were selected for treatment, and both expansion and contraction joints were treated throughout the section.

A mixture of 94 lb. of portland cement to 18 lb. of calcium aluminate cement was used in all except a few of the joints. An average of approximately one and one-half batches ($1\frac{1}{2}$ bags of portland cement) was used at each joint.

No difficulty was experienced in placing the slurry beneath the pavement. The mixture was made almost water-thin, and was usually forced up through the center joint, or along the edge of the pavement. Practically no lifting of the pavement occurred. It was evident that there was a large amount of thin mud slurry on the subgrade as the result of recent heavy rains, and this mud was frequently forced from beneath the pavement.

The treated and untreated joints have been inspected several times since the installation of the treatments, and numerical ratings of severity noted. The total amount of faulting has also been recorded for each joint, on two different inspections. These measurements were made on both the treated and untreated lanes. A total of nearly 800 different measurements have been made. It has become evident that the amount of faulting has not been a satisfactory criterion on joint performance on this particular road, up until the present time, because the faulting has not yet progressed to a point where it is a good indication of the condition of each individual joint. It may be that, after another winter season, the amount of faulting can be used for comparing the performance of treated and untreated joints.

TABLE 5
TEST SECTION III
(Treatments in July, 1946)
Summary of Joint Performance Data by Average Numerical Ratings

	No. of Jts.	Average Numerical Ratings		
		May 2 1947	July 23 1946	Change in Ratings*
Contraction Joints				
Non-treated	34	1.5	0.8	−0.7
Treated	20	1.2	2 5	+1.2
All	54	1.4	1.4	0
Expansion Joints				
Non-treated	19	2.2	1.6	−0.6
Treated	9	0.6	2.6	+2.0
All	28	1.7	1.9	+0.2
All Joints				
Non-Treated	53	1.8	1.1	−0.7
Treated	29	1.0	2 5	+1 5
All	82	1.5	1.6	+0.1

* Note: "Change in ratings", plus sign represents *improvement* of joint condition.

Scale of Numerical Ratings:
0 = Good joint, no pumping
1 = Trace of pumping
2 = Moderate pumping
3 = Severe pumping without faulting
4 = Severe pumping and faulting
5 = Pavement at joint completely failed

The numerical ratings of the severity of pumping for the treated and untreated joints have been compared. A definite indication has been found that the deterioration of the treated joints has been much less than that of the untreated joints, and that the expansion joints show a greater response to the treatment than do the contraction joints. However, the treatments have not been considered entirely satisfactory, as several of the treated joints are now pumping to some extent. There seems to be a definite indication that the presence of excessive moisture on the subgrade, especially in the form of a mud-slurry, prevents the proper installation of the cement slurry, as all of these treatments were made after heavy summer rains. It is also true that the work was done by an inexperienced crew, using methods which had not yet been completely developed.

Test Section IIA

When it was first decided that the State highway maintenance crews were to do regular production work on Test Section I and II, many joints which were measured for faulting were intended to be omitted from the treatment operations. These joints were to be used for control comparisons, at a later date. However, as the work progressed more successfully than was first expected, and it became apparent that the treatments were at least deferring the need for concrete replacement patches, the work was gradually extended until it included both the occasional joints which had been omitted, and also the control sections on either end of the test sections. Because of the need for comparisons of treated and untreated joints, it then became necessary to use the south end of Test Section II, in which the south-bound outside lane is treated and the opposite north-bound outside lane is untreated. This portion of Test Section II has been referred to as Test Section IIA.

In November, 1947, the amount of faulting in the north-bound untreated lane averaged 0.26 in. per joint, while in April, 1947, the south-bound lane averaged 0.27 in. per joint. This indicates that in April the north-bound lane was faulted less than the south-bound lane. Because of the warm weather during the time of treatment, the jack was not used successfully on many of the joints where its use was indicated. However, the average amount of faulting was reduced from 0.27 in. to 0.17 in. and, more important, the amount of faulting has remained constant, indicating a general absence of settlement on all treated joints during a 6-mo. period, including the season of the fall rains. Inspection of the joints shows that the number of pumping joints has been greatly reduced by the treatment.

Miscellaneous Treatments

U S 52, Lafayette By-Pass. The first joint to be lifted by the pavement jack and treated with cement slurry was faulted 0.75 in. This joint has been subjected to heavy truck traffic for approximately two years, and is now faulted less than $\frac{1}{8}$ in. Other joints which were faulted approximately 1 in. were lifted and treated in November, 1946. These joints are still in service, and the amount of faulting is negligible. At one of the joints, it was decided that the pavement was so badly broken that it should be removed and replaced by a concrete patch. In order to test the distribution characteristics of the slurry, this joint was treated in the regular manner but without lifting the slabs. The pavement was then removed as a regular repair operation. It was found that the slurry had completely covered the subgrade for a minimum distance of 10 ft. in each direction, and had completely filled the existing void. Although approximately 30 ft. of the pavement lane was removed, it was found that the slurry had been forced under the remaining pavement, extending for some unknown distance at each end of the opening. Near the edges of the area, the mixture had set up in a continuous layer only $\frac{1}{16}$ to $\frac{1}{32}$ in. thick. The material was dense, with no evidence of bleeding, and appeared to be structurally sound. (Figs. 6 and 7.)

U S 30, near Valparaiso. Some of the early experimental work with the pavement jack and cement slurry was done on this four-lane pavement. Although some of the joints were successfully lifted, and several more were treated without lifting, several of the joints have since failed, and have been replaced. This was partly due to the bad condition of the pavement, and the heavy truck traffic, but the treatments were also probably inadequate.

U S 50, near Shoals. During the 1946 construction season, this concrete pavement was resurfaced with a bituminous binder. The contract included two courses of binder, but

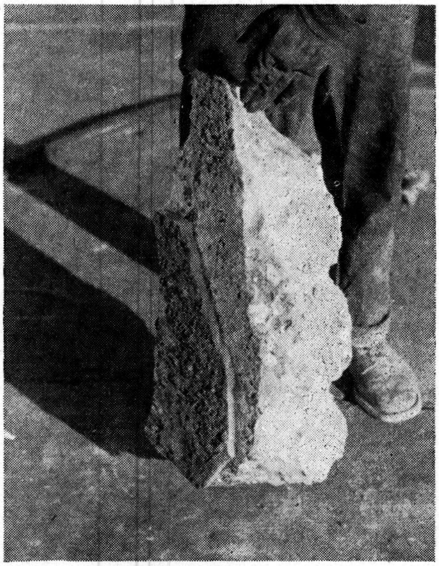

Figure 6. Cement Slurry Attached to Underneath Side of Slab

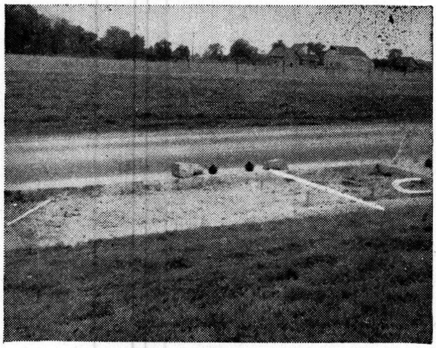

Figure 7. Subgrade After Removal of Pavement at Joint Which had been Previously Treated. White lines at ends show extent of coverage by cement slurry. Joint and locations of holes for treatment are indicated by white line and stakes.

only one course was applied on most of the road during the first season. The cracks had been pumping before the resurfacing was placed, and it was thought that the continued pumping might cause failures in the resurfacing. Consequently, the State forces drilled holes at locations where the pumping was in evidence, and pumped slurry though the resurfacing material and the concrete. The work was done with a large, air-pressure type mud-jack, and accurate cost records were maintained. Portland cement and calcium aluminate cement were used in the slurry. Although there are some indications of pumping which may eventually damage the resurfacing, it was generally agreed that the treatments were more than moderately successful. In Table 6, the average cost is shown for each hole, instead of for each joint, as given in other cost data.

TABLE 6

COST DATA

Pavement Stabilization on U. S. 50 near Shoals, Indiana[a]
Work Done in April, 1947
Length of Project, 14.4 Miles

Drilling Costs		
Patrolman 64 hr.		$ 67.70
Machine Operator 177hr.		$ 168.15
Laborers 110 hr.		$ 99.00
Two Trucks 173 hr.		$ 306.21
OneAir Compressor 89 hr.		$ 133.50
One Rock Drill 89 hr.		$ 111.25
Pumping and Stabilizing Costs		
408 Bags Portland Cement		$ 326.40
102 Bags Lumnite Cement		$ 255.00
Gen. Foreman 120 hr.		$ 138.00
Patrolman 336 hr.		$ 352.80
Machine Operators 477 hr.		$ 453.15
Laborers 200 hr		$ 180.00
Three Trucks 336 hr.		$ 594.72
Mud Jack 112 hr.		$ 334.88
Summary		
Man Hours	1484	$1458.80
Equipment Hours	799	$1480.56
Material		$ 581.40
	2283	$3520.76
Total Cost		$3520.76
Holes Drilled		998
Cost per hole for drilling and stabilizing, $3.53.		

[a] Information furnished by Maintenance Department, State Highway Commission of Indiana.

U S 67, near Bloomfield. The expansion joints in this 20-ft. concrete pavement were pumping severely, frequently in rock cuts. Cement slurry was used beneath these joints with only moderate success. It was thought by those who observed the treatments that there was a large amount of mud-slurry on the subgrade, and that the cement slurry or any other known filling material could not have been properly placed.

U S 31, near Columbus. This was the site of the first use of a new, large mud-jack, which had a mixer attached. The usual slurry mixture was used, and although some difficulty was at first encountered in the mixing of the water-thin slurry, this type of mud-jack may be practical on a long project, where a large amount of slurry is needed for each joint. No performance or cost data are available, as the work was done recently.

U S 31, near Seymour. This is an old concrete road containing a large number of cracks that are pumping severely An old mud-jack, of the air pressure type, is being used on a production basis, and several miles of pavement have been stablized by the use of the cement slurry. This road will probably be resurfaced soon.

U S 41, South of Vincennes. This is an old concrete road, located on the edge of a glacial river terrace, and is, for the most part, in good condition. There are a few short sections where the soil is plastic, and the pavement has failed. In one of the early experiments with the pavement jack, a short section of failed pavement was corrected and treated. Although the location was selected as an extreme condition, some of the lifted slabs are still in place, and a few of the cracks which were treated have not yet resumed pumping. However, some of the slabs have been replaced by concrete patches.

Economic Considerations

Inspection of the cost data given in Tables 1 and 3 will show that the labor and equipment costs are more than half of the total cost of the treatments, despite the fact that in the field study relatively expensive materials were used. This would indicate that the continued use of high cost materials for use in pavement pumping correction is warranted, if the performance continues to be satisfactory and frequent re-treatments eliminated.

An even more important comparison is that of the cost per joint of the pavement lifting and slurry treatment versus the replacement of the damaged pavement with a concrete patch. At locations where the repair is not to be followed by resurfacing, the new patch will generally be smoother, and its future performance somewhat more dependable, but the saving by the use of the treatment is considerable. The average experimental cost of lifting and treating faulted joints is approximately $7.50, while the estimated cost of replacement is at least $60.00. This estimate is based upon a patch 10 ft. long in an 11-ft.

lane, with a conservative unit cost of $5.00 per sq. yd. for removal and replacement.

Comparisons between the use of cement-slurry to stabilize rocking slabs prior to resurfacing, and the omission of such treatments hardly warrant consideration, as the latter practice is obviously unsound. However, if consideration should be given to resurfacing without correcting rocking slabs, experience has shown that the thickness of the resurfacing courses must be so great that the economy of using stabilizing treatments is evident. A bituminous resurfacing costs approximately $5,000 per mile per inch of thickness, while on Test Sections I and II, which were badly faulted and pumping severely, the total experimental costs were only $2300 per mile of two-lane pavements, completely stabilized. This cost would amount to less than the cost of increasing the thickness of a bituminous resurface course ½ in. to provide for the inadequate base.

Considering a pavement upon which the pumping has progressed only to a limited extent, and where the pavement has not become seriously faulted, it appears probable that corrective treatment alone would be adequate, without the need for immediate resurfacing. Even if a resurface should be considered advisable, the use of the corrective treatment is still justified, in that a thinner resurfacing course will be adequate.

CONCLUSIONS

1. The cement slurry mixture, consisting of portland cement, calcium aluminate cement, and water, is easily installed. It maintains a thin consistency for approximately ten minutes, after which it hardens rapidly, without shrinkage, and produces a sound, durable filling material.

2. Based upon almost two years of performance study, the use of a cement-slurry mixture, containing only portland cement, calcium aluminate cement and water, has been satisfactory in stabilizing pumping joints in rigid pavements.

3. Materials that can be used to advantage in treating pumping joints do not provide the proper lifting action to correct vertical mis-alignment of pavement slabs. The mechanical pavement jack will accurately adjust faulted slabs, and will repair damaged pavement joints, when used in connection with cement-slurry treatments.

4. On test sections containing severely pumping pavements, the average cost for experimental lifting and treating was approximately $7.50 per joint for one lane, and for experimental treating with slurry, approximately $4.25.

5. Cement-slurry treatments as well as treatments using other types of filling material, can be used most effectively when there is no mud slurry on the subgrade. The pavement jack is more effective in cooler weather, when the pavement is contracted.

6. It is logical that early treatment of pumping joints is the most economical procedure. A dollar spent on preventing the development of severe pumping or faulting will salvage more square yards of otherwise sound pavement than a dollar spent on a pavement that has already been severely damaged. This fact has been brought out repeatedly during the course of experimental treatments.

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PROGRESS REPORT OF COMMITTEE ON SALVAGING OLD PAVEMENTS BY RESURFACING

N. F. Schafer, *Chairman*

Commissioner, Indiana State Highway Commission

SOME PRACTICES USED BY OHIO IN THE SALVAGING OF OLD PAVEMENTS

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Salvaging of old pavements is the most important contribution of the highway industry to todays traffic needs. Ohio is fortunate in having many miles of all types of pavements of varying ages which provide a continuous test project for the development of methods and equipment for resurfacing and widening practices. Owing to the many comparatively recent developments in design and construction methods, this discussion is limited to widening with non-rigid bases of the macadam and bituminous concrete types and resurfacing with bituminous concrete.

It is very important that salvaging of a pavement be done at the proper time to avoid unnecessary costs. One of the most important items in salvage construction is to place the pavement in readiness for the salvage work to follow. In the case of old concrete pavements with rocking or broken slabs this may consist of undersealing or adding an insulation course to the surface. Economical procedure has proved it more practical to add extra leveling material as separate courses over areas of partial failure rather than to remove and replace the old pavement. Most salvage projects now include widening. Placing of widening courses of macadam or bituminous concrete or a combination of the two general types without the use of forms has increased production, decreased labor and improved the stability of the widening. Placing of widening with self propelled strike off units has improved results and increased production. Use of the same composition bituminous concrete mix in narrow base widening courses as used in leveling and some top courses has improved the density and stability of the course, and at the same time improved the contractor's operations. Asphalt of lower penetration is now being used on high traffic routes to provide increased stability. The open minded approach to salvage construction permitting the development of equipment and methods has resulted in improvements in equipment, methods and the finished product.

With an eye to the future, Ohio is today taking active steps to meet our present traffic demands.

It is our prerogative to speculate as to the probable demands of traffic 25 years in the future but it is purely a guess based on our