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Page

SUMMARY

This report evaluates the two methods used in New York State to underseal structurally distressed concrete pavements: Asphalt-cement subsealing and lime-cement jacking.

Seven experimental sections of state highways which were subsealed in 1963, and five sections of the New York State Thruway lime-jacked during 1963-64 were investigated. Measurements of transverse joint and crack faulting, precise leveling and roughness, and visual surveys were made before and at periodic intervals after treatment for approximately one year.

It is concluded that asphalt-subsealing as performed by New York State does not improve the condition of distressed pavements or adequately fill the voids beneath the pavements. Some improvement may be achieved by modifying the procedure, for example, by drilling two longitudinal rows of holes in each lane instead of a single row, and increasing the pumping temperature of the asphalt. It is doubtful, however, that these changes would make the treatment more permanent. In contrast, the results of lime-jacking indicate a marked improvement in pavement condition and suggest that long-term satisfactory performance can be anticipated.

Therefore, it is recommended that the Department discontinue the practice of subsealing and substitute the lime-cement jacking procedure practiced by the Thruway Authority. It is further recommended that future jacking operations be documented by the districts to provide data for a more complete evaluation of this method.

HIGHWAY RESEARCH BOARD

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2101 CONSTITUTION AVENUE, N.W. WASHINGTON, D.C. 20418

AN INVESTIGATION OF
ASPHALT CEMENT SUBSEALING AND LIME-CEMENT JACKING

Conducted Under Phase 1
of
Physical Research Project No. 25
"Analysis of Rigid Pavements"

INTRODUCTION

Cavities which develop in the foundation soil supporting concrete pavements are often a cause of structural distress. Since the cavities are not visible from the surface, their occurrence and progressive growth are not detected until the unsupported portions of pavement develop characteristic symptoms such as excessive pumping, faulting at transverse joints, cracking, and distorted cross-sections. Restoration of the pavement then becomes a difficult operation because it is more economical to completely fill the cavities with a stable material without removing the affected pavement.

Numerous methods have been used to fill the voids and re-establish the original profile of distressed pavements. However, experiences have varied and no single procedure enjoys widespread acceptance. For example, the New York State Department of Public Works pumps hot asphalt through holes drilled in the pavement, primarily to fill the voids. This method called "subsealing" does not realign the slabs or correct structural distress. On the other hand, the New York Thruway Authority has developed a jacking method in which a lime-cement slurry is pumped under sufficient pressure to fill all voids, raise the slabs, and decrease faulting.

The need for a general review of this subject and an evaluation of the corrective procedures currently used in New York forms the basis for this investigation.

Background

One of the earliest methods of pavement restoration which was used extensively in many areas of the country from about 1932 to 1961 is called "mud-jacking." A soil-cement slurry of fine-grained sandy loam, portland cement, and water is pumped through holes drilled in the pavement. While this process has been found to reduce pumping and faulting, and restore the original pavement profile, it provides only temporary improvements. This has been

explained by Benkleman (1)* who established that the organic constituents of loam increase shrinkage and reduce the strength of the cured mix, thus promoting early deterioration.

Another problem experienced with mud-jacking is the need for a mix thin enough to flow into narrow voids and yet thick enough to raise the slabs without seeping through the joints and shoulders. Field tests reported by Whitton (2) for the state of Missouri, and Green (3) for Indiana demonstrate that a soil-cement slurry must have a watery consistency to fill the thin, wedge-shaped voids which develop during initial stages of pumping. Goetz (4) corroborates these findings by an extensive laboratory program, and also determines that such lean mixes would successfully fill all the cavities only if the pavement were first raised into the desired position by an independent method. Green developes a simple but time-consuming mechanical pavement-lifting device for this purpose. Because of these limitations, most attempts with mud-jacking have been compromises which have produced unacceptable results.

The limited success with mud-jacking prompted investigations of other procedures. In New York State, for example, the first substantial use of asphalt subsealing occurred during 1948 in the Rochester area (5, 6). An asphalt emulsion conforming to AASHO specifications for RS-1 was poured through joints and cracks. In 1951, the process was improved by pumping a heavier grade emulsion, heated to 130-140 degrees Fahrenheit through holes drilled in the pavement. While this procedure was reported to have produced very satisfactory results, other areas of the state found that the emulsion remained soft and worked out of the joints and cracks. Department of Public Works specifications for subsealing were revised in 1962 to require a 15-30 penetration asphalt cement (New York Item 71-C) pumped into drilled holes at a temperature of 375 to 425 degrees Fahrenheit. These requirements were based, in part, on reports of investigations conducted in Ohio (7), Missouri (8), Illinois (9), and Texas (10), which concluded that a low penetration asphalt effectively seals the voids and provides permanent support for the pavement. However, little quantitative data is given in support of these conclusions.

The New York Thruway Authority developed a lime-cement jacking mix in 1962. LaFleur (11) reports that the mix contains finely-ground limestone, portland cement, water, and a wetting agent. The latter constituent overcomes the high viscosity normally associated with thick mixes, thereby permitting thorough filling of thin voids and simultaneous slab-lifting as required. While this procedure has been in use less than four years, satisfactory results have been reported.

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* Numbers denote appended references

Purpose and Scope

This report describes an investigation conducted during 1963-64 to evaluate and compare the effectiveness and economy of asphalt cement subsealing as practiced by the New York State Department of Public Works, with the lime-cement jacking method used by the New York State Thruway Authority.

Pavements scheduled for treatment were selected for this study so that conditions immediately before and after treatment could be compared. No attempt was made to modify the treatment procedures normally used. In addition to the investigation of work in progress, observations were made on previously subsealed pavements, and data were obtained from the Thruway Authority on earlier lime-jacking work.

The investigation consisted of measurements of transverse joint faulting, precise leveling and pavement roughness, and a visual survey of cracking, patching and pumping for the subsealed pavements. To avoid prolonged interference of fast-moving traffic on the Thruway, only faulting measurements and a visual survey were made for the lime-jacking study. Both procedures were documented and a cost analysis was performed.

INVESTIGATION

Test Sites

Five pavements in Public Works District 8 and two in District 6 which were scheduled for treatment during 1963 were selected for this investigation. Although in fair condition, they were characterized by transverse structural cracks and frost heaving. Collectively, they varied in slab length, load transfer devices, traffic volumes and age (Table No. 1). Moreover, they all contain relatively flat and straight sections of continuous pavement long enough to provide satisfactory test sections. Except for the south bound lanes of Site 8-10, which received an application of asphalt emulsion, none of the pavements had been previously subsealed.

TABLE NO. 1 - TEST SITE DATA

Site No.	Highway Designation	Year Const.	Cont. No.	Location			Cement Concrete Pavement (1)						Traffic	
				County	Route	SH No.	Pavement Thickness	Slab Width	Slab Length	No. (2) Slabs	Cracks Per Slab	Gravel Subbase	24 Hr. AADT	% Trucks
				ASPHALT CEMENT SUBSEALING										
8 - 10	Austerlitz-Flatbrook New Lebanon Pt. 2	1949	FARC 47-81	Columbia	NY 22	9081	8"	11'	95'	21	3.8	9"	2000	5
8 - 20	Austerlitz - New Lebanon Pt. 1B	1949	FARC 47-81	Columbia	NY 22	8531 8532	8"	11'	95'	21	1.4	9"	1500	5
8 - 31	Millerton - Conn. State Line	1928	1778	Dutchess	US 44	1778	8"-7"-8"	9'	78'	21	2.8	None	2100	5
8 - 32	Millerton - Conn. State Line	1928	1778	Dutchess	US 44	1778	8"-7"-8"	9'	78'	20	1.3	None	2100	5
8 - 40	Amenia - Wassaic	1925	RC 3089	Dutchess	NY 22& US 44	537	7½"-6"-7½"	9'	40'	21	0.7	None	2600	5
6 - 10	Elmira - Lowman City of Elmira Lowman Road Lowman-Waverly Pt. 1	1950	FARC 49-128	Chemung	NY 17 EB	5043	9"	12'	98'	21	1.0	6"	5400	7
6 - 20	Same as 6 - 10	1950	FARC 49-128	Chemung	NY 17 WB	5043	9"	12'	98'	21	1.7	6"	5400	7
				LIME-CEMENT JACKING										
TWY-1	Mile Post 132.3 S.B.	1954	C.T. 52-8P	Albany	I-87	None	9"	12'	100'	21	0.0	12"	5300 (3)	13
TWY-2	Mile Post 132.3 N.B.	1954	C.T. 52-8P	Albany	I-87	None	9"	12'	100'	21	0.0	12"	5300 (3)	13
TWY-3	Mile Post 132.9 N.B.	1954	C.T. 52-8P	Albany	I-87	None	9"	12'	100'	21	0.1	12"	5800 (3)	13
TWY-4	Mile Post 140.1 N.B.	1954	C.T. 52-8P	Albany	I-87	None	9"	12'	100'	21	0.2	12"	8000 (3)	13
TWY-5	Mile Post 77.7 N.B.	1954	C.T. 53-10	Ulster	I-87	None	9"	12'	100'	10	0.1	12"	6900 (3)	13

Note: (1) All two lane reinforced concrete pavement
(2) Per lane
(3) One Way

Two variations of subsealing are practiced in New York, the difference being in the placement of drill holes through which hot asphalt is pumped. In District 8, where spotted coverage is used, the holes are drilled adjacent to and on the low side of faulted joints and cracks and at other distressed locations (Figure 1). In contrast, the blanket coverage technique practiced in District 6 requires the holes to be uniformly spaced at about 10 foot intervals throughout the entire length of slab and near faults and cracks. In both methods, the holes are arranged in a single longitudinal row in the approximate center of each lane.

Five sections of the New York State Thruway were studied for the lime jacking investigation (Table 1). The first three sites listed were treated for the first time in the fall of 1963, and the remainder during the summer of 1964. To prepare for lime-cement jacking, two longitudinal rows of holes were symmetrically placed about six feet apart in each lane. The holes were spotted according to the condition of the pavement, but generally they were spaced ten feet on centers for pavement requiring complete coverage. Where fault reduction only was required, a single pair of holes was drilled about five feet away from the affected joint or crack.

Subsealing and lime-jacking procedures are described in Appendices A and B.

Measurements

The following observations and measurements were made to evaluate the effectiveness of these procedures:

Faulting - The permanent vertical displacement of one side of a joint or crack relative to the other side was measured to the nearest sixteenth of an inch before, and at various intervals after treatment. Typical locations of fault measurements are shown in Figure 1.

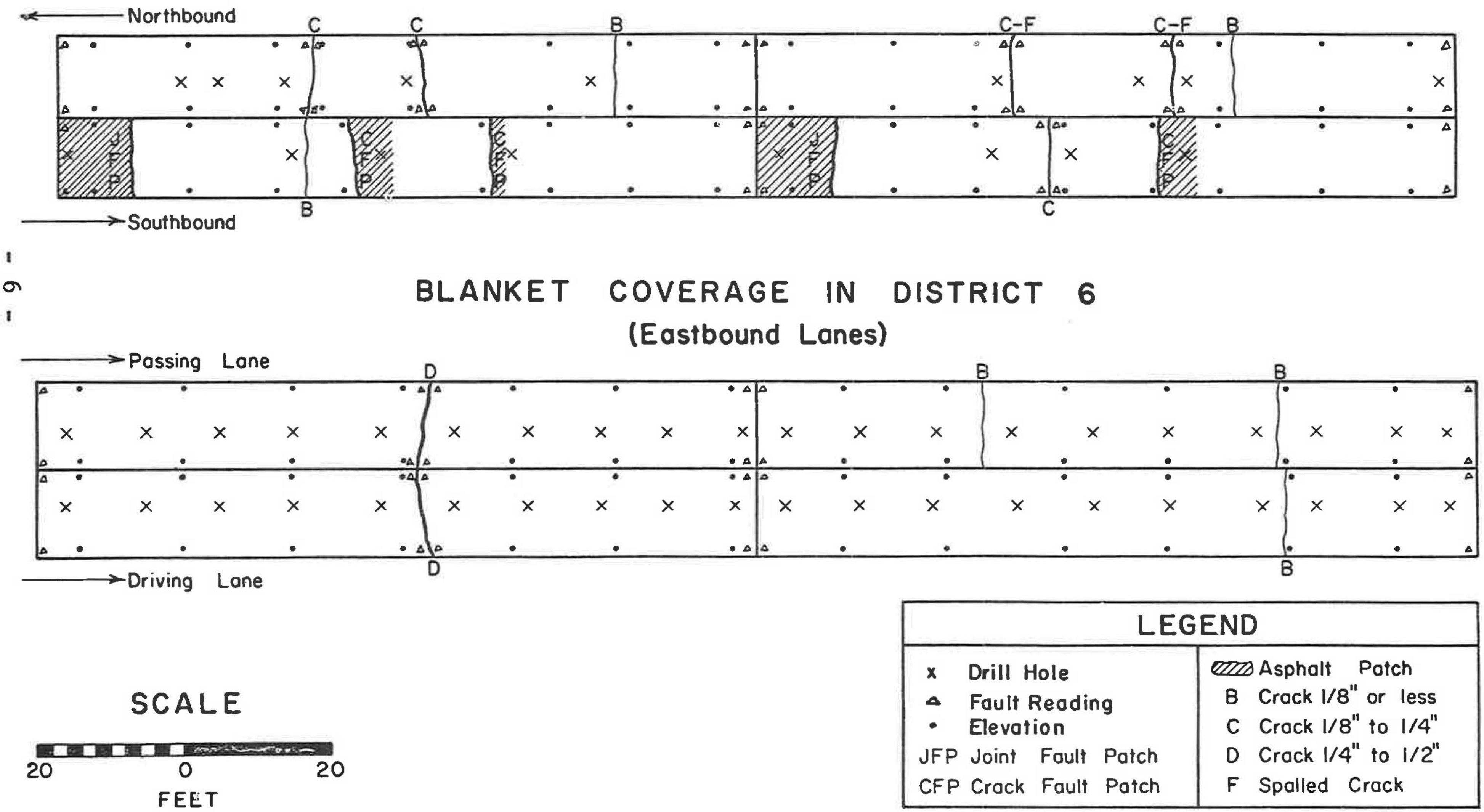
Cross-Sections - Surface elevations were determined to the nearest 0.01 foot on all subsealed pavements before and after treatment. Measurements were made about every 15 feet longitudinally, one foot from the edges of each lane, as shown in Figure 1.

FIGURE NO. 1

TYPICAL LAYOUT ON SUBSEALED PAVEMENTS

SPOTTED COVERAGE IN DISTRICT 8

BLANKET COVERAGE IN DISTRICT 6
(Eastbound Lanes)



Present Serviceability - The condition of the subsealed pavements before and after treatment was determined by the Present Serviceability Index formula. This required a visual inspection in which all cracks and patches were measured and recorded (Figure 1). The lengths of cracks greater than 1/8 inch and the area of all patches were used in the PSI formula. Surface roughness also was measured, first with the Thruway's CHLOE profilometer (Figure 2), and later with a BPR type roughometer acquired by the Department (Figure 3). The correlation of the two devices is given in Appendix C.

FIGURE 2 - CHLOE Profilometer

FIGURE 3 - BPR-Type Roughometer

RESULTS

Faulting

Among the various types of distress found in concrete pavements, faulting of joints and cracks is perhaps the most annoying to the public and maintenance forces. Faulting, which generally occurs at transverse joints, sometimes becomes so excessive that adjacent sections of the longitudinal joints also become faulted and create a potential safety hazard (Figure 4). Therefore, an important objective in restoring distressed concrete pavements is to retard further vertical displacement of joints and cracks. Ideally, the pavement should be returned to its original unfaulted condition, but this is extremely difficult to accomplish.

FIGURE 4 - Longitudinal and Transverse Joint Faulting

The results of transverse fault measurements at each subsealing and jacking site immediately before treatment, and at various intervals for a period of one year are presented graphically in Figure 5. Each value plotted represents the combined average of two measurements per lane at 20 successive transverse joints and at major cracks, except for Sites 8-32 and TWY-5 where 19 and 9 joints, respectively are contained in the test sections. The computed averages are given in Table No. 2.

Spotted subsealing coverage is represented by Figures 5a and 5b. The three pavements shown in Figure 5a were approximately 36 years old when subsealed and exhibited average total faulting of about 1/16 to 3/16 of an inch. Subsealing was performed in accordance with the State Public Works specifications (12), which require that pumping be discontinued as soon as the voids are filled and before any movement of the pavement occurs. In contrast, a deliberate attempt was made to eliminate the 3/16 inch to 1/4 inch faulting in the two pavements represented by Figure 5b, both of which were 14 years old when treated. Here, pumping was carefully continued until asphalt began rising through the joints and cracks and no further movement of the slabs could be detected.

FIGURE NO. 5

EFFECT OF TREATMENT ON TRANSVERSE FAULTS

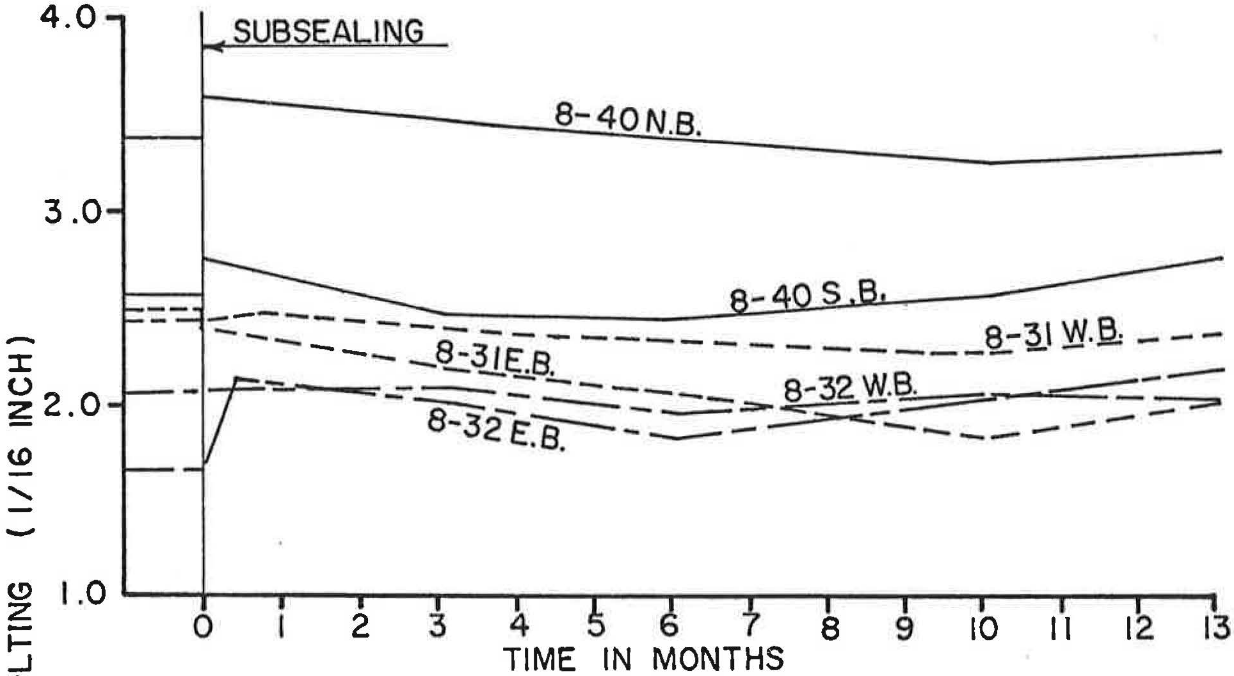


FIGURE 5A - SPOTTED SUBSEALING COVERAGE (SPECIFIED PROCEDURE)

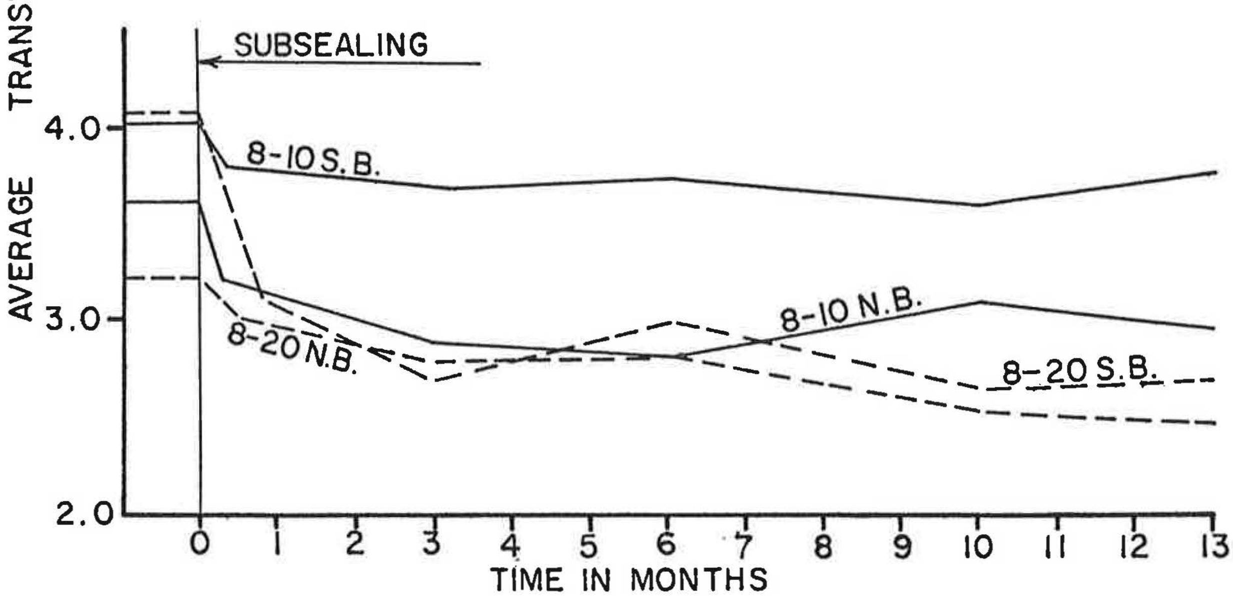


FIGURE 5B - SPOTTED SUBSEALING COVERAGE (FAULT REDUCTION ATTEMPTED)

These results indicate that transverse faulting was reduced slightly where pumping was continued; however, where the specified procedure was used faulting remained essentially unchanged. During the first six to ten months after subsealing, faulting decreased slightly and then remained unchanged or increased for the balance of the thirteen month recording period. Significantly, the faulting measured at the end of this period was, in almost every case, essentially the same as before the pavements were subsealed.

The two pavements in District 6 which received blanket coverage are represented by Figure 5c. These pavements were approximately 13 years old when treated and had faults which averaged from 1/8 to 5/16 of an inch. Considerable difficulty was experienced in controlling pavement movement because of the overlapping effect of the more closely spaced subsealing holes.

FIGURE NO. 5

EFFECT OF TREATMENT ON TRANSVERSE FAULTS

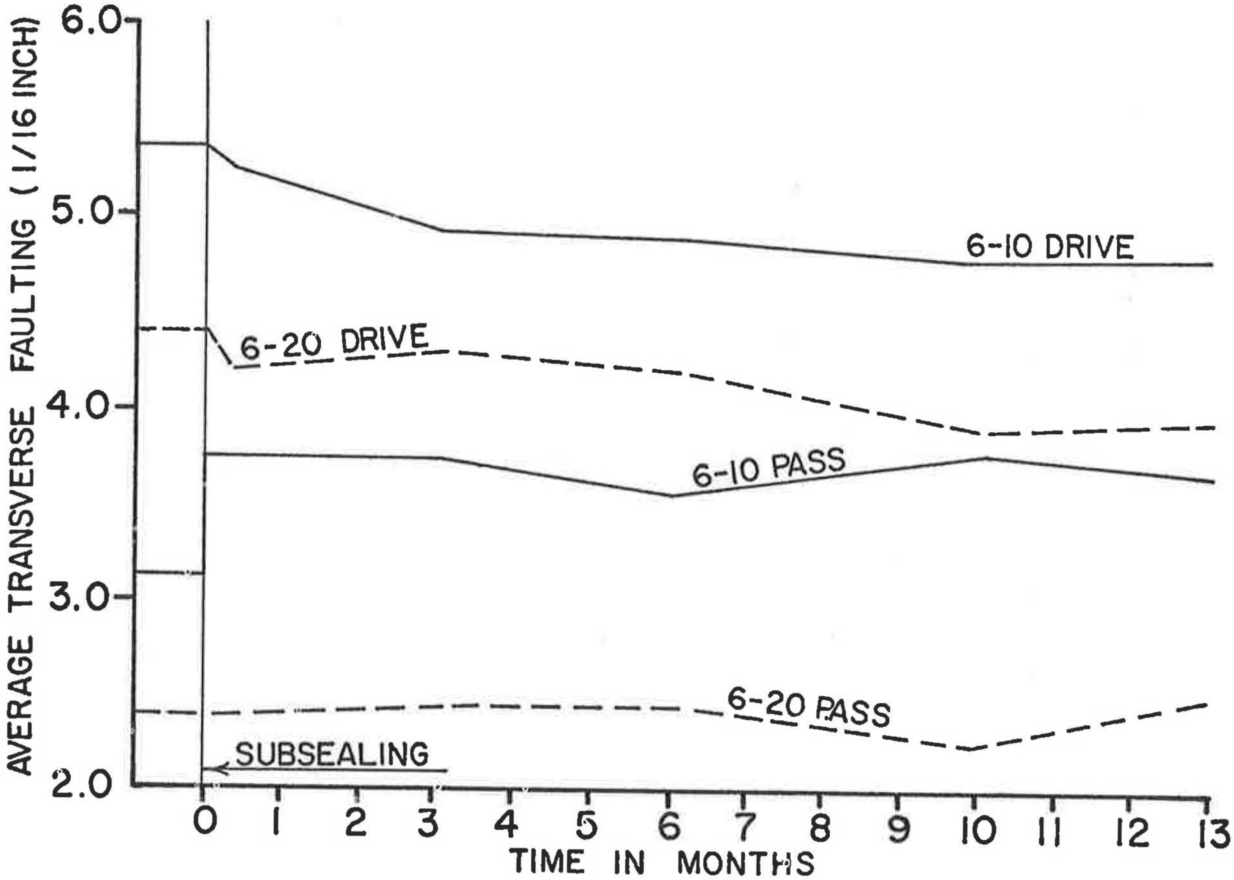


FIGURE 5 C — BLANKET SUBSEALING COVERAGE (SPECIFIED PROCEDURE)

TABLE NO. 2 AVERAGE TRANSVERSE FAULTING

Site No.	Lane	Faulting (units of 1/16 inch) Before Treatment	Months After Treatment 0[1]	3	6	10	13
			Asphalt Cement Subsealing				
8-10	NB	3.6	3.2	2.9	2.8	3.1	3.0
	SB	4.1	3.8	3.7	3.7	3.6	3.8
8-20	NB	3.2	3.0	2.8	2.8	2.5	2.5
	SB	4.1	3.2	2.7	3.0	2.7	2.7
8-31	EB	2.5	2.3	2.2	2.1	1.8	2.0
	WB	2.5	2.5	2.4	2.4	2.3	2.4
8-32	EB	1.7	2.1	2.0	1.8	2.0	2.2
	WB	2.0	2.1	2.1	2.0	2.0	2.0
8-40	NB	3.4	3.6	3.5	3.4	3.2	3.3
	SB	2.6	2.8	2.5	2.4	2.5	2.8
6-10	Drive	5.4	5.3	4.9	4.9	4.8	4.8
	Pass	3.1	3.8	3.8	3.6	3.8	3.7
6-20	Drive	4.4	4.2	4.3	4.2	3.9	3.9
	Pass	2.4	2.4	2.4	2.5	2.3	2.5
			Lime Cement Jacking				
TWY-1	SB	5.3	4.2	-	3.9	3.7[4]	3.5
TWY-2	NB	5.2	4.0	-	4.7	4.5[4]	4.5
TWY-3	NB	5.2	4.3	-	4.3	4.3[4]	4.4
TWY-4	NB	4.8	2.5	1.4[2]	1.5[3]	2.2[4]	-
TWY-5	NB	6.0	5.4	3.9[2]	3.2[3]	3.1[4]	-

NOTES:

(1) One to three weeks after subsealing, and on the same day as jacking.
(2) One week after treatment.
(3) Four months after treatment.
(4) Nine months after treatment.

As a result, the pavement was raised uniformly approximately 3/8 inch over its entire length. However, this had no apparent beneficial effect on faulting, and after 13 months the net change in faulting was small. It appears, therefore, that blanket subsealing has no advantage over spotted coverage, and that neither procedure effectively reduced transverse faulting.

Because of the relatively short period represented by the data, a prediction of long-term performance is difficult. The light traffic currently carried by these pavements, as indicated in Table 1, suggests that any additional faulting will occur at essentially the same rate that existed before treatment. A heavier volume of truck traffic would, undoubtedly, hasten deterioration.

The effect of lime-jacking on transverse joint and crack faulting is illustrated in Figure 5d. Sections 1, 2, and 3 were nine years old when jacked and they exhibited average faulting of about 5/16 inch immediately before treatment. Jacking was discontinued on these sections when the high side of the faults started to rise. Initially, this treatment reduced faulting about 1/16 inch, slightly more than was obtained with subsealing (Figure 5b). However, at the end of the 13 month period, Sections 2 and 3 rebounded to within 1/32 inch of the original faulting and Section 1 decreased only an additional 1/32 inch. Therefore, lime-jacking did not appreciably reduce faulting on these sections of pavement.

Based on the performance of these jacked pavements, the Thruway Authority modified the procedure when Sections 4 and 5 were treated the following year. These pavements were faulted 5/16 inch and 3/8 inch, respectively, and were about ten years old. In this new procedure, as yet unproved, the low side of the fault was raised sufficiently to "bind" the joint and cause incipient lifting of the high side. At that point, jacking continued slowly as both sides were raised an amount equal to the magnitude of the remaining faulting. It was reasoned that this procedure should create a void beneath the high side of the joint equal to the magnitude of the fault, and the low side should be fully supported by the lime-cement. Subsequent traffic should then force the high side down until it is seated firmly and flush with the low side. That this may be occurring is suggested by Figure 5d which shows that faulting was initially reduced by 70 percent on Section 4 and 35 percent on Section 5. After nine months, the net reduction in faulting was 54 percent and 48 percent, respectively. Further surveys will establish whether any significant rebounding occurs. It is apparent, however, that this over-jacking procedure has effectively reduced faulting during the initial post-treatment period.

FIGURE NO. 5

EFFECT OF TREATMENT ON TRANSVERSE FAULTS

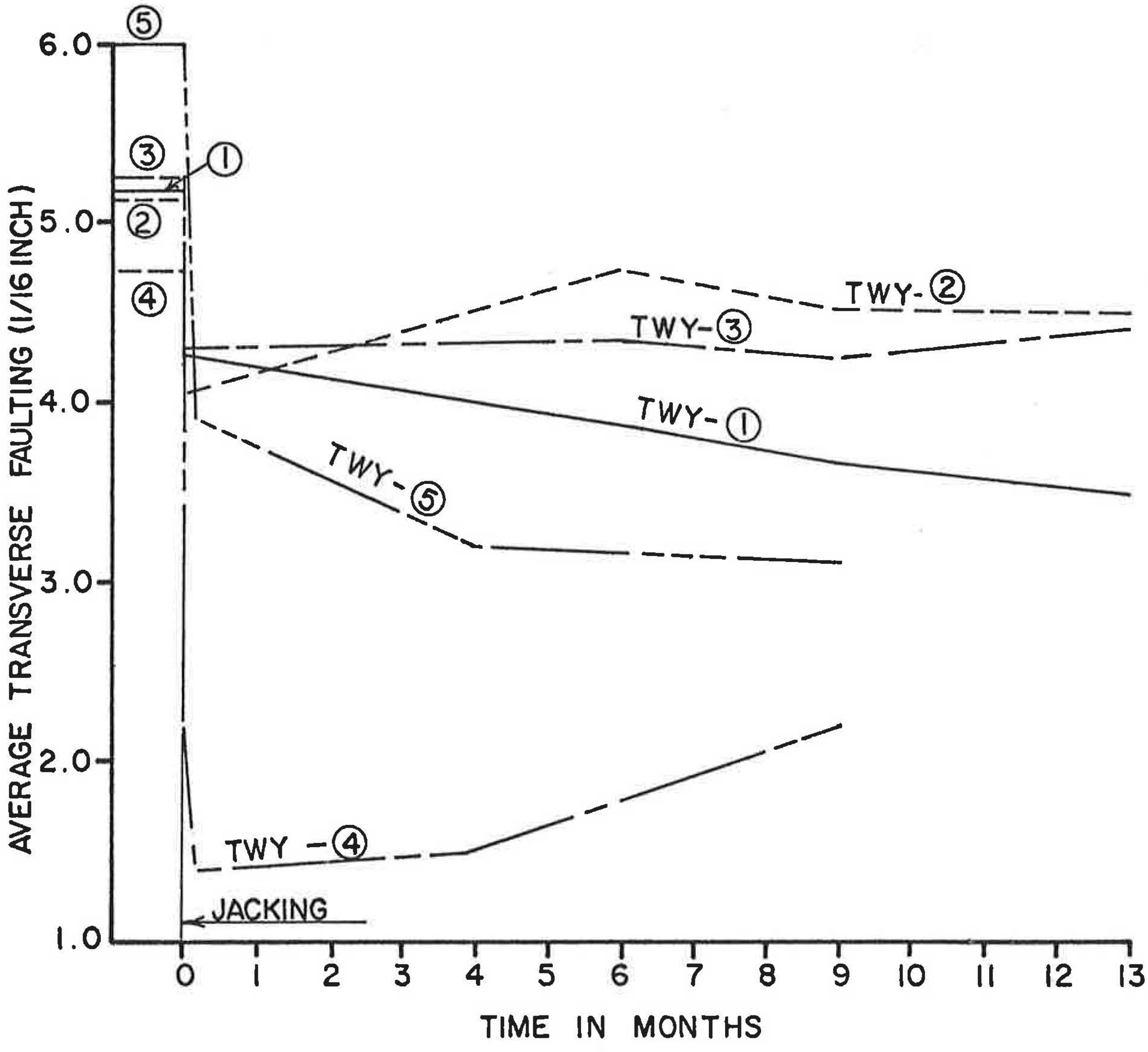


FIGURE 5D - LIME CEMENT JACKING

One result of the subsealing operations was a marked increase in longitudinal joint faulting which averaged about 1/4 inch before treatment. A comparison of pavement cross-sections, determined by plotting precise elevations before and after treatment, and augmented by periodic direct measurements, established that longitudinal faulting increased initially on all pavements, except at Site 8-32 WB, where there was a slight decrease. Increases of 17 to 54 percent in longitudinal faulting were recorded immediately after subsealing where spotted coverage was used, and 88 to 106 percent on the two sites which received blanket coverage. Moreover, these increases were still evident at the end of the 13-month recording period. This suggests that subsealing can create a hazardous condition, unless precautionary measures are taken to patch longitudinal joints which become excessively faulted (Fig. 6). No evidence of additional longitudinal faulting was noted on the lime-jacked pavements.

FIGURE 6 - Patching Required After Subsealing
Route 20, New Lebanon, June 1963

Extrusion

Asphalt extrusion contributes to the temporary nature of the fault reduction achieved by subsealing. Within a few days after treatment, asphalt began extruding from many of the tranverse joints on Sites 8-10 and 8-20. By the following summer, the extrusion reached the proportions illustrated in Figure 7, and showed no sign of diminishing. Approximately 25 gallons of asphalt per hole were used on these pavements, except the southbound lane of Site 8-20 which required only 16 gallons per hole (Table 3). Similar extrusion occurred at Sites 6-10 and 6-20 where the quantity of asphalt was about 30 gallons per hole.

FIGURE 7 - Extruded Subsealing Asphalt. Site 6-20, Route 17, Elmira (June 1964)

This loss of subsealing material is reportedly a common occurrence in the State. Significantly, however, no extrusion has been observed on Sites 8-31, 8-32 and 8-40 which received about twelve gallons of asphalt per hole and where no attempt was made to remove the faulting or raise the pavement. It appears, therefore, that where large quantities of asphalt are used, the asphalt becomes less viscous during warm weather, and is subject to extrusion. In contrast, no loss of material has been noted on the lime-jacked Thruway test pavements.

TABLE NO. 3 SUBSEALING QUANTITIES

Site No.	Lane	Estimated Cracks Per Slab	Estimated Gallons Per Hole[1]	Actual Cracks Per Slab	Actual Gallons Per Hole	Actual Holes Per Slab
8-10	NB	3.4	20.0	1.5	24.9	2.7
	SB	3.4	20.0	1.2	23.7	2.9
8-20	NB	1.2	20.0	1.1	28.2	1.8
	SB	1.2	20.0	0.4	15.5	1.4
8-31	EB	4.7	20.0	2.3	10.9	3.2
	WB	4.7	20.0	3.3	11.3	3.7
8-32	EB	4.7	20.0	1.1	13.9	1.8
	WB	4.7	20.0	1.5	14.7	2.5
8-40	NB	1.2	20.0	0.8	12.4	1.4
	SB	1.2	20.0	0.5	9.8	1.4
6-10	Drive	---	25.8	0.4	29.6 [2]	9.8
	Pass	---	25.8	0.1	29.6 [2]	10.3
6-20	Drive	---	25.8	0.3	29.6 [2]	10.4
	Pass	---	25.8	0.7	29.6 [2]	10.1

NOTES:

(1) Gallons of Item 71-C asphalt @ 60 degrees Fahrenheit.

(2) Computed from daily quantities; number of gallons used divided by the number of holes.

Void Filling

An important requirement of a satisfactory subsealing or lime-jacking method is the need to fill all voids. When this is not accomplished, the remaining voids are likely to form the nucleus of a new void system which becomes progressively larger and eventually results in additional pavement distress.

Inasmuch as pumping was continued on all of the subsealed pavements investigated until movement was incipient or actually occurred, it was assumed that the voids had been adequately filled. To verify this, arrangements were made to remove a portion of pavement in District 8 after subsealing. The pavement, a four-lane divided section of US Route 9W, south of Newburgh, was subsealed in June 1964 by the spotted coverage method. The portion selected for inspection, however, was sufficiently distressed to warrant additional subsealing holes at intermediate points where large voids were believed to exist. Consequently, this section of pavement received the equivalent of blanket coverage with the holes spaced about ten feet apart. In general, pumping was discontinued when the voids were considered to be filled; no attempt having been made to raise the slabs.

Four successive 95 foot slabs in the driving lane were removed one week after subsealing. The slabs were broken up with a drop weight, which damaged the subsealing asphalt and disturbed the subgrade. However, some valid observations were possible. For example, it was found that the maximum thickness of asphalt was about five inches, the minimum thickness was about one-eighth inch, and many thinner voids were not filled. Moreover, appreciable areas between successive subsealing holes in each lane and between adjacent lanes received no asphalt. This suggests that two rows of holes are required in each lane to insure complete coverage. This practice is followed by the Thruway Authority in its lime-jacking operations.

Another common occurrence revealed by removing the slabs was that voids deeper than about one inch were only partially filled. In most instances, a thin layer of asphalt (1/4 to one inch thick) was found along the top of voids where they contacted the pavement. The balance of the voids beneath the asphalt were unfilled. An example of this is shown in Figure 8. It is difficult to explain how the asphalt was able to follow this path and fill only the upper portion of voids. A plausible explanation is that the voids were filled with water which floated the asphalt and caused it to be deposited at the top. Figure 9, which shows a substantial amount of water flowing beneath, and some above, an apparently asphalt-sealed void channel supports this conclusion. The fact that the surface of the hardened asphalt resembled a sponge suggests that the hot asphalt encountered water and cooled rapidly before filling the voids entirely.

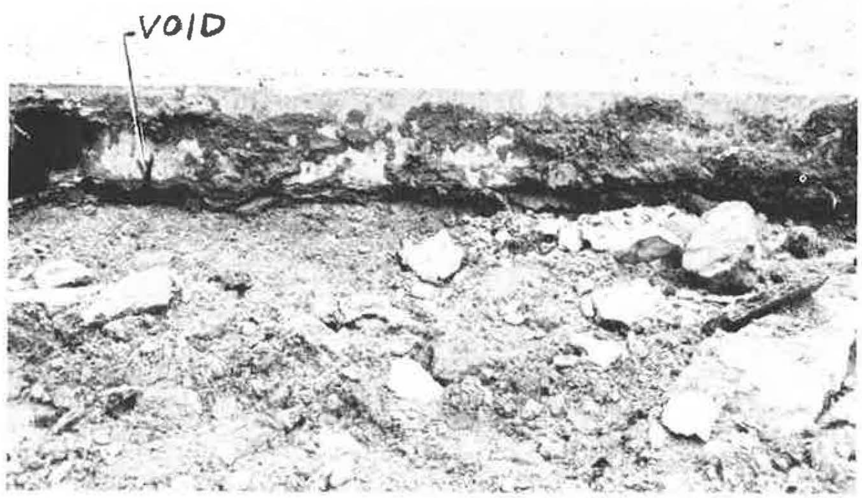


FIGURE 8 - Unfilled Void Beneath Subsealed Pavement. Route 9W, West Point (June 1964)

FIGURE 9 - Water Seeping Through a Subsealed Void. Route 9W, West Point (June 1964)

The State specifications require that mud or water encountered beneath the pavement be removed prior to subsealing. The specified procedure consists of digging trenches in the shoulders adjacent to joints and cracks, and expelling the mud or water through the trenches with compressed air forced into the drilled holes. In practice, this operation is generally performed only when an extremely wet condition is encountered, since attempts under drier conditions have been ineffective. Accordingly, this step was not included in the treatment of the test sites.

There is reason to expect that greater areal coverage and more complete void filling can be achieved by using a hotter asphalt. The State specifications require the temperature of subsealing asphalt to be maintained between 375 and 425 degrees Fahrenheit during placing. This temperature range is equivalent to viscosities of approximately 240 and 100 centipoises, respectively, for the 15-30 penetration asphalt now in use. Figure 10 delineates these requirements on a temperature-viscosity graph prepared from the results of Brookfield viscosity tests on samples of the asphalts used at the test sites. In contrast, the literature indicates an overwhelming preference for pumping temperatures of 400 to 475 degrees Fahrenheit based on asphalts of essentially similar characteristics (7, 8, 10, 13). It can be seen that the corresponding viscosities are reduced almost 50 percent to about 130 and 55 centipoises, respectively. On this basis, an increase of 25 degrees Fahrenheit in the temperatures now specified would reduce the viscosities significantly, and still provide a 25 degree margin below the specified minimum 475 degrees Fahrenheit flash point.

The New York Thruway Authority has removed portions of lime-cement jacked pavement and found that the voids were completely filled. In addition, LaFleur (11) presents pictorial evidence of a thin, continuous layer of lime-cement exposed by trenching along the edge of a treated pavement. He interprets this as indicating that the voids between the edge of the pavement and the longitudinal center line of jacking holes in each lane are filled. Essentially the same procedure is being used successfully on the Ohio Turnpike, as substantiated by an investigation where portions of pavement were removed. All voids were filled, which lends support to LaFleur's interpretation.

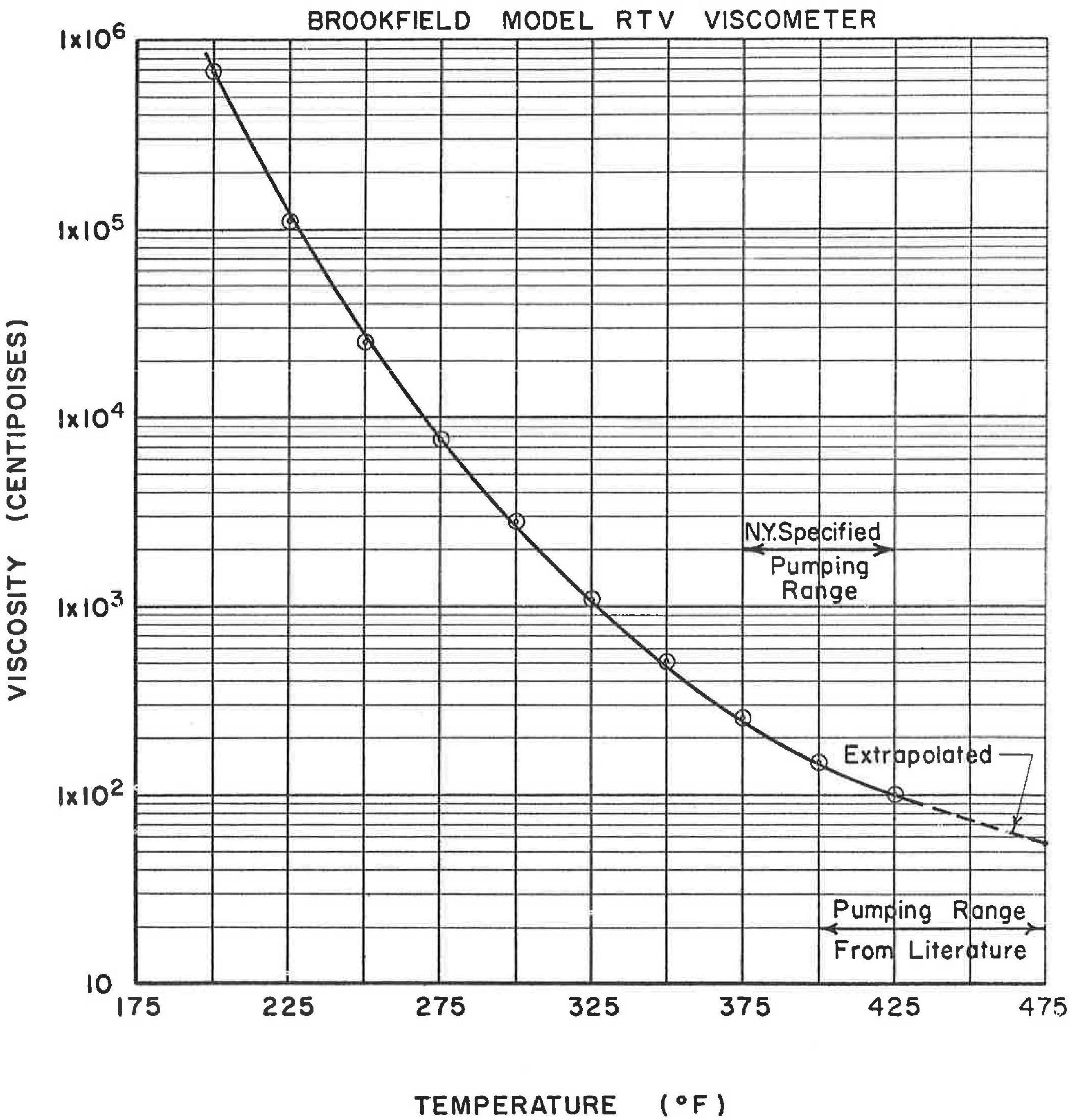
Other Observations

Pumping of concrete pavements is usually described as the ejection of soil, generally in the presence of water, at joints or along the exterior edges of the pavement. It occurs most frequently where transverse joints and structural cracks meet the shoulders as these areas experience repetitive dynamic deflections. If this condition is not corrected, the continued loss of soil eventually creates voids large enough to cause structural distress in the pavement.

FIGURE NO. 10

TEMPERATURE - VISCOSITY RELATIONSHIP

15 - 30 PENETRATION ASPHALT



Since evidence of pumping on the subsealed test pavements was noted only in a few isolated instances prior to treatment and, in fact, was not a primary consideration in the decision to subseal, a detailed survey was not performed at that time. However, in February 1964, approximately eight months after subsealing, the five sites in District 8 were carefully inspected. The number of occurrences of pumping appeared to have increased, but in the absence of a similar survey before treatment it was difficult to validate this observation. It is clear, however, that subsealing did not prevent pumping. This is not surprising, since it has been demonstrated that the subsealing asphalt seldom sealed to the edges of the pavement, and water was not prevented from entering the subgrade beneath the pavement.

During this post-subsealing inspection in District 8, a survey was also made of the amount of water flowing from beneath the pavements. There appeared to be an increase in the quantity and occurrence of water flowing up through joints and cracks, as well as through some subsealing holes. In most instances, the points of exit coincided with the low end of gently sloping grades and the "down" side of superelevated curves. In view of the evidence of incomplete void filling previously described, it was reasoned that the same quantity of water which flowed unrestricted beneath the pavement before subsealing was now confined in flow paths of reduced cross-sectional area. In addition, subsealing most likely cut off some of the void channels so that the water was redirected. Under these conditions, the water sought out and found points of relief along the pavement. This phenomenon emphasizes the importance of filling all voids, regardless of the method used.

Cross Slope

Another important aspect of undersealing is its effect on the transverse slope of the pavement. A procedure which can affect uniform changes in cross slope, when required, is obviously preferable to one which permits little or no control of movement. Another consideration is the long-term permanency of any corrective movements achieved initially. These factors were evaluated on the subsealed test sections with precise levels performed before and at various intervals after treatment. Prior to subsealing, the pavements had cross slopes of about 3/16 inch per foot, which is the minimum required by current design standards. Consequently, an increase of about 1/16 inch per foot could be easily tolerated, and, in fact, was desirable, while any reduction would create substandard conditions.

The results indicated that, immediately after subsealing, approximately two-thirds of the cross-sections on each of the five sites in District 8 showed an increase of about 1/4 inch over a full lane width (about 1/40 inch per foot). Of the remaining cross-sections, the majority showed a decrease in cross-slope of about the same magnitude, while only a few remained unchanged. On the other hand, the two pavements in District 6 where blanket coverage was used exhibited a decrease of cross-slope of about 1/4 inch over a full lane in about 80 percent of the cross-sections, while only 20 percent showed an increase.

Although these variations in cross-slope are minor, they serve to illustrate that precise control of movement is difficult with subsealing as compared with lime-jacking. Dial gages placed across a transverse joint and the adjacent longitudinal joint on one of the Thruway jacking sites verified that movements could be regulated to within two to three thousandths of an inch. This has been attributed to the two rows of drilled holes and the slower rate of pumping (6 gallons per minute compared to about 60 gallons per minute for subsealing) which reduces residual movements after pumping is discontinued. As a final comment, within nine months after subsealing, the pavements in District 8 had regained their original cross-slope and those in District 6 nearly so. Whether the Thruway pavements behaved differently was not established; however, the faulting data previously discussed suggests that jacking has a more permanent and more beneficial effect.

Present Serviceability Index

The concept of designating the overall adequacy of a pavement by means of a single numerical value called the Present Serviceability Index was developed as part of the AASHO Road Test. This method rates the condition of a pavement according to measured variations in longitudinal profile and the extent of cracking and patching. While this approach has shortcomings which limit the applicability of the results when comparing absolute ratings, it is the most practical method currently available for evaluating a large volume of pavements. Since the PSI method has received widespread acceptance, it was used in this investigation.

As previously noted, PSI determinations were made for all of the subsealed test pavements using the Thruway's CHLOE profilometer before treatment and a BPR-type roughometer after treatment. Equivalent evaluations of the Thruway jacking sites were not performed. However, the results of similar determinations made by the Thruway Authority on a previously jacked portion of pavement are included in the discussion. The equation used in this study is shown on the next page.

$$PSI = 5.41 - 1.80 \log (0.40R - 33) - 0.09 \sqrt{C+P}$$

Where: PSI = Present Serviceability Index, with empirical limits of about 0.5 to 4.5, the upper limit denoting a very smooth pavement.

R = Inches of roughness per mile as measured by the roughometer.

C = Total length of cracking in feet per 1,000 square feet of pavement.

P = Total area of patching in square feet per 1,000 square feet of pavement.

Table No. 4 presents the results of roughness measurements and PSI determinations for all the subsealed test pavements before, immediately after, and three months after treatment. A significant improvement in PSI was generally achieved immediately after treating the four pavements whose slabs were raised (Sites 8-10, 8-20, 6-10 and 6-20). The PSI was decreased on the remaining three pavements where no attempt was made to raise the slabs. More important, however, after three months the PSI of most of the pavements was about the same as or less than it was before subsealing. Since the changes in faulting and cross-slope were not permanent, it seems reasonable to expect that the final stabilized PSI values will be essentially the same as those before subsealing. Therefore, it appears justifiable to conclude that subsealing has not materially improved the serviceability of these pavements.

The Thruway Authority has used a CHLOE profilometer on numerous sections of the Thruway during the past several years. Objectives have been to evaluate the effect of lime-jacking on pavement serviceability and the permanency of any improvements in pavement roughness resulting from jacking. One section of pavement which has been thoroughly documented is approximately eight miles long and is located midway between test sections TWY 1 & 2 and TWY 5. It was selected for this discussion because measurements made before lime-jacking established that with very few exceptions the transverse joints were faulted less than 3/8 inch (14). This is important since the profilometer does not record faults greater than 3/8 inch. Profilometer surveys on one-tenth mile segments of successive half-mile portions of pavement established that the average PSI one to six months after treatment had increased from 3.46 to 3.69 in the north bound direction and from 3.17 to 3.54 south bound. Significantly, none of the individual segments showed a decrease in PSI after treatment. Therefore, lime-jacking was more effective than asphalt subsealing in improving pavement serviceability.

TABLE NO. 4

SERVICEABILITY OF SUBSEALED TEST SITES

Site No.	Lane	Before: $.09\sqrt{C+P}$	Before: Roughness[1] (in./mi.)	Before: PSI	Immed. After: Roughness (in./mi.)	Immed. After: PSI	3 Mos. After: Roughness (in./mi.)	3 Mos. After: PSI
8-10	NB	0.33	122	2.92	106	3.33	113	3.12
	SB	1.02	150	1.81	129	2.10	137	1.98
8-20	NB	0.20	110	3.33	103	3.57	108	3.39
	SB	0.14	115	3.26	106	3.52	114	3.29
8-31	EB	0.43	170	2.20	183	2.09	189	2.05
	WB	0.48	178	2.08	182	2.05	197	1.94
8-32	EB	0.37	158	2.38	174	2.23	190	2.10
	WB	0.35	159	2.38	165	2.33	171	2.27
8-40	NB	0.38	204	1.99	201	2.01	211	1.95
	SB	0.45	200	1.95	218	1.84	246	1.69
6-10	Drive	0	116	3.39	114	3.43	124	3.21
	Pass	0.14	104	3.59	101	3.71	114	3.29
6-20	Drive	0.13	117	3.23	123	3.10	133	2.94
	Pass	0.17	94	4.05	100	3.72	110	3.37

NOTES:

(1) Initial roughometer values determined from correlation with profilometer, Appendix C.

Treatment Costs

Cost is the final yardstick by which subsealing and jacking are evaluated in this report. A complete cost study would analyze the length of time that each treatment is effective and the maintenance required between successive treatments. However, such an analysis is beyond the scope of this report and, therefore, only treatment costs are reviewed.

The five subsealed test sections in District 8 which received spotted coverage were part of one subsealing contract, RC 63-24, involving a total of 109 lane-miles of treated pavement on six state highways. The two experimental sections in District 6 which were treated by blanket subsealing were similarly included in one contract, RC 63-26, involving 28 successive lane-miles on one highway. Table 5 lists the actual total quantities and corresponding costs for each contract, as well as the composite cost per lane mile of subsealing and lime-jacking.

TABLE 5 - SUMMARY OF COSTS

Treatment	Lane Miles	HOLES Number	HOLES Unit Cost	ASPHALT Gallons	ASPHALT Unit Cost	Maint. of Traffic	Lane Mile Cost
Subsealing							
Spotted	109	17,577	$0.40	347,980	$0.205	$10,000	$ 808
Blanket	28	15,395	0.20	462,712	0.160	2,000	2817
Lime-Jacking	900	-	-	-	-	-	625

The cost per lane mile indicated for each contract is the average for the entire contract. Actual costs per mile varied widely depending on the extent of pavement cracking, the volume of voids to be filled, and other local conditions. Therefore, these data are useful only as general cost guides for estimating projects of similar size.

The cost per lane mile of blanket subsealing and spotted subsealing differ in the ratio of about 3½:1. This difference is largely the result of the greater number of holes and quantity of asphalt required for blanket coverage. An even greater difference probably would have occurred if the spotted subsealing had been performed on one highway rather than on several, because the cost of moving equipment and materials, and of maintaining traffic is included in the cost per lane mile.

The average total cost to lime-jack one lane-mile of Thruway pavement with maintenance forces was reported by LaFleur (11) to be $625 in 1962, which included overhead. This figure is based on a crew of ten men who would require two days to drill 132 holes per mile and to install 16,000 pounds of lime and 3,200 pounds of cement. Additional unpublished data furnished by the Thruway indicates that these figures were still valid in 1963 for approximately 900 lane-miles of jacked pavement. It is concluded, therefore, that lime-jacking can be performed by State forces as economically as asphalt subsealing by contract.

CONCLUSIONS

The results of this investigation of asphalt subsealing performed on seven sections of State highways, and lime-cement jacking carried out on the New York Thruway warrant the following conclusions:

1. Subsealing did not improve the condition of the pavements with regard to transverse joint and crack faulting, cross-slope, and Present Serviceability Index. In addition, on some pavements, longitudinal joint faulting was increased.

2. Subsealing did not adequately fill the voids beneath the pavements.

3. The initial results of subsealing may be improved by increasing the pumping temperature of the asphalt to 400 - 450 degrees Fahrenheit, and by using two longitudinal rows of holes in each lane. However, evidence of asphalt extrusion after subsealing suggests that any improvements would be temporary.

4. Lime-jacking significantly improved the condition of the pavements immediately after treatment. Moreover, measurements and observations over a nine month period indicate that satisfactory long-term performance is probable. This improvement is attributed to the use of a material which can flow into thin voids and cure in the presence of water; the superior control and coverage obtained with two rows of drill holes in each lane; and the over-jacking of faulted joints and cracks.

5. Lime-jacking and asphalt subsealing are comparable in cost.

RECOMMENDATIONS

It is recommended that the Department discontinue the use of subsealing to rehabilitate pavements and substitute lime-cement jacking. All jacked pavements should be observed periodically by the Districts so that the long-term effectiveness of this method can be evaluated.

ACKNOWLEDGEMENTS

This investigation was conducted in cooperation with the United States Bureau of Public Roads under the State-Federal Physical Research Program.

Subsealing was performed in District 8 under the supervision of District Engineer M. N. Sinacori, and in District 6, under the supervision of District Engineer W. J. Dennis. Their cooperation contributed materially to the success of this investigation. Mr. V. Wadsworth, Project Engineer in District 8, also provided valuable information. The subsealing contractors, Peckham Road Construction Company, in District 8, and Allied Asphalt Company, in District 6, allowed various measurements to be made during the subsealing operations.

The investigation of lime-cement jacking on the New York State Thruway was performed with the permission of Mr. C. H. Lang, Chief Engineer. The assistance of Mr. John Robertson, Superintendent of Thruway Maintenance, in arranging for the use of the Thruway's Chloe Profilometer and in providing considerable useful data is gratefully acknowledged.

The Bureau of Physical Research analyzed all data and prepared the following report.

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Bureau of Physical Research

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* 58-2 Roller Efficiency on Embankment Materials (Vibratory Roller)

58-1 Polyethylene Sheets as Curing Covers For Concrete Pavements

APPENDIX A

ASPHALT CEMENT SUBSEALING

The subsealing described in this report was performed in accordance with the New York State Public Works Specifications of January 2, 1962 (12). The exception was the attempted fault reduction on Sites 8-10 and 8-20, as explained under Faulting. Each operation of the subsealing procedure is discussed separately in the following.

Drill Holes

All holes drilled in the pavements were 1 3/4 inches in diameter. For spotted coverage, the holes were placed on the low side of faulted transverse joints and cracks at a maximum distance of about five feet, but not less than 1 1/2 feet away. On crowned sections, the holes were located one foot left of the centerline of each lane; and on superelevated sections three feet from the high edge of each lane.

Where blanket coverage was used, the holes were one foot left of the lane centerline and ten feet on centers. Holes in adjoining lanes were transversely aligned. A hole was also drilled three feet from both sides of transverse joints and cracks.

The drilling was accomplished with a pneumatic drill mounted on a self-propelled air compressor of the type shown in Figure A1. The average time to set up, drill, and move to the next hole location was three minutes. Average output per day was 200 holes for spotted coverage and slightly higher for blanket coverage. In District 6 the contractor drilled and subsealed one lane at a time, whereas in District 8 both lanes were drilled prior to subsealing. The only discernible difference was that the holes in the adjoining lane made it easier to estimate the area covered by the asphalt.

FIGURE A-1 - Typical Subsealing Drill used on Site 6-20.

Subsealing

Immediately prior to subsealing, the entire area around the drill holes was wetted thoroughly to prevent asphalt spilled on the pavement from adhering to it. Plain water was used in District 6, and a lime-water solution in District 8, both of which were equally effective. The asphalt (NYS Item 71C) was supplied in transport tankers equipped with propane gas heaters to maintain the specified temperature range of 375-425 degrees Fahrenheit. Figure A-2 shows the tanker and auxiliary low pressure pump used in District 8 to obtain a flow rate of about 60 gpm. Control of the asphalt during pumping was facilitated by means of a tapered nozzle which fitted snugly in the drilled hole (Figure A-3). The actual subsealing operation required about one minute per hole. Average daily output for a ten-hour day was about 570 holes for blanket coverage and 400 holes for spotted coverage.

FIGURE A-2 - Asphalt Tanker & Trailer-mounted subsealing pump used in District 8.

FIGURE A-3 - Subsealing nozzle used on Sites 6-10 and 6-20.

At the first sign of pavement movement or extrusion of asphalt, pumping was discontinued (except in the cases previously noted), the nozzle was removed from the hole and replaced by a wooden plug. After about five minutes, the plug was removed and the hole filled with semi-hardened asphalt.

APPENDIX B

LIME-CEMENT JACKING

The following is based primarily on personal observations of jacking operations conducted by Thruway personnel. Supplementary information includes data from the report by LeFleur (11) and pertinent comments by Thruway personnel.

Mix: After considerable experimenting, the Thruway decided on a mix of three to four parts ground limestone to one part Type II cement by weight with 15-18 gallons of water. The limestone was a special grind with the following gradation: passing the #40-100%, #60-94%, #200-60 to 20%. A wetting agent, used to increase flowability by reducing the surface tension of the water to about 30 dynes per centimeter, was added to the water at the rate of one part per thousand by volume. The resulting mix had a compressive strength of about 250 psi at 7 days and 1000 psi at 28 days.

The richer mix, which contained the higher water content, was generally used to provide high flowability for filling shallow but areally extensive voids encountered in correcting minor faulting and undesirable profile or cross section conditions. The leaner mix with the lower water content was used to reduce drying shrinkage and minimize material costs when filling deep voids or making high lifts. Thruway personnel have suggested the need for additional research on two aspects of the mix: (1) The optimum mix for maximum freeze-thaw resistance and minimum viscosity, and (2) Characteristics of limestone required to produce optimum mix uniformity.

Drilling: Drilling was done with carbide-tipped bits on 18 inch drill steel. The average cycle time for the simultaneous drilling of two 2 5/8 inch diameter holes was reported by LaFleur (11) to be six minutes and we verified this. The hammers are 45 pound air-controlled Schramm sinkers mounted on a Schramm 125 cfm self-propelled air compressor as in Figure B-1. The Thruway drill pattern was two holes spaced six feet apart transversely and spotted in the longitudinal direction according to the condition of the pavement. Drilling was usually done just prior to jacking so that both crews could be protected by the same traffic control devices. These operations were also restricted to one lane at a time for the same reason.

FIGURE B-1 - Standard NYS Thruway Jacking Drill

According to Thruway personnel, the two-hole pattern was selected after extensive experimenting showed that no single hole drill pattern provided adequate control over slab rotation during lifting. We were able to verify that, by alternately jacking first one hole and then the other, slab position could be controlled to within a few thousandths of an inch.

Jacking: The size of mixer used depending on the pavement condition and the length of time it could be closed to traffic. When a large volume of slurry was required, a towed Model 13-S type paving mixer was used. When the anticipated quantity was small, or slower production could be tolerated, the 8 cubic foot mortar mixer shown mounted on the rear of the supply truck in Figure B-2 was used. The required mixing time varied widely so mixing was continued until a uniform consistency was reached. The mix was then dumped into the hopper of a Koehring Model 10 mud-jack (Figure B-3).

FIGURE B-2 - Eight cubic foot mixer being dumped into a Koehring Model 10 mud-jack.

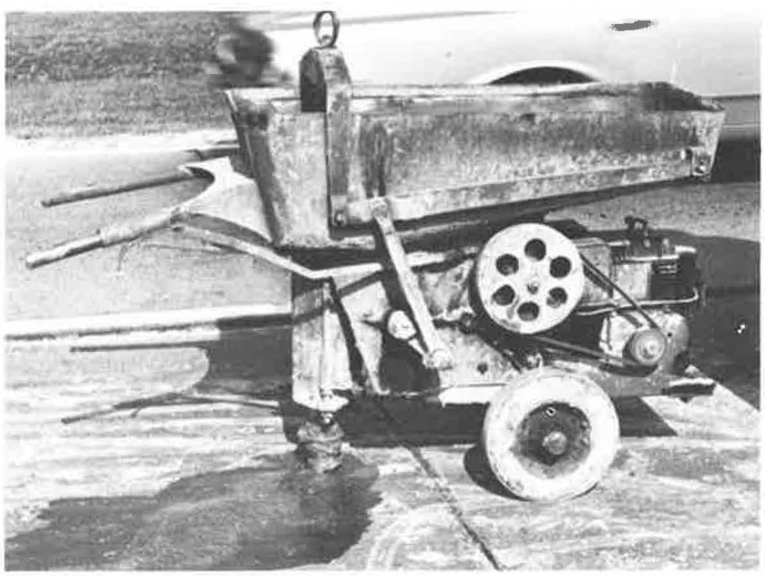

FIGURE B-3 - Model 10 Mud-jack with engine and pump exposed.

The mud-jack consists of a mix hopper and a slow speed, single cylinder, piston pump driven by a single cylinder 2 hp gasoline engine. The pump was designed to handle a maximum of 47 cfh (5.9 gpm) at a maximum pressure of 100 psi. These pump characteristics appear to be about the optimum for making limited lifts because they provide exact control over pavement displacements. However, when large pavement displacements must be made or large voids filled, Thruway personnel report that a pump having higher capacity would greatly increase production.

APPENDIX C

CORRELATION STUDY

It was necessary to correlate the Thruway's CLOE type profilometer and New York State's BPR type roughometer because the initial surface roughness values on the subsealing test sites were made with the profilometer while subsequent values were determined with the roughometer.

For the correlation study, concrete pavements were selected with a range of roughness values wide enough to encompass the expected values on the subsealing test sites. Four test tracks are on the west bound lanes of the Berkshire Section of the Thruway and are used by the Thruway to check the calibration of their profilometer. Three of the subsealing test sites, including both traveling lanes, were also selected. Table C-1 is a tabulation of the roughness values.

The selected sections were measured with each device three to four times and the average values were used to compute the regression equations. The coefficient of variation for each unit on each section is listed in Table C-1 as a measure of reproducibility.

In order to estimate the roughometer values, the profilometer readings were considered the independent variable and several regression equations were computed. A fourth order polynomial regression equation having the lowest standard error of estimate, plus or minus 6.5 inches per mile, was selected (Figure C-1).

A similar polynomial regression analysis using the roughometer as the independent variable showed that a fourth order equation having a standard error of estimate of plus or minus 0.09 was the best regression line obtainable (Figure C-1). It should be noted that these equations are only applicable for the range of values used in this study and must not be extrapolated. The correlation coefficient, a function of the angle of intersection of the two regression lines is not given because it has no significance for a curvilinear relationship and, in fact, cannot be computed.

TABLE NO. C-1 CORRELATION STUDY OF

N.Y.S. ROUGHOMETER & N.Y.S. THRUWAY PROFILOMETER

TEST LOCATION	RUN NO.	PROFIL-OMETER CSV	AVE.	ROUGHOMETER INCHES/MILE	AVE.	PROFIL-OMETER $\%V_c$	ROUGHOMETER $\%V_c$
N.Y.S. Thruway Berkshire Section							
Test Track 1 Drive W.B.	1	1.86		116			
	2	1.90		117			
	3	1.64		118			
	4	1.75	1.79	114	116	6.5	1.5
Test Track 2 Drive W.B.	1	1.92		123			
	2	1.79		124			
	3	2.14	1.95	126	124	9.1	1.6
Test Track 3 Pass W.B.	1	2.08		129			
	2	1.76		127			
	3	1.93		127			
	4	1.97	1.94	---	128	6.9	1.0
Test Track 4 Pass W.B.	1	1.74		120			
	2	1.87		118			
	3	2.08	1.90	118	119	8.3	0.8
District #8							
Section 820 NB Rte NY 22 SH8531 & 8532	1	1.96		104			
	2	1.79		107			
	3	1.83	1.86	106	106	4.8	0.7
Section 820 SB Rte NY 22 SH8531 & 8532	1	1.96		106			
	2	1.86		108			
	3	1.92	1.91	106	107	7.7	0.7
Section 83A EB Rte US 44 SH1778	1	4.99		180			
	2	4.49		181			
	3	4.52	4.67	181	181	5.8	0.1
Section 83A WB	1	4.66		182			
	2	4.81		188			
	3	4.55	4.67	184	185	5.4	1.7
Section 840 NB Rte NY 22 & US 44 SH537	1	6.17		204			
	2	6.43		198			
	3	5.95	6.18	202	201	4.1	1.6
Section 840 SB Rte NY 22 & US 44	1	8.85		223			
	2	8.40		230			
	3	8.79	8.68	234	229	2.8	2.3

FIGURE NO.C-1 CORRELATION STUDY OF N.Y.S. ROUGHOMETER & N.Y.S. THRUWAY PROFILOMETER