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Experimental Project on Grout Subsealing in Illinois: A 20-Month Evaluation

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ABSTRACT

Several experimental features were included in an undersealing project conducted by the Illinois Department of Transportation during the fall of 1983. This experimental project evaluated the performance of limestone-cement slurries versus that of pozzolan-cement slurries, the effects of admixtures (water reducer and superplasticizer) on these slurries, and the effects of various pumping pressures (10, 20, and 30 psi) on the undersealing operation. Initial studies indicated that the fly-ash grouts were generally superior to limestone grouts on the basis of the higher strengths exhibited by the fly-ash grouts regardless of admixtures, the greater improvements in deflections produced by the fly-ash mixes, the possible damaging effects produced by the limestone mixes when grouting is done in areas that display low initial deflections, and, finally, the greater flowability of the fly-ash mixes. Four slabs that were removed after undersealing verified this superior ability of the fly-ash grouts to flow into voids. Fly-ash grouts either with no admixture or with superplasticizer produced the greatest decrease in the pavement deflection at cracks and joints, whereas limestone grouts with admixtures produced the least decreases in deflections. It was also observed that, for a given pavement, a limiting deflection value exists below which deflections will not be reduced. In addition, if the initial deflection is low, it appears better not to grout the pavement, because deflections may increase. Pumping pressures investigated had a negligible effect on undersealing operations. Pavement deflections measured 7 and 20 months after undersealing supported the initial evaluations of undersealing materials.

Rehabilitation and restoration of portland cement concrete (PCC) pavements in Illinois have traditionally included the patching of failed areas followed by the placement of a bituminous overlay. Although overlaying the pavements will improve the ride quality, it does not correct the problems caused by the development of voids beneath the concrete slab. The purpose of undersealing or subsealing is to restore support to a pavement structure by filling these voids with grout under pressure without intentionally raising the pavement. The inclusion of pavement subsealing in conjunction with patching and resurfacing, therefore, appears to be a more effective rehabilitation technique.

Because of the projected increase in the use of this technique in the state, the Illinois Department of Transportation (IDOT) studied the design and proper application of grout slurries in undersealing. Specifically, this experimental project evaluated the performance of limestone-cement slurries versus that of pozzolan-cement slurries, the effects of admixtures on these slurries, and the effects of various pumping pressures on the undersealing operation.

EXPERIMENTAL PROCEDURES

Description of Test Area

A 71,000-ft section of a planned 3.15-mi restoration project was designated as the test section. This restoration project was performed on a four-lane divided concrete pavement segment of I-55 in Sangamon County, Illinois. The original pavement structure, constructed in 1963, consisted of 10-in. standard reinforced PCC pavement with load transfer contraction joints at 100-ft spacings over 6-in. Type A granular subbase material. Included in the restoration were full- and partial-depth patching, undersealing, underdrain installation, and profiling.

Experimental Features

In an attempt to learn more about the penetrating characteristics of grout, several variations in the mix design and injection pressures were planned. All test slurries were a combination of portland cement, the appropriate aggregate (limestone or fly ash), water, and, where indicated, the appropriate admixture (water reducer or superplasticizer). Six variations in the mix design were tested as follows:

1. Fly ash with superplasticizer,
2. Fly ash with no admixture,
3. Fly ash with water reducer,
4. Limestone with no admixture,
5. Limestone with water reducer, and
6. Limestone with superplasticizer.

In addition, three injection pressures--10, 20, and 30 psi--were chosen to investigate the feasibility of pumping grout at lower pressures to minimize the potential for pavement damage. The resulting design matrix is given in Table 1.

TABLE 1 Experimental Design Matrix

Section	Aggregate	Admixture	Pressure (psi)	Length (ft)
F-1	Fly ash	SP	30	300
F-2	Fly ash	SP	20	300
F-3	Fly ash	SP	10	300
F-4	Fly ash	None	30	300
F-5	Fly ash	None	20	300
F-6	Fly ash	None	10	300
F-7	Fly ash	WR	30	300
F-8	Fly ash	WR	20	300
F-9	Fly ash	WR	10	300
L-1	Limestone	None	30	300
L-2	Limestone	None	20	300
L-3	Limestone	None	10	300
L-4	Limestone	WR	30	300
L-5	Limestone	WR	20	300
L-6	Limestone	WR	10	300
L-7	Limestone	SP	30	300
L-8	Limestone	SP	20	300
L-9	Limestone	SP	10	300

Note: SP = superplasticizer; WR = water reducer.

Each test section consisted of three 100-ft panels. After each test section, a transition panel 100 ft long was designated before the next test section. The purpose of this transition panel was to allow the holding tank to be emptied and the appropriate mix design to be prepared. All test panels were located in the northbound driving lane of I-55.

Mix Designs

The limestone aggregate mix design selected was 1,499 lb of mineral filler (limestone dust), 589 lb of cement, and 938 lb of water. Water reducer (Hoycol, W.R. Grace Company) or superplasticizer (WRDA 19, W.R. Grace Company) was added at the rates of 8.5 or 17 oz per hundredweight of cement, respectively. Aggregate was required to meet the following gradation:

Passing Sieve No.	Percent Passing
30	100
100	92 ± 8
200	82 ± 8

The fly-ash aggregate mix design selected was 1,387 lb of fly ash, 605 lb of cement, and 915 lb of water. Again, a water reducer or superplasticizer was added at the rate of 8.5 or 17 oz per hundredweight of cement, respectively.

Field Operations

Deflection data were taken by IDOT on all experimental sections before grouting. The test method employed included the use of the Model 2008-X Road Rater with a peak-to-peak dynamic force of 8,000 lb operating at a frequency of 15 Hz. Measurements were taken in the outer wheel path 30 in. ± 5 in. from the outside pavement edge.

After deflection data were taken, a hole pattern was chosen. A three-hole and a five-hole pattern were used in this study and are shown in Figure 1. Either pattern was used on a given crack or joint. The holes, drilled with a pneumatic track drill, were 2 ± 1/4 in. in diameter and extended into the granular subbase approximately 4 in. Drilling was completed within 2 days before undersealing.

All the mixing and proportioning were done at the grout plant. The grout was mixed with an auger and sent to a holding tank until ready for pumping. Admixtures, when used, were added at the base of the auger by way of an automatic mechanical dispenser system.

The group packer was inserted into the drilled hole in the slab and pumping was initiated. A gauge mounted on the discharge pipe near the holding tank monitored the pumping pressure. Temporary surge pressures of short duration (1 to 3 sec), often exceeding 50 psi but maintained below 100 psi, were sometimes necessary to initiate grout flow. A Dynasonics Model UFT0601 (S/N 2965) Doppler flow meter indicated grout velocities and total volume. Also noted was the pumping time required to complete a given hole. A modified Benkelman beam was used to monitor the vertical movements of the slab. Lifting of the slab was kept below 0.05 in. total movement. Pumping was continued until (a) there was a significant movement of the gauge monitoring the slab lift; (b) slurry was forced up through a nearby crack, joint, or drilled hole; or (c) after a reasonable amount of time there was no indication of slab movement or grout take. Grout that was not routed to the packerhead for injection was recirculated back into the grout holding tank.

Samples of the grout mixtures were taken during the undersealing operations and were tested for compressive strength. Consistency of the mixtures was monitored with a standard flow cone. After pumping, the nozzle was removed and a temporary wooden plug was immediately inserted into the hole. These temporary plugs were removed after the back pressure

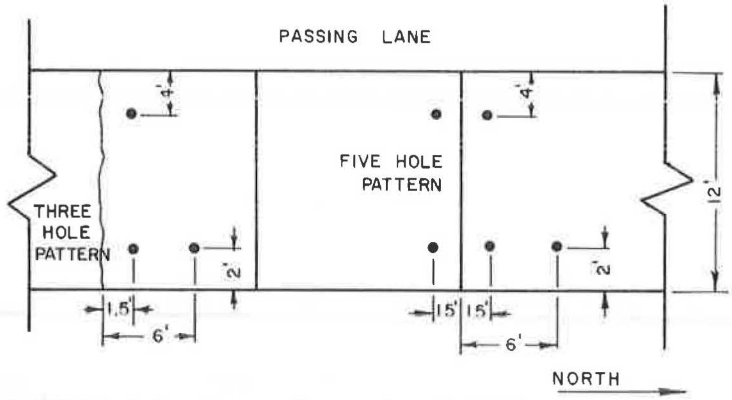

FIGURE 1 Hole patterns used in experimental section.

had subsided sufficiently to assure that the grout would not be forced out of the hole. On completion of the subsealing, all drill holes were grouted flush with the surface of the pavement with a sand-cement grout. Undersealing of the experimental section was begun September 22, 1983, and was completed by September 26, 1983.

Three days after the undersealing was completed, deflections were again measured. After a review of the deflection data, four locations were selected for removal of the slab and examination. Of the four locations, two were chosen from areas treated with limestone and two from areas treated with fly-ash mix. Of the two locations treated with a given aggregate mix, one location was chosen that displayed considerable improvement in deflection values and the other location was one that displayed a less than satisfactory change.

RESULTS

Pumping Pressures

Undersealing was performed at pressures of 10, 20, and 30 psi. At these low pumping pressures, total slab rise was easily maintained below the maximum of 0.05 in. The effects of pumping at pressures of 20 and 30 psi on the undersealing operation were negligible. However, time required for injection at 10 psi appeared to be longer. Because of the negligible differences at 20 and 30 psi, further results and discussion will be limited to an evaluation of materials.

Material Strength and Fluidity

Grout materials were evaluated on the basis of compressive strength, slurry fluidity or flowability, and ability to restore support to the pavement structure as indicated by the resulting deflection changes following treatment.

Samples of the grout mixtures were periodically taken during field operations and tested for compressive strength. Results are summarized in Table 2.

As shown in Table 2, fly-ash aggregate consistently produced mixes of greater strength; the highest strength is achieved with the mixture of fly ash and water reducer and the lowest with the limestone and no admixture. Only three of the six mix designs studied displayed compressive strengths greater than 1,000 psi. High compressive strengths may prove to be one solution to the problem of erosion.

Improved pumpability of the grout material will likely reduce wear to the pumping equipment, reduces clogging of the equipment, and, most important, improves the capability of the grout to fill voids. Average flow rates at 30 psi of the various mix designs as determined from Doppler flow meter data analysis are also given in Table 2.

TABLE 2 Compressive Strengths of Mix Designs and Average Flow Rates

Aggregate	Admixture	Avg Compressive Strength[a] (psi)	Flow Rate (ft^3/sec)
Fly ash	None	935	0.11
Fly ash	Superplasticizer	1,888	0.11
Fly ash	Water reducer	3,495	0.07
Limestone	None	628	0.04
Limestone	Superplasticizer	722	0.08
Limestone	Water reducer	1,089	0.04

[a]Compressive strengths were determined from 4-in. diameter cylinders (ASTM C 39) at 7 days.

As indicated, the fly-ash aggregate generally produced mixes capable of achieving greater flow rates; the greatest flow rate was achieved with the mixture of fly ash and superplasticizer and with fly ash and no admixture.

A Doppler flow meter was used in determining average flow rates. This nonintrusive measuring instrument is a suitable device for measuring the higher flow rates of grouting materials. Doppler flow meters are known, however, to be unreliable at lower flow rates typical of such a pressure-grouting operation.

An average of 2.00 ft^3 of grout was pumped per crack or joint in the test section treated with the fly-ash grout, whereas only 1.71 ft^3 of grout was injected per crack or joint in the test section treated with limestone grout. Only those cracks and joints with initial deflections, both leave and approach, that were in the range of $x \pm 1\sigma$ were included in these stated averages. Therefore, the possibility that a greater amount of fly-ash grout was pumped because of larger existing voids in the fly-ash test section was minimized. It is more likely that a greater amount of fly-ash grout was pumped because of its greater fluidity.

Deflection Analysis

Immediately Following Treatment

Deflection measurements were taken on all cracks and joints in the experimental section before undersealing operations began. Results, excluding those used for controls, are as follows (peak-to-peak dynamic force of 8,000 lb):

	Initial Deflection (mils)		
	Cracks and Joints	Cracks	Joints
Approach	7.45	7.10	7.83
Leave	7.94	7.42	8.51

Initial leave deflections were approximately 7 percent greater than initial approach deflections. Joint leave deflections were approximately 13 percent greater than crack leave deflections before grouting.

Three days after the undersealing in the experimental section had been completed, deflections were taken at all locations measured in the initial analysis. It is known that deflections fluctuate substantially with changes in such variables as temperature of the slab and moisture conditions of the subgrade (1). All experimental sections contained cracks or joints that were not treated and can therefore be considered experimental controls. These controls would indicate to what approximate degree the uncontrollable environmental conditions affected the deflection measurements stated here. The average approach deflections of those cracks and joints designated as controls increased 0.12 mil. Average leave deflections increased 0.10 mil.

Initial analyses indicated that grouting was effective in decreasing deflections that were higher than average but was ineffective for average or below-average deflection locations. That is, the greatest improvements will be experienced by those cracks or joints with unusually high initial deflections, and lesser degrees of improvement will be evident as the initial deflections approach that of the mean. Indeed, in several instances, those cracks or joints with below-average deflections experienced an increase in deflection after undersealing. An attempt to confirm these suspicions involved the analysis of cracks or joints with initial leave deflections that fell beyond the range of $x + 1\sigma$, where x is 7.94 mils and σ is 2.76 mils.

The average initial leave deflection of those cracks or joints that fell above $x + 1\sigma$ was 12.8 mils. After undersealing, this average deflection was decreased to 9.33 mils, a 27 percent decrease in mean deflection. When all cracks and joints with initial deflections greater than the average were included in the analysis, only a 21 percent decrease in measured deflection resulted. As indicated earlier, when a crack or joint with a low initial deflection is undersealed, deflections often increase. Evidence would appear to indicate that this is especially true when a limestone mix is used. Table 3 contains deflection measurements for those cracks and joints with initial approach and leave deflections less than or equal to the average. Initial approach deflection is 7.45 mils and initial leave deflection is 7.94 mils.

TABLE 3 Deflection Changes for Cracks and Joints Displaying Low Initial Deflections

	Aggregate	
	Fly Ash	Limestone
Approach		
Before (mils)	6.48	5.87
Immediately after (mils)	5.63	6.48
Percent improvement	13[a]	−10
Leave		
Before (mils)	6.43	5.81
Immediately after (mils)	5.48	6.85
Percent improvement	15	−18

[a]Decreases in deflections are considered positive and increases are considered negative throughout this paper.

As indicated in Table 3, leave deflections decreased by an average of 15 percent in sections treated with the fly-ash grout, whereas leave deflections increased by an average of 18 percent in sections treated with the limestone grout. Tables 4 and 5 contain these same deflection measurements for the designated mix designs. Table 4 contains the deflection information for the cracks and joints treated with the fly ash and the designated admixtures. Table 5 contains the deflection information for the cracks and joints treated with the limestone mix designs.

TABLE 4 Deflection Changes of Cracks and Joints Displaying Below-Average Initial Deflections and Treated with Fly Ash Mix

	Admixture		
	None	Superplasticizer	Water Reducer
Approach			
Before (mils)	6.00	6.88	6.54
Immediately after (mils)	4.75	6.44	5.71
Percent improvement	21	6	13
Leave			
Before (mils)	5.75	7.25	6.44
Immediately after (mils)	4.75	6.31	5.50
Percent improvement	17	13	15

TABLE 5 Deflection Changes of Cracks and Joints Displaying Below-Average Initial Deflections and Treated with Limestone Mix

	Admixture		
	None	Superplasticizer	Water Reducer
Approach			
Before (mils)	6.28	5.32	6.83
Immediately after (mils)	6.34	6.04	7.83
Percent improvement	−1	−14	−15
Leave			
Before (mils)	6.22	5.24	6.77
Immediately after (mils)	6.50	6.26	8.85
Percent improvement	−5	−19	−31

As Tables 4 and 5 show, the greatest decreases in deflections were obtained by the grout with fly ash and no admixture, whereas the greatest increases were obtained with the mixture of limestone and water reducer. These results would appear to indicate that blanket undersealing could have an adverse effect on below-average deflection areas, especially when a limestone grout mixture was used. On an intuitive basis, it appears that selective undersealing is a more efficient process in many situations regardless of mix design.

In an attempt to not be biased by the influence of treating below-average deflections, only those cracks or joints with above-average initial deflections were considered for further analyses and presented here. Deflection results for cracks and joints treated with the fly-ash and limestone grouts and showing above-average initial deflections are given in Table 6. As indicated, initial leave deflections were higher than initial approach deflections by approximately 15 percent and the greater amount of improvement (21 versus 15 percent) was experienced by the leave deflections. Initial joint deflections were similar to initial crack deflections and they both experienced approximately the same degree of improvement.

TABLE 6 Deflection Changes for Cracks and Joints Displaying Above-Average Initial Deflections

	Cracks and Joints	Cracks	Joints
Approach			
Before (mils)	9.39	9.27	9.47
Immediately following (mils)	7.98	7.89	8.05
At 7 months (mils)	7.43	7.57	7.33
At 20 months (mils)	6.54	6.50	6.57
Percent improvement			
Initially	15	15	15
At 7 months	21	18	23
At 20 months	30	29	31
Leave			
Before (mils)	10.81	10.76	10.85
Immediately following (mils)	8.52	8.55	8.50
At 7 months (mils)	8.10	8.64	7.72
At 20 months (mils)	6.02	6.14	5.92
Percent improvement			
Initially	21	21	22
At 7 months	25	20	28
At 20 months	44	41	45

Table 7 displays deflection changes for cracks and joints treated with either fly-ash or limestone aggregate. Inspection of Table 7 indicates that greater improvements in mean deflections were experienced by those cracks and joints undersealed with the fly-ash mix. These cracks and joints experienced a 33 percent decrease in leave deflections, whereas those undersealed with the limestone aggregate mix experienced only a 13 percent decrease. Likewise, a 26 percent decrease in approach deflections was noted for those cracks and joints undersealed with the fly-ash mix and only a 6 percent decrease for those undersealed with the limestone mix. On the average, improvements in deflections were 20 percent greater for areas treated with the fly-ash grout than for areas treated with limestone grout.

TABLE 7 Deflection Changes for Cracks and Joints Displaying Above-Average Initial Deflections

	Aggregate	
	Fly Ash	Limestone
Approach		
Before (mils)	9.94	8.99
Immediately following (mils)	7.38	8.41
At 7 months (mils)	6.72	7.94
At 20 months (mils)	5.91	6.97
Percent improvement		
Initially	26	6
At 7 months	32	12
At 20 months	41	22
Leave		
Before (mils)	10.88	10.76
Immediately following (mils)	7.31	9.39
At 7 months (mils)	6.97	8.91
At 20 months (mils)	5.69	6.24
Percent improvement		
Initially	33	13
At 7 months	36	17
At 20 months	48	42

Table 8 contains deflection information for cracks and joints treated with the fly-ash mix design and its designated admixtures. Table 9 contains the corresponding information for the limestone mix design. As Tables 8 and 9 indicate, the greatest improvements were produced by the fly ash with no admixture (an average decrease of 44 percent in the leave deflections) followed by the mixture of fly ash and superplasticizer (an average decrease of 36 percent in the leave deflection). The most disappointing results were produced by the limestone mixes with admixtures.

TABLE 8 Deflection Changes for Cracks and Joints Displaying Above-Average Initial Deflections and Treated with Fly Ash Mix

	Admixture		
	None	Superplasticizer	Water Reducer
Approach			
Before (mils)	8.15	10.64	9.79
Immediately following (mils)	5.40	7.66	8.38
At 7 months (mils)	5.98	6.63	7.57
At 20 months (mils)	4.33	5.50	7.84
Percent improvement			
Initially	34	28	14
At 7 months	27	38	23
At 20 months	47	48	20
Leave			
Before (mils)	9.15	12.11	9.46
Immediately following (mils)	5.10	7.71	8.21
At 7 months (mils)	6.42	6.83	7.77
At 20 months (mils)	4.32	5.30	7.46
Percent improvement			
Initially	44	36	13
At 7 months	30	44	18
At 20 months	53	56	21

TABLE 9 Deflection Changes for Cracks and Joints Displaying Above-Average Initial Deflections and Treated with Limestone Mix

	Admixture		
	None	Superplasticizer[a]	Water Reducer
Approach			
Before (mils)	9.24	7.75	8.80
Immediately following (mils)	7.86	8.00	9.06
At 7 months (mils)	7.96	7.20	7.96
At 20 months (mils)	6.27	7.91	7.75
Percent improvement			
Initially	15	-3	-3
At 7 months	14	7	10
At 20 months	32	-16	12
Leave			
Before (mils)	11.79	8.00	9.78
Immediately following (mils)	8.60	8.25	10.34
At 7 months (mils)	9.14	7.50	8.74
At 20 months (mils)	5.61	7.28	6.93
Percent improvement			
Initially	27	-3	-6
At 7 months	22	6	11
At 20 months	52	9	29

[a]Only one crack or joint treated with the limestone superplasticizer.

Of those areas treated with the limestone mix, only the limestone without admixture material reduced deflections (an average decrease of 27 percent in the leave deflections). The limestone aggregate with admixtures actually increased deflections; that is, the limestone mix with the superplasticizer admixture produced an increase of 3 percent in leave deflection measurements. Likewise, the limestone mix with the water reducer admixture also produced an average increase of 6 percent in leave deflection measurements.

Twenty-Month Evaluation

Pavement deflections were remeasured 7 and 20 months after undersealing had been completed. Results supported many of the original evaluations of undersealing materials. Because temperature changes and other environmental conditions affect pavement deflections, all results are only relevant to a given period of time. That is, it is possible to compare the current performance of the undersealing materials; however, it is not possible to judge, with accuracy, the degree of change over time.

As Table 6 indicates, deflection improvements in joints were greater than those in cracks, although earlier deflections (both before treatment and immediately following treatment) had been similar. Leave deflections continued to show a greater amount of improvement than did approach deflections, probably because of large initial voids.

Deflection results for the cracks and joints treated with the fly-ash or limestone aggregate slurries are contained in Table 7. As expected, the cracks and joints treated with the fly-ash slurries generally continue to show a greater degree of improvement with time. A trend appears to be developing that shows the limestone-treated areas approaching the performance of the fly ash-treated areas. Immediately following treatment, leave slabs treated with the fly-ash slurries showed a decrease in deflections 20 percent greater than those treated with the limestone slurries. Seven months later this difference had decreased to 19 percent and most recently (20 months later) 6 percent, as shown in Table 7. The most likely explanation for this trend is the decreasing performance of the slabs treated with fly ash and water reducer and the increased performance of the slabs treated with the slurry that contained limestone and no admixture (see Tables 8 and 9) in comparison with other treated slabs.

At present, the mixes that have resulted in the greatest decreases in pavement deflections have been the fly-ash mixes with either the superplasticizer or without an admixture. The deflection measurements continue to indicate that poorest results occurred with slabs undersealed with the limestone slurries that contain admixtures.

One final comment should be made concerning the performance of the treated cracks or joints as compared with the untreated ones. Untreated cracks and joints were chosen mainly because, on the basis of visual evidence, undersealing was not necessary. Before undersealing, these pavement cracks and joints deflected an average of 7.9 mils. Cracks and joints that were to be treated deflected an average of 10.8 mils. Twenty months later, the leave deflections of untreated cracks and joints deflected an average of 4.8 mils. Treated cracks and joints deflected an average of 6.02 mils or only 26 percent more than the untreated ones. Cracks and joints treated with the mixture of fly ash and superplasticizer actually deflected less than the untreated controls, as shown in Figure 2. Therefore, it can be assumed that the treated areas are behaving similarly to the untreated areas and thus the undersealed pavement is performing adequately.

These results indicate, therefore, that greater improvements were achieved with a fly-ash aggregate mix. If an admixture is desired, it should not be of the water-reducing type. A superplasticizer with fly ash is acceptable and may be desirable because of strengthening characteristics produced by the superplasticizer. Reactions, however, can vary when pozzolans from different sources are combined with various admixtures. Mix designs must always be developed by using the specific pozzolan and additives. If a limestone aggregate mix is chosen, it should not be used in conjunction with either a superplasticizer or a water reducer.

In an attempt to develop a better method for estimating grout quantities, relationships between initial deflections and the volume of grout pumped were investigated. No strong correlations were found. It would appear, therefore, that initial deflections alone may not be a good basis for estimating grout quantities. The only effective method remains the use of historical averages. Approximately 0.86 ft^3 of grout was pumped into an average hole. This quantity falls within the average range previously noted by others.

Another research project was conducted by the University of Illinois simultaneously with the IDOT project (2). Procedures were developed under NCHRP Project 1-21 for void detection by using nondestructive deflection testing (NDT) for locating and dimensioning areas of voids beneath the pavement. Their comprehensive method requires three major inputs: (a) the thickness of the PCC slab, (b) deflection measurements taken at slab centers and corners along the pavement lane, and (c) measurement of deflection load transfer at the joint or crack.

Thirty-six joints were tested in the fly-ash grout

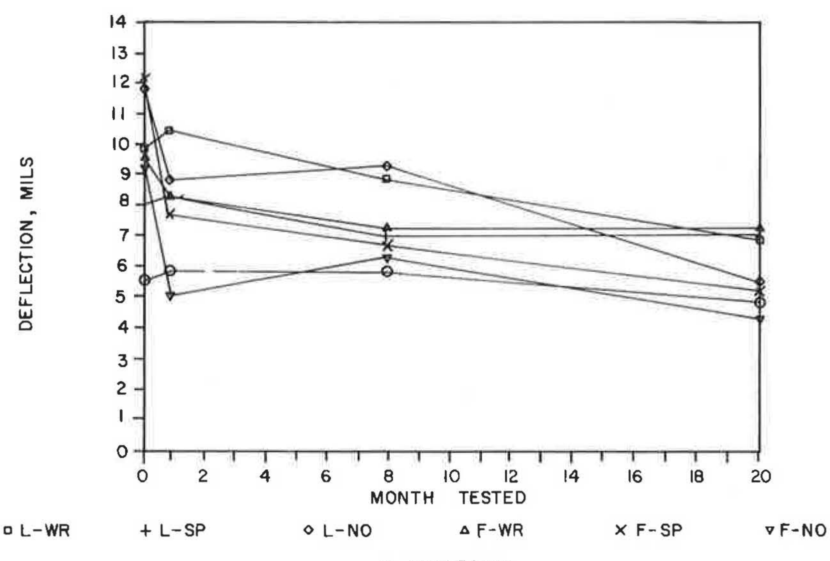

FIGURE 2 Deflection changes for treated and untreated cracks and joints (leave side only).

section and 36 in the limestone section. Fifty percent of the joints in the limestone section were found to have voids with an average size of 7 ft^2. Fifty-three percent of the joints in the fly-ash section were found to have voids with an average size of approximately 12 ft^2.

After grouting in the limestone section, voids were located at 61 percent of the joints and had an average size of approximately 10 ft^2. After grouting in the fly-ash grout section, voids were located at 28 percent of the joints tested and had an average size of approximately 8 ft^2.

Results of this study therefore supported the IDOT findings; that is, undersealing with a fly-ash grout can prove more efficient than undersealing with a limestone grout.

Slab Removal

Removal of the four slabs after undersealing operations also verified the superior ability of the fly-ash grouts to flow into the voids. The fly-ash grout successfully filled the voids and adhered to the bottom of the pavement and the aggregate base course. In one instance, only one of the three drilled holes injected with the limestone grout showed evidence of grout take. Fly-ash grout traveled from the adjacent lane to fill the void not filled by the limestone grout.

"Coning," fracturing of a conical portion on the underside of the concrete slab because of the drilling operation, was evident. Coning leaves the slab in a weakened condition and it will, in time, crack. Coning can be minimized by limiting the downfeed force of the drill.

Additional Project Observations

In addition to the experimental features of the test section, assessments of other factors in the undersealing operation were made. Specifically, the effect of undersealing on existing underdrain systems was observed and the capability of undersealing to stabilize poorly performing patches was investigated. Significant results are as follows:

1. Previously placed underdrains that had originally been backfilled with sand of FA-1 gradation were uncovered and inspected for grout intrusion. None was observed. It is believed that distressed pavements located where underdrains have been previously installed are candidates for pavement undersealing without significant risk to the underdrain system.
2. Several recently patched areas of I-55 displayed extremely high deflections and poor load transfer. These patches were successfully undersealed with a limestone grout. Deflections decreased by an average of 67 percent after grouting. One year later, however, pavement deflections were again as high as they had been before undersealing. Corings indicated that the grout was intact. Therefore it is believed that the void system simply redeveloped beneath the grouted pavement. It is believed that had these cracks at the patch and existing pavement interface been sealed, improvements would had proved more lasting.
3. A portion of I-55 previously patched and overlaid with bituminous concrete contained several rocking patches. Reflective cracking was soon to require maintenance. Patches were undersealed at the boundaries in an attempt to prolong the overlay life. Deflections decreased by an average of 13 percent.

CONCLUSIONS

1. The fly-ash grouts were stronger than limestone grouts treated with identical admixtures used in this study.
2. The fly-ash grouts were more flowable than limestone grouts.
3. Initial deflections at joints were slightly higher than those at cracks. Follow-up studies indicated that undersealing joints may prove more effective than undersealing cracks.
4. Initial leave deflections were slightly higher than initial approach deflections.
5. Fly-ash grouts either with no admixture or with superplasticizer produced the greatest decrease in the deflections of cracks and joints.
6. Limestone grouts with admixtures (superplasticizer or water reducer) produced the least decrease in deflection.
7. If initial deflections were low (below the calculated average for a given pavement), undersealing was ineffective. That is, cracks and joints treated with a limestone slurry experienced an increase in deflection readings and improvement was minimal when a fly-ash mix was used.
8. There appeared to be a limiting deflection value for a given pavement below which deflections would not be reduced. Similarly, greatest improvements were experienced by those cracks or joints with high initial deflections where voids and loss of support existed.
9. Initial deflection measurements in the wheel path alone were not a good basis for estimating grout quantities.
10. Undersealing, when done properly, can restore support to the pavement structure not only in the short term but also in the long term.

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