

EXPERIMENTAL PROJECT ON GROUT SUBSEALING IN ILLINOIS

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Several experimental features were included in a recent undersealing project conducted by the Illinois Department of Transportation (IDOT). This experimental project evaluated: 1) the performance of limestone-cement versus pozzolan-cement slurries, 2) the effects of admixtures (water reducer and superplasticizer) on these slurries and 3) the effects of various pumping pressures, 69, 138, and 207 kPa (10, 20, and 30 psi) on the undersealing operation. Initial studies indicated that the flyash grouts were generally superior to limestone grouts based upon the higher strengths exhibited by the flyash grouts regardless of admixtures, the greater improvements in deflections produced by the flyash mixes, the possible damaging effects produced by the limestone mixes when grouting in areas which display low initial deflections, and, finally, the greater flowability of the flyash mixes. Four slabs which were removed after undersealing verified this superior ability of the flyash grouts to flow into void areas. Flyash grouts with either no admixture or with superplasticizer produced the greatest decrease in the pavement deflection at cracks and joints while 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. Additionally, if the initial deflection is low, it appears better not to grout the pavement as deflections may increase. Pumping pressures investigated had a negligible effect on undersealing operations. Pavement deflections measured seven months after undersealing supported the initial evaluations of undersealing materials.

Rehabilitation and restoration of portland cement concrete pavements in Illinois have traditionally included the patching of failed areas followed by the placement of a bituminous overlay. While 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: 1) the performance of limestone-cement versus pozzolan-cement slurries, 2) the effects of admixtures on these slurries and 3) the effects of various pumping pressures on the undersealing operation.

Experimental Procedures

Description of Test Area

A 2165 m (7100 ft.) section of a planned 5.07 km (3.15 mile) 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 25.4 cm (10 in.) standard reinforced PCC pavement with load transfer contraction joints at 30.5 m (100 ft.) spacings over 15.2 cm (6 in.) Type A granular subbase material. Included in the restoration was 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 flyash), water and, water reducer or superplasticizer. Six variations in the mix design were tested as follows:

1. Flyash with superplasticizer.
2. Flyash with no admixture.
3. Flyash with water reducer.
4. Limestone with no admixture.
5. Limestone with water reducer.
6. Limestone with superplasticizer.

In addition, three injection pressures, 69, 138, and 207 kPa (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 (kPa)	Length (m)
F-1	Flyash	SP*	207	91.4
F-2	Flyash	SP	138	91.4
F-3	Flyash	SP	69	91.4
F-4	Flyash	None	207	91.4
F-5	Flyash	None	138	91.4
F-6	Flyash	None	69	91.4
F-7	Flyash	WR**	207	91.4
F-8	Flyash	WR	138	91.4
F-9	Flyash	WR	69	91.4
L-1	Limestone	None	207	91.4
L-2	Limestone	None	138	91.4
L-3	Limestone	None	69	91.4
L-4	Limestone	WR	207	91.4
L-5	Limestone	WR	138	91.4
L-6	Limestone	WR	69	91.4
L-7	Limestone	SP	207	91.4
L-8	Limestone	SP	138	91.4
L-9	Limestone	SP	69	91.4

Note: 1 meter = 3.28 feet
1 kPa = 0.145 lbf/in.²

* SP = Superplasticizer

** WR = Water Reducer

Each test section consisted of three 30.5 m (100 ft.) panels. After each test section, a transition panel, 30.5 m (100 ft.) in length, 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 prepared. All test panels were located in the northbound driving lane of I-55.

Mix Designs

The limestone aggregate mix design selected was 679.9 kg (1499 lb.) of mineral filler (limestone dust), 267 kg (589 lb.) of cement, and 425 kg (938 lb.) of water. Water reducer (Hycol, W. R. Grace Co.) or superplasticizer (WRDA 19, W. R. Grace Co.) was added at the rates of 250 or 500 ml³ (8.5 or 17 oz.) per hundred weight of cement, respectively. Aggregate was required to meet the following gradation:

Passing No. 30 Sieve	100%
Passing No. 100 Sieve	92+8%
Passing No. 200 Sieve	82+8%

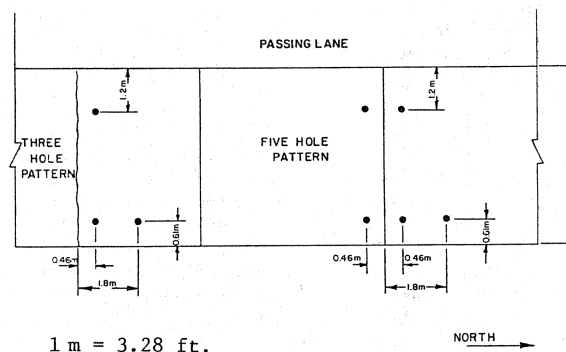
The flyash aggregate mix design selected was 629 kg (1387 lb.) of flyash, 274 kg (605 lb.) of cement and 415 kg (915 lb.) of water. Again, a water reducer or superplasticizer was added at the rate of 250 or 500 ml³ (8.5 or 17 oz.) per hundred weight of cement, respectively.

Field Operations

Deflection data was taken by the Illinois Department of Transportation on all experimental sections prior to grouting. The test method employed included the use of the Model 2008-X Road Rater with a peak-to-peak dynamic force of 1799 N (8000 lbs.) operating at a frequency of 15HZ. Measurements were taken in the outer wheel path, 76.2 cm ± 12.7 cm (30 in. ± 5 in.) from the outside pavement edge.

After deflection data was taken, a hole pattern was chosen. A three hole and a five hole pattern were used in this study and are illustrated in Figure 1. Either pattern was used on a given crack or joint. The holes, drilled with a pneumatic track drill, were 5.1 ± .6 cm (2+1/4 in.) in diameter and extended into the granular subbase approximately 10.2 cm (4 in.). Drilling was completed within two days prior to undersealing.

Figure 1. Hole patterns used in the experimental section.



All of the mixing and proportioning was 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 via an automatic mechanical dispenser system.

The grout 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 seconds) often exceeding 345 kPa (50 psi), but maintained below 690 kPa (100 psi), were sometimes necessary to initiate grout flow. A Dynasonics Model UFT0601 (S/N 2965) Doppler flowmeter 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 0.13 cm (0.05 inch) total movement. Pumping was continued until there was: 1) a significant movement of the gauge monitoring slab lift, or 2) slurry was forced up through a nearby crack, joint or drilled hole, or 3) after a reasonable amount of time there was no indication of slab movement or grout take. Grout which 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 flowcone. 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 had subsided sufficiently to assure that the grout would not be forced out of the hole. Upon 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 reviewing 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 flyash mix. Of the two locations treated with a given aggregate mix, one location was chosen which displayed considerable improvement in deflection values and the other location was one which displayed a less than satisfactory change.

Results

Pumping Pressures

Undersealing was performed at pressures of 69 kPa, 138 kPa, and 207 kPa (10 psi, 20 psi, and 30 psi). At these low pumping pressures, total slab raise was easily maintained below the maximum of 0.13 cm (0.05 inch). The effects of pumping at pressures of 138 kPa (20 psi) and 207 kPa (30 psi) on the undersealing operation were negligible. However, time required for injection at 69 kPa (10 psi) appeared to be longer. Due to the negligible differences at 138 kPa (20 psi) and 207 kPa (30 psi), further results and discussion will be limited to an evaluation of materials.

Materials - 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.

Table 2. Compressive strengths of mix designs and average flowrates.

Aggregate	Admixture	Average Compressive Strength * (kPa)	Flowrate (m ³ /sec.)
Flyash	None	6448	.0031
Flyash	Superplasticizer	13020	.0031
Flyash	Water Reducer	24103	.0020
Limestone	None	4331	.0011
Limestone	Superplasticizer	4979	.0023
Limestone	Water Reducer	7510	.0011

Note: 1 kPa = 0.145 lbf/in²
1 m³/sec = 35.29 ft³/sec

* Compressive strengths were determined from 4 inch diameter cylinders (ASTM C 39) at 7 days.

As illustrated in Table 2, flyash aggregate consistently produced mixes of greater strengths with the highest strength achieved with the flyash-water reducer mix and lowest with the limestone-no admixture mix. Only three of the six mix designs studied displayed compressive strengths greater than 6900 kPa (1000 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 importantly, improves the capability of the grout to fill voids. Average flowrates at 207 kPa (30 psi) of the various mix designs as determined from Doppler flowmeter data analysis are also given in Table 2.

As indicated, the flyash aggregate generally produced mixes capable of achieving greater flowrates with the greatest flowrate achieved with the flyash-superplasticizer and flyash-no admixture mixes.

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

An average of 0.057 m³ (2.00 ft³) of grout was pumped per crack/joint in the test section treated with the flyash grout while only 0.048 m³ (1.71 ft³) of grout was injected per crack/joint in the test section treated with limestone grout. Only those cracks and joints with initial deflections, both leave and approach, which were in the range of $x \pm 1\sigma$ were included in these stated averages. Therefore, the possibility that a greater amount of flyash grout was pumped because of larger existing voids in the flyash test section was minimized. It is more likely that a greater amount of flyash grout was pumped because of its ability to achieve greater flowrates.

Deflection Analysis

Deflection measurements were taken on all cracks and joints in the experimental section before undersealing operations began. Results, excluding those used for controls, are shown in Table 3.

Table 3. Initial deflection for cracks and joints * (excluding control areas).

	Cracks & Joints	Cracks	Joints
Approach Deflection, Initial (mm)	0.189	0.180	0.199
Leave Deflection, Initial (mm)	0.202	0.188	0.216

Note: 1 mm = 39.37 mils

* Peak to peak dynamic force of 1799 N (8000 lbs.)

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

Three days after completing the undersealing in the experimental section, 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, among others (1). All experimental sections contained cracks or joints which 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 herein. The average approach deflections of those cracks and joints designated as controls increased 0.0030 mm (0.12 mils). Average leave deflections increased 0.0025 mm (0.10 mils).

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, greatest improvements will be experienced by those cracks or joints with unusually high initial deflections with lesser degrees of improvement 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 which fell beyond the range of $x + 1\sigma$, where $x = 0.202$ mm (7.94 mils) and $\sigma = 0.070$ mm (2.76 mils).

The average initial leave deflection of those cracks or joints which fell above $x + 1\sigma$ was 0.325 mm (12.8 mils). After undersealing, this average deflection was decreased to 0.237 mm (9.33 mils), a 27% decrease in mean deflection. When all cracks and joints with initial deflections greater than the average were included in the analysis, only a 21% decrease in measured deflection resulted. As indicated above, 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 using a limestone mix. Table 4 contains deflection measurements for those cracks and joints with initial approach and leave deflections less than or equal to the average. Initial approach deflection = 0.189 mm (7.45 mils) and initial leave deflection = 0.202 mm (7.94 mils).

Table 4. Deflection changes* of cracks and joints displaying low initial deflections (by aggregate type).

	Flyash	Limestone
Approach - Initial (mm)	0.165	0.149
- Final (mm)	0.143	0.165
% Improvement	13% Decrease	10% Increase
Leave - Initial (mm)	0.163	0.148
- Final (mm)	0.139	0.174
% Improvement	15% Decrease	18% Increase

Note: 1 mm = 39.37 mils

* Decreases in deflections are considered positive and increases in deflections are considered negative throughout this paper.

As Table 4 indicates, leave deflections decreased by an average of 15% in sections treated with the flyash grout while leave deflections increased by an average of 18% in sections treated with the limestone grout. Tables 5 and 6 contain these same deflection measurements for the designated mix designs. Table 5 contains the deflection information for the cracks and joints treated with the flyash and the designated

admixtures. Table 6 contains the deflection information for the cracks and joints treated with the limestone mix designs.

As Table 5 and 6 illustrate, the greatest decreases in deflections were obtained by the flyash - no admixture grout, while the greatest increases were obtained with the limestone - water reducer mix. These results would appear to indicate that blanket undersealing could have an adverse effect on below average deflection areas, especially, when using a limestone grout mixture. Selective undersealing intuitively appears to be a more efficient process in many situations regardless of mix design.

Table 5. Deflection changes of cracks and joints displaying below average initial deflections and treated with flyash mix (by admixture type).

	No Admixture	Superplasticizer	Water Reducer
Approach - Initial (mm)	0.152	0.175	0.166
- Final (mm)	0.121	0.164	0.145
% Improvement	21%	6%	13%
Leave - Initial (mm)	0.146	0.184	0.164
- Final (mm)	0.121	0.160	0.141
% Improvement	17%	13%	15%

Note: 1 mm = 39.37 mils

Table 6. Deflection changes of cracks and joints displaying below average initial deflections and treated with limestone mix (by admixture type).

	No Admixture	Superplasticizer	Water Reducer
Approach - Initial (mm)	0.160	0.135	0.173
- Final (mm)	0.161	0.153	0.199
% Improvement	-1%	14%	-15%
Leave - Initial (mm)	0.158	0.133	0.172
- Final (mm)	0.165	0.159	0.225
% Improvement	-5%	-19%	-31%

Note: 1 mm = 39.37 mils

In an attempt to not be biased by the influence of treating below average deflections, only those cracks or joints whose initial deflections were above average were considered for further analyses and presented herein.

Deflection results for cracks and joints treated with the flyash and limestone grouts with above average initial deflections are given in Table 7.

Table 7. Deflection changes for cracks and joints displaying above average initial deflections.

	Cracks & Joints	Cracks	Joints
Approach - Initial (mm)	0.239	0.235	0.241
- Final (mm)	0.203	0.200	0.204
- Follow-up* (mm)	0.189	0.192	0.186
% Improvement - Final	15%	15%	15%
% Improvement - Follow-up*	21%	18%	23%
Leave - Initial (mm)	0.275	0.273	0.276
- Final (mm)	0.216	0.217	0.216
- Follow-up* (mm)	0.206	0.219	0.196
% Improvement - Final	21%	21%	22%
% Improvement - Follow-up*	25%	20%	28%

Note: 1 mm = 39.37 mils

* 7 months after undersealing

As indicated, initial leave deflections were higher than initial approach deflections by

approximately 15% and experienced the greater amount of improvement (21% vs. 15%).

Initial joint deflections were similar to initial crack deflections and experienced approximately the same degree of improvement.

Table 8 displays deflection changes for cracks and joints treated with either flyash or limestone aggregate.

Table 8. Deflection changes for cracks and joints displaying above average initial deflections (by aggregate type).

	Flyash	Limestone
Approach - Initial (mm)	0.252	0.228
- Final (mm)	0.187	0.214
- Follow-up* (mm)	0.171	0.202
% Improvement - Final	26%	6%
% Improvement - Follow-up*	32%	12%
Leave - Initial (mm)	0.276	0.273
- Final (mm)	0.186	0.239
- Follow-up* (mm)	0.177	0.226
% Improvement - Final	33%	13%
% Improvement - Follow-up*	36%	17%

Note: 1 mm = 39.37 mils

* 7 months after undersealing

Inspection of Table 8 indicates that greater improvements in mean deflections were experienced by those cracks and joints undersealed with the flyash mix. These cracks and joints experienced a 33% decrease in leave deflections while the cracks and joints undersealed with the limestone aggregate mix experienced only a 13% decrease. Likewise, a 26% decrease in approach deflections were noted for those cracks and joints undersealed with the flyash mix and only a 6% decrease for those undersealed with the limestone mix. On the average, improvements in deflections were 20% greater for areas treated with the flyash grout than areas treated with limestone grout.

Table 9 contains deflection information for cracks and joints treated with the flyash mix design and the designated admixtures. Table 10 contains the corresponding information for the limestone mix designs.

Table 9. Deflection changes for cracks and joints displaying above average initial deflections and treated with flyash mix (by admixture type).

	No Admixture	Superplasticizer	Water Reducer
Approach			
- Initial (mm)	0.207	0.270	0.249
- Final (mm)	0.137	0.195	0.213
- Follow-up* (mm)	0.152	0.168	0.192
% Improvement - Final	34%	28%	14%
% Improvement - Follow-up	27%	38%	23%
Leave			
- Initial (mm)	0.232	0.308	0.240
- Final (mm)	0.130	0.196	0.209
- Follow-up* (mm)	0.163	0.173	0.197
% Improvement - Final	44%	36%	13%
% Improvement - Follow-up	30%	44%	18%

Note: 1 mm = 39.37 mils

* 7 months after undersealing

As Tables 9 and 10 indicate, the greatest improvements were produced by the flyash - no admixture material (an average decrease of 44% in the leave deflections) followed by the flyash - superplasticizer material (an average decrease of

36% in the leave deflection). The most disappointing results were produced by the limestone mixes with admixtures.

Table 10. Deflection changes for cracks and joints displaying above average initial deflections and treated with limestone mix (by admixture type).

	No Admixture	Superplasticizer	Water Reducer
Approach			
- Initial	0.235	0.197	0.224
- Final (mm)	0.200	0.203	0.230
- Follow-up* (mm)	0.202	0.183	0.202
% Improvement - Final	15%	-3%	-3%
% Improvement - Follow-up*	14%	7%	10%
Leave			
- Initial	0.299	0.203	0.248
- Final (mm)	0.218	0.210	0.263
- Follow-up* (mm)	0.232	0.191	0.222
% Improvement - Final	27%	-3%	-6%
% Improvement - Follow-up*	22%	6%	11%

Note: 1 mm = 39.37 mils

* 7 months after undersealing

** Only one crack or joint treated with the limestone superplasticizer.

Of those areas treated with the limestone mix, only the limestone - no admixture material reduced deflections (an average decrease of 27% 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% in leave deflection measurements. Likewise, the limestone mix with the water reducer admixture also produced an average increase of 6% in leave deflection measurements.

Pavement deflections were remeasured the following spring, seven months after undersealing had been completed. Results supported many of the original evaluations of undersealing materials.

Deflection results for the treated cracks and joints are contained in Table 7. Only those cracks and joints whose initial deflections were above average were included in the following analyses. 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 present day performance of the undersealing materials, however, it is not possible to judge, with accuracy, the degree of improvement over time.

As Table 7 indicates, joint deflection improvements were greater than the improvements in crack deflections although earlier deflections (both before treatment and immediately following treatment) had been similar (See Table 8). 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 flyash or limestone aggregate slurry are contained in Table 4.

As expected, the cracks and joints treated with the flyash aggregate slurry continued to display greater decreases in deflections. These improvements were of the same degree as had been recorded immediately following treatment. That is, the reductions in the approach side deflections of the cracks and joints treated with the flyash aggregate slurry were 20% greater than those treated with the limestone aggregate slurry immediately following treatment (see Table 8) and in the seven month follow-up evaluation.

Reductions in the leave side deflections treated with the flyash aggregate were also 20% greater than those treated with the limestone aggregate slurry immediately following treatment and 19% greater in the follow-up study.

As before, the effect of admixtures on mix performance was also investigated. Table 5 contains the deflection information for the cracks and joints treated with the flyash slurry and either no admixture or one of the two designated admixtures. The corresponding information for the limestone mix designs are contained in Table 6.

Although the greatest improvements were initially produced with the flyash mix with no admixture, the follow-up study indicated that the cracks and joints treated with the flyash - superplasticizer mix were presently displaying the greater degree of improvement. Limestone mixes continued to display smaller improvements than the flyash mixes. Poorest performing mixes remained the limestone mixes with admixtures (superplasticizer and water reducer). The limestone mix without admixtures continued to be competitive with the flyash with a water reducing admixture. Although both cracks and joints were included in the analysis, trends were essentially the same when analyzing cracks and joints separately.

These results indicate, therefore, that greater improvements were achieved with a flyash aggregate mix. If an admixture is desired, it should not be of the water reducing type. A superplasticizer 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 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 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 0.024 m^3 (0.86 ft^3) of grout was pumped into an average hole. This quantity falls within the average range previously noted by others.

A simultaneous research project was conducted by the University of Illinois (2). Procedures were developed at the U of I under NCHRP Project 1-21 for void detection using non-destructive deflection testing (NDT) for locating and dimensioning areas of voids beneath the pavement. Their comprehensive method requires three major inputs: 1) the thickness of the PCC slab, 2) deflection measurements taken at slab centers and corners along the pavement lane and 3) measurement of deflection load transfer at the joint or crack.

Thirty-six joints were tested in the flyash grout section and thirty-six in the limestone section. Fifty percent of the joints in the limestone section were found to have voids with an average size of 0.65 m^2 (7 ft^2). Fifty-three percent of the joints in the flyash section were found to have voids present with an average size of approximately 12 square feet.

After grouting in the limestone section, voids were located at 61% of the joints with an average size of approximately $.93 \text{ m}^2$ (10 ft^2). After grouting in the flyash grout section voids were

located at 28% of the joints tested with an average size of approximately 0.74 m^2 (8 ft^2).

Results of this study, therefore, supported the findings of the Illinois Department of Transportation. That is, undersealing with a flyash 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 flyash grouts to flow into the void areas. The flyash 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. Flyash 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 due to the drilling operation, was evident. Coning leaves a weakened condition in the slab which will, in time, crack the slab. 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, 1) the effect of undersealing on existing underdrain systems was observed and 2) the capability of undersealing to stabilize poorly performing patches was investigated. Significant results are given below:

1. Previously placed underdrains which had originally been backfilled with sand of FA-1 gradation were uncovered and inspected for grout intrusion. None was observed. It is felt 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 contained several patches which displayed extremely high deflections and poor load transfer. These patches were successfully undersealed. Deflections decreased by an average of 67% after grouting.

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%.

Conclusions

1. The flyash grouts were stronger than limestone grouts treated with identical admixtures used in this study.

2. The flyash grouts were more "flowable" than limestone grouts.

3. Initial deflections at joints were slightly higher than 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. Flyash grouts with either 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 using a flyash mix.

8. There appeared to be a limiting deflection value for a given pavement below which deflections would not be reduced. Similarly greatest improvements was 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.

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