Concrete Slabs Stabilized by Subsealing: A Performance Report

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Correcting concrete slab movement or pumping problems by subsealing is common practice. Subsealing fills voids beneath the slab, eliminating pumping and restoring uniform support to the slab, hence prolonging slab life. The North Carolina Department of Transportation has experienced accelerated slab cracking after subsealing operations in several projects. The problem has caused enough concern that a study was initiated to investigate the procedure of subsealing operation and the performance of slabs that were stabilized by subsealing. In order to compare reliability of different void detection techniques, several devices were used to locate voids beneath concrete slabs in a test road. Test results indicated that none of these devices produced compatible data. The test section was monitored for 4 years. Conditions of stabilized and unstabilized slabs were mapped and analyzed. Results indicated that, if not handled properly, subsealing can cause performance problems.

Concrete slabs move up and down constantly during their service life. There are two types of slab movements: (a) curling caused by temperature or moisture gradients in the slab, and (b) deflection caused by heavy loading. Curling causes slabs to move very slowly. Movements caused by loading normally have rapid action. When water is present under the slab, rapid slab movement causes ejection of water through joints, cracks, and slab edges. Yoder and Witczak (*1*) described this pumping action in great detail. They further indicated that four factors, namely, free water, voids, low-permeability soil, and loading, must be present for concrete pavement pumping to occur.

Water in pumping action can carry fines from the base or subgrade material if it is erodible. The pumping problem escalates as loss of fines creates greater voids, eventually causing loss of uniform support to the slab. Loss of uniform support leads to premature slab failure.

Darter's definition of subsealing is the insertion of material beneath the slab by pressure to fill voids and provide a thin layer to reduce deflection and resist pumping (*2*). Engineers usually perform subsealing operations to correct the pumping problem. The subsealing operation includes detecting the voids, drilling fill holes through the concrete slab, and filling the voids with nonerodible material. Subsealing is performed in order to achieve the following: (a) filling of voids to prevent the existence of free water, hence eliminating pumping; and (b) restoring of uniform support to the slab.

In the mid-1980s, the North Carolina Department of Transportation (NCDOT) completed several concrete pavement restoration (CPR) projects. Included as part of the CPR work was stabilization of slabs by subsealing with fly ash and cement grout. In those projects, division personnel observed an alarming increase in the rate of slab cracking. Therefore, they raised questions concerning the effectiveness of concrete slab subsealing. Their concerns included the technique for detecting voids under the slab, the threshold for subsealing, the hole pattern, procedures, equipment operation, etc. All of these could be summarized into one question: Was subsealing in fact solving problems or causing problems?

The division's concern was supported by the fact that stabilized slabs have broken faster than slabs that were not subsealed. This concern prompted a series of investigations to look into the subsealing operations and the performance of stabilized slabs.

This study was proposed to answer the following questions.

1. Does the rate of slab cracking change after subsealing? If so, what is the difference?
2. Is the technique of subsealing advanced enough to be used on a routine basis?

STUDY SECTION

A section of I-40 in Catawba County, North Carolina, was identified as the test section for this study. This section was selected because it had just been stabilized and no further CPR was scheduled. This selection provided a sample section with an ordinary subsealing operation. Slab performance observed in this section provided a set of unbiased data.

The evaluation section extended from the Catawba River bridge to just west of NC-16. Slabs were stabilized by means of subsealing with cement–fly ash grout in late 1984. Each lane of this four-lane divided highway contained 1,498 30-ft slabs. The number of slabs stabilized are presented in Table 1.

No work was performed to restore joint sealing in this section of highway. These old joints were mostly open. Wu and Hearne (*3*) found that a large quantity of water can infiltrate a tight, unsealed longitudinal joint. Although the purpose of subsealing is to fill voids under slabs and eliminate the free water reservoir, it cannot stop free water that moves by infiltration.

PAVEMENT PERFORMANCE SURVEY

During the first year beginning in April 1985, pavement condition surveys were performed once every 3 months. Field data were collected twice a year thereafter.

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TABLE 1 SUMMARIZED SLAB STABILIZATION

Lane No *	Total Slab Number	Stabilized Slab Number	%
1	1498	399	26.6
2	1498	385	25.7
3	1498	5	0.3
4	1498	14	0.9
All	5189	803	13.4

* Lane number 1, eastbound outside lane
2, westbound outside lane
3, eastbound inside lane
4, westbound inside lane

Field surveys were done slab by slab. Both longitudinal and transverse cracks were carefully mapped. Growth of the crack was recorded. The numbers of total cracked slabs before subsealing operations are presented in Table 2.

The numbers of new cracks on stabilized slabs found in each survey, the accumulated cracked slabs for each lane, and the total cracked slabs for all lanes are presented in Table 3. The same information is presented in Table 4 for the unstabilized slabs.

The percent of additional slab cracking for every survey is presented in Table 5. Changes of the rate of slab cracking for different lanes are shown in Figures 1–5.

VOID DETECTION

In order to prove its effectiveness, the American Concrete Pavement Association with the help of the NCDOT put on a project to demonstrate subsealing procedures in August 1986. One of the objectives of this project was to illustrate the technique of detecting voids beneath slabs. Results of this demonstration project were provided by Oppermann (*4*).

Four different void-detecting devices were applied. These were the Benkelman beam (operated by NCDOT), falling weight deflectometer (FWD) (operated by NCDOT), Dynaflect deflectometer (operated by Austin Research Engineering), and a radar void detector (operated by Gulf Applied Technology).

All these devices were used to detect voids before and after the subsealing operation. The amount of grout taken at each location was recorded. A total of 34 joints were tested. After the subsealing and testing were completed, five slabs were cut with a concrete saw and raised to investigate the actual grout distribution.

Before-and-after test results and the acceptance of grout at all the joints are presented in Table 6. If acceptance of grout is used as an indicator of the presence of void, then comparing grout taken with results of the other void detection techniques will offer some indication of the effectiveness of that technique. Tables 7–10 indicate the relationship between these void detection technique test results and grout acceptance. These results indicate that, if grout acceptance demonstrates a void existing beneath the slab, the accuracy of detecting a void for any one of these methods is less than 70 percent.

Relative test results among the Benkelman beam, FWD, the radar, and grout taken are presented in Table 11. This table presents percent of matching results for both before and after testing.

After the subsealing operation, five slabs were sawed, raised, and removed carefully. Areas under these slabs were inspected and grout spreading was mapped. Results for the five slabs removed are as follows:

1. Joint 4. All methods indicated deflection decreased after subsealing. Very little grout was taken. A thin layer of grout was observed under the slab. Grout was also observed at the joint.
2. Joint 13. Again, all methods indicated deflection decreased after subsealing. A large amount of grout was taken. A large area of grout was found under the slab.
3. Joint 17. No void was detected by either radar or FWD, yet a large amount of grout was taken. Grout was apparent in the joint and a cone of grout was formed under the grout hole.
4. Joint 20. Both Benkelman beam and FWD indicated voids before and after subsealing; however, no grout was taken. Very little grout was spread under the slab. A cone was formed under a grout hole.

TABLE 2 NUMBER OF CRACKED SLABS BEFORE SUBSEAL

Date	Lane	Cracked Slab		% of Total Slab	
		Stabil.	Unstabil.	Stabil.	Unstabil.
04/84	1	2	12	0.5%	1.0%
04/84	2	7	10	1.8%	0.9%
04/84	3	0	7	0%	0.5%
04/84	4	1	7	7.1%	0.5%
04/84	All	10	36	1.2%	0.7%

TABLE 3 ADDITIONAL SLABS CRACKED (STABILIZED)

	Lane	New Cracks					Accumulate				
		1	2	3	4	All	1	2	3	4	All
	04/84	2	7	0	1	10	2	7	0	1	10
D	07/85	2	1	0	1	4	4	8	0	2	14
A	11/85	3	0	1	0	4	7	8	1	2	18
T	03/86	1	2	0	0	3	8	10	1	2	21
E	08/86	1	1	0	0	2	9	11	1	2	23
	12/86	0	0	0	0	0	9	11	1	2	23
	05/87	0	0	0	0	0	9	11	1	2	23
	03/88	6	2	0	0	8	17	13	1	2	31

TABLE 4 ADDITIONAL SLABS CRACKED (UNSTABILIZED)

	New Cracks					Accumulate				
Lane	1	2	3	4	All	1	2	3	4	All
04/84	12	10	7	7	36	12	10	7	7	36
07/85	2	1	0	0	3	14	11	7	7	39
11/85	0	1	0	0	1	14	12	7	7	40
03/86	0	4	0	0	4	14	16	7	7	44
08/86	1	1	1	0	3	15	17	8	7	47
12/86	0	1	1	1	3	15	18	9	8	50
05/87	1	0	0	0	1	16	18	9	8	51
03/88	2	3	2	1	8	18	21	11	9	59

TABLE 5 SLAB CRACKING RATE

DATE	STABILIZED(%)	UNSTABILIZED(%)
04/84	1.25	0.69
07/85	0.49	0.06
11/85	0.49	0.02
03/86	0.37	0.08
08/86	0.25	0.06
12/86	0.0	0.06
05/87	0.0	0.02
03/88	1.0	0.15

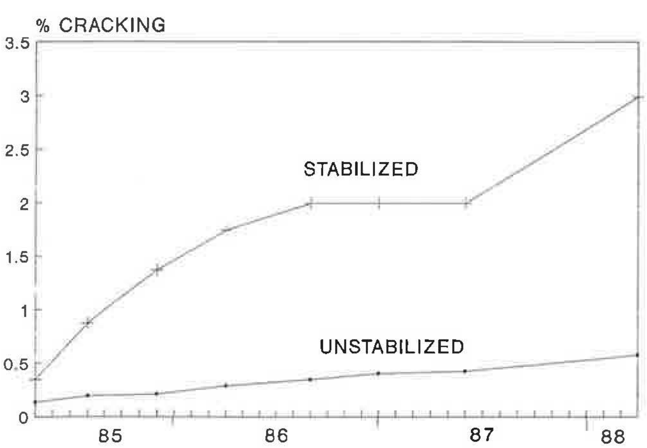

FIGURE 1 Transverse cracking (all lanes).

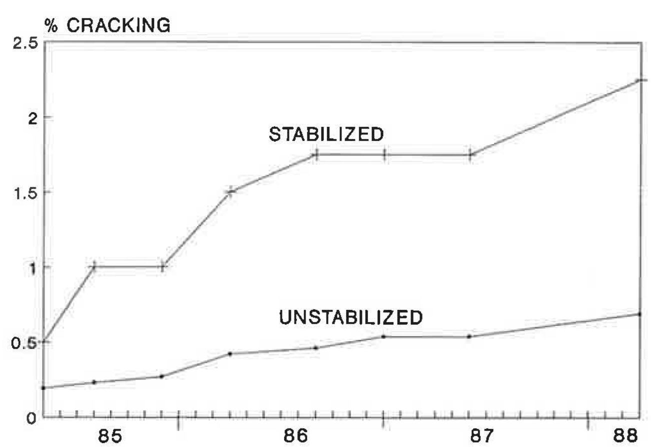

FIGURE 2 Transverse cracking (westbound, both lanes).

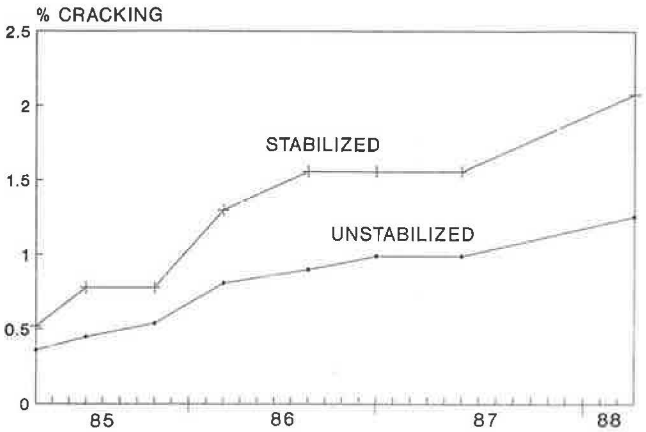

FIGURE 3 Transverse cracking (westbound, outside lane).

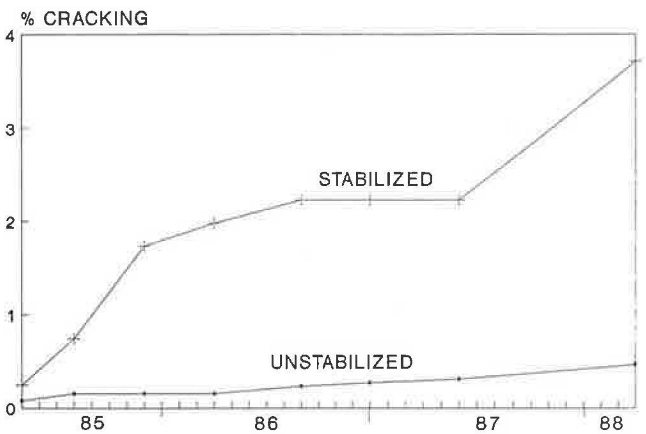

FIGURE 4 Transverse cracking (eastbound, both lanes).

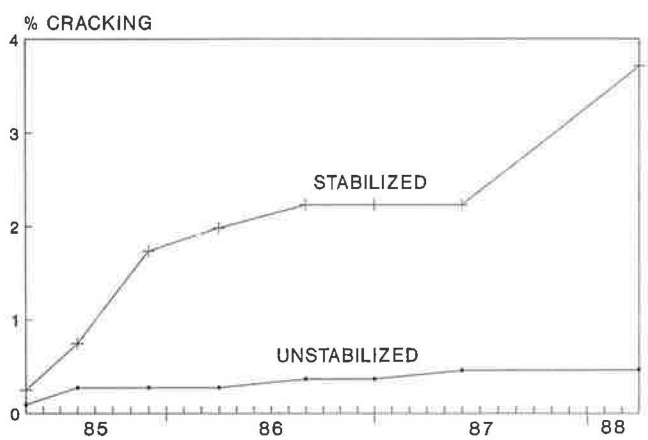

FIGURE 5 Transverse cracking (eastbound, outside lane).

5. Joint 22. Both radar and FWD indicated large voids on both sides of the joint; however, Benkelman beam indicated there is no need for subsealing. A large amount of grout was accepted. Under the slab, a large flow of grout was observed.

In all cases, when grout spread to the joint, some degree of grout penetration to the joint opening was observed.

To detect voids under slabs, a slab deflection reading is used for all these techniques except radar. The amount and shape of deflection determines if a joint needs to be stabilized. The field reading from another study (*3*) indicated that the magnitude of the deflection reading is a function of the degree of the slab curling movement. The deflection reading at the same joint varies depending on the time of day the testing is performed. The difference between maximum and minimum reading in a 24-hr period is greater than 10-fold.

RESULTS AND FINDINGS

Survey results indicated that the rate of cracking is greater in stabilized slabs than unstabilized slabs. The rate of cracking for the stabilized slabs increased rapidly soon after the subsealing operation. The rate of growth became steady a year later. However, in the last year of the monitoring period, a rapid growth rate was detected (see Figures 1–5).

This three-stage cracking phenomenon of the stabilized slabs can be explained by the following hypothesis.

- First Stage. After the slab was stabilized by filling the voids, the support conditions changed. Depending on the change, the new situation may be harmful to the slab. Filling the voids may induce stress caused by temperature change, uneven subgrade support, and restriction of deformation. This extra stress is in addition to the normal stress induced by traffic loading. The resulting stress can cause slab cracking in the first stage.
- Second Stage. After slabs that were disturbed by the subsealing operation cracked and subgrade support was reestablished, the cracking rates slowed down and followed the same pace as the unstabilized slabs.
- Third Stage. Slabs that were stabilized had been subject to poor support conditions for a period of time. Theoretically speaking, fatigue life of the slab is a function of the applied stress. The same wheel loading causes less stress in slabs with uniform support than in poorly supported slabs. Therefore the stabilized slabs have a shorter life expectancy. This hypothesis explains the rate of increase of the third stage.

Although every void detection technique was claimed to be capable of identifying voids beneath concrete slabs, it is not possible to prove that one technique is more reliable than the others from the results presented in Table 6. In fact, none of the five techniques participated in the study demonstrated consistent results.

During the subsealing operation, the operator stops grout injection when the slab starts moving upward or when grout spills from the joints, cracks, or grout holes. Usually, subsealing is performed in the fall and winter when joints are wide open. Grout under pressure may be forced into the opened joint. Observations of grouting operation and the following slab removal sustain this concern. Introducing incompressible material to the joint opening prevents slab expansion. Depending on the percentage of stabilized slabs, filling up joints will prevent them from functioning properly.

CONCLUSIONS

On the basis of this study, it is concluded that

1. Subsealing can fill the voids, thereby restoring slab support, if it is done properly.

TABLE 6 RESULTS OF DEFLECTION TESTING

Joint	Benkelman B	Benkelman A	FWD B	FWD A	Radar B	Radar A	Deflect *	Grout Taken
1	N	N	Y	Y	Y	Y	- 8%	N
2	Y	Y	Y	Y	Y	Y		L
3	Y	N	Y	N	Y	Y	-48%	L
4	Y	N	Y	Y	Y	Y	-43%	N
5	Y	N	Y	N	Y	Y	-20%	G
6	Y	N	Y	N	Y	Y	-40%	G
7	Y	N	Y	N	Y	Y	+45%	G
8	Y	Y	Y	Y	Y	N	+40%	N
9	Y	N	Y	Y	Y	Y		G
10	Y	N	Y	N	Y	Y	-25%	G
11	Y	N	Y	Y	Y	Y	-20%	G
12	Y	N	Y	Y	Y	Y	-27%	G
13	Y	N	Y	N	Y	Y		G
14	Y	N	Y	Y	Y	Y	-15%	G
15	Y	Y	Y	N	Y	N	-17%	N
16	Y	N	Y	N	N	Y	-25%	G
17	Y	N	N	N	N	Y	-13%	G
18	Y	Y	Y	Y	Y	N	+ 7%	N
19	Y	Y	Y	Y	N	N	+20%	N
20	Y	Y	Y	Y	Y	N	+ 7%	N
21	N	N	Y	N	Y	N	0%	L
22	N	N	Y	N	Y	Y	+38%	G
23	Y	N	Y	N	Y	Y	-22%	G
24	Y	N	Y	N	N	Y	+13%	G
25	Y	N	Y	N	Y	Y	+ 7%	G
26	Y	Y	Y	Y	Y	N	+ 6%	N
27	Y	Y	Y	Y	Y	N	0%	N
28	Y	Y	Y	Y	Y	Y	0%	G
29	Y	Y	Y	Y	Y	Y	+60%	G
30	Y	N	Y	N	Y	Y	0%	G
31	Y	N	Y	Y	Y	Y	+25%	L
32	Y	Y	Y	Y	Y	Y	+25%	G
33	Y	N	N	N	Y	Y	-32%	G
34	Y	Y	Y	N	Y	Y	0%	G

Y: Void detected
N: No void detected
G: Grout taken
L: Low grout taken
N: No grout taken
* Percent change of deflection (before and after)

TABLE 7 BENKELMAN BEAM TEST RESULTS

Indicated Void Before	Indicated Void After	Grout Taken	Number of Joints
Y	Y	Y	5
Y	Y	N	7
Y	N	Y	17
Y	N	N	2
N	N	Y	2
N	N	N	1
		TOTAL	34

TABLE 8 FWD TEST RESULTS

Indicated Void Before	Indicated Void After	Grout Taken	Number of Joints
Y	Y	Y	9
Y	Y	N	8
Y	N	Y	14
Y	N	N	1
N	N	Y	2
		TOTAL	34

2. To eliminate free water effectively, all joints must be resealed following subsealing.

3. If it is not executed properly, subsealing can be harmful to the slab because it may result in raising of slabs and in uneven grout distribution.

4. While using deflection as an indicator in selecting slabs for stabilization, setting the threshold for such selection must also consider the time of day and the season in which testing is performed.

5. The timing of slab stabilization is important. Restoring support is too late if damage to the slab from loss of support has already occurred.

6. There is no reliable nondestructive testing method to detect voids underneath concrete slabs.

TABLE 9 RADAR TEST RESULTS

Change of Deflection	Grout Taken	Number of Joints
increase	Y	7
increase	N	5
no change	Y	4
no change	N	1
decrease	Y	11
decrease	N	3
	total	31*

* No report at 3 joints

TABLE 10 DYNAFLECT DEFLECTOMETER TEST RESULTS

Indicated Before	Void After	Grout Taken	Number of Joints
Y	Y	Y	21
Y	Y	N	2
Y	N	Y	1
Y	N	N	6
N	N	N	1
N	Y	Y	3
		total	34

TABLE 11 PERCENT OF MATCHING TEST RESULTS

	Benkelman	FWD	Radar
Benkelman	**	85 (74)	79 (18)
FWD	**	**	88 (38)
Grout Taken	67 (73)	67 (65)	73 (6)

Note: before (after)

7. The subsealing operation can introduce incompressible material to joint openings. Such filled joints will obstruct slab expansion.

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