# Evaluation of Highway Undersealing Practices of Portland Cement Concrete Pavements

RAMZI TAHA, ALI SELIM, SA'D HASAN, AND BLAIR LUNDE

Pumping and faulting of undoweled portland cement concrete pavements has become a serious problem in South Dakota. When a pavement becomes faulted the rideability of the pavement becomes objectionable to the traveling public. One of the rehabilitation measures used to reduce the progression of faulting has been undersealing. This process does not correct depressions, increase the design structural capacity, or eliminate faulting, but rather restores the structural integrity of the slab by reducing deflections. The success of an undersealing operation depends on the selection of an acceptable undersealing material, testing of the pavements for voids, estimation of grout quantities, determination of the optimal time in a pavement's life cycle to perform undersealing work, and adequate construction practices. The results of a survey of current undersealing practices in the United States are presented. Of the 33 states that responded to the survey, only 16 are implementing undersealing as a rehabilitation strategy. Areas of concern to highway agencies include cost-effectiveness of undersealing, the adequacy of construction practices, and the long-term performance of undersealed pavements.

Pumping is a load-actuated erosion phenomenon by which material from the pavement foundation or shoulder is moved about by water. When fine material is removed from beneath the slab by pumping action there is a reduction in slab support, which leads to a greater slab deflection and more severe pumping. This process may lead to faulting at joints if positive load transfer is not present. When a pavement becomes faulted the rideability of the pavement becomes objectionable to the traveling public and in some cases can impair the structural integrity of the pavement.

Research (*1*) has shown that four basic conditions must be present simultaneously to create pumping and a faulted slab. They are

1. Free water under the slabs,
2. Frequent heavy axle loads,
3. Cracks or joints in the pavement, and
4. Unstabilized or erodible material under or adjacent to the slabs.

If any of these factors is absent, pumping and faulting will not occur. A combination of visual surveys and nondestructive testing can be used to detect pumping, faulting, and the presence of voids beneath the slab.

The rehabilitation strategies necessary to correct the pumping and faulting of slabs depend on the condition of the pavement and other factors such as available funding and minimum life extension. For each distress type one or more repair or preventative rehabilitation methods can be applied. For example, faulting can be removed or repaired by (a) diamond grinding or (b) placement of a thick overlay. However, faulting of transverse joints can be prevented by (*2*)

1. Undersealing to fill voids and restore support,
2. Reestablishing load transfer across the joint with mechanical devices (this helps to prevent further pumping by reducing deflection),
3. Resealing the transverse and longitudinal joints (this helps to prevent further pumping), and
4. Providing subdrainage (this helps to prevent further pumping).

The successful implementation of an undersealing operation requires the following:

1. The determination of joints or cracks that need undersealing has been a difficult and controversial question. Only those joints or cracks that exhibit loss of support (voids) should be undersealed. Visual surveys, deflection measurements (falling-weight deflectometer), and Benkelman beam, Road Rater, ground-penetrating radar (*3*), and pulsed electromagnetic wave (*4*) technologies can be used to locate and measure voids beneath portland cement concrete (PCC) pavements.
2. The proper undersealing material must be selected. The undersealing material must be capable of penetrating very thin voids, yet it must have sufficient strength and durability to resist loading, moisture, and temperature effects. Asphalt cements (*5*), pozzolanic (fly ash)-cement grouts (*6*), limestone dust-cement grouts (*7*), and polyurethane and silicone rubber foam (*8*) have been used for undersealing.
3. The estimation of grout quantities is extremely difficult, but it can be accomplished by using past experience, the extent of visual distress such as faulting and pumping, and deflection testing for voids or loss of support.
4. The undersealing procedures must be carefully controlled in the field. The success of the operation depends highly on the skill and the knowledge of the contractor and the crew doing the grout injection. Slab lift must be closely controlled to avoid overgrouting, which may result in premature slab breakup. The down force exerted during the drilling of grout injection holes must be controlled to avoid causing deterioration or spalling at the bottom of the slab near the hole. Pumping pressures must be limited to avoid damage to the pavement from excessive slab lift.

R. Taha, Department of Civil and Environmental Engineering, Washington State University, Pullman, Wash. 99164-2910. A. Selim and S. Hasan, Civil Engineering Department, South Dakota State University, Brookings, S. Dak. 57007-0495. B. Lunde, Office of Research, South Dakota Department of Transportation, 700 Broadway Avenue East, Pierre, S. Dak. 57501-2586.

5. The long-term effectiveness of undersealing depends on preventing free moisture from accumulating in the pavement structure. All joints and cracks should be properly sealed, and subdrains should be placed to get rid of moisture (*2*).

Finally, the success of a pavement undersealing project also depends on other rehabilitation work that should be performed in conjunction with undersealing.

The main objectives of this paper are to summarize the pertinent results obtained from the survey of current practices.

## SUMMARY OF CURRENT PRACTICES

Summarized in this section is part of the survey of current practices dealing with PCC pavement undersealing. The survey was sent out to all 50 states and Puerto Rico (referred to here as a state for data analysis purposes). The relevant questions on undersealing were

1. The criteria used to establish when to implement undersealing work,
2. The types of grouts used in undersealing,
3. The construction methods used in undersealing, and
4. The criteria used to determine the long-term effectiveness of undersealing.

To collect the needed information two survey techniques were used: the initial information request and follow-up requests. Thirty-three states responded to the survey. As shown in Figure 1, of the 33 states that responded only 16 are implementing undersealing as a rehabilitation strategy. The other 17 states do not implement undersealing for the following reasons:

1. The difficulty of locating voids beneath the slab,
2. The difficulty of filling all voids,
3. The damage to the pavement that overgrouting could cause,
4. The dependence of undersealing on the experiences and skills of the contractors, and
5. The lack of cost-effectiveness of undersealing.

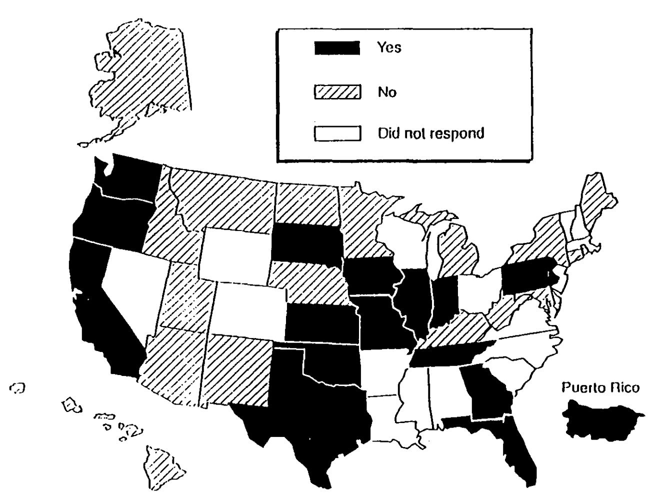


**FIGURE 1 States that responded to survey.**

However, even some of those states that underseal their PCC pavements do so only on a limited basis for the above-mentioned reasons. Only Indiana is clearly satisfied with its undersealing operation. However, the Indiana Department of Transportation is seeking more information on the means of locating voids beneath the pavement slab.

### Criteria Used in Implementation of Undersealing Work

Of the 16 states that use undersealing in their pavement restoration work, 9 use visual surveys, as indicated by pumping or faulting in combination with nondestructive testing, to locate voids beneath a slab. The other seven states rely on nondestructive testing for void detection. Table 1 presents the means used by the various states to determine the locations of slabs that need undersealing work. The falling-weight deflectometer (FWD) and the Benkelman beam are the most commonly used equipment.

Table 2 presents the criteria used for determining the slabs that need undersealing. These values are also used for determining the effectiveness of an undersealing operation. Generally, corner deflections greater than 0.025 cm (0.01 in.) to greater than 0.09 cm (0.035 in.) are adopted. Some states such as Pennsylvania and Missouri use a load transfer efficiency (LTE) value of less than 65 percent as a criterion for determining those slabs that need undersealing. Load transfer at joints and cracks can be determined by using one of the following equations:

$$\text{LTE} = (d_{UL}/d_L) \times 100 \quad (1)$$

or

$$\text{LTE} = [(2d_{UL})/(d_L + d_{UL})] \times 100$$

where

LTE = load transfer efficiency (percent),
$d_{UL}$ = deflection of the unloaded slab, and
$d_L$ = deflection of the loaded slab.

### Types of Grouts Used in Undersealing

Figure 2 shows the types of grouts used in the various states. As shown in Figure 2, pozzolan (fly ash)-cement grout is the most popular material used in the states. Indiana is the only state that uses asphalt cement, with very satisfactory results. For pozzolan-cement grouts, a 7-day compressive strength of 4138 kPa (600 lb/in.$^2$) to 5517 kPa (800 lb/in.$^2$) and an average flowability of 10 to 16 sec are generally recommended and used.

### Construction Methods Used in Undersealing

All 16 states except Puerto Rico limit their undersealing operations to those conditions when the temperature is above 0°C

**TABLE 1 Techniques Used To Determine Locations of Slabs That Need Undersealing**

| State | Visual | Benkelman | FWD[a] | GPR[b] | Dynaflect | Road Rater |
|---|---|---|---|---|---|---|
| California | x | | | | | |
| Florida | x | x | | | | |
| Georgia | x | x | | | | |
| Kansas | x | | x | | | |
| Illinois | x | | x | | | |
| Indiana | | | | | x | |
| Iowa | x | | | x | | x |
| Missouri | x | | x | | | |
| Oklahoma[c] | | | | | | |
| Oregon | | | x | | | |
| Pennsylvania | | x | x | | | |
| Puerto Rico | | x | | | | |
| South Dakota | x | x | x | | | |
| Texas[d] | x | | x | x | | |
| Tennessee[e] | | | | | | |
| Washington | | x | x | | | |

a: Falling Weight Deflectometer.
b: Ground Penetrating Radar.
c: Not specified.
d: The Spectral Analysis of Surface Waves (SASW) technique is also used.
e: A pre-rolling method is used.

(32°F). In cold weather states undersealing also is not allowed if the subgrade is frozen.

The maximum allowable pumping pressure (excluding the initial pumping pressure) used by highway agencies varies from 138 kPa (20 lb/in.$^2$) to 1035 kPa (150 lb/in.$^2$). Pumping pressures ranging from 345 kPa (50 lb/in.$^2$) to 414 kPa (60 lb/in.$^2$) seemed to be the most preferred values. Table 3 presents the maximum allowable pumping pressures specified by state highway agencies.

Maximum vertical slab movement allowed during pumping varies from 0.04 cm (0.0175 in.) to 0.64 cm (0.25 in.). Table 4 shows the maximum allowable vertical slab movements specified by the states.

The survey also revealed that pumping should be stopped when one of the following conditions prevails:

1. The maximum allowable pumping pressure has been attained.
2. The maximum allowable vertical slab movement has been measured.
3. The time limit for pumping grout into the holes has been attained (recommended by some states).
4. The grout starts to flow from adjacent holes or comes out of the joints (recommended by some states).

Finally, all states adopt some type of pavement restoration work in conjunction with undersealing. This may include joint or crack sealing, patching, the use of edge drains, grinding, dowel retrofitting, the use of overlays, spall repair, and full-depth repair.

### Long-Term Effectiveness of Undersealing Operations

All 16 state highway agencies use the corner deflection measurements and joint transfer efficiency values presented in Table 2 to establish the acceptance of undersealing work. If a joint fails the contractor may be required to rework the slab. No guidelines were provided to establish the long-term effectiveness of undersealing. All states rely on long-term monitoring of the concrete panels to observe that pumping and faulting are not resumed.

## CONCLUSIONS

The survey revealed the following:

1. Undersealing is performed on a limited basis by 16 state highway agencies.
2. Visual surveys and FWD testing are the most common means used for void detection.
3. Corner deflections greater than 0.025 cm (0.01 in.) to greater than 0.09 cm (0.035 in.) or a load transfer efficiency of less than 65 percent are adopted as criteria in the determination of those slabs that need undersealing.
4. Fly ash–cement grout is the preferred material used in undersealing.
5. Pumping pressures are generally limited to a maximum of 414 kPa (60 lb/in.$^2$).

**TABLE 2 Corner Deflection and Joint Efficiency Values (cm) Used To Determine Location of Slabs That Need Undersealing**

| State | > 0.025 | > 0.038 | > 0.051 | > 0.064 | > 0.076 | > 0.089 | JE[a] < 65 |
|---|---|---|---|---|---|---|---|
| California[b] | | | | | | | |
| Florida | | x | | | | | |
| Georgia | | | | | x | | |
| Kansas[c] | | | | | | | |
| Illinois[b] | | | | | | | |
| Indiana[d] | | | | | | | |
| Iowa[b] | | | | | | | |
| Missouri[e] | | | | | | | x |
| Oklahoma[b] | | | | | | | |
| Oregon[f] | | | | x | | | |
| Pennsylvania | | | x | | | | x |
| Puerto Rico | | | | | x | | |
| South Dakota | x | | | | | | |
| Texas | | | x | | | | |
| Tennessee | | | | | x | | |
| Washington | | | | | | x | |

1 in. = 2.54 cm

a: JE = Joint Efficiency.
b: Not specified.
c: If corner deflections are greater than a base value established from the interior slab deflection.
d: Judgement + Modified Majidzadeh Criteria.
e: Corner deflection greater than 0.045 cm is also used.
f: Darter/Crovetti slope intercept method is also used (based on a deflection of 10 mils).

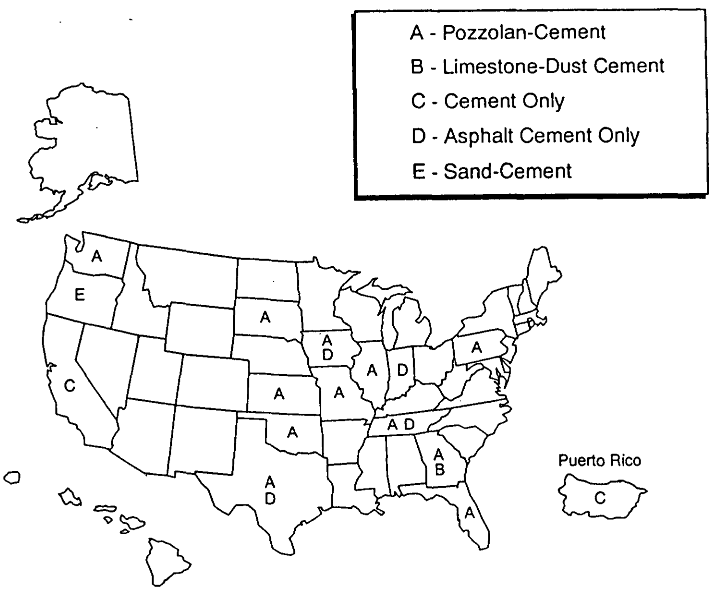


**FIGURE 2 Typical undersealing materials used by different states.**

**TABLE 3 Maximum Allowable Pumping Pressures (kPa) Specified by Various Highway Agencies**

| State | 138 | 276 | 345 | 414 | 690 |
|---|---|---|---|---|---|
| California | x | | | | |
| Florida[a] | | | | | |
| Georgia | | | | | x |
| Kansas | | | | x | |
| Illinois | | x | | | |
| Indiana[b] | | | | | |
| Iowa | x | | | | |
| Missouri | | | x | | |
| Oklahoma | | | | x | |
| Oregon[b] | | | | | |
| Pennsylvania[b] | | | | | |
| Puerto Rico[b] | | | | | |
| South Dakota | | | | x | |
| Texas | | | x | | |
| Tennessee | | | x | | |
| Washington[b] | | | | | |

1 psi = 6.9 kPa

a: As low as possible.
b: Not specified.

**TABLE 4 Maximum Allowable Vertical Slab Movements (cm) Specified by Various Highway Agencies During Pumping**

| State | 0.089 | 0.127 | 0.254 | 0.318 | 0.508 | 0.635 |
|---|---|---|---|---|---|---|
| California[a] | | | | | | |
| Florida | | | | x | | |
| Georgia | | x | | | | |
| Kansas | | | | x | | |
| Illinois | | x | | | | |
| Indiana | | | | | | x |
| Iowa | | | x | | | |
| Missouri | | | | | x | |
| Oklahoma | x | | | | | |
| Oregon[b] | | | | | | |
| Pennsylvania | | x | | | | |
| Puerto Rico | | x | | | | |
| South Dakota | | | | x | | |
| Texas | | | | x | | |
| Tennessee | | | x | | | |
| Washington[c] | | | | | | |

1 in. = 2.54 cm

a: Zero to profile grade of surface.
b: A deflection of 0.064 cm is specified.
c: A deflection of 0.051 cm is specified.

6. The maximum vertical slab movement allowed during pumping varies from 0.04 cm (0.0175 in.) to 0.64 cm (0.25 in.).

7. All states adopt some type of pavement restoration work in conjunction with undersealing.

8. The long-term effectiveness of undersealing is generally established by observing that pumping and faulting distresses are not resumed in the concrete panels.

## ACKNOWLEDGMENTS

The survey results presented in this paper were part of a research study sponsored by the South Dakota Department of Transportation. The authors express their appreciation for the information provided by the various state highway agencies.

## REFERENCES

1. Allen, H. Final Report of Committee on Maintenance of Concrete Pavements as Related to the Pumping Action of Slabs. *HRB Proc.*, Vol. 28, 1948.
2. Darter, M. I., E. J. Barenberg, and W. A. Yrjanson. *NCHRP Report 281: Joint Repair Method for Portland Cement Concrete Pavements.* TRB, National Research Council, Washington, D.C., 1985.
3. Ransom, R. C., and J. T. Kunz. Nondestructive Detection of Voids Beneath Pavements. *Public Works*, Vol. 117, 1986.
4. Steinway, W. J., J. D. Echard, and C. M. Luke. *NCHRP Report 237: Locating Voids Beneath Pavement Using Pulse Electromagnetic Waves.* TRB, National Research Council, Washington, D.C., 1981.
5. Sudol, J. J., and J. W. Muncaster. Undersealing Concrete Pavements: The Indiana Method. *Public Works*, Vol. 117, 1986.
6. Sliffer, J. C., M. McPeter, and W. E. Burns. Experimental Project on Grout Subsealing in Illinois: A 20-Month Evaluation. In *Transportation Research Record 1041*, TRB, National Research Council, Washington, D.C., 1985.
7. *Pavement Rehabilitation Manual.* Report FHWA-ED-88-025. FHWA, U.S. Department of Transportation, 1985.
8. Neal, B. F. *California PCC Pavement Faulting Studies: A Survey.* Report FHWA-CA-TL-85-06. California Department of Transportation, 1985.

*Publication of this paper sponsored by Committee on Pavement Rehabilitation.*