CONCRETE PAVING Technology

Slab Stabilization Guidelines For Concrete Pavements

Introduction

Concrete pavement restoration (CPR) is an effective solution for extending the life of concrete pavement. An agency can use CPR for low-cost rehabilitation as a concrete road reaches or exceeds its service life. One problem that causes distress and serviceability loss in concrete pavements is loss of support due to voids underneath the pavement slabs. The voids usually occur near cracks or joints, or along the pavement edge, and are often not much deeper than 3 mm (0.125 in). Some of the most common destructive forces that cause voids are 1):

1. Pumping—the expulsion of water and soil through an open joint or shoulder as traffic drives over the joint,
2. Consolidation—the compaction of base materials beneath the slab caused by repeated heavy truck traffic,
3. Subgrade failure caused by overloading of the subgrade near joints or loss of load bearing capacity due to saturation of the subgrade, and
4. Bridge approach failure caused by consolidation and washout of fill material.

Heavy traffic loads induce the highest slab deflections near transverse joints and working cracks. These deflections may cause pumping, consolidation, and loss of the subbase or subgrade support. Figure 1 shows the progression of slab deterioration for a jointed concrete pavement caused by the development of voids from pumping and loss of support. Without support underneath the slab, the stresses in the concrete increase and may cause faulting, corner breaks, and extensive cracking.

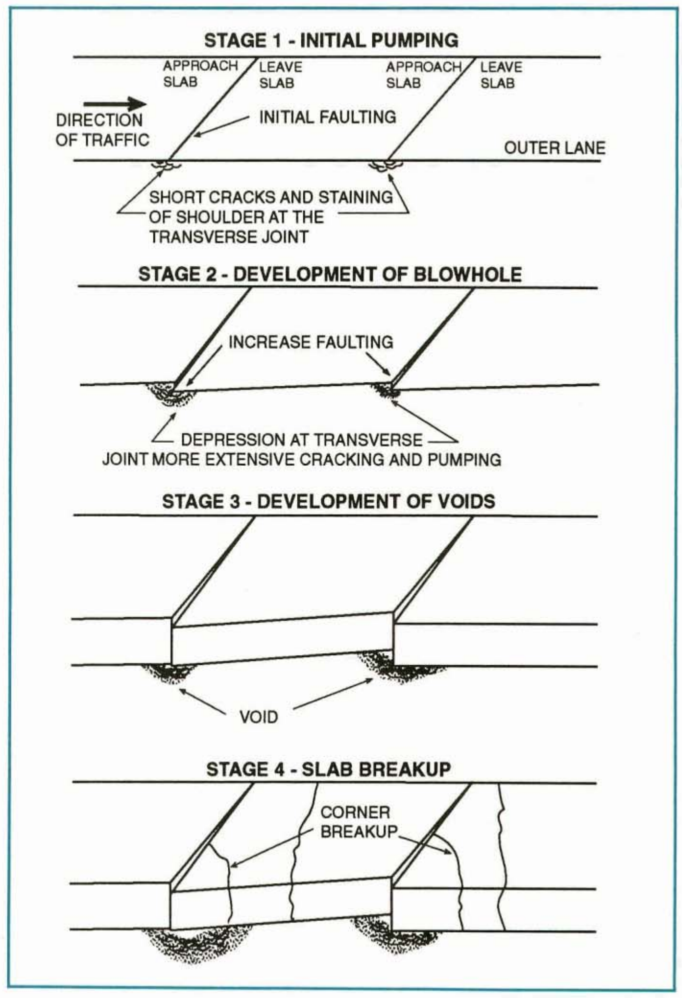

Figure 1 *Typical stages of loss of support and void development leading to concrete pavement deterioration.*

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Also called undersealing, subsealing, or pavement grouting, slab stabilization is a nondestructive, void-filling, corrective process that restores slab support without raising the concrete pavement. Slab stabilization should usually accompany other CPR techniques including patching and diamond grinding.

The success of stabilization depends on:

1. Determining the optimal time to stabilize.
2. Accurately detecting voids.
3. Selecting acceptable stabilization materials.
4. Correctly estimating material quantities.
5. Using appropriate construction practices.

This publication examines when slab stabilization is a viable option and explains stabilization procedures.

New slab stabilization methods, materials, and equipment are available to accomplish the process more rapidly and efficiently than in the past. The process consists of pumping a cement-grout or polyurethane mixture through holes drilled through the slab. The grout can fill small voids beneath the slab and/or subbase (e.g., about 0.125 to 6.350 mm (0.005 to 0.250 in) deep). The grout also displaces free water and helps keep water from saturating and weakening support under the joints and the slab edge after stabilization is complete.

Slab stabilization should not be confused with "slab jacking." During slab jacking the contractor forces a grout or polyurethane mixture underneath a depressed section of pavement or slab to lift it to its original elevation or to a uniform profile. In the past, slab jacking has sometimes caused uneven slab support and even slab cracking. However, with proper procedures and materials a contractor can lift the pavement back into position, and effectively restore support to the slab.

Limitations & Concurrent Work

Slab stabilization does not correct depressions, increase the design structural capacity, stop erosion, or eliminate faulting. Rather, it restores the slab support thereby decreasing deflections under load. This helps to maintain the structural integrity of a slab and reduce the progression of pumping, faulting, and slab cracking. Research has shown that *stabilization should only be performed at joints and cracks where loss of support exists* (2). Attempting to stabilize a joint or crack that does not have a void may cause the slab to rise and possibly create uneven support.

Where severe pumping is evident on a pavement, it is important to perform other rehabilitation work to maximize the benefit of stabilization. The agency should take measures to reduce excessive slab deflection and remove water to prevent the recurrence of pumping. Like other CPR procedures, it is essential to address the cause of the voids and distress.

An agency can limit the entry of surface water into the pavement by sealing open transverse and longitudinal joints. The pavement surface is just one of five entry points for water into a pavement and subgrade. However, surface water is typically the largest source and has the greatest impact on the pavement system.

Removing water from the structural section requires the installation of edge drains. Pavement sections built in a "bathtub" could benefit from edge drains to rapidly remove free moisture. However, sometimes adding edge drains may accelerate the loss of support if the pumping is severe. The agency should perform a drainage analysis to determine the benefit of drain installation. Where drains exist along the pavement, the contractor must avoid filling the drains with stabilization material (1,2).

Improving ride quality and structural integrity through patching, full-depth replacement, spall repairs, and diamond grinding will reduce impact loads and slab deflection (2,3). In a complete CPR project, the agency should sequence stabilization work after full-depth repair, but before partial-depth repair. It may be advantageous to stabilize several areas requiring full-depth repair for evaluation at the start of construction. Removing and examining these test slabs will indicate stabilization effectiveness.

Some contractors suggest a minimum length of 3 km (2 mi) of pavement be made available for stabilization at one time to accommodate the various operations and to achieve the greatest efficiency from labor and equipment (4).

Retrofitting dowel bars in transverse joints and adding tied concrete shoulders can also reduce slab deflection under load. An agency should consider these options along with slab stabilization wherever the existing load transfer is poor (less than 50%). Retrofitting dowel bars may cut free corner deflection and stress in half.

Void Detection

It is best to perform slab stabilization as soon as any loss of support is evident at slab corners. Voids generally develop under the leave slab corner of mainline traffic lanes, but also can exist under the shoulders (2). To stabilize concrete slabs effectively requires an effective method for locating voids. Available techniques include: visual inspection, deflection measurement, and ground penetrating radar.

Visual Inspection

Visual inspection is the simplest manner to attempt finding voids. Transverse joint faulting and the presence of fines at or near joints and cracks on the traffic lane or shoulder are good indications of pumping and voids. Other signs that a void exists are corner breaks and shoulder drop-off. Depressions or holes at the edge of the shoulder and deposits of base/subgrade material along the shoulder edge also may indicate a void exists.

Visual inspection has several deficiencies that limit its effectiveness. It provides only marginal accuracy in determining void presence. It is also difficult to estimate the size of a void and quantity of stabilization material necessary to fill a void completely. It is also not possible to determine visually how well the stabilization filled a void and how much the support improved after stabilization. As a result of these deficiencies some agencies require the contractor to stabilize all joints and working cracks along a project. This is poor practice because it often leads to pumping grout into areas without voids. The results are serious problems such as slab lift, broken slabs, excessive material usage, and generally poor performance (5).

Pumping of fines on a rural highway. (Light areas near the transverse joints are the pumped fines.)

Deflection Testing

Another common procedure to locate voids is to measure vertical movement at joints or cracks from static or dynamic loads. Excessive deflections indicate low support and probable voids. However, movement also may be a sign of a weak subbase or subgrade. It is optimal to perform deflection testing between the hours of midnight and 10:00 a.m. when daily temperatures are relatively cool (6). At cooler temperatures joints are generally open and load deflections are at their highest. Deflections may not indicate a void during hot temperatures when slab expansion and aggregate interlock is maximum.

Figure 2 Static load deflection test using a Benkelman beam.

Static—The most common static test uses a loaded truck and deflection gauges. The gauge must be capable of measuring movement to 0.025 mm (0.001 in). Figure 2 shows a static test using a Benkelman beam. However, any device that provides the necessary accuracy is acceptable for static testing. The test technicians take one test at each joint by placing the measuring instrument across the joint, so one gauge rests on the slab corner near the shoulder edge. When using a Benkelman beam, technicians should angle the device at 45° to the pavement edge. After zeroing the gauges, a technician directs a truck driver to position a loaded truck so that the center of the loaded axle is about 300 mm (12 in) behind the joint and about 300 mm (12 in) from the pavement edge. The axle should weigh 80 kN (18,000 lb). After the technician reads both gauges, the truck driver moves the truck to a similar position about 300 mm (12 in) past the joint. Most specifications consider a deflection greater than 0.5 to 0.6 mm (0.02 to 0.025 in) excessive. However, the deflection limit can vary based on subgrade type (6,7).

Dynamic—Falling-Weight Deflectometer, Dynaflect, Road Rater, and Heavy Load Deflectometer devices measure the deflection response of a pavement to a dynamic load (4,7). The trailer-mounted devices either drop falling weights or oscillate loads on the pavement. Seismic deflection transducers mounted on the trailer measure the deflections and transmit the information for storage on computer. The advantage of these devices are that they (4,5):

1. Apply a reasonably heavy range of loads,
2. Measure the deflection directly beneath the center of the load,
3. Measure the deflection basin as far as 915 to 1830 mm (36 to 72 in) from the center of load plate, and
4. Measure slab deflections across joints and cracks simultaneously.

Reference 6 describes two void detection procedures using deflection equipment. The first method is a rapid and simple field method that indicates void presence. The second method is a more thorough approach that gives void location and size. This publication describes only the simple method — for more information on the detailed approach see reference 6.

The rapid void detection procedure locates voids beneath the slab corners. Since the procedure does not take into account available load transfer, determining exact void size is impossible. The procedure entails three steps:

Step 1: Measure corner deflections. Place the loading device close to the slab corner with a deflection sensor on both sides of the joint or crack, and then load the pavement at three different load levels. The loads should include 40.0 kN (9,000 lb), such as 26.6, 40.0 and 53.3 kN (6,000, 9,000 and 12,000 lb). To avoid problems caused by temperature differential (slab curl) and slab expansions (joint closure), measure pavement deflections while the temperature is from 10 to 21°C (50 to 70°F) or between midnight and 10:00 a.m.

Dynamic Load Deflection Devices: (Top) Falling Weight Deflectometer (Bottom) Dynaflect.

Step 2: Plot Results. Plot the measured results directly on the load-versus-deflection graph as shown in Figure 3. Draw the best-fit straight line through all three points and compare this line with the line formed by the simple connection of the three points. Marked differences between these lines indicate possible void locations.

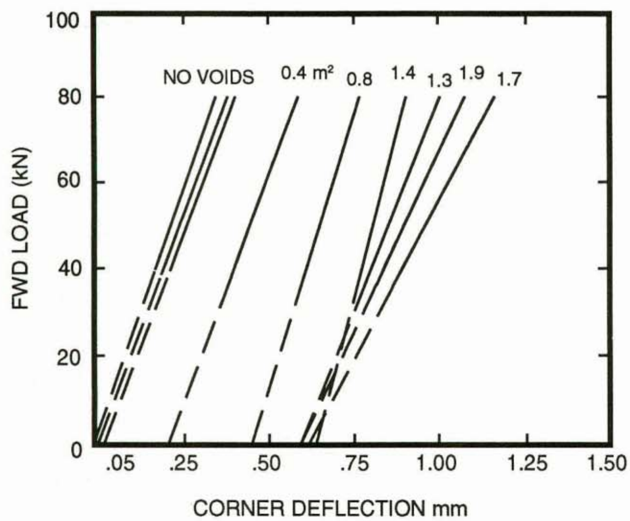


Figure 3 *FWD load versus corner deflection (void sizes obtained from the comprehensive method).*

Step 3: Locate Voids. If the best-fit line is satisfactory, extend the line to the horizontal (deflection) axles and note the intercept value. Locations with full support (no voids) generally have intercept values along the horizontal axis of less than 0.05 mm (0.002 in). Intercept values less than zero also indicate full support. Intercept values more than 0.05 mm (0.002 in) indicate voids under the joint. As void size increases the intercept value also increases.

This procedure is appropriate for measuring void presence both before and after stabilization. It provides information on the number of joints that require subsealing and the effectiveness of the subsealing operation. Figure 4 shows an example plot of load deflections from a selected joint on Interstate 77 in Ohio. Note that the leave-side response shifted after subsealing to indicate satisfactory stabilization (5).

Ground Penetrating Radar

A void estimation technique that is gaining popularity uses ground penetrating radar (GPR) and pulsed

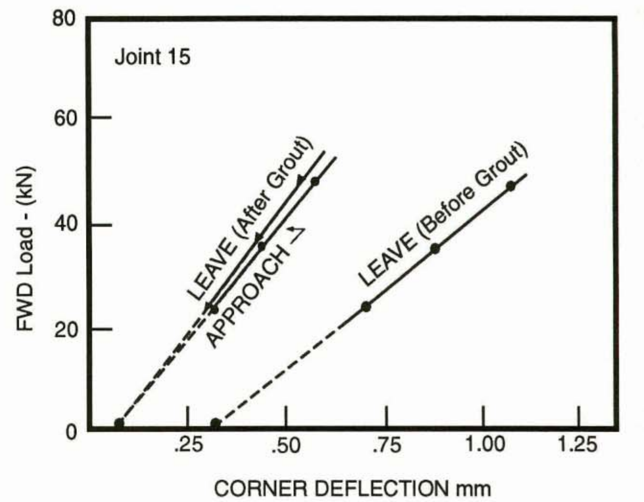


Figure 4 *FWD load versus corner deflection before and after stabilization (I-77, Ohio).*

electromagnetic wave (PEW) technology. GPR and PEW work by directing a short pulse of electromagnetic wave into the pavement, then abruptly ceasing the transmission for a short interval during which a transmitter-receiver detects the signals reflected back from the pavement. Changes in the characteristic reflection pattern indicate the presence of a void.

Figure 5 shows a schematic of the principle of radar detection. At each interface boundary (air-concrete, slab-subbase, and subbase-subgrade), a portion of the electromagnetic energy reflects back to the transducer, while the remaining energy propagates through the pavement until it strikes another boundary. The portion not reflected at this interface penetrates through that layer and repeats the

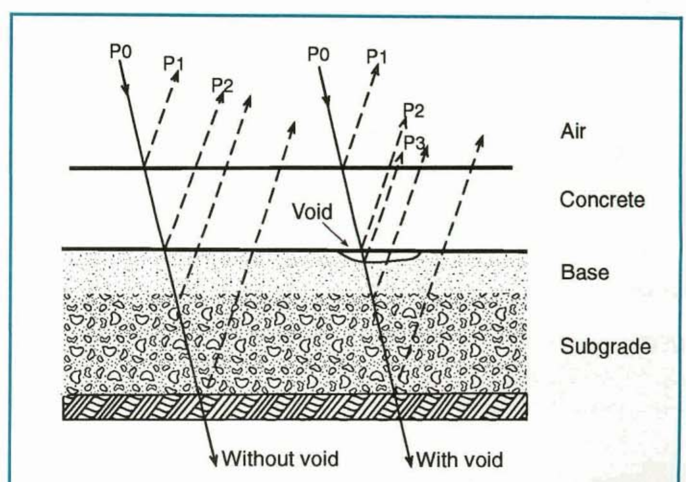


Figure 5 *Propagation of electromagnetic waves through a concrete pavement with and without a void under the slab.*

reflection-and-penetration process until the original energy completely dissipates. The maximum penetration depends on the moisture content of the materials below the concrete slab.

When there is a void below the concrete slab, there are two interfaces that reflect the wave back to the device. The concrete-void and void-subbase boundaries replace the single concrete-subbase boundary, which causes additional reflections and creates recognizable changes in the reflection pattern. The characteristic reflection pattern of most deep voids is easily recognizable in the reflection profile (Figure 6).

Measurement speed is the main advantage of GPR and PEW. During a survey, the radar unit repeatedly transmits electromagnetic pulses through the pavement creating a stream of radar reflection profiles. The radar equipment mounts on a vehicle and can function while the vehicle moves at 8 to 32 km/h (5 to 20 mi/h). Even at slow speeds the degree of public traffic interference is minimal.

One drawback of this technique is that it is only marginally effective in spotting shallow voids. Preliminary tests found it to be quite accurate for detecting voids deeper than 3 mm (0.125 in). However, the magnitude of reflections for a very shallow or small void may be undetectable by the radar unit. In some cases a user may also misinterpret the reading of a shallow void. On occasion excessive moisture below the slab can disrupt the radar signal and give false readings. Most highway personnel recognize the potential of GPR, but feel that it will not be fully practical in void detection for slab stabilization until manufacturers improve overall accuracy (8,9).

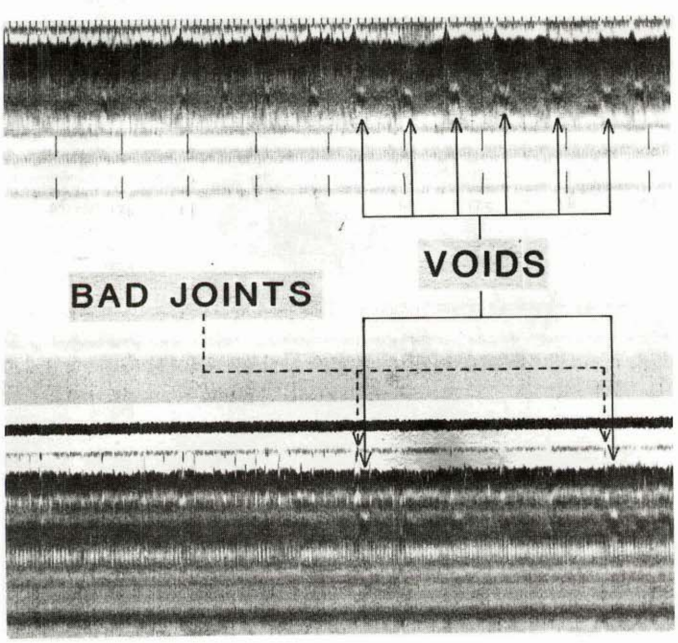


Figure 6 *Microwave reflection profile from a GPR test section (I-81, Virginia).*

Epoxy/Core Test

The epoxy/core test is a new procedure that can confirm void presence found by some other visual or mechanical method. It is not practical to use the test to locate voids. The test consists of drilling a 25- to 50-mm (1- to 2-in) hole through the pavement and into the subbase with dry-bit rotohammer. The technicians then pour a two-part epoxy into the hole. The epoxy is dyed with red food coloring for visual clarity and should have a viscosity like pancake syrup, about 0.4 pascal seconds (4 poise). As the epoxy percolates down into the subbase/subgrade it penetrates any voids that might be present. Along with filling the void, the epoxy bonds to the underside of the pavement. Once the epoxy has hardened, the technicians drill a core through the drill hole and epoxy. If a void is present, the epoxy will stick to the core and provide physical evidence of the void as well as a measurement of its thickness (10).

Materials

It is possible to use many different stabilization materials, but pozzolan-cement grout and polyurethane are the most common (11). Contractors and agencies have tried many other materials, such as Portland cement, asphalt cement, limestone dust with cement, and sand with cement. Figure 7 shows the various areas that are using or have tried these various stabilization materials.

The principle requirements for slab stabilization materials are strength and the ability to flow into or expand to fill small voids. A good stabilization material should have adequate strength to support a slab and remain insoluble, incompressible, and nonerodible after installation and hardening. It should have low internal friction so that it is fluid enough to flow into very small voids and water channels (7). If the material is too stiff, it will create a "seat" below the grout hole and will not fill the entire void. If the viscosity is too low, the grout may not develop enough strength to support the slab and may have a

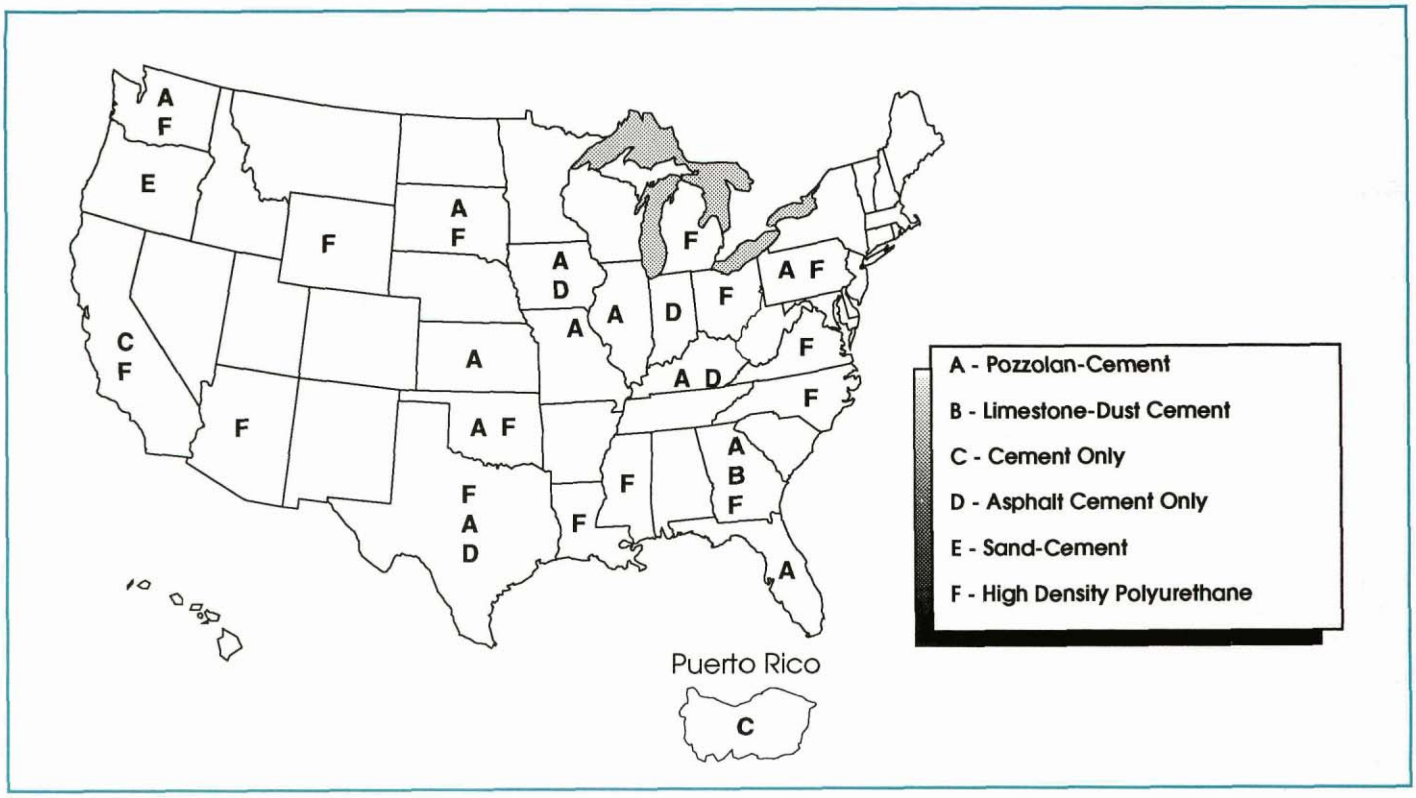


Figure 7 Typical stabilization materials used throughout the United States.

large degree of drying shrinkage (12). At the proper consistency the grout should have sufficient body to displace free water from under the slab.

Pozzolan-Cement Grouts

Most agencies and contractors use pozzolan-cement grouts. These materials are readily available within a reasonable distance of most projects, and are usually inexpensive. The fineness and spherical shape of pozzolans cause a ball-bearing effect that enhances the flow properties and allows the grout to fill very thin voids. Although most pozzolan particles are extremely small silt-like particles, some pozzolan particles are larger. These larger particles provide sufficient grading to reduce segregation during grout pumping and injection (2). Finally, the hydration of cement produces lime, which reacts with the pozzolans. This additional hydration enhances grout strength, stability and effectiveness.

Available pozzolanic materials include natural pozzolans (volcanic ash and diatomaceous earth) and artificial pozzolan (fly ash), a waste material from the combustion of coal. There are two types of fly ashes, Type C and Type F, classified under the following standards: ASTM C 618, and CAN/CSA A23.5-M86 (15,16). For slab stabilization, natural pozzolans and both Type C and Type F fly ash will produce a high-strength, durable mix when combined with Portland cement.

A typical cement-pozzolan mix uses one part cement to three parts pozzolan. The cement may be either Type I, Type II, or Type III. For each mix, technicians determine the quantity of water necessary to meet flow cone requirements, which typically is about 1.5 to 3.0 parts by weight (1). However, before employing the grout the contractor or agency must ensure that each cement-pozzolan grout passes all the physical and chemical tests (2).

Less cement may be necessary in mixes containing certain Type C fly ashes from the western United States that have sufficient reactivity to enhance hydration. Therefore contractors and agencies can elect to reduce the cement content without sacrificing strength. However, highly reactive fly ash can also undergo an early or flash set. If this occurs, it is advisable to add more cement to retard the set of the grout mix. As a result of this volatility, it is important to test all grout mixes thoroughly.

Specifications for a pozzolan-cement grout typically suggest a 7-day compressive strength of 4.1 to 5.5 MPa (600 to 800 psi) and a flow-cone test time of 10 to 16 seconds (11).

Flow Cone Test

To evaluate grout fluidity and determine water content, engineers use the flow cone test (Figure 8). The test measures the time necessary for a known quantity of grout to completely flow out of and empty the cone. For pozzolan-cement grout, an efflux time in the range of 10 to 16 seconds gives the optimal viscosity and strength. Limestone dust grout requires about 16 to 22 seconds (7).

Engineers also use the flow cone during mix design to determine an adequate quantity of water. However, the quantity of water for grout fluidity far exceeds the quantity needed for hydration. For quality control, the specifications should require that the contractor check the grout consistency twice each day using the flow cone (4). The following standards cover the flow cone test method: American Society of Testing Materials (ASTM) C 939, Canadian Standards Association Standard (CAN/CSA) A23.2-1B (13,14).

Polyurethane

In 1979, a Finnish company introduced a new polyurethane material for slab stabilization. The polyurethane is made from two liquid chemicals that combine under heat to form a strong, light-weight, foam-like substance. When injected under the pavement, the chemical reaction between the two materials causes the polyurethane to expand and fill the voids. For slab stabilization purposes the polyurethane density is about 64 kg/m^3 (4 lb/ft^3) and the compressive strength ranges from about 0.4 to 1.0 MPa (60 to 145 psi).

The main advantages of polyurethane grout are tensile strength and fast cure time. Typically the agency can allow traffic on to the stabilized pavement fifteen to thirty minutes after the repair. Good tensile strength also allows the polyurethane grout to withstand traffic vibration once it is under the pavement (17).

Other Grouts

Several agencies have also had success specifying a grout made from combining limestone dust with

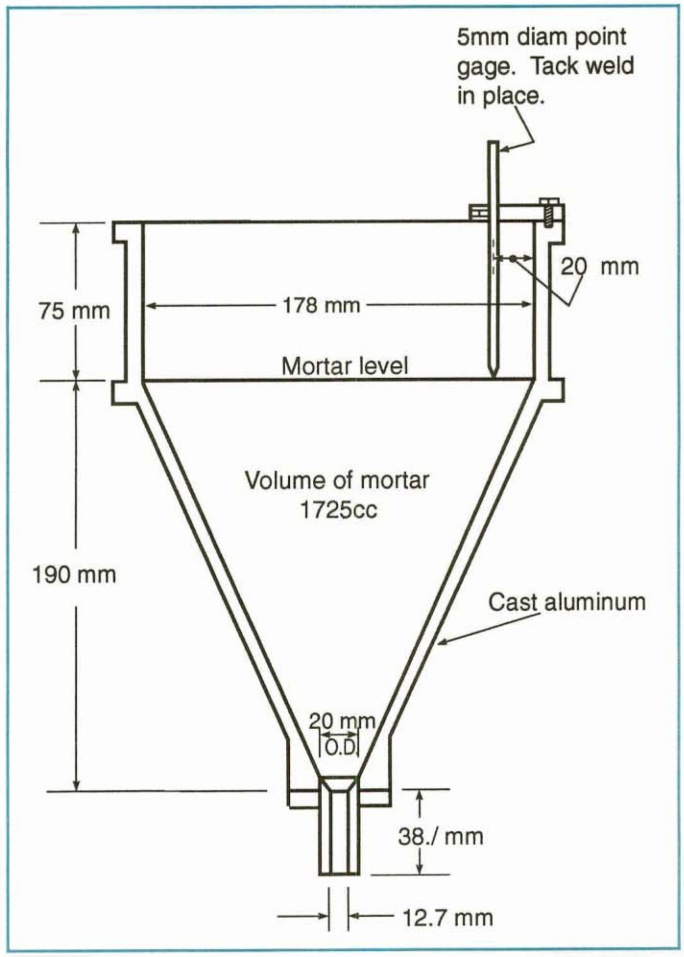


Figure 8 *(Top) Cross section of a flow cone. (Bottom) Grout discharge and timing check.*

cement. The grout usually consists of three to four parts of finely ground limestone mixed with one part Portland cement. The ground limestone should pass the 425 μm sieve (#40 sieve) and 20 to 60% should pass the 75 μm sieve (#200 sieve). The mix design requires adding enough water to give a flow-cone test time of 16 to 22 seconds. Sometimes the agencies specify adding a wetting agent to reduce the surface tension and increase the grout fluidity (7). Specifications for grout with limestone dust should emphasize that the limestone dust particles be round or spherical crystalline structure. Flat and other non-spherical grain structures do not flow well and tend to solidify in the pump hopper during grouting operations (2).

Portland cement-water grout has been a successful stabilizing material in many areas. Some contractors use it for very shallow and small voids and where post-testing indicates further stabilization is necessary. Typical cement-water grouts have water-cement ratios of 1.0 to 6.0 (7).

Slab stabilization using sand-cement has not been satisfactory. Sand-cement grouts infiltrate the joints during cold weather and can induce blowups. They are also usually viscous and do not flow well to completely fill voids.

Additives

Agencies and contractors should avoid specifying additive use in stabilization grout whenever possible. Preferably the agency should allow the contractor to choose additives if they are necessary for the mix. Certain combinations of fly ash and cement may require additives or admixtures to achieve necessary mix properties. It is important to test the mix because additives often produce unpredictable results in grouts with a large quantity of pozzolan. Laboratory tests have shown widely varying reactions from combinations of one specific additive and pozzolans from different sources. Similar variation results when combining one specific pozzolan with different manufacturer's additives. Whenever a contractor uses additives, the agency should request that the contractor provide documentation of test results for the mix.

Additives that some contractors and agencies use include: calcium chloride accelerators, set retarders, water reducers, powdered alumina, friction reducers, and wetting and dispersing agents. Accelerators, such as calcium chloride, reduce grout set time and allow the contractor to open the pavement to traffic faster than normal. Retarders increase grout set time and the workability time of fast-reacting cementitious materials. Powdered alumina induces grout expansion to offset drying shrinkage. Friction reducers or pumping aids improve flow through pump hoses, increase flow into voids, and ease equipment cleaning. Wetting and dispersing agents can improve mixture uniformity; and water reducing agents can lower the necessary water content and increase strength.

Verification & Testing

Specifications for stabilizing grout should require the contractor to submit certifications of the materials including information from mill tests for the cement, chemical and physical analysis for the pozzolans, and grain structure analysis for the limestone dust. This is particularly important because of the inherent variability of fly ash and other pozzolans. The specifications should also require independent tests of the 1-, 3-, and 7-day compressive strengths, flow cone times, initial set time, water retention and shrinkage, and expansion characteristics of the mix (2,4,7).

Determining initial set time of the grout in laboratory tests is useful when comparing various mixes. The following penetration resistance tests provide adequate but somewhat conservative results: ASTM C 406, CSA/CAN A23.2-26C (18,19).

Typical set times under penetration tests are about 1.5 to 2 hours for a typical pozzolan-cement grout. However, none of these tests considers that the grout loses fluidity about 20 to 30 minutes after injection during normal temperatures, or that the grout is virtually always in total confinement under a slab. After injection is complete, the combination of confinement and draining of excess water from the grout helps increase the in-place strength (20). These factors reduce actual grout set times and allow the stabilized slab to support substantial loads in less time than the tests indicate. In fact, laboratory and field analysis found no evidence of pumping or displacement of 1-hour-old grout upon opening to traffic (2,21).

For typical pozzolan-cement grout, the ultimate strength generally ranges from 10 to 27 MPa (1,500 to 4,000 psi) (1). Most specifications include a minimum strength requirement to ensure grout durability. A typical minimum strength requirement is 4.1 MPa (600 psi) at 7 days using ASTM C 109 or CSA/CAN A5-M88 (22,23). The California Department of Transportation found that a grout needs a minimum compressive strength of 5.2 MPa (750 psi) at 7 days to withstand erosion due to hydraulic activity under a heavily trafficked pavement (3,6,24).

Equipment

Most stabilization contractors use very mobile, self-contained, modern equipment that carries all the tools and materials needed for slab stabilization. The dry materials come either in uniform-volume bags or by bulk weight quantities (4). As stabilization procedures become more sophisticated, more contractors are using automated bulk transport and metering plants for materials. These systems can reduce both labor and materials costs by as much as 30 to 50% (20). In the past, many contractors used labor-intensive, small batch mixers with bagged materials exclusively.

Mixing

Colloidal mixing equipment provides the most thorough mixing for pozzolan-cement grouts. A grout mixed in a colloidal mixer will remain in suspension and resist dilution by free water. The two most common types of colloidal mixers are the centrifugal pump and the shear blade. The centrifugal pump pulls the grout through a mixing chamber at high pressure and high velocity. On a shear-blade mixer, the blades rotate at 800 to 2,000 revolutions per minute. Both mixing systems remove air from between the small particles and enable the mix water to contact the particles and develop a homogeneous mixture (20).

Automated bulk transport and metering plant.

Whenever possible, contractors should avoid using paddle-type drum mixers for cement-pozzolan grouts. Thorough mixing is difficult with this equipment because it is hard to wet the cement and fly ash particles thoroughly through low agitation. To obtain a grout with the same fluidity requires more water in paddle-type mixing than colloidal mixing. However, thorough mixing of limestone dust grouts is possible with paddle-type mixers (6).

Contractors should not mix any type of stabilization grout with a conveyor, with a mortar mixer, or in a ready-mix truck. These mixers require adding too much water for fluidity and the solids tend to agglomerate and clump in the mix. The partially wet clumps of grout can plug voids near the injection hole and prevent good lateral grout penetration to fill the voids (20).

Pumps

The contractor should place the grout using either a positive-displacement injection pump, or a non-pulsing progressive-cavity pump. Piston pumps do not work well. The pulsating piston causes pressure surges that prematurely squeeze water out of the grout (1).

High pumping pressures drive off excess water and thicken the grout, which reduces the grout's ability to penetrate and fill voids. When a contractor begins filling a shallow void less than 1.5 mm (1/16 in) thick, a high pumping rate can cause an immediate pressure rise and thicken the grout by forcing out water (20).

It is important that the injection or progressive cavity pump is capable of beginning and maintaining low pumping rates and injection pressures. A desirable pumping rate is about 5.5 liters per minute (1.5 gallons per minute). The pump should work well maintaining pressures between 0.15 and 1.4 MPa (25 and 200 psi) during grout injection. These pumping ranges ensure better placement control and lateral coverage, and usually keep the slab from rising (6).

Drills

Any hand-held or mechanical drill that produces a clean hole with no surface spalling or breakouts on the underside of the slab is acceptable. Pneumatic and hydraulic rotary percussion drills with carbide or diamond tips are common for drilling grout injection holes (20). Some agencies are also trying high-speed coring equipment. This method may cost more, but can eliminate breakouts.

For productivity some contractors put high-speed rock drills on large rubber-tire tractors. It may be necessary to add ballast weight to the tractor frames to increase the drill pressure. The New York Department of Transportation found satisfactory results using rock drills less than 20 kg (45 lb). Heavier drills may result in conical spalling or break through by the drill near the bottom of the slab.

High-speed drilling equipment mounted to a tractor.

The downward pressure of any drill, whether hand-held or mechanical, should be less than 90 kg (200 lb) to avoid conical spalling and break through of the slab. Conical spalling can seriously weaken the slab and may result in radial and transverse cracking through the drill hole (25). The spalled material can seal off the entrance to the void and become an obstacle to the grout during injection (2,20). Where this occurs it is usually impossible to fill the void.

The agency should allow the contractor to select a hole size within an appropriate range so the contractor can best utilize his existing equipment (4). An appropriate drill hole diameter is 30 to 50 mm (1.25 to 2.0 in) for pumping pozzolan-cement grouts. Larger diameter drill bits more easily break through the slab bottom, and smaller drills do not make a hole efficient for pozzolan-cement grout injection. For polyurethane stabilization, hand-held electric-pneumatic rock drills are typical for drilling the injection holes. The maximum hole diameter should not exceed 15 mm (5/8 in) for the polyurethane injection.

Injection Devices

To prevent grout extrusion or backup during injection, the injection equipment must include a grout packer that is capable of sealing the hole. There are two common grout packers, but any device that can hold the injection nozzle in place and adequately seal the hole is acceptable. Drive packers are pipes that taper and fit snugly into the injection hole by tapping with a small hammer. Contractors primarily use drive packers for hole diameters about 25 mm (1.0 in). For larger holes, contractors use some type of expandable packer, such as an expanding rubber packer. Expanding-rubber packers consist of a pipe with a short rubber sleeve near the nozzle that expands to fill the hole during injection (20). When available, expanding-rubber packers are preferable to drive packers for holding the injection pipe and discharge nozzle tightly in place. Drive packers do not provide as tight a fit and can allow some grout to extrude during injection.

The diameter of the hoses that transport the grout from the pump to the grout packer should be 20 to 40 mm (0.75 to 1.5 in). Hoses within this size range induce adequate grout velocity and less tendency for the grout to separate.

Grout packer.

The injection equipment should also include either a return hose from the grout packer to the grout tank, or a fast-control reverse switch to stop grout injection quickly when workers detect slab movement on the uplift gauge. Quick response is necessary to minimize slab movement and provide better control of the injection pressure. The use of a grout-circulation return system also helps eliminate the problem of grout setting in the injection hoses because the grout circulates back to the pump after pumping ceases (2).

Urethane grouting operations use slightly different injection equipment. Instead of large grout packers, the operator inserts plastic nozzles into the holes. The nozzles screw onto the injection hose (17).

Uplift Beams

Contractors use uplift beams to monitor slab deflection. The uplift beam must have sensitive dial gauges capable of detecting movements of 0.025 mm (0.001 in) (6,7). Some contractors also use laser levels to monitor uplift.

The injection crew monitors an uplift beam to detect upward movement of the slab during stabilization (Figure 9). Excessive slab lift is undesirable, but some slab lift may be necessary to ensure proper spread of the grouting material. Most stabilization specifications limit slab lift to less than 1 to 2 mm (0.05 to 0.10 in). Excessive lift can create voids under the pavement and develop uneven support.

Positioning the uplift beam is important to ensure that deflection readings are accurate. The contractor should place the monitoring gauge near the point of injection and place the support end somewhere off the slab. The support end should be far enough away from the injection area that it does not rise with slab movement. Any upward movement of the support end would decrease the accuracy and dependability of the deflection monitoring setup.

Installation

Installation requires three steps after void detection. In order, these steps are:

- Locating and drilling holes,
- Grout injection, and
- Post-testing the stabilized slabs.

Locating & Drilling Holes

The contractor must drill several holes through the concrete surface to reach the void. The contractor can use information from the void detection process to determine hole location. The hole depth will depend on the type and thickness of subbase beneath the concrete. Usually, the contractor will establish a typical pattern for the project.

The objective of hole location is to ensure that the hole enters the void near the boundary farthest from the nearby joint or crack. Voids are typically deepest

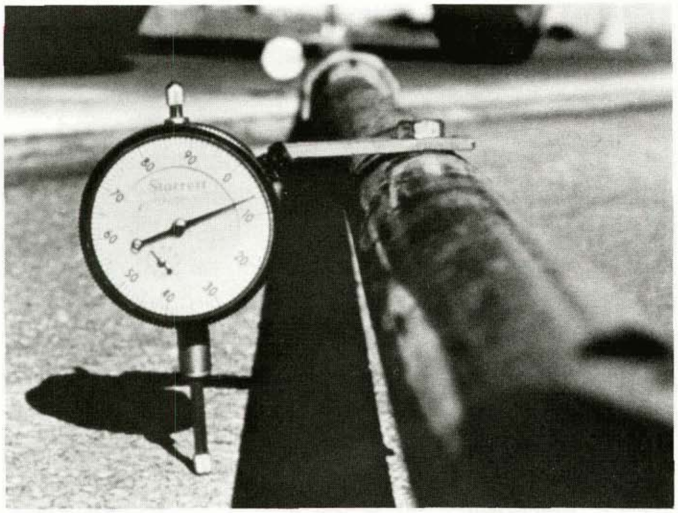


Figure 9 *Uplift beam being used to monitor movement in a stabilized slab.*

near the joint or crack corner and become more shallow toward inner slab locations. Once pumping begins the grout should flow mainly from the injection hole toward the joint or crack. The contractor should not drill holes beyond the void boundary or slab lift may occur during injection (20).

Hole patterns for slab stabilization vary depending on whether the pavement is plain jointed, jointed reinforced, or continuously reinforced. The optimal hole pattern and location also may depend on joint spacing, slab condition, and other noticeable slab distress (4,7). Usually, the preliminary deflection or radar testing will provide some assistance in selecting initial hole locations. For example, these tests can determine the approximate size of the void and whether it is on the leave or approach side of the joint (5,8).

Grout fluidity can also influence the optimum hole pattern. Typically the contractor wants the holes to be in close, so that grout flows from one hole to another or to the nearest joint. A contractor may elect to increase the spacing between holes if the grout flows easily between holes before sufficient back pressure occurs in the injection. If the grout does not flow easily, the contractor may elect to reduce the spacing.

Figure 10 shows some typical hole patterns for different pavement types and void conditions. A four-hole pattern is common in slab stabilization. Using the four-hole pattern, the contractor places two holes in each wheel path of the truck lane. One hole is on the approach side and one hole is on the leave side of a transverse joint or crack. The holes in the approach slab are approximately 300 to 460 mm (12 to 18 in) from the joint and the holes on the leave side are approximately 460 to 600 mm (18 to 24 in) from the joint. Any voids underneath the longitudinal lane or shoulder joints will require more injection holes. Usually one hole 460 mm (18 in) from the shoulder and 1.2 to 2.7 m (4 to 9 ft) from the transverse joint or crack is adequate.

Concrete pavements built on asphalt- or cement-stabilized subbase materials, require the contractor to drill the holes through the stabilized base and into the subgrade. The drill hole should not extend more than about 75 mm (3 in) beneath the subbase. Experience has shown that voids will develop beneath a stabilized subbase. For pavements on granular subbases drilling should cease when the bit reaches through the slab and just into the base. In either case, the drill operator must watch the drill down pressure to avoid conical spalling and break through

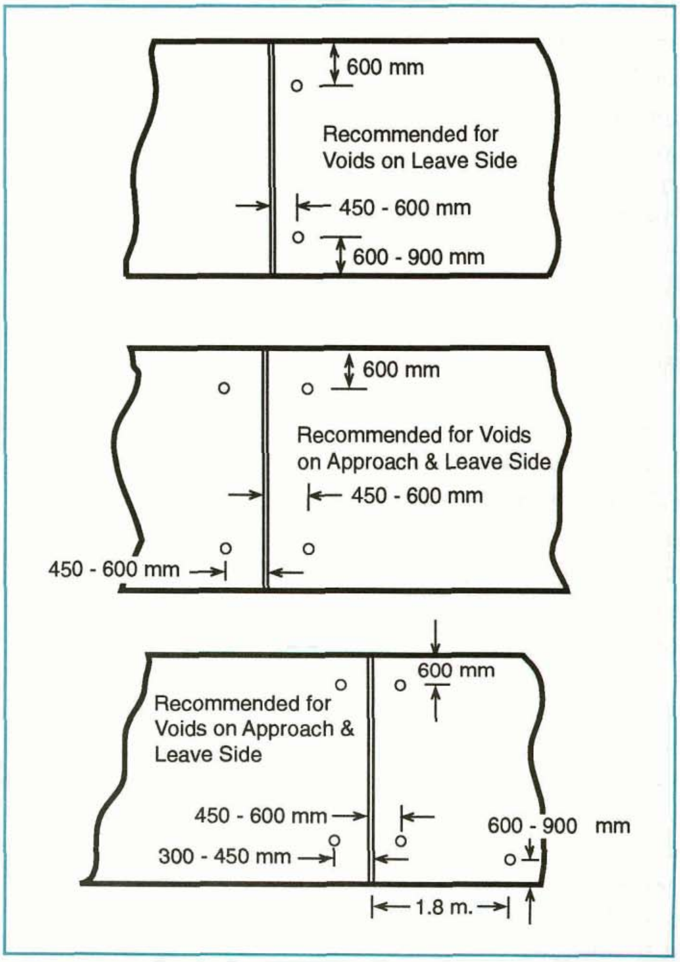


Figure 10 *Typical hole patterns used for slab stabilization.*

of the drill bits. Some cutting residue from the drills can seal off a thin void and prevent grout penetration. To clear the blockage it may be necessary to pump a small quantity of water or air into the hole to create a cavity that will allow grout to flow into the void (2,4,7,20).

Each project is unique and some experimentation is necessary when beginning a project. For this reason, contract specifications should have some flexibility to allow a contractor to change the hole pattern for changing project conditions. A contractor can then monitor the grouting operation and make adjustments in hole locations to improve stabilization (2,20).

Grout Injection

In most cases, grout injection should start at the centerline holes in each slab and work toward holes near the shoulders. This injection pattern will drive away water from under the slab and move it toward the outside edge where it can escape through transverse and shoulder joints. The crew should wait until after pumping the standard holes before pumping additional holes that are for voids beneath longitudinal shoulder joints and other areas. When pumping through holes near the edge of the pavement, the contractor must use care to avoid raising the shoulder (4). Stabilization material can fill voids beneath the shoulders, but because shoulders are thinner than the mainline slabs they are easier to lift.

On occasion a transverse joint will be open wider than a longitudinal joint. In these situations, it may be desirable to begin injection through holes near the shoulder joint and drive the excess water out of through a transverse joint. The contractor's supervisor must be capable of making this decision in the field during the grout injection operation (1,20).

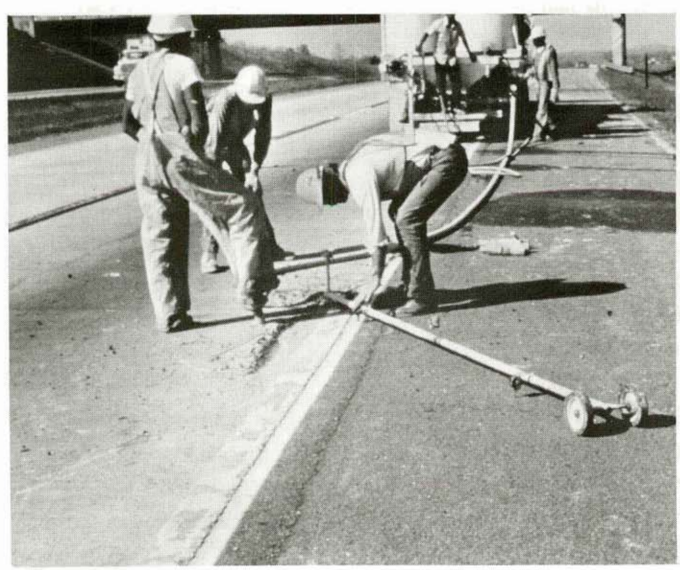
The grout injection should start at a low pumping rate and pressure. Grout injection pressure is usually in the range of 0.3 to 0.5 MPa (40 to 75 psi) with a maximum recommended pressure of 0.7 MPa (100 psi) (1,7,21). Initially, a short pressure surge may be necessary to clear debris from the grout hole and to prompt the grout to penetrate the void (2,6). The initial surge can be as high as 1.4 to 2.1 MPa (200 to 300 psi) for 2 to 3 seconds. If the pressure does not drop after three seconds, there is likely some other problem, such as a hole blockage or poor hole placement.

The crew should cease pumping when the any of the following conditions occur: the slab begins to rise, the grout no longer pumps at the maximum allowable pressure, or the grout begins to flow up through an adjacent hole. When the grout is displacing water from beneath the slab, the crew should observe the water as it flows out through the adjacent joints or cracks and continue pumping until they observe an undiluted mixture of grout flowing from the same area. Some contractors also use relief holes to help determine when to cease pumping.

In no case should injection continue if after 1 minute there is no evidence of grout in any adjacent hole, joint or crack, and the uplift gauge has not registered any slab movement. This condition indicates that the grout is flowing into a large washout or cavity that will require correction by another repair procedure (2).

During grouting, the discharge end of the grout packer pipe should not extend below the bottom of the pavement. This will fill any voids that exist between the pavement and the base (2,6).

Traditionally after completing injection, the contractor removes the grout packer and places a tapered wooden plug into the hole (26). The plug prevents pressure from quickly dissipating and keeps the



Grout injection operation on a rural interstate.

grout from backing up. The crew removes the wooden plugs only after they complete injection at all nearby voids and sufficient time passes for the grout to set.

There are some indications that plugging injection holes may not be necessary and can be detrimental. Because the intent of slab stabilization is to fill voids without raising the slab, it is not necessary to maintain pressure beneath the slab. By omitting the wooden plugs, any excess grout can flow out of the holes as the slab settles. Excessive grout extrusion onto the slab surface usually occurs only at the beginning of a project or if there is excessive slab lift. The crew should have no problem with backflow of the grout after injecting several areas on a project.

During the void detection procedure, it is not always necessary to determine the exact void size or amount of stabilization material necessary. Typical material differences between "high grout jobs" and "low grout jobs" are usually not more than 20%.

If 80 to 90% of the slabs require stabilizing on a project, blanket coverage may seem feasible. Unfortunately, experience shows that forcing grout beneath slabs that do not have voids will likely result in unstable support, high corner load deflections, and eventually slab cracking. Therefore, the contractor must be cautious on projects with blanket stabilization and ensure that the crew follows injection pressure guidelines. Proper injection techniques should dictate that slabs that do not have voids will not accept grout (28).

Environmental Conditions

The contractor should stop pozzolan-cement stabilization activities when the ambient air temperature drops below 4°C (40°F) or if the subgrade freezes (4). Stabilizing during the cold weather may result in the stabilization material infiltrating the crack under the joint. This can cause spalling and blowups the following spring and summer when the slabs warm up and expand.

There are no quantity differences between stabilization done during the day or stabilization done at night. Some engineers theorize that quantities should vary due to the effects of temperature curling. Another theory proposes that the grout will prevent relaxation of the slab as the temperature differential dissipates in the morning after nighttime stabilization work. This is thought to increase slab stresses or cause faulting or stepping in the opposite direction. There is currently no evidence showing these effects (2).

When the ambient air temperature drops below about 10°C (50°F), the contractor should consider adding an accelerator to the grout mix. The accelerator will increase the strength-gain rate of the grout in the cool weather and help the contractor open the pavement to public traffic more quickly.

Post-testing

Twenty-four to forty-eight hours after stabilization, the agency or contractor should test the stabilized slabs using a deflection testing method. The post-testing will show the benefit from the stabilization operation. For comparison, the post-testing also should include some joints that the contractor did not stabilize. High deflections indicate that the first stabilization attempt did not restore support and the area will require a second attempt. After the second stabilization operation, the contractor should test again for support condition. For each stabilization operation at a particular area, the contractor should drill new holes. If high deflections still occur after three attempts, the agency and contractor should consider replacing or patching the slab.

A contractor or agency also may use GPR after stabilization to check the effectiveness of grouting. Figure 11 shows the reflection profile for a portion of a stabilized pavement and the GPR test results during the following season. The figure shows a sufficient difference between the dielectric properties of the grout and the base material and will enable detection of the grout. More important, the profile found that there are still voids in both antenna paths and that the area requires a second grouting operation (8).

Opening to Traffic

Deflection measurements taken after slab stabilization have shown that pozzolan-cement grout hardens in about 1 to 3 hours. Deflections reduce within the

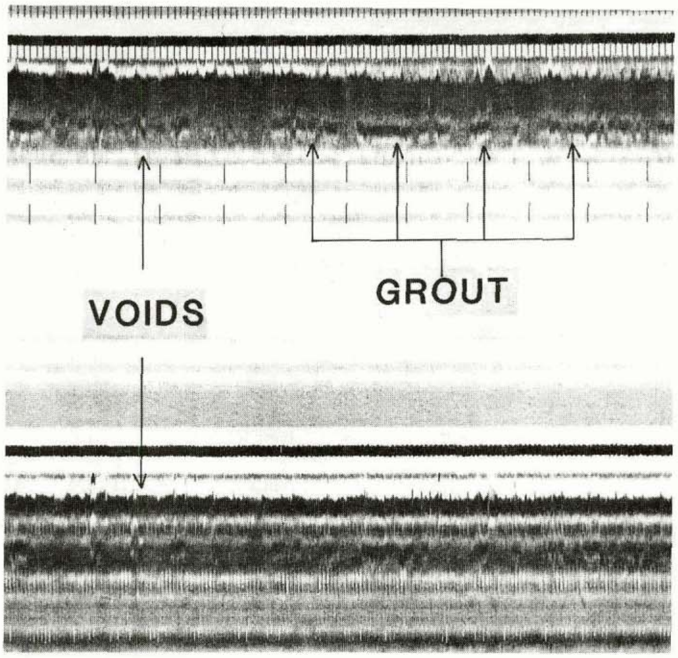


Figure 11 *Microwave reflection profile for a grouted test section showing grouts and voids (I-81, Virginia).*

same period. However, grout hardening depends on the temperature, degree of confinement, and material properties. In cold weather, accelerators can decrease the set time of pozzolan-cement grout (7). For urethane grout the set time is only about 15 to 30 minutes (17).

It may be possible to monitor deflections and determine the set time requirements for each job (2). Typical specifications recommend set times from 30 minutes to 3 hours depending on the mix composition and the degree of confinement of the grout (4). In many cases, traffic can begin to use the pavement within 1 hour after stabilization. There has been no case where grout pumping or displacement occurs after traffic opening.

Preparing Plans & Specifications

In many ways, slab stabilization remains an art. The quality of a project depends on the skill and expertise of the contractor and the workers. The agency should require the contractor to furnish a number of references indicating the quality of stabilization projects. The consequences of using an inexperienced contractor may be poor quality work and large grout material overruns (26).

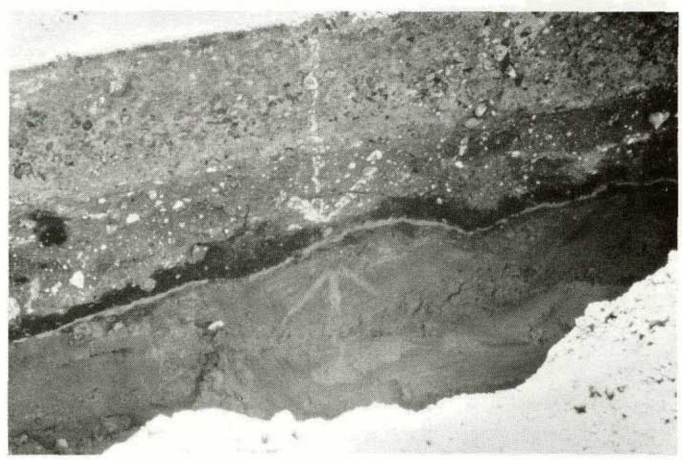
The most effective methods to estimate grout quantities are comprehensive void detection by deflection testing, results of GPR, and experience (5,8). A general estimate for grout necessary to stabilize each joint or crack is about 0.03 to 0.08 m^3 (1 to 3 ft^3). Any individual location may greatly overrun or fall short of this general estimate. Projects with extensive pumping may exceed this estimate (2).

Payment

Most agencies pay for pozzolan-cement stabilization on a unit cost of cubic meters (cubic feet) for dry bulk materials (cement, fly ash, limestone dust), along with mobilization and traffic control. The unit-cost item includes all preliminary testing, hole-drilling, labor, additives, etc (26). This approach can create a tendency for the contractor to inject too much grout at each location when the agency does not closely monitor field procedures. It is preferable that estimates for quantities be set up for number of holes drilled and volume of dry grout (2).

A little-used payment approach worthy of consideration is to pay for slab stabilization by the square meter (square yard). Although this procedure is not widespread, it does coincide with the objective of stabilizing slabs. However, it is possible that contractors will bid slightly high to cover uncertainty in the volume of grout necessary for a project (2).

Agencies pay for polyurethane stabilization on the basis liquid kilograms (pounds) for component materials. The contractor makes material consump-



Successfully grouted void. Note the thin layer of grouting material between the slab and subbase.

tion estimates from the number of holes or joints and cracks that require stabilizing. The contractor determines the average material necessary per hole or joint and crack from experience (17).

Summary

This publication presents guidelines necessary to specify and complete slab stabilization for concrete pavements. The publication also discusses new methods, materials, and equipment that are available to accomplish the process rapidly and efficiently. The following items are the keys to slab stabilization success:

1. Determining the optimal time to stabilize.
2. Accurately detecting voids.
3. Selecting acceptable stabilization materials.
4. Correctly estimating material quantities.
5. Using appropriate construction practices.

Slab stabilization can improve the results of a complete concrete pavement restoration project on slabs that have lost subbase or subgrade support. With proper materials there is no practical life expectancy of well-engineered stabilization materials (Table 1). Improving ride quality and structural integrity by using all restoration techniques will extend the life of existing concrete pavements.

Additional Information

For guide specifications or additional information regarding slab stabilization, contact the American Concrete Pavement Association. Technical publications are also available on all other CPR procedures.

Table 1. **Example Expected Life for Restoration Techniques.**

Restoration PCC	
• Diamond Grinding	10-15 years with concurrent restoration work
• Full-Depth Repair	10-15 years
• Partial-Depth Repair	10-15 years
• Slab Stabilization	no practical limit
• Load Transfer Restoration	8-10 years
• Edge Drains	no practical limit
• Joint Resealing	5-15 years
• Crack Sealing	10 years

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Other technical publications and audiovisual materials on concrete pavement restoration available from the American Concrete Pavement Association:

TITLE	**NUMBER**
Guidelines for Full-Depth Repair	TB002P
Guidelines for Partial-Depth Repair	TB003P
Diamond Grinding & CPR 2000	TB008P
Joint & Crack Sealing and Repair for Concrete Pavements	TB012P
Pavement Rehabilitation Strategy Selection	TB015P
Utility Cuts & Full-Depth Repairs in Concrete Streets	IS235P
The Ultimate Handbook (Binder of Technical Info.)	TB100P
Full-Depth Repair of Concrete Pavements (slide set)	SS502P
Partial-Depth Repair of Concrete Pavements (slide set)	SS503P
Diamond Grinding of Concrete Pavements (slide set)	SS508P
Resealing Concrete Pavement Joints (slide set)	SS512P

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