1. Most states have had the best performance from pavement in which only contraction joints are used. Skewed joints are being used successfully in many areas.
2. Joint size can be related to slab length and temperature range.
3. Slab lengths are progressively shortening because of the presence of midslab cracks in the longer slabs. Midslab cracks are usually not seen in slabs 6.4 m (21 ft) or less in length.
4. Although many different types of load-transfer devices have been tried, the standard dowel is still the most commonly used and is quite successful. Plastic-coated dowels have performed well in preventing dowel corrosion.
5. Treated subbases have been effective in reducing pavement curl and midslab cracking in longer slabs.
6. Although the effect of moisture is acknowledged, it is generally ignored in design. The design of slab length is based on temperature range.
7. Material properties have a marked effect on the service life of a pavement. Angular aggregates give better aggregate interlock. The tensile and shear strength of the aggregate and paste affect the amount of spalling in the pavement.

REFERENCES

1. Design, Construction, and Maintenance of PCC Pavement Joints. NCHRP, Synthesis of Highway Practice 19, 1973.
2. R. Sharp. European Concrete Road Standards and Practices. Proc., International Conference on Concrete Pavement Design, Purdue Univ., Lafayette, IN, 1977, pp. 73-96.
3. P. J. Nussbaum and E. C. Lokken. Design and Construction of Concrete Pavements. Proc., International Conference on Concrete Pavement Design, Purdue Univ., Lafayette, IN, 1977, pp. 19-72.
4. J. B. Thornton. Investigation into the Performance of Rigid Pavement Joints and Sealants. Proc., International Conference on Concrete Pavement Design, Purdue Univ., Lafayette, IN, 1977, pp. 435-446.
5. E. Tons. A Theoretical Approach to Design of a Road Joint Seal. HRB, Bull. 229, 1959, pp. 20-53.
6. Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices. NCHRP, Research Results Digest 35, 1972.
7. J. P. Cook and I. Minkarah. Development of an Improved Contraction Joint for Portland Cement Concrete Pavements. Ohio Department of Transportation, Columbus, Aug. 1973.
8. I. Minkarah and J. P. Cook. A Study of the Field Performance of an Experimental Portland Cement Concrete Pavement. Ohio Department of Transportation, Columbus, May 1975.
9. I. Minkarah and J. P. Cook. A Study of the Effect of the Environment on an Experimental Portland Cement Concrete Pavement. Ohio Department of Transportation, Columbus, Aug. 1976.
10. Joint-Related Distress in PCC Pavement: Cause, Prevention, and Rehabilitation. NCHRP, Synthesis of Highway Practice 56, 1979.
11. R. Springenschmid. Design Concepts of Concrete Pavements in Europe. Proc., International Conference on Concrete Pavement Design, Purdue Univ., Lafayette, IN, 1977, pp. 109-119.
12. F. O. Schuster. Die Raumfugen: Und Bewehrungslose Betondecke im Zuge der BAB-Neubaustrecke Darmstadt-Heidelberg—Planung, Bau, und Beton. Verlag GmbH., Dusseldorf, 1969.
13. J. E. Bryden and R. G. Phillips. Laboratory and Field Evaluation of Plastic-Coated Dowel Bars. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, Res. Rept. 22, 1974.
14. J. C. Dixon, W. J. Anderson, and J. T. Paxton. Investigation of Plastic-Coated Dowels in Ohio. Ohio Department of Transportation, Columbus, June 1970.
15. J. E. Bryden and R. G. Phillips. The Catskill-Cairo Experimental Rigid Pavement: A Five-Year Progress Report. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, Res. Rept. 17, 1973.
16. F. C. Lang. Temperature and Moisture Variations in Concrete Pavements. Proc., HRB, Vol. 21, 1941. pp. 260-271.
17. L. W. Teller and E. C. Sutherland. Observed Effects of Variations in Temperature and Moisture on the Size, Shape, and Stress Resistance of Concrete Pavement Slabs. Public Roads, Vol. 16, Nos. 8, 9, 10; Vol. 17, Nos. 7, 8; Vol. 12, No. 8; 1935-1942.
18. W. T. Burt, D. G. Azar, and J. C. Myers. Evaluation of Joint Sealant Materials: Interim Report No. 1. Research and Development Section, Louisiana Department of Highways, Baton Rouge, Res. Rept. 62, 1972.
19. H. Allen. Report on Committee on Warping of Concrete Pavement. Proc., HRB, Vol. 25, 1945, pp. 199-250.

Publication of this paper sponsored by Committee on Sealants and Fillers for Joints and Cracks.

Pavement Restoration Measures to Precede Joint Resealing

J. B. Thornton and Wouter Gulden

Various methods of rehabilitating jointed concrete pavement are discussed, based on the experience of the Georgia Department of Transportation. Special emphasis is given to techniques that may be required before joints are resealed. The measures discussed are stabilizing moving

slabs, spall patching, slab replacement, edge drains, and grinding. Joint sealing is briefly described, and the use of low-modulus silicone sealant in resealing joints is emphasized. There is a need for adequate condition surveys of existing pavements so that the rehabilitation needs of an individual project can be established. A condition survey is also useful in establishing priorities among projects and in determining deterioration rates and performance of rehabilitated pavements. Attention is given to rehabilitation strategies, since it is only rarely that any one treatment is successful. For each individual treatment to be effective, a combination of treatments is required, such as slab stabilization and joint resealing.

Many state transportation departments are faced with the need to rehabilitate older sections of the Interstate system. Increasing interest is being shown in rehabilitation methods and repair techniques for concrete pavements. At one time, it was thought that concrete roads would last for a long time without the need for any kind of maintenance. The effects of the combination of water and heavy loads on the pavement system were either unknown to or ignored by designers, and so little or no provision was made for drainage. Typical designs showed the concrete pavement surrounded by impervious materials. Either transverse joints were left unsealed, or the sealant used was inadequate for long-term performance. No attempt was generally made to seal longitudinal shoulder joints.

Studies done by such states as California and Georgia have shown that the entrance of free surface water through these joints and cracks, in combination with heavy loads and the presence of erodible materials, causes the types of pavement distress commonly found on heavily traveled jointed concrete pavements—e.g., faulting and slab cracking.

Much research has been done to improve joint-seal materials, joint-shape factors, and the design of base and pavement sections. Concrete pavement designs in Georgia now call for econocrete base, 6.1-m (20-ft) joint spacing, silicone sealants, dowel bars, and concrete shoulders. These improvements for newly designed pavements, however, did not address the deterioration of existing pavements. Yearly condition surveys showed jointed concrete pavements in Georgia to be deteriorating at an accelerated rate as a result of increasing volumes of truck traffic.

Increasing emphasis has been placed recently on restoration and rehabilitation techniques for jointed concrete pavements. Several major research studies in this area are currently planned or under way, such as NCHRP Project I-21, Repair of Joint-Related Distress in Portland Cement Concrete Pavements. This paper describes the Georgia experience with various methods of pavement restoration.

REHABILITATION CONCEPTS

Rehabilitation or restoration of concrete pavements can mean different things to different people. The restoration measures used in Georgia are undersealing, drainage, slab replacement, spall patching, joint sealing, and grinding. Overlays of concrete pavements, although a valid restoration method, are not considered to be within the scope of this paper and will not be discussed.

In pavement restoration, decisions must be made on when to rehabilitate and how much restoration is needed. It is important to conduct condition surveys to establish the relative amount of distress that is present in comparison with other projects. Condition surveys will also provide the basic data required to make the initial decisions on the type of treatment that is needed. Annual surveys will also establish the rate of deterioration of the pavement, which should be taken into consideration when restoration priorities are determined for various projects.

Many levels of restoration are available, ranging from sealing joints as a preventative measure to full restoration, which would include all six measures mentioned above. By use of a condition survey, all of the projects involved can be rated and the type of treatment that is needed can be established.

A restoration program should not necessarily concentrate on the worst-distressed pavements only but should perhaps be balanced between preventive joint sealing, to prevent future and larger expenses, and complete restoration. A project that shows distress but still has acceptable serviceability might not be given as high a priority as a project that shows less distress but has a higher rate of deterioration and a larger projected truck volume.

Once it has been decided to restore or rehabilitate a project, decisions must be made on the degree of restoration needed. Undersealing of unstable slabs will be of little value if it is not immediately followed by resealing of the joints because the pumping process will continue if no provisions are made to prevent water infiltration. In the same manner, the addition of edge drains will not be sufficient if moving slabs are not stabilized. Joint sealing can be done without other activities if the project is in good condition and the slabs are stable. A project will generally need several different restoration treatments to get the maximum benefit out of each individual treatment.

CONDITION SURVEYS

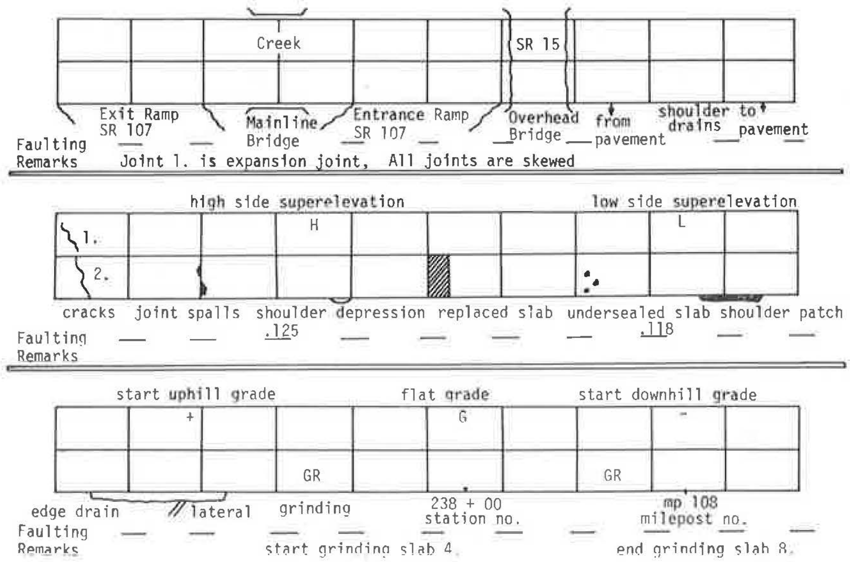
The Georgia Department of Transportation (DOT) conducts annual condition surveys of the jointed concrete pavements on its Interstate system, which totals approximately 1200 km (750 miles). The surveys were started in 1971 and initially used a sampling method in which approximately 10 percent of each mile was measured for faulting and observed for distress. This method was sufficient to determine the general condition of a project and the rate of deterioration. In 1977, the procedure was modified so that observations and a record of distress are now made for every slab and faulting measurements are made on every fourth joint. This change in procedure was required so that the data could be used for detailed planning of the restoration requirements of individual projects and for evaluation of the performance of the rehabilitated projects.

In the condition survey, all distress on each slab is recorded on strip maps along with other pertinent information such as ramp locations, station numbers, mileposts, curvature, grade, and previously performed maintenance activities. In addition, the faulting measurements are recorded on the strip map at the appropriate joint. An example of such a strip map is shown in Figure 1.

The data are reduced to give the condition of the pavement on a mile-to-mile basis and to show the faulting index, roughness, number of cracked slabs, and number of replaced slabs. This information is used in priority ranking the restoration needs for the various areas.

As a means of determining rate of deterioration and as a tool for follow-up evaluation of the effectiveness of restoration treatments, condition surveys are an important aspect of a rehabilitation program for planning purposes.

Figure 1. Example of pavement condition survey sheet.



STABILIZING CONCRETE PAVEMENT SLABS

Reasons for Stabilizing Slabs

One of the three major contributing factors in faulting and pumping of concrete pavement slabs is excessive movement of the slab corners under loads. Some movement should always be expected. The magnitude of movement varies with the type of subbase, slab interlock, and amount of curling. Only when an erodible base course is present in combination with a void space filled with water will the movement of the slabs become detrimental to the performance of the pavement.

One of the important steps in rehabilitating concrete pavement, either by using an overlay or by grinding, is to identify slabs that show excessive movement and attempt to stabilize them by undersealing. Undersealing appears at first to be a simple process that consists of drilling a hole in the concrete and forcing grout material into the cavity under the slab. But several basic problems are associated with proper undersealing methods:

1. Determination of slabs to be undersealed,
2. Flow characteristics of the grout material,
3. Proper distribution of the grout material,
4. Determination of when to stop undersealing a slab, and
5. Determination of the effectiveness of the undersealing effort.

Determination of Slabs to Be Undersealed

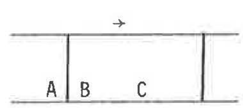
Undersealing slabs that do not really need it can do more harm than good by causing an uneven lifting of the slabs and thus loss of support at the slab edges and center. The primary reason for undersealing a slab is to reduce its movement under load. The criterion for determining whether a slab needs undersealing, therefore, should logically be the magnitude of the movement of the slab when it is subjected to a specific load. In many instances, grout can be forced under a slab that shows little movement under a load. This is especially true when there is a slight separation between the slab and the base that allows the slab to be raised easily so that grout can be forced under it. A slight separation between a concrete pavement slab and the base course will not be detrimental if slab movement is minimal and water is kept out from under it. As stated earlier, damage can be done to a slab when an attempt is made to fill small separations by creating larger voids elsewhere under the slab.

Determination of Excessive Movement

Movement of concrete pavement slabs can be determined by static or dynamic means. Static measurements are obtained by using a dial gauge to measure the movement of a slab when an 80-kN [18 000-lbf (18-kip)] axle load is placed on the slab corner. Dynamic deflections are obtained in Georgia by using the Dynaflect, which vibrates the pavement through an oscillating 4.4-kN (1000-lbf) load at 8 cycles/s.

Slab movement varies during the day as well as during the year because of daily curling effects and expansion and contraction of joints. Slabs can have a high rate of deflection at night or early in the morning and show no movement in the afternoon. An example of this change of deflection during the day is shown in Figure 2.

Movement is also dependent on the stiffness of the subbase and the subgrade. Slabs should be measured when the largest movement is expected, since this time period would be most critical to the performance of a slab. The curling movement of slabs varies from day to day and cannot be controlled. An example of the amount of curling that can take place is given in Table 1 for several Georgia locations. The following diagram shows the points in the slabs at which the measurements were taken:



Curling and temperature measurements for I-85 in Fulton County made in November 1977 are given below (1°C = 1.8°F; 1 mm = 0.039 in):

Item	11/9/77	11/15/77
Maximum temperature difference between slab sections (°C)		
Top slab	-3.3	-6.1
Bottom slab	+6.7	+9.4
Total movement (mm)		
Leave slab, joint 1	0.70	1.68
Approach slab, joint 2	0.25	1.17

Figure 2. Changes in deflection: northbound lane of I-85 in Coweta County on June 21, 1977.

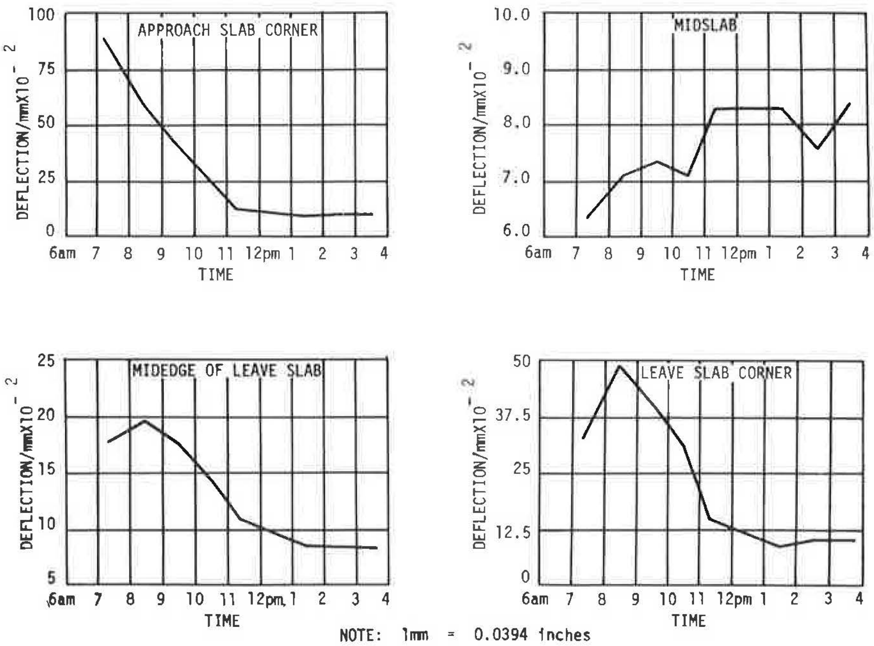


Table 1. Corner curl measurements.

Location	Type of Base Course	Date	Time	Surface Temperature (°C)	Curl[a] (mm) A	B	C
I-85, Troup County, under construction, no shoulders	Econocrete	7/26/77	7:00 a.m.- 3:00 p.m.	20-29	0.914	0.813	0.051
I-85, Coweta County	Cement-stabilized graded aggregate	7/22/77	7:00 a.m.- 3:00 p.m.	24-41	1.295	1.880	-
I-75, Monroe County, southbound lane	Bituminous-stabilized soil aggregate	7/19/77	7:20 a.m.- 1:05 p.m.	19-35	0.203	0.533	-
I-85, near airport, abandoned section	Soil aggregate	7/16/77	7:00 a.m.- 5:00 p.m.	19-28	0.406	0.432	0.254
		8/19/77	7:00 a.m.- 3:00 p.m.	23-37	0.686	0.584	0.254
		8/23/77	7:00 a.m. 4:00 p.m.	26-46	0.686	0.635	0.381
I-85, Troup County, under construction, no shoulders	Cement-stabilized graded aggregate and 25.4 mm asphaltic concrete	8/24/77	7:00 a.m.- 2:30 p.m.	25-43	0.381	0.279	0.584

Note: $t° = (t°F - 32)/1.8$; 1 mm = 0.039 in.
[a]See diagram in text.

The substantial difference in the total amount of curl measured on two different days can be accounted for by the differences in temperature ranges. In addition, on November 15, the slab temperature was much colder early in the morning and the joint opening was probably larger than it was on November 9. The wider joint opening would put less restriction on the vertical movement of the slab corner. The curl movement indicated in the table above relates to the total upward and downward movement but does not distinguish between the amount of upward curl and downward curl. The question as to what is excessive movement is, therefore, difficult to answer when so many factors influence the deflections that are measured at any given time. In addition, excessive movement of a slab does not necessarily indicate the existence of a void beneath the pavement slab, since other factors such as a weak base or subgrade can cause high deflections.

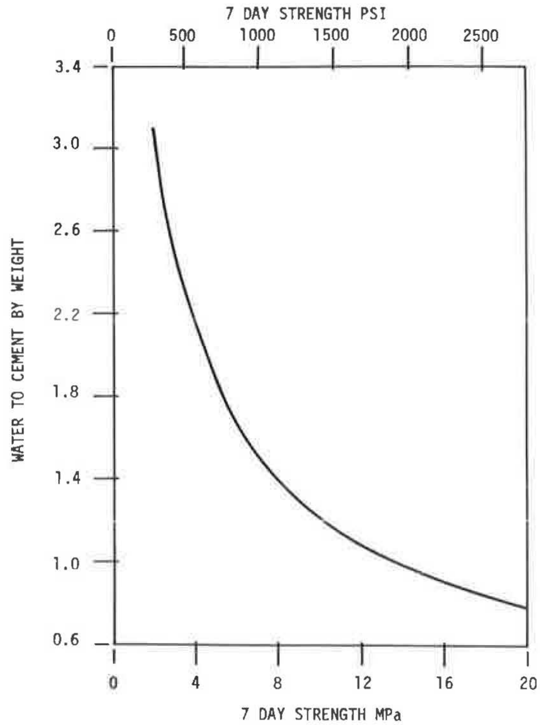
Through experience and observation of grout take versus slab deflection, a limiting criterion of 0.64 mm (0.025 in) of movement under an 80-kN single-axle load is currently used in Georgia. It is assumed that any slab that shows movement of 0.64 mm or less does not show sufficient movement to warrant stabilizing. It does not mean that these slabs will not take grout because almost any slab can be made to take grout. The potential of damaging a slab that exhibits small deflections outweighs any advantage that may be gained by reducing the movement of the slab through undersealing.

Grout Mixes for Undersealing

The type of grout used in undersealing is an important factor in obtaining a good, stable slab. If the grout is too stiff, there will be "stooling" of the material around the grout hole and little distribution of the material under the slab. If the material is too soupy, there is a loss of strength and a large amount of shrinkage can be expected. The type of materials that are selected to make up the grout also greatly affects the consistency and strength of the grout mix.

Many grout mixes were prepared and tested by the Georgia DOT in an attempt to determine the most practical mixes for field trials and to establish the properties of mixes already being used. Cement, limestone dust, and fly ash were the main ingredients used in the grout mixes tested in the laboratory. Hydrated lime has not been used in grout mixes in Georgia because it makes

Figure 3. Strength of grout mixes.



the mix so costly. Among the various mixes tested, the best strength was obtained by using cement and limestone dust only. The relation between the seven-day strength and the water-cement ratio of the various mixes tested is shown in Figure 3. The results showed that good correlation existed between strength and water-cement ratio, which was independent of any other added mix ingredients. The mixes that included added ingredients such as fly ash showed less strength because of the additional water required for fly ash to obtain a good flow consistency.

The grout mixes that are approved for use in Georgia are given below:

Grout Type	Material (percentage by weight of dry materials) Cement	Limestone Dust	Fly Ash	Fine Aggregate
1	25		25	50
2	25	25		50
3	25	75		
4	25	50	25	
5	100			

Although this table contains five mixes, in reality only mix 3, which consists of one part cement and three parts limestone dust, is used. A mix with cement, fly ash, and limestone dust has also been used. But there is no obvious advantage in using this mix rather than the cement-limestone mix and, in addition, it requires one more component, which makes batching slightly more complicated. In Georgia, it has been found that a sand or soil mix is not suitable for undersealing pavement slabs. Grout mixes that contain sand are still in the specifications because they may be needed for purposes such as filling large voids at bridge approaches.

The flow of the mix is also important. The specifications require a flow of 16-22 s when measured with a flow cone. It is preferred that the mix used on the job have a flow of 16 s to facilitate the distribution of the grout under the slab without excessively lifting the slab. Although limited laboratory work has been done in Georgia on the use of additives in the grout, such as water-reducing agents and calcium chloride, no additives have been used in actual practice and further investigation is needed.

Undersealing a Slab

Close inspection by the contractor and the state inspector is required during the undersealing process. The purpose of undersealing is merely to stabilize the slab by filling existing voids with grout and not to raise the slab back to grade.

Excessive lifting of slabs can be very detrimental to the pavement and can cause the creation of voids elsewhere as well as overstress the slab and eventually cause cracking of the pavement. The Georgia specifications allow the slab to be lifted up to 3.2 mm (0.125 in). A device to monitor lift is therefore a necessity on a project. Georgia uses a modified Benkelmen beam device that indicates total movement as well as the differential lift between adjacent slabs at the corner. This device, shown in Figure 4, can be used to control the amount of pumping that is done in each hole. Other factors that are used to determine when to cease pumping in a hole are the appearance of grout in adjacent holes and joints or cracks and the displacement of water from under the slab. Another indication that grouting should cease is the pumping time on a hole. When no evidence of grout appears in joints or a hole, and no lift is being recorded on the gauge after a reasonable amount of time, grouting should cease. This is especially true when grout is being pumped next to the centerline, where the grout is liable to be pumped under the adjacent lane. In some instances, when the outside lane was being stabilized, the grout broke through the inside shoulder.

There is no set procedure that can guarantee that a slab has been properly undersealed. Experience is a key factor in the undersealing operation.

A variety of hole patterns have also been used in Georgia; frequently, some experimentation at the start of a project is necessary to determine the hole pattern that gives the best results. A typical hole pattern that works well on many projects is shown in Figure 5. This hole pattern is designed to fill voids that exist under the corner of the slab, since experience has shown that the void generally does not extend 3 m (10 ft) beyond the joint.

Effectiveness of Undersealing

The primary indication of the effectiveness of undersealing is the performance of the rehabilitated pavement. Undersealing is not effective if no provision is made to seal out surface water or rapidly remove infiltrated surface water. Undersealing alone does not stop slab pumping and faulting.

The effectiveness of undersealing in stabilizing the slab can be determined by measuring the movement of the slab corners again. If the movement is still greater than 3.2 mm (0.125 in), the slab is regrouted in case voids were formed during the initial undersealing attempt or the existing voids were not entirely filled. No additional grouting attempt should be made after the second attempt.

SPALL REPAIR AND SMALL PATCHES

Concrete pavements have been overlaid with asphalt because basically sound concrete developed spalling at slab

Figure 4. Lift-measuring device.

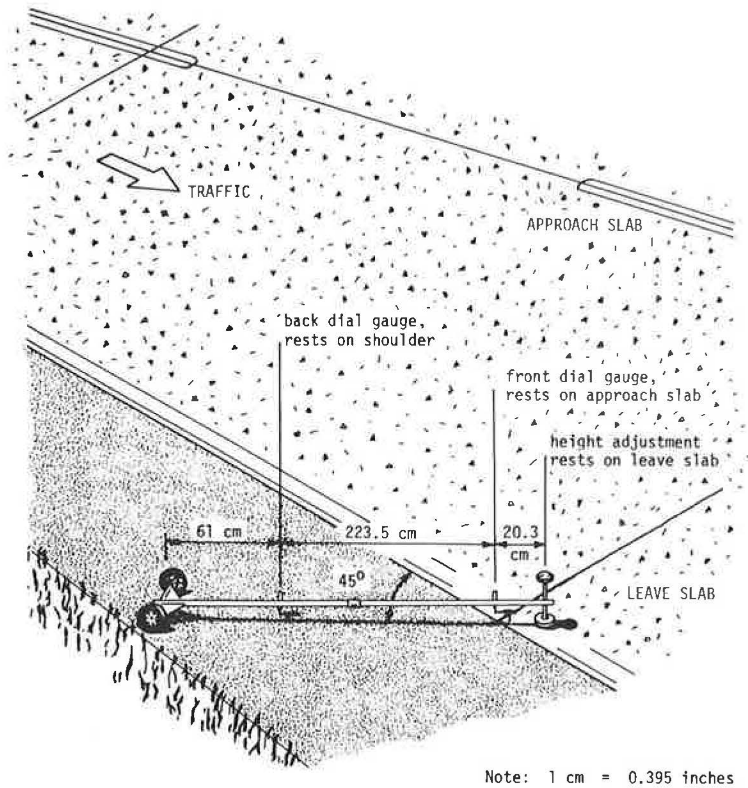
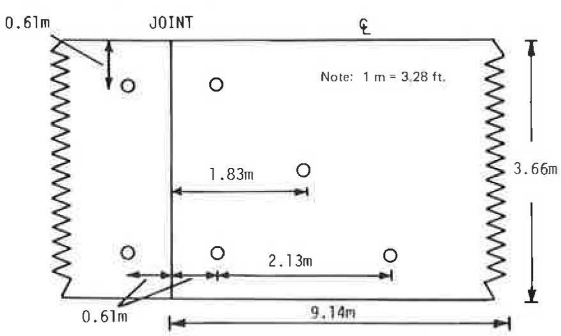


Figure 5. Typical hole pattern for underseal.



corners and at joints. The alternative would have been very costly, labor-intensive patching and joint sealing and questionable performance. The value of a patch cannot be predicted because of a lack of historical data on which to base empirical equations for comparisons with other alternatives. The results are more predictable for an overlay, which can be done in stages with specialized equipment, in contrast to tedious patch preparation and placement, which require much labor and skill if the desired results are to be constantly obtained.

Patching may most often be the most feasible solution to the spalled pavement problem. Patch preparation is the most important phase of spall patching. Surfaces must be free of oil, dust, dirt, traces of asphaltic concrete, and other contaminants, and some methods and materials require neatly sawed vertical edges to prevent feather edges. The materials must have the necessary properties, and they must be properly used.

Georgia has had some experience with three types of patching:

1. Twenty-four-hour accelerated-strength concrete bonded with an epoxy adhesive for bonding plastic concrete to hardened concrete,
2. Rapid-setting patching materials of cement-mortar-like consistency, and
3. Epoxy mortar or epoxy concrete.

Repair Method 1

Use of 24-h accelerated-strength concrete bonded with type 2 epoxy requires that the edges of the patch be vertical and not feathered. The practice in this type of patching has been to prepare the spalled area by sawing around the periphery of the deteriorated area and removing the deteriorated material, leaving vertical edges not less than 3.8 cm (1.5 in). The concrete does not gain strength as fast as some of the patching grouts, and traffic control must be extended for longer periods. Normally, concrete with 2 percent calcium chloride is used for the patching, and the time it takes this mix to develop strength is well established.

These patches have been used with reasonable success, but consideration must be given to the following characteristics:

1. Time required for the concrete mix to gain sufficient strength to support traffic,
2. Coefficient of thermal expansion of the epoxy mortar, and
3. Hydrostatic pressure.

The coefficient of thermal expansion is in the range of 36-54 $\times 10^{-6}$/°C (20-30 $\times 10^{-6}$/°F) compared with 5-11 $\times 10^{-6}$/°C (3-6 $\times 10^{-6}$/°F) for concrete. Experience has shown that, for the 0.25- to 0.50-mm (10- to 20-mil) thickness, no bond failure occurs. Apparently, the very thin epoxy section is restrained by the concrete, and the epoxy is strong enough to withstand the induced stress.

Patches of some permeable materials have been known to unbond for no apparent reason. Some of this problem has been attributed to hydrostatic pressure on an impermeable face. The success of an epoxy-bonded patch may well depend on the ratio of permeability of the substrate to the bonding agent. If an area was not "wet" with epoxy, low pressure distributed over a large area may exert enough force to unbond the epoxy. Pressure from water confined under tires may cause high pressure in concrete voids and unbond patches at the periphery.

Repair Method 2

Most extensive patching has involved the use of rapid-setting patching materials. Magnesium phosphate patching grouts meet this specification. When the area to be patched is properly prepared, these patches perform well.

Repair Method 3

Epoxy mortar and epoxy concrete mixes have been used with good success. Most experience in Georgia with this method is in the patching of small spalls on new construction. Sometimes concrete ravels at joints when it is necessary to saw early to prevent cracking. Small spalls that cannot be corrected by a final saw cut must be repaired if preformed seals are to be used or the seal will not be watertight. Good results can be achieved by patching these spalls, which are usually small, with an epoxy-concrete mix. Accurate forming of the joint through these patches is not always possible, and it is sometimes necessary or desirable to place the patch so that excess material can be cut from the patch adjacent to the joint by running the saw through the joint. If there are spalls, they should be patched before the final joint saw cut.

In summary, the following observations are made concerning patches:

1. Filler stone used in conjunction with repair method 2 sometimes contains too many fines, which kills the ability of the patching material to wet the surface that is to be bonded. This problem can usually be corrected by reducing the quantity of stone used in the mix.
2. Inadequate consolidation sometimes leaves too many large voids in the patch.
3. Many patches are installed in such a way that they span an initial fracture when the relief crack was not vertical. This practice should not be permitted because the patch is sure to fail. When such a condition exists, two patches should be made and a joint formed between them, as shown in Figure 6.
4. Retempering of the mix in an attempt to use old batches should not be permitted. Set occurs very fast, and care must be taken not to mix too much material at one time.

SLAB REPLACEMENT

Most of the slab cracking on plain concrete pavement originates because of loss of support under the slab corners. When faulting progresses to a certain degree, the slab becomes cantilever and a crack develops. This crack represents a structural failure that requires repair. Usually the crack separates a relatively large portion of slab from the original slab. Since partial support is regained when the slab cracks and resets on the base, deflection under load is often reduced when the slab cracks. Some advantage can be gained by removing and repouring the slab:

1. The soft base can be removed and good support restored.
2. Dowels can be added by drilling and epoxied in place.
3. The surface can be corrected so that the impact from loads over a faulted joint is reduced.
4. The replacement unit is somewhat larger than that removed and therefore more stable.
5. The resulting joints are in better condition and easier to seal.

Some minimum slab size exists below which performance is jeopardized. The minimum slab length used in Georgia is 2.9 m (9.5 ft). A single transverse crack in the middle third of a 9.1-m (30-ft) slab and nearly normal to the centerline should be grouted and sealed unless evidence of excessive slab movement occurs under load. In case of excessive movement that requires reconstruction of the base and/or the subgrade, the repair is made so that no slab portion left in place or repoured is shorter than 2.9 m (9.5 ft). It may be necessary to remove the whole slab. Portions of slabs that have interconnected cracks are removed. The base and/or subgrade is reconstructed as necessary or replaced to a minimum depth of 35.6 cm (14 in) with concrete unless the base is cement stabilized. If the base is cement stabilized, only the loose material that may be present is removed.

A device has been developed in Georgia that permits drilling of three holes at one time to insert dowels into the existing slab. A single drill, however, can sometimes drill as many holes as the three drills together, since a large volume of air is required to operate the drills. The diameter of the dowels is 3.2 cm (1.25 in), and the spacing is 40.6 cm (16 in). The hole size should be no larger than is necessary to accommodate the dowel, and a high-viscosity epoxy should be applied in such a way that it is forced to fill the void and be extruded slightly from the joint when the bar is inserted. A detail of the slab replacement and dowel spacing is shown in Figure 7.

Figure 6. Proper patching over relief crack.

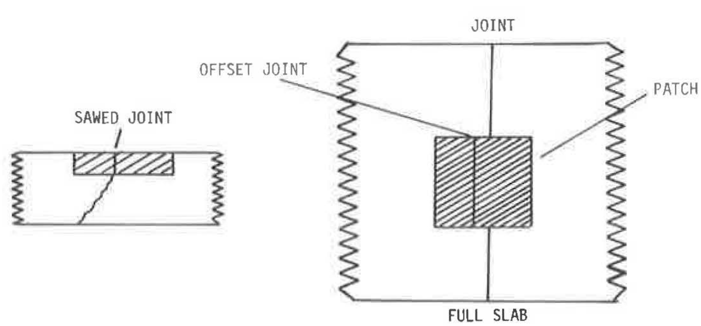


Figure 7. Details of dowel placement in repair of concrete slabs.

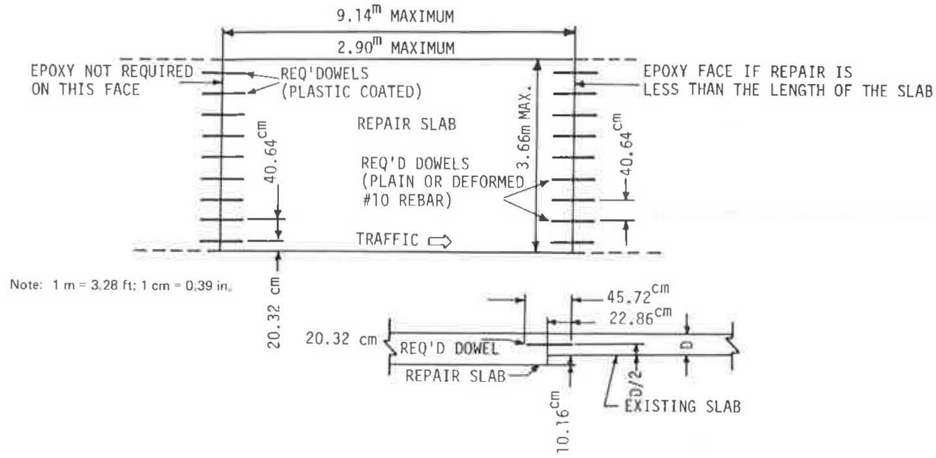
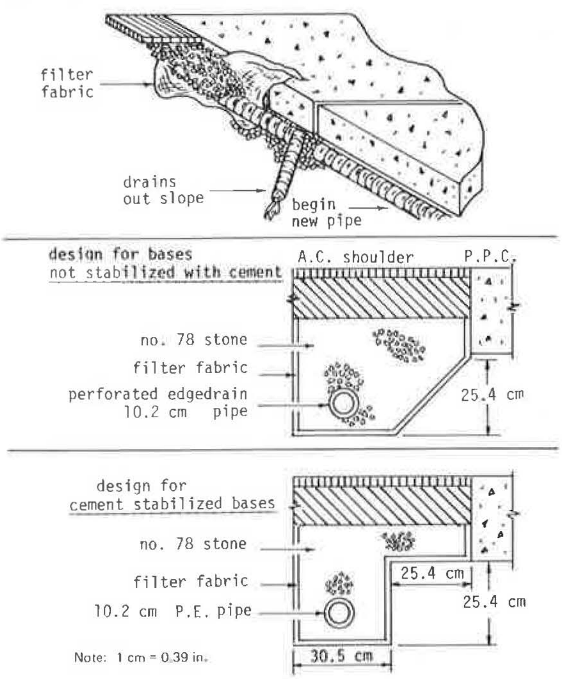


Figure 8. Section of edge-drain system.



EDGE DRAINS

One of the factors that contributes to the deterioration of jointed concrete pavements is the entrance of surface water into the pavement system. The removal of free surface water or the prevention of the entrance of water into the system in the first place plays an important part in the rehabilitation process.

In 1974, the maintenance department of the Georgia DOT began installing longitudinal edge drains with corrugated plastic pipe for rapid removal of water from under slabs. Previous efforts had been concentrated on placing lateral stone drains at pumping joints. This type of drainage system was generally ineffective because water entered the pavement system at places other than the transverse joint and dirt and grass would eventually clog the daylighted lateral drain.

A complete review of existing edge-drain designs, including field observations, was performed in 1978 after it became apparent that there were potential problems in some areas with the performance of the edge-drain systems.

Sections were excavated on several projects to determine the contamination of the drainage stone and to observe the general condition of the system. It was evident that contamination of the stone was severe around the pipe and that some material was still being pumped from under the slab into the drainage system. Faulting data from some of the first projects where edge drains had been placed also showed that the presence of the drains did not necessarily stop the faulting process. One of the key factors in the contamination of the drainage stone and continued pumping was the presence of moving slabs. It was found in some areas that the slabs were moving considerably after they had been stabilized.

The investigation produced several recommendations that were implemented immediately. A typical section of the edge-drain system after the modifications were made is shown in Figure 8. The major changes included adding filter fabric, increasing the asphalt cap thickness from 7.6 to 15.2 cm (3-6 in), and making each outlet drain its own section of the roadway rather than placing a continuous longitudinal pipe with lateral drains tied in to the main pipe.

During the investigation, a test section that contained various filter fabrics was also removed for examination. It was evident that the fabrics were effective in preventing contamination of the drainage stone. It was also evident that a caking of soil about 3.2 mm (0.125 in) thick was formed behind the filter fabric along the vertical face of the pavement edge. Samples of the fabric were tested in the laboratory to determine the flow rate of clean sections and caked sections. The container used in the test measured 51 mm (2 in) in diameter and 79 mm (3.1 in) in height. A significant reduction in flow rate was found, as indicated below:

	Drain Time (s)	
Material	Clean Fabric	Caked Fabric
Stabilenka T-100	20	31
Bidim C-22	23	120
Mirafi 140	20	36
Typar 3401	20	360 (for 37 percent of volume)
Supac	23	78

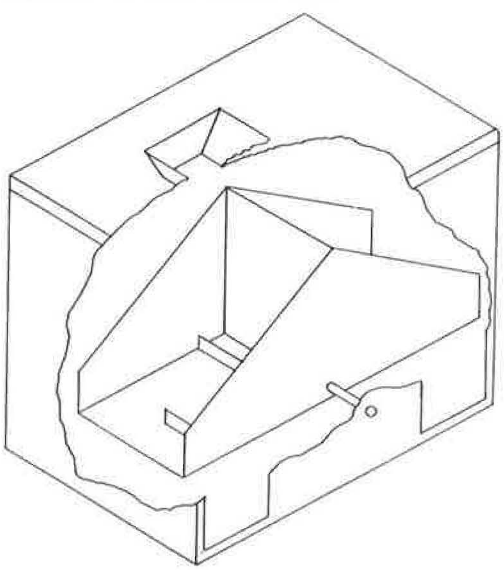
Filter fabrics are designed to aid in the formation of a natural filter layer behind the fabric. The use of filter fabric may therefore defeat the purpose for which edge drains are installed in the first place—the rapid removal of infiltrated surface water. Our investigation has shown, however, that without filter fabric there is a possibility of continuing or even accelerating loss of material from under the slab. Experience with some of the earlier installations and with the filter-fabric test sections indicates that the use of edge drains along concrete pavement may not be effective on a long-term basis. The Georgia DOT has imposed a moratorium on any additional edge-drain installations until the performance of the existing 454 km (282 miles) of edge drains, especially those that use the current design, can be evaluated.

This evaluation consists of condition surveys and faulting measurements. In addition, flow measurements are being made at selected sites that have various design features to determine the volume of water that enters the drainage system. Five sites have been instrumented to determine flow through the edge drains in correlation with rainfall. Other sites at which various joint-sealing treatments and edge-drain designs have been used will also be instrumented.

The measurements are made by using a tipping bucket similar to one used by the University of Illinois in a previous study (see Figure 9). Rainfall is measured by using a smaller-scale tipping bucket at each site.

The evaluation is in the early stages, and a large amount of data on the flow characteristics is not yet available. A typical graph obtained at one site is shown

Figure 9. Flow-gauge tipping bucket.



in Figure 10. This graph indicates the capability of the edge-drain system to remove large volumes of water in a relatively short time after the commencement of rainfall. It also points out the need for proper sealing of all joints and cracks to prevent water from infiltrating the area under the pavement in the first place.

GRINDING

Although grinding of the pavement is not required on projects when joints are to be sealed or resealed, it is an essential part of some projects to restore rideability and skid resistance and can be a part of a complete rehabilitation project. The type of grinding machine used and whether grinding is done before or after joint sealing have a bearing on the joint-sealing procedure.

Georgia has experimented with several types of texture-restoring machines, including diamond-blade grinding, Klarcrete, CMI Rotomill, and Barber-Greene Dynaplane. Diamond-blade grinding was found to be the only method that did not damage the joints if the joints were not prepared before grinding. The other texturing and grinding devices cause severe joint spalling, which would make it extremely difficult to seal the joints properly.

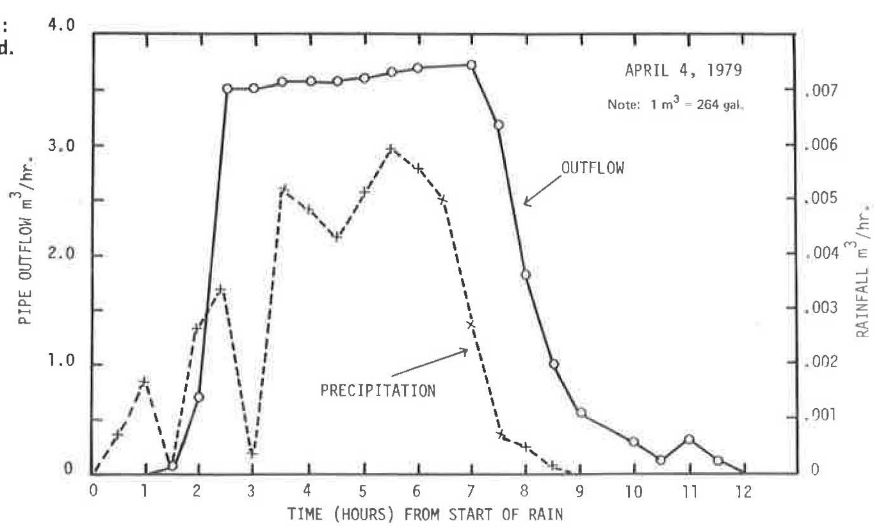
Some experimentation was done with packing the joints with grout, epoxy, and other material, but only moderate success was obtained with Set-45. The texture produced by the Rotomill, Dynaplane, and Klarcrete was also noisier and less uniform than that produced by diamond-blade grinding.

It is preferred that grinding be done before joint sealing. Grinding, however, is the slowest of the rehabilitation operations, and it is imperative that the joints be sealed within a short time after the slabs have been stabilized to minimize the entrance of surface water under the stabilized slabs. Grinding, therefore, is generally done after the joints are sealed, and this must be taken into account in determining the depth at which the joint sealant is placed.

JOINT SEALING

A complete discussion on joint sealing is beyond the scope of this paper, but justice cannot be done to the topic of rehabilitation without some mention of joint sealing. In the opinion of many highway engineers, effective sealing of joints in concrete pavement is still not possible or at least not practical. There are at least

Figure 10. Edge-drain outflow and precipitation: transverse joints sealed, shoulder joints not sealed.



six different philosophies concerning joint sealing. These are listed below:

1. Watertight sealing of joints is not possible and may as well not be attempted.
2. Joints should be sealed with relatively inexpensive sealant. Although adhesive or cohesive failure occurs in cold weather, the sealant is very effective in reducing the quantity of water that can infiltrate a joint.
3. Joints should be filled with a material that will keep incompressibles from restricting closing movement. The sealant probably will not be watertight but will keep water infiltration through joints to a minimum.
4. Sealing of transverse contraction joints is of no value unless the longitudinal shoulder joint is sealed.
5. Sealing of transverse contraction joints in conjunction with edge drains located near the longitudinal shoulder joint is effective.
6. A pavement system can be effectively sealed with sealants now available. An attempt should be made to keep transverse and longitudinal joints sealed. Edge drains will not be needed to remove infiltrated water. Underdrains should be used as required to remove subsurface water.

Advances in joint-sealing materials have been made in recent years to the point that joints can be sealed effectively for extended periods of time. Georgia has test installations of low-modulus-silicone sealant that have been in place for almost five years and have given excellent performance. The few failures on these joints can be explained as follows: (a) The sealant was in contact with traffic, (b) old rubber-asphalt contaminated the joint face, and/or (c) fractured concrete was present at the time of sealing. The joints or portions of joints that were properly prepared are well sealed after almost five years, and the only deterioration is in the surface skin that has been contaminated by oil, dirt, tire rubber, etc.

It appeared evident from these small test installations that low-modulus silicone was capable of sealing transverse contraction joints in concrete pavement. Maintenance crews in Georgia were equipped to install this material in order to provide a larger amount of seal for an evaluation and to develop installation techniques. The results of these installations were excellent, and silicone joint sealant is now used on rehabilitation projects as well as on new construction.

Some failures have occurred on completed projects, but virtually all of the failures with low-modulus-silicone joint sealant can be traced to faulty joint preparation. The joint should be uniform, clean, and dry, and the concrete in the joint area should be sound. Guidelines established in Georgia for sealing joints with silicone cover joint preparation from sawing to sealing as well as proper inspection procedures.

SUMMARY

The successful performance of a rehabilitated jointed concrete pavement depends on choosing the correct treatments for the condition of the pavement. In order for joint sealing to be effective (assuming proper installation techniques and the use of proper materials), other corrective measures must generally be used. Restoration techniques that should be considered include the use of undersealing, spall repair, edge drains, slab replacement, and grinding. Each of these techniques is important to the overall success of a rehabilitated pavement and to the performance of each individual treatment.

ACKNOWLEDGMENT

The material, concepts, and data presented in this paper are the result of a research study funded by the Federal Highway Administration and the Georgia Department of Transportation.

The contents of this paper reflect our views, and we are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Georgia Department of Transportation or the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

Publication of this paper sponsored by Committee on Pavement Maintenance.

Conditions and Operations for Joint and Crack Resealing of Airfield Pavement

Charles B. McKerall, Jr.

Joint-sealing techniques used by the Air Training Command are summarized. Methods of ensuring maximum sealer life, the treatment of reflective cracking, and the use of compression seals are briefly discussed.

Joint resealing or joint maintenance is probably one of the most neglected facets of pavement maintenance. Resealing joints at the proper time and using the proper materials and methods will reduce the overall maintenance cost and prolong the life of the pavement.

To establish a good joint-maintenance program, it is first necessary to be able to evaluate the existing sealer. It must be kept in mind that the joint sealer performs three functions: (a) It maintains a water barrier, (b) it keeps incompressibles out of the joint, and (c) it reduces the potential of damage from fallen objects.

In evaluating the condition of the sealer, it must be determined which of the above functions is paramount in a particular location. For example, in the Air Train-