Use of Ground-Penetrating Radar for Detecting Voids Under a Jointed Concrete Pavement

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A survey of a jointed, reinforced concrete pavement with ground-penetrating radar indicated that radar provides a nondestructive inspection technique that can be used at a minimum rate of 5 lane-miles of pavement per hour with only minimal interference with traffic. The coring of some slabs and subsequent use of a devised water test revealed that the radar was effective in detecting voids deeper than 1/8 in. but considerably less effective in spotting shallow voids. The overall accuracy was approximately 68 percent, which indicates that the sensitivity of the equipment needs to be improved. The location component used with the radar unit showed insufficient accuracy. A regression analysis of the recorded quantities of grout used daily in subsealing portions of the pavement versus the total linear feet of voids detected under the slabs grouted each day yielded only a 51 percent correlation. However, the regression was found to be significant at a 95 percent probability level. It is believed that if the width and depth of each void can be conveniently estimated so that the extent of voids can be expressed in terms of volume instead of length alone, an even more successful method of estimating grout quantities would be available. It has been shown that information derived from a radar survey can be useful in developing a sound and cost-effective slab stabilization operation in which grout holes are properly placed.

Each year an increasing number of miles of concrete pavement become in need of maintenance and repair. Because the formation of voids beneath concrete slabs is a major cause of pavement failure, there is an urgent need for a rapid, nondestructive inspection technique for detecting such voids before failures occur. The value of knowing the location and extent of voids when planning for slab stabilization is immeasurable.

Recent studies *(1–5)* have shown that cavities under concrete sidewalks, runways, and approach slabs to bridges can easily be detected with ground-penetrating radar (GPR). Consequently, there is a trend toward increasing use of this technique in the inspection of concrete pavements. However, with concrete pavements, failures can occur when the gap (or void) between a slab and the subbase is only 0.125 in. deep, and the ability of GPR to consistently provide accurate indications of this type of void had not been evaluated and reported.

GPR was used to survey a 14.5-mi section of Interstate 81 in southwestern Virginia for the purpose of *(a)* evaluating the accuracy of GPR in detecting voids, *(b)* determining if the radar could be used as a reliable method for estimating the quantities of grout needed to fill the voids, and *(c)* examining other possible uses of the technique.

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PRINCIPLE OF GPR

The GPR systems used generally have been of the short-pulse type. This type operates on the principle of inducing a single pulse from a transmitter, then abruptly ceasing transmission for a short interval (typically on the order of microseconds) during which reflected signals return to a receiver. In all recent studies, the transducers (i.e., the combined transmitter and receiver) used have had a pulse width of approximately 1 nanosecond (nsec). These transducers operate at relatively high frequencies (typically 1 GHz) to provide both sufficient penetration (approximately 3 ft) and the best available resolution. This is in contrast with the low-frequency transducers that are more suitable for geological and similar surveys because they yield relatively greater penetration albeit poorer resolution.

When a pulse of electromagnetic energy is directed into a concrete pavement (Figure 1), a portion (P1) is reflected back to the transducer at the air-concrete boundary, which is the first boundary between two media having highly contrasting dielectric properties (Table 1). The remaining energy propagates through the concrete until it strikes another boundary, which would be the concrete-base boundary, where another

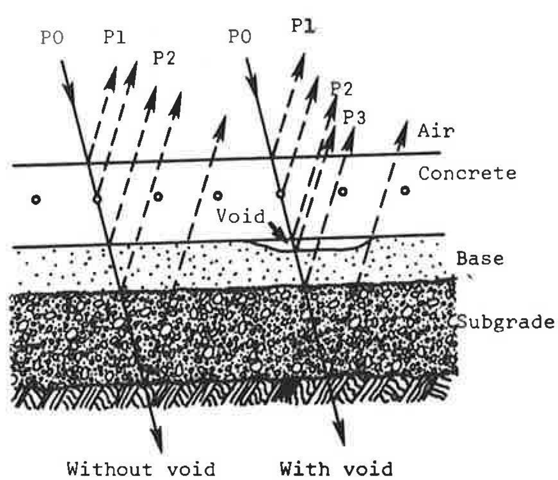

FIGURE 1 Propagation of microwave pulses through a concrete pavement without and with a void under the concrete slab.

TABLE 1 DIELECTRIC CONSTANTS OF MATERIALS RELEVANT TO PAVEMENTS

Material	Relative Dielectric Constant (ε)
Air	1
Concrete	6–8
Sand (dry)	4–6
Granite (dry)	5
Limestone (dry)	7–9
Dolomite	6–8
Soil	3–12
Water	81

portion (P2) is reflected back. The portion not reflected penetrates through the layer of base material and other subsequent layers of materials and repeats the reflection-and-penetration processes until the original energy is completely dissipated. (The maximum penetration would depend on the moisture content of the materials below the concrete slab.)

As is shown in Figure 1, when a void exists below the concrete slab, an additional reflection (P3) is caused by the additional air-base (void-base) boundary. In addition, the P2 reflection would become stronger (i.e., have a larger amplitude) than that where no void exists because of a change in the nature of the boundary (i.e., from concrete-base to concrete-air or void, and a corresponding increase in the reflectivity at the boundary. These recognizable changes in the reflection pattern of a pavement, as shown in Figure 2, make possible the detection of voids beneath the concrete slab.

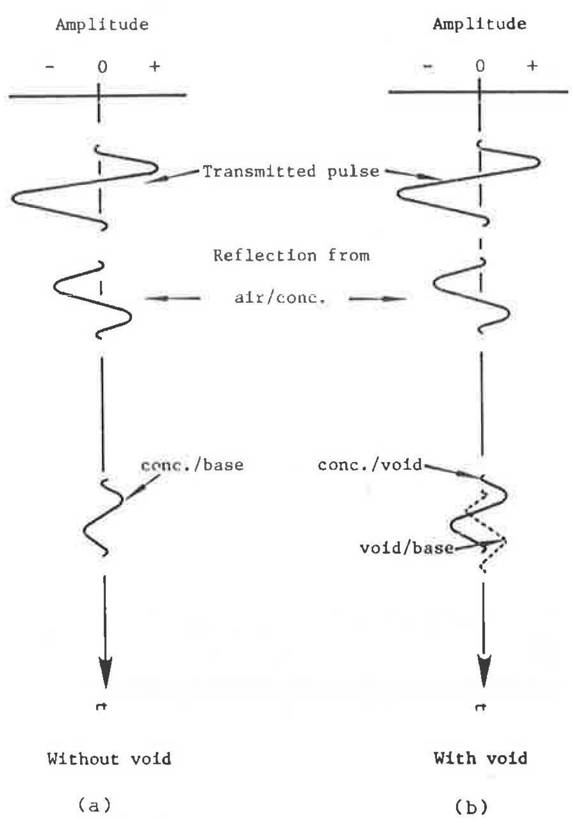

FIGURE 2 Microwave reflection profile for concrete pavement without and with a void.

The amplitude *(A)* and polarity of the energy reflected from a boundary are governed by

$$\rho = A/A_o = (\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2})/(\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}) \qquad (1)$$

where

ρ = reflection coefficient at the boundary,
A_o = amplitude of the incident energy,
ε_1 = relative dielectric constant of medium (or material) 1, and
ε_2 = relative dielectric constant of medium (or material) 2.

In accordance with this equation, the surface of the concrete pavement (i.e., the air-concrete boundary) would have a reflectivity of negative value because concrete has a dielectric constant greater than that of air, as indicated in Table 1. Therefore the energy reflected from the surface of the pavement would have a negative polarity with respect to that of the transmitted pulse in Figure 2*a* and an absolute amplitude proportional to A_o and ρ air-concrete.

The polarity and amplitude of the reflection P2, at the concrete-base boundary, would depend on the base material used. In the section of I-81 surveyed the base material was a 2-in. sand leveling course over a 6-in. layer of crushed stone (either limestone or dolomite). If the sand is dry during the survey, P2 will likely be positive and have an amplitude only about one-tenth that of P1, as shown in Figure 2*a*. However, if the sand is moist, its dielectric constant could be considerably greater than that of concrete, so that P2 would become negative and stronger.

Where there is a void beneath the concrete slab, the concrete-base boundary is, of course, replaced by a concrete-void and then a void-sand boundary. In this case reflection P2 would remain positive, although its amplitude would become larger, maybe about one-third that of P1. In addition to this change, an additional reflection (P3) would occur and assume a negative polarity of considerable amplitude (Figure 2*b*).

The difference in the times at which any two successive reflections reach the receiver would depend on the thickness and the dielectric constant (ε) of the material between the reflection boundaries; that is,

$$t = 2D\sqrt{\varepsilon}/(11.81) \qquad (2)$$

where

t = pulse arrival time, or separation from a preceding reflection, in nanoseconds, and
D = thickness, in inches.

According to this relationship, reflections P1 and P2 would arrive at the receiver about 3.3 nsec apart, assuming an average slab thickness of 9 in. This is considerably more than the minimum 1 nsec (the pulse width that characterizes the transducer) needed to prevent their overlapping and interfering with each other.

Because the relative dielectric constant of air is 1, according to Equation 2 reflection P3 from the bottom of a void would be behind P2 in proportion to the depth of the void; that is,

$t = D/5.9$ (3)

where D is the depth, in inches, of the void. It was suspected that the voids beneath the pavement slabs on I-81 would probably be no deeper than a few eighths of an inch and that P3 and P2 thus would be separated by no more than 0.06 nsec. This implies that P3 would often overlap P2 and, therefore, affect its amplitude, as is shown in Figure 2*b*. Again, it is by observing these changes in the reflection corresponding to the bottom of the concrete slab that voids can be detected.

During a survey the electromagnetic pulse is repeatedly transmitted through the pavement (at a rate of 50 kHz for one radar system) while the radar system travels slowly (5 to 10 mph) over the pavement. This creates a stream of radar reflection profiles that contain information on the pavement being surveyed.

RADAR SYSTEM FOR SURVEY OF PAVEMENTS

The radar survey of I-81 was contracted to Gulf Applied Research of Marietta, Georgia (mention of a company does not constitute endorsements by the authors). The system used, as diagrammed in Figure 3, has a radar unit and a location reference unit integrated with a wide-angle video unit that records pavement surface conditions for possible correlation with subsurface conditions derived from radar data. The radar unit operated two antennas simultaneously, which provided coverage over two survey paths, each approximately 18 in. wide, in a traffic lane in a single pass.

The system was also equipped with a reference marking unit that automatically sprayed a paint mark on the pavement at 1,000-ft intervals during the survey. (This capability has since been improved to apply the marking at intervals as short as 10 ft.)

SURVEY PROCEDURE

The antennas were set up 5 ft apart. Then the survey vehicle was driven over each lane on a course such that Antenna 1 was approximately 3 ft from the edge of the pavement shoulder or the longitudinal joint (Figure 4). The survey of the entire 14.5-mi section of this four-lane highway, which translates to 58.0 lane-miles of jointed concrete pavement, was accomplished with five runs made in approximately 12 hr. Only minimal traffic control was necessary because any lane closure necessary for setting up antennas or extracting cores for verification was quite brief.

RESULTS AND DISCUSSION

Microwave Reflection Profiles of Concrete Pavement

Figure 5 shows a pair of microwave reflection profiles for 950 ft of pavement recorded on magnetic tape during the survey and later transferred to a strip chart recorder. The top and bottom profiles correspond to the 3- and 8-ft wheelpaths, respectively. (The horizontal scale in each pattern corresponds to the traveled distance from a starting point, and the vertical scale corresponds to the arrival time of the reflection at the antenna receiver or to the depth of the various materials when the dielectric constants involved are known.)

In the portion of pavement shown in Figure 5, numerous

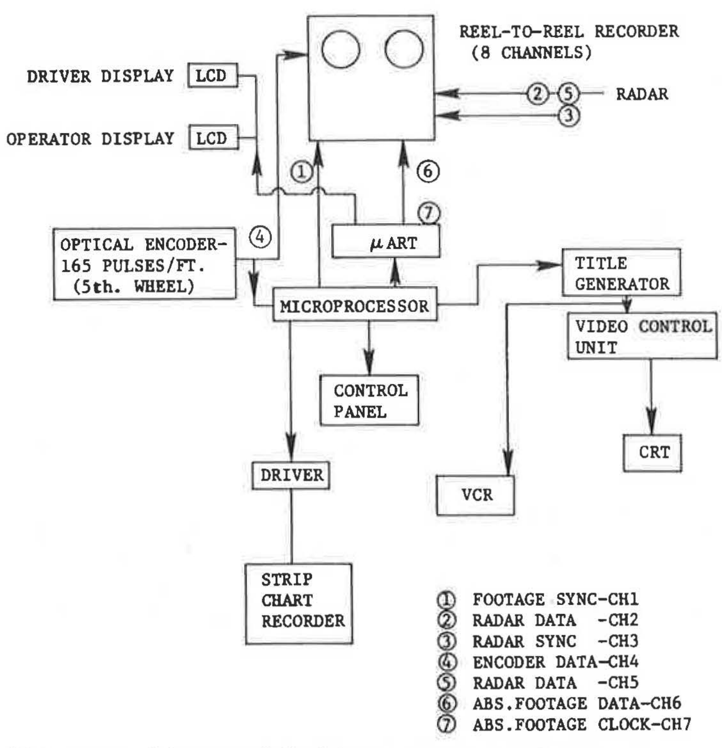

FIGURE 3 Diagram of Gulf Applied Radar's RODAR unit.

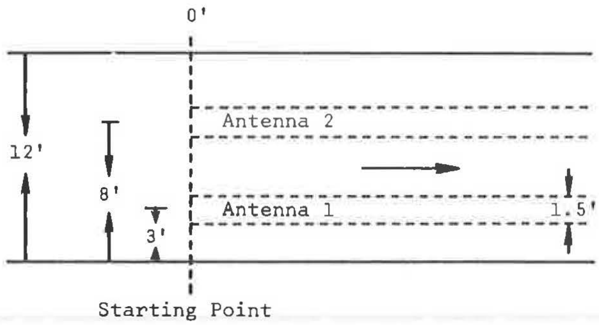

FIGURE 4 Antennae paths on each lane.

voids of various sizes were evident. Each was manifested by a pair of relatively intense white-then-black bands at the concrete-base boundary caused by reflection P3 and its interaction with P2, as discussed earlier. The transverse joints, which were 61.5 ft apart, were readily recognizable as peaks at the top of a reflection profile, especially the upper one. Careful examination of this set of reflection profiles would also show that practically all of the voids were downstream of the joints with respect to the direction of traffic flow, which is from left to right of the chart. This is particularly noteworthy because it provides a cross-sectional "picture" of what occurs under the concrete slab and around a joint or crack. [This picture appeared to support the view of experts in pavement rehabilitation that during pumping there is a movement of particles counter to the direction of traffic across a joint that often results in a buildup of loose materials under the slab upstream of the joint (i.e., the approach slab) while some fine materials are pumped out, through the joint or crack, from under the slab downstream of the joint (i.e., the leave slab) to create a void there.]

Although not all joints showed up readily in the reflection patterns recorded, joints with severely damaged sealant were quite distinct. This was also true of severely faulted joints or cracks. Although not shown, bridges had a typical reflection pattern distinct from that of the pavement.

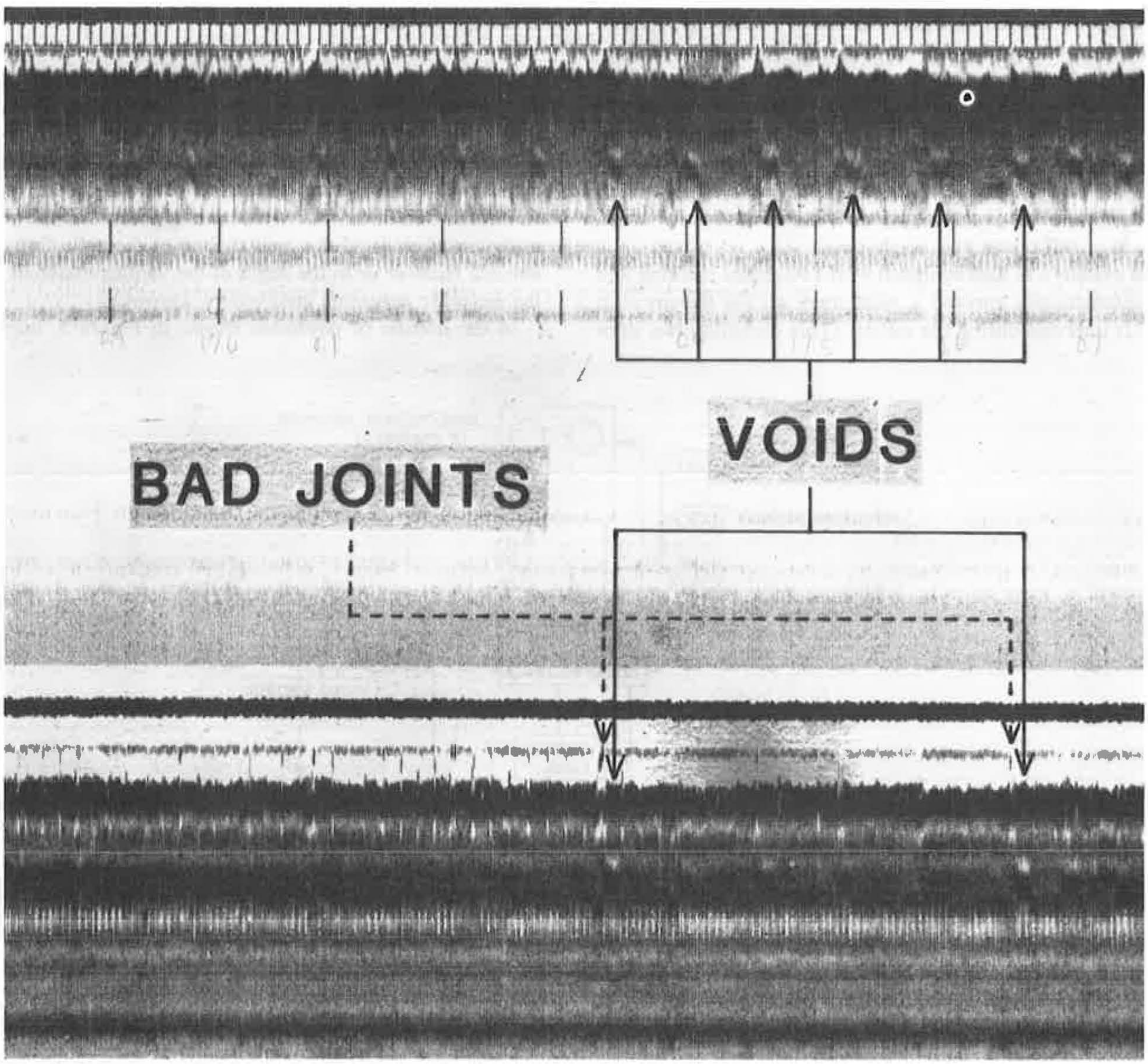

FIGURE 5 Reflection profile for a 950-ft section in the northbound travel lane of I-81 in Botetourt County, Virginia.

Detection and Location of Voids

Briefly stated, the detection and location of a void involves two steps: *(a)* sensing the reflection associated with the void by the radar unit and *(b)* location of the void, with respect to the entire pavement, by the location reference unit. Each step can contribute an error that affects the overall accuracy of a pavement survey.

Error from the Location Reference Unit

To determine the reliability of the location reference unit, the distances (to the nearest foot) between consecutive reference markers in a travel lane were measured. Each distance was then compared with the intended distance (or interval) of 1,000 ft.

The results, shown in Figure 6, indicated that the measured distances were consistently greater than 1,000 ft. The errors, which assumed a normal distribution, ranged from 0 to 10 ft and averaged 4 ft. These errors may have been caused by improper tire pressure in the fifth wheel and pulse counts missed by the optical encoder. This second source of error can be minimized by using an optical encoder that counts more than the 25 pulses per foot produced by the encoder used in this survey. Use of such an encoder would make occasional missed pulses less significant. It has also been suggested that mounting the fifth wheel at the center at either the front or the rear of the survey vehicle instead of at the side would minimize error.

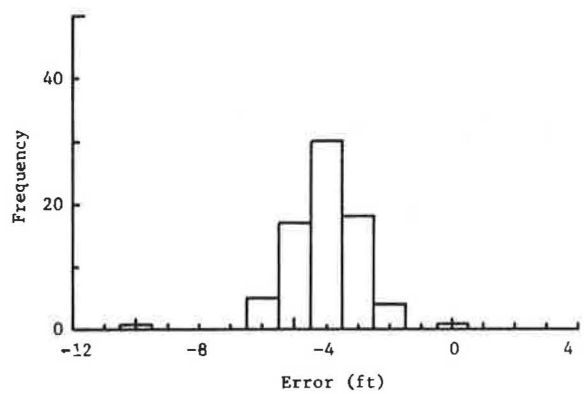

FIGURE 6 Observed errors in the location reference unit.

If sealing the detected voids is planned, reference marks with errors of such magnitude as those obtained in the study could not be used with confidence by maintenance crews. Fortunately, for jointed pavements such as the section of I-81 surveyed, this problem can be remedied by *(a)* associating each void with the slab that is above it and *(b)* locating this void in terms of its distance from the upstream joint or the beginning of the slab. This distance is then determined by subtracting the position of the upstream joint from that of the void (both positions are measured with the location reference unit).

Using a shorter spacing, say 50 or 100 ft, between the reference marks may render error less significant. For continuously reinforced concrete pavements, using a short spacing is the only recourse because the remedial procedure for jointed pavements is not applicable.

Error Associated with the Radar Unit

The characteristic reflection pattern of most voids is readily recognizable in a reflection profile (Figure 5). However, the reflections for very shallow or small (in area) voids may be so small in magnitude that they cannot be detected by the radar unit; or, if detected, they may not all be interpreted as voids by the user. The latter situation is likely to occur when the reflections received by the antenna are presented on graphs or a video monitor as bands of varying gray tones. The voids that are either undetected or misinterpreted contribute to the errors that affect the overall accuracy of the radar technique, which will be discussed in the next subsection.

Overall Accuracy of Radar in Detecting Voids

Cores were taken from some slabs to verify the presence of radar-detected voids. If the core dropped more than 1/8 in., it was obvious that a deep void was present. If the core dropped 1/8 in. or less, the hole was inspected for grout. If grout was found, it was obvious that the void had been filled with grout between the time the radar survey was conducted and the time the core was taken. If no grout was present, the hole was filled with water, and the quantity of water was measured. The volume of the void was then estimated by subtracting from the total volume of water used, the volume of water required to fill the hole in the slab and the volume that drained through the subbase material. As will be explained later, a volume of ≤ 0.005 ft^3 was not considered to be indicative of a void. If the water test did not indicate a void, the void condition was designated "uncertain."

The method used to determine the quantity of water that drained through the subbase material was based on the assumption that the flow through the subbase was at a constant rate. For a constant flow rate the volume of water that flowed through the subbase was assumed to be equal to the volume of water in the core hole in the slab, which was approximately 9 in. deep, multiplied by the time required to fill the subbase, void, and core hole and divided by the time required for the water to drain from the hole in the slab. Typically, from 10 to 30 sec were required to fill the subbase, void, and core hole in the slab, and 5 min were required for the water to drain from the core hole. An evaluation of the permeability of the subbase revealed that when the subbase consisted of a 2-in. layer of sand over material with a California bearing ratio (CBR) of 30, the permeability coefficient was approximately 10^{-3} cm/sec. Therefore the error in estimating the flow through the subbase was negligible because of the small amount of water that flowed through the subbase during the test. In areas where there was no sand over the CBR-30 material, the permeability coefficient was approximately 10^{-1} cm/sec. For this condition if the CBR-30 material was not saturated before the water test was run, it could absorb as much as 0.3 lb of water, which amounts to a volume of 0.005 ft^3. All but one void identified by the water test had a volume in excess of 0.005 ft^3. Therefore the test method was reliable for the project conditions.

Table 2 gives the void condition at the locations that were cored. The detailed radar analysis included corrections for errors due to the location reference unit and interpretation of

TABLE 2 VOID CONDITIONS DETERMINED BY CORING AND RADAR

Condition Based on Coring		Condition from Detailed Radar Analysis	
Condition	No. of Cores	Voids	No Voids
Uncertain	28	10	18
Shallow	39	21	18
Deep	29	26	3
Grout	7	4	3

data. It can be seen that 103 cores were taken. Unfortunately, at 28 locations there was uncertainty as to whether there was a void. At only 10 of these locations did the radar indicate that a void existed. A void condition could be determined by coring at 75 locations: a shallow void was found at 39 locations, a deep void at 29, and grout at 7. It is obvious from these data that the radar survey had a high rate of success when the voids were deep. Twenty-six (or 90 percent) of the 29 deep voids were located by the radar. On the other hand, the radar identified only about half (21 of 39) of the shallow voids. Thus, as would be expected, the survey showed that radar is more likely to miss small or shallow voids than large or deep voids. It can be seen that, overall, radar found confirmed voids 68 percent (51 of 75) of the time.

Estimation of Quantity of Grout

Estimating the quantities of grout needed for a stabilization operation has been quite difficult. Reported attempts to correlate initial pavement deflections and the volume of grout pumped have not been successful *(6)*. As a last recourse, various historical averages of quantities of grout per grout hole have been used, even though this approach lacks any scientific basis.

It is the belief of the authors that the radar survey technique has the potential to provide a sounder basis for estimating grout quantities from the extent of detected voids. Consider that, theoretically, the total quantity of grout used (say, in a day) should be equal to the total volume of all of the voids beneath the slabs grouted; that is,

$$G = \sum V_i \tag{4}$$

where

G = total quantity of grout in cubic feet,
V = volume of an individual void in cubic feet, and
i = 1, 2, 3, . . . nth voids.

It is conceivable that voids can assume different shapes or that, in a simple case, a majority could assume the shape of a rectangle, a triangle, or a combination of both. To simplify this discussion, assume that each void is practically a rectangle that can be defined by a width (W_i), a length (L_i), and a depth (D_i). The total volume could then be expressed so that Equation 4 becomes

$$G = \sum W_i L_i D_i \tag{5}$$

If the three independent variables can be measured by radar with reasonable accuracy, it should be possible to arrive at a reasonably accurate estimate of the quantity of grout needed to fill the voids.

Unfortunately, the radar used had two limitations that prevented the adoption of this rigorous approach. First, the radar gave limited areal coverage. This limitation is apparent in Figure 7, which shows an actual void that had been filled with grout then exposed by carefully removing the entire concrete slab. In this example, only about 40 percent of the void, the area directly below the coverage of one of the two antennas, would be detected; and only its length could be defined or measured. (This limitation can be easily eliminated by building a radar system with the capability of using three, or even four, antennas simultaneously. With such a system, both L_i and W_i could be estimated with better accuracy.)

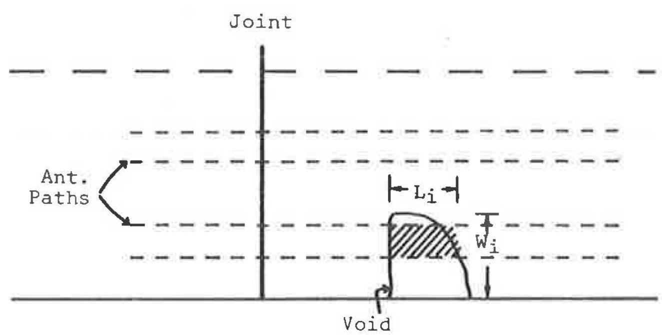

FIGURE 7 Limitation on coverage by radar; only the shaded portion of this void would be detected and defined by radar.

The second limitation concerned the determination of depth. As discussed earlier, most voids are no deeper than a few eighths of an inch, so the reflection from the bottom of a void (P3) would be overlapped by the reflection from the bottom of the slab (P2). This means that it would be extremely difficult, if not impossible, to estimate the time separation between these reflections so that the depth of a void could be calculated from Equation 3. This problem can be remedied by using the existence of a linear relationship between the amplitude of P3 and the void depth. This approach, however, also entails difficulty because it requires that a reasonably good correlation between these two variables be established by coring the pavement above a sufficient number of properly selected voids of various depths.

Because there was not sufficient information on void width and depth to make possible the use of the rigorous approach outlined in Equation 5, a simpler version was attempted.

Correlation of Grout Quantity with Length of Void

For a simpler version of Equation 5, it was assumed *(a)* that the depths of all voids were practically uniform (i.e., constant) and

(b) that the widths of all voids also were practically constant. It is obvious that the first assumption would be more acceptable than the second. Nevertheless, with these assumptions, Equation 5 becomes

$$G = WD \sum L_i = k \sum L_i \quad (6)$$

To determine the utility of this approach, the daily total quantities of grout pumped under various sections of pavement during 22 days of slab stabilization operations were measured. These daily total quantities were then correlated with the total length of radar-detected voids (in linear feet) underneath the slabs that were subsealed each day. (The pattern of grout holes used is shown in Figure 8. During the actual pumping of grout, the contractor and inspector used a modified Benkelman beam type of device to inspect and pumping was ceased when the grout appeared in adjacent holes or joints, to avoid raising any slab above grade.)

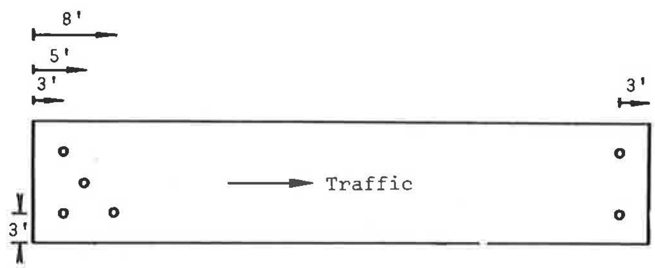

FIGURE 8 Pattern of grout holes used in slab stabilization.

As Figure 9 shows, there was only a 51 percent correlation between the lengths of the voids detected by radar and the quantities of grout used. It appeared that the correlation suffered at low void lengths, as is evident at the low end of the regression line.

The following points should be noted:

1. Any void in the area between the two antenna paths (Figure 5) obviously would not be detected and therefore was not included in the estimation of the total extent of voids, even though the void would be grouted.
2. Some of the detected voids were a considerable distance from joints, so they would be missed by the grout holes and not be filled.
3. There was a strong belief that more grout than was needed was pumped under some slabs, even though the construction crew took care not to lift the slabs.

Although the correlation was relatively poor, statistical tests indicated that the regression line was significant at the 95 percent probability level. This indicates that the rigorous approach to the estimation of grout quantities expressed in Equation 5 would be even more successful and should be tried as soon as the necessary three- or four-antenna radar units become available.

Other Uses of Radar Survey

Checking the Effectiveness of a Grouting Operation

So far the discussion has dealt only with the use of radar for detecting and locating voids under pavement slabs before pave-

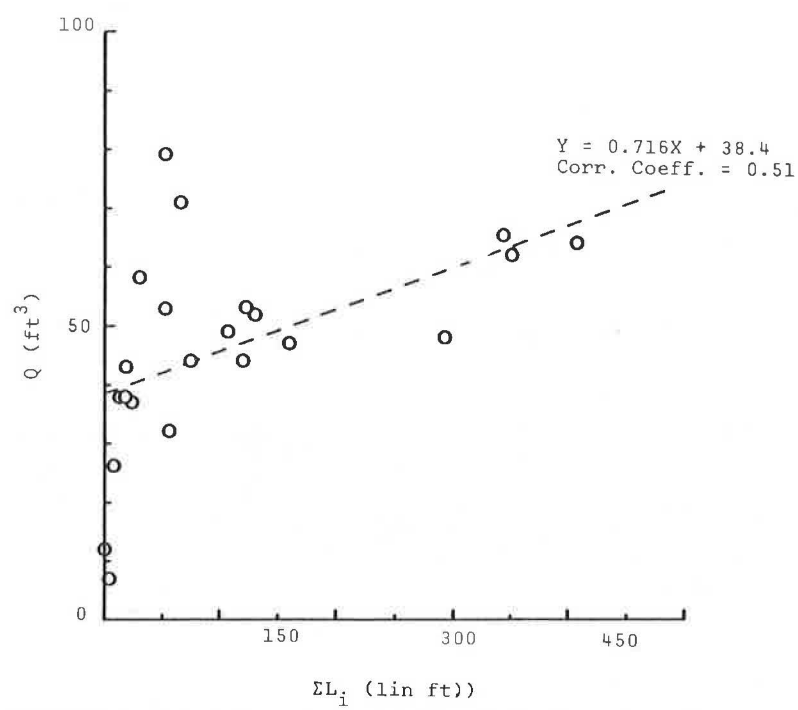

FIGURE 9 Correlation between total length of voids and grout quantity.

ment rehabilitation and restoration. Radar, however, can also be used after the repair to check whether the grouting operation was effective.

Figure 10 shows the reflection profile for a portion of the pavement that was covered in the radar survey and also happened to have been grouted during a preceding maintenance season. As is evident in this example, there was a sufficient difference between the dielectric properties of the grout and those of the base material for the presence of grout to be detected. More important, the profile also shows signs of voids in both antenna paths. It is possible that the voids were missed in the grouting operation or formed subsequently. There were also two joints that were likely to be defective; one happened to be next to the voids, and the other was only one slab (61.5 ft) away.

Designing Effective Patterns of Grout Holes

At the beginning of a slab stabilization project, it is common to select a pattern for the grout holes based on engineering judgment, and, depending on the results obtained during the course of the project, this may be changed. The information that radar provides on the location of voids can be useful in this selection process. To illustrate, consider some of the radar results obtained for the southbound lanes of I-81 that have yet to be rehabilitated. For some 13,000-ft sections of the southbound travel lane, where most voids were located, Figure 11 shows that, in general, a majority of the voids were centered around the joints for both wheelpaths. At the 3-ft wheelpath, 88 percent of the voids were centered within 7 ft downstream of a joint, 4 percent were centered within 2 ft upstream, and only 8

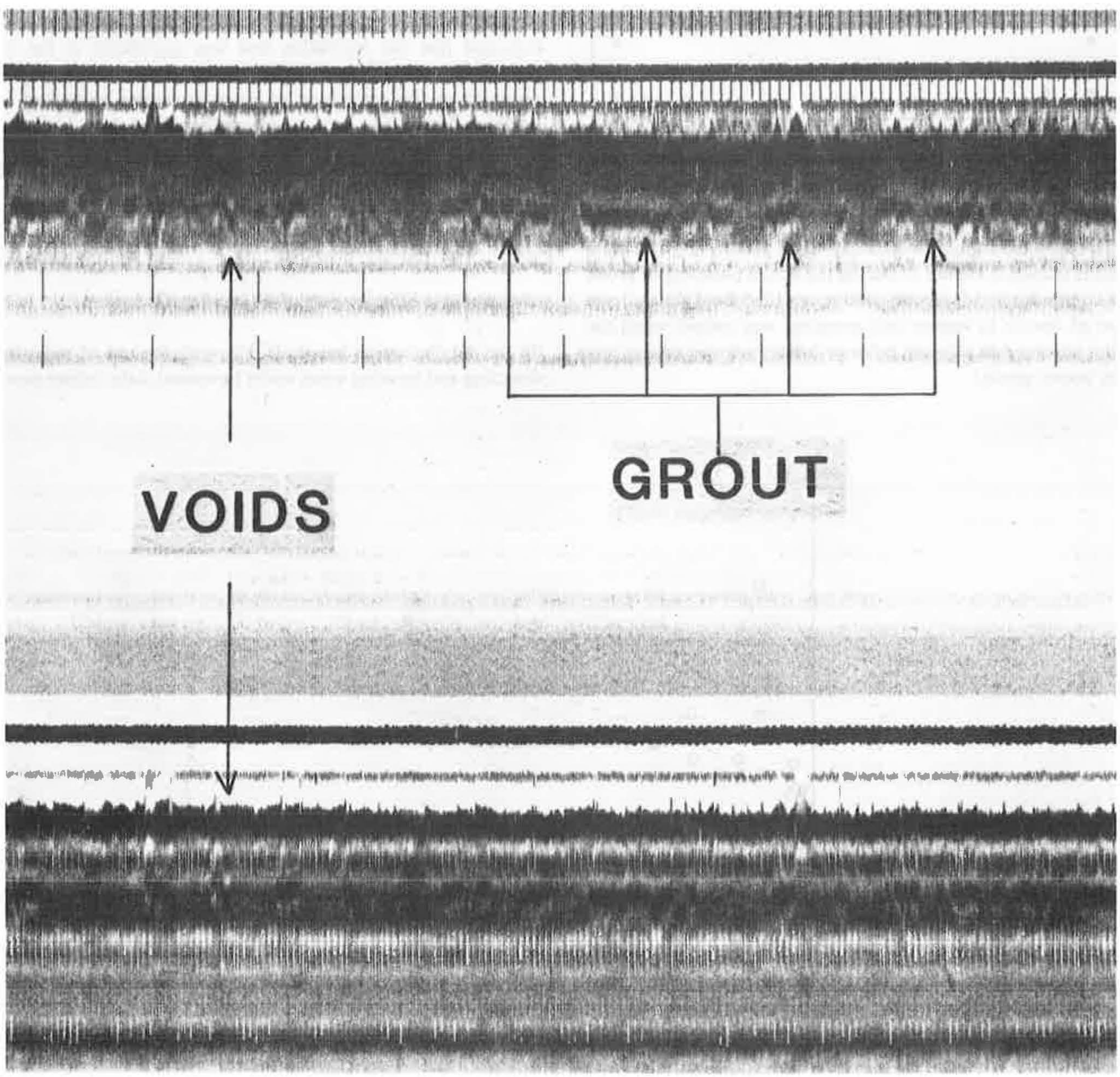

FIGURE 10 Reflection profile for a portion of a grouted concrete pavement showing grout and voids.

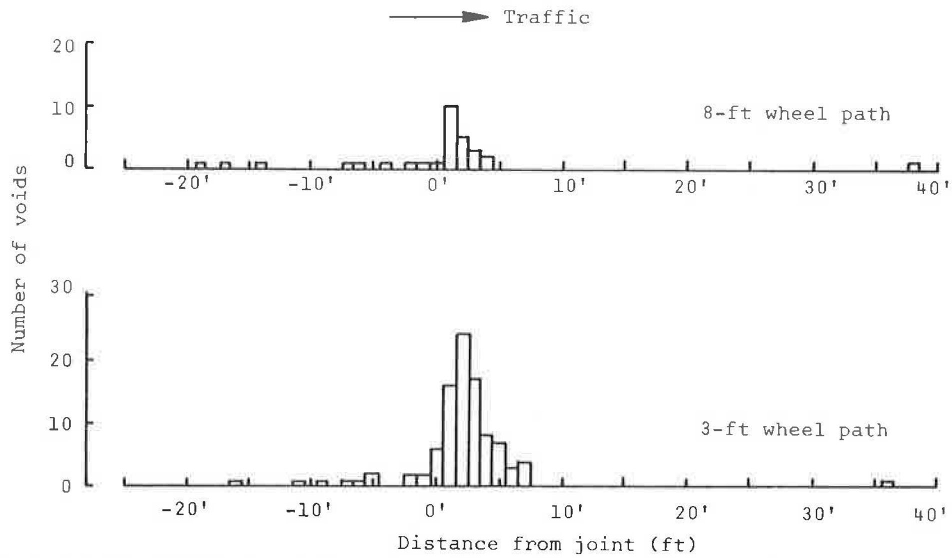

FIGURE 11 Distribution of the centers of the voids detected by radar in the southbound travel lane of I-81.

percent were relatively far from a joint. At the 8-ft wheelpath, 66 percent of the voids were centered within 4 ft downstream of a joint, 13 percent were centered within 2 ft upstream, and 21 percent were relatively far from a joint.

A further analysis can provide clues on how effective a specific hole pattern would be if used in filling these voids. Consider the use of the six-hole pattern shown in Figure 8 and assume that if a grout hole falls no farther than 1 ft from either end of a void, the void would be effectively filled by grout pumped from that hole. Also assume that the two top holes in this pattern coincide with the 8-ft wheelpath and that the three bottom holes coincide with the 3-ft wheelpath, thus allowing for some reasonable drifts around these intended wheelpaths during the survey. On the basis of these assumptions, the relative effectiveness of the grout holes, except the middle one, can be assessed.

Figure 12 shows the number of a particular grout hole that would coincide with a void, based on the analysis of 103 slabs. In the 8-ft wheelpath only 5 of the No. 1 holes and 19 of the No. 2 holes would hit or coincide with a void. The highest frequency of a hole coinciding with a void would occur at the No. 4 hole in the 3-ft wheelpath. At this location 76 of the 103 holes would coincide with a void. Also, note that, between the grout holes at each end of the slabs, 7 voids in the 8-ft wheelpath and 17 voids in the 3-ft wheelpath would not receive grout. It is obvious that, at a cost of $8.40 per hole, which equates to $63,000 for the 14.5 lane-miles, it would have been cost-effective to prepare the grouting contract on the basis of the results of a radar survey that cost only $6,000 for 14.5 lane-miles.

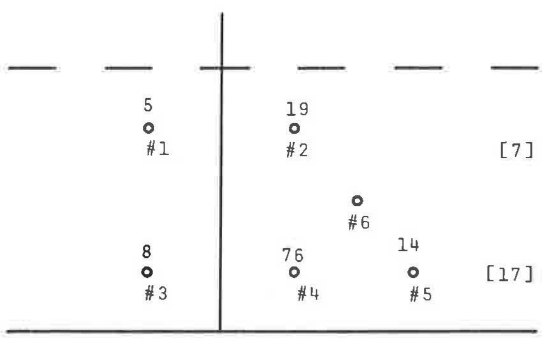

FIGURE 12 Number of each of the six standard grout holes that coincides with a void for 103 slabs; the bracketed numbers represent the number of voids in their respective vicinities that would be missed by the grouting operation.

Miscellaneous Uses

Other interesting information can be derived from the radar survey conducted on I-81. An example is shown in Figure 13, which shows the size distribution of voids detected by radar in the two southbound lanes. These log-normal distributions indicate that there were 10 times more voids in the travel lane than in the passing lane. (Similar types of distributions were observed for the northbound lanes, except that in the travel lane there were only four times more voids than in the passing lane.) Such a disparity between the extent of voids under a travel lane compared with a passing lane has also been inferred from reported deflection measurements made on concrete pavements. This disparity arose because travel lanes, in general, carry more traffic and more heavy truck traffic than do passing lanes.

Although not investigated in this survey, radar may also be useful in detecting poor drainage in a subbase, which is another cause of pavement distress.

CONCLUSIONS

On the basis of the preceding discussion, the following conclusions can be drawn:

1. A complete radar survey can be carried out at a minimum rate of 5 lane-miles of pavement per hour with minimal interruption of traffic.

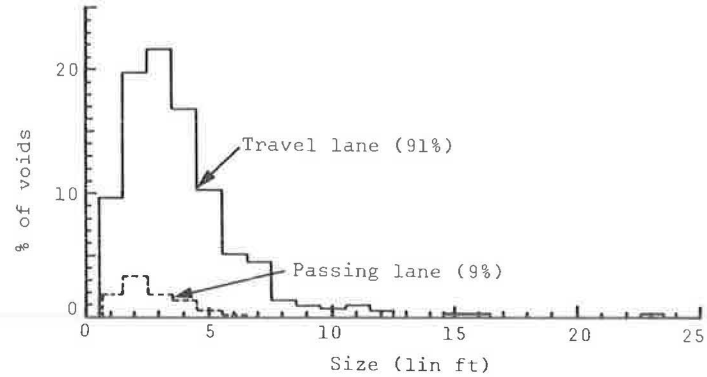

FIGURE 13 Size distribution of voids detected under southbound lanes of I-81.

2. The location reference unit used by the contractor in conjunction with his radar unit did not provide sufficient accuracy, which should probably be no less than ±1 ft.

3. Compared with data corrected for errors in the location reference unit and the interpretation of radar, cores taken from the slabs showed that the radar found known voids 68 percent of the time. As expected, radar found deep voids (>1/8 in.) 90 percent of the time and shallower voids only 54 percent of the time.

4. Despite this deficiency, GPR can already be used as a rapid nondestructive tool for surveying concrete pavement for underlying voids.

5. A regression analysis of data on daily grout quantities versus total linear feet of detected voids yielded a less than desirable degree of correlation (51 percent). This finding indicates that grout quantities cannot be estimated with reasonable accuracy from linear feet of voids detected.

6. However, the regression was statistically significant at the 95 percent probability level.

7. Radar surveys can be useful not only in detecting and locating voids before planning the stabilization of a concrete pavement but also for checking on the effectiveness of completed stabilization.

8. Radar surveys also provide information that is useful in deciding where to pump the grout for a cost-effective slab stabilization operation.

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