Final Report
Iowa Highway Research Board
Project HR-250

A NONDESTRUCTIVE METHOD FOR DETERMINING THE THICKNESS OF SOUND CONCRETE ON OLDER PAVEMENTS

Donohue & Associates, Inc.

December 1983

In Cooperation with the
Highway Division
Iowa Department
of Transportation

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IOWA DEPARTMENT OF TRANSPORTATION HIGHWAY DIVISION AND IOWA HIGHWAY RESEARCH BOARD

A NON-DESTRUCTIVE METHOD FOR DETERMINING THE THICKNESS OF SOUND CONCRETE ON OLDER PAVEMENTS

1983

RESEARCH PROJECT HR 250

Donohue

February 18, 1983

Iowa Department of Transportation
Highway Division
800 Lincoln Way
Ames, Iowa 50010

Attention: Mr. Vernon J. Marks
Research Engineer

Re: A Non-Destructive Method
For Determining The Thickness
Of Sound Concrete On Older
Pavements
Research Project HR-250
Donohue Project No. 11696.000

Dear Mr. Marks:

We are respectfully submitting our report which summarizes the results of the radar inspections conducted in 1982. The report documents the techniques and equipment used and summarizes the survey results. Additionally, the report summarizes the technical merits of the radar system.

Following your review of this report we would be pleased to meet with you to discuss the material contained herein.

Very truly yours,

DONOHUE & ASSOCIATES, INC.

William D. McElwee

William D. McElwee, P.E.
Vice President

WDM/pm

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A NON-DESTRUCTIVE METHOD FOR DETERMINING THE THICKNESS OF SOUND CONCRETE ON OLDER PAVEMENTS

FOR

IOWA DEPARTMENT OF TRANSPORTATION - HIGHWAY DIVISION

AND

IOWA HIGHWAY RESEARCH BOARD

RESEARCH PROJECT HR-250

Donohue & Associates, Inc.
Engineers & Architects

Project No. 11696.000

ACKNOWLEDGEMENTS

Iowa Department of Transportation - Highway Division

Vernon J. Marks, Research Engineer

Iowa Highway Research Board

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William D. McElwee, P.E., Vice President
Jerry W. Eales, P.E., Project Engineer

RESPONSIBILITY FOR CONTENT

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Highway Division of the Iowa Department of Transportation.

REFERENCES

Research Proposal for "A Non-Destructive Method For Determining The Thickness Of Sount Concrete On Older Pavements" presented to the Iowa Highway Research Board, Vernon J. Marks, July 20, 1982.

INTRODUCTION

The reduction in funds available for new highway construction has resulted in increasing emphasis being placed on maintenance and rehabilitation of existing pavements. This has in turn resulted in the need for testing equipment and cost-effective techniques that can nondestructively collect data on existing pavements to determine their present condition, predict the remaining life, and establish effective maintenance and rehabilitation programs.

A major problem affecting Portland Cement Concrete (PCC) pavements is severe joint deterioration. This joint deterioration manifests itself as corner cracking, offsetting of the pavement slabs at the joints, and the development of small cracks parallel to joints. A form of the latter, which has been observed not only at sawed joints, but also at random cracks and free edges of the pavement, has been given the name "D-cracking". D-cracking is believed to be a freeze-thaw induced failure of concrete, the severity of which has been associated with the durability of the coarse aggregate used for the concrete. The Iowa Department of Transportation (DOT) has established a relationship between the durability of the coarse aggregate, predominantly crushed limestone or dolomite, and the geographic location of the source from which it was obtained.

D-cracking appears to begin at the bottom of the slab. As deterioration increases the cracking expands both outward from the joint and upward from the bottom of the slab. A schematic diagram of D-cracking is shown on Figure 1. Identification of D-cracking at the joints is currently done by core drilling each joint. Visual observation of D-cracking from the surface is not possible until complete joint failure occurs. Core drilling is a time consuming and expensive process. Therefore, it would be advantageous if a rapid, non-destructive technique could be found to locate and assess the subsurface pavement deterioration.

PURPOSE

The primary purpose of this project was to assess the potential of a non-destructive remote sensing system, specifically, ground penetrating sub-surface interface radar, for identification and evaluation of D-cracking

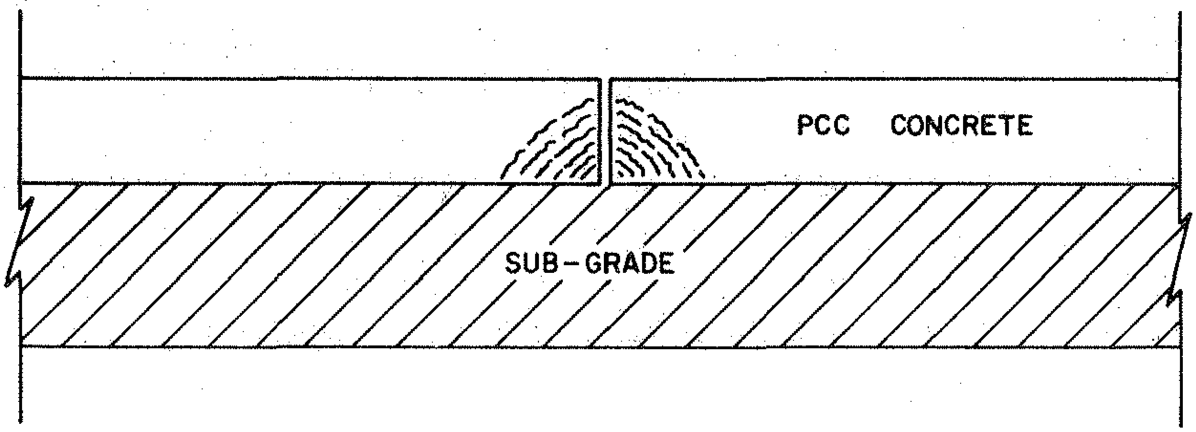

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FIGURE I
D-CRACKING

pavement failures. A secondary purpose was to evaluate the effectiveness of this technique for locating voids under pavements and determining the location of steel reinforcement.

EQUIPMENT AND OPERATING PROCEDURES

The radar equipment utilized for this study was a SIR System 8 manufactured by Geophysical Survey Systems, Inc. (GSSI). The system consists of a control unit, transducer (radar transmitter, receiver, and antenna), and an EPC model 2208S graphic chart recorder. The radar equipment operates on 12 volts DC which was obtained from the electrical system of the van used for the data collection. The chart recorder required 110 volts AC which was provided by a small gas driven generator.

Radar transducers operating at different frequencies and wave lengths can be used with this equipment. In general, lower transducer frequencies will yield greater depth of penetration of the radar signal, while higher frequencies, although not able to penetrate the earth as deeply, give the greatest resolution. This greater resolution gives the higher frequency transducers the ability to discriminate between closely spaced objects and interfaces. The antenna used for this study was a GSSI model 3100 which operates at a center frequency of 1 GHz ($1X10^9$Hz), which is the highest frequency available. This transducer yields the best near-surface resolution of those available while still providing adequate depth penetration for the purposes of this study.

In operation, a brief pulse of electromagnetic energy, 0.8 nanoseconds (0.8×10^{-9} seconds) is directed into the pavement. When this energy encounters an interface between two materials of differing dielectric properties a portion of the energy is reflected back to the transducer. The reflected energy is received by the transducer and processed within the control unit where it is amplified and the time differential between initial transmission of the electromagnetic pulse and the reception of the reflected wave is determined. The electromagnetic wave travels through the medium at a velocity dependent on its dielectric characteristics, so the time differential can be converted into depth. This requires knowledge of the dielectric constant of the medium or, more commonly, on-site determination of the depth of a visible radar target.

The electromagnetic pulse is repeated at a rate of 50 KHz (50 x 10^3 cycles/second) and the resultant stream of radar data is fed to the chart recorder where a continuous hard-copy profile of the data is produced as the transducer is moved along the surface.

At the control unit the operator has an oscilloscope display upon which the reflected wave form can be continuously monitored. Controls are also available which are used to adjust and optimize the wave form to produce the best output on the graphic chart recorder.

DISCUSSION

General

To test the effectiveness of ground penetrating radar as a non-destructive tool for pavement evaluation, 32 individual tests were undertaken. The tests were performed at 30 separate locations across the state from Council Bluffs to Dubuque from October 19 to October 21, 1982 and on December 21, 1982. The tests were performed to evaluate the system's ability to locate and determine the extent of "D-Cracking", void areas under the pavement, and the location of steel reinforcement within the pavement slab.

In the majority of the tests, four separate longitudinal scans were taken. These scans were 200 feet or more in length and were usually located 2 feet, 4 feet, 6 feet, and 8 feet from the reference edge of the pavement. These multiple scans were taken to assure adequate coverage and to permit verification and correlation of the data collected. Additionally, transverse scans were taken at some locations, primarily where the purpose of the investigation was to locate the steel reinforcement within the pavement.

The locations tested and the type of test conducted at each site are listed in Table 1.

TABLE 1

TES LOCATIONS

Test Number	Roadway	Location Milepost	Station	Type of Test
1	I-680	24.80	624-627	D-Cracking
2	I-680	24.80	624.50±	Steel placement
3	I-80	36.00	1428-1430	D-Cracking
4	I-80	62.00		D-Cracking
5	I-80	81.00		D-Cracking
6	I-80	87.00		D-Cracking
7	Adair P28	5.3 Mi S. of I-80		D-Cracking
8	Adair P28	9.3 Mi S. of I-80		D-Cracking
9	IA 92	94.00	202-204	D-Cracking
10	Madison P53	2.7 Mi N. of IA 92	139-141	D-Cracking
11	Madison P53	5.9 Mi N. of IA 92	312-314	D-Cracking
12	I-80	115.00	902-904	D-Cracking
13	I-35	92.20	269-	Voids
14	I-35	93.60	328-330	Voids
15	I-35	105.00	170-173	D-Cracking
16	I-35	110.00	434-437	D-Cracking
17	I-35	115.00	745-747	D-Cracking
18	I-35	115.00	745±	Steel Placement
19	U.S.30	147.90	123±	Steel Placement
20	U.S.30	147.90	1231-1233	D-Cracking
21	U.S.30	152.00	1397-1395 (W.Bound)	D-Cracking
22	U.S.30	175.00	323-325	D-Cracking
23	U.S.30	205.00		D-Cracking
24	I-80	194±	810-812	D-Cracking
25	I-80	195.00	860-862	D-Cracking
26	U.S.518		1255-1270	Steel Placement
27	U.S.151	53.40	404-	Voids
28	U.S.151	58.00	648-650	Voids
29	U.S.151	58.10	655-	Voids
30	U.S.151	58.50	665-667	Voids
31	U.S.151	61.10	810-812	Voids
32	Madison G4R		192-196	D-Cracking

Test Results Summary

The results of each individual test are summarized below. Examples of typical radar strip charts are presented on Figures 2 and 3. One complete set of the original radar charts have been provided to the Iowa Department of Transporation as part of this project.

Test Numbers 1,2; I-680, Milepost 24.8, Eastbound, Driving Lane

Scans taken at 1 ft, 5 ft, 7.5 ft and 10 ft N. of S. edge of pavement, 200 feet in length. Material - Portland cement concrete.

Anomolies indicating distressed pavement on all scans at stations 624+05, 624+11 and 624+14. Additionally, scan taken one foot from outside edge of pavement indicates distress at stations 624+17, 624+20 and 624+24. This test area included older pavement and new pavement patch. Base for older pavement is well-graded crushed gravel and that for patch is open-graded crushed limestone. Interface between concrete and limestone does not produce signal return nearly as strong as gravel-concrete interface at bottom of older pavement.

Transverse scan also taken at this location to determine location of load trasfer dowels. Core drilled over bar at point determined from radar data was within 1/8 inch of center of bar.

Test Number 3; I-80, Milepost 36.0, Eastbound, Driving Lane

Scans taken at 2.5 ft, 5 ft, 7.5 ft and 10 ft N. of S. edge of pavement, 200 feet in length. Material - Portland cement concrete -bonded overlay.

Anomolies indicating distressed pavement on all scans at stations 1428+35, 1428+50, 1429+28 and 1429+28 and 1429+38. Scan taken 2.5 feet from outside edge of pavement indicates distress over most of length. Additional interface visible 3 inches to 5 inches (varies) below surface.

Test Number 4; I-80, Milepost 62.0, Eastbound, Driving Lane

Scans taken at 2.5 ft, 5 ft and 8 ft N. of S. white edge line, 200 feet in length. Material - Asphaltic concrete over Portland cement concrete.

Interface at bottom of pavement masked by reinforcing mesh. Appears to be distressed pavement at third through sixth joints east of milepost 62. Full depth patch between first and second joints east of milepost 62. Base material under patch is different than that under balance of pavement. Interface visible 1 1/2 inch to 3 inches (varies) under surface.

Test Number 5; I-80, Milepost 81.0, Eastbound, Driving Lane

Scans taken at 2 ft, 4 ft and 8 ft N. of S. white edge line, 200 feet in length. Material - full depth asphalt.

Anomolies indicating distressed pavement at all joints from milepost 81.0 to 200 feet east (3 joints). Additional interfaces visible 2 inches to 3 inches below surface and 5 inches ± below surface. Interface 2 inches to 3 inches down not as well defined as other.

Test Number 6; I-80, Milepost 87.0, Eastbound, Passing Lane

Scans taken at 2 ft, 4 ft and 6 ft S. of N. yellow edge line, 200 feet in length. Material - Asphaltic concrete.

All scans show anomolies indicating distressed pavement at milepost 87.0 and at 39 feet and 70 feet east of milepost 87.0. Additionally, outer two scans (4 feet and 6 feet south of yellow line) indicate distressed pavement from 117 feet to 124 feet east of milepost 87.0.

Test Number 7; Adair County Road P28, 5 miles south of I-80, Southbound Lane Scans taken at 2 ft, 4 ft and 8 ft east of west pavement edge, 200 feet in length. Material - Portland cement concrete.

All joints show distress in pavement. Particularly severe at third joint past reference. Additional distressed area evident from approxiamtely 45 feet south to approximately 55 feet south of reference. On scans taken 4 ft, 6 ft and 8 ft from edge, distressed pavement is indicated between fourth and fifth joints past reference.

Test Number 8; Adair County Road P28, 9.3 miles south of I-80, Southbound Lane Scans taken 2 ft, 4 ft, 6 ft and 8 ft east of west pavement edge, 200 feet in length. Material - Portland cement concrete.

All joints show evidence of pavement distress. Also, area from reference joint to a point approximately 25 feet south appears distressed on all scans. Scan taken 2 feet from pavement edge shows distress along majority of its length except for area from third to fourth joints south (southerly 50 feet ±).

Test Number 9; IA Highway 92, Station 202 to 204, Eastbound Lane Scans taken 2 ft, 4 ft, 6 ft and 9 ft north of south pavement edge, 200 feet in length. Material - Portland cement concrete.

All joints show evidence of pavement distress. Additionally, scans 2 ft, 4 ft and 6 ft north of pavement edge show distress from station 203+60 to 203+65 and from 203+76 to 203+85.

Test Number 10; Madison County Road P53, Station 139 to Station 141, Northbound Lane. Scans taken 2 ft, 4 ft, 6 ft and 9 ft west of east pavement edge, 200 feet in length. Material - Portland cement concrete.

Joints appear sound. Possible minor distress at joints at stations 140+15± and 140+45± on scans taken 2 ft, 4 ft and 6 ft from pavement edge.

Test Number 11; Madison County Road P57, Station 312 to 314, Northbound Lane
Scans taken at 2 ft, 4 ft, 6 ft and 9 ft west of east edge of pavement, 200 feet in length. Material - Portland cement concrete.

Distressed pavement indicated at all joints and at stations 312+28, 312+35, 313+45 and 313+64 on all scans. Additionally, scan taken two feet from edge of pavement shows distress from station 312+18 to approximately 312+84.

Test Number 12; I-80 Milepost 115.0, Station 902 to 904, Eastbound Outside Lane
Scans taken at 2 ft, 4 ft and 9 ft north of south pavement edge, 200 feet in length. Material - Portland cement concrete.

Very irregular pattern at bottom of pavement interface indicate pavement distress over majority of area. Particularly evident on scan taken 2 feet from pavement edge and appears most severe at stations 902+45, 902+70, 902+95, 903+05, 903+60 and 903+70 on all scans.

Test Number 13; I-35, Milepost 92.2, Station 269 to Bridge, Northbound, Driving Lane
Scans taken at 2 ft, 4 ft, 6 ft and 9 ft west of east pavement edge. Material - Portland cement concrete.

Pavement base one inch to two inches thinner from fifth joint to seventh joint south of bridge. Pavement distress evident at sixth joint south of bridge. Voids under pavement evident at second and fifth joint north of station 269+00 and at first slab south of bridge on all scans.

Test Number 14; I-35, Milepost 93.6, Station 328 to Bridge, Northbound, Driving Lane

Scans taken 2 ft, 4 ft, 6 ft and 9 ft west of east pavement edge. Material - Portland cement concrete.

Radar signature indicative of void under pavement immediately south of bridge abutment. First joint south of station 329+00 shows evidence of pavement distress on all scans and evidence of void on scan taken 2 feet from edge of pavement.

Test Number 15; I-35, Milepost 105.0, Station 170 to 173, Northbound Driving Lane

Scans taken 2 ft, 4 ft, 6 ft and 9 ft west of east pavement edge, 300 ft in length. Material - Portland cement concrete.

Evidence of pavement distress at joints at station 171+00 and 172+45. Minor distress indicated at joints at stations 170+20 and 171+75 (more severe at 2 ft and 4 ft from east pavement edge).

Test Number 16; I-35, Milepost 110.0, Station 434 to 437, Northbound, Driving Lane

Scans taken 2 ft, 4 ft, 6 ft and 11 ft west of east pavement edge, 300 feet in length. Material - Portland cement concrete.

Evidence of pavement distress at all joints on all scans. Additional indication of distress at station 435+15 on scan 2 feet from pavement edge.

Test Numbers 17 and 18; I-35, Milepost 115.0, Station 745 to 747, Northbound Driving Lane

Scans taken 2 ft, 4 ft, 6 ft and 9 ft west of east pavement edge, 200 feet in length. Material - Portland cement concrete.

Severe interference from reinforcing steel at this test site obscures data. Evidence of pavement distress at stations 745+50 and 746+20 on all scans. Test number 18 was run as demonstration to locate reinforcing steel.

Test Numbers 19 and 20; USH 30, Milepost 147.9, Station 1231 to 1233, Eastbound Lane

Scans taken 2 ft, 4 ft, 6 ft and 9 ft north of south pavement edge, 200 feet in length. Material - Portland cement concrete.

Evidence of pavement distress at all joints on all scans. Test number 20 was run as demonstration to locate steel load transfer dowels.

Test Number 21; USH 30, Milepost 152.0, Station 1397 to 1395, Westbound Lane

Scans taken 2 ft, 5 ft, 8 ft and 11 feet south of north pavement edge, 200 feet in length. Material - Portland cement concrete.

Pavement distress evident on all scans at joints at stations 1395+80 and 1396+20. Scans at 2 ft, 5 ft and 8 ft indicate pavement distress at joint at 1396+40. Scans at 5 ft, 8 ft and 11 ft indicate pavement distress at joints at 1395+20 and 1396+80.

Test Number 22; USH 30, Milepost 175.0, Station 323 to 325, Eastbound Lane

Scans taken at 2 ft, 5 ft and 8 ft north of south pavement edge, 200 feet in length. Material - Portland cement concrete.

No significant evidence of pavement distress on any scan.

Test Number 23; USH 30, Milepost 205.0, Eastbound Lane

Scans taken at 2 ft, 5 ft and 9 ft north of south pavement edge, approximately 200 feet in length. Material - Asphaltic concrete over Portland cement concrete.

Distressed pavement indicated approximately midway between first and second joint east of milepost 205 and at second and twelfth joints east of milepost 205 on all scans. On scans taken 5 feet and 9 feet from pavement edge, distress is evident at sixth and eleventh joint east of milepost 205.

Test Number 24; I-80, Milepost 194.0, Station 810 to 812, Eastbound, Passing Lane

Scans taken 2 ft, 5 ft, 8 ft and 11 ft south of north pavement edge, 200 feet in length. Material - Portland cement concrete.

Pavement distress evident on all scans at stations 810+10, 810+20, 810+60, 811+14 and 811+32. Scans taken at 2 ft, 5 ft and 8 ft showed evidence of distress at station 811+85. Scans taken at 2 ft and 5 ft indicate distress at 811+54. On scan taken 2 ft from edge, distress is evident at stations 810+52, 810+81 and 811+69.

Test Number 25; I-80, Milepost 195.0, Station 860 to 862, Eastbound, Driving Lane

Scans taken at 2 ft, 5 ft, 8 ft and 10 ft north of south pavement edge, 200 feet in length. Material - Portland cement concrete.

Pavement distress evident on all scans at stations 859+92, 860+17, 860+23, 860+72, 861+47, and 862+23. On scan taken 2 feet from edge of pavement, additional distress noted at stations 860+09, 860+33, 860+52, 860+84, 861+09, 861+26 and 862+00.

Test Number 26; USH 518, Station 1262+37

Several tranverse scans were taken to determine the location of steel load transfer dowels.

Test Number 27; USH 151, Milepost 53.4, Station 404± to Bridge, Eastbound Lane

Scans taken at 2 ft, 5 ft and 9 ft north of south pavement edge, approximately 200 feet in length. Material - Asphaltic concrete over Portland cement concrete.

No evidence of voids detected on any scan.

Test Number 28; USH 151, Milepost 58.0, Station 648 to 650, Eastbound Lane

Scans taken at 3 ft, 6 ft and 9 ft north of south pavement edge, 200 feet in length. Material - Portland cement concrete.

No voids detected on any scan. Pavement has been mud jacked.

Test Number 29; USH 151, Milepost 58.1, Eastbound Lane

Scans taken at 3 ft, 6 ft and 9 ft north of south pavement edge, approximately 200 feet in length from milepost 58.1 to bridge. Material - Portland cement concrete.

Evidence of void area under pavement toward west one-half of slab between third and fourth joints west of bridge. All scans also show evidence of pavement distress at fifth and seventh joints west of bridge.

Test Number 30; USH 151, Milepost 58.5±, Station 665 to 667, Eastbound Lane Scans taken at 3 ft, 6 ft and 9 ft north of south pavement edge, 200 feet in length. Material - Portland cement concrete.

No evidence of voids under pavement. Pavement distress evident on all scans at stations 665+80, 666+20, 666+40, 666+60 and 666+80. Additionally, scan taken 3 ft from pavement edge shows evidence of distress from station 666+25 to station 666+50. Some distress also evident in same area on scan taken at 6 feet, but to lesser extent.

Test Number 31; USH 151, Milepost 61.1, Station 810 to 812, Eastbound Lane. Scans taken at 3 ft, 6 ft and 9 ft north of south pavement edge, 200 feet in length. Material - Portland cement concrete.

No evidence of voids under pavement. Pavement has been mud jacked.

Test Number 32; Madison County Road G4R, Station 192 to 196, Eastbound Lane. One longitudinal scan taken 2 feet north of south pavement edge, 400 feet in length. Additional four foot long longitudinal scans and two transverse scans taken at joints at stations 193+70 and 196+40±.

This test was run on December 21, 1982. Chart was recorded on newly acquired Adtek SR8000 graphic chart recorder.

Distress is evident at stations 192+10, 192+50, 192+90, 193+30, 193+70, 194+90, 195+30 and 195+70. Joints at 194+10 and 194+50 appear to be sound. Additional pavement distress is indicated from approximately station 193+40 to station 193+45.

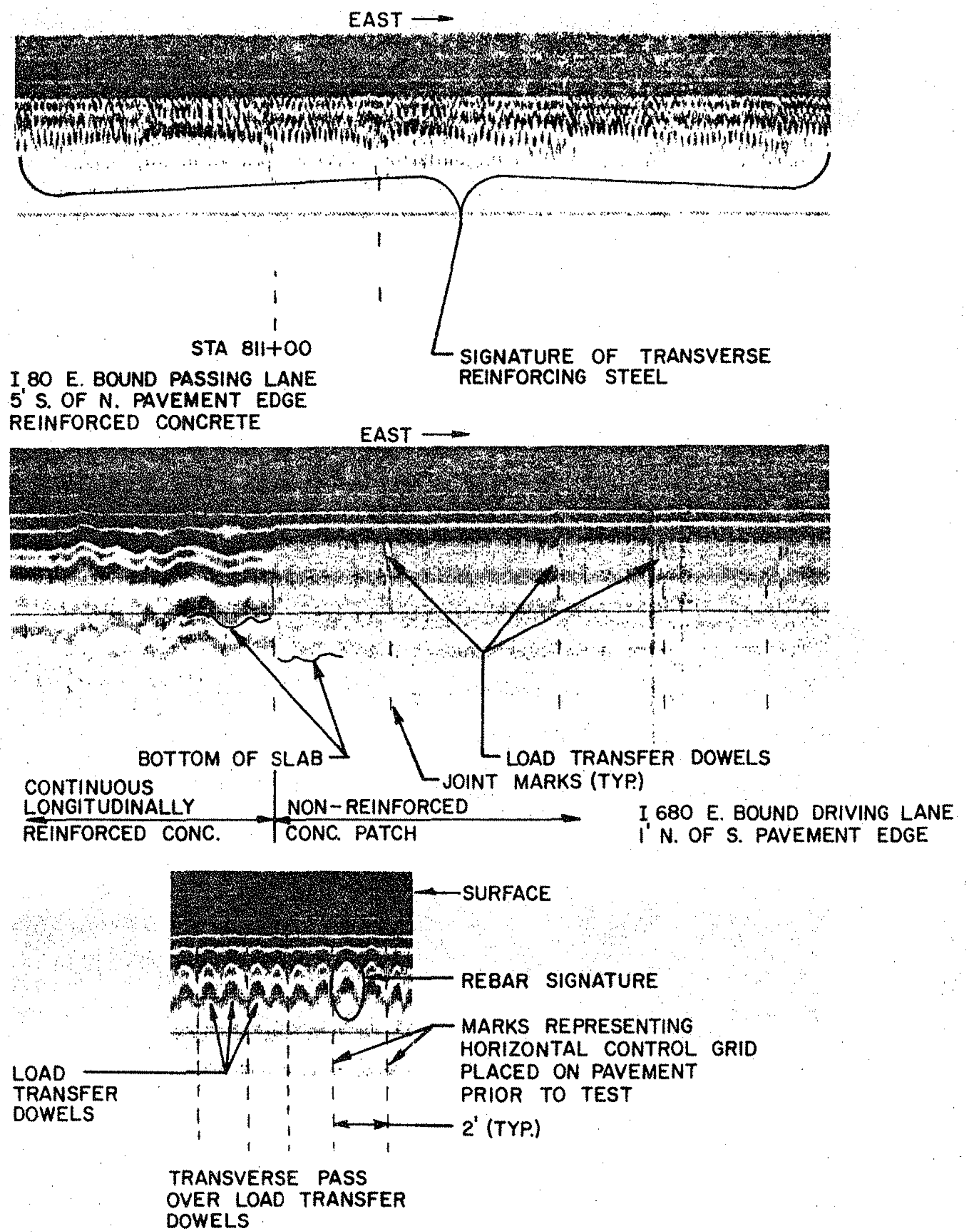
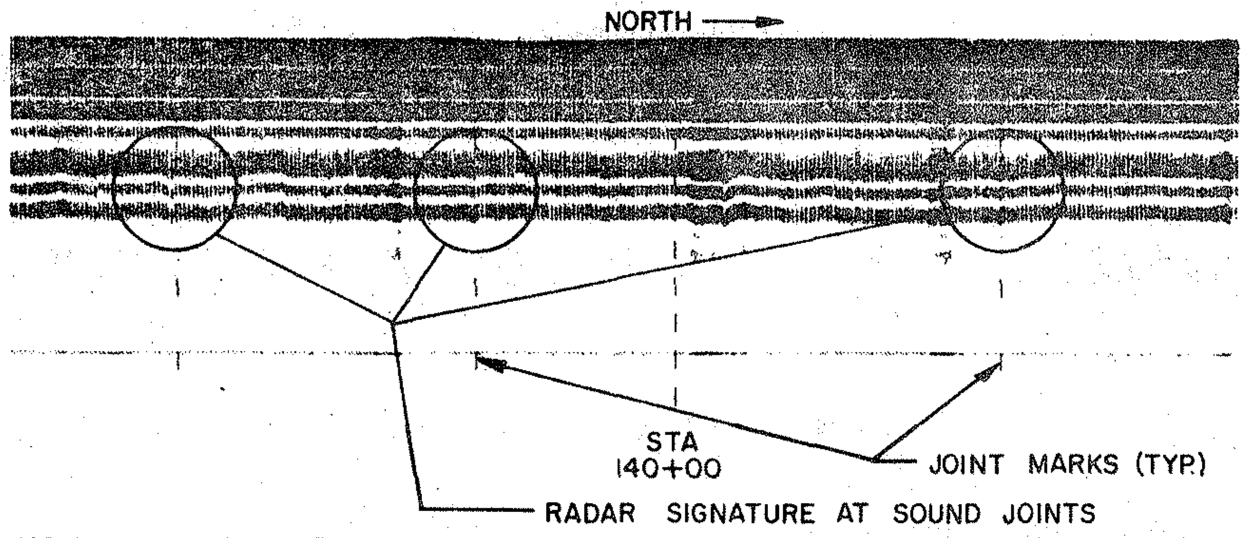
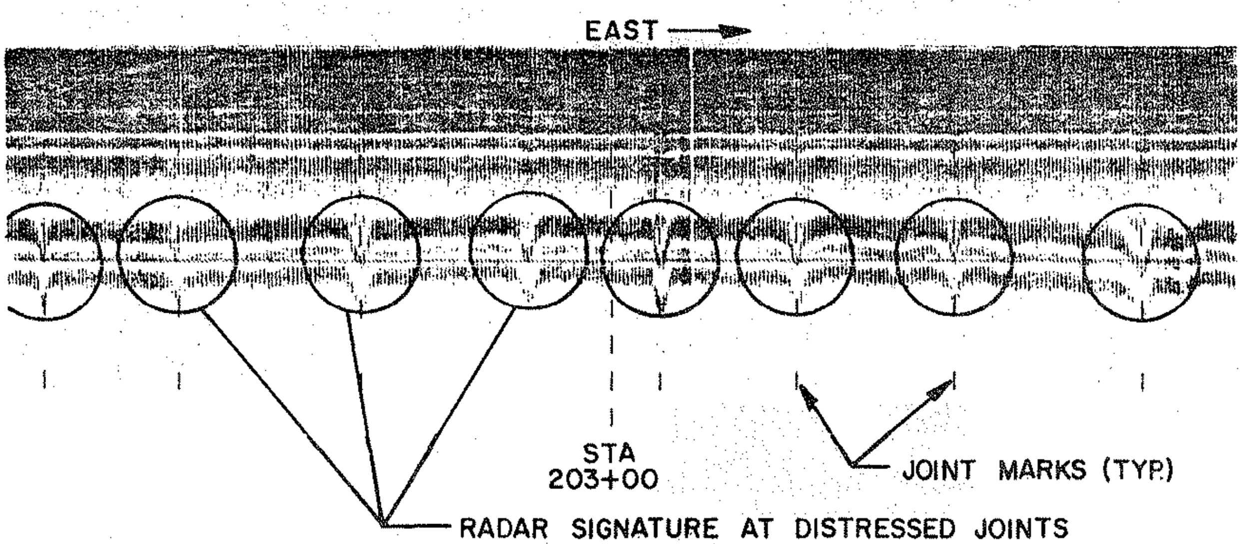


FIGURE 2
RADAR SIGNATURES AT STEEL REINFORCEMENT



MADISON CO. RD. P-53
N. BOUND LANE
9' W. OF E. PAVEMENT EDGE
NON-REINFORCED CONCRETE



IOWA HIGHWAY 92
E. BOUND LANE
6' N. OF S. PAVEMENT EDGE
NON-REINFORCED CONCRETE

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FIGURE 3
RADAR SIGNATURES AT SOUND AND DISTRESSED JOINTS

Verification of Radar Inspection Results

To adequately assess the effectiveness of the ground penetrating radar system as a tool that can be used in the future to identify the types of pavement failures investigated under this study, it will be necessary to conduct a pavement coring program. The data collected under such a program will provide the field truthing necessary to prove the accuracy of the radar system to identify pavement and subsurface defects.

Ideally, pavement cores should be taken at every joint on all of the test locations and at every additional pavement failure that was identified. This would be a massive undertaking, however, and it is felt that with careful selection of the truthing locations, a valid data base can be established from which to assess the accuracy of the system.

To assure the validity of the data, the locations selected should include several from each category of failure investigated as well as a significant sampling of locations that appear on the radar charts to be free of defects. Additionally, there were several locations at which the radar signature was marginal and it was difficult to assess whether or not a particular failure was being observed. Coring of these locations will provide further verification and, additionally may provide data that will allow some degree of quantification of the suspected failure. Table 2 provides a listing of the suggested coring locations.

System Evaluation

From the results of this study to date several conclusions can be drawn regarding the suitability of the radar system used and of the data collected. Further determinations will be possible following collection and evaluation of the coring data.

TABLE 2

SUGGESTED CORING LOCATIONS

Test Location	Roadway	Station	Lateral Location	Remarks
5	I-80	All 3 cracks	Any	
6	I-80	120 ft ± E. of MP 87	4' to 6' S	
8	Adair P28 9.3 mi S. of I-80	25' S	4' E	
		130' S	2' E	
		180' S	2' E	
10	Madison P53	140+15	4' W	@ joint
		140+45	4' W	@ joint
		139+80	4' W	@ joint
11	Madison P53	312+28	2' W	
		313+64±	4' W	
		Any joint	Any	@ joint
12	I-80	902+95	4' N	
		203+60	Any	
13	I-35	Just N. of 2nd jnt N of 269+00	4' W	check for void
		Just N. of 5th jnt N of 269+00	4' W	check for void
		1st slab S of bridge	2' W	check for void
14	I-35	1st slab S of bridge	4' W	check for void
		1st jnt S of 329+00	2' W	check for void
15	I-35	170+20	2' W	@ joint
		170+20	6' W	@ joint
		170+20	9' W	@ joint
17	I-35	745+50	2' W	
		745+50	4' W	
		746+50	2' W	
		746+50	4' W	

TABLE 2 (continued)

Test Location	Roadway	Station	Lateral Location	Remarks
21	US 30	1395+20	2' S	@ joint
		1395+20	5' S	@ joint
22	US 30	Any	Any	2 cores where distress is suspected
24	I-80	811+14	5' S	
		811+32	2' S	
27	US 151	Any	Any	2 cores where void is suspected
28	US 151	Any	Any	2 cores where void is suspected
29	US 151	W. half slab between 3rd & 4th jnt W of bridge	Any	Check for void
		5th jnt W of bridge	9' N	
30	US 151	665+80	3' N	
		Any	Any	2 cores where void is suspected
32	Madison G4R	193+43	2' N	
		193+70	2' N	@ joint
		194+50	2" N	@ joint

The transducer selected for use on this project, a GSSI Model 3100, appears to have been an appropriate choice for detection of the types of pavement structure failures being investigated. This unit was selected because it operates at a high frequency which gives it the ability to resolve closely spaced, near surface interfaces. The high frequency operation does, however, limit the depth of penetration of the signal, but the depth of penetration observed on this project was adequate at all locations tested.

Of the specific categories of tests made under this study, there is no question of the system's ability to locate reinforcing steel within the pavement structure. The difference between the dielectric constants of the steel and of the surrounding concrete is extremely large and the return signal from this interface is unmistakeable. The only limiting factor regarding the accuracy of this data is the accuracy and frequency of the horizontal grid placed on the pavement for marking and referencing the strip charts. Figure 2 is an example of the signature of a series of reinforcing bars.

The data collected to date also indicate that qualitative judgements can be made regarding the presence of D-cracking at joints and random cracks. The radar signatures at joints known to have this failure appears distinctive and is significantly different than that at joints that are known to be sound. Figure 3 illustrates examples of the strip charts at both D-cracked and sound joints. Cores taken at joints identified as having this failure as well as at those presumed to be structurally sound will further verify this conclusion.

At D-cracked joints, it was believed that the system would be able to detect the thickness of the remaining sound concrete over the distressed zone. This does not appear to be possible with the graphic recording equipment that was used for this study. Observation of the return signal on the oscilloscope display revealed that information is present on the return wave form in the zone of sound concrete. However, both graphic chart recorders used for this project, and probably this type of recording device in general, have insufficient resolution and inadequate gray-scale capabilities to depict these very subtle changes in the wave forms. For these reasons, the joints listed in Table 1 at locations inspected for the presence of D-cracking are listed only as "distressed". It was not felt that the specific nature of the distress could be determined from the data collected. It does appear that broad categorization of the severity of the distress may be possible however, as examination of the signatures on figure 2 reveals some size differences in the joint anomolies. This may allow identification of joints as "moderately distressed", "severely distressed", etc. The Summary of Test Results contains some locations where this type of quantification was made. The coring results will serve to verify this conclusion.

A similar observation was made regarding the detection of voids under pavement slabs. The graphic chart recorders used for this project do produce a distinctive signature when voids are encountered, but quantitative judgements as to the size of the void area, particularly when it is small and the interfaces are closely spaced, are difficult to make.

The graphic chart recorders used for this project have proved to be excellent devices for many applications in the past and the results of this study further substantiates their value. They will adequately depict pavement thickness, reinforcing steel location, and can allow qualitative judgements to be made regarding distress zones in pavements and void areas under slabs. It is apparent, however, that an improved recording device is required that will allow additional quantitative evaluation of pavement structure defects. In an attempt to address this requirement, an oscillographic recorder has been purchased and this device will be interfaced with the radar system in the near future. This recorder will print out individual facsimilies of the return wave forms which will allow closer examination and identification of closely spaced interfaces necessary to make the desired evaluations.

Conclusions

From the data collected and the analysis performed to date, the following conclusions can be made regarding the ground penetrating radar system used for this study:

1. Steel reinforcement can be accurately located.

2. Pavement thickness can be determined.

3. Distressed areas in pavements can be located and broadly classified as to severity of deterioration.

4. Voids under pavements can be located.

5. Higher resolution recording equipment is required to accurately determine both the thickness of sound pavement remaining over distressed areas and the depth of void areas under pavements.

Part II
Iowa Department of Transportation
Discussion of the Donohue Engineers and Architects Report Entitled:
A Non Destructive Method for Determining
the Thickness of Sound Concrete on Older Pavements

OBJECTIVE AND ADDITIONAL STUDIES

The major objective of this research was to evaluate the potential of determining the thickness of sound concrete by ground penetrating or down looking radar. In addition to the main objective, radar surveying was to be conducted of voids, steel placement and thickness of a concrete slab.

FIELD SURVEYS BY DONOHUE AND ASSOCIATES

Donohue and Associates visited Iowa and conducted a testing survey from October 19 through October 21, 1982. Donohue personnel were not entirely satisfied with the operation of their strip chart recorder or their magnetic tape recorder during the first visit to Iowa. An improved strip chart recorder and magnetic tape recorder were added to the ground penetrating radar system and additional testing was conducted in Iowa on Madison County Road G4R between Des Moines and Winterset on December 21, 1982. Donohue personnel were again not entirely happy with the resolution of the thickness of sound concrete remaining at a D-crack deteriorated transverse joint. Donohue personnel indicated that an improved computer system for analyzing and resolving that data was soon to be developed and that they would be returning to Iowa to demonstrate the newest innovation in the near future. On October 12, 1983 Donohue and Associates visited Iowa and conducted testing again on Madison County Road G4R. Iowa DOT personnel were expecting some updating of the initial Donohue and Associates report. Communication with Donohue and Associates personnel indicated that the data obtained on October 12, 1983 did not significantly alter the data contained in the report. The Donohue personnel would then allow the report to remain as previously submitted.

THICKNESS OF SOUND CONCRETE AT A DETERIORATED JOINT

As noted in Figure 3 of the Donohue and Associates report there is a definite difference between the radar signature at sound joints and the radar signature at distressed joints. Iowa DOT personnel had indicated to Donohue and Associate personnel the desire to be able to identify the sound concrete remaining at a deteriorated joint within 1 inch. As noted in the Donohue and Associate report, a potential of that capability was demonstrated. Donohue and Associates, however, in their conclusions note that higher resolution recording equipment is required to provide this capability. The October 12, 1983 field testing was the final effort under this project to demonstrate that higher resolution with the computer reduction system could determine sound concrete to an accuracy within one inch.

IOWA DEPARTMENT OF TRANSPORTATION CORE DRILLING

Cores were drilled on April 15, 1983 in an effort to determine the validity of the data provided by the ground penetrating radar system. A core was drilled on October 19, 1982 during the first field testing by Donohue and Associates to calibrate the thickness of pavement as identified by the ground penetrating radar. Donohue and Associates indicated In Figure 2 that the thickness of the initial slab was near 8 inches and the thickness of the new patch was near 10 inches. A core drilled over this location yielded the fact that the original concrete measured 7 3/4 inches and the new patch was ten inches. The ground penetrating radar, therefore, exhibited an excellent capability after being calibrated of determining the thickness of the slab at least within ± 1/2 inch. Due to personnel and time limitations, cores were not drilled at all of the suggested core locations of Table 2 of the Donohue and Associate report. Cores, however, were drilled from test locations 2, 10, 11, 12, 13, and a series of cores at test location 32.

VERIFICATION OF TEST LOCATION 2 - STEEL PLACEMENT

The ground penetrating radar was utilized to locate a 1 1/4 inch dowel bar 4.8 inches deep in the concrete. A core drilled at that time indicated that the radar determined the location of the steel within 1/2 inch, not 1/8 inch as noted in the Donohue report. The Donohue down looking radar, however, is not presently designed to locate steel. An improved system for steel location could be developed if this were desired. At present a grid system is laid out over an area, the radar antenna is passed across the grid and impulses are placed at the grid lines. From this data the steel location is identified. If a computerized system could be developed to indicate the maximum deviation of the strip chart signal, this would yield a more accurate steel identification system.

VERIFICATION OF TEST LOCATION 10 - SOUND CONCRETE

Donohue and Associates report noted possible minor distress at the joint at station 140+15. A core was drilled at this joint and some cracking was identified at the bottom of the core which corresponds to the results indicated by the ground penetrating radar.

VERIFICATION OF TEST LOCATION 11 - SOUND CONCRETE

The Donohue and Associate report indicated distressed pavement at the joint at station 312+28. A core was drilled at that location and the core was determined to be sound, but with some aggregate fracturing.

VERIFICATION OF TEST LOCATION 12 - SOUND CONCRETE

The Donohue report indicated a very irregular pattern at the bottom of the pavement interface indicating pavement distress over the majority of the area. Core drilling on April 15, 1983 at station 902+95 revealed a core in excellent condition. This pavement has mesh reinforcement which may have caused the irregular pattern which was interpreted as pavement distress as noted in the Donohue report.

VERIFICATION OF TEST LOCATION 13 - VOIDS

The Donohue report noted voids under the pavement at the second and fifth joints north of the station 269. Cores were drilled at these locations and a 1/4 inch void was identified at the second joint north of 269 and a 1/2 inch void was identified at the fifth joint north of 269. Again the Donohue ground penetrating radar had properly identified these voids.

VERIFICATION OF TEST LOCATION 32 - SOUND CONCRETE

Nine cores were drilled on this Madison County Road G4R between stations 192+90 and 193+42. A complete analysis of these cores was not completed due to the conclusion by Donohue and Associates that they could only indicate deterioration on a general scale which might be indicated as slight, moderate, substantial and extreme.

VERIFICATION OF TEST LOCATION 26 - STEEL PLACEMENT

Ground penetration radar data at two transverse joints on U.S. Highway 518 at station 1262+40 and 1263+00 indicated a skew deviation from parallel to centerline on both of these locations. Subsequent core drilling indicated a skew deviation at the station 1262+ 40, but indicated a dowel bar parallel to centerline at 1263+00.

IOWA DOT CONCLUSION

From the research conducted by Donohue and Associates, it can be concluded that:

1) The ground penetrating radar system demonstrates a definite potential for accurately determining:
    a. steel reinforcement placement
    b. pavement thickness
    c. thickness of sound concrete in distressed areas
    d. voids under pavement slabs
2) Higher resolution equipment is needed to provide the accuracy desired by the Iowa Department of Transportation to determine the items listed above.