VALUE ENGINEERING

EVALUATION OF A GROUND PROBING RADAR DEVICE FOR DETECTING VOIDS WITHIN AND BENEATH CONCRETE
(Type B Study)

Caltrans

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
OFFICE OF VALUE ENGINEERING

EVALUATION OF A GROUND PROBING RADAR DEVICE FOR DETECTING VOIDS WITHIN AND BENEATH CONCRETE
(Type B Study)

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16. ABSTRACT

The Penetradar Corporation short pulse radar Model PS-24 was subjected to a limited evaluation to determine its effectiveness in detecting small voids beneath PCC pavement slabs. Its ability to determine delamination between pavement layers and delamination of concrete caused by rebar corrosion was also evaluated. The results of this study indicated that the Model PS-24 in its present state of development is not suitable for this type of work.

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INTRODUCTION

Aberrations in the form of voids sometimes develop in and around certain concrete elements of highway facilities. Their presence is a manifestation of some adverse condition that threatens the service life of the concrete in question. Of particular concern in this study were voids associated with the following:

(1) Pavement slabs - Voids develop beneath concrete highway pavements because of the pumping action of the slabs. The presence of free water, curled slabs from temperature and moisture gradients, and heavy wheel loads combine to provide this mechanism. The result is pumping and erosion of the base material, nonuniform support of the pavement slab, and eventual breakup of the concrete.

(2) Bridge approach slabs - Consolidation of embankments and subsidence of original ground results in the settlement of pavement abutting bridge structures founded on piles. As this condition develops, the bridge approach slab must span the void thus formed. Overstressing of the slab and eventual breakup usually follow.

(3) Bridge deck delamination - The penetration of deicing chemicals into deck concrete causes corrosion of reinforcing steel. As rust forms, the increase in volume stresses the concrete, thereby resulting in separation of the concrete and the reinforcement.

In the three conditions mentioned above, early and accurate detection of voids is highly desirable in order that effective repair and restoration can be accomplished.

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Pressure grouting with a cement-fly ash slurry is used to restore support to pavement slabs and bridge approaches. Correcting deck problems involves removal of the delaminated concrete, cleaning or replacement of the steel, and construction of a bonded deck patch.

Accurate information about the location and extent of the void system would allow a better assessment of the particular problem and would mitigate the unknown conditions which tend to complicate rehabilitation contracts.

Methods of Void Detection

Numerous approaches have been tried to locate voids beneath concrete surfaces. By far the most successful and most widely used is the simple practice of dragging a short length of chain over the suspect area. The audible ring of the links of chain changes perceptibly when going from sound concrete to delaminated areas. Tapping the surface with a hammer will achieve the same result. Large areas can be surveyed quite efficiently under ideal conditions. However, limitations are imposed by the human response factor and ambient noise levels. Audible detection of voids is only successful on relatively thin layers of concrete such as that associated with deck delamination. It does not serve to locate voids beneath thicker sections such as pavement and approach slabs.

Coring of the concrete can be used to provide definitive information at a specific location. However, this operation has serious limitations and is quite expensive, requiring lane closures, special equipment, and patching materials, all of which are labor intensive.

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More sophisticated systems have been developed in several technological disciplines. These include: (1) ultra sonics, (2) infrared photometry, (3) pavement deflection measurement, and (4) concrete penetrating-radar.

Research conducted by others for NCHRP and presented in Report 237(1) proved that radar technology as incorporated in fairly recently developed equipment has the sensitivity and accuracy, under controlled conditions, to provide the location and size of underlying voids. The radar equipment used in the NCHRP study was manufactured by Penetradar Corp. and was chosen over several other approaches incorporating radar because it was more advanced in the detection of voids.

The research which is reported herein was completed by TransLab under the Value Engineering Research Project titled "Detecting and Sizing Voids Under Pavement and Detecting Delamination of Concrete." This was a federally financed Type B Study.

The data were collected and summarized in a report provided by Penetradar Corporation of New York under Value Engineering Project No. 13-625104, Contract G13,558 which is appended. The field work by Penetradar Corp. was performed between June 20 and 23, 1983.

CONCLUSIONS AND RECOMMENDATIONS

1. The Penetradar PS-24 is not suitable for purposes of detecting and measuring small voids or delaminations.

2. Further research with this particular equipment is not recommended.

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DISCUSSION

Objectives of This Research

The objectives of this research were to evaluate the effectiveness of Penetradar Corp. radar Model PS-24 in detecting:

1. Small voids (0.1-0.25 inch) typical of those beneath faulted pavement joints,

2. Large voids (0.25-8 inches or more) typical of those beneath bridge approach and leave slabs,

3. The extent of delamination in bridge decks due to rebar corrosion, and

4. The extent of delamination or loss of bond of surface overlays (PCC over PCC and AC over PCC).

Methodology

Radar waves that strike metallic objects (conductors) tend to be almost entirely reflected whereas radar waves

striking nonconductors (dielectrics) tend to be absorbed. The absorbed radio frequency (RF) wave will propagate through the dielectric material until it strikes a boundary or discontinuity. At this point, a portion of the RF energy will be reflected and a portion will be transmitted through the boundary. In theory, the very short pulse time (1 nanosecond) should allow maximum resolution of boundaries or discontinuities for resolution and thereby indicate the location and size of any subsurface discontinuities.

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Equipment

The equipment studied consisted of a radar transmitter/ receiver, radar main console, oscilloscope and antenna. This assortment of equipment was mounted on a wood cart which the Penetradar Corporation called their Model PS-24 radar (refer to Photos 1 and 2).

Description of Test Specimen and Sites

Test Specimen #1. - 0.27' x 1' x 7' polymer concrete (QM867) epoxy bonded overlay on PCC (slab edges debonded).

Test Specimen #2. - 0.25'x 1' x 8' portland cement concrete, grout bonded overlay on PCC (slab edges debonded).

Test Specimen #3. - 0.25' x 3' x 3' portland cement concrete grout bonded overlay on PCC (slab edges debonded).

Test Specimen #4 - 0.45' x 6' x 7' reinforced concrete slab (severe delamination of the slab caused by rebar corrosion).

These test specimens had been cast as a part of other ongoing Transportation Laboratory research projects.

Test Site #1. Eastbound #2 lane of the Sly Park Bridge deck on 3-ED-50. The deck is AC on PCCP with possible delaminations and corrosion of rebars.

Test Site #2. Southbound lane #4 of the Church St. U.C. approach slab on 10-SJ-5. This experimental 70 foot long reinforced slab has capped holes through the slab for the purpose of studying the development of voids beneath the slab.

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Penetradar Corp. Model PS-24

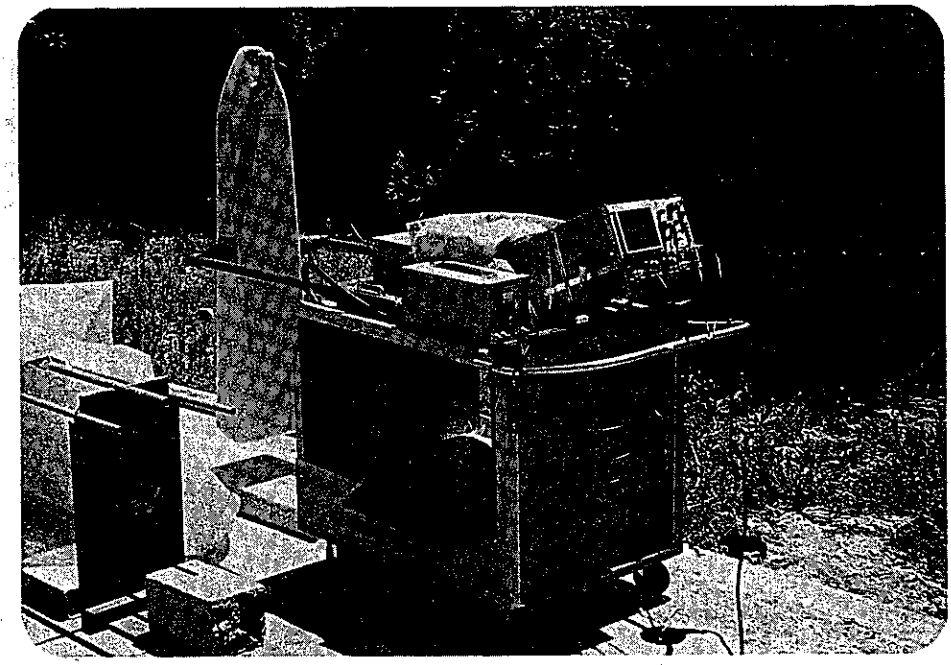

Photo #1

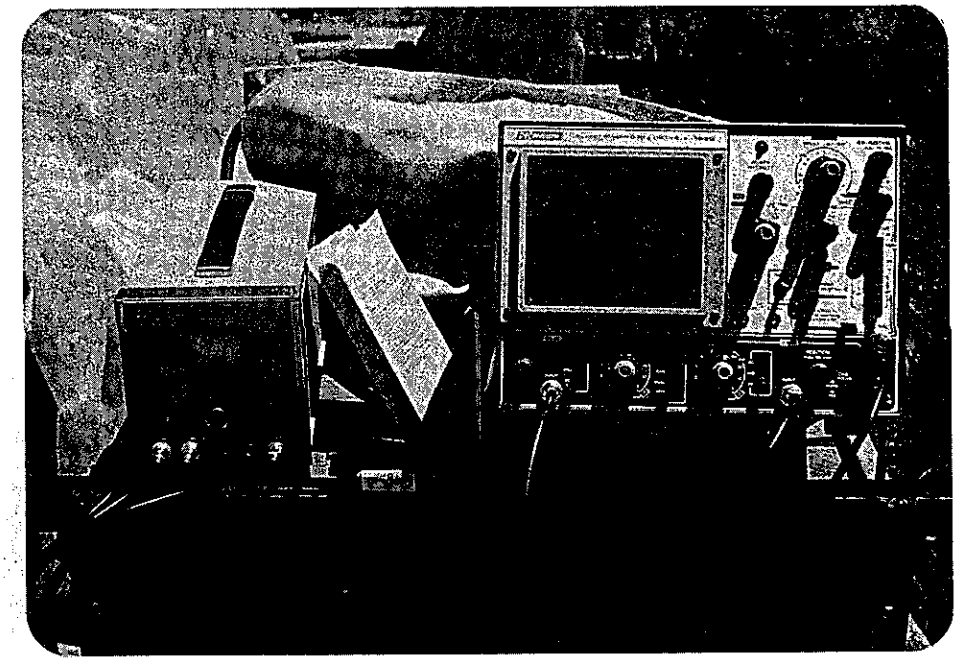

Photo #2

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Evaluation of Effectiveness

Evaluation of the PS-24 oscilloscope traces of the various bonded and debonded test slabs indicated that it would be difficult or impossible to predict the presence of small voids (<1/8") under a PCC slab or a delaminated thin slab.

Radar estimates of known overlay thickness varied as much as 3/4" from actual thicknesses.

Drawbacks to Penetradar PS-24 equipment for detecting and measuring voids (test specimens 1, 2 and 3) is that it must be "calibrated" for a particular pavement and void location. This would require extensive coring and lane closures and thereby eliminate its practical use as a survey type technique. Penetradar Corporation's report indicates that this equipment is not suitable for determining if delaminations are present along the edge of bonded concrete slabs. The presence of water in voids underneath PCC slabs produces wave forms that could not be interpreted by Penetradar personnel. Because water commonly occurs in this situation, the application of this equipment is severely limited.

Radar traces of the severely delaminated reinforced concrete slab did not indicate the presence of any delaminations in test specimen #4.

Radar traces of the reinforced concrete bridge deck (test site #1) were difficult to evaluate due to the amount of reinforcing steel, which acted as a conductor. This tended to indicate the presence of voids when there were none.

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The Penetradar PS-24 was unable to evaluate test site #2 because data could not be interpreted by Penetradar personnel.

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APPENDIX

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SUMMARY REPORT

CONTRACT NO. G13,558

SEPTEMBER 12, 1983

This work was performed for the State of California
Department of Transportation

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1.0 Introduction

A Penetradar unit was utilized in a series of tests at the Caltrans, Translab facility on June 20th, at the Caltrans Sly Park bridge deck undercrossing on June 21th and at the Caltrans Stockton, Church Street undercrossing approach slab on June 22.

Test results in the Translab facility were inconclusive since test conditions were not conducive for proper evaluation of the radar equipment. Tests on the Sly Park Bridge were recorded and brought back to the Penetradar facility for processing. Computer generated maps of the inspected part of the bridge deck are presented in this report. Some areas of weak disturbances are indicated on the maps. No regions of serious disturbance were detected or indicated on the maps. Tests for the presence of voids beneath a 12" thick approach slab at the Stockton, Church Street undercrossing were negative. The radar did not penetrate the slab material, however, the radar easily penetrated the adjacent concrete bridge deck and even detected the presence of the supporting structure beneath the bridge deck pavement. Subsequent tests with the same radar equipment on a 12" solid concrete wall at the Penetradar facility showed that it was easily penetrated and the echoes from the front and back surfaces are normal. The attenuation of the signal through the wall and the time delay of the echo for that thickness is normal for concrete. That data is also included in this report. It is suspected that the Stockton bridge approach slab contains some substance making it impervious to penetration by the radar signal.

2.0 Translab Tests

2.1 Comments on Site Test Conditions

In order to obtain useful test data with the PS-24 Penetradar equipment certain requirements on the test conditions must be met. It will be noted that these test requirements were not satisfied during the radar inspection of selected test specimens located within the Translab test site.

2.1.1 Test Area Size

The inspection specimen size, length and width, should be at least as large as the antenna footprint, 9" by 12" or greater. For test areas smaller than 9" by 12" such as the thin bonded test slabs, the antenna will illuminate not only the slab but also the base and the edges. Each of these will give rise to its own echo so that the net result is a signal which is a composite of all three echoes. This complicates the signal so that it may be difficult to isolate the signal from the disturbed

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region from the unwanted signals. Under normal highway conditions the area is many times larger than the antenna spot size so that unwanted echoes described above are not present. For disturbances smaller in area than the antenna footprint, the signal arising from the disturbance will be proportionately smaller than the signal would be if the disturbance covered the entire antenna footprint. In the case of the thin bonded slab, debonding was suspected along a narrow region near the edge of the slab. This region was much smaller than the antenna footprint yielding inconclusive results. Generally, under real highway conditions, the disturbances are large in cross sectional area relative to the footprint of the antenna. These disturbances have been detected by radar.

2.1.2 Discrete Verses Continuous Test

Some types of pavement disturbances produce signals which are readily discernable with either discrete or continuous testing such as air filled voids beneath pavements while other disturbances such as delamination or deterioration of concrete internal to the pavement are best detected with continuous testing. Voids are detected by their very characteristic waveshape, negative going and then positive going, the void thickness also determines the amplitude of the waveshape as well as the duration of the waveshape.

Inspection of pavement for an internal disturbance such as delamination or deterioration is best accomplished by means of continuous testing. Data are taken and recorded continuously as the radar is moved over a test site at a relatively constant speed. Review of the recorded data will show that a disturbed area of concrete, such as an internal region of delamination, the echoes arising from it will show an increse in signal amplitude and maximize over the disturbance when the antenna footprint completely illuminates the disturbance. The signal will then decrease in amplitude as the antenna footprint is displaced off of the region of disturbance.

2.2 On Site Tests

2.2.1 Equipment Setup

Monday morning, June 20, was spent assembling the radar equipment, oscilloscope, and instrumentation tape recorder on the Translab test cart and was checked out for proper operation. Modifications were made to the cart for installation of the distance marker wheel.

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2.2.2 On Site Translab Tests

These tests were performed on Monday afternoon on test specimens located on Translab site.

a. Thin Bonded Slab
On monday afternoon radar tests were performed for debonding on a thin bonded concrete slab. The slab was approximately 8" wide by 3" thick. The width of the slab was approximately the width of the antenna footprint, however the area of the debonded surface was a small proportion of the antenna area. This made detection of the debonded area virtually impossible. Debonding was suspected to be present by Caltrans but was not positively verfied. In conclusion, this particular test specimen was not appropriate for radar evaluation of debonding.

b. Thick Bonded Slab
Radar tests were performed on a three foot by three foot concrete slab bonded to a concrete base. Low level signals were observed around the edges of the slab which may have been caused by debonding, the edge effect or a combination of both. Tests were inconclusive due to the test conditions.

c. Delamination Test
Discrete radar tests were performed on a concrete slab with rebars for the presence of delamination. Different signals were observed at different portions of the slab. The testing was static and photographs taken at fixed locations, the corners and the center of the slab. Photographs were retained by Caltrans personnel. Since the tests were not performed in a continuous manner it was difficult to make a relative determination of good and bad spots.

d. Tests were performed on a large concrete slab which utilized a hydraulic press to simulate pumping action in concrete pavement. The slab was soaked with water to provide moisture for the pumping action. This setup was designed to simulate conditions which produce voids, however, it is not certain whether voids actually existed. If they did exist it is unknown whether they would be water filled or air filled. In any event, the signals observed were unfamiliar and not like the usual air filled void signals. These signals could have been produced by water filled or by rubber filled voids used to simulate air filled voids. Rubber has a much higher dielectric constant than air, therefore, for radar it is not a good simulation of an air filled void.

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2.3 Sly Park Tests

Radar tests were performed on tuesday morning at the Sly Park undercrossing, Route 50 Eastbound number 2. lane. The lane was tested in five passes, three of these passes were recorded on magnetic tape and analyzed at the Penetradar facility. The bridge deck consists of approximately 3 - 4 inches of asphalt/concrete over six inches of reinforced Portland cement concrete. The inspection passes were west to east and forty meters in length. The inspection swath was approximately one foot in width. The radar equipment was mounted on a wooden cart, furnished by Caltrans, and inspection passes were made at walking speeds. The three passes which were recorded were #1, at the north most end of lane two, pass #2 which was three feet south of pass #1 and pass #3 which was three feet south of pass #2. Computer assisted manual processing techniques were employed in the analysis of the data. The data was played back on an oscilloscope, when the signals observed appeared to be caused by delamination their presence was manually indicated to a computer which automatically logged their location. Upon completion of the test run the data was organized into maps by the computer. The data was viewed three separate times and three bridge deck maps were generated, one for each time the data was analyzed.

Comparison of the three maps generated indicates good correlation between the detected disturbances. Correlation between maps helps decrease false targets with this method of processing. Valid targets should appear fairly consistantly in each of the maps and in approximately the same location. Map No. 2, pass 1 at 24 meters shows a probable false target since it does not appear in the other maps. Likewise the area between 16 through 18 meters, passes 1,2,3 shows a consistant detection,since the disturbance occurs in all three maps. Pass 3, between 25 and 31 meters seems to represent a region of disturbance. The point in pass three at approximately 12 meters appears to be an isolated disturbance and may be a rebar junction, as it does not extend spatially. The clustering within a particular map tends to improve upon successive inspections of the data as the detection decision making criteria becomes better defined.

In summary, the percentage disturbance was about 5% of the inspected deck area, however, the signal levels were quite low indicating the deterioration was at a relatively early stage. The signals were very low level, therefore the false alarm will increase since these signals are the same level as those from rebars. Normally signals from delamination or deterioration are many times the amplitude of those from rebars. It should be emphasized that the detection technique used employs a manual decision making process. The computer is used to log the location of the disturbance, organize the data and generate the bridge map. Some variability is introduced by the human operator in the decision making process as indicated by the difference in the three maps.

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A fully automated, signal processor will eliminate this variability between inspection runs and yield more consistant analysis of the data. This type of processor is presently under development.

2.4 Stockton Approach Slab Tests

On wednesday tests were performed on the approach slab on Route 5 at the Stockton, Church Street undercrossing. The approach slab was constructed with 12 inch thick concrete. Holes were bored through the slab with metering rods in place to indicate the void depth. The radar inspection consisted of three passes 1.5 feet apart with the center pass directly over the metering rods. In all three passes no echoes were present from pavement depths greater than two or three inches. Beyond the three inch depth no signals were present except the residual internal radar noise. Tests were run on the radar equipment to verify that it was operating correctly. A flat plate calibration test confirmed proper operation of the system. By placing the radar equipment on the bridge deck it further verified that the equipment was operating correctly as the radar signal easily penetrated the bridge deck concrete slab. Radar echoes were received from the bottom as well as from the support structure beneath the deck. This leads us to believe that some unusual condition was present in the approach slab which caused a very high attenuation or loss of the radar signal in the approach slab. This caused the void signals from beneath the slab to be non-discernable. Later tests on a 12 inch Portland cement concrete wall with the same equipment at the Penetradar facility show that the 12 inch wall was easily penetrated.

2.5 Twelve Inch Concrete Wall Tests

A test was performed at the Penetradar facility to evaluate the penetration capability of the radar, the same unit that was used in the Caltrans tests. The test site consisted of a 12 inch thick Portland cement concrete wall. The radar signal easily penetrated the wall as illustrated in the accompaning data. Figure A. is the radar transmitter waveform. Figure B. is the radar echo from a flat metal plate held against the end of the antenna. A metal plate represents a perfect reflector of radar waves. The significance of this test is to demonstrate the absence of reverberation within the radar system. This property allows the detection of small signals such as those from voids, delamination and other signals arising from within the pavement structure. Figure C. shows the radar signals from the front surface of the wall and from the back side of the wall. The time delay between the two echoes corresponds to 5.25 divisions on the figure. For dry concrete 2.4 inches of thickness corresponds to one division on the figure. The radar thickness measurement is therefore 12.6 inches. This gives a measurement deviation of approximately 5%. This measurement

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deviation can be further reduced by calibration of the radar time base.

3.0 Conclusions

Results at the Translab facility were inconclusive because test conditions were not appropriate for radar testing. Test conditions should meet the criteria stated in section.2.1.

Sly Park computer generated maps indicated some evidence of low level deterioration for the bridge deck area that was tested. It would be useful to map out the remainder of the bridge deck and to periodically test it over a long term in order to determine the life cycle of a bridge deck pavement. This type of information would be useful for pavement life management.

The Stockton approach slab yielded no void data because of the inability to penetrate the media. Tests on the adjacent bridge deck which had a higher concentration of rebar were positive. The bridge deck was easily penetrated. Additional tests on a 12 inch concrete wall at a Penetradar facility was also easily penetrated. It is unknown why the radar signal did not penetrate the Stockton approach slab. It is suggested that the composition of the approach slab be examined for the presence of unusual materials.

The radar equipment has demonstrated the ability to detect voids beneath the pavement and delaminations within bridge decks as found by many highway orgainzations. It is therefore suggested that in order to more properly evaluate the usefulness of this radar for rapid, non-destructive inspection of Caltrans highways and bridge decks, that a more extensive and detailed test program be implemented over a more appropriate time period such as three months. Penetradar would be willing to provide a set of radar equipment and train Caltrans personnel on the proper operation of the equipment.

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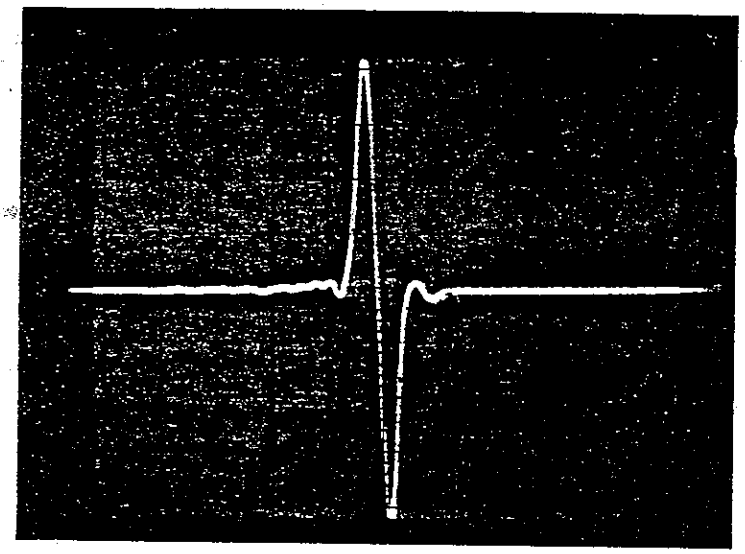

FIGURE A

Transmitter waveform

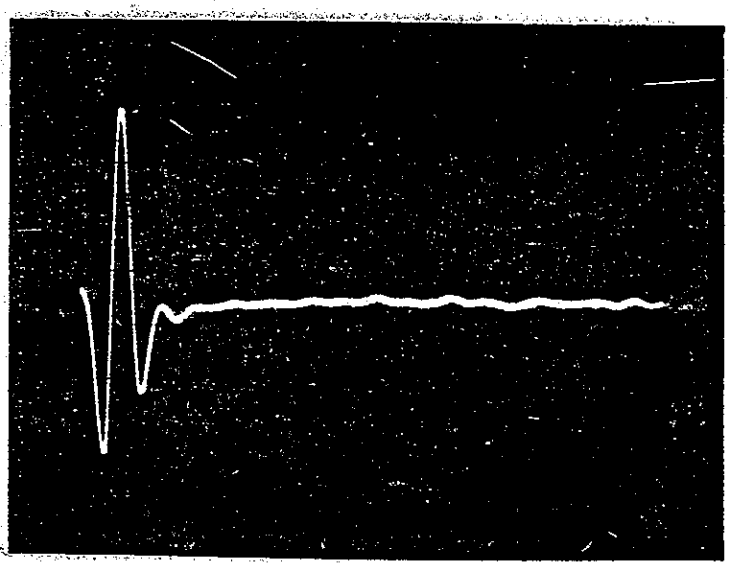

FIGURE B

Echo from flat metal plate

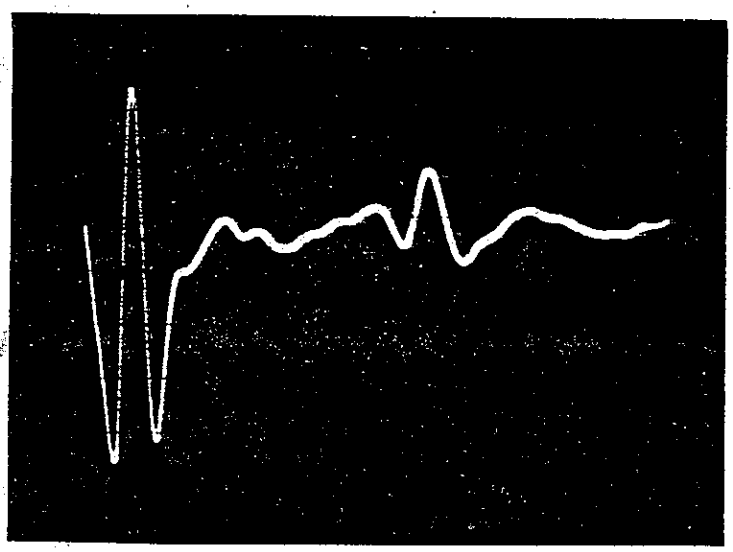

FIGURE C

Echoes from front and back of 12 inch concrete wall

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DISTANCE (METERS)	PASS NUMBER 1	2	3
0	.	.	.
1	.	.	.
2	.	.	.
3	.	.	.
4	.	.	.
5	.	.	.
6	.	.	.
7	.	.	.
8	.	.	.
9	.	.	.
10	.	.	.
11	.	.	.
12	.	.	#
13	.	.	.
14	.	.	.
15	.	.	.
16	#	.	.
17	#	.	.
18	.	.	#
19	.	.	.
20	.	.	#
21	.	.	.
22	.	.	.
23	.	.	.
24	.	.	.
25	.	.	.
26	.	.	#
27	.	.	#
28	.	.	.
29	.	.	.
30	.	.	.
31	.	.	#
32	.	.	#
33	.	.	.
34	.	.	.
35	.	.	.
36	.	.	.
37	.	.	.
38	.	.	.
39	.	.	.
40	.	.	.

RUN 1

DISTURBANCE IN 4 % OF SURVEY

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SET-YARR OVERPASS

DISTANCE (METERS)	PASS NUMBER 1	2	3
0	.	.	.
1	.	.	.
2	.	.	.
3	.	.	.
4	.	.	.
5	.	.	.
6	.	.	.
7	.	.	.
8	.	.	.
9	.	.	.
10	.	.	.
11	.	.	.
12	.	.	#
13	.	.	.
14	.	.	.
15	.	.	.
16	.	.	.
17	#	#	.
18	#	.	.
19	.	.	#
20	.	.	.
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22	.	.	.
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24	#	.	.
25	.	.	.
26	.	.	#
27	.	.	#
28	.	.	.
29	.	.	#
30	.	.	#
31	.	.	.
32	.	.	.
33	.	.	.
34	.	.	#
35	.	.	.
36	.	.	.
37	.	.	.
38	.	.	.
39	.	.	.
40	.	.	.

RUN 2

DISTURBANCE IN 5 % OF SURVEY

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SLY PARK OVERPASS

DISTANCE (METERS)	PASS NUMBER 1	2	3
0	.	.	.
1	.	.	.
2	.	.	.
3	.	.	.
4	.	.	.
5	.	.	.
6	.	.	.
7	.	.	.
8	.	.	.
9	.	.	.
10	.	.	.
11	.	.	#
12	.	.	.
13	.	.	.
14	.	.	.
15	.	.	.
16	.	.	.
17	#	.	.
18	#	#	.
19	.	#	#
20	.	.	.
21	.	.	.
22	.	.	.
23	.	.	.
24	.	.	.
25	.	.	.
26	.	.	#
27	.	.	#
28	.	.	.
29	.	.	.
30	.	.	#
31	.	.	#
32	.	.	#
33	.	.	#
34	.	.	.
35	.	.	.
36	.	.	.
37	.	.	.
38	.	.	.
39	.	.	.
40	.	.	.

RUN 3

DISTURBANCE IN 5 % OF SURVEY

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