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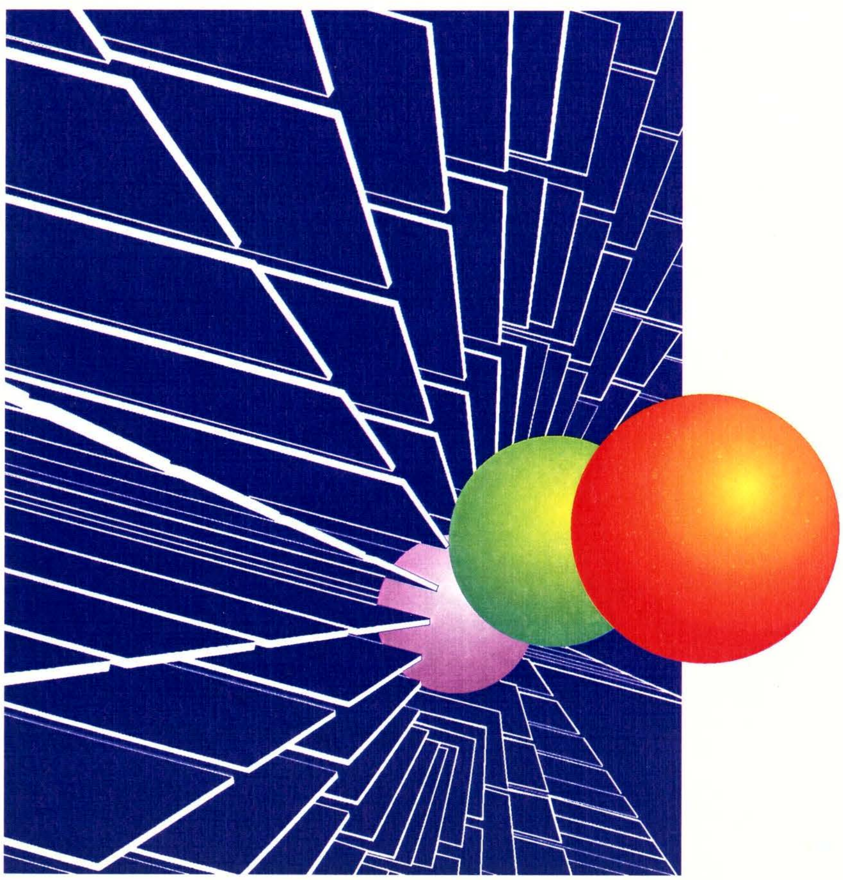
RDT 00-013

Evaluation of SHRP Products and Other Non-Destructive Test Equipment for Pavement, Pavement Thickness, and Bridge Deck Applications

RI 94-006



September, 2000

Final Report

RI94-06

Evaluation of SHRP Products and Other Non-Destructive Test Equipment for Pavement, Pavement Thickness, and Bridge Deck Applications

MISSOURI DEPARTMENT OF TRANSPORTATION
RESEARCH, DEVELOPMENT AND TECHNOLOGY

BY: John D. Wenzlick, P.E.

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16. Abstract

The first part is the use of Ground Penetrating Radar (GPR) and Infrared Thermography (IR) for use in bridge deck delamination surveys and also the use of GPR for analysis of pavements. The second part is the analysis of the use of the Seismic Pavement Analyzer (SPA) to evaluate rigid and flexible pavements. Two sets of "Conclusions" and "Recommendations" are given, one at the end of each part of the report.

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The report of this study is broken into two parts. The first part is the use of Ground Penetrating Radar (GPR) and Infrared Thermography (IR) for use in bridge deck delamination surveys and also the use of GPR for analysis of pavements. The second part is the analysis of the use of the Seismic Pavement Analyzer (SPA) to evaluate rigid and flexible pavements. Two sets of "Conclusions" and "Recommendations" are given, one at the end of each part of the report.

PART 1

Ground Penetrating Radar (GPR) and Infrared Thermography (IR) for use in Bridge Deck Delamination Surveys and also the use of GPR for Analysis of Pavements

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Bridge Decks

In May 1995, we tried two different companies using Ground Penetrating Radar, GPR, to inspect two bridges and three different pavements. Our bridge deck condition survey crew had sounded the whole decks of both bridges in April to have baseline data for the amount of debonding and delamination. The GPR correlated fairly well with our surveys.

For overlay debonding on Bridge L-821R, Big Bend over Route I-64, St. Louis County, Pulse Radar showed 8.6%, Penetradar 4.6% compared to 5.2% found by our survey. For delamination in the concrete deck at the level of the rebar, Pulseradar showed 17.8%, Penetradar 14.5% compared to MoDOT at 27.2%. However, maintenance patched 15.2% of this deck, a lot closer to radar results, so we may have overestimated with our sounding. Incidentally, we also tested both bridges with Infrared Thermography coupled with direct contact GPR. The direct contact GPR was used over only one location during the scan and only to correlate the depths of anomalies picked up by the IR camera. The infrared had consistently much lower results, 2.8% debonding and only 8.9% delamination.

(See Table 1)

Copies of the deck sounding surveys by MoDOT for Bridge L-821R, NB & SB, both with the asphalt overlay on done on 5/2/95 and after its removal on 6/2 and 5/95 are attached in Appendix I.

On Bridge A-2518, Route I-55/Flat River, Jefferson County, a bare concrete deck, delamination picked up by Pulse Radar was 18.6%, Penetradar 12.1% compared to MODOT at 16.5%. Infrared showed only 2.9% of the area of the bridge deck delaminated. Actual construction patching was 28.1%, however, the contractor went back a second time after removal of what the RE's office had laid out and found additional patching. We believe if the contractor had taken more care in concrete removal the first time the percent of patching would have been less. Infrared showed only 2.9% of the area of this bridge deck delaminated.

(See Table 2)

Copies of the deck sounding surveys by MoDOT for Bridge A-2581, NB & SB, are attached in Appendix II.

The percentages were good for both radars on a bare deck or through an asphalt overlay compared to our ground truth percentages obtained by sounding and doing a comprehensive deck survey. The percentages of the infrared thermography under estimated by about two thirds. However, on locating the deteriorated concrete as compared to ground truth (our crews testing) and the actual patching done to repair the decks none of them did very well. Neither of the two GPR scans or the Infrared scans had their indications match the same locations as the soundings (Figures 1A, 1B & 1C) or actual patching (Figures 2A, 2B & 2C), or for that matter against each other (Figure 3).

The figures are overlays of data from Bridge A-2518 which had a bare concrete deck (no overlay). Figure 1A compares Pulse Radar Inc. data against our crews sounding of the deck. Pulse Radar areas are marked red for delamination at the lower rebar mat, green for the upper rebar mat and blue (labeled debonding) is deterioration near the surface since there is no overlay to be debonded. Deterioration near the surface would be scaling or spalling which our survey showed very little of (less than 1% of the deck area). The sounding shows black outlined circles which denoted hollow areas, shown on this deck as usually starting around cracks. You can tell that the colored blocks very seldom land on top of the black circles. Figure 1B is a comparison of Penetradar's plot of the delaminated areas and our sounding. Penetradar uses filled in black boxes and you can see they very rarely coincide with the hollow areas from our sounding. Figure 1C shows Entech Co.'s infrared scan of the deck versus our sounding. The green blocks represent surface debonding (as with Pulse Radar this is deterioration near the surface since there is no overlay to debond) and yellow blocks as delamination at the top rebar mat. There are far fewer locations shown in color because the infrared estimated one third of the areas that either radar did. However, again only about half of the blocks cover areas where the sounding showed hollow. Figues 2A, 2B and 2C compare the same test data from the three companies compared to the actual repair patches made, which are blocks outlined in black. Again, the test data does not overlay very well with the patches underneath. Figure 3 compares the test data of the three companies against each other and you can see that they don't overlap much either.

Table 1
Bridge L-821R, Big Bend over Route I-64, St. Louis County
(with AC overlay)

Method	Debonding	Delamination
Pulseradar	8.6%	17.8%
Penetradar	4.6%	14.5%
Infrared	2.8%	8.9%
Sounding	5.2%	(27.2%)
Actually patched		15.2%

Table 2
Bridge A-2518, Route I-55 over the Flat River, Jefferson County
(No overlay)

Method	Debonding	Delamination
Pulseradar	0%	18.6%
Penetradar	0%	12.1%
Infrared	0%	2.9%
Sounding	0%	16.5%
Actually patched		28.1%

Pavements

In testing pavements, we had two objectives: First, finding the thickness of pavement layers, AC overlay and PCCP. Second, to find any deterioration within or below the pavement. We also tested 11 SHRP special pavement study sections, SPS-7, Route 67, Jefferson County, which is a bonded concrete overlay. We were looking for debonding between the overlay with the original PCC pavement and also to find any voids or moisture under the pavement.

In testing the pavement thickness, the GPR units were not correlated with ground truth cores as per ASTM D4748. In earlier studies done by the Texas Transportation Institute it has been shown that with cores used to calibrate the GPR that accuracy on calculating layer thickness is within 5%. Cores are needed to get a relative dielectric constant but this has to be done for every characteristics change in the material (each different mix). We envision GPR will be most useful to us as an inventory tool for the NHS system for thickness needed for FWD (Falling Weight Deflectometer) for determination of pavement layer thickness and as part of the data for a pavement management system. Taking cores in this case would be impractical since we have so many different asphalt projects on the same routes. So we had both companies test blind (with no cores), they picked a dielectric coefficient from experience.

We tested 3.8 miles of AC overlaid PCCP on Route 100, Manchester Road, St. Louis County. We also tested a SHRP GPS (General Pavement Study) site on Route 79, St. Charles County, and one section on the SPS-7 test site on Route 67, Jefferson County, mentioned earlier for AC overlay thickness.

On the thickness of the AC overlay on Route 100, Pulseradar had an error of 23.5% and Penetradar of 38.7%. Penetradar had an error of 9.6% on the PCCP layer. Pulseradar didn't supply any data on concrete thickness (Rt. 100 proved to be a bad location for this testing. It is a vey old 20 ft. wide pavement that has been widened several times, the PCCP is broken and cracked, and had over 8" of AC overlay at some locations.
(See Table 3)

Cores on SPS-7, Site 290759, had an error compared to the 4 cores taken at one location ranging from 10.0% to 44.0%, with an error in the average thickness of 4.9% for Pulseradar and 28.9% for Penetradar. (See Table 4)

The SHRP GPS site 295393 was compared to original construction data from 1990 which showed 1.2" Type B and 1.8" Type C, 3.0" total. Averaging the readings in the right wheelpath for the 500' lead in section Pulseradar had an error of 1% and Penetradar 11.7%.

(See Table 4)

Table 3

AC Overlaid PCCP, Route 100, Manchester Rd., St. Louis County

Radar Used	% Error vs. cores AC thickness	 PCCP thickness
Pulseradar	23.5%	N/A
Penetradar	38.7%	9.6%

Table 4

SHRP AC Overlay Sites

SPS-7, 290759	% Error vs. Cores	vs. Avg. Thickness
Pulseradar	10.0% to 44.0%	4.9%
Penetradar	N/A	28.9%
GPS Site 295393	% Error vs. Cores	vs. Avg. Thickness
Pulseradar	12.6%	1.0%
Penetradar	23.6%	11.7%

DISCUSSION AND COST COMPARISON

Doing bridge deck condition surveys using radar would give more accurate surveys and could be accomplished with some time savings.

As far as accuracy, the radar units need to run on bridge decks at 15 mph. at 3' spacings. Traffic control would still be needed. The whole deck could be checked instead of just one 12' lane. On Bridge A-2518 for example (213.33' long x 38' wide = 8107 S.F.). Pulseradar started at 8:50 a.m. and finished at 9:37 a.m., 47 minutes, which included 12 radar passes and changing signs and traffic control once from right lane to left lane. Penetradar did the same bridge in 33 minutes. This compared to our crew spending 4 hours on May 3 sounding the deck, being rained out all day May 4 and taking 2 hours to do an underdeck survey and returning on May 30 to do half cell potentials taking another 2 hours or 8 hours total survey time. (Normally it would have taken 3-4 hours since our crew would only do 1-12' wide lane and not the whole 38' wide deck.)

Using radar, we would still have to go back and do the half-cell potentials and take chloride samples. This requires three men plus 1 to 2 flagmen depending on whether there is two-way traffic. A minimum crew of 4 to 5 would still be required. There would be substantial savings in time for delamination survey and paperwork. Addressing paperwork first, no time would be required in the office to prepare strip maps for surface profile or half-cell this would all be done electronically by the radar unit at the bridge site. We may need to take some notes and would still do an underdeck survey.

Plotting and computations afterward would be done by computer and printed out on a color copier for delamination surveys and half cell surveys. In terms of time, I would envision a 3-4 man crew to run radar (2 to set signs, radar driver and operator) and the decks in an area would be done all at once. Then another 4-5 man crew would come back to do half cells and chlorides.

Setting signs and testing the entire width of a bridge not just one 12' lane would take approximately 1 hour per bridge to do the radar scan.

For example, we now have 7 bridges on Route I-29, Atchison County, both mainline NBL and SBL and overpass bridges. We could do the delamination surveying on all of them in 7 hours or less. The cost for GPR inspection of 118,114 sq. ft. at $0.11/S.F. would be approximately $13,000.00. Taking chlorides and half cells would take about 2 hours a bridge. That means 3 hours per bridge. A possible savings of 1 1/2 hours per bridge as our average the last 4 years has been 1.75 bridges per day. There would be more consistency in results, since delaminations and half-cells are being done electronically. Estimating repair quantities would be more accurate since a scan of the whole bridge deck for delamination is being done, not just one 12' lane.

As for renting versus buying a Radar unit, Penetradar quoted $0.15/S.F. if done on the 44 bridges we inspected last year, the cost for delamination surveying only would be $16,265 for a 12' lane only, for full deck width using 30' as an average the cost would have been $40,662, versus a purchase price of $175,000. Pulseradar gives a per job rate pricing which works out to $0.08 to $0.11/S.F., a range of $21,686 to $29,818 for full width inspection versus a purchase of $88,000 ($68,000 radar plus $20,000 van).

MoDOT might want to contract the first year to check our savings in time and personnel before deciding to purchase a unit. Pulseradar had a very good turn around time on their report - one month from test time. Penetradar took almost 4 months because they were working on building a van for the FHWA.

It was recommended doing part of the next year's bridge decks by contract with Pulseradar since we only had experience from 2 bridges, and do the others using a regular crew. MoDOT, however, did not contract bridges by GPR in 1997. We did compare the FHWA radar van from the FHWA –SHRP Assesessment of Concrete Bridges Showcase to five bridges on I-435 in Kansas City surveyed by our field crew. The GPR survey on these bridges was done using 3 antennas (the 4th antenna was not working)to do three scans for a 12' wide lane at the same time and without traffic control at 45 mph. Correlation to ground truth survey data was very poor.

COST FOR BRIDGE DECK ANALYSIS BY GPR

Pulse Radar	Bridge L-821	Lump Sum	**$1875.00 ($0.13/SF)**
	Bridge A-2815	Lump Sum	**$1875.00 ($0.23/SF)**
Penetradar	Bridge L-821	Lump Sum	**$1924.00 ($0.14/SF)**
	Bridge A-2815	Lump Sum	**$1924.00 ($0.23/SF)**

Entech	Infrared Thermography Per Sq.Ft.		**$0.66**
	Ground Penetrating Radar Per Sq.Ft.		**<u>$0.50</u>**
		Total Per Sq.Ft.	**$1.16**

Cost of buying or renting a GPR unit are as follows:

Pulse Radar Outright Purchase **$68,000.00***

*(Includes Radar System and 4 days training in Houston -vehicle must be provided, they will send plans for altering vehicle to accept antenna and will help install system during the 4 days training)

This is one antenna and all hardware and software which is all we would need.

Rental **$1,750.00/day***

* plus expenses & traffic control

Penetradar Outright Purchase **$175,000.00***

*(Includes vehicle, $125,000.00 for complete radar system alone)

Rental **$0.10-0.15/Sq.Ft.***

* depends on travel, location, etc.

CONCLUSIONS

The accuracy of predicting delaminations by GPR is good enough at this time to replace chain dragging or sounding for locating and estimating repair quantities for bridge rehabilitation. On the May, 1995 bridge GPR estimated 12 % to our survey crews 16 %. The overall percentage of deteriorated concrete were very close but the locations did not correlate well with the ground truth. Hopefully with new methods of analyzing reinforced concrete bridge decks the GPR industry can improve locating the defects. Infrared Thermography consistently underestimated delaminations on bridge decks and aquiring good data is very dependent on the weather and time the surveys can be done. We do not recommend using infrared for bridge deck delamination surveys.

The accuracy is not very good using GPR to find pavement thickness without cores taken for correlation, ± 25% error from our limited data. This is not good enough for inventorying the NHS. (If cores are taken to determine the dielectric constant, GPR could get thickness within ± 5%. At this time, however, it would be necessary to calibrate the GPR on many cores.) Very little was learned from this study on locating defects within or below the pavements using GPR.

RECOMMENDATIONS

To implement the findings of this study it is recommended that the following additional research be done using sophisticated Ground Penetrating Radar (GPR) systems.

1. Automatic Bridge Deck Condition Analysis - Best Equipment - Test Methodology: See if periodic GPR surveys correlate close enough to chloride content and half-cell potential tests to eliminate these two tests and initiate high speed GPR testing alone.
2. Automated Pavement Analysis - Best Equipment - Test Methodology: Use GPR as a pavement management tool to measure layer thickness and pavement, base and subgrade conditions. Test a significant number of sites (31 LTPP Test Sections and one supplementary route) and compare

with historical ground truth data to see if accurate. Additionally test up to 50 miles of PCCP on I-44 in Joplin and 370 miles of PCCP on I-70 to develop a pavement rehabilitation plan.

INSERT:

Figures 1A, 2A, 3A

Figures 2A, 2B, 3B

Figure 3

APPENDIX I

GPR and IR Study

Bridge deck Inspection Sheets for Bridge L-821 NB & SB

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

Division Of Materials and Research
BRIDGE DECK CONDITION SURVEY SUMMARY

SPECIAL INSPECTION
SPR 1995 15S

County St. Louis Route Big Bend Blvd. Bridge No. L-821 NB

Over I-64 Job No. SPR 15S, RI94-06

Year Built 1958 Survey Date 05/02/95

Type Structure Concrete Box Girder With Slab Spans at Each End

Spans 12',32',128',49',12' Design Depth of Steel 1 1/2" T

Overlay AC Limestone 1 1/2"

Sealcoat

NOTE: This summary sheet should not be used without reference to the attached figures for additional comments and detailed information on the areas surveyed, the locations of observation sites, and the distribution of observed distress. All depth measurements are referenced to top of concrete.

1. **Measured Depth of Steel:** Min. (4) Max. (4) Avg. (4)

2. **Half Cell Potential**, v, referenced to Cu-$CuSO_4$ half cell, % of readings:

0 to -0.20	-0.21 to -0.35	<-0.35
21	34.5	44.5

NOTE: Half cell potential data should be interpreted with caution when an overlay or sealcoat is present.

3. **Chloride**, (lbs./yd.^{3}) of concrete (assumed weight 3900 lbs./yd.^{3}) from areas of presumed good concrete,
samples composited at depths of:

	1/4" to 3/4"	3/4" to 1 1/4"	1 1/4" to 1 3/4"	1 3/4" to 2 1/4"	2 1/4" to 2 3/4"	2 3/4" to 3 1/4"
DL	6.2	4.7	3.5	3.1	1.9	1.6
PL	6.2	4.7	4.3	3.5	2.7	0.5

4. **Other Data:** (Percents of Surveyed Areas Only)

a. Fracture Planes 25.1 b. Patching 14.7

c. Spalling 0.1 c. Efflorescence **(See Underdeck Survey)**

5. **Notes:**
1. The northbound driving and passing lanes were tested to represent the whole NBL.
2. 51.5% of the patched area is debonded.
3. Patching noted on the surface profile is the AC overlay. The amount of patching in the deck is unknown.
4. Actual depth of steel measurements taken with a ruler are shown on the surface profile sheet. (actual steel measurements)
5. Slab Edge Deterioration (linear feet), East 40'

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT
Division Of Materials and Research
BRIDGE DECK CONDITION SURVEY SUMMARY

SPECIAL INSPECTION
SPR 1995 15S

County St. Louis Route I-64 Bridge No. L-821 NB

Over Big Bend over I-64 Job No. SPR 15S, RI94-06

Year Built 1958 Survey Date 6/2 & 5/95

Type Structure Concrete Box Girder with Slab Spans at Each End

Spans 12',32',128',49',12' Design Depth of Steel 1 1/2" Trans.

Overlay None-Milled off by Dist. 6 M & T

Sealcoat

NOTE: This summary sheet should not be used without reference to the attached figures for additional comments and detailed information on the areas surveyed, the locations of observation sites, and the distribution of observed distress. All depth measurements are referenced to top of concrete.

		Min.	Max.	Avg.
1. **Measured Depth of Steel:**	PL	1.8	2.8	2.3
	DL	1.2	2.9	2.4

2. **Half Cell Potential**, v, referenced to Cu-$CuSO_4$ half cell, % of readings:

0 to -0.20	-0.21 to -0.35	<-0.35
21.8	34.4	43.8

NOTE: Half cell potential data should be interpreted with caution when an overlay or sealcoat is present.

3. **Chloride**, (lbs./yd.^{3}) of concrete (assumed weight 3900 lbs./yd.^{3}) from areas of presumed good concrete,
samples composited at depths of:

1/4" to 3/4"	3/4" to 1 1/4"	1 1/4" to 1 3/4"	1 3/4" to 2 1/4"	2 1/4" to 2 3/4"	2 3/4" to 3 1/4"
N/A	N/A	N/A	N/A	N/A	N/A

4. **Other Data:** (Percents of Surveyed Areas Only)

a. Fracture Planes 14.2 b. Patching 3.8

c. Spalling 0.8 c. Efflorescence **(See Underdeck Survey)**

5. **Notes:**
1. The driving lane was tested on 06/02/95 and the passing lane tested on 06/05/95.

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT
Division Of Materials and Research
BRIDGE DECK CONDITION SURVEY SUMMARY

SPECIAL INSPECTION
SPR 1995 15S

County St. Louis Route Big Bend Blvd. Bridge No. L-821 N & S

Over Big Bend over I-64 Job No. SPR 15S, RI94-06

Year Built 1958 Survey Date 06/12/95

Type Structure Concrete Box Girder With Slab Spans at Each End

Spans 12',32',128',49',12' Design Depth of Steel 1 1/2" T

Overlay None-Milled off by District 6 Maintenance & Traffic

Sealcoat None

NOTE: This summary sheet should not be used without reference to the attached figures for additional comments and detailed information on the areas surveyed, the locations of observation sites, and the distribution of observed distress. All depth measurements are referenced to top of concrete.

1. **Measured Depth of Steel:** Min. N/A Max. N/A Avg. N/A

2. **Half Cell Potential**, v, referenced to Cu-$CuSO_4$ half cell, % of readings:

0 to -0.20	-0.21 to -0.35	<-0.35
N/A	N/A	N/A

NOTE: Half cell potential data should be interpreted with caution when an overlay or sealcoat is present.

3. **Chloride**, (lbs./yd.^{3}) of concrete (assumed weight 3900 lbs./yd.^{3}) from areas of presumed good concrete,
samples composited at depths of:

1/4" to 3/4"	3/4" to 1 1/4"	1 1/4" to 1 3/4"	1 3/4" to 2 1/4"	2 1/4" to 2 3/4"	2 3/4" to 3 1/4"
N/A	N/A	N/A	N/A	N/A	N/A

4. **Other Data:** (Percents of Surveyed Areas Only)

a. Fracture Planes N/A

b. Patching NB 17.4 (2) SB 14.4 N & S 15.2

c. Spalling N/A

c. Efflorescence **(See Underdeck Survey)**

5. **Notes:**
1. The whole bridge deck was tested.
2. Measured patches placed by District 6 Maintenance and Traffic.

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT
Division Of Materials and Research
BRIDGE DECK CONDITION SURVEY SUMMARY

SPECIAL INSPECTION
SPR 1995 15S

County St. Louis Route Big Bend Blvd. Bridge No. L-821 SB

Over I-64 Job No. SPR 15S, RI94-06

Year Built 1958 Survey Date 05/02/95

Type Structure Concrete Box Girder With Slab Spans at Each End

Spans 12',32',128',49',12' Design Depth of Steel 1 1/2" T

Overlay Limestone AC

Sealcoat

NOTE: This summary sheet should not be used without reference to the attached figures for additional comments and detailed information on the areas surveyed, the locations of observation sites, and the distribution of observed distress. All depth measurements are referenced to top of concrete.

1. **Measured Depth of Steel:** Min. (4) Max. (4) Avg. (4)

2. **Half Cell Potential**, v, referenced to Cu-$CuSO_4$ half cell, % of readings:

0 to -0.20	-0.21 to -0.35	<-0.35
6.2	9.9	83.9

NOTE: Half cell potential data should be interpreted with caution when an overlay or sealcoat is present.

3. **Chloride**, (lbs./yd.^{3}) of concrete (assumed weight 3900 lbs./yd.^{3}) from areas of presumed good concrete,
samples composited at depths of:

	1/4" to 3/4"	3/4" to 1 1/4"	1 1/4" to 1 3/4"	1 3/4" to 2 1/4"	2 1/4" to 2 3/4"	2 3/4" to 3 1/4"
Ramp	5.1	4.3	2.7	2.0	1.6	1.6
DL	5.8	5.8	4.7	5.1	4.7	1.2
PL	7.0	5.8	3.9	3.1	2.3	1.2

4. **Other Data:** (Percents of Surveyed Areas Only)

a. Fracture Planes 37.3
b. Patching 30.3
c. Spalling > 1
c. Efflorescence **(See Underdeck Survey)**

5. **Notes:**
1. The whole southbound deck was tested.
2. 21.1% of the patched area is debonded.
3. Patching noted on the surface profile is the A.C. overlay. The amount of patching in the deck is unknown.
4. Actual depth of steel measurements taken with a ruler are shown on the surface profile sheet.
5. Slab Edge Deterioration (linear feet), West 36.

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT
Division Of Materials and Research
BRIDGE DECK CONDITION SURVEY SUMMARY

SPECIAL INSPECTION
SPR 1995 15S

County St. Louis Route I-64 Bridge No. L-821 SB

Over Big Bend over I-64 Job No. SPR 15S, RI94-06

Year Built 1958 Survey Date 6/2 & 5/95

Type Structure Concrete Box Girder with Slab Spans at Each End

Spans 12',32',128',49',12' Design Depth of Steel 1 1/2" Trans.

Overlay None-Milled off by Dist. 6 Maintenance & Traffic

Sealcoat

NOTE: This summary sheet should not be used without reference to the attached figures for additional comments and detailed information on the areas surveyed, the locations of observation sites, and the distribution of observed distress. All depth measurements are referenced to top of concrete.

	Min.	Max.	Avg.
DL	1.5	3.1	2.3
Rp.L	0.7	2.8	1.5

1. **Measured Depth of Steel:** DL Min. 1.5 Max. 3.1 Avg. 2.3; Rp.L Min. 0.7 Max. 2.8 Avg. 1.5

2. **Half Cell Potential**, v, referenced to Cu-$CuSO_4$ half cell, % of readings:

0 to -0.20	-0.21 to -0.35	<-0.35
12.7	24.4	62.9

NOTE: Half cell potential data should be interpreted with caution when an overlay or sealcoat is present.

3. **Chloride**, (lbs./yd.^{3}) of concrete (assumed weight 3900 lbs./yd.^{3}) from areas of presumed good concrete,
samples composited at depths of:

1/4" to 3/4"	3/4" to 1 1/4"	1 1/4" to 1 3/4"	1 3/4" to 2 1/4"	2 1/4" to 2 3/4"	2 3/4" to 3 1/4"	
N/A	N/A	N/A	N/A	N/A	N/A	

4. **Other Data:** (Percents of Surveyed Areas Only)

a. Fracture Planes 35.9　　b. Patching 12.6

c. Spalling 1.1　　c. Efflorescence **(See Underdeck Survey)**

5. **Notes:**
1. The southbound passing lane was tested 6/2/95 and the southbound ramp lane and driving lane were tested on 06/05/95.
2. Steel measurements were not taken in the passing lane.

APPENDIX II

GPR and IR Study

Bridge deck Inspection Sheets for Bridge A-2518 SB

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT
Division Of Materials and Research
BRIDGE DECK CONDITION SURVEY SUMMARY

SPECIAL INSPECTION
SPR 1995 15S

County St. Francois Route 67 SB Bridge No. A-2518

Over Flat River Job No. SPR 15S, RI94-06, J0P0475

Year Built 1969 Survey Date May 3, 4 and 30, 1995

Type Structure Continuous Composite I-Beam

Spans 5 @ 42' Design Depth of Steel 2" Clear

Overlay None

Sealcoat None

NOTE: This summary sheet should not be used without reference to the attached figures for additional comments and detailed information on the areas surveyed, the locations of observation sites, and the distribution of observed distress. All depth measurements are referenced to top of concrete.

1. **Measured Depth of Steel:**

	Min.	Max.	Avg.
SBPL	1.7	2.6	2.1
SBDL	1.3	2.2	1.7

2. **Half Cell Potential**, v, referenced to $Cu\text{-}CuSO_4$ half cell, % of readings:

0 to -0.20	-0.21 to -0.35	<-0.35
46.1	30.0	23.9

NOTE: Half cell potential data should be interpreted with caution when an overlay or sealcoat is present.

3. **Chloride**, (lbs./yd.^{3}) of concrete (assumed weight 3900 lbs./yd.^{3}) from areas of presumed good concrete,
samples composited at depths of:

	1/4" to 3/4"	3/4" to 1 1/4"	1 1/4" to 1 3/4"	1 3/4" to 2 1/4"	2 1/4" to 2 3/4"	2 3/4" to 3 1/4"
SBDL	7.8	2.0	0.2	0.1	0.1	--
SBPL	4.7	3.9	0.3	0.1	0.1	0.1

4. **Other Data:** (Percents of Surveyed Areas Only)

a. Fracture Planes 14.9 b. Patching 1.9

c. Spalling 0.1 c. Efflorescence **(See Underdeck Survey)**

5. **Notes:**
1. The entire deck surface was tested.
2. 84.8% of the patched area is debonded.

The report of this study is broken into two parts. The first part is the use of Ground Penetrating Radar (GPR) and Infrared Thermography (IR) for use in bridge deck delamination surveys and also the use of GPR for analysis of pavements. The second part is the analysis of the use of the Seismic Pavement Analyzer (SPA) to evaluate rigid and flexible pavements. Two sets of “Conclusions” and “Recommendations” are given, one at the end of each part of the report.

PART 2

Use of the Seismic Pavement Analyzer (SPA) to Evaluate Rigid and Flexible Pavements

LIST OF FIGURES – PART 2 SPA Study

LIST OF TABLES

Appendices

Seismic Pavement Analyzer

The Seismic Pavement Analyzer (SPA) and Lunch Box SPA were used to test condition and thickness of the same bonded concrete overlay (rigid pavement) tested by Ground Penetrating Radar as mentioned earlier and a full depth asphalt pavement (flexible pavement). The SPA is intended to measure such conditions as voids or loss of support under a rigid pavement, moisture infiltration in an asphalt concrete pavement, fine cracking in pavements, delamination of overlays, and aging of asphalt. The SPA combines several seismic testing techniques as listed in Table 1 below.

Table 1 - Strengths of Five Techniques Used by Seismic Pavement Analyzer

Testing Technique	Strengths
Ultrasonic Body Wave	Young's Modulus of top paving layer
Ultrasonic Surface Wave	Shear modulus of top paving layer
Impulse Response	Modulus of subgrade reaction of foundation layers
Spectral Analysis of Surface Waves	Modulus of each layer Thickness of each layer Variation in modulus within each layer
Impact Echo	Thickness of paving layer or depth to delaminated layer

The contractor was Geomedia Research and Development, the same group from the University of Texas - El Paso (UTEP) that developed the SPA for SHRP.

The information obtained on layer thickness from SPA testing on rigid pavements (see Table 2) showed good accuracy. On the section with no overlay (control section) the results showed an accuracy of 1% or 0.1 inches on an 8" PCCP. The remaining six sections ranged from 1.1% (0.1") to 17.0% (1.8") on five of the sections with overlay layers of 3"- 5", and on the one with the AC overlay of 3" accuracy was only 19.3% (0.6"). As you can see this is a wide range of variation and not as accurate for smaller thicknesses.

A description of the rigid pavement sites is given in Table 2. On the rigid pavement the results from up to three testing techniques are reported in Table 4. These tests were the Ultrasonic-Surface-Wave(USW), the Impact-Echo(IE), and the Impulse-Response(IR) methods. The USW method was used to determine the variation in modulus of the PCC or the overlay (columns 3 and 6 in Table 4). The IE method and/or USW method was used to determine the thickness of the slabs (columns 4 and 7). The IR method provides the condition of the support under the slab.

Table 2 - Specific Pavement Section & Experiment in Jefferson County, Missouri

Section	Section	Nominal Overlay Thickness, mm	Surface Preparation	Grouted	Tested with SPA
1	290701	Control			yes
2	290702	76	cold milled	Yes	no
3	290703	76	cold milled	No	yes
4	290704	76	shot blasted	No	no
5	290705	76	shotblasted	yes	no
6	290706	127	shotblasted	yes	yes
7	290707	127	shotblasted	no	yes
8	290708	127	cold milled	no	no
9	290709	127	cold milled	yes	yes
10	290759	76	AC Overlay		yes
11	290760	102	Cold milled And shotblasted	Yes	yes

[INSERT TABLE 4]

The variations of the Young's modulus of the top layer amongst the sections tested are shown in Figure 1. For each section, the average and bounds of ±1 standard deviations are shown. In general the PCC at Section 290701 was slightly of higher quality than the PCC at the other sections. For section 290706 a greater variability in results is observed at the center of the slab. This can be attributed to the highly heterogeneous nature of the section because of wide spread cracks. Section 290759 corresponds to an AC overlaid section, therefore, the reported modulus is substantially lower than the other sections.

For section 290703, the thickness of the overlay could not be determined perhaps because of a favorable bond between the overlay and the PCC slab. The thickness of the layer is about 260 mm, which is about 20 mm thinner than the specified as built thickness. In all other sections, the overlay seems to be either debonded from the underlaying layer or the original PCC is badly deteriorated so that significant differences in the modulus of the overlay and the PCC exists.

The IR method was used to obtain the average effective moduli of the subgrade for the sections tested and that data is shown in Figure 2. Subgrade modulus will significantly decrease due to the existence of delamination, debonding, cracks and other defects. If a methodology based on the assumption that the PCC slab is intact and does not include cracks and defects, and the subgrade modulus still shows a decrease, then the decrease is because of lack of support or voids beneath the slabs. For the center of the slab, the effective modulus is between 70 MPa and 100MPa (this represents marginal subgrade support). A modulus value of less than 70 MPa corresponds to an undesirably low structural support condition for a rigid pavement section. The center of the slab Sections 290701 (control) and Section 290709 are structurally the weakest sections tested (Figure 2(a)). The large coefficients of variation measured for different sections is an indication of large variation in the quality of the support from test point to test point. (Figure 1(a) - section 290706, also see example data in the Appendices A & C) For the edge of slabs, most sections are quite weak and also show a high coefficient of variation. Sections 290760 (recommended MoDOT PCC overlay design) followed by Section 290759 (AC overlay) exhibit the best structural support.

[INSERT FIGURE 10]

[INSERT FIGURE 12]

Results from Flexible Pavement Sections

The tests on flexible pavements are summarized in Table 5. For a thorough inspection the results can be found in Appendices H through N of the Geomedia Research and Development report. For flexible pavement the results from the Spectral Analysis of Surface Waves (SASW) method as well as the IR method are reported. From the SASW tests at each section, the modulus values for the AC, base and subgrade are reported, as well as, the best estimate of the thickness of each layer. The AC layer could not be modeled as one layer because of significant differences in stiffness of the layer from the top to the bottom. The AC was modeled as a two layer system. The modulii of the two AC layers are shown in Figure 3. There is a greater coefficient of variation of the modulus on the lower AC layer. The sensors used to measure the modulus at this depth are farther away from the source (up to 600mm) and cracking and defects will have more affect on measurements. The average modulus for this layer is between 1 Gpa and 2 Gpa corresponding to a high quality asphalt-stabilized base or a low quality AC. The modulus of the base varies between 300 MPa and 400MPa, and corresponds to an average to below average base material. The large coefficient of variation is mostly because of different levels of distress observed from point to point, and partly due to the inherent lack of sensitivity of the SASW method to thin base layers. The modulus of the subgrade is shown in Figure 4. It varies between 200MPa and 350 MPa and corresponds to a high quality subgrade. (An example of the data included in Geomedia's report is attached in Appendix H)

[INSERT TABLE 5]

[INSERT FIGURE 13]

[INSERT FIGURE 16]

Conclusion and Recommendations

GPR results look a lot better than the Seismic Pavemant Analyzer's (SPA) accuracy for pavement thickness. The SPA is better at finding cracks and distress in both rigid and flexible pavements than GPR, however, and GPR can not be used to find structural properties of the pavement as the SPA does. We believe that the SPA will be a good tool to investigate problem sections of pavement. However, with only a couple of prototypes out and both of them at UTEP, availability of the equipment is limited. We have used other NDT methods such as GPR and FWD on the I-44 and I-70 work mentioned earlier, or carried out destructive testing (coring) so far to try and measure pavement distress but only with partial success. The Seismic pavement Analyzer would be another good tool in our pavement evaluation toolbox. We may consider at some time in the future to use the SPA again as a research tool on a problem pavement, possibly on I-44 at Joplin.

APPENDIX 1

SPA Study

Results from Rigid Pavement Section 290701

APPENDIX 2

SPA Study

Results from Rigid Pavement Section 290706

APPENDIX 3

SPA Study

Results from Flexible Pavement Section 1