FIELD COMPARISON OF

INFRARED THERMOGRAPHY AND

MANUAL SURVEY RESULTS

Report 88-3
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16. Abstract

Infrared Thermographic Testing (IRT) was performed on four bituminous concrete covered structures on Interstate 91 in southern Vermont. Two structures which were undergoing rehabilitation, were selected for field comparison of the IRT results with standard deck condition information gathering methods. Following removal of the bituminous concrete pavement, manual sounding and corrosion surveys were performed and the results were compared with those obtained with the IRT. Additional correlations were made through examination of cores taken from the structures.

Plots of the delaminations identified with the IRT were overlaid with plots of delaminations and areas of high corrosion potential found by the comparison surveys. Correlation between the test methods ranged from 70% to 85%. The study revealed the inadequacies of manual soundings which suggests that there is no reason to expect 100% agreement between the manual and IRT methods.

The resulting conclusion is that IRT can be a reasonably accurate, effective method for obtaining bridge deck condition information.

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INTRODUCTION

Throughout the United States, especially in the cold weather states, the deterioration of reinforced concrete bridge decks is a costly and ever growing problem. In Vermont, decisions on repair or rehabilitation have been supported by a variety of bridge deck information gathering techniques, including analysis of historical data, visual inspection and field condition surveys which include sampling for chloride content and testing for corrosion activity on reinforcing steel.

A newer method of condition survey, INFRARED THERMOGRAPHY, (IRT) is addressed here. This method shows promise as a rapid and reasonably accurate technique for screening larger numbers of bridges (at a higher cost) than can be accomplished with the methods presently in use.

INFRARED THERMOGRAPHY INFORMATION PROVIDED BY THE CONTRACTOR*

Infrared Thermography is used to identify delamination/debonding of bridge decks. An infrared scanner is used to locate these areas by observing the temperature difference between delaminated/debonded areas and sound concrete which exists when the pavement or bridge deck is warmed by the sun's energy. Voids in a delaminated/debonded area act as an insulator, permitting the delamination/debond to become warmer than the surrounding, more massive, pavement. Temperature differences can reach 5°C on bright, sunny days. The technique works for exposed concrete decks and decks overlaid with asphalt or concrete, and has the principal advantages of faster data collection, less operator judgment and more accurate results than traditional sounding procedures.

On overlaid bridge decks, the infrared equipment is not always capable of differentiating between a delamination in the concrete deck and a debond of the overlay. In general, if both debonding and delamination are present, slightly different thermal signatures will exist for each. Delaminations generally are oval in configuration and have a uniform temperature. Debonded areas tend to be larger in size, non-circular and have a non-uniform temperature which is caused by differing degrees of contact between the overlay and the deck. When viewed with the infrared system, debonded areas appear as a marbled surface which is most pronounced in flexible overlays where the overlay is free to lift away from the concrete.

The infrared scanner used by Donohue for this work is a small, lightweight field instrument capable of detecting emitted thermal radiation. It produces a standard video signal that allows thermal imagery to be recorded on videotape. This scanner is capable of measuring temperature differences of 0.2°C. The scanner uses a mercury cadmium telluride (HgCdTe) detector which is cooled by liquid nitrogen. A 45° expander lens is used, which allows the operator to view a pavement width of one and one quarter lanes. This permits some overlap from lane to lane for analysis purposes and allows minor vehicle movement during data collection. A color video camera and recorder are also used to obtain control images of the pavement. This camera is equipped with a zoom lens which allows the field of view for the control image and the infrared image to be matched.

A digital distance measuring device is used to reference the imagery to a known starting point. Distance measurements are superimposed on both the infrared and control images. A digital contact thermometer is used to measure the temperature difference between sound and deteriorated pavement for calibration purposes. An anemometer is used to measure wind speed and a sling psychrometer is used to measure the relative humidity.

* The contractor was DONOHUE and ASSOCIATES, INC. Engineers and Architects, 1020 North Broadway, Suite 400, Milwaukee, Wisconsin 53202.

The infrared scanner and video camera are mounted on the front of an inspection van and raised to approximately 14 feet above the bridge deck. Black and white video produced by the infrared scanner, and color video produced by the control camera, are displayed on monitors in the van. The operator controls the quality of the graphic data being recorded. The speed of the scanning van is held to approximately 2 miles per hour along the centerline of each traffic lane. A single pass is made for each lane of the bridge. During the scanning operation, the van may be stopped periodically at an area of suspected delamination/debond to confirm the infrared data. This consists of sounding the pavement to confirm the presence of a delaminated or debonded area. Surface temperature measurements are also taken at both the suspect area and an adjacent sound area. Confirmatory core locations are also marked on the deck for later coring.

Certain environmental conditions are required for thermography to be effective. Clear skies, winds less than 15 MPH, and dry pavement produce suitable temperature differentials between sound and delaminated/debonded areas. If these conditions do not occur, a detectable temperature differential is not established.

Traffic control varies with traffic conditions, but since the IRT is done with a moving vehicle, extensive lane closures are not usually required. The survey vehicle is equipped with amber beacons and a directional arrow for additional traffic control.

The cost of this procedure ranges from $0.10 to $0.12 per square foot plus the cost of traffic control, and a mobilization cost.

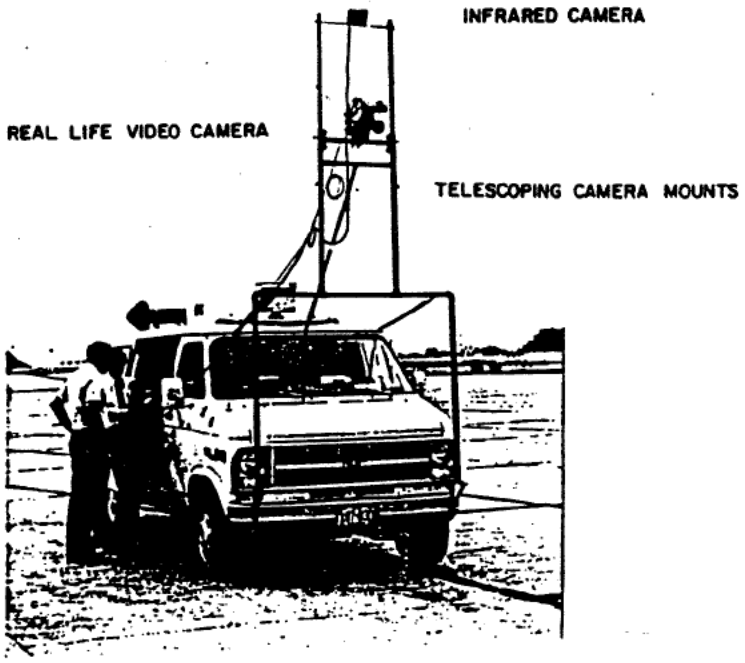


FIGURE 1 THERMOGRAPHY SCAN VEHICLE

VERMONT'S STANDARD DECK SURVEY TECHNIQUES

Vermont currently acquires bridge deck condition information by conducting a corrosion survey utilizing the copper-copper sulphate half cell (referred to hereafter as half cell). Although a half cell survey does not locate delaminations, it has been found to indicate areas where they are most likely to occur or have occurred. The survey is conducted on either bare or bituminous covered decks using a five foot grid interval and the percent of area $\geq$ -0.35 volts and $\geq$ -0.40 volts is reported. Pulverized concrete samples are also taken at the 1" to 2" depth for determination of chloride content. The field testing is conducted during the winter season by Materials & Research personnel.

Vermont also has an ongoing bridge inspection program which consists of visual inspection of each structure. The visual inspection, analysis of the structure's history and the surveys described above are all used to aid in making decisions on the type of repair or reconstruction to specify.

The cost of a deck condition survey averages $0.05 per square foot which includes labor, expenses, equipment rental and traffic control. The deck condition information is available immediately. Plots depicting active corrosion areas can be computer generated, if desired.

Lane closure to traffic is required in order to insure the safety of the survey personnel and the motoring public. A three person crew can expect to survey approximately 100 linear feet of two lane deck in one hour.

After the rehabilitation process has begun and the pavement has been removed, manual soundings with chain drag and hammer are done to locate delaminations.

DISCUSSION OF IRT TESTING

During the third week of April, 1988, an infrared thermographic survey was performed on four* bridges by DONOHUE & ASSOCIATES, INC. (Hereafter referred to as Donohue) The survey crew was present and ready to perform the survey on April 20th. However, due to weather limitations, they were unable to accomplish the survey until the fourth day, April 23d, on which day there were three hours of suitable conditions. During those three hours, four structures were surveyed.* Had the survey not been accomplished at that time there would have been a three day wait until suitable weather occurred again.

As the day began, it was 28 $^{\circ}$ F. at 8:30 AM and had warmed to 46° by 10:00. There was a 5 MPH breeze by 10:15 AM when filming of the first bridge (24N) began. After some initial delay, due to an early lack of clarity, and the operator forgetting to activate the recorder, the structure was completed by 10:50.

* Those portions of four structures called for by agreement.

At 11:00 bridge 24S was begun but, due to equipment problems, was restarted at 11:06 and again at 11:16. The travel lane was completed by 11:30, the passing lane begun at 11:35 and the structure was completed by 11:37.

By 11:50, when structure 28S was begun, the clouds had reduced sunlight levels. By 12:02 the area was 100% overcast but by 12:25, shadows were observable even with the overcast and the IRT survey of bridge 33 N was begun. This structure was completed by 12:40 P.M.

At this time, the crew began drilling check cores in the structures from areas which had been previously selected. Evaluation of the cores would be used to confirm the interpretation of the IRT imagery.

Cores No. 1, 2 and 3 were taken from structure 24N. The first confirmed no delamination, as expected. The second was taken from the edge of a depression and showed no delamination to the 3" depth but did demonstrate pavement debonding. The third confirmed delamination at 1-3/8" and also other fractures. Thus, on bridge 24N, two of three cores confirmed the IRT initial field interpretation and the third provided the information to interpret the debonded area.

Core No. 4 was taken from structure 24S and confirmed that there was no delamination at that location.

Three cores were taken from bridge 28S. Core No. 5 revealed several delaminations at the 1" - 2" level and also that the top 1" of concrete was no more than rubble. Cores 6 and 7, which were taken from areas where the IRT survey indicated no debonding or delamination, confirmed that the concrete was not delaminated.

Four cores were taken from bridge 33N over Vermont Route 44 and Mill Brook. All four (Nos. 8 through 11) were delaminated in one or more places and all confirmed the IRT interpretation.

Cores taken by Donahue are used immediately to verify on-site interpretations and thus there should be no differences between reported interpretation and the core findings.

COMPARISON PROCEDURE

In order to verify that an IRT survey is an accurate procedure a detailed study of major portions of two of the four bridges which were studied by IRT was planned. Confirmation was to be based upon a comparison between Donouhe's identified delaminations and one or more of Vermont's standard information gathering techniques.

Manual soundings would be used, as any delaminations located by that method are virtually certain, although it was known that soundings are known to be inadequate to discover all existing delaminations.

Half cell corrosion surveys locate corroding reinforcing steel. The volume gain of rebars from corrosion products is known to cause delamination at the rebar level. Readings of $\geq$ -0.40V are considered

to indicate active corrosion areas while $\geq$ -0.35 is considered to be the threshold of corrosion activity. If half cell readings of $\geq$ -0.40V were to be found in areas identified by IRT as delaminated, the area would be considered a confirmed delamination because the readings indicate a high likelihood of delamination.

The third method, coring, is the most certain but is destructive and was reserved to check areas which could not be confirmed by the first two.

Chain drag soundings and corrosion surveys were conducted after the pavement had been removed for rehabilitation. Each section was sounded with a chain drag. Delaminations identified were confirmed by spreading fine sand in the area, then tapping with a hammer. This tapping causes vibrations in delaminations which move the grains of sand to the edges and thus outline in fine detail the located delaminations. With the pavement removed, debonding was not at issue. Following the soundings each section was surveyed by half cell, on a five foot grid and then in as fine detail as needed to precisely define the areas with potential readings of -0.40 volts or greater. Both delaminations and "hot spots" were plotted to scale.

When plots of the delaminations found by IRT were received from Donohue, reduced copies were made and overlays showing both delaminations and high potential areas found by Vermont A.O.T. personnel were made. The overlays provide a visual correlation of the two evaluations.

COMPARISONS

I91 Bridge 28S

Upon removal of the pavement, in April of 1988, numerous spalls, cracks, rust stains, and areas of severe scaling were visible on the surface of the deck. A detailed chain drag and hammer survey was conducted on a 1283 square foot area covering the travel lane from the southerly abutment to a point 95' north. A total of 37 delaminated areas were identified, totaling approximately 34 square feet or 3% of the area evaluated.

A corrosion survey done on a 5' grid was used to plot contours representing areas of high corrosion potential ($\geq$ -0.40V). From this plot 53% or 686 SF of the area surveyed displayed a high potential for delamination.

Donohue's findings for this area were 24 areas of delamination totaling 520 square feet.

Nine cores were taken by A.O.T. personnel in areas where Donohue had identified delaminations. Each was taken in an area where corrosion readings were $\geq$ -0.40 volts but no delamination had been identified by sounding. Six (67%) of the cores revealed evidence of delamination at the 2" depth of the reinforcing steel. The other three cores, although not showing visual evidence of delamination, such as rust stains or fine cracks, broke off with only moderate

pressure, suggesting the locations were in the early stages of fracture plane development.

An overlay of the delaminated areas, areas of high corrosion potential, greater than $\geq$ -0.40V, and core locations was made. This was then used to overlay a reduced copy of Donohue's plot and a visual comparison was made. Approximately 85% of the area identified as delaminated by IRT was considered to be confirmed by the overlay procedure. (See Figure 2 Page 8)

I91 Bridge 33N

Upon removal of the pavement in April of 1988, no spalls, rust stains, or areas of severe scaling were visible on the surface of the deck. There were some transverse cracks. A detailed chain drag and hammer survey was conducted on a 4656 SF area covering the travel lane on four sections of the deck from the south abutment to a point 389' north. A total of 8 delaminated areas were identified, totaling approximately 15 square feet. A corrosion survey conducted over the same area identified 40 areas representing 380 square feet or 7% of the deck with potentials of $\geq$ -0.40V. Five cores were taken in areas of high corrosion readings and all revealed delamination which had not been evident by sounding.

Later, while marking the deck for removal of delaminated concrete, the resident engineer identified 21 more areas of high potential which agreed with Donohue's identification.

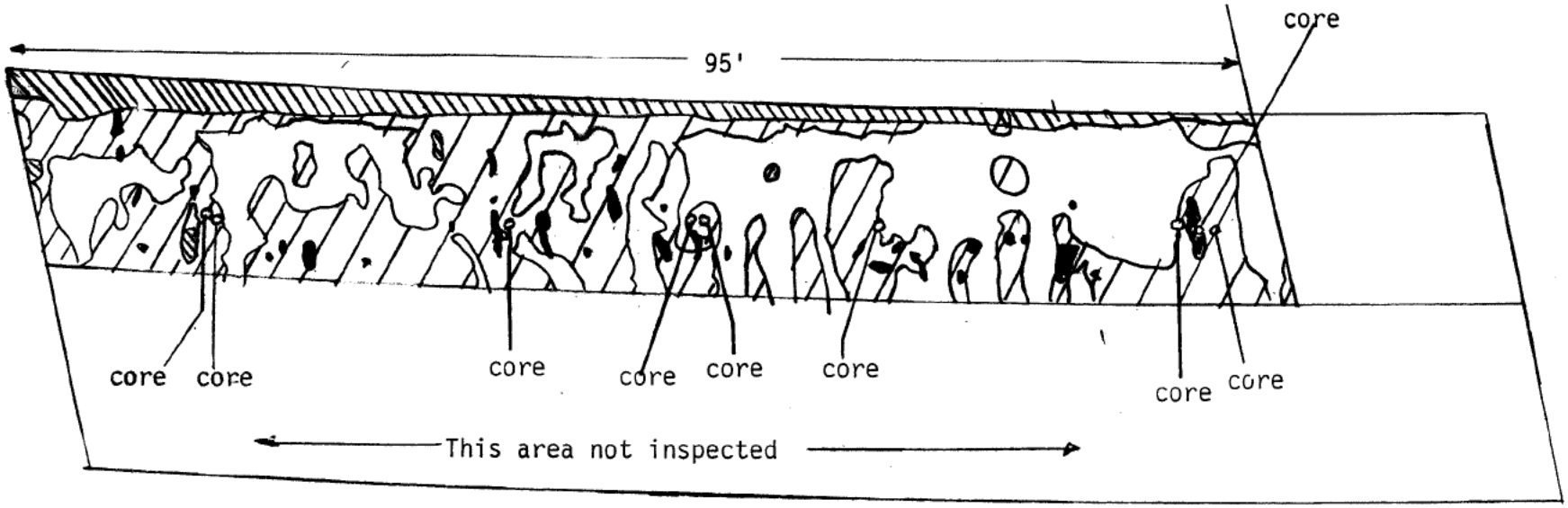
DONOHUE'S findings for the area were 115 areas of delamination totaling 819 square feet or 18% of the area evaluated.

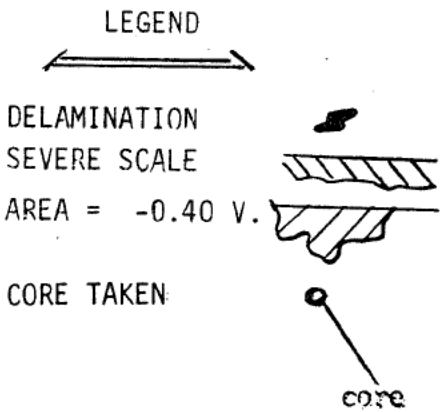
Since standard methods confirmed only 58%$\pm$ of the delaminations identified by IRT, further study was undertaken. Eighteen locations were selected for confirmation by coring at locations where Donohue's plot showed delamination but where no delamination had been identified by sounding or corrosion survey.

Upon field inspection, it was found that five of the 18 locations had already been identified and removed by the Resident Engineer. Transverse cracks, which had not been observed in the earlier surveys, were visible on the surface at ten of the locations. Three 2" diameter cores were taken which confirmed delaminations in locations where cracks were present. All ten of the selected areas which had cracks were thus considered to be delaminated.

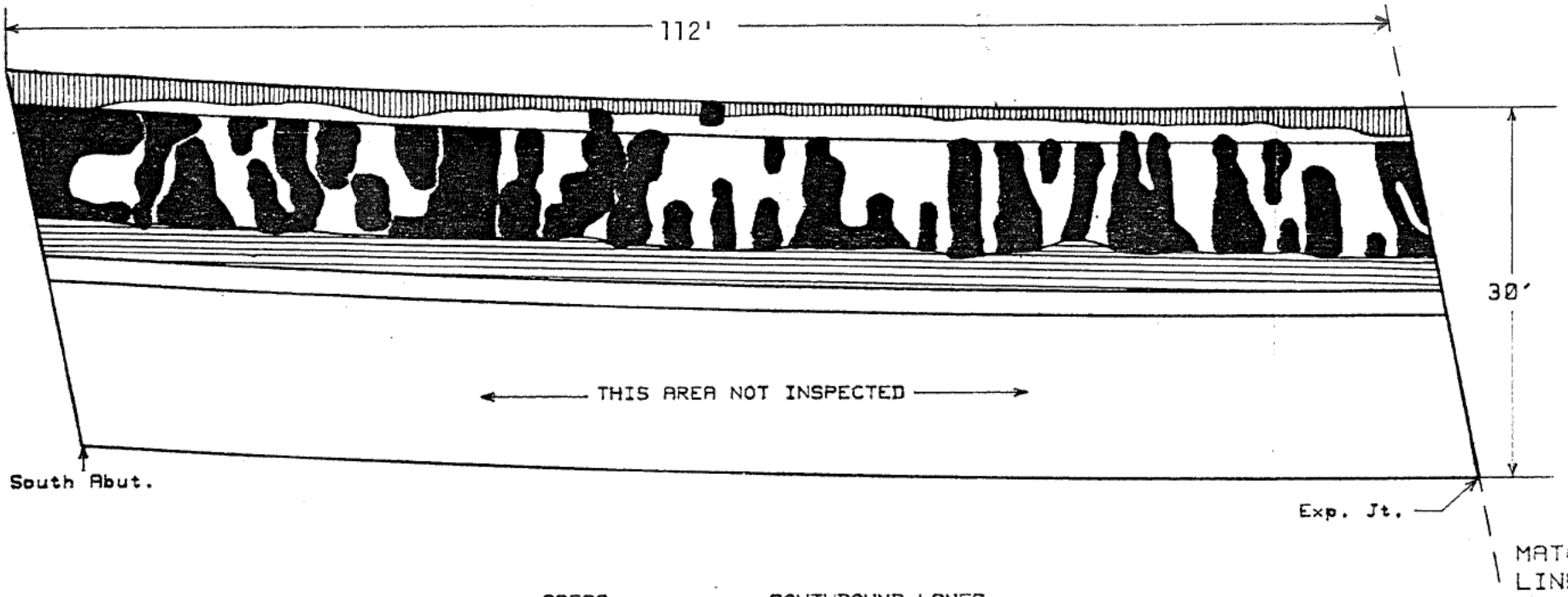
Three other cores were taken where there were no visible cracks. All three broke off easily at the 1-7/8" to 2-3/8" rebar level, indicating a weakness or delamination. The determination that these three were also delaminated raised the confirmations to 70%. Because the 20 check cores on the two decks confirmed the accuracy of the IRT survey, no attempt was made to check the 34 remaining unconfirmed delaminations on Bridge 33N. (See Figure 3 page 9 and Table 1. Page 11)

FIGURE 2





OVERLAY OF DELAMINATIONS FOUND BY SOUNDINGS AND AREAS WHERE 1/2 CELL POTENTIAL READINGS EQUALED OR EXCEEDED -0.40V ON 4/16/88



AREAS	SOUTHBOUND LANES (sq. ft.)
Total Area	3,020
Area In Shade	600
Area Inspected	2,420
Delamination	1,060 (43.8%)
Debond	None
Debris	295 (12.2%)
Inspection Date:	April, 1988

LEGEND

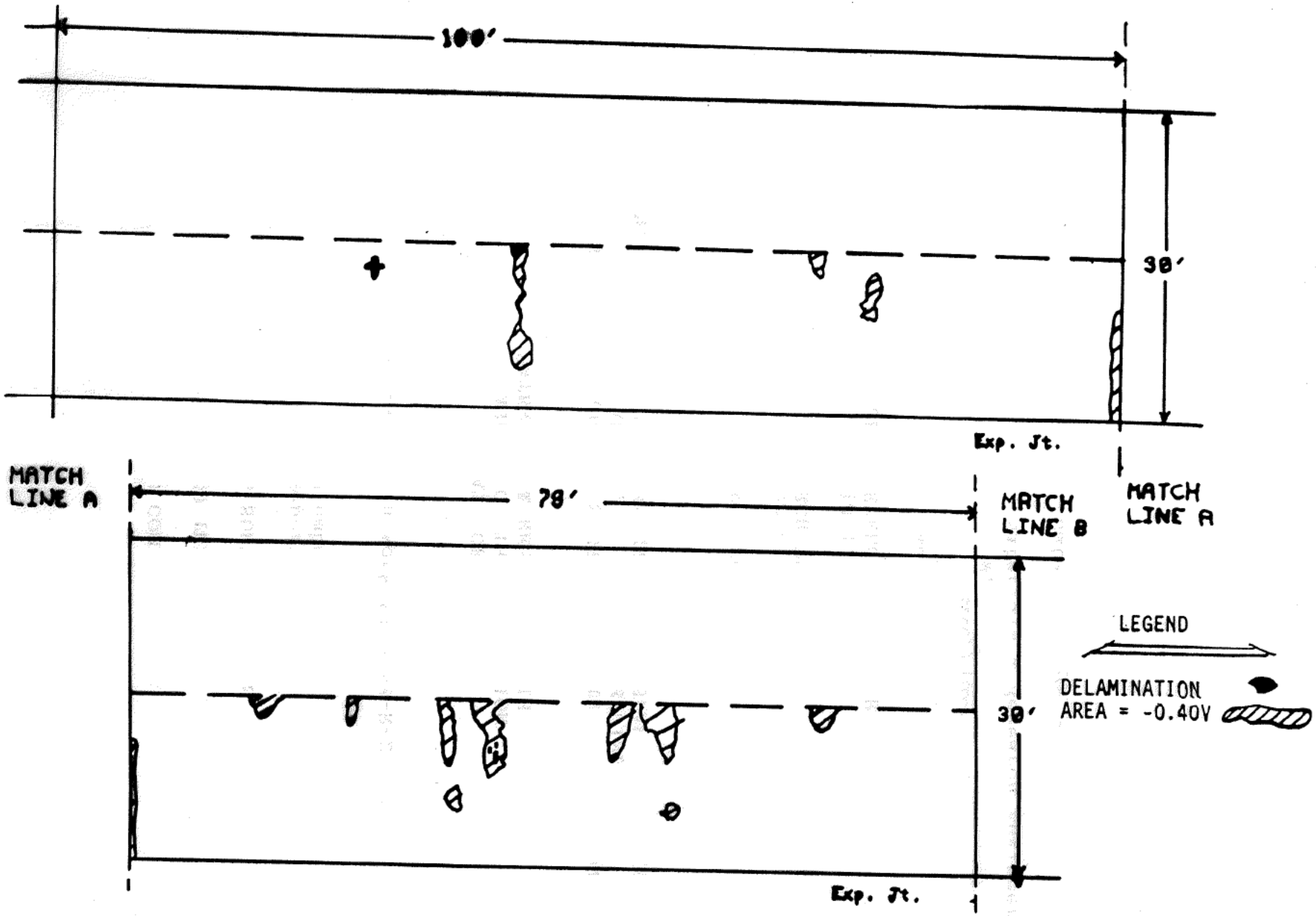
- Delamination
- Debond
- Debris
- Area In Shade

0' 10'

N

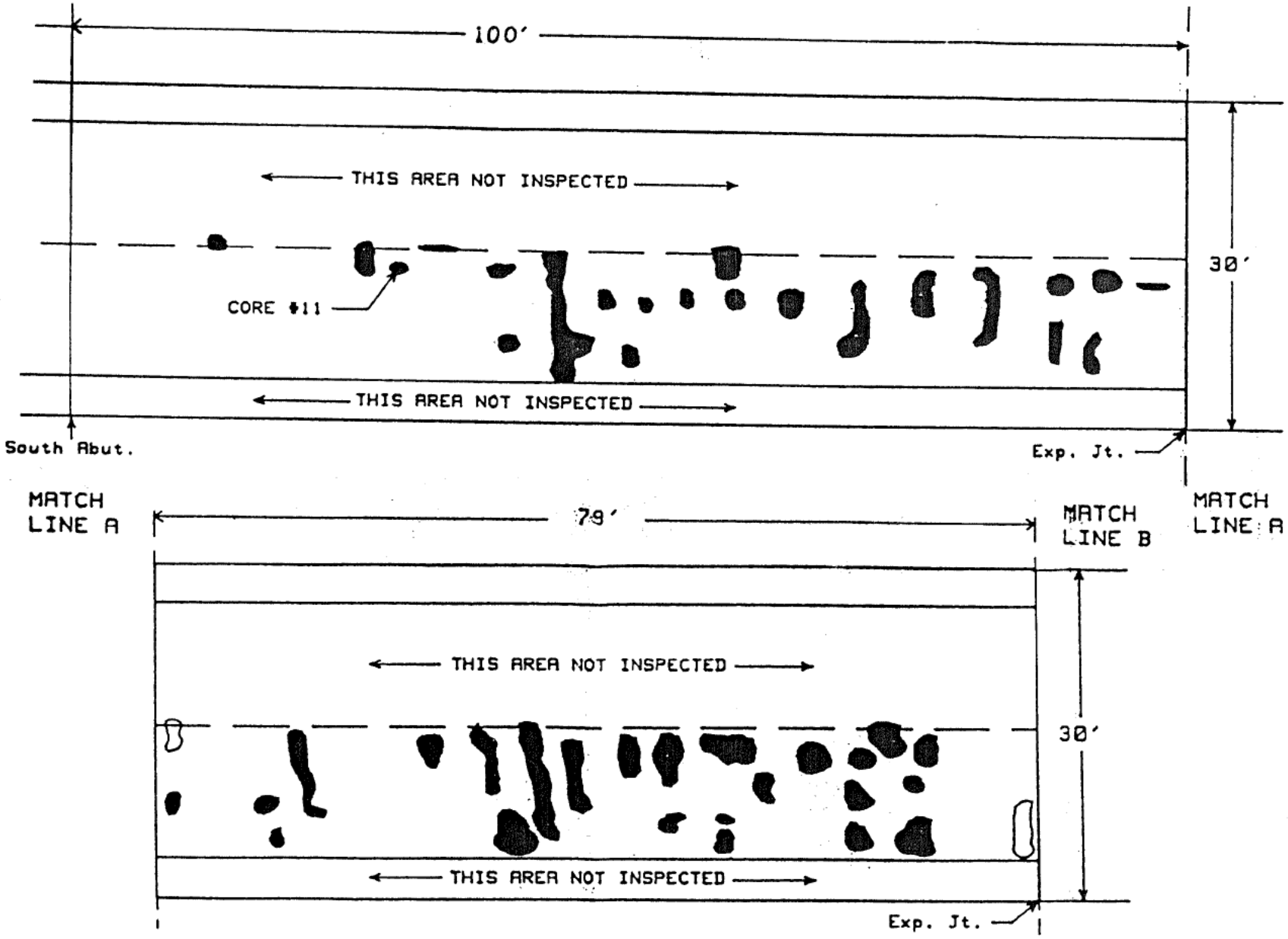
BRIDGE 28S

INFRARED THERMOGRAPHIC INVESTIGATION OF
I-91 - SPRINGFIELD INTERCHANGE
VERMONT AGENCY OF TRANSPORTATION



By K.M.R.

FIGURE 3 Sheet 1 of 2.

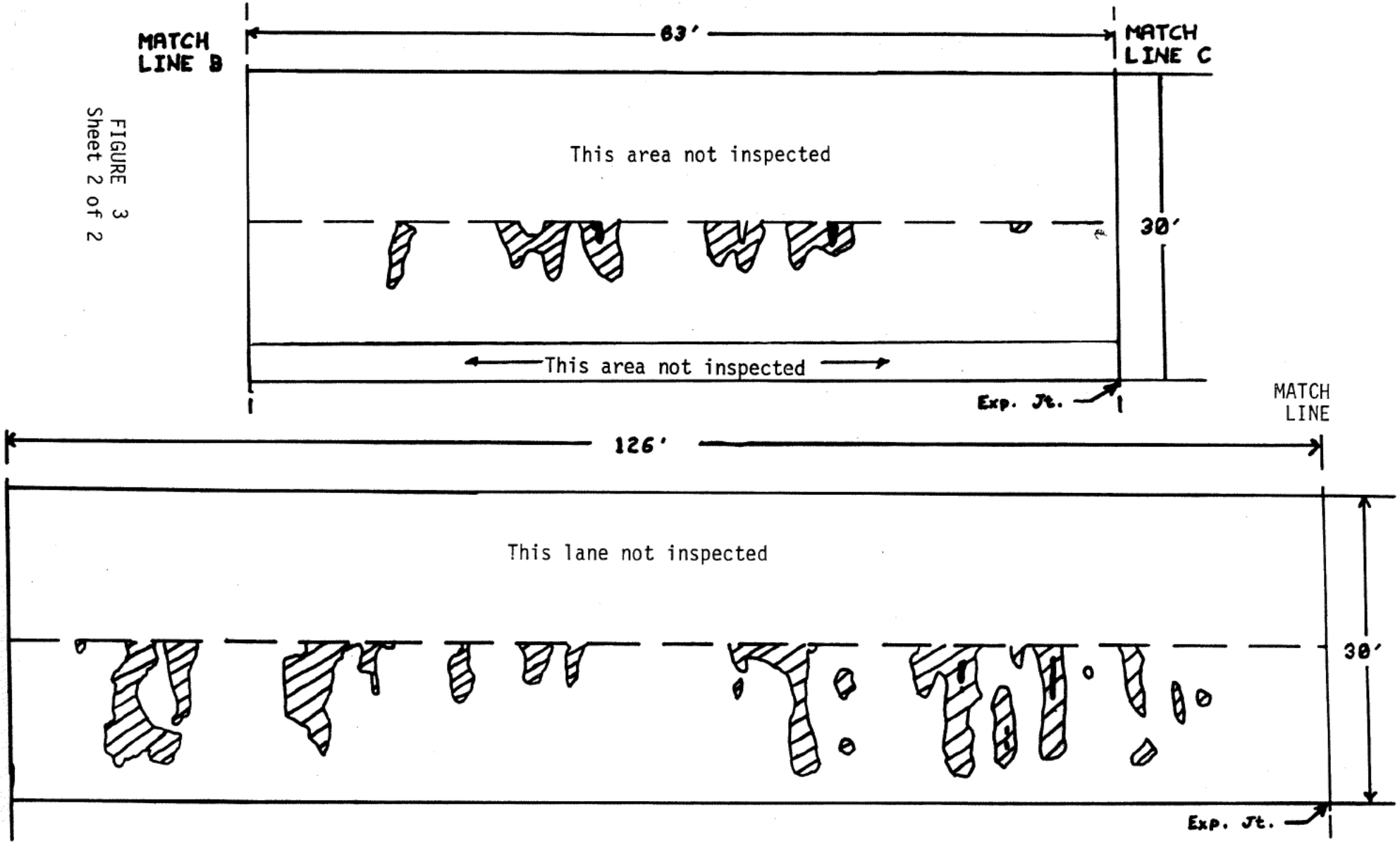


BRIDGE 33N

Donohue
Engineers & Architects

INFRARED THERMOGRAPHIC INVESTIGATION OF
I-91 OVER VT. RTE. 44 AND MILL BROOK
VERMONT AGENCY OF TRANSPORTATION

FIGURE 3
Sheet 2 of 2



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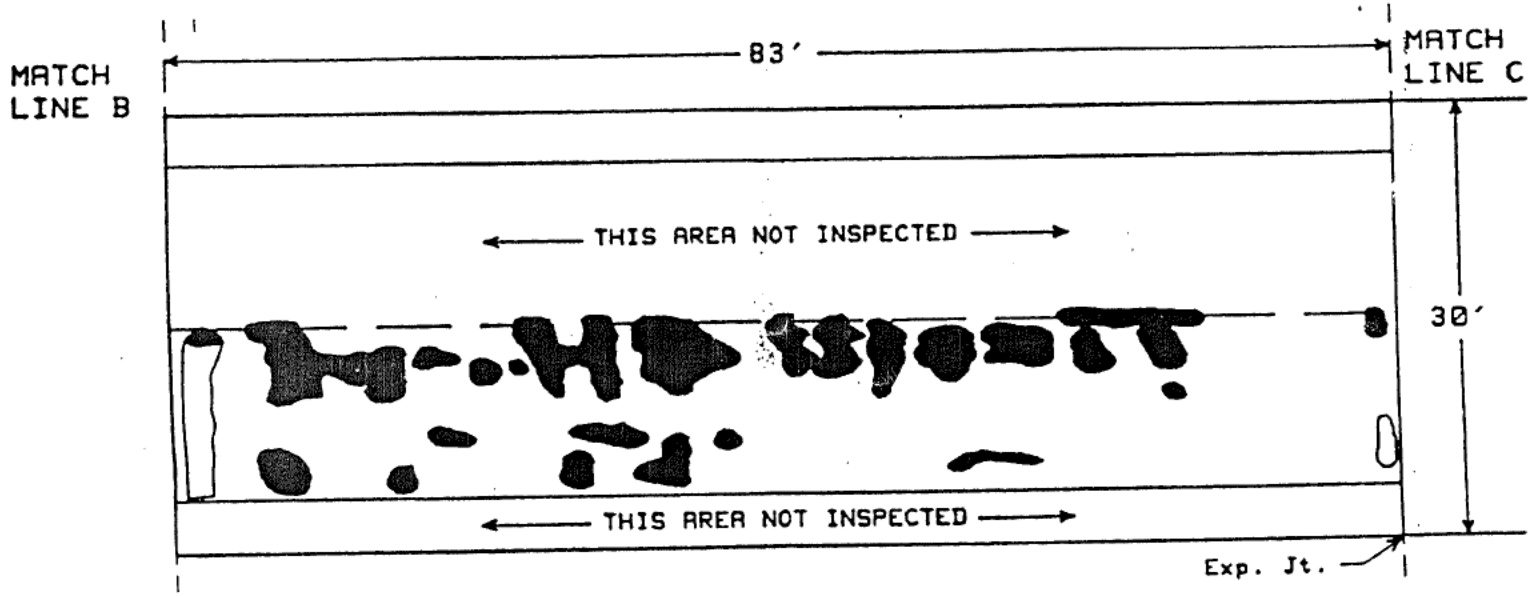

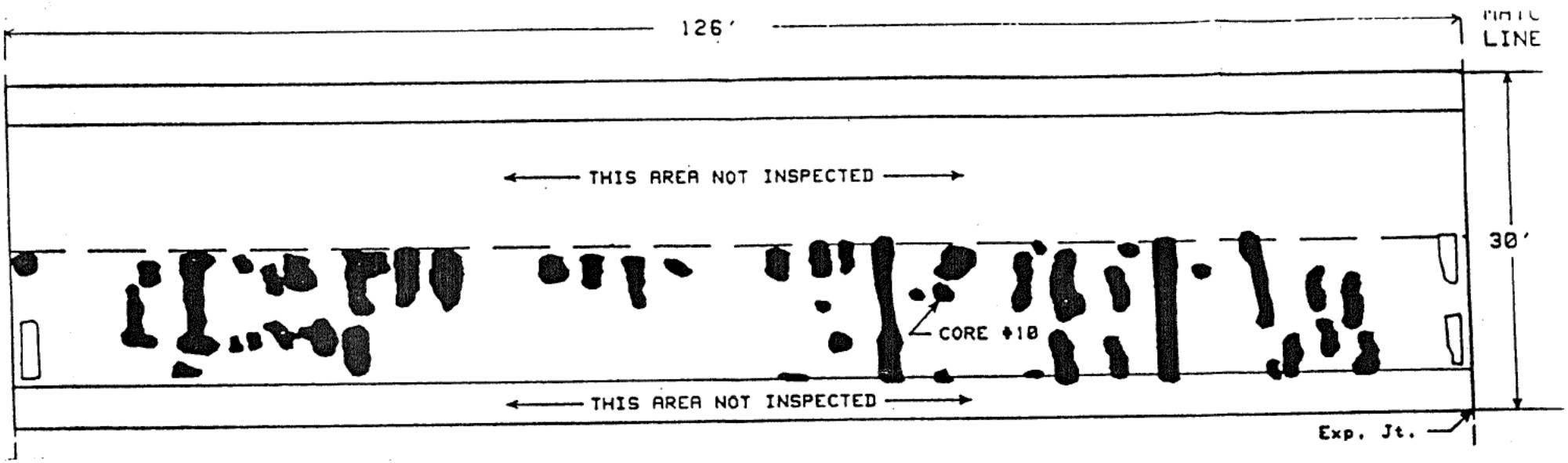

BRIDGE 33N

Donohue
Engineers & Architects

INFRARED THERMOGRAPHIC INVESTIGATION OF
I-91 OVER VT. RTE. 44 AND MILL BROOK
VERMONT AGENCY OF TRANSPORTATION

TABLE 1.

No. of Delaminations by IRT	Confirmed by Initial Research Surveys		Later Survey by Resident Engineer	Resurvey of Selected Sites	Total Confirmed
	Sounding	Half Cell			
115	8*	46**	21	13	81
	7%	40%	18%	12%	70%

* Seven were also confirmed by half cell corrosion survey and counted only once; thus the total is 81 not 88.
** Includes 5 Core locations.

COST COMPARISON

The average cost of a deck condition survey is $0.05 per square foot which includes labor, expenses, equipment and traffic control.

The cost of this IRT survey was $0.12 per square foot plus a $3000.00 mobilization fee and $60.00 each for 11 cores. The total cost works out to $0.19 per SF. Traffic control was estimated to cost less than $0.01 per SF but, allowing $0.01 per SF, the overall price for this survey was $0.20 per SF which is four times as much as the average for Vermont's present deck condition survey procedures.

SUMMARY

The following observations have been made about this evaluation.

The IRT field survey technique is much more rapid than manual sounding and half cell surveys.

The IRT survey requires good weather, ie., some sunshine, and its rapidity will be somewhat offset by any non-availability of suitable weather conditions. The rapidity of data gathering is also offset by this contractor's 90± day report preparation period.

The IRT survey technique requires check cores to distinguish between pavement overlay debonding and concrete delamination.

This attempt to verify IRT results underscored the inadequacy of manual sounding as a test method. This investigation proved that manual sounding does not find all the delaminations and in fact may miss significant amounts on bridge decks where the concrete cover over the top mat of reinforcing steel is in the range of 2 inches.

Manual sounding requires removal of the pavement overlay in order to eliminate debonding from being incorrectly interpreted as delamination.

Manual sounding and half cell corrosion surveys can be done in marginal weather, ie., no sun and low temperature, but require more time to accomplish.

High corrosion readings are an indicator of areas that are likely to contain delaminated concrete caused by corrosion of the reinforcing steel, but they cannot identify the delaminations themselves.

In combination with half cell surveys, manual soundings on the decks tested identified from 70% to 85% of the delaminations found by IRT. None of the locations identified as delaminated by Donohue were found not to be delaminated.

The actual transfer of the delamination locations from the report layouts to the bridge deck for marking out removal areas would be expedited if the present report format provided stationing adequate to precisely locate the delaminations on the deck.

CONCLUSIONS

The Infrared Thermography survey results obtained on these decks were considered to be accurate enough for estimating the quantity of concrete removal required. Caution should be used in applying this conclusion to other decks which may have different conditions which could affect the accuracy.

Although data acquisition is faster with IRT than with the techniques presently used in Vermont, this advantage was negated by the lengthy evaluation and report time.

PROSPECTS FOR FUTURE DEVELOPMENT

As is often the case with technology under development, solutions to problems identified during experimental applications can be expected.

The cost differential between IRT and standard methods will decrease due to market factors. Wider use of the technology will provide a greater volume of work which will encourage more contractors to enter the field. Competition and contracting procedures will then reduce the price.

The need to provide results more rapidly will spur development of more rapid analysis probably through greater use of computers both on-site and in the office.

The problem of precise relocation of identified delaminations is solvable with existing technology in a variety of ways. Undoubtedly the solution will differ with provider, user, and site conditions.