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Maintenance of the Highway Infrastructure

Automated Data Collection for Bridge Decks

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ABSTRACT

A systemmatic approach to bridge deck rehabilitation requires considerable data on the condition of decks. In the past, data has been collected using the traditional methods of visual inspection supplemented by physical testing and coring. Such methods have proved to be tedious, expensive, and of limited accuracy.

Research studies were undertaken to develop methods for the rapid and automatic collection of data on the condition of bridge decks. The result of the studies has been the DART System (Deck Assessment by Radar and Thermography). As the acronym implies, DART utilizes two basic systems: impulse radar and infrared thermography.

A prototype vehicle has been equipped with both the radar and thermography equipment. The vehicle is driven slowly across the bridge deck and data is collected and stored on magnetic tape. Programs have been written which will then retrieve the data and process it automatically to produce a scaled plan of the bridge showing the location and type of deterioration which is present. DART can be used on exposed concrete decks and on concrete bridge decks covered with a bituminous wearing course.

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1/ INTRODUCTION

The development of a systemmatic approach to bridge deck rehabilitation (1) created the need for considerable data on the condition of the bridge decks in Ontario. Defects and deterioration need to be located for two principal reasons:

1/ to establish priorities for rehabilitation,

2/ to determine the method of rehabilitation and prepare the contract documents.

In the first case, it is sufficient to determine the extent of any deterioration only approximately since the information is used to develop the future rehabilitation program. This information has traditionally been collected through a visual inspection together with a limited amount of physical testing. However, much of the deterioration can be hidden and go undetected. In the second case, an accurate measurement of the size and location of each type of deterioration is required. This information not only affects the selection of the method of rehabilitation, but also the quantities to be included in the repair contract. In the past, the data has been collected through a detailed condition survey of the deck (2). Existing procedures require a thorough visual inspection supplemented by physical testing which includes a chain drag survey and measurement of electrical potentials. Cores are taken and tested for chloride content, air-void analysis, strength and, sometimes, a petrographic analysis is made. The testing is expensive; while costs vary with deck size and location, the average is \$10 per m^2 or about \$5000 for a typical bridge deck.

Despite this systemmatic approach, the information is sometimes of limited accuracy. This is especially true where the deck has a bituminous surfacing. Even though sections of the surfacing are removed at selected locations in the course of a detailed condition survey, it is very difficult to determine the condition of an asphalt-covered concrete deck slab with any degree of confidence. A further disadvantage of the traditional methods of investigation are that the survey of a bridge deck usually takes a few days, and this results in a major disruption to the flow of traffic.

Research studies were undertaken to investigate improved methods of detecting defects in exposed concrete (3) and asphalt-covered bridge decks (4). The culmination of these studies was the development of the

DART System (Deck Assessment by Radar and Thermography). This paper summarizes the results of the research studies and describes the prototype DART unit.

2/ TYPES OF DETERIORATION

The most serious form of deterioration is that which is caused by corrosion of embedded reinforcement. In Ontario the corrosion is initiated by de-icing salts, used for snow and ice control in the winter months, penetrating the concrete. In arid climates, the corrosion can be initiated by chloride ions contained in the mix ingredients. Similar problems are experienced in structures exposed in a marine environment.

As the reinforcing steel corrodes, it expands and creates a crack or subsurface fracture plane in the concrete at or just above the level of the reinforcement. This is illustrated in Figure 1. The fracture plane, or delamination, may be localized or may extend over a substantial area, especially if the concrete cover to the reinforcement is small. It is not uncommon for more than one delamination to occur on different planes between the concrete surface and the reinforcing steel. Delaminations are not visible on the concrete surface. However, if repairs are not made, the delaminations progress to open spalls and, with continued corrosion, eventually affect the structural integrity of the deck. Spalls on exposed concrete decks seriously impair the riding quality of the deck.

Scaling, which is the breakdown of the cement-paste matrix, is also a serious problem wherever it occurs. The disintegration of the concrete, which is caused by the freezing of concrete which is critically saturated with water, begins at the surface and gradually progresses so that the full depth of a deck slab may be affected. In Ontario, scaling most commonly occurs in older, asphalt-covered deck slabs built without the benefit of air entrainment or a waterproofing membrane. A similar kind of deterioration can occur in other climates as a result of sulphate attack on the concrete. Disintegration of concrete can also result from undesirable chemical reactions between the aggregate particles and the alkalis in the cement paste.

On asphalt-covered decks, bond failure may occur between the concrete deck slab and the bituminous surfacing. Debonding can result in moisture being trapped on the surface of the concrete and, where thin surfacings are used, to failure of the bituminous surfacing. Although debonding is not as serious as either delamination or scaling, it can be confused with these two phenomena in surveys and, consequently, it is important to be able to identify and define debonded areas.

Cracking is the most common defect in concrete. However, with the exception of delaminations, cracks are usually easy to identify and were, therefore, not included in the research studies.

3/ INVESTIGATION ON EXPOSED CONCRETE DECKS

The first studies were conducted on exposed concrete decks during the period 1977-9 and were designed specifically to investigate methods of detecting delamination.

Most methods, including the use of a hammer or a chain, rely upon the fact that a delaminated area produces a characteristic dull sound when the surface of the concrete is struck. These methods are tedious and rely upon the skill of the operator. They can be difficult to use when a bridge deck is only partially closed to traffic and there is noise from vehicles in adjacent lanes. A machine was developed (5) to eliminate the subjective judgement of the operator. It consists of three basic components: a tapping device, a sonic receiver, and a system of signal interpretation. However, it has been found to have only limited accuracy.

The detection of delaminations by infrared thermography is based on the difference in surface temperature which exists between sound and unsound concrete under certain atmospheric conditions.

Figure 2 illustrates a typical temperature variation over a 24 hour period in the top 240 mm of a thick slab deck with an exposed concrete surface on a summer day under clear skies. A substantial temperature gradient was recorded in the top 65 mm of the deck where delaminations occur most frequently. During the hottest part of the day, the concrete temperature decreased with the depth below the deck surface and at night the situation was reversed. Similar temperature distributions have been recorded on thin slab decks in both summer and winter, though the temperature gradient was less in winter. Figure 3 shows the temperature variation in sound and delaminated concrete measured by thermocouples installed 6 mm below the surface. During the test period the difference in surface temperature between the solid and the delaminated concrete reached 3°C.

Infrared detection systems are used for the remote measurement of the surface temperature of an object. A typical system consists of an infrared sensitive camera, a display monitor and a power source. The typical temperature differences shown in Figure 2 are well within the capabilities of many cameras which have a sensitivity of better than 0.2°C. The image from the camera is displayed on a cathode ray tube and indicates the surface temperature of the object being viewed in a continuous range of grey tones from black to white. During daytime hours delaminated areas are hotter than the surrounding solid deck surface and appear white against a dark background. A permanent record of the image can be made using an instant camera or a video recorder. Colour monitors are also available but are not well suited to bridge deck applications because of the difficulty in interpreting the image.

The first series of tests were made at ground level using targets to locate the position of the image. This is illustrated in Figure 4. Although the delaminations were easily identified, the method was impractical because of the limited field of view and the difficulty of constructing a plan of the deck from photographs taken at an oblique angle.

Airborne testing was undertaken using a camera mounted in a helicopter. Although this method had the advantage of not requiring lane closures, the quality of the image was substantially reduced. The use of the helicopter was also complicated by the requirement to obtain a waiver of air regulations to fly at low altitude over the bridge decks. The best compromise between these two extremes was the use of a vehicle-mounted camera which resulted in an acceptable field of view and good definition of the delaminations.

4/ INVESTIGATIONS ON ASPHALT-COVERED DECKS

During a period 1980-2, the work on exposed-concrete bridge decks was extended to a much more detailed evaluation of methods of investigating the condition of asphalt-covered decks. The objective of this research was to identify reliable methods of defining the type and extent of defects and deterioration. It was also desirable that the methods be rapid, inexpensive, non-contact, and be capable of having the data transcribed to a scale plan of the bridge deck using automated equipment.

The procedure which was used was to create a test site by selecting a typical bridge which was exhibiting corrosion-induced distress. This deck was surveyed and then paved with two 40 mm thick lifts of bituminous surfacing without first making repairs. Areas of scaling and debonding were simulated prior to paving. Consequently, the locations and type of deterioration were known and the capabilities of different test methods could be evaluated under controlled conditions.

Eight test methods were investigated (4) and the results obtained are summarized in Table 1. The most promising techniques were found to be infrared thermography and impulse radar.

4.1/ Thermography

Several commercial infrared systems were tested at ground level, from a boom truck and, in some cases, from a helicopter. This work confirmed that the truck was the most practical platform from the points of view of accuracy, cost, and speed. The optimum height above the deck was in the range 4 to 6 m to give the best definition of delaminated areas with the least interference from reflected radiation.

Temperature measurements showed that a delamination in the concrete deck slab produced a difference in the surface temperature of the bituminous surfacing during periods of heating. This occurs because the delamination interferes with heat flow through the deck and a higher surface temperature is associated with areas of delamination. However, the maximum difference in surface temperature recorded was 2°C at 14:00 h and the time of day when delaminations could be identified was limited to 11:00 h to 18:00 h. The ability to detect delaminations on asphalt-covered decks was also found to be much more sensitive to atmospheric conditions such as wind, humidity, and cloud cover than on exposed concrete decks.

Despite the dependence on weather conditions, the results using thermography to detect delaminations were very encouraging. The system detected more than 90 percent of the known delaminations, some of which were less than 150 mm in diameter. Debonding was not detected because it did not produce a thermal discontinuity. The inability to detect scaling was ascribed to the fact that the areas of simulated scaling were all adjacent to the curbs and any differences in surface temperature was masked by the difference in emissivity between the asphalt deck surface and the concrete curbs. The major technical problem to be overcome was identified as the production of scaled hard copy from the image stored on videotape.

4.2/ Radar

The use of low power, high resolution, ground penetrating radar for detecting deterioration in concrete bridge decks is a relatively new technique first reported in 1977 (6). The equipment consists of a monostatic antenna, a control console containing a transmitter and receiver and an oscilloscope. A one nanosecond pulse of low power, radio frequency energy is directed into the bridge deck and the echo is received and displayed on the oscilloscope.

For the purposes of the investigation described here, the equipment was mounted on a cart which was pushed by hand along the deck. The waveforms were recorded at grid points using an instant camera and analysed manually. Figure 5(a) shows a typical radar signal for a sound portion of the deck and Figure 5(b) shows the signal for a section known to be delaminated. In areas where the concrete is deteriorated or the character of the interface changes, the amplitude and time of the echo also change.

The radar identified 51% of the grid points located over delaminations and the simulated scaling. It did not identify the debonding and also falsely indicated numerous grid points to be delaminated. Despite these results, the radar was found to have considerable potential if the interpretation of the waveforms could be improved. The hand-operated cart was rather crude and it was apparent that the next step in the development of the radar system should be vehicle-mounted equipment in which the signal was recorded continuously on magnetic tape for off-line processing, using software specifically developed for the purpose. A useful feature of the radar is that it permits an accurate measurement of the thickness of the asphalt surfacing because of the well-defined echos from the surface of the asphalt and from the asphalt-concrete interface. Except for the presence of moisture on the deck, the radar is independent of constraints by the weather.

5/ THE DEVELOPMENT OF DART

Following the completion of the research studies described above, development work concentrated on construction of a prototype unit and automated data processing techniques.

A van was dedicated to the project and equipped with the following:

1/ A rail attached to the front of the vehicle so that the radar antenna can be positioned 150 mm over the deck anywhere within the width of the vehicle.

2/ A folding rack for mounting the infrared camera approximately 5 m above the deck surface. A standard video camera can also be mounted on the rack.

3/ Vibration controlled racks in the vehicle for mounting electronic equipment.

4/ Air conditioning for the proper functioning of the electronic equipment in hot weather.

5/ A fifth wheel used to give an accurate readout of speed and distance. The device is also connected through an interface to produce distance pulses on the thermal and radar tapes.

6/ A trailer which contains an electrical generator to supply power to the electronic equipment in the vehicle.

Figure 6 shows the vehicle with the radar antenna and infrared camera in position. Figure 7 shows the interior of the vehicle. A schematic representation of the equipment in the infrared and radar components of the prototype unit is given in Figure 8.

The radar signal passes from the antenna through the transmitter/receiver to the control unit. The waveform is displayed on an oscilloscope so that the operator can ensure that valid data is being collected. The waveforms, together with distance pulses from the distance interface are stored on a seven channel FM recorder for analysis using a microcomputer.

The thermographic image passes from the camera through the monitor/control unit to the scan converter. The purpose of this piece of equipment is to convert the camera signals to a standard video signal scan rate to facilitate digital processing. The converted signal together with distance pulses are recorded on a high resolution video recorder for later processing. The image is also displayed on a video monitor so that the operator can verify the quality of the image being collected. The distance pulse can also be monitored using an oscilloscope.

Once all the connections have been made, operation of the equipment is relatively straightforward. The radar system must be calibrated using a standard procedure and the infrared camera focussed. The radar antenna is positioned within one metre of the curb or right-hand edge of the traffic lane and the vehicle driven over the deck at a constant speed of 5 km/h. A second pass is made with the antenna positioned between the wheel tracks. The field of view of the infrared camera is such that a full lane width can be scanned on one pass.

Numerous checks have been designed in the system so that the operator can verify the validity of the data collected before leaving the bridge site. The operator can also recognize whether the bridge deck under investigation is in poor condition, in which case it is advantageous to make additional passes with the radar antenna along different grid lines.

Two research contracts with McMaster University have led to the development of software which will process the radar waveforms automatically (7). The program provides a printout of the thickness of the bituminous surfacing and a plan of the deck showing the type and extent of the deterioration along each grid line traversed. Software has also been developed to utilize the microcomputer to analyse the infrared image. The videotape is first digitized and then sampled in such a way that the oblique distortion on the videotape is eliminated. Defects are identified through a combination of operator and machine interpretation and a scaled image of the deck showing the areas of delamination and scaling is produced. Debonding is very difficult to identify and cannot be predicted with certainty at the present time.

The radar system has the advantages that it is virtually independent of weather conditions and well suited to use on asphalt-covered decks. It is less well suited to use on exposed concrete decks because of interference between the waveform reflected from the deck surface and any delamination just below the surface. This is not a problem on asphalt-covered decks because the asphalt is approximately 80 mm or more in thickness. Radar also only produces data along the grid lines traversed by the antenna and, unless several passes are made, areas of deterioration may be missed. Conversely, thermography is much more sensitive on exposed concrete decks than asphalt-covered decks. It also produces information on the entire deck surface and not just along grid lines. Its major disadvantage is its dependence on the weather, especially for asphalt-covered decks. Consequently, the two systems complement each other extremely well.

6/ FUTURE RESEARCH

The next stage in the development of this system is to operate the prototype unit under field conditions in 1985 in order to assess its accuracy and reliability. Initially it will be used to investigate a large number of bridge decks in order to assess priorities for rehabilitation. It is thought that the unit is particularly well suited to this application because only limited accuracy of the data is required. As experience is gained in the use of the equipment, it is expected that a number of the activities now included in detailed condition surveys can be eliminated. The potential exists to carry out detailed surveys using the DART system supplemented by a small amount of physical testing and sampling. This is expected to lead to improvements in the accuracy of the data, a reduction in survey costs, and less disruption to traffic.

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Table 1/ Summary of Results of Procedures Evaluated on Asphalt-Covered Decks

TEST PROCEDURE	SUMMARY OF EVALUATION
Chain Drag	Only a small percentage of delaminations identified, but no false results. Independent of weather and inexpensive. Useful screening device in conjunction with other prcedures.
Sonic Reflection	Very low accuracy.
Ultrasonic Transmission	Impractical.
Micro-Seismic Refraction	Identified anomolies but interpretation difficult. Procedure is very slow.
Resistivity	Results did not correlate with area of deterioration.
Potential Survey	Useful indication of corrosion activity. Does not identify other forms of deterioration. Requires drilling through asphalt.
Radar	Good correlation with known deterioration. Many false results but accuracy could be improved by better methods of signal interpretation. Offers potential for rapid, non-contact procedure independent of weather.
Thermography	Excellent correlation with areas of deterioration with no false results. Main disadvantage is dependence on weather.

Figure 1/ Corrosion-Induced Delamination in a Concrete Core

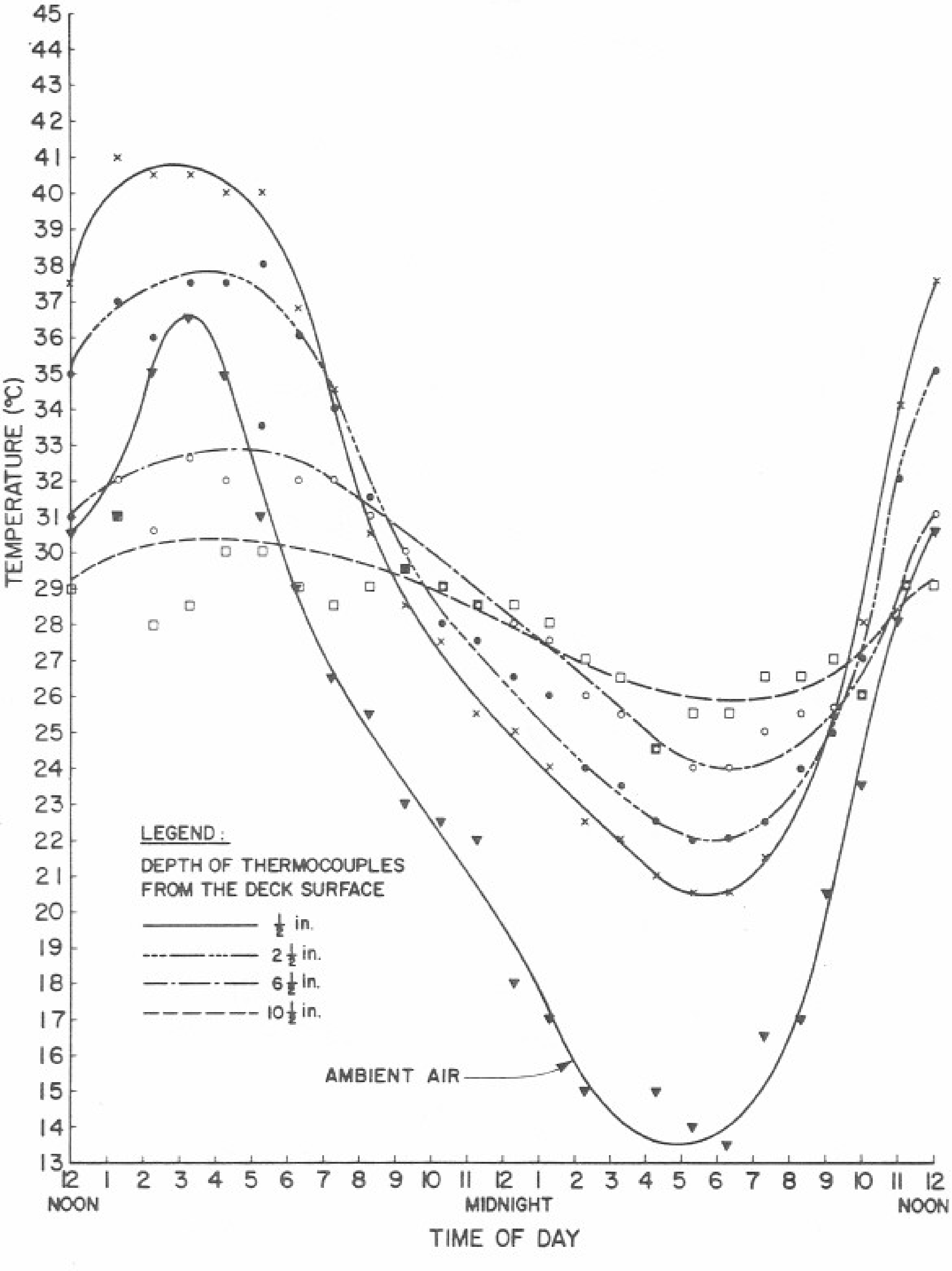


Figure 2/ Typical Diurnal Temperature Distribution in a Thick Slab Deck in Summer

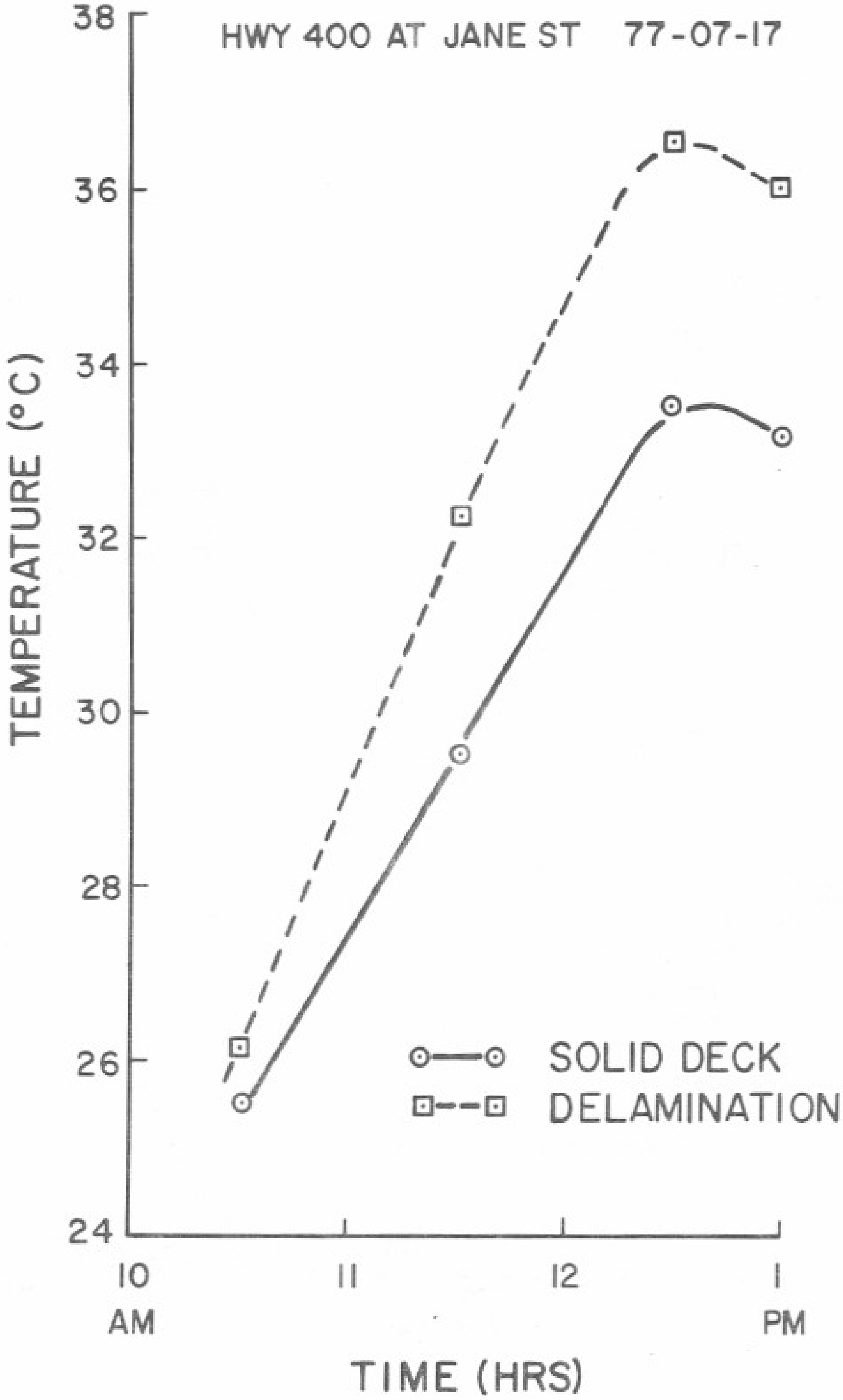


Figure 3/ Difference in Temperature Between Solid and Delaminated Concrete on a Thin Slab Deck

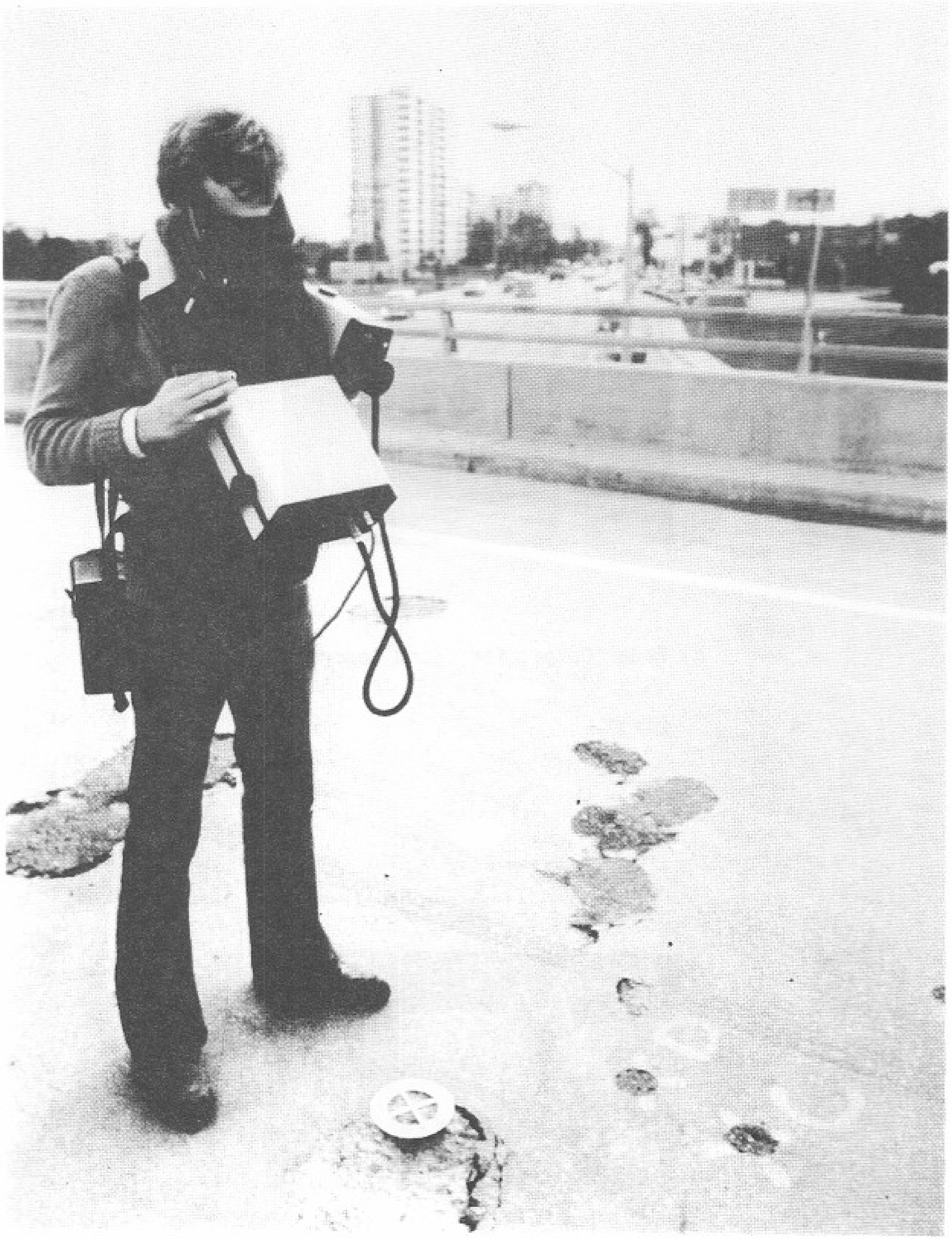
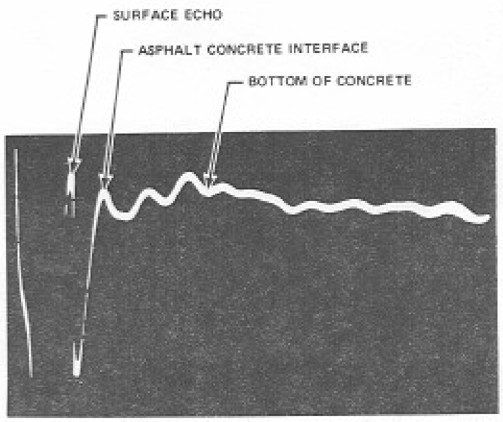
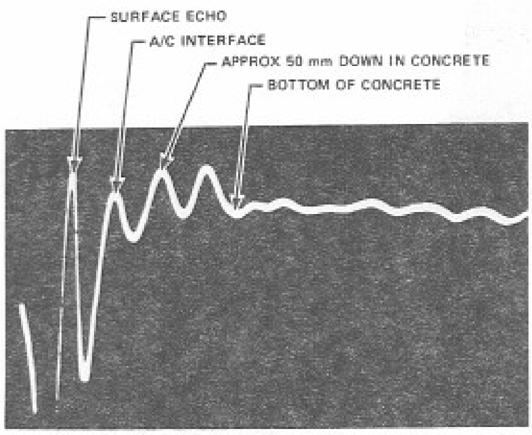


Figure 4/ Infrared Thermovision Equipment Being Operated at Ground Level



a) Radar Output for Sound Concrete



b) Radar Output for Delaminated Concrere

Figure 5/ Typical Radar Waveforms

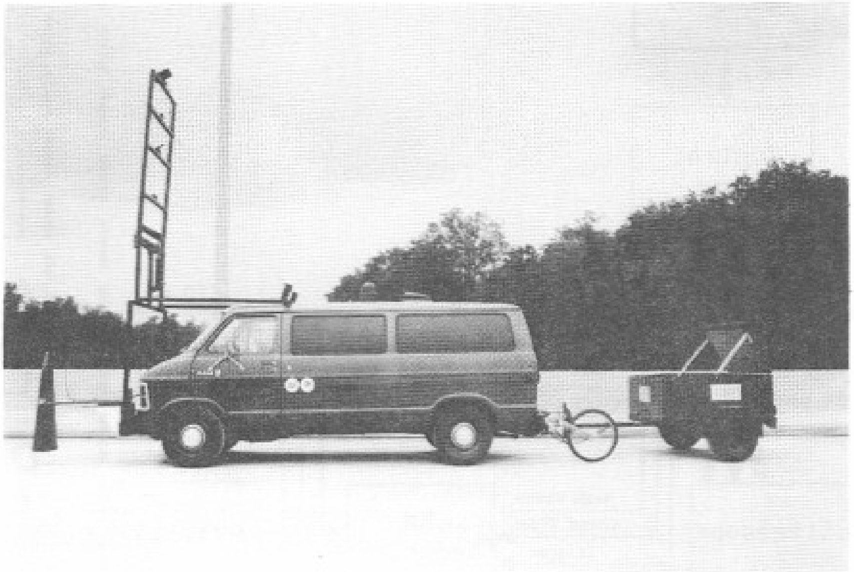


Figure 6/ DART System with Radar Antenna and Infrared Camera Mounted on the Front of the Vehicle

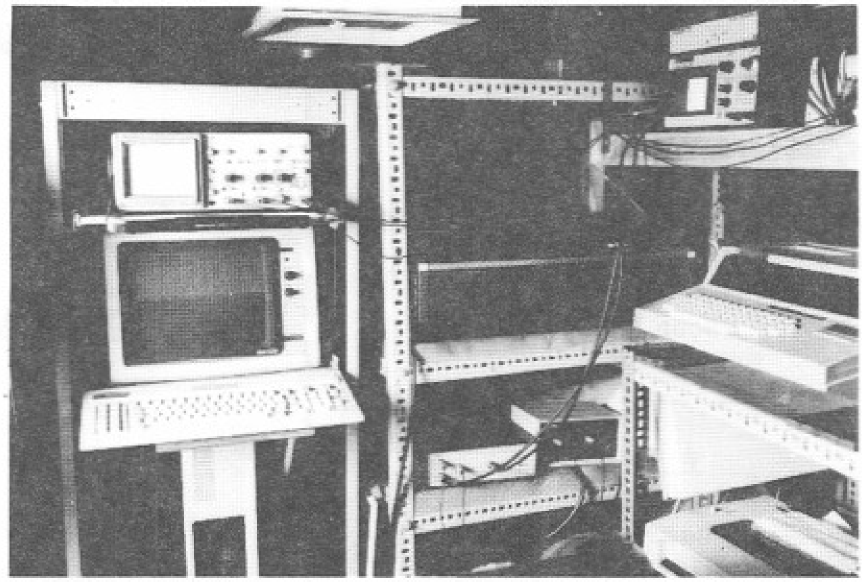


Figure 7/ Interior of DART Vehicle

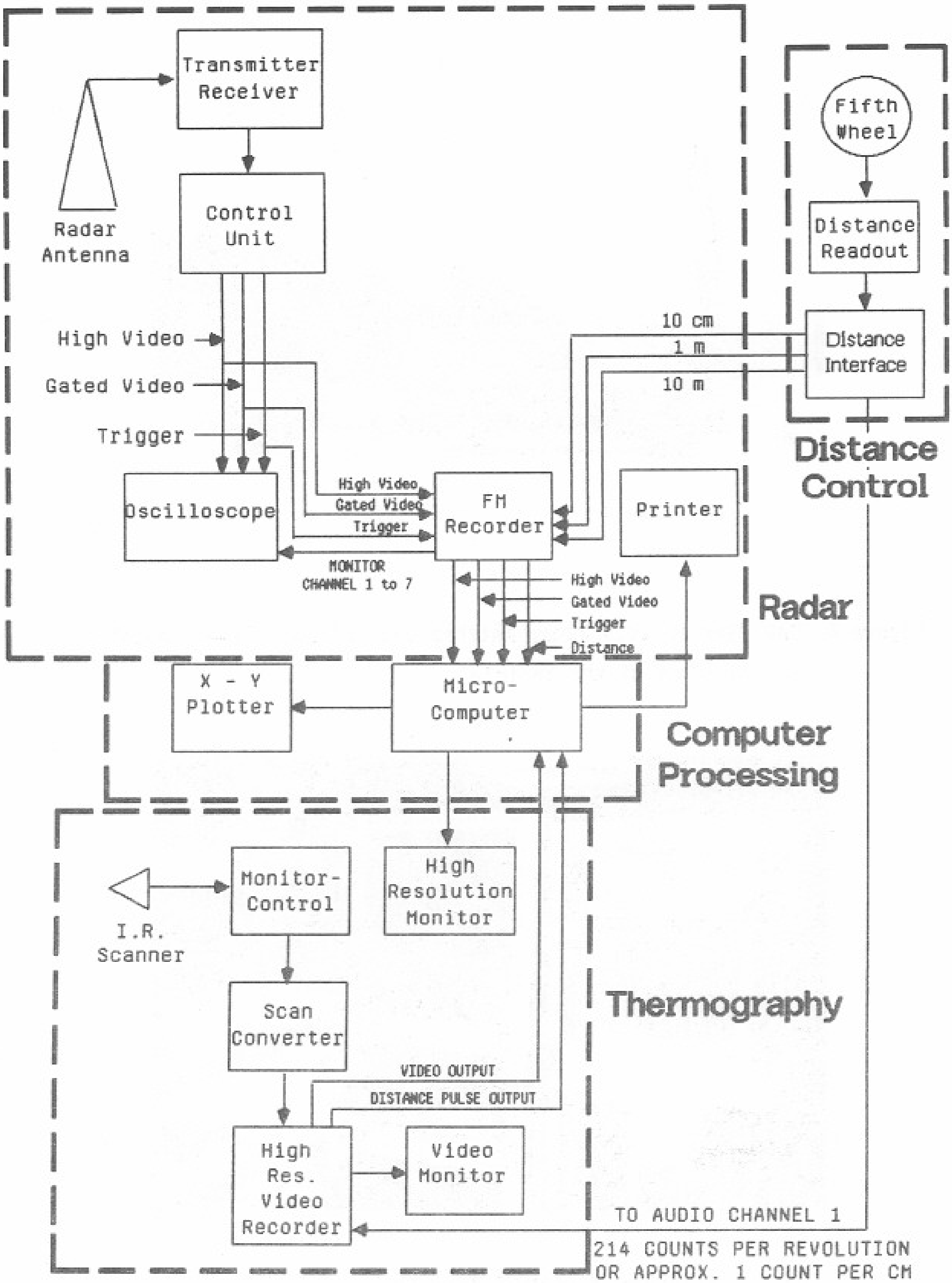


Figure 8/ Shematic Representation of the DART System