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APPLICATION OF INFRARED THERMOGRAPHY TECHNIQUE FOR EVALUATION OF EXISTING CONCRETE STRUCTURES

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ABSTRACT

This investigation was carried out to review the available literature on infrared thermographic technique for evaluation of existing concrete structures; and, to apply the knowledge to existing concrete structures. A detailed field study was undertaken to assess the damage condition of a bridge deck at a freeway interchange in Milwaukee, Wisconsin, USA, using an infrared thermographic scanning system.

Past investigations have demonstrated that infrared thermography (IRT) scanning can be used to inspect damage to roofs and exterior walls, deficient and missing insulations, deficient construction, air leakage, and quality of construction of buildings. A few investigators have successfully used IRT techniques to evaluate subsurface anomalies in sewer lines, wastewater pipes, and tunnels. Currently IRT scanning is more commonly used for rapid and accurate evaluations of subsurface defects of structures such as bridge decks, highways, and airport pavements to avoid costly repairs. The IRT technique is capable of locating and measuring horizontal dimensions of subsurface defects present in these structures. In order to characterize these anomalies with respect to depth or thickness, a ground penetrating radar system is generally used along with IRT system.

In the present investigation, the infrared thermography inspection of a bridge deck showed several subsurface defects that were not detectable by surface visual inspection. Based on this investigation, it was concluded that IRT scanning of the bridge should be conducted at regular intervals in order to select cost-effective method for its maintenance and rehabilitation.

NTRODUCTION

Deterioration in concrete increases with time due to induced stresses. The induced stresses can result from applied loads, especially fatigue loadings, and expansive reactions in concrete. The expansive reactions can result from sulfate attack, alkali-silica reaction, carbonation, freezing and thawing actions, rust forming reactions, etc. However, in cold climates, occurrence of expansions due to freezing and thawing actions, and rust forming reactions is more common. When water penetrates into concrete and freezes, cracking and spalling of concrete occurs due to the resulting expansion. The spalling can lead to formation of "pot holes". Additionally, when deicing chemicals, especially chloride-based chemicals are used, chloride ions penetrate into the concrete and favor rust forming expansive reactions around the top of the reinforcement mat. The resulting expansion causes cracking and eventually spalling of concrete cover. This type of cracking is referred to as delamination. Damage to concrete due to the above expansive reactions can range from micro-cracks to macro-cracks that can lead to sudden failure of structures.

Initial stages of cracking in concrete is not detectable by visual inspections. With a view to avoid catastrophic failure and massive repair of structures, it is essential to determine damage at low levels. To accomplish this, a number of nondestructive test methods have been developed and used. Nondestructive methods for concrete can be categorized into two major types. The first type of nondestructive testing (NDT) methods are primarily concerned with determination of in-place strength properties. Whereas, the second type of NDT methods are employed to locate hidden flaws in existing structures. The flaws include cracks, voids, honeycombing, delaminations, and debonding of reinforcement. The second type of NDT methods include infrared thermography, ground penetrating radar, electrical/magnetic, radioactive/nuclear and impact-echo [Carino, 1991]. Of these, infrared thermographic testing is an area testing method, while other techniques are either point or line testing methods. Additionally, it is fast and accurate in subsurface flaws detection of existing structures. The present investigation is primarily concerned with infrared thermography for NDT structures. The major objectives of the present investigation are:

(1) to evaluate state-of-the-art information on infrared thermographic application for NDT of existing concrete structures; and,

(2) to determine damage condition of a bridge deck of a freeway interchange in Milwaukee, Wisconsin, USA, using an infrared thermography scanning system.

INFRARED THERMOGRAPHIC PRINCIPLES AND TECHNIQUES

Infrared thermography is used to measure concrete surface temperature, or temperature differences of concrete surface or other objects. The temperature measurements may be done at any time of day or night as long as heat transfer is taking place; that is, as long as the surrounding environment is warmer or cooler than the concrete mass being investigated.

It is a fundamental principle of thermodynamics that thermal energy will always flow from warmer areas to cooler areas. The three ways that thermal energy can be transferred are: conduction, convection, and radiation.

Thermal energy passes from the surface to the interior by means of conduction and convection within the mass. Similarly, any internal heat must be transferred to the surface by internal conduction or convection. Solid concrete is a reasonably good conductor of heat and any effects of convection within the mass can be considered negligible. If the concrete has voids caused by delaminations or poor placement, the conduction paths is disrupted. The disruptions in the flow of thermal energy lead to temperature differences on the surface, which can be detected by infrared thermography (IRT). During the day, subsurface anomalies cause localized increases in heat absorption, so the surface above these areas registers warmer than the surrounding areas. At night, the anomalies cause the surface above them to dissipate heat faster than the surrounding solid areas, so they register cooler.

Maser and Roddis (1990) reported that the width of the delamination crack has a pronounced effect on the temperature differences between the solid and delaminated concrete. Considering this fact, the IRT method not only detects delaminations but also indicates their severity. One important consideration is that the temperature difference between the solid and delaminated area is only detectable if the crack is dry (i.e., air filled). A debonded area with a 0.05 inch air filled crack has up to a 4° C temperature difference compared to a solid slab. If the same crack is filled with water, the temperature difference is essentially undetectable (less than 0.2° C).

IRT detects the temperatures radiated by the surface of the pavement. Radiation is the process that allows the mass of the concrete to transfer energy to and from the ambient environment. The ability of a body to radiate energy is affected by surface characteristics such as the roughness and color. The measure of the ability to radiate thermal energy is called emissivity. A perfect "black body" has an emissivity of one. This means that, at any given temperature difference with the environment, it radiates the maximum possible energy. The emissivity is higher for darker colors and higher for rougher surfaces. Radiant emission is described by the Stefan-Boltzmann law, which states that the infrared power radiated by a body is directly proportional to the fourth power of its absolute temperature.

Radiant heat transfer is also affected by environmental factors. Clouds reflect the infrared energy, so the heat transfer process is slowed. Wind accelerates surface cooling and may negate temperature differences caused by subsurface anomalies. Moisture tends to increase the dissipation of heat, which also can negate temperature differences caused by subsurface anomalies. Also, as mentioned previously, if the moisture penetrates the cracks, the temperature differences are minimized. Thermographic testing should be done on days with no significant cloud cover, with the wind speed below 15 mph, and with the surface to be evaluated dry [Kunz & Eales, 1985]. In summary, the factors affecting the radiated energy include: surface emissivity, surface temperature, surface moisture, ambient air temperature, wind velocity, and environmental factors such as cloud cover and the intensity of sunlight.

Infrared thermography can also detect debonding between an asphalt overlay and the underlying concrete. There is a distinctive thermal signature difference between a delaminated and a debonded area [Kunz & Eales, 1985]. Delaminations are generally circular in plan view and have a uniform temperature within the delaminated area. Debonded areas, on the other hand, are generally larger, non-circular, and have non-uniform temperatures within the debonded area. Through the infrared scanner, the debonded areas have a marbled appearance.

LITERATURE REVIEW

The first use of infrared system for detection of anomalies and air leaks in buildings was reported to be in the year 1965 by AGA Infrared System [Ljungberg, 1994]. However, rapid progress in infrared technology began after 1975, primarily in the USA, Canada, and Sweden. Major developments in the infrared technology have occurred during the last 10 to 15 years. Recent developments in signal processing and numerical algorithm have led to increased use of imaging technology like infrared thermography in several fields. Infrared thermography technique is routinely being used in biomedical, geophysical, oceanographical sciences, and nondestructive testing of materials and structures [Pla-Rucki & Eberhard, 1995]. Additionally, it is being used in military applications in missile guidance, target tracking, surveillance, etc.

Infrared Thermography of Buildings

A number of investigations [Ljungberg, 1994; Schott & Biegel, 1982; Tobiasson, 1988; Ljunberg, 1987; Ljungberg & Lyberg, 1990; Allen, 1987; Ljunberg, 1988; Melballe, 1989; Epsosti & Meroni, 1995; Stanley, 1994; Schickert, 1985] have been directed toward damage and energy efficiency evaluation of buildings using infrared thermography scanning systems. Ljugberg (1994) presented information on successful applications of infrared thermography of buildings as briefly presented below.

Generally short-wave (2-5.6 μm range) or intermediate-wave (8-14 μm) range portable thermo vision systems are used for indoor thermography. The radiation intensity is lower in the short-wave system compared to the intermediate-wave infrared systems. To some extent the decreased radiation in the case of short-wave systems is compensated by using highly sensitive detectors. For outdoor thermography, infrared line scanners or forward looking infrared systems with a wide field of view (40 - 80°) are preferred. For accurate determination of thermal anomalies of a small building, indoor infrared thermography is preferred. Whereas, outdoor thermography is used for determination of radiation pattern of tall buildings or a group of several buildings. Infrared systems can be mounted either on stable fixed wing aircraft, on a helicopter, or on a top of vehicle for outdoor thermography. A combination of indoor and outdoor infrared thermography can be used for obtaining better results.

Outdoor infrared (airborne infrared) thermography is used to detect moisture damage to roofs. This is accomplished by determining wet insulation in roofs. An airborne infrared survey of a wet roof insulation exhibits a bright diffused temperature radiation pattern on a dark background in the thermograph. In the indoor infrared thermography, a dark temperature pattern of a wet roof insulation on a bright background is observed. Core samples are taken from these areas to verify the infrared results. Moisture damage and cracks in exterior walls occur due to poor design, deterioration of surface materials, leakage from internal water pipes, etc. Such damage can also be determined similar to that described for roof insulation. Other building problems such as deficient and missing insulation and air leakage have also been determined through the use of IRT inspections.

Sewer Systems, Wastewater Pipes, and Tunnels

Damage to soil around a sewer line can occur due to high groundwater levels and water leaks from pressurized pipes or other sources. These leaks cause formation of voids and erosion of soils around the sewer lines. Consequently, the support to the sewer is decreased, causing excessive deformation in sewer line that can lead to formation of cracks. Similar damages can also occur to wastewater pipes and tunnels. In order to avoid sudden collapse and costly repair of such structures, it is essential to detect voids in and around these structures to determine priority for their repair and maintenance.

Traditionally sewer voids have been detected manually [Weil, 1984]. The manual methods are costly, time consuming, intrusive to traffic, and unreliable. Additionally, they are limited in scope and can cover only small percentage of long sewer lines.

Weil (1984) carried out an investigation to detect sewer voids by using infrared thermography technique. The infrared results were compared to a falling weight deflectometer, a soil boring, and a physical crawl through test results. The author concluded that: (1) infrared thermography was capable to detect voids around sewer system due to temperature differentials that existed between various types of materials, effluent, and cavities; (2) thermal scanning process could be used to obtain faster and more accurate results compared to manual or electronic methods; and, (3) wet and dry voids could be differentiated by means of infrared thermographic inspection technique. More recently, in Sweden, an encased short-wave infrared system (Agema THV 781) has been successfully used to evaluate inside condition of wastewater pipe, water leaking into wastewater pipe, and causes of the pipe damage [Ljungberg, 1994].

Recently, Weil (1993) carried out an IRT inspection of a tunnel (4,400 ft.) for potential voids and erosion areas caused by leaks from steam, gas, and chemical pipelines, and other anomalies. The tunnel was composed of masonry wall with five-layer thick twin archways ceiling and earth fill enclosing the whole structure. A total of 30 anomalies were uncovered. Ten of these anomalies were attributed to steam lines having either poor insulation or leaks. Additionally, GPR testing was carried out to characterize these anomalies with respect to depth and width.

Bridge Decks and Pavements

Probably the earliest published work concerning the use of IRT for delamination of concrete was by Ontario Ministy of Transportation and Communication in 1973 [Weil, 1991]. Ontario's another investigation [Holt & Mannings, 1978] evaluated delamination of bridge decks using both ground level and airborne thermographic test methods. They also collected bridge delamination damage data using manual methods. Based on the test results the authors concluded that: (1) both ground level and airborne thermographic testing methods were adequate to determine delamination on bridge decks; (2) the differences in surface temperatures were related to thickness of delaminations; and, (3) thermal images can be used to determine delaminated area more accurately compared to that with manual methods.

Hillemeir (1994) used an IRT technique to locate steel reinforcement embedded in concrete. The reinforcement was heated inductively without heating the concrete. An infrared video system was used to record thermal image of the reinforcement to determine the position of the reinforcement.

Maser and Roddis (1990) developed a thermal model of delaminated bridge decks. The deck properties such as thickness of cover, delamination, bottom part of deck layers, the thermal conductivity, volumetric heat of sound and damaged concrete, and the heat transfer coefficients for the top and bottom of the deck needed to be known. The input parameters for the models are ambient temperature and incident solar radiation. The postulated thermal laminated model used finite element formulation with capabilities for transient heat flow analysis. The thermal model solves for temperature as a function of time and depth. The model results for infrared thermography showed that this technique is capable of detecting delamination. However, this method's predictability decreases when asphalt thickness is large, delamination opening is small, and cracks are deep. Field studies were also conducted to evaluate capabilities of IRT for bridge deck deterioration assessment. The main objective of the field investigations was to collect radar and infrared data on asphalt-overlaid decks that were scheduled for maintenance and rehabilitation. Field studies results were in a good agreement with the model's predictions. The model predicted area of delamination was within 5% of field results observed.

At the present time, infrared thermography is well developed [EnTech Engineering, Inc., 1996; Weil, 1989 & 1991a; Maser & Roddis, 1990]. It has been successfully used to locate voids and delaminations in concrete structures such as bridge decks, highways, and airport pavements. Studies [Love, 1986] have shown that infrared thermography is able to detect most of the delaminated area on bridge decks at a cost competitive with less accurate methods.

Kunz and Eales (1985) reported the use of thermography on a 11 mile, eight-lane, heavily travelled, Dan Ryan Expressway located in Chicago, Illinois, USA. The infrared thermographic data were collected at about 5 miles per hour using an infrared system mounted on a mobile van. For this investigation, traffic control was provided by two sign-board vehicles behind the van.

The thermographic test data were collected in 14 hours on five different days in October of 1982. This testing required significantly lower amount of time than it would have taken for other inspection methods.

IRT inspection can cover large areas more efficiently than other NDT methods. It can locate and image horizontal dimensions of anomalies in concrete structure. This method cannot determine depth or thickness of these anomalies. GPR is commonly used to measure depth or thickness of anomalies accurately. Therefore, when a complete characterization of these anomalies is required, a combination of infrared thermographic and ground penetrating radar technique should be used for efficient, accurate, and economical evaluation of concrete [Weil, 1991b].

More recently, Applied Technologies, Inc. (1994), conducted an investigation to locate and characterize anomalies present in the pavement materials or directly beneath the pavement materials for City of West Allis, Wisconsin, USA. These anomalies included flaws in pavement, uneven moisture areas, poor backfill, thin and weakened sub-base material, and deterioration of the subgrade scanned. The anomalies were inspected by EnTech Engineering, Inc. using a van mounted IRT and GPR systems. The IRT and GPR test data were recorded at three geographical locations: West Holt Avenue; West Verona Court; and, South 122nd Street in the City of West Allis. The analysis of the test data showed presence of subsurface anomalies at all these locations.

The West Holt Avenue pavement had 0 to 2 in. voids in 19% of the pavement area and greater than 2 in. voids in 14% of the pavement area. The West Verona Court pavement exhibited 0 to 2 in. voids in 47% of the pavement area, and greater than 2 in. voids in 29% of the pavement area. The South 122nd Street pavement showed 0 to 2 in. voids in 30% of the pavement area and greater than 2 in. voids in 28% of the pavement area. Based on extensive deterioration of the pavement materials and subgrades observed in the study, it was recommended that all three pavements be reconstructed.

Concrete Dams

Concrete arch and gravity dams show cracks of varying sizes as they get older and deteriorate. These cracks are formed during concrete setting and hardening as well as during their operations. Additional cracking can result from expansive reactions in concrete. In order to avoid instability of dams due to the formation of such cracks, it is essential to have an early detection of cracks so as to select the most appropriate options for their repair and maintenance.

Madrid (1990) carried out an analytical and experimental investigations to evaluate the feasibility of detecting deep cracks in concrete dams by using infrared thermography measurements. Both air-filled and water-filled deep cracks in arch and gravity concrete dams were studied. A simplified scale-down model of the non-flow section in a conventional concrete dam and its reservoir was designed and constructed. A one dimensional theoretical heat transfer model of the simulated dam reservoir was also developed. Infrared thermography scanning of the model at its downstream face was performed using a high-resolution CMT thermal imager (BSI 7000 Equipment). The results obtained from the measurements were found to be comparable to that predicted by using the analytical model. The test results further indicated that infrared thermography technique is appropriate to detect deep cracks in concrete dams.

CASE HISTORIES

EnTech Engineering, Inc. (ETCI), St. Louis, Missouri, USA, is extensively involved in nondestructive testing and evaluation of bridge decks, highways, and airport pavements. Primarily, ETCI has used two nondestructive methods, namely infrared thermography and ground penetration radar, in order to locate voids and delamination in bridge decks, highways, and pavements. Infrared thermography was used to locate and image the horizontal dimensions of voids and delaminations, while ground penetrating radar was used to measure depth or thickness of anomalies. A few case histories related to bridge deck pavements, highway pavement, and airport taxiway pavement, are reported by Weil (1991b).

Over the last several years, ETCI has carried out IRT inspection of over 100 bridge decks for the Illinois Department of Transportation. Size of these bridge decks varied from very small, such as those found in rural areas, to very large such as the Poplar Street Bridge Complex over the Mississippi River. Initial testing involved the use of IRT supplemented by selective coring of the concrete deck. This process was found to be very successful. However, it was able to provide 80% of the information needed by the Illinois state officials. Although the method provided drawings showing location of anomalies, it lacked greatly in providing severity of anomalies. Additionally, repair contractors found difficulty in locating the anomalies marked on drawings. Thus, referencing was a major problem. In order to solve these problems, ETCI used IRT inspection in combination with GPR technique without the use of corings. The ETCI's improved referencing system, when linked to an infrared system mounted on a mobile van, was found to be accurate within 1% on all bridge decks inspected. In this technique, IRT data were first recorded and then reproduced on scale drawings. Thereafter, only GPR inspection was carried out on the pavement. The radar antenna was placed only on the specific anomalies that were previously located on the drawing by using IRT. After confirming the location of anomalies by GPR, further attempts were made to determine the cause of anomalies such as debonding of the overlays, void or delamination above and below the rebar, etc. The inspection results were found to reproducible and thus the need for physical coring or major traffic control was eliminated.

ETCI performed an infrared inspection on a two-lane section of interstate I-70 highway pavement for a length of about 4,000 ft. in 1991, for the Missouri Department of Transportation (MO-DOT), to detect voids. The pavement was being rehabilitated with all new concrete because of extensive damage. The major aim of the inspection was to locate non-homogeneity of the pavement that might have occurred due to the presence of pockets of pure sand with no binder or aggregate. About 4,000 sq. ft. area was inspected by infrared thermography scanning system. Testing of the entire area was completed and the results were provided to the repair contractor and the MO-DOT officials the same night of testing. Five non-homogeneous areas, indicating the presence of anomalies were detected by the IRT inspection. These areas were excavated and repaired by the contractor. The contractor reported that four of the anomalies contained loose sand or void, and the fifth anomaly had excess concrete and miscellaneous debris that were not removed during the excavation of old pavement.

Damage to a DC-10 plane occurred due to collapse of airport taxiway pavement on May 2, 1990 at the Manchester International Airport, New Hampshire. The landing gear of the plane with full passenger load sank into the pavement while approaching its unloading gate. The resulting damage to the airplane was in the order of half million dollars. During the removal of the airplane, an air void (6' x 6' x 8') under the pavement was observed. The void formation was due to leaks and infiltration of soil into a buried storm water drainage system. The drainage system was 40 years old and located throughout the airport pavement. To avoid future accidents, upon recommendation of consultants, airport authorities decided to have the pavement inspected for leaks and voids that might be present. Infrared thermography inspection method was selected because of its speed and 100% area coverage without interrupting airport traffic. Infrared thermographic inspection was carried out on the pavement for locating leak and voids. A total of about 2,000,000 sq. ft. area was inspected at night after 11:30 P.M., to minimize interruption of airport traffic. The entire inspection was completed in three days. This inspection detected 12 major subsurface voids, some of which could have caused collapse of the pavement due to airplane loads.

FIELD TESTING PROGRAM

Test Equipment

The primary measuring equipment consists of an infrared scanner mounted on a telescopic boom on the front of a specially equipped van. The infrared scanner is similar to a video camera, except that the optical system is sensitive to short (3 to 5.6 μm) and intermediate (8 to 12 μm) wave radiation. The camera uses a mercury cadmium telluride detector that, for maximum sensitivity, is cooled to a very low temperature (- 200° C) by circulation of liquid nitrogen or by an integral refrigeration system. By maintaining a low temperature on the detector it is possible to measure temperatures differences of 0.2 degrees C or less. A 45 degree view-expander lens is used to allow a full pavement width (14 feet) to be viewed at one time. Also on the boom, mounted adjacent to the infrared scanner, is a video camera. The video camera has a zoom lens that is focused and aimed on the same area of pavement that is being scanned by the infrared camera. This combination of real and infrared images allow the correct interpretation of temperature differences caused by environmental factors such as oil spots, asphalt and tar patches, paint, etc. Some people prefer conducting the thermographic study at night because of reduced traffic and elimination of thermal differences due to shadows. Other people prefer to work during the day so that the video camera can have the maximum resolution, thereby minimizing errors in interpretation of the thermal anomalies. The important consideration to remember is that infrared thermography can be performed at any time of the night or day as long as heat transfer is taking place. The actual time of testing is a matter of preference with the operator.

As the instrument-laden van moves along the roadway, both the real and infrared images are recorded on a video tape, along with a digitally superimposed distance counter that is coupled with the vehicle's drive train. In the office, the two tapes are played back, and the infrared anomalies are digitized onto a CADD-based plan view of the bridge deck for further study and evaluation.

Zoo Interchange Testing

An IRT scan of the bridge deck at the "Zoo interchange" located in Milwaukee, Wisconsin, USA, was conducted. The testing was performed by the Donohue consulting firm, under the direction of Dan Ulrikson. In performing an IRT test, the roads leading to the area to be tested were marked with "ROAD CONSTRUCTION" signs as a warning to the traffic. The thermography equipment containing test van was followed by two traffic control trucks that had arrow boards directing traffic away from the equipment van. Following the sign trucks was a marked Sheriff's squad car. The van, traffic control trucks, and the squad car, drove at about five miles per hour, so the freeway traffic normally could go around. This process has been successfully used on many projects except when inspecting a single lane roadway.

To calibrate the system the van was driven along the Zoo interchange (Fig. 1) pavement to be tested until the infrared camera sensed an anomaly. The infrared image was coordinated with the real image to see if the anomaly was caused by any environmental factor (paint, water, or oil on the pavement, asphalt patch, etc.). The image from the two cameras was also fine adjusted for focus, aim, depth of field and brightness. If the infrared camera found an anomaly that appeared to be not a solid concrete, then the technician left the truck to check the anomaly by sounding the spot with a hammer. If an exact size and shape of the delaminated area was desired then the surface was covered with fine sand prior to hammer tapping. The tapping caused vibrations in the delaminated area which moved the grains of sand to the edges and thus outlines the area in fine detail. The size of the sounded anomaly was then compared to that predicted by the infrared image. A contact thermometer was then placed on the surface of the anomaly and also the surface of the surrounding solid concrete. The measured temperature difference was compared to the indicated temperature difference from the infrared camera, and, if necessary, the infrared camera was calibrated to match. The entire checking and calibration process took only a few minutes. Once all factors were in agreement, the van resumed scanning and recording the data. After the data were recorded, they were taken back to the office and digitally analyzed as described earlier.

Test result of this investigation showed several subsurface anomalies of the Zoo interchange bridge deck that were undetectable in visual inspection. A sample of the test results is presented in Fig. 1.

SUMMARY AND CONCLUSIONS

Infrared thermography, a no-contact, remote sensing, NDT test method has been used in several fields. This method has proved to be an important and accurate tool in the detection of flaws in structures, often before any visible signs of damage exist. Although the equipment is costly, the test can be performed quickly over a large area resulting in a minimal operating cost per unit area. The major aim of this investigation were: (1) to study the literature concerning various uses of IRT inspection for damage evaluation of structures; and, (2) to evaluate damage condition of bridge deck at the "Zoo interchange" in Milwaukee, Wisconsin, for planning repairs and rehabilitation strategy.

Past investigations have shown successful application IRT scanning for location of moisture damage to roofs and walls, locations of deficient and missing insulations, air leakage, and quality control in construction of buildings. It has also been used in detection of defects in sewer lines, wastewater pipes, tunnel, etc. Currently it is more commonly used in detection of subsurface flaws in bridge decks, highway and airport pavements, etc. to avoid costly repairs and catastrophic failure.

The present investigation showed numerous subsurface defects in the Zoo interchange bridge deck that were not noticed during visual inspection. It is recommended, based upon this study, that bridge decks, roads, etc. be scanned at regular intervals as a form of preventative maintenance. A database should be created and maintained of how the deterioration of the pavement progresses from year to year. In such systematic evaluation, any pattern of deterioration could be discovered before it reaches critical levels needing massive repairs. Similarly, trends might be found relating severity of weather, amount of deicing salt used, traffic counts, and other factors leading to the deterioration of the pavement. With an accurate database, road repair budgets and plans for preventative maintenance could be prepared with greater accuracy.

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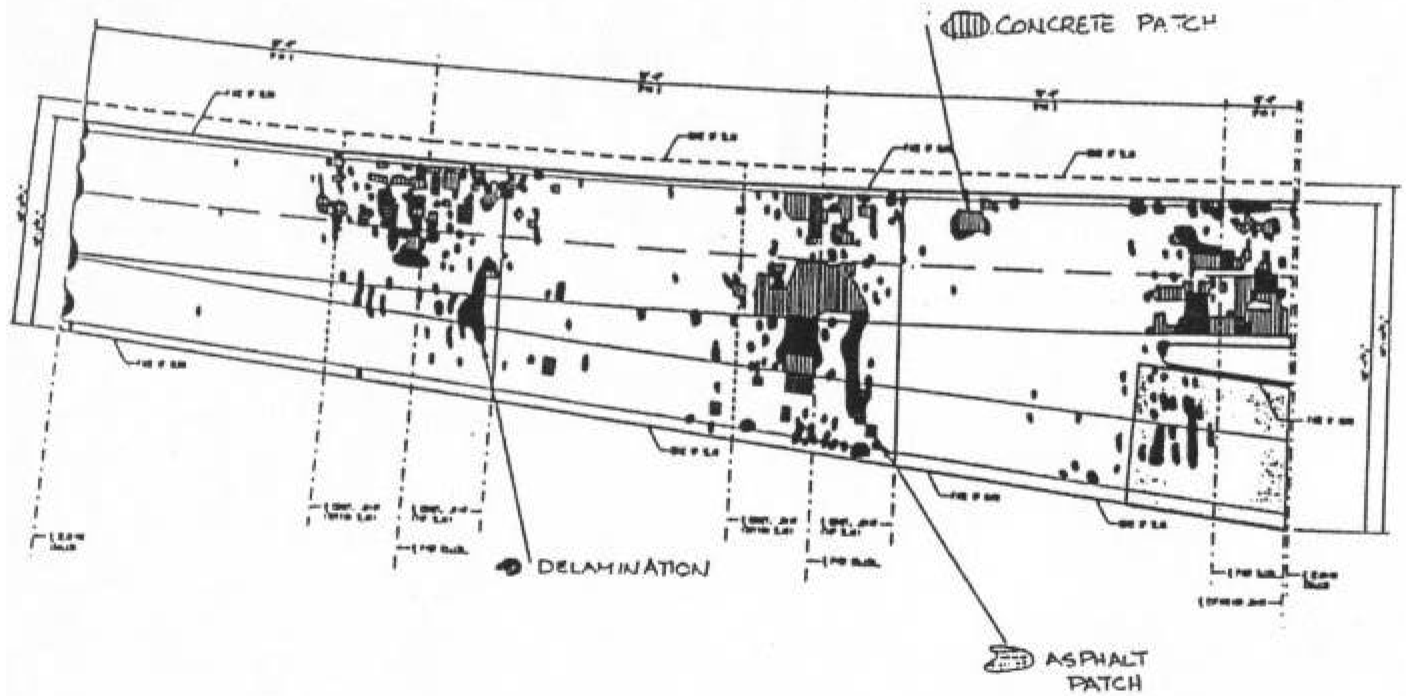

Fig. 1: Example of Thermography Results