

Health Monitoring of Bridges

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ABSTRACT: the process of implementing a damage detection and characterization strategy for bridges is referred to as health monitoring of bridges. Here damage is defined as changes to the material or geometric properties of structural system which adversely affect the performance of bridges. Many of the reported collapses of in-service structures can be attributed to strength degradation caused by environmental stressors. In recent studies deteriorating bridge structures under various environmental stressors have been evaluated in a reliability context. There are several degradation mechanisms are present in concrete highway bridges as, sulphate attack, alkali-silica reaction, freeze-thaw cycle attack, and corrosion, etc.

KEYWORDS: Health monitoring, degradation, sulphate attack, concrete bridges.

I. INTRODUCTION

Bridges are the critical component of the transportation infrastructure. Regular inspections and maintenance are the essential components of any bridge management program to ensure structural integrity and user safety. This is a grand challenge due to enormous number of existing bridges. Health monitoring of bridge concept is widely applied to various forms of infrastructure, ranging from bridge to skyscraper.

Health monitoring is used for detecting the existence of damage on the infrastructure, locating the damage, identifying the types of damage and quantifying the severity of damage. The area of health monitoring process that receives the most attention in the technical literature is the identification of data features that allow one to distinguish between the damaged and undamaged structure.

II. BRIEF DISCUSSION ON AGING INFRASTRUCTURE

The transportation infrastructure is quickly aging. Traffic and variable loading conditions greatly influence the performance, durability, and safety of the bridge structure throughout its service life [1-2]. Continuous monitoring can provide basis for determining the deterioration rate and for estimating the remaining service life, thus assisting in making important decisions regarding bridge maintenance. Bridge engineers need a reliable way to assess structural integrity of bridges to maintain the continuous operation of the road network while ensuring the safety of the public. Traditional visual inspection techniques are both time consuming and expensive. They are also qualitative and can only assess outward appearance. Any internal damage may go unnoticed for a long period of time. Many old highway bridges are rated as structurally deficient or obsolete. How does a bridge engineer keep track of these problems? Are inspections conducted every other year enough? A possible solution to these issues is to conduct health monitoring of bridges. This technique can detect changes in bridge superstructure and in some cases predict impending failures [3].

III. OBJECTIVES

The main objective of this thesis is to ensure bridge safety and to identify its damages or deterioration. It helps to improve the knowledge on various health monitoring techniques used in bridges. This technique will extend the

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

lifetime of deficient bridge [4]. This method can monitor bridges in real time and warn engineers about possible problems to avoid tragedies. Thus it optimises operation and maintenance costs

IV. NEED FOR THE STUDY

In India many of bridges was constructed during the period of 1950's i.e. the age of bridge is more than 55 years. The maintenance of bridge was not carried out compared when compared to other western countries. Due to infrastructure development and heavy traffic, the bridges are subjected to very high dynamic loadings. To avoid collapse of bridge it is mandatory to assess the condition of existing bridge [5].

Aging phenomenon of concrete in bridges is difficult to predict and this can lead to accidents and losses. It is important to make sure that they are in good condition. This is where health monitoring of bridges has a role to play. It gives a way to overcome these drawbacks with minimum damage and loss. This report provides an overview of the issues related to the inspection, condition assessment, evaluation and maintenance of highway bridges. Thus, the condition of bridge can be determined my various health monitoring techniques [6].

V. DETERIORATION OF CONCRETE IN BRIDGES

- Rebar corrosion
- Cracking
- Chemical attack
- Honeycombing
- Creep, Shrinkage and Volume changes
- Freeze-Thaw damage

VI. DEFINITION OF HEALTH MONITORING OF BRIDGES

Bridge monitoring is the application of structural health monitoring and inspection techniques to bridge structures. Health monitoring for buildings has been evolving over the past decade from methods used in the health monitoring of other structures (e.g., aircraft, rotating machinery, etc). A definition of the terminology associated with health monitoring is necessary before further discussion of the technologies used for bridge monitoring [7].

According to Chang (1999), the goal of structural monitoring is to gain knowledge of the integrity of in-service structures on a continuous real time basis. Scheduled maintenance and periodic inspection offer only limited knowledge of structural condition and these methods are costly in terms of extensive labour and downtime. However, advances in sensing technologies, material and structural damage characterization, and monitoring diagnostic technologies enable the integration of distributed sensors for real time inspection and damage detection [8-9]. Thus, the essence of structural health monitoring is the development of autonomous systems for the continuous monitoring, inspection and damage detection of structures with minimum labour involvement.

VII. METHODOLOGY

In the present work, a detailed study on literature regarding the study on health monitoring of bridges have been done. Health monitoring on bridges are most important since most bridges are becoming old, generally sensor based method of health monitoring is performed but assessment of bridge condition using NDT can also be used for that purpose [10]. A large range of Non-Destructive Testing (NDT) techniques are employed for a wide variety of applications within Civil Engineering. To inspect existing structures, visual inspection is the easiest and the most fundamental method. But this method may not be applicable for inspecting defects which does not appear on the surface. For such defects, Non-destructive inspection is the only method which can be applied. Non-destructive testing plays an important role for quality evaluation. India has been producing concrete structures since long times. And now it is becoming important problem to maintain these existing concrete and steel structures. This presentation aims on the explanation of NDT techniques and their application to structures. Non-Destructive Testing (NDT) techniques can be used effectively for investigation and evaluating the actual condition of the structures. These techniques are relatively quick, easy to use, and cheap and give a general indication of the required property of the concrete without damaging the structure [11].

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

Steps Involved In Methodology:

- Study of various NDT techniques for health monitoring of bridges
- Selection of bridge and collection of its details
- Testing of specimen casted in laboratory
- Health monitoring on bridges using various NDT techniques
- Conclusions and recommendations

VIII. NON-DESTRUCTIVE TESTS FOR HEALTH MONITORING OF BRIDGES

A. Schmidt Hammer Test

The Schmidt rebound hammer is principally a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. There is little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. However, within limits, empirical correlations have been established between strength properties and the rebound number. Further, Kolek has attempted to establish a correlation between the hammer rebound number and the hardness as measured by the Brinell method [12].

With the hammer pushed hard against the concrete, the body is allowed to move away from the concrete until the latch connects the hammer mass to the plunger. The plunger is then held perpendicular to the concrete surface and the body pushed towards the concrete. This movement extends the spring holding the mass to the body. When the maximum extension of the spring is reached, the latch releases and the mass is pulled towards the surface by the spring.

The mass hits the shoulder of the plunger rod and rebounds because the rod is pushed hard against the concrete. During rebound the slide indicator travels with the hammer mass and stops at the maximum distance the mass reaches after rebounding. A button on the side of the body is pushed to lock the plunger into the retracted position and the rebound number is read from a scale on the body [13].



Fig 1 Rebound Hammer Test

B. Ultrasonic Pulse Velocity Testing

A pulse of longitudinal vibrations is produced by an electro-acoustical transducer, which is held in contact with one surface of the concrete under test. When the pulse generated is transmitted into the concrete from the transducer using a liquid coupling material such as grease or cellulose paste, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves develops, which include both longitudinal and shear waves, and propagates through the concrete. The first waves to reach the receiving transducer

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

are the longitudinal waves, which are converted into an electrical signal by a second transducer [14-15]. Electronic timing circuits enable the transit time T of the pulse to be measured. The equipment consists essentially of an electrical pulse generator, a pair of transducers, an amplifier and an electronic timing device for measuring the time interval between the initiation of a pulse generated at the transmitting transducer and its arrival at the receiving transducer.



Fig 2 ultrasonic pulse velocity test

Longitudinal pulse velocity (in km/s or m/s) is given by

$$V = L/T$$

Where V is the longitudinal pulse velocity,
L is the path length,
T is the time taken by the pulse to traverse that length.

C. Combined Use Of Rebound Hammer And Ultrasonic Pulse Velocity Method

Combination of UPV and rebound hammer methods can be used for the assessment of the quality and likely compressive strength of in-situ concrete. Assessment of likely compressive strength of concrete is made from the rebound indices and this is taken to be indicative of the entire mass only when the overall quality of concrete judged by the UPV is “good” [16]. When the quality assessed is “medium”, the estimation of compressive strength by rebound indices is extended to the entire mass only on the basis of other collateral measurement e.g. strength of controlled cube specimen, cement content of hardened concrete by chemical analysis or concrete core testing. When the quality of concrete is “poor”, no assessment of the strength of concrete is made from rebound indices [17].

D. Pull Off Test

Pull off tester is microprocessor based, portable hand operated mechanical unit used for measuring the tensile strength of in situ concrete. The tensile strength obtained can be correlated with the compressive strength using previously established empirical correlation charts. The apparatus for pull off test shall consist of the following

1. 50mm dia steel disc with threaded rod screw
2. Pull off tester

The pull off test is based on the concept that the tensile force required to pull a metal disk, together with a layer of concrete, from the surface to which it is attached, is related to compressive strength of concrete. There are two basic approaches that can be used. One is where the metal disk is glued directly to the concrete surface and the stressed

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

volume of the concrete lies close to the face of the disk, and the other is where surface carbonation or skin effect are present and these can be avoided by use of partial coring to an appropriate depth [18].

E. Pull Out Test

The pull out test measures the force needed to extract an embedded insert from a concrete mass. By using a previously established relationship, the measured ultimate pullout load is used to estimate the in place compressive strength of the concrete [19]. The equipments required for pull out test shall consist of the following

1. Specially shaped steel rod or discs
2. Dynamometer to apply the force
3. Loading ram seated on a bearing ring for applying pull out force

The pullout test measures the force required to pull an embedded metal insert with an enlarged head from a concrete specimen or a structure [20]. The test is considered superior to the rebound hammer and the penetration resistance test, because large volume and greater depth of concrete are involved in the test

F. Windsor probe test

The Windsor probe, like the rebound hammer, is a hardness tester, and its inventors' claim that the penetration of the probe reflects the precise compressive strength in a localized area is not strictly true. However, the probe penetration does relate to some property of the concrete below the surface, and, within limits, it has been possible to develop empirical correlations between strength properties and the penetration of the probe.

The area to be tested must have a brush finish or a smooth surface. To test structures with coarse finishes, the surface first must be ground smooth in the area of the test. Briefly, the powder-actuated driver is used to drive a probe into the concrete. If flat surfaces are to be tested a suitable locating template to provide 178 mm equilateral triangular pattern is used, and three probes are driven into the concrete, one at each corner. A depth gauge measures the exposed lengths of the individual probes. The manufacturer also supplies a mechanical averaging device for measuring the average exposed length of the three probes fired in a triangular pattern. The mechanical averaging device consists of two triangular plates. The reference plate with three legs slips over the three probes and rests on the surface of the concrete. The other triangular plate rests against the tops of the three probes. The distance between the two plates, giving the mechanical average of exposed lengths of the three probes, is measured by a depth gauge inserted through a hole in the centre of the top plate. For testing structures with curved surfaces, three probes are driven individually using the single probe-locating template. In either case, the measured average value of exposed probe length may then be used to estimate the compressive strength of concrete by means of appropriate correlation data.

G. Permeability test

Permeability of concrete is important when dealing with durability of concrete particularly in concrete used for water retaining structures or watertight sub-structures. Structures exposed to harsh environmental conditions also require low porosity as well as permeability. Such adverse elements can result in degradation of reinforced concrete, for example, corrosion of steel leading to an increase in the volume of the steel, cracking and eventual spalling of the concrete. Permeability tests measure the ease with which liquids, ions and gases can penetrate into the concrete.

Two of the most widely established methods are the Initial Surface Absorption Test (ISAT) and the modified Figg air permeability test. The former measures the ease of water penetration into the surface layer of the concrete while the latter can be used to determine the rate of water as well as air penetration into the surface layer of the concrete which is also called the covercrete. Another newly developed technique uses a modification of the laboratory test to determine chloride ion permeability. All the site tests emphasize the measurement of permeability of the outer layer of concrete as this layer is viewed as most important for the durability of concrete.

IX. NON-DESTRUCTIVE TESTS FOR CORROSION ASSESSMENT IN BRIDGES

A. Half-Cell Potential Method

The method of half-cell potential measurements normally involves measuring the potential of an embedded

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

reinforcing bar relative to a reference half-cell placed on the concrete surface. The half-cell is usually a copper/copper sulphate or silver/silver chloride cell but other combinations are used. The concrete functions as an electrolyte and the risk of corrosion of the reinforcement in the immediate region of the test location may be related empirically to the measured potential difference. In some circumstances, useful measurements can be obtained between two half-cells on the concrete surface. ASTM C876 - 91 gives a Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete.

Measurements are made in either a grid or random pattern. The spacing between measurements is generally chosen such that adjacent readings are less than 150 mV with the minimum spacing so that there is at least 100 mV between readings. An area with greater than 150 mV indicates an area of high corrosion activity. A direct electrical connection is made to the reinforcing steel with a compression clamp or by brazing or welding a protruding rod. To get a low electrical resistance connection, the rod should be scraped or brushed before connecting it to the reinforcing bar. It may be necessary to drill into the concrete to expose a reinforcing bar. The bar is connected to the positive terminal of the voltmeter. One end of the lead wire is connected to the half-cell and the other end to the negative terminal of the voltmeter. Under some circumstances the concrete surface has to be pre-wetted with a wetting agent. This is necessary if the half-cell reading fluctuates with time when it is placed in contact with the concrete. If fluctuation occurs either the whole concrete surface is made wet with the wetting agent or only the spots where the half-cell is to be placed. The electrical half-cell potentials are recorded to the nearest 0.01 V correcting for temperature if the temperature is outside the range $22.2 \pm 5.5^\circ\text{C}$. Measurements can be presented either with a equipotential contour map which provides a graphical delineation of areas in the member where corrosion activity may be occurring or with a cumulative frequency diagram which provides an indication of the magnitude of affected area of the concrete member.

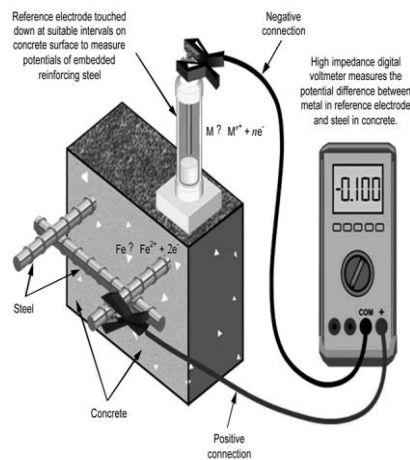


Fig 3 Apparatus for half cell potential method

B. Resistivity Test

There are many techniques used to assess the corrosion risk or activity of steel in concrete. The most commonly used is the half cell potential measurement that determines the risk of corrosion activity. Whilst the half cell potential measurement is effective in locating regions of corrosion activity, it provides no indication of the rate of corrosion. However, a low resistance path between anodic and cathodic sites would normally be associated with a high rate of corrosion than a high resistance path. Such resistivity measurements determine the current levels flowing between anodic and cathodic portions, or the concrete conductivity over the test area, and are usually used in conjunction with the half-cell potential technique. This is an electrolytic process as a consequence of ionic movement in the aqueous pore solution of the concrete matrix. An alternative technique to estimate the rate of corrosion, which is becoming increasingly popular, is the linear polarization resistance. The combination of resistance measurement by resistivity meter and potential measurement by corrosion analyzing instrument give very reliable information about the corrosion condition of the rebar.

Resistivity measurement is a fast, simple and cheap non-destructive method to obtain information related to

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

the corrosion hazard of embedded reinforcement. The spacing of the four probes determines the regions of concrete being measured. It is generally accepted that for practical purposes, the depth of the concrete zone affecting the measurement will be equal to the electrode spacing. If the spacing is too small, the presence or absence of individual aggregate particles, usually having a very high resistivity, will lead to a high degree of scatter in the measurement. In addition, increased error can also be caused by the influence of the embedded steel when larger spacing is employed. A spacing of 50 mm is commonly adopted, gives a very small degree of scatter and allows concrete sections in excess of 200 mm thick to be measured with acceptable accuracy. . However, this procedure is not practical for site use.

C. Tests for Carbonation of Concrete

Carbonation of concrete in cover results in loss of protection to the steel against corrosion. The depth of carbonation can be measured by spraying the freshly fractured concrete surface with a 0.2% solution of phenolphthalein in ethanol. Since phenolphthalein is a pH indicator, the magenta (pink colour) area presents uncarbonated concrete and the remaining (colourless) portion, the carbonated area. The change in colour occurs at around pH 10 of concrete. The test must be applied only to freshly exposed surfaces, because reaction with atmospheric carbon dioxide starts immediately. Relating carbonation depth to concrete cover is one of the main indicators of corrosion.

D. Tests for Chloride Content of Concrete

The presence of chloride in the concrete is the contributory factor towards corrosion of reinforcement. Portable equipments are available in the market, which can be used for rapid onsite measurement of chloride content of concrete. The chloride content of concrete can also be determined by chemical analysis of concrete in the laboratory. A rotary percussion drill is used to collect a pulverized sample of concrete and a special acid extracts the chlorides. The amount of acid soluble chloride is determined directly by a chloride sensitive electrode connected to an electrometer. If different samples are obtained from different concrete depths, it can be established whether the chloride contamination was there in the original concrete or the same has come from the environment.

E. Endoscopy Technique

Endoscopy consists of inserting a rigid or flexible viewing tube into holes drilled into concrete bridge components or cable ducts and views them with light provided by optical glass fibres from an external source. This is a most useful method for inspecting or detecting voids in the grout and corrosion in steel in the cable ducts. It is also useful for detail examination of other part of the bridge structure, which could not otherwise be assessed. Endoscopes are available as attachments for a camera or a TV monitor. It, however, needs an experienced engineer to make assessment of most likely locations of voids in the grout and probable points of entry of chlorides into the ducts.

X. NON DESTRUCTIVE TESTS FOR DETECTION OF CRACKS/ VOIDS/DELAMINATION

A. Infrared Thermography Techniques

The Thermo grams taken with an infrared camera measure the temperature distribution at the surface of the object at the time of the test. It is important to take into consideration that this temperature distribution is the result of a dynamic process. Taking a thermogram of this object at an earlier or later time may result in a very different temperature distribution. This is especially true when the object has been heated or cooled.

Since the infrared system measures surface temperatures only, the temperatures measured are influenced by three factors: (1) subsurface configuration, (2) surface condition, and (3) environment. As an NDT technique for inspecting concrete, the effect of the subsurface configuration is usually most interesting. All the information revealed by the infrared system relies on the principle that heat cannot be stopped from flowing from warmer to cooler areas, it can only be slowed down by the insulating effects of the material through which it is flowing. Various types of construction materials have different insulating abilities or thermal conductivities. In addition, differing types of concrete defects have different thermal conductivity values. For example, an air void has a lower thermal conductivity compared with the surrounding concrete. Hence the surface of a section of concrete containing an air void could be

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

expected to have a slightly different temperature from a section of concrete without an air void.

In order to perform an infrared thermographic inspection, a temperature gradient and thus a flow of heat must be established in the structure. The deck should be cleaned of all debris. Traffic control should be established to prevent accidents and to prevent traffic vehicles from stopping or standing on the pavement to be tested. The scanner head and either a regular film-type camera or a standard video camera should be aligned to view the same sections to be tested.

The next step is to locate a section of concrete deck and establish, by coring, that it is sound concrete. Scan the reference area and set the equipment controls so that an adequate temperature image is viewed and recorded. Next, locate a section of concrete deck known to be defective by containing a void, delamination, or powdery material. If a black and white monitor is used, better contrast images will normally be produced when the following convention is used: black is defective concrete and white is sound material. If a colour monitor or computer enhanced screen is used, three colours are normally used to designate definite sound areas, definite defective areas, and indeterminate areas. Once the controls are set and traffic control is in place, the vehicle may move forward as rapidly as images can be collected, normally 1 to 10 miles (1.6 to 16 km) per hour. If it is desired to mark the pavement, white or metallic paint may be used to outline the defective deck areas. At other times, a videotape may be used to document the defective areas, or a scale drawing may be drawn with reference to bridge deck reference points. Production rates of up to 130m²/day have been attained. Once data are collected and analysed, the results should be plotted on scale drawings of the area inspected. Defective areas should be clearly marked so that any trend can be observed.

B. *Acoustic Emission*

Acoustic emissions are microseismic activities originating from within the test specimen when subjected to an external load. Acoustic emissions are caused by local disturbances such as microcracking, dislocation movement, intergranular friction, etc. An acoustic signal travels to a number of piezoelectric transducers, which convert the acoustic signals (mechanical waveforms) to electric signals. A digital oscilloscope captures the electric signals. The time of arrival of the signal at each transducer depends on the distance of the transducer from the AE source. The source, frequency and amplitude of the AE events have been used to quantify the nature of microfracture in various materials. AE sources are determined by calculating the difference in time taken for the wave to arrive at the different transducers. The velocity of the waves in the specimen is determined using the ultrasonic pulse velocity method.

C. *Short Pulse Radar Method*

Short Pulse radar systems are used in applications related to inspection of concrete. This is the electromagnetic analog of sonic & ultrasonic pulse echo methods. In this method, the electromagnetic waves propagate through materials of different dielectric constants. A basic radar system consists of a control unit, a monostatic antenna (i.e. an antenna that is used for both transmitting & receiving), an oscillograph recorder, and a power converter for DC operation.

D. *Stress Wave Propagation Methods*

There are several test methods, based on stress wave propagation, used for non-destructive testing of concrete. The echo methods (impact echo and pulse echo) are used for thickness measurements, flaw detection and integrity testing of piles. The impulse response method is also used to test piles and slab like structures. The following stress wave propagation methods are generally used for testing of concrete.

- Pulse Echo method
- Impact Echo method
- Impulse response method

E. *Crack Detection Microscope*

It is a high quality product designed for measuring crack width, both in concrete and other materials. The high definition microscope is connected to an adjustable light source which provides a well illuminated image under all

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

working conditions. The image is focused by turning the knob at the side of the microscope and the eye-piece can be rotated through 360° to align with the direction of the crack under examination. The 4 mm range of measurement has a lower scale divided into 0.2 mm divisions. These 0.2 mm divisions are sub-divided into 0.2 mm divisions.



Fig 4 Crack detection microscope

F. Spectral analysis of surface waves (SASW)

SASW techniques, based on the dispersion variances for different material properties, hold promise in several areas. These methods are particularly useful for characterization of damping and response parameters. During repair operations, the member can be monitored after each step to evaluate the effectiveness of repair efforts. The method is based on a significant velocity change of surface waves (also called Rayleigh waves) in damaged areas of concrete. In tests, there has been excellent consistency between SASW results and visual observations. In addition, SASW revealed more areas that were not evident under visual inspections. Studies have shown potential for SASW to determine the depth of cracking as well. One advantage to SASW is the need to access only one side of the member, versus the two sides needed for many other wave propagation techniques. If a crack is between the two receivers, a drop in velocity will be seen for all wavelengths, increasing the odds of detection. When a multiple ray wave model is used, the superposition method allows for an exact formulation to be used, with no simplifying assumptions. This results in a more accurate characterization of the system. There are some limitations to the method, however. If the depth of a crack is less than half the depth of the beam from the opposite side, it may not be detected by all of the wavelengths. Also, if the wavelength is more than the depth of the beam, the lamb wave effect may prevent the waves from detecting flaws. There is also a 'threshold' crack area for detection, which is dependent on the wavelength.

XI. CONCLUSION

Health monitoring of bridges are most important since most bridges are becoming old, generally sensor based method of health monitoring is performed but assessment of bridge condition using non-destructive tests can also be used for that purpose. This technique will allow inspectors to get a more accurate view of the condition of the bridge and to locate damage earlier. The literature study is done for the health monitoring of bridges. The degradation mechanism of highway bridges has been studied. A detailed study of various NDT techniques adopted for health monitoring of bridges and references is carried out. The methodology for health monitoring of bridges is analysed for further study. The laboratory testing of specimen is carried out. The NDT tests is further carried out in phase II thesis

ACKNOWLEDGMENT

I am grateful to Prof. M.MALA, CEO, Jerusalem College of Engineering for extending all the facilities needed to carry out this seminar work.

Author thanks to Dr.N.S.ELANGO VAN, Head of the Department, department of Civil Engineering for his understanding and constant efforts in bringing out the seminar in the stipulated time.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

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