# Review on Structural Health Monitoring for Bridges and Buildings

**Arti Shivkumar Morge[1], Dr. Saswati Datta[2] , Ashwini R. Patil[3]**

[1](PG Student, Department of Civil Environmental Engineering, D.Y.Patil College of Engineering, Akurdi, Pune, India)

[2](Associate Professor, Department of Civil Environmental Engineering, D.Y.Patil College of Engineering, Akurdi, Pune, India)

**Abstract -**The field of monitoring is one of rapid development. Advances in sensor technologies, in data communication paradigms and data processing algorithms all influence the possibilities of Structural Health Monitoring, damage detection, traffic monitoring and other implementations of monitoring systems. Bridges are a very critical part of a country's infrastructure, they are expensive to build and maintain, and many uncertainties surround important factors determining the serviceability and deterioration of bridges and Buildings. As such, bridges are good candidates for monitoring. Monitoring can extend the service life and avoid or postpone replacement, repair or strengthening work. Many bridges and Buildings constitute a bottleneck in the transport network they serve with few or no alternative routes. The amount of resources saved, both to the owner and the users, by reducing the amount of non-operational time can easily justify the extra investment in monitoring. This papers consists of an extended summary and three appended papers. The papers presents advances in sensor technology, damage identification algorithms and Bridge Weigh-In-Motion techniques. This paper provides a review on the development of structural health monitoring of bridges and buildings, with an emphasis on the type, strategy, and utilization of monitoring systems. The review focuses on bridge and building structures using vibration-based techniques. Structural monitoring systems historically started with the objective of evaluating structural responses against extreme events. In the development of structural monitoring, monitoring systems and collected data were used to verify design assumptions, update specifications, and facilitate the efficacy of vibration control systems. Strategies and case studies on monitoring for the design verification of long-span bridges and tall buildings, the performance of seismic isolation systems in building and bridges, the verification of structural retrofit, the verification of structural control systems (passive, semi-active, and active), structural assessment, and damage detection are described. More recently, the application of monitoring systems has been extended to facilitate efficient operation and effective maintenance through the rationalization of risk and asset management using monitoring data. This paper also summarizes the lessons learned and feedback obtained from case studies on the structural monitoring of bridges and buildings.

**Keywords:** Structural Health Monitoring.

## 1. INTRODUCTION

Health monitoring is the continuous measurement of the loading environment and the critical responses of a system or its components. Health monitoring is typically used to track and evaluate performance, symptoms of operational incidents, anomalies due to deterioration and damage as well as health during and after an extreme event [1]. A successful health monitor design requires the recognition and integration of several components. Identification of health and performance metric is the first Component which is a fundamental knowledge need and should dictate the technology involved. Current status and future trends to determine health and performance in the context of damage prognosis [6].

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 [1]. This approach will enable us to find suspected zones, thereby reducing the time and cost of examining a large mass of concrete. The choice of a particular NDT method depends upon the property of concrete to be observed such as strength, corrosion, crack monitoring etc. The subsequent testing of structure will largely depend upon the result of preliminary testing done with the appropriate NDT technique [11].

## 2. MONITORING OF BRIDGE STRUCTURE

### 2.2.1 Cameras

Cameras have been used in the past to measure deflection in bridges under thermal loading, dead and traffic loads, as well as crack lengths and widths, and to monitor corrosive damage [34]. . The analysis of visual information gathered by arrays of cameras can be relatively easily done with commercial software developed specifically for that purpose. Algorithms for target recognition and motion extraction have been successfully used in bridge monitoring for dynamic measurementsnIn [35].

**2.2.2 Fibre Optic**

The most commonly used Fibre Optic Sensor (FOS) for measuring strain is the Interferometry FOS. In this sensor the light is divided into two beams, one sent through the measuring strand and the other through a passive reference strand. When they are recombined the relative phase differences can be measured and associated with a given physical value (most commonly strain, or displacement) [14]

**2.2.3 Sensors**

the use of sensors to acquire in a systematic fashion intensity, temperature) into electrical signals that can be easily digitalized and stored[15]. Some of the most commonly used sensor types are listed in table 1. A short review of sensing technologies and their usage in bridge monitoring is provided in this papers, with the main aim of providing basic information for a better understanding on the current state, and on the possibilities for bridge monitoring. Focus is placed on sensors that, without being new technologies per se, are relatively new in the field of bridge monitoring and that are used preferentially in long-term monitoring as opposed to temporary instrumentation [30,35]

.

| **Physical quantity** | **Sensor** |
|---|---|
| Displacement | Linear variable differential transformer (LVDT)<br>Long gauge Fibre optics<br>Optical<br>Laser |
| Acceleration | Piezoelectric accelerometer<br>Capacitive accelerometer<br>Force balanced accelerometer<br>MEMS |
| Strain | Electrical resistance strain gauges<br>Vibrating wire sensors<br>Bragg grating Fibre optics<br>Long gauge Fibre optics (Interferometry) |
| Force | Electrical resistance load cells<br>Piezoelectric load cells |
| Temperature | Electrical resistance thermometers<br>Thermocouples<br>Thermistors<br>Fibre optics based sensors |

**Table 1: Typical sensors used in structural monitoring [35]**

## 3. MONITORING OF BUILDING STRUCTURE

The different types of sensors which can be used for SHM in general the performance of PZT sensor is better than other sensors and also very cost effective. PZT is capable of serving as a sensor of the global dynamic technique and can suitably quantify such damages as well as locate them.[26] The concept of multi-scale wireless sensor networks is introduced in this study with the restricted input network activation scheme and the integration of data from heterogeneous sensor array to improve damage detection for low order models. [27,28]. a concise prologue to shrewd detecting innovation, recognizing some of the chances, just as a portion of the related difficulties. Brilliant sensors dependent on the Mote worldview will give the force to advancement of the up and coming age of auxiliary wellbeing observing frameworks, opening new skylines for innovative work. Multi-operator framework innovation offers a computational system for new calculations execution. [29] [30]

Wireless sensor systems are one of the supporting innovations in basic well being observing. Through keen, self-sorting out methods, they associate sensor hubs, with a wide range of test items and working standards into a system alongside elements of information preparing and incorporation. Basic well being checking is an intermingling region, with an assortment of sensor and data preparing advances. In this examination, we considered clock-synchronization over a WSN and how clock-float issue was illuminated on the checking site. [31] Samgmin et al. in

2018 proposed a model in AR-based Smart Building and Town Disaster Management System to solve problem like fire accident in a big building. In his modal test the proposed system using geographic information system, building information, and radio frequency identification etc., and the modal system installed in a ten system device like electric leak detectors, humidity sensors, networks cameras etc [32] In 2018, Shehal R.Shinde et al. proposed a smart way to monitor environment with low cost system. Shehal tested based on the four parameters. The information passed through from the system using IoT concept and tested successfully. [33]

## 4 STRUCTURAL HEALTH MONITORING BY USING NDT METHODS

### 4.1 Planning and selection of NDT method

the basic working principle, advantages & disadvantages of various NDT methods used for the evaluation of civil infrastructures. Depending on cost, available time, reliability and simplicity, some methods are preferred over others. Ideally, it is required to adopt a method which can detect all important defects and anomalies present in the structure.[1] Therefore, the selection of NDT method must be based on the yielding of the information. In construction industry, most of the field engineers and specialists are dissatisfied by use of NDT methods due to using inappropriate method for a specific problem. Therefore, it is recommended to do preliminary study before selecting any NDT method.

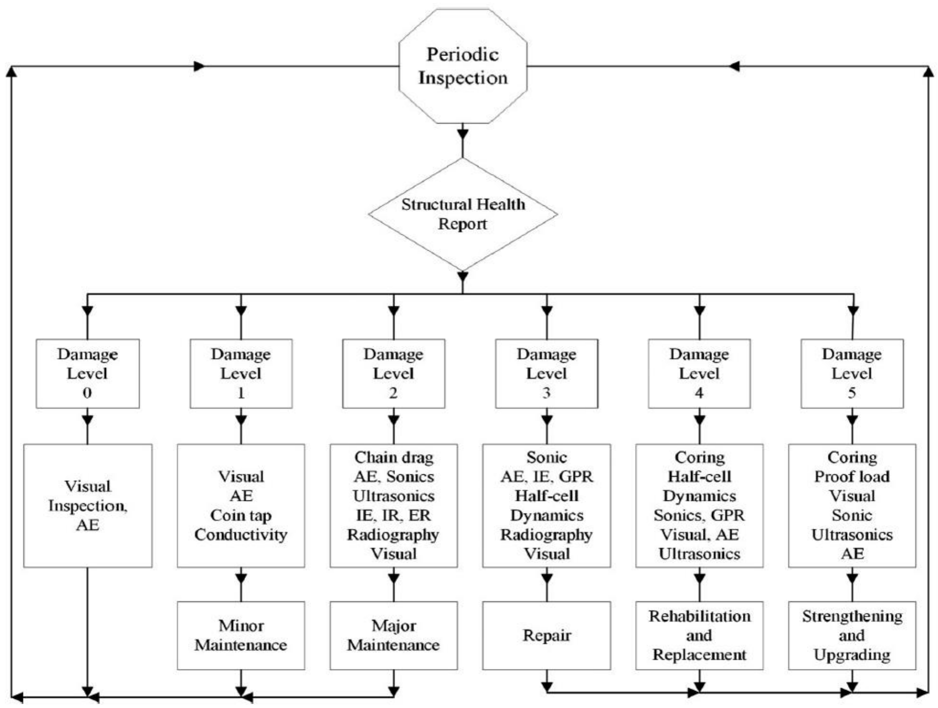


**Figure 01. Schematic layout of SHM procedure, NDT method selection and potential remedial measure.[1]**

NDT methods applicable to structures are reviewed. The methodology, advantages and disadvantages along with up to date research on NDT methods are presented. Different damage levels, having less dependence on inspector judgment, are suggested. Moreover, a flow chart based on damage level along with NDT methods and potential remedial measures are proposed for periodic health monitoring of structures. NDT methods are also suggested to address specific problems related to structures. Finally, the relation between some of the well-known NDT methods and most common problems encountered by the field engineers is proposed. Hence, the importance of structural health monitoring is highlighted Maintaining safe and reliable civil infrastructures for daily use is important for the well-being of mankind. Operation and maintenance have become more complex with the increased age of the structures. The process of determining and tracking structural integrity and assessing the nature of damage in a structure is often referred as health monitoring [1].

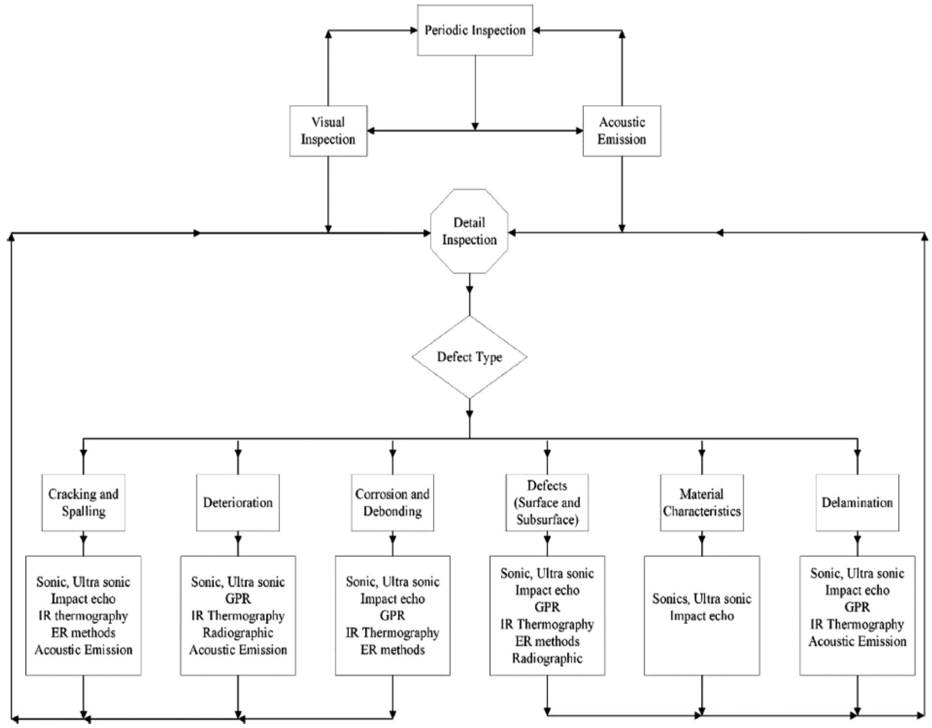


**Figure 02. Selection of NDT based on different defects and damages.[1]**

## 4.2 Nondestructive Test (NDT) methods

In civil engineering field, engineers and specialists mainly used NDT methods for providing the counter check information related to structures rather than as an integral part of testing procedures.

The main reason for this is the lack of awareness about testing procedures, equipment handling and data collection using NDT [6]. McCann and Forde [6], presented variety of NDT methods which are appropriate for civil structures. NDT methods are used in construction industry mainly due to following reasons.

1. Quality control in new construction.
2. Troubleshooting of problems.
3. Condition assessment of existing structures.
4. Quality assurance of repair works.

### a. Audio–Visual methods

### 1. Visual inspection

Visual inspection is one of the versatile and powerful NDT methods for inspecting visible surfaces. However, its effectiveness depends on the experience and knowledge of the investigator especially with structural behavior, materials and construction methods. Visual inspection is most extensively used for monitoring the damages in structures.[1]

### 2.Chain drag test

This test is used to mark the delaminated areas on the surface of the deck. Initially a grid system is laid on the bridge deck. Thereafter, chains are dragged on the surface of the deck and all those areas where a dull or hollow sound is heard by the operator are marked.[1]

**3.Impact Echo Technique**

In impact echo testing, a stress pulse is introduced into the interrogated component using an impact source. As the wave propagates through the structure, it is reflected by cracks and disbonds. The reflected waves are measured and analysed to yield the location of cracks or disbonds. Though the technique is very good for detecting large voids and delaminations, it is insensitive to small sized cracks.[25,36]

**4 Eddy current technique** : The eddy currents perform a steady state harmonic interrogation of structures for detecting surface cracks. A coil is employed to induce eddy currents in the component. The interrogated component, in-turn induces a current in the main coil and this induction current undergoes variations on the development of damage, which serves an indication of damage[6]. The key advantage of the method is that it does not warrant any expensive hardware and is simple to apply. However, a major drawback of the technique is that its application is restricted to conductive materials only, since it relies on electric and magnetic fields. A more sophisticated version of the method is magneto-optic imaging, which combines eddy currents with magnetic field and optical technology to capture an image of the defects.[6]

**b. Stress-wave methods**

**1. Acoustic emission**

Acoustic emission (AE) test is most extensively used for damage detection in several fields in general and transportation sector in particular, Hopwood for the first time applied the concept of AE testing for structural health monitoring[9]. Carter and It reviewed the application of AE in bridge monitoring. AE testing is used for three major areas of damage i.e. source location, source identification and severity assessment. The automated source location capability of AE make this technique more distinguished in NDT. This test is based on transient elastic waves. These elastic waves are produced from the structure under observation by rapid release of energy and the transducers are used to collect these waves. Thus, two integral components are necessary for AE test. The first is the material deformation which produces the elastic waves and becomes the source while the second is transducers that receive these elastic stress waves[21].

**2. UltraSonic pulse velocity test**

Non-destructive sonic test was abundantly used in past for assessing and determining the civil structures and materials. This method is based on the stress waves. Mechanically, stress waves are transmitted into the structure and when intervene by any discontinuity; these waves reflect and collected by the receivers. Transmission modes for sonic wave tests include (a) direct, (b) semi-direct, (c) Indirect. In direct transmission method compressional waves of frequencies ranging from 500 Hz to 10 kHz penetrate through the structure. Waves are transmitted from one side of structure and received at opposite site. Upgraded form of direct transmission is semi-indirect transmission mode. Semi-indirect transmission method, also known as sonic tomography, is used on the paths which are not transverse to wall surfaces of structure. The efficiency of results is increased by adopting a dense grid system for data recording it used the recorded travel time data of sonic signal waves to draw 3-D velocity distribution across the entire structure.

**3. Impulse response (IR)**

Impulse response (sonic mobility) is a stress wave method that is especially used for deep foundations. This method uses low-strain impact to produce the stress waves. When the hammer strikes the concrete, compressive stress waves are generated whose frequency can vary from 0 to 3000 Hz depending on the material used in the hammer (soft rubber, metal). The force (measured by load cell) and the velocity (measured by the receiver) time based signals are recorded by the data acquisition system, which is then transformed by computer into frequency domain using fast Fourier transform algorithm. The ratio of the velocity response spectra and impact spectra is termed as mobility spectrum. However, if measured response is displacement, the ratio of the displacement and impact spectra represents a flexibility spectrum while the inverse ratio is termed mechanical impedance (dynamic stiffness spectrum). In some analyses, the flexibility spectrum is matched by a flexibility spectrum (response spectrum) for an assumed single-degree-of freedom (SDOF) system. Once the two spectra are matched, the modal properties of the SDOF system provide information about the stiffness and damping properties of the system. The underlying assumption of this process is that a structure’s response can be approximated by the response of SDOF system.[1]

**c. Electro-magnetic methods**

**1. Ground penetrating radar (GPR)**

GPR is the most successful and well-known Non-destructive test for investigation of bridge decks and pavements. It is used for structural health monitoring of concrete structures like buildings, bridges and tunnels and provides an electromagnetic (EM) wave-reflection survey. GPR is rapid and quick method for assessing in-depth characteristics of subsurface[24]

**2. Conductivity**

Electromagnetic conductivity is a technique which provides geometrical, electrical information and degree of saturation about the materials. Alteration in the conductivity characteristics of concrete indicates the damage in concrete. This method uses the response of the ground against the propagation of electromagnetic fields[23]. The electromagnetic fields, which are generated through the transmitting coils, passes through the object and their response is monitored. Since the receiving and the transmitted fields are different both in amplitude and phase, hence, this difference provides certain information on materials geometry and electrical properties. In this method, normally a grid system is laid on the surface of the material and the measurements are taken on specific grid points. For better results and maximum accuracy level, it is suggested to have overlapped reading for every half meter. Data is then recorded by the digital data recorder and later on, it is transferred to the computer for plotting contour maps of the conductivity distribution in both horizontal and vertical plane [23,24].

**3. Half-cell potential**

Half-cell potential is an electrical technique used for evaluation of corrosion activity of steel reinforcement. The standard equipment consists of a copper–copper sulfate half-cell, connecting wires and a high voltmeter so that very little current flows through the circuit. When a metal is submerged into an electrolyte, positive metal ions will resolve (oxidation) and will accumulate at the metal–liquid interface. As a consequence, the metal–liquid interface becomes positively charged, and a double layer is formed. Anions, from the electrolytic solution, are attracted to the positively charged side of this double layer and accumulate there, forming the so-called half-cell. A potential difference between the metal and the net charge of the anions in the electrolyte builds up, which depends on the solubility of the metal and the anions present in the solution. This potential difference will give us information about the corroded reinforcement, if the reinforcement is corroding, the electrons would tend to flow from the reinforcement to the half-cell, where copper ions would be transformed into copper atoms deposited on the reinforcement. A display of more negative reading on the voltmeter would be an indication of high probability that the reinforcement is corroding.[9,25]

**4. Electrical resistivity measurement**

Electrical Resistivity (ER) (the inverse of the conductivity) of concrete is the ratio between applied voltage and resulting current in a unit cell. It is mainly influence by the moisture content and varies. By comparing different reading points, valuable information regarding the concrete inner surface characteristics can be extracted. In this method, minimum two electrodes are used out of which one is the reinforcing steel bar[9]. A voltage/current is applied between the electrodes and resulting current/voltage is measured. The ratio of voltage and current gives the resistance while the resistivity is calculated by multiplying resistance with a factor known as cell constant. The distribution of concrete resistivity in reinforced concrete is depended upon several factors like location of steel and depth to surface value. The top surface layer is another important parameter. If the top surface is too much dried out, the resistivity will be higher than the normal concrete while if it is wet then the resistivity will be less as compared with normal concrete. This problem can be minimized by using the four point method.[12]

**d. Deterministic methods**

**1. Proof load test**

Proof load test provides the actual load carrying capacity of structures. It is also used as diagnostic test to verify analytical or predictive structural models. This test is appropriate only when either unsatisfactory load rating is indicated by the analytical procedures or it is not possible to perform analytical test on structure due to lack of structural documentation or deterioration. Therefore, it is suggested to perform proof load test on all those structures on which assessment is not possible due to insufficient structural drawings or it does not meet with requirements of the most advanced assessment theories.

**2. Coring**

Cores are considered as semi-destructive method and are used to determine the internal defects in structures. It provide the standard test method for obtaining and testing the drilled cores. Cores are extracted to measure the compressive, splitting tensile and flexural strength of in-situ concrete. These are used to check the quality of construction and measure the strength of old structures. Strength of concrete is affected by the location of the cores, amount and distribution of moisture and orientation of cores. Core drill and saw is used for the drilling of cores from specimen. [11]

**e. Miscellaneous tests**

**1. Dynamic/vibration testing**

Vibration testing is most commonly used for measuring the structural health of structures. In late 19th century, vibration/dynamic field tests were applied to different concrete structures. Various researches used this method on bridges to assess their condition and structural health. In dynamic test, the structure is subjected to excitation forces and its response is measured by means of transducers. Natural frequency, mode shapes and modal damping values are measured during testing and are known as modal parameters. The values of these modal parameters change whenever a structure deteriorates. After inspecting these parameters it is easier to find out the structural health and condition of the structure. It is worth mentioning here that the changes in these parameter mainly depend upon the location, type and severity of defects and flaws. Two types of methods (ambient and forced vibration) are used for vibration testing. In ambient vibration testing method, there is no control on the input or applied force while in forced vibration testing method, the input/applied forces is controlled.[17]

**2. Infrared thermography**

Infrared thermography, a global inspection method, allows large surface area to be inspected in a short span of time. Concrete surfaces absorb the solar energy in day and release it in night. Therefore, Infrared thermography is used for detecting the delamination's and anomalies in concrete surface. The three main properties that influence the heat flow and distribution within a material include the thermal conductivity, specific heat capacity (Cp), and the density (q). The electromagnetic spectrum range used to measure the Infrared thermography is shown. Infrared thermography for testing concrete is based on two heat transfer mechanism, radiation and conduction. In the first mechanism, a surface emits energy (electromagnetic radiation) and the rate of energy emitted by the surface per unit area.[25]

**3. Radiography**

Radiography is a nuclear NDT method in which high energy electromagnetic radiation passing through the test object/member is recorded on a photographic film placed on the other side of the member. This method can be effectively used to detect reinforcement location, voids in concrete, material heterogeneity and layers of different materials, honeycombing and voids in grouting of post-tensioning ducts. However, the test personnel require specialized safety training and licensing. The radiation can be produced by X-ray tube (X-radiography) or radioactive isotope (gamma radiography). Schematic illustration is given. Radioactive isotope generate radiations which pass through the concrete and sensed by the detector. The detector converts these radiations into the electrical pulses, which are further analyzed or counted by other techniques. The selection of radiation source and amount of energy absorbed by the material depends on the thickness and the density of the member as well as the exposure time that can be tolerated. On the radiation based photograph, high density materials (reinforcement) appear as a light area while low density regions (voids) appear as a dark area.[10]

**Conclusions**

In this paper, various NDT methods which are applicable especially to concrete bridges are reviewed. The methodology, advantages and disadvantages along with the up to date research on NDT methods are presented. Following are some of the important conclusions. For those structures which are inaccessible, dynamic testing, infrared and radar technology are the better choice. Moreover, global and local monitoring of structures in real time make AE a preferred method with compared to other NDT methods. For long span bridges, it is very difficult to inspect visually all the portions or elements of bridge, especially soffit of bridge. Proof load test is especially good for stone and masonry structures, whose drawings and design parameters are unknown. However, in reinforced concrete structures their structural details can be found by using electromagnetic method and coring. The Coin tap, chain drag and hammer tests are inexpensive in nature but these tests are depended on human factor, which make these tests less reliable. The investigators can use these methods for periodic inspection as they will give some better understanding about structure. The sonic and ultra-sonic tests are more reliable and have more capabilities to address maximum problems if coupling issue is properly resolved. GPR, Impact echo and Infrared thermography also provide reliable analysis of structure. If the shortcomings of these methods (GRP, Impact echo and IR) are addressed than these methods can provide the deterministic results. Electric based tests can be performed rapidly at any time and in any circumstance, but these tests provide information related to reinforcement only. Moreover, electric based tests are not helpful for brick masonry and stone structures. Radiation based tests provide good information about voids and cracks but X-ray, gamma rays and neutron rays are hazardous for the operator and community. Therefore, great care is required during these tests. Dynamic and vibration tests are reliable and extensively used in civil industry. However, these tests are unable to pick the problem related to elastomeric bearing pads. If NDT tests are used in combinations then it provides detailed and reliable information e.g. using chain drag in combination with GPR test or with sonic/ultrasonic tests. Different damage levels based on crack lengths, spalling of concrete cover, support settlement, titling of foundation (due to settlement of subsoil or erosion of soil) and corrosion of reinforcement are suggested, which will limit dependence on the inspector judgment. A flow chart based on damage level along with NDT methods and potential remedial measures are proposed for periodic health monitoring of structures. Most of the time field engineers are familiar with the problem related to concrete structures specifically bridges. However, they require precise NDT method which addresses their problem. Therefore, NDT methods are also suggested according to different issues related to structures. Finally, the relation between some of the well-known NDT methods and most common problems encountered by the field engineers is proposed. This will provide an ease to the field engineers to select the NDT method. Hence, this research tries to overcome the misperception about the NDT methods and encourage the field engineers an ease to use NDT as integral part of testing. Some of the NDT methods are developed for some specific industries, like radiography for the medical industry, GPR for the geologist and geo-physics, Electrical based methods for solving the electrical problems. Hence, there is a strong need to introduce a new discipline which bridges the gap between civil engineering and these technologies

**References**

[1] Sardar Kashif Ur Rehman ,Zainth Ibrahim,Shazim Ali Memon (2016) Non destructive test methods for concrete bridges :A review ,Construction and Building Materials

[2] Yozo Fujino,Dionysus M. Siringoringo ,Yoshiki Ikeda (2019) Research and implementations of structural monitoring for bridges and Buildings in japan

[3] K. Chrzanowski (2001) “Evaluation of thermal camers for non destructive thermal testing application”Infrared physcis & Technology 42(2001) 101-105.

[4] Brian Hobbs , Mohamed Tchoketch Kebir (2007)“Non-destructive testing techniques for the forensic engineering investigation of reinforced concrete buildings” forensic science International 167-172.

[5] Akash Jain , Ankit Kathuria, Adarsh Kumar, Yogesh Verma, and Krishna Murari (2013) “Combined Use of Non-Destructive Tests for Assessment of Strength of Concrete in Structure” The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering.

[6] Bachir Maouche , Rezak Alkama , Mouloud Feliachi (2009) ” Semi-analytical calculation of the impedance of a differential sensor for eddy current non-destructive testing” NDT&E International 42 (2009) 573– 580

[7] K. Mori, A. Spagnoli, Y. Murakami, G. Kondo, I. Torigoe, A new non-contacting non-destructive testing method for defect detection in concrete, NDT and E Int. 35 (6) (2002) 399–406.

[8] Anders Bostrom Journal of science direct ”Therotical Modeling of Ultrasonic Non-destructive testing”

[9] Harsh Rathod , Rishi Gupta (2019) “Sub-surface simulated damage detection using Non-Destructive Testing Techniques in reinforced-concrete slabs” Construction and Building Materials 215 (2019) 754–764

[10] F. S ARASINI and C. SANTULLI (2014) “Non-destructive testing (NDT) of natural fibre composites: acoustic emission technique”

[11] Scottish school of non destructive testing (2003) Non destructive testing

[12] Rama Seshu D.and Dakshina Murthy N.R. (2013) “Non Destructive Testing of Bridge Pier - a Case Study ” The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering

[13] Navdeep Singh, S.P. Sing (2018)” Evaluating the performance of self compacting concretes made with recycled coarse and fine aggregates using non destructive testing technique ” Construction and Building materials

[14] M. SOUTSOS and J. BUNGEY, University of Liverpool (2014) “ Introduction: key issues in the non-destructive testing of concrete structures”

[15] F AnsAri, University of illinois at Chicago, USA (2009)” Fiber optic sensors for structural health monitoring of civil infrastructure systems ”

[16] D InauDI, SMaRTEC Sa, Switzerland (2009) " Structural health monitoring of bridges: general issues and applications"

[17] V M Karbhari, University of alabama in huntsville, USa, h GUan, hDr, USa and C SiKorSKy (2009)" Operational modal analysis for vibration-based structural health monitoring of civil structures " California Department of Transportation, USa

[18] M Shinozuka, university of California, irvine, uSa and B ManSour "Synthetic aperture radar and remote sensing technologies for structural health monitoring of civil infrastructure systems "

[19] R A SwARtz and J P Lynch" Wireless sensors and networks for structural health monitoring of civil infrastructure systems " University of Michigan, USA

[20] K Y Wong, Highways Department, Hong Kong and Y Q ni, (2009) " Structural health monitoring of cable-supported bridges in Hong Kong " The Hong Kong Polytechnic University, Hong Kong

[21] K Worden, G Manson and s rippenGill," Statistical pattern recognition and damage detection in structural health monitoring of civil infrastructure systems " University of Sheffield, UK

[22] Peter C. Chang and S. Chi Liu " Recent Research in Nondestructive Evaluation of Civil Infrastructures " 10.1061/~ASCE!0899-1561~2003!15:3~298!

[23] Zhengqi Li, Ph.D., P.E., M.ASCE ; and Jigar Desai, Ph.D., P.E., M.ASCE (2019) "Investigative Assessment of Concrete Slab Using Non-Destructive Evaluation Techniques"

[24] Shamim N. Pakzad ; Gregory L. Fenves ; Sukun Kim ; and David E. Culle (2008) " Design and Implementation of Scalable Wireless Sensor Network for Structural Monitoring "

[25] Junwon Son " A Reviw of non destructive test Methods for Bridges" .

[26] "An Integrated approach for Structural Health Monitoring(SHM)",Mr.Ramashankar,IIT-2009

[27]"History, current status and challenges to Structural Health monitoring systems Aviation Field"Abid Ali Khan, Suhaib Zafar, NadeemShafi Khan, (Institute of Space Technology-Pakistan).

[28] Ahmed Abdelgawad and Kumar Yelamarthi, "Internet of Things (IoT) Platform for Structure Health Monitoring", Wireless Communications and Mobile Computing, Volume 2017, Article ID 6560797, 10 pages.

[29]Billie F. SPENCER Jr, Manuel Ruiz-Sandoval, Narito Kurata, "Smart Sensing Technology for Structural Health Monitoring", 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper No. 1791.

[30] Xinlong Tong, Hailu Yang, Linbing Wang and Yinghao Miao, "The Development and Field Evaluation of an IoT System of Low-Power Vibration for Bridge Health Monitoring", Sensors 2019, 19, 1222; doi:10.3390/s19051222

[31][17]Damon Parsy*, Mohamed-Yosri Jaouadi, "Shaping the Future of Structural Health Monitoring With IoT Sensors", International Symposium on Structural Health Monitoring and Nondestructive Testing4-5 October 2018, Saarbruecken, Germany.

[32] Sangmin Park, Soung Hoan Park , Lee Won Park 2,, Sanghoon Lee "Design and Implementation of a Smart IoT Based Building and Town Disaster Management System in Smart City Infrastructure" in Appl. Sci. 2018, 8, 2239; doi:10.3390/app8112239. 2018.

[33] snehal r. shinde, mr. a. h. karode, dr. s. r. suralkar " iot based environment monitoring system" volume-7 | issue-2 | february-2018 | issn no 2277 - 8179 | if : 4.176 | ic value : 93.98

[34] Kai H. Hsieh "Structural Damage Detection Using Dynamic Properties Determined from Laboratory and Field Testing" Journal of Performance of Constructed Facilities, Vol. 22, No. 4, August 1, 2008. ©ASCE, ISSN 0887-3828/2008/4-238

[35] T. R. Nunez "Validation of a Construction Process Using a Structural Health Monitoring Network"Journal of Performance of Constructed Facilities, Vol. 27, No. 3, June 1, 2013. ©ASCE, ISSN 0887- 3828/2013/3-270–282/$25.00

[36] Jennifer C. Wood, David Evans and Associates" Nondestructive Testing of the Lawrence Street Bridge" ASCE