Condition Assessment of Structure Using Piezo-Ceramic Smart Material

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Abstract- *At the time of construction, it is impossible to ensure about uniform quality and strength at every section so, there is variation of strength from various section to section. Structure can be considered as damage free up to certain limit, but if it is beyond limit due to excessive loads which results into damage. Damage is defined as a change to the material and geometric properties of the structural system including changes to the boundary condition and system connectivity, which adversely affect the performance structure as a whole beyond a threshold. The ultimate failure strength of the material, component or system is its maximum load-bearing capacity. When this limit is reached, damage in the materials occurs, and its load-bearing capacity is reduced permanently, significantly and quickly.*

Keywords- Performance Structure, Damage in the Materials, Maximum Load-Bearing Capacity, Strengthof the Material

I. INTRODUCTION

Structural Health Monitoring

Structural health monitoring (SHM) is a process in which determining the presence, location and severity of damages and the remaining life of structure after the occurrence of damage. This term is usually referred to all aerospace, civil and mechanical engineering infrastructure.

Damage identification is the basic objective of SHM. There are mainly four levels in damage identification (Rytter, 1993):

Level 1: Determination that damage is present in the structure
Level 2: Level 1 plus determination of the geometric location of the damage
Level 3: Level 2 plus quantification of the severity of the damage
Level 4: Level 3 plus prediction of the remaining service life of the structure

SHM involves periodically observation of the structure. In long term SHM, the output of this process is updated to provide information regarding the ability of the structure to perform its function in light of the inevitable aging and degradation which results from operational environments. After extreme events, such as earthquakes or blast loading, SHM is used for quick condition screening and aims to provide real time and reliable information regarding the integrity of the structure (Doebling et al., 1998).

Non Destructive Evaluation

Non-destructive evaluation (NDE) of concrete has historically been a niche discipline within civil engineering and a process carried out by an individual operator in the field to evaluate the extent of known or suspected flaws within a concrete structure. NDE techniques such as Ground Penetrating Radar, Ultrasound, and Eddy Current methods depend heavily on the expertise and diligence of the operator to maintain accuracy and are prone to producing sparse, subjective data. For these reasons, NDE methods such as eddy current methods, ultrasound, and ground-penetrating radar (GPR) are typically called upon by governing agencies and only to identify the extent of known defects or defects suspected to be present.

Concrete NDE techniques have shown the potential to reliably identify many forms of structural deficiency including poor material quality, poor consolidation, insufficient cover (thickness of protective concrete layer over reinforcing steel), and subsurface cracking and delamination due to damage. The application of such methods for quality control purposes, however, requires spatially dense, exhaustive data collection performed in an irrefutable manner suitable for holding construction agencies responsible for the product they produce. The list of NDE methods that have successfully been applied to concrete structures is incredibly long and is growing every day. While one of the main goals of the development of the automated system was to create a system capable of expansion to include new NDE instruments, a review of a myriad of potential instruments to be included in future research is not necessary for comprehension of this work.

Need of Structural Health Monitoring and Non Destructive Evaluation

In the prolonged life span of a structure proper maintenance is required to prevent catastrophic failure. Higher operational loads, complexity of design and longer life time periods imposed to civil structure make it increasingly important to monitor the health of these structures. Economy of a country depends on the transportation infrastructures like bridges, railways, roads etc. Any structural failure of these causes severe damage to the life and economy of the nation. Every nation is spending millions of money every year for the rehabilitation and maintenance of civil engineering structures. Failure of civil infrastructure to perform at optimum level may affect the gross domestic production of the country. Strength of structures decreases due to continuous loading and impact of environment. Hence, it should be evaluated if the performance of the structure is satisfactorily or not after such deterioration. If structural strength falls down below a certain threshold level, sudden failure is possible which might result in accident and affect the serviceability of the structure. Early detection of damage is of special concern for civil structures. If not identified in time, damage may have serious consequences for safety of occupants. There are several natural events which may affect the strength of structure. It should be ensured that the structure is safe after such natural events. If structures are monitored periodically or continuously, better understanding will be achieved about the behaviour of the structure. If damage or cracks developed before failure, are detected at an early stage, proper measures can be taken.

Structures are designed for a certain life span, and it is assumed that during this period the structure is maintained properly. By proper monitoring, it may be possible that the life of the structure be increased and serviceability enhanced, resulting in huge savings. Fatigue assessment can be determined, if continuous monitoring is done. It may possible that a new constructed structure may not be performing well with respect to design parameters, either due to inferior material or faulty construction. This can be ensured by proper health monitoring.

Structural Health Monitoring and Non Destructive Evaluation Techniques

Until very recently and to great extent even today, visual inspection by trained personnel had been the most common tool to identify the external signs of damage in buildings, bridge and industrial structures. Once gross assessment of the damage location is made, localized techniques such as acoustic, ultrasonic, radiography, eddy currents, thermal, magnetic field or electro-magnetic impedance can be used for a more refined assessment of the damage location and severity. If necessary, test samples may be extracted from the structure and examined in the laboratory. One essential requirement of this approach is the accessibility of the location to be inspected. In several cases, critical parts of the structure may not be accessible or may need removal of finishes. This procedure of health monitoring can therefore be very tedious and expensive. Also, the reliability of the visual inspection is dependent, to large extent, on the experience of the inspector.

Non Destructive Evaluation by Global Dynamic Techniques

In these techniques, the test-structure is subjected to low-frequency excitations, either harmonic or impulse, and the resulting vibration responses such as displacements, velocities or accelerations are picked up. First few mode shapes and the corresponding natural frequencies of the structure are determined, which, when compared with the corresponding data of healthy state, yield information pertaining to the locations and the severity of the damage. Damage in a structure alters its modal parameters, such as modal frequencies, modal damping, and mode shape. Changes also occur in structural parameters, namely the stiffness and the damping matrices. Health of structure is judged after comparing the current structural parameters with the base line parameters. However, the basic drawback of this technique is low sensitivity to incipient damage.

Non Destructive Evaluation by Electro-Mechanical Impedance (EMI) Technique

In the EMI technique, a piezo-electric ceramic (PZT) sensor patch is bonded/ embedded in the structure (whose health is to be monitored) using high strength epoxy adhesive. The conductance signature of the patch is acquired over a high frequency range (30-400kHz). This signature forms the benchmark for assessing the structural health. At any future point of time, when it is desired to assess the health of the structure, the signature is acquired again and compared with the benchmark signature. The signature of the bonded PZT patch is usually acquired by means of commercially available impedance analysers. This research work carried out with objective of integration of EMI technique with global dynamic techniques for expanding the SHM capabilities of piezo-sensors.

Lamb Wave Theory

Non-destructive evaluation using Lamb wave techniques have been emerging as one of the most effective methods to detect structural damage. Lamb waves are guided elastic waves, which can travel relatively large distances with very little amplitude loss they offer the advantage of large-area coverage with a minimum number of installed sensors. Characteristics of Lamb wave propagation in metallic plates with integrated piezoelectric transducers. For Lamb waves, at a given frequency, at least two modes (one symmetric and one antisymmetric) are generated. As frequency increases, the number of simultaneously existing wave forms also increases. Lamb wave propagation is usually highly dispersive. A_O and S_O are referred to as the fundamental modes. These two modes are the most important because they exist at all frequencies, and they carry more energy than the higher order modes in most situations. Two important concepts to be understood in wave propagation are dispersion and attenuation. In general, the broad field of SHM encompasses many advanced technologies that, when integrated, provide a system that can potentially identify and characterize the performance. Main components of Lamb wave technique are Digital oscilloscope, Function generator and Piezocermic patches for generation of Lamb waves.

II. ADVANTAGES

SHM using PZT have been effective in making online assessment of a structure. The main advantage of SHM being,

i. Large coverage area of inspection (global).
ii. Coverage of inaccessible areas of the structure.
iii. Rapid inspection without disassembly.
iv. Adjustable frequency range for interrogation for various size/types of damage SHM is most suited for health monitoring of plate and shell type structure with limited extension to thin walled beams, stiffeners and other parts of airframes.
v. Structural Health Monitoring (SHM) requires PZT transducers for both excitation and sensing of elastic waves to interrogate the structures in order to detect, locate and characterize defects and damage.

The PZT generate both symmetric and antisymmetric mode simultaneously. The sensor-actuator approach enhances the control over the damage-sensitive feature being extracted from acquired signals. A conventional ultrasonic probe excites and senses waves indirectly through the interaction between activated guided waves and structural surface, whereas a PZT element excites and senses the waves directly through in-plane strain coupling. There are two possible ways to utilize piezoelectric materials [29]. First, piezoelectric materials can be used as sensors (direct effect). Second, piezoelectric materials can be used as actuators (converse effect). Piezoelectric (PZT) sensors used to generate Lamb waves can be used as both exciter and receiver which provides the very important benefit of having the capability of controlling the input excitation [34].

III. LIMITATIONS

i. A PZT patch is sensitive to structural damages over a relatively small sensing zone ranging from 0.4m to 0.2m only, depending upon the material and geometrical configuration.
ii. This technique is unable to assess overall structural stability.

IV. OBJECTIVES AND SCOPE OF THE WORK

i. To study the theoretical and technological developments in the field of structural health monitoring and non-destructive evaluation.
ii. Damage assessment of aluminium plate, and concrete cubes is covered by PZT patches.
iii. Non-destructive evaluation all specimen with the help of regression analysis.
iv. To calculate changes in different parameters of signature which is depend upon stiffness and damping coefficient.
v. To check response for humidity condition.

V. CONCLUSION

i. Conventionally, surface bonded PZT patches are used to monitor the health of structures. There are several difficulties like protection from harsh environment and external wiring associated with the surface bonded PZT patches, hence PZT sensor has been protected with plastic fibre in structure at the time of construction. It is successfully demonstrated that protected sensor acts well in both dry condition as well as in humid condition.
ii. Apart from detection, damage ranging from incipient to near failure (severe) can be located and quantified using the proposed technique. Incipient damage can be located using extracted equivalent parameters from the PZT signatures. Basic advantage of proposed technique is that location of damage can be predicted with desired accuracy. Once the damage is located approximately, its exact location can also be traced accurately.
iii. Severity of damage has been quantified in term of original stiffness using the proposed technique.

Conventional methods fail to differentiate the damage in terms of higher grade of concrete from moderate to severe damage due to higher strength of concrete and aggregate size.

iv. This technique useful for calibration of piezo-ceramic transducers for damage assessment of concrete. In the frequency range 10-30 kHz, stiffness was found to reduce and the damping increase with damage progression. This enabled the calibration of the piezo-impedance transducers in terms of damage severity and can serve as a practical empirical phenomenological damage model for quantitatively estimating damage severity of concrete.

v. A new experimental technique was reported for determining the in situ concrete strength non-destructively using the Lamb wave principle. The new technique is much superior than the existing strength prediction techniques, such as the ultrasonic techniques. In addition, the paper demonstrated the feasibility of monitoring curing of concrete using the EMI technique, which was found to share a sensitivity much higher than the conventional NDE techniques.

vi. The signatures are at the same time highly prone to deviation by humidity. Plastic fibre is experimentally shown to be a sound material for protecting PZT patches against humidity. In the case of aluminium plate it is observed that 5% of fall in signature occurred in humid condition as compared to dry condition. In case of steel plate, very negligible change is occurred in signature of humid condition, in this work it is clearly observed that damages at incipient, moderate damage, severe damage from change in strength, damping coefficient, damping ratio. In case of hollow beam, it is observed that 4% changes in baseline signature in dry condition as compared to humid condition. Lamb wave theory clearly observed incipient, moderate, severe damages for these section.

vii. The new developments reported here could improve SHM/ NDE, using the Lamb wave technique, for a wide spectrum of structural systems.

viii. Over the last three decades, a number of studies have been reported to replace the visual inspection by some sort of automated method, which enable more reliable and quicker assessment of the health of the structure. The idea of smart structures is thought to be an alternative to the visual inspection methods. Because of their inherent 'smartness', the smart materials such as piezo-ceramic patches exhibit high sensitivity to any change in environment.

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