LONGEVITY ASSESSMENT AND LIFE SPAN ENHANCEMENT OF CIVIL ENGINEERING STRUCTURES

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Abstract - *Most of the civil engineering structures are made up of concrete. These structures show early signs of deterioration and distresses because of the unfavorable conditions of exposure, use of prevailing design and construction practices and other allied problems. The conventional testing practices suffer from certain limitations and hence, in view of this, new technological breakthroughs, particularly in the field of Non – Destructive Testing (NDT) methods are emerging as a powerful, valid, quality control tool for condition assessment. This paper reviews some of the prominent investigations carried on the damage detection in respect of building, bridges, roads, tunnels, and dams using various approaches, which reveals that a very little work related to the condition assessment of buildings is reported. This emphasizes the necessity of such work on the building structures and the necessity of more experimental work in order to quantify the damage from the response of the building structure using more realistic approach is also underscored.*

***Key Words*: Longevity assessment, Structural Health Monitoring, Non-Destructive Test (NDT), conditional assessment, damage, deterioration, structures.**

1. INTRODUCTION

Aging and degradation of concrete structures is an international problem which can have serious consequences on the safety of users. The unfavorable conditions of exposure, use of prevailing design and construction practices and other specific problems are some of the reasons due to which the structures start showing signs of distresses and deterioration in many civil engineering structures. As against the expected service life, structures constructed barely 20-30 years ago are suffering from extensive deteriorations thus warranting regular and systematic inspection and investigations for the condition assessment.

1.1 Conditional Assessment

'Condition assessment' means the assessment of damage caused to structures including evaluation of the causes of damage, degree and amount of damage. It also includes the evaluation of the anticipated progress of damage with time and its effect on structural behaviour and serviceability of structures. In other situations, the regulations or operating conditions have changed over time. Existing structures and older must meet more stringent requirements that had been originally intended, and mainly in the case of highway bridges subjected to traffic loads that increase in intensity and frequency. In this case, the owners wanted to know if these structures are able to meet the new service requirements.

1.2 Structural Health Monitoring

Structural Health Monitoring (SHM) can have a very wide definition and be implemented in many different ways for varying motives, but all the approaches have common component classes at different levels: Sensors, Data storage, Data transmission, Database management leading to feature extraction, Data mining for feature extraction, Load/effect model development from study of data, Learning from past experience (heuristics), and Decision-making based on identified features in combination with identified models.

Structural health monitoring is a common practice in condition assessment of structures to monitor the structural physical dynamic properties of the structure under Non-Destructive Testing (NDT) in order to identify and locate damage at the earliest stage of development. Thus, the assessment of structural condition is not only beneficial for on-time decision making regarding maintenance, rehabilitation, and possibly replacement but also increases the overall efficiency of operation and life-span of important infrastructure. Therefore, an effort is made in the subsequent section to review some of the significant investigations carried out in the context of condition assessment of the civil engineering structures such as buildings, R.C.C framed structures, bridges, tunnels and dams in the sequential manner.

1.3 Advantages

The main advantage of longevity assessment is that, the ideal Longevity Assessment system provides you with on-demand information about your structure's integrity and serviceability, as well as warnings concerning any damage detected. Therefore, SHM significantly reduces repair costs through early damage detection, making the monitored structure safer and increasing the cost efficiency of its maintenance. Some other advantages include: -

- Increased understanding of in-situ structural behavior.
- Assurance of structural strength and serviceability.
- Decreased down-time for inspection and repair.
- Development of rational maintenance/management strategies and
- An increased effectiveness in allocation of scarce resources.

Structural Monitoring can significantly reduce insurance premiums for those operating - or in charge of - the safety of infrastructure such as bridges, railways or tunnels. Additionally, SHM enables and encourages the reliable use of new and innovative materials and designs in both architecture and engineering.

2. LITERATURE REVIEW

1. Various methods and approaches:

Based on the observations that changes of stiffness lead to changes in the natural frequencies of the structure and further, stress distribution through a vibrating structure is non-uniform and is different for each natural frequency (mode), Ca Wley and Adams [1] proposed a method to detect, locate and quantify damage in structures from measurement of the natural frequencies. The method has the advantage that only one dynamic finite element analysis need be performed on a given type of structure and requires access to only one point of the structure and, if the measurement of the natural frequencies were carried out using transient techniques, the test time would be very short. The presence of damage is indicated immediately from changes in the natural frequencies without the need for any computation.

Chen et al. [2] presented the correlation between frequency of a structure and degree of damage by testing a full-scale beam both statically and dynamically. To improve the quality of test data and reduce the effort for identifying the fundamental frequency of the beam, preloads are applied to the beam before conducting the dynamic tests. Test results have confirmed that the frequency of the beam itself depends on the load history while that of the beam plus sufficient preloads can be identified independently. This is because preloads can keep cracks open so that the cracked beam vibrates in a linear fashion.

The process of vibration-based structural health monitoring as fundamentally one of statistical pattern recognition paradigm was recognized by Farrar et al [3]. This process was composed of the four portions: Operational evaluation; Data acquisition and cleansing; Feature selection and data compression, and Statistical model development. This process involved the definition of potential damage scenarios for the system, the observation of the system over a period of time using periodically spaced measurements, the extraction of features from these measurements; and the analysis of these features to determine the current state of health of the system.

Further, Farrar and Jauregui [4] extended experimental part to the numerical examples. A finite element model of a continuous three-span portion of the I- 40 bridge was constructed and correlated the dynamic properties of the undamaged and damaged bridge that were predicted by the numerical models with the experimental model analysis results. Further, to verify the multiple damage scenarios eight new damages were introduced into the numerical model. This study indicated that some methods performed better when they were applied to unit-mass-normalized mode shape data. It showed that the methods were inconsistent and did not clearly identify the damage locations when they were applied to the less severe damage cases.

A nondestructive methodology was presented for detecting structural damage in structural systems by John B. Kosmatka and James M. Ricles [5]. The procedure was based on using experimentally measured modes and frequencies in conjunction with vibratory residual forces and a weighted sensitivity analysis to estimate the extent of mass and/or stiffness variations in a structural system. The experimental results show that the method can accurately predict the location and severity of stiffness change as well as any change in mass for different damage scenarios. The use of an analytical model that is correlated to the baseline test data is shown to improve the prediction; however, reasonable results are also obtained using an uncorrelated analytical model.

Bart and peter [6] addressed two key issues of a real-life vibration-based structural health monitoring system. While the first issue is the determination of an experimental model of a vibrating structure from output-only data, the second one is the detection of damage under varying environmental conditions. From the relation between Finite Element (FE) models of the vibrating structures, stochastic state-space models and modal models it was concluded that the stochastic system identification methods are preferred methods to detect damage successfully under varying environmental conditions by estimating the modal parameters of a structure excited by white noise.

Jaishi and Ren [7] used a practical and user-friendly sensitivity-based FE model updating technique in structural dynamics for real structures using ambient vibration test results. The main contribution of work by Jaishi and Ren was the objective function consisting of a combination of eigenvalue residual, mode shape related function, and modal flexibility residual is minimized using the least-squares algorithm.

A comprehensive review on modal parameter-based damage identification methods for beam or plate-type structures was presented by Wei Fan and Qiao [8]. Based on the vibration features, the damage identification methods were classified into four major categories: Natural frequency-based methods; Mode shape-based methods; Curvature mode shape-based methods, and; Methods using both mode shapes and frequencies,

V. Meruane and W. Heylen [9] studied real-coded parallel Genetic algorithms (GA) which are implemented to detect structural damage. The objective function is based on operational modal data; it considers the initial errors in the numerical model. False damage detection is avoided by using damage penalization. The algorithm is verified with two experimental cases. First, a test structure of an airplane subjected to three increasing levels of damage. Second, a multiple cracked reinforced concrete beam that is subjected to a nonsymmetrical increasing static load to introduce cracks. In both cases, the detected damage has a good correspondence with the experimental damage.

An empirical model based on experimental results to account for the reflection produced from reinforcing bars embedded within the concrete using Electromagnetic (EM) waves was developed by Halabe et al [10]. Concrete and reinforcing bar models have been utilized to synthesize waveforms for representative reinforced concrete bridge deck geometries. Numerical studies have been carried out to observe the influence of various conditions (e.g., cracks) on the computed waveform. A least squares inversion procedure has been applied to the synthetic waveforms. Results from this inversion show that spatial variations in volumetric water content, salt content, and reinforcing bar cover can be determined by analyzing radar waveforms.

Artificial intelligence protocols (AIP) for SHM of the Composite Structures was used by Kesavan et al [11]. The study considered two structures- a composite beam and a T-joint structure used in ships. The artificial neural networks (ANN) were used in tandem with a pre-processing program developed, called as the damage relativity assessment technique (DRAT) to determine the presence of the damage and then predict its size and location.

Wang et al [12] reviewed the recent development in damage detection and condition assessment techniques based on VBDD and statistical methods. The VBDD methods based on changes in natural frequencies, curvature/strain modes, and modal strain energy (MSE) dynamic flexibility, artificial neural networks (ANN) before and after damage and other signal processing methods like Wavelet techniques and empirical mode decomposition (EMD) / Hilbert spectrum methods were studied.

Three wavelet-based damage-sensitive features (DSFs) extracted from structural responses recorded during earthquakes to diagnose structural damage were introduced by Hae Young Noh et al [13]. Because earthquake excitations are nonstationary, the wavelet transform, which represents data as a weighted sum of time-localized waves, was used to model the structural responses. These DSFs are defined as functions of wavelet energies at particular frequencies and specific times. The DSFs can be used to diagnose structural damage.

Sharayu D. Holey and S. A. Rasal [14] reviewed various literature studies regarding retrofitting of bridges which summarized that most of the damage happened to the structures were due to lack of seismic resistance, as in the late 19^{th} and early 20^{th} centuries, the seismic design considerations were not considered in the designs. The main aim of the study was to find the reasons and solutions of deterioration of structures. Although the exact reason of failure or deterioration couldn't be specified, it was summarized that, some of the reasons were found out and some of the best techniques of strengthening the structure were epoxy putty, external steel plate bonding and FRP wrapping.

2. **Work related to buildings:**

J.M.W. Brownjohn [15] presented the monitoring of buildings and their performance during earthquakes and storms. The low-amplitude dynamic response was obtained from vibration testing, but it has always been preferable to know the building response during a typical but not ultimate large amplitude loading event, and this has required long-term monitoring.

3. CONCLUSIONS

Through this study, it has been observed that the many innovative techniques as well as conventional methods which are available in application for longevity assessment and life span enhancement of civil engineering structures. The paper has provided the comprehensive review of the various methods, approaches and several investigations into the condition assessment of civil engineering structures. Although most of the research work is carried out on the damage detection of the bridges by using various approaches, a very few studies report such investigation for the building structure including RCC structure and composite structure. Also, some of the investigation is found in the field of masonry infill structures. Although remarkable progress has been observed in this field, there is still substantial scope for future research, such as for different types of bridges like prestressed concrete, timber bridges, composite bridges etc.

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