A SURVEY ON POST SEISMIC DAMAGE DETECTION APPROACH BASED ON PIEZOELECTRIC SENSOR

By

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ABSTRACT

The concept of Structural Health Monitoring of concrete structures under the seismic load condition has recently made the more attention in the research community of earthquake and structural engineering. Due to destruction of expensive structures, this research makes the attraction of researchers who are doing their research work in the field of damage detection based on the piezoelectric smart sensor. In this review work, the way of post seismic damage detection of structure using the smart aggregate a piezoelectric – based device which have embedded in the reinforced concrete structure and the way to monitor their damage after the effect of an earthquake. During this presented review, a study work has conducted to describe the methodology that has employed to detect the post-seismic damage of concrete structure and the methodology of electro-mechanical impedance sensor that has been used for the health monitoring of the structure. The PZT which was embedded in the structure during the construction and the variation in the impedance of the sensor before and after the seismic attacks were extracted as the damage sensitive features are utilized to detect the area of damage. This technique is very important in non –destructive testing and have also tried to attract the attention of the reader. After analyzing the damage of the structure through the attack of an earthquake, the required repair and serviceability can be provided to structure to sustain the structural failure.

Keywords: SHM, PZT, RMSD, Smart Materials, EMI.

INTRODUCTION

India loss $9.8 billion every year due to multi hazard disasters as its 58.6% land is proven to earthquake and 8.5% area in effective cyclone [1]. Earthquakes are frequented and have very high intensities in the areas once the attack of the earthquake takes place, and the structural damage is detectable. Recently in the past, progressive research works have gained the popularity. It is desperately attracts to develop the damage investigation technique for civil engineering structures after the hazardous attack of the earthquakes. There are certain difficulties arising for the currently using non-destructive test technique to detect the seismic damages in larger structures such as, dams. In the recent year, piezoelectric material have been successfully applied to health monitoring of concrete structures due to their advantages, on concrete structures, as active sensing, cost effective, quick response, accessibility in different shapes, and simplicity for implementation [2].

The application of smart material like as piezoelectric ceramics and PZT (piezoelectric lead zirconate titatare) in the Structural Health Monitoring (SHM) technique is a recent and very promising development.

The implementation of a piezoelectric sensor in the structural health monitoring system became efficient due to the development of Electro-Mechanical Impedance (EMI) method [3]. This process is based on the direct relation created between the impedance PZT and the reinforced concrete structure's mechanical impedance, which is affected by the pressure of damage. The advantages of EMI technique are to increase sensitivity and efficiency in monitoring localized damage in real time utilizing peak – frequency excitations without requirement of experienced technique and complicated equipment [4,5]. The EMI technique has been sensitive to the damage that appear near the PZT location, when the excitation of the host structures becomes more than one of the PZT sensor, the impedance measurement for health monitoring of large and bulky structures becomes difficult.

Wen I. Liao, C.H. Lin, J.S. Hwang and G. Song [2] studied a piezoelectric based device called "smart aggregate" as shown in Figure 1 used for the health monitoring of RC frame structure under earthquake excitation. Three RC moment frames instrumented with aggregate sensor were tested by using a shakable with different excitation intensities. Piezo-ceramic based "Smart aggregate sensor" were embedded in the RC structure and used to monitor the structural health condition during the tests shown in Figure 1. The displacement ductility demand of structural members was calculated and compared with the damage index to determine the health condition of the frame structure.

1. Methodology Involved in Post Seismic Damage Detection

In the post seismic damage detection of R.C.C or steel structures, the EMI technique have gained so much popularity in the recent years. Based on the concept of electro-mechanical coupling effect between the host structures, they embed PZT sensor (Park et at., 2006). The PZT is powered by voltage or current. The integrated electro-mechanical system may be electrically represented by the excitation of PZT and the host structure [7]. The principal of EMI based damage detection have been given below the electro mechanical impedance techniques that provide the damage detection and health monitoring because it directly measures the high frequency which is very sensitive to local damage.

To capture the damage, proper monitoring system is required by recording the damage and the healthy signature becomes more effective and precise. The

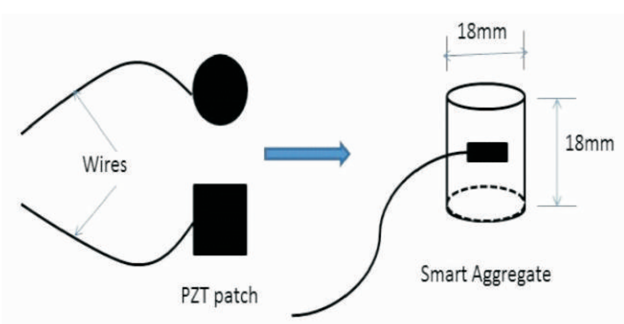

Figure 1. Piezoelectric based device "Smart Aggregate"

Figure 2. Smart Aggregate

recording instrument record the signatures of damaged and healthy stages of monitoring structures, which help in quantifying the damage and its position.

The mechanical impedance of the structures idealized as a SDOF system in Figure 3 is defined as the ratio of a harmonic excitation force F(w) at an angular frequency w to the velocity response x(w) in the frequency domain. The electrical impedance Z_a of the PZT patch is defined as the ratio of harmonic input voltage V(w) at an angular frequency w to current response in the frequency domain .

The EMI Z of the patch as coupled with structure is given by the equation,

$$Z(c)=\left[iwc\left(1-k_{31}^{2}\,X\,\frac{Z_s(w)}{Z_a(w)+Z_s(w)}\right)\right]^{-1} \quad (1)$$

2. Damage Detection through EMI Sensor

Due to the development of an embedded PZT approach which is called as "smart aggregate", is used to detect damage in the civil engineering structure (Song et al., 2008) and smart aggregate was formed by embedding a

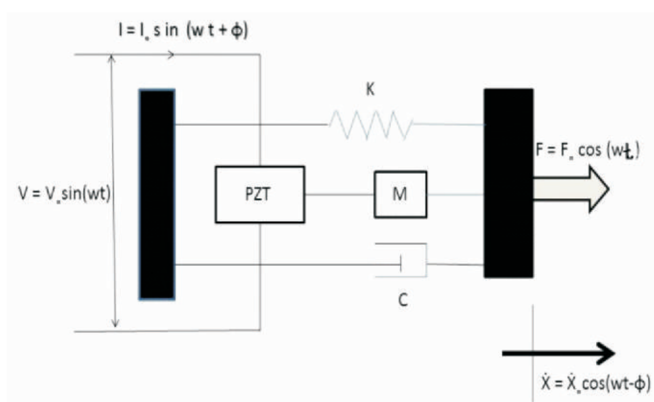

Figure 3. A SDOF System under Dynamic Excitation

waterproof PZT patch with co-axial wire into a small concrete block before casting them into a constructing structure. This smart aggregate does not affect the host structure stability, it was only applied to an elastic wave-based approach for SHM. But later, it was used for EMI based damage detection for concrete structures.

To estimate the damage, several pattern identification techniques have been proposed by the researcher (Park et al., 2003). Root Mean Square Deviation (RMSD) was firstly introduced as damage index by Giurgiutiu and Roger's (1997) to quantify the change that take place in the signature due to the damage.

The effectiveness of RMSD as a damage index has been proposed by numerical simulation as well as experimental studies (Park et al., 2006, yang et al., 2008)

$$\text{RMSD (\%)} = \sqrt{\frac{\sum_{i=1}^{n}\left(R_i^1 - R_i^0\right)^2}{\sum_{i=1}^{n}\left(R_i^0\right)^2}}\, X\, 100 \qquad (2)$$

R_i^0 is measured in healthy condition of the concrete structure, R_i^1 is corresponding to the post damage value at i^{th} measurement point, and n indicates the number of sampling.

3. Major Development during the Last 10 Years in the Field of Post Damage Detection

Major contribution and development made by various researchers in the area of post damage detection technology during the last 10 year are summarized as follows. A very detailed review of various studies has been described by a mechanical impedance approach for structural identification health monitoring and non-destructive evaluation using impedance transducers by Dr. Suresh Bhalla.

Application of EMI technique was first introduced by Sun et al. (1995) for SHM of a lab size truss structure. This study was extended to a large scale prototype truss point by Ayres et. al. (1998) .

Lopes et al. (1999) trained the natural network using damage identification area under the Root Mean Square (RMS) of the conductance curve between damage and healthy curves using experimental data. The trained network will provide the location of damage and the quantity of damage.

Suresh Bhalla et.al. (2011) have made dual use of PZT patches as a sensor in global dynamic and local electro mechanical impedance technique for SHM to find damage detection.

X. Feng, E.T. Dandjekpo & J. Zhou et al. (2012) have conducted researcher on post – earthquake damage detection using embedded electro-mechanical impedance sensor for concrete dams. In this, they have used PZT as an embedded sensor installed before the construction for the evaluation of post – earthquake damage detection.

Wen I Liao et.al. (2013) have made an effort for seismic health monitoring of RC frame structure using smart aggregate. “Smart aggregate” are formed by embedding waterproof piezoelectric patch with lead wires into concrete blocks. A small concrete block was placed into a large concrete structure before construction, these embedded smart aggregate does not effect the host structure and the damage to the host RC frame can be identified.

C.E. Chalioris et al. (2015) has proposed an experimental application of a Wireless Earthquake Damage Monitoring System (WiAMS) using PZT transducer in the reinforced concrete beam [6].

4. Barriers that arised During Damage Detection using Piezoelectric Smart Sensor

A piezoelectric material/sensor is sensitive to structural damage over a relative ranging from 0.4 to 2 meters only. This depends upon the geometrical configuration and material properties. So, monitoring of large structure like bridge, high rise building, dam etc, requires a thousands of PZT patches for real – time monitoring of structures. Large number of PZT patch increases the cost of the project, it also creates a disturbance and obstacles in the wiring system, data processing and the collection of the data due to increasing the number of PZT patch difficulties arises in data handling.

Since all the mechanical and civil structures are statically indeterminate, cracking of the few joints may not affect the overall stability and safety of structures that has to be monitored, thus a drawback of this technique is its inability to access the overall stability of the civil structures.

PZT sensors and the related technologies are only supplementary steps in addition to good mechanics and design. Many researchers are only focusing on improving the development of the sensors. But even the best –designed structures could have a problem, therefore it is justified to explore the application of smart material or sensors for detail damage detection in advances (Reddy, 2001).

5. Scope of the Study

The study work presented in this paper is an attempt to demonstrate the approach to find out the post seismic damages or a crack that has been induced in the structure either visually or non-visually that can be detected by a piezoelectric sensor with the help of different methodology. Impedance based health monitoring, vibration characteristics approach and Lamb wave based health monitoring [8] methodology did help both to quantify and track the location of damage which may help in the repair and serviceability. The following are the scopes of the study listed below:-

- These techniques are automated non-destructive evaluation techniques that enables the continued health monitoring of concrete structure [9], (S. Park, et al., 2006).
- The proposed electromechanical impedance based. Monitoring technique that has presented in this paper has the advantages of low cost, portability and simplicity in the measurement which may be useful in checking the condition of R.C.C. Structure after the attack of seismic, so that the required repair can be provided to the structure to make it durable and serviceable for a long time period.
- The installation and cost of smart piezoelectric sensor both are advantageous because it is easily installed, which is either surface bounded or embedded make its suitable for existing as well as undergoing constructed structure and it's low cost US $5 to US $10 make it more effective and suitable for monitoring the condition of the structure.
- This method can be implemented any time for the structure, which makes it very effective and the scope of piezoelectric sensor and it's biased damage detection methodology can enable the loss of seismic attack so that the required service can be provided to the structure.
- Piezoelectric sensor that has been used for the structural monitoring shows greater damage sensitivity than other sensor [10].
- These concerned technology not only applies to the civil engineering structures such as, the nation's bridges, highways and building but also to other types of structure such as, the aging of aircraft that are currently in use [11].
- Future scope of a piezoelectric smart sensor is growing rapidly due to the development of advanced impedance and guided wave technologies. These technologies may help in the damage detection of not only civil engineering structures, but these may in aircraft, aerospace and navigation based satellites [12].

Conclusion

Finally, this review article tried to simulate different novel methods to detect the post- seismic damage to the civil engineering structures, embedded or surface bounded EMI sensor that have been used for damage detection and capturing the of the host structure. The embedded EMI sensors excitement record the impedance and admittance of the embedded EMI sensor after before the earthquake. These sensor records the admittance of healthy states of the structure and damage state of structure at different load levels and for monotonic and cyclic loading. These differences clearly identify the presence of damage and it might detect that, as the damage level gets increases, an increasing tendency of RMSD can be traced. As a result, the RMSD method was found to be more sensitive than any other damage detection indices.

With the help of smart piezoelectric sensor and effective monitoring approach, the quantity and location of damage can be identified so that, the required quantity of repair and services that has to be provided to the structure to sustain against failure and collapse of the structure from aftermath of the earthquakes.

By using this non-destructive testing, continuous monitoring of structure can be possible and repair can be done through the damage analysis.

It can be concluded that, the suggested methods of the embedded sensor can effectively detect the seismic damage for the structures which provides a potential means of real time monitoring of the structures.

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