SSDL

Smart Structures and Dynamics Laboratory

DEPARTMENT OF CIVIL ENGINEERING

IIT DELHI

Presents

Concrete Vibration Sensor (CVS)

Indian Patent no. 412929

in New Avatar

Completely “Made-in-India”

This is much ahead of "Make in India“, which refers to manufacturing in India primarily based on foreign technology

What’s New in the 2025 Version?

- A completely non-shrink high-strength body
- New completely Indian PZT element

How does CVS work?

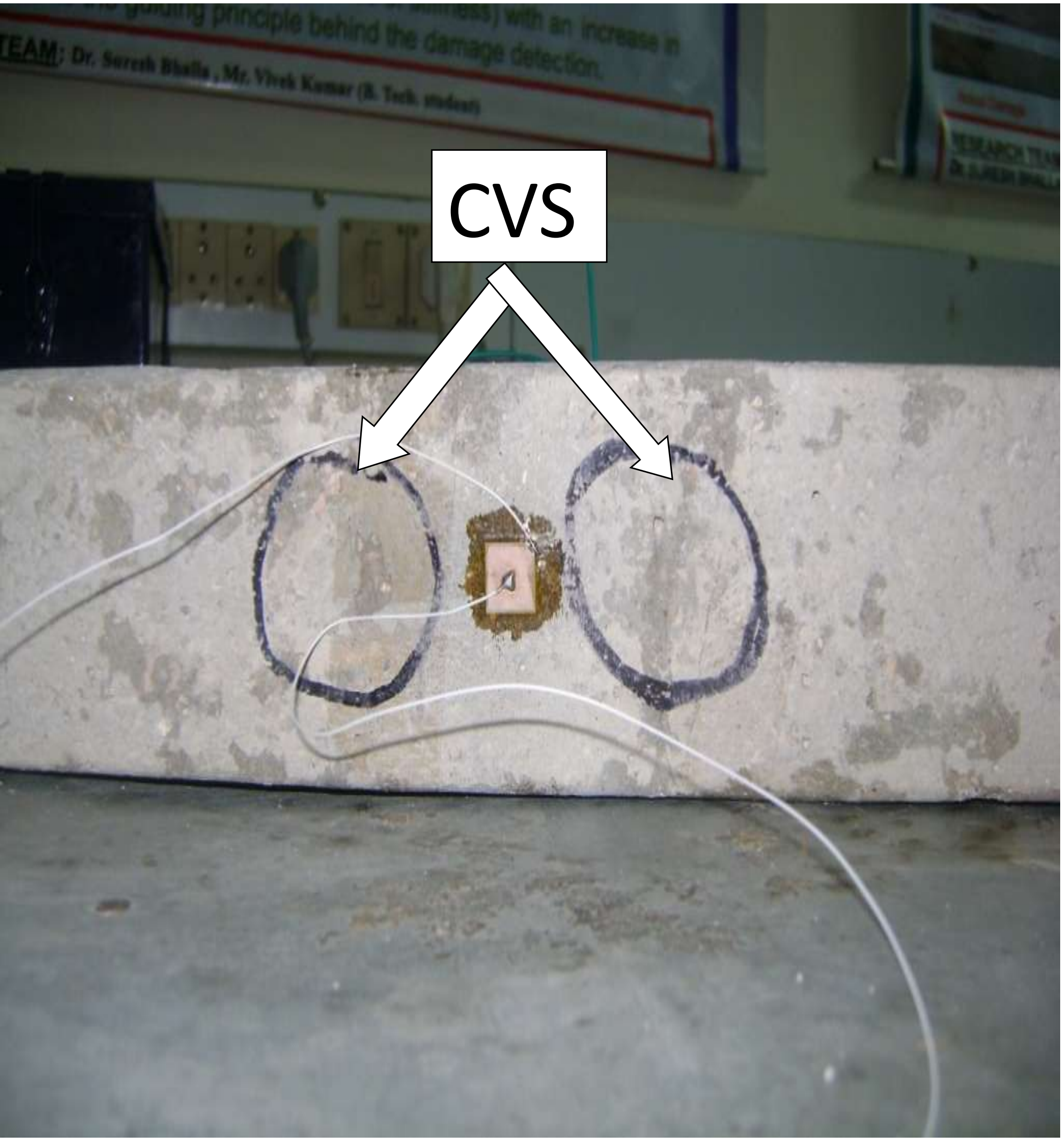
CVS converts strain into voltage by virtue of piezoelectric effect. Houses most versatile lead zirconate titanate (PZT)-based sensing element

Sensitivity?

Of the order of 200mV per micro strain

Any specific signal conditioning needed?

Raw signal itself of excellent quality, natural noise immunity



How is CVS instrumented?

It is a packaged "ready-to-use" sensor which can be embedded in an RC member during or after casting.

Once embedded, it become a permanent life-long part of the structure.

What can be measured using CVS?

- Dynamic strain
- Dynamic deflection in flexural members
- Acceleration in flexural members

It is fully capable of replacing expensive (foreign made) accelerometers for operational modal analysis (OMA)

Proven Applications

- Dynamic strain history
- Direct curvature mode shapes
- Operational modal analysis (OMA) on real-life bridges
- Concrete fatigue analysis
- Impact/ blast load monitoring
- Can act as sensor for the most versatile electro-mechanical impedance (EMI) technique for detection of incipient damage

Application Structures

- Bridges
- Multi-storey buildings
- Machine foundations
- Airport runways/ pavements

International peer review of technology done in numerous high impact international journals

Excellent reviews received

International Journal of Fatigue 113 (2018) 98–112

Contents lists available at ScienceDirect

International Journal of Fatigue

journal homepage: www.elsevier.com/locate/ijfatigue

Prognosis of low-strain fatigue induced damage in reinforced concrete structures using embedded piezo-transducers

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ARTICLE INFO

Keywords:
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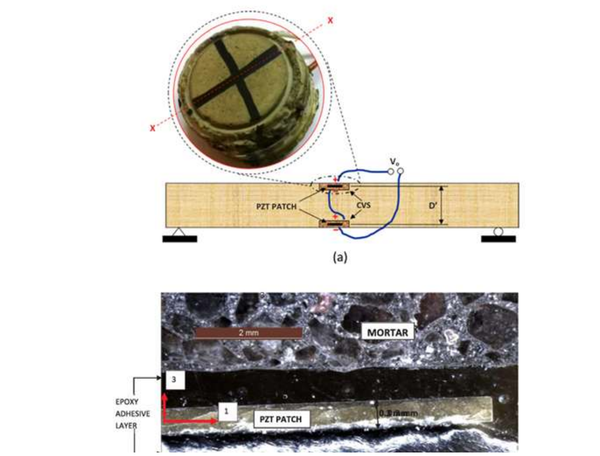
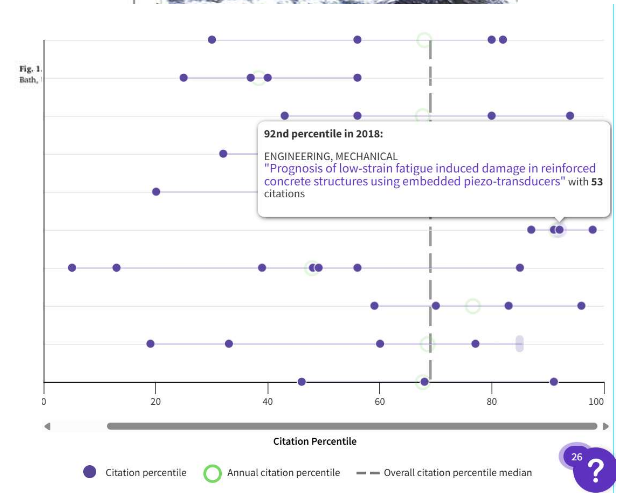
Concrete vibration sensor (CVS)
Piezoelectric ceramic lead zirconate titanate (PZT)

ABSTRACT

Fatigue induced damage under low-strain conditions is a commonly encountered phenomenon in reinforced concrete (RC) structures subjected to continuous vibrations, such as bridges under vehicular loads, buildings under wind and structures directly supporting or in the vicinity of vibration emitting machinery. This type of fatigue tends to weaken the structure silently, and quite often, its timely cognizance is missed out in the life-cycle management of the structure. Among the various structural health monitoring (SHM) frontiers, very scarce research has been devoted to this kind of damage in RC structures. This paper covers a long-term experimental study related to low-strain fatigue damage monitoring encompassing a real-life sized RC structure. The experimental specimen was subjected to over eight million cycles of flexural loading with the maximum bending strain values restricted to 50 μm/m. The structure was instrumented with piezo-based composite concrete vibration sensors (CVS), which were embedded inside the beam near the surface. The CVS operated in dual mode, acting as sensor for the global vibration technique as well as the local electro-mechanical impedance (EMI) technique. As EMI sensors, they facilitated the determination of the equivalent stiffness parameter (ESP), and were found to be very expedient for damage detection as well as localization during the incipient stages of fatigue damage, coinciding with the appearance of first few cracks. The ESP served to represent the diminishing trend to actual residual stiffness fairly well during the initial stages. Acting in the global mode, determination of the overall stiffness of the structure by the same CVS provided an alternate damage measure, in terms of a realistic estimate of the overall residual flexural stiffness. This proved useful parameter during moderate to severe damage conditions, and in particular near the final failure of the structure. The monitoring paradigms presented in the paper pave way for effective prognosis of fatigue induced damage in real-life RC structures.





92nd percentile
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Development and evaluation of an external reusable piezo-based concrete hydration-monitoring sensor

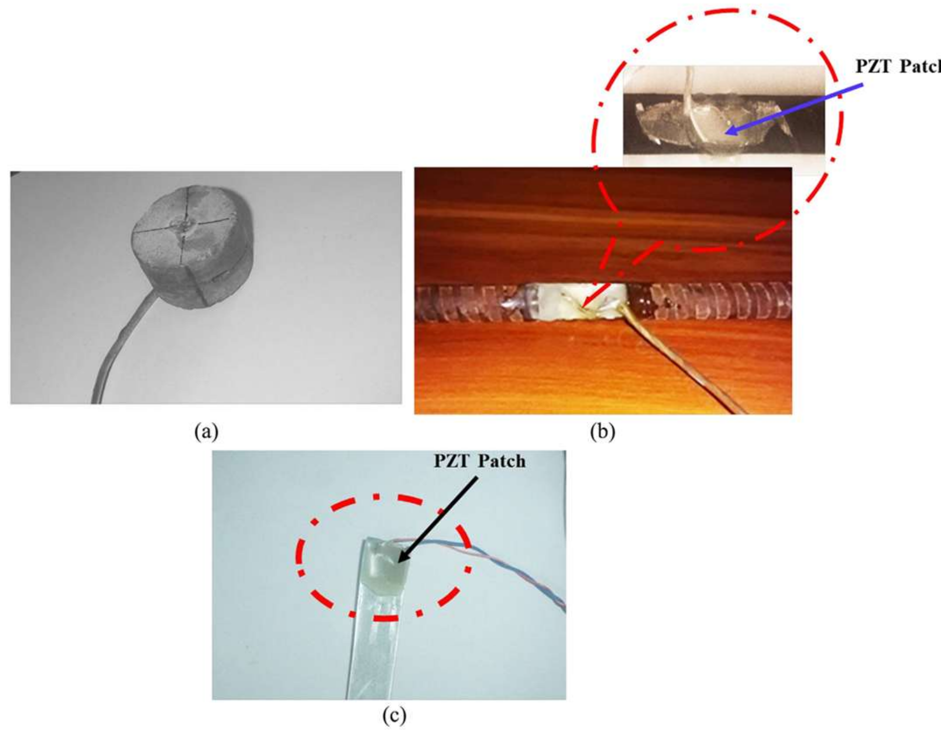
Sumedha Moharana[1] and Suresh Bhalla[2]

Abstract

Hydration of concrete is a very complicated and multiphase process, where the cement gel transforms into a hardened state from plastic/semiplastic phase. Proper progression of the hydration process ensures the development of targeted mechanical properties such as the elastic modulus, the coefficient of thermal expansion, the Poisson's ratio, and finally, the characteristic strength of concrete. Concrete experiences large thermal variations during the early phase of hydration due to the heat generated during the formation of cement hydration compounds, which contributes to shrinkage and cracking, somewhat making ground for the ultimate failure in the long run. Therefore, it is utmost important to monitor the progression of hydration for enhancing performance during the curing and the early service life. This article presents a new reusable external configuration of piezo-impedance transducers to monitor the hydration process in concrete structures using the electro-mechanical impedance technique. The proposed configuration consists of a thin metal foil instrumented with piezoelectric ceramic patch at the free end with the other end of the foil embedded inside the concrete. This configuration is compared against a piezoelectric ceramic patch directly bonded on the rebar used for reinforcement and another one embedded in the concrete surrounding the rebar. The sensing capability of the proposed metal foil configuration is clearly evident from the coupled admittance signature quantitatively vis-à-vis the other configurations. As a preliminary analysis, root mean square deviation values are employed to monitor the hydration process quantitatively. A piezo-equivalent mechanical model is also developed wherein the piezo-identified mass, stiffness and damping parameters are investigated for the cement hydration process so as to chalk out rigorous quantifiers of hydration progression. The employability of the proposed configuration is further proven by explanation of the physio-chemical products developed during various stage of hydration with step-by-step explanation along with corelation of the piezo-identified mass, stiffness and damping parameters. Overall, the proposed reusable configuration carries a high potential for field deployment in concrete industry for early detection of physio-chemical changes.

Keywords

Cement, concrete composite, hydration, lead zirconate titanate (piezoelectric ceramic), metal foil–based piezo sensor, electro-mechanical impedance technique



Sensors and Actuators A 274 (2018) 116–131

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Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Prognosis of fatigue and impact induced damage in concrete using embedded piezo-transducers

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Impact
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Lead-zirconate-titanate (PZT)
Residual life

ABSTRACT

Concrete structures are often subjected to a wide array of load conditions, such as fatigue and impac and the consequent damages. Recently, smart materials, in particular the piezoelectric materials, hav received high attention from the point of view of structural health monitoring (SHM). In this connec tion, the electro-mechanical impedance (EMI) is one of the latest and most effective techniques. Th technique harnesses the piezoelectric property of lead-zirconate-titanate (PZT) patches to sense an incipient damage. In the research covered in the paper, embedded PZT patches are employed to monito the accumulating damage in plain cement concrete subjected to fatigue and impact type loadings. Con crete specimens (150 mm cubes and 100φ × 200 mm cylinders) of grade M-25 are cast with embedde concrete vibration sensors (CVS). The impact loading is simulated by a free falling iron-ball of mass 5 k dropped from variable heights of 2 m, 2.5 m and 3 m above the top surface of the test cubes. For fatigu tests, a 4000 kN cyclic compression testing machine is used to apply the fatigue load in a sinusoidal forr The admittance signatures from the embedded PZT patches for impact and fatigue tests are acquired usin an LCR meter. These signatures are used to determine the PZT-identified equivalent system propertie (damping, stiffness and mass) of the specimens at varying damage states. For impact tests, strain histor during the impact process is acquired in addition to the admittance signatures. The results for impac tests show an increase in the maximum strain induced in the patch with the number of impacts, while th equivalent damping computed from the admittance signature is found to decrease with increasing dam age. For fatigue tests, the equivalent damping is again found to decrease with increasing damage, finally undergoing a phenomenal increase near the failure. Based on these measurements, separate relationships have been developed for impact and fatigue induced damages linking the PZT-identified damping with remaining life.

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Piezo-impedance based fatigue damage monitoring of restrengthened concrete frames

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ARTICLE INFO

Keywords:
Structural health monitoring
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Piezo sensors
Plate debonding

ABSTRACT

The present study proposes a novel application of wavelet transform energy of piezo-impedance signatures in monitoring the premature fatigue damage of restrengthened reinforced concrete (RC) frames. The steel plates on one column of the damaged RC frame and carbon fibre reinforced polymer (CFRP) wrap on the other are utilized as the local strengthening elements. The lead zirconate titanate (PZT) patches bonded externally to the retrofitted elements were used to acquire the global and local vibration response of the test frame under high-cycle and low-strain fatigue loading environment. The electro-mechanical impedance (EMI) technique combined with discrete wavelet transform (DWT) is employed on frequency domain PZT-admittance signatures to identify, localize, and quantify the severity of premature fatigue damages. The EMI-identified structural damping and DWT energy based damage dependent models shows extraordinary ability in estimating residual fatigue life of the structure. The results of combined local and global dynamics technique indicate the higher performance of the PZT-identified equivalent stiffness parameters (ESP) in detecting and quantifying plate debonding failures. Further, for the first time, the miniature AD5933 chipset displays a higher correlation of ESP in estimating premature fatigue damages, ultimately proving its efficacy for using it as a low-cost impedance-based health monitoring solution for retrofitted RC structures.

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Health monitoring of reinforced concrete structures under impact using multiple piezo-based configurations

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HIGHLIGHTS

- Four different configuration of piezo based sensors were compared in embedded condition in concrete.
- Three RC slabs were instrumented with the sensors and were subjected to impact loading from a steel ball.
- Structural parameters were found out to analyse the remaining life of structures after each impact.

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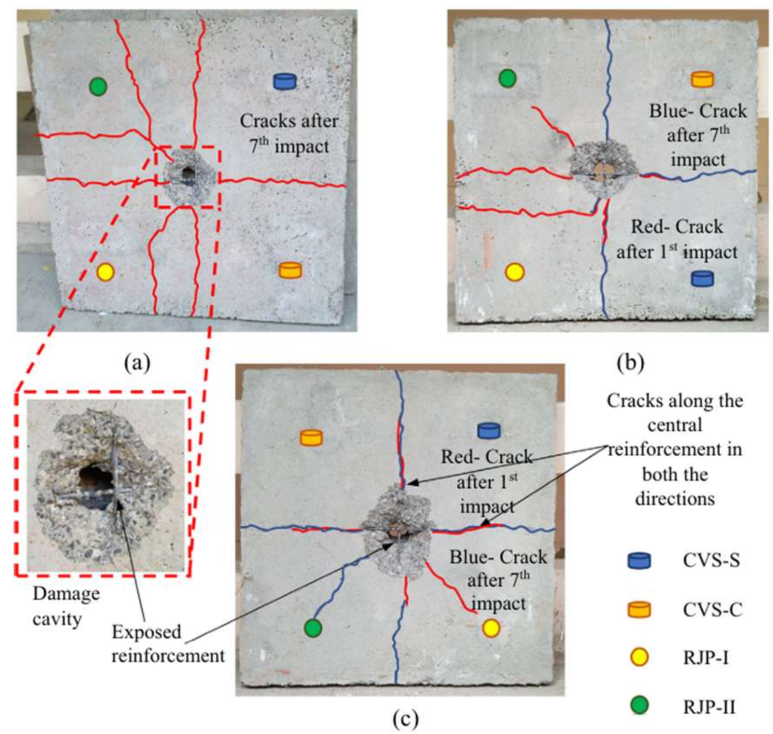
Resin jacketed piezo
Concrete vibro-sensors
Electro-mechanical impedance technique
Impact testing

ABSTRACT

With new advancements in construction technologies, the researchers and engineers have started taking a greater interest in structural health monitoring (SHM). Some of these techniques involve monitoring of structures using piezo sensors, made of smart materials such as Lead Zirconate Titanate (PZT) in form of thin patches. One of such techniques which has shown promising results in detecting damage at incipient stages is the electro-mechanical impedance (EMI) technique. In this study, damages incurred due to impact loading on reinforced concrete (RC) slabs were studied using four types of piezo-based configurations, namely concrete vibration sensor (CVS) with circular PZT patch (CVS-C), CVS with square PZT patch (CVS-S), resin jacketed piezo (RJP) sensor with a single layer of epoxy (RJP-I) and RJP with double layer of epoxy (RJP-II). The tests showed a successful detection of damage due to impacts by all the four types of piezo-based configurations. The CVS-C and RJP-I proved to be more sensitive in quantifying damage via root mean square deviation (RMSD) variation, i.e. increasing RMSD values with an increase in the number of impacts. In addition, CVS-C, CVS-S, and RJP-II, specifically detected an imminent failure in one of the RC slabs. The equivalent structural parameters computed from the admittance signatures showed a reduction in the equivalent stiffness with the incremental damage. An empirical model was successfully developed for each of the sensors to determine the remaining life of the structure based on a non-dimensional stiffness loss factor. The equivalent stiffness-based model was found to be an improvement over the previous damping-based models which can be reliably used in the field.



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Original Article

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Damage and retrofitting monitoring in reinforced concrete structures along with long-term strength and fatigue monitoring using embedded Lead Zirconate Titanate patches

Naveet Kaur[1], Suresh Bhalla[2] and Subhash CG Maddu[2]

Abstract

This article aims at developing a generic system for the damage and retrofitting monitoring along with long-term strength and first-stage fatigue monitoring of reinforced concrete structures using embedded Lead Zirconate Titanate sensors in the form of concrete vibration sensors. The concrete vibration sensor is a ready-to-use sensor, and its unique packaging renders it very compatible for embedment in reinforced concrete structures. In addition to cost-effectiveness, the concrete vibration sensors are also characterized by excellent structure-compatibility and durability. In this article, both finite element method and experimental investigations have been employed to establish the feasibility of using curvature (second-order derivative) and other higher order derivatives of displacement mode shapes for damage detection and retrofitting assessment. The experiments are conducted on a real-life-sized reinforced concrete beam. The concrete vibration sensors embedded on the outer faces of the reinforced concrete beam are coupled to obtain the curvature and higher order mode shapes of the beam in pristine, damaged and retrofitted conditions. It is found that the curvature mode shape–based response of concrete vibration sensors can successfully identify the location of damage both numerically and experimentally. However, the third-order mode shape is unable to correctly identify the location of damage. Before introducing damage in the beam, the effect of long-term dynamic loading from Day 6 to Day 108 after casting of the reinforced concrete beam is also monitored. Both the global monitoring technique (in which flexural rigidity of the beam is monitored) and the local electro-mechanical impedance technique (where the equivalent stiffness identified by concrete vibration sensors is monitored) successfully detected the decreasing fatigue strength of the reinforced concrete beam. Degradation of the strength of reinforced concrete beam results due to the development of micro-cracks in the concrete because of the continuous vibrations (9.3 million load cycles) experienced by it via shaker. This is the first-of-its-kind proof-of-concept application of equivalent stiffness concept for monitoring curing of a large-sized reinforced concrete structure. It is also the first study on first-stage fatigue monitoring carried out before the 'retrofitting-stage' of the structure. Complete experimental investigations after the 'retrofitting-stage' covering all three stages of fatigue have been covered by the authors in their related publication.

Keywords

Retrofitting, embedded lead zirconate titanate patches, real-life reinforced concrete structure, concrete vibration sensor, structural health monitoring, reinforced concrete structures, fatigue monitoring

Construction and Building Materials 169 (2018) 489–498

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Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

ELSEVIER

Investigations on effectiveness of embedded PZT patches at varying orientations for monitoring concrete hydration using EMI technique

Check for updates

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[b] *CSIR-CRRI, Mathura Road, New Delhi 110025, India*

HIGHLIGHTS

- Orientation study on embedded PZT patches.
- Hydration monitoring in real life RC beam.
- Inclined PZT patches does not work effectively.

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Electro-mechanical impedance
Embedded sensors
Hydration
Lead zirconium titanate
Reinforced concrete beam
Sub-frequency interval approach

ABSTRACT

The electro-mechanical impedance (EMI) technique has already been established to be an effective technique for detecting incipient damages in engineering structures including reinforced concrete (RC) using smart piezo-electric sensors. Its effectiveness in monitoring the hydration of concrete, using surface bonded and embedded lead zirconium titanate (PZT) patches has also been investigated well. However, the influence of patch orientation while embedding them in concrete is still unexplored. The present study investigates the effectiveness of the EMI technique using PZT patches embedded at different orientations (here, 0°, 45° and 90°) with the axis of the structure, while monitoring the hydration of a real-life prototype RC beam. Further, the effectiveness of the PZT patches in monitoring the strength gain in concrete is investigated. It is observed that the PZT patch placed in the inclined orientation (45°) least efficient in capturing the progressive changes of hydration in the concrete in comparison to the other two orientations. The EMI technique showed best results when PZT patch was placed in horizontal position (0°) with the longitudinal axis of the beam.

Combined Energy Harvesting and Structural Health Monitoring Potential of Embedded Piezo-Concrete Vibration Sensors

Naveet Kaur[1] and Suresh Bhalla[2]

Abstract: Piezoelectric materials have proven their efficacy for both energy harvesting and structural health monitoring (SHM) individually. Piezoelectric ceramic (PZT) patches, operating in d_{31}-mode, are considered best for SHM. However, for energy harvesting, built up configurations such as stack actuators are more preferred. The proposed study in this paper provides a proof-of-concept experimental demonstration of achieving both energy harvesting and structural health monitoring from the same PZT patch in the form of concrete vibration sensor (CVS), designed specifically for RC structures. This packaged sensor (CVS), composite in nature, has better compatibility with surrounding concrete and can withstand the harsh conditions encountered during construction. The paper covers experiments carried out in the laboratory environment to measure the voltage and the power generated by a CVS embedded in a life-sized simply-supported RC beam subjected to harmonic excitations. An analytical model is developed to compute the power output from the embedded CVS, duly considering the effect of the shear lag associated with the bonding layers between the encapsulated PZT sensor and the surrounding concrete. The performance of the CVS is compared with the surface-bonded PZT patch. Utilization of the same patch for SHM through a combination of the global vibration and the local electro-mechanical impedance (EMI) techniques is also covered. Harvesting potential of vibration energy by PZT sensors during idle time is experimentally demonstrated and extended to real-life structures based on the validated analytical model.
DOI: 10.1061/(ASCE)EY.1943-7897.0000224.

Author keywords: Energy harvesting; Structural health monitoring; d_{31} mode; Real life structure; Embedded PZT patches; Concrete vibration sensor (CVS); Traffic loads.

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Fatigue damage monitoring of reinforced concrete frames using wavelet transform energy of PZT-based admittance signals

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Damage monitoring
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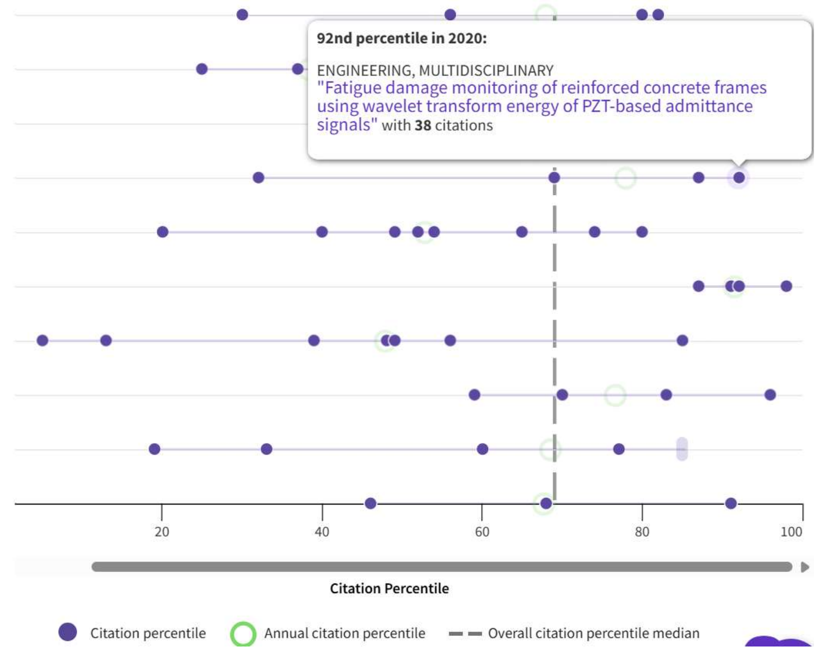
Wavelet transform
Power spectral density
RC frame

ABSTRACT

The paper presents a novel structural health monitoring approach based on the wavelet energy of admittance signals to detect, localize and estimate the severity of the damages caused by fatigue in reinforced concrete (RC) frames. Admittance signatures are acquired in user-defined frequency ranges experimentally using six piezo-cement composite disks (embedded at different locations in RC specimens) at various stages during fatigue testing of the frame on a shake table. For purpose of estimating wavelet energies, discrete wavelet transformation (DWT), continuous wavelet transformation (CWT) and power spectral density (PSD) analysis are applied on real-admittance signals (conductance) in frequency domains. Mathematical models based on global dynamic and wavelet energy approach are developed and validated in order to estimate residual life of RC frames. Overall, the experimental results verify the superior performance of the DWT based optimum methodology in enabling full-fledged real-time damage prognosis of RC structures under low-strain and high-cycle fatigue.



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TECHNIQUES

by S. Bhalla and S.K. Deb

A COST-EFFECTIVE APPROACH FOR TRAFFIC MONITORING USING PIEZO-TRANSDUCERS

Traffic management is key to proper functioning of any big metropolitan city. This in turn is dependent on the real-time assessment of traffic volume as well as the composition at key locations of the city. In general, traffic planners are interested in vehicle count, speed, class, gap, occupancy, and weight. A reliable and cost-effective system to measure these parameters in real time, with no or minimal disruption to traffic, is very much desirable. The following techniques, currently in vogue, are based on sensors located above ground: video image processing, microwave/laser radar, infrared, ultrasonic, and acoustic techniques. Of these, the vision-based video image techniques have received some acceptance from transportation engineers and the research community. For example, Messelodi et al.[1] recently proposed an algorithm employing support vector machines for vehicle classification using video image processing. However, the image-based techniques are not only expensive but also involve complex processing of the measured data. In

mechanical stress, which is called the direct effect; and conversely, undergo mechanical deformations in response to an applied electric field, which is called the converse effect. This unique capability of the piezoelectric materials to exhibit a "stimulus-response" characteristic qualifies them to be members of the group of so-called smart *materials.*[3] The physical electromechanical model associated with PZT materials is illustrated in Fig. 1. The patch undergoes strain in direction "1" when an electric field E_3 is applied in direction "3." The patch has length l, width w, and thickness h. The behavior of the patch is governed by the following constitutive relationships:[2,4]

$$D_3 = \overline{\varepsilon_{33}^T} E_3 + d_{31} T_1 \quad (1)$$

$$S_1 = \frac{T_1}{\overline{Y_{11}^E}} + d_{31} E_3 \quad (2)$$

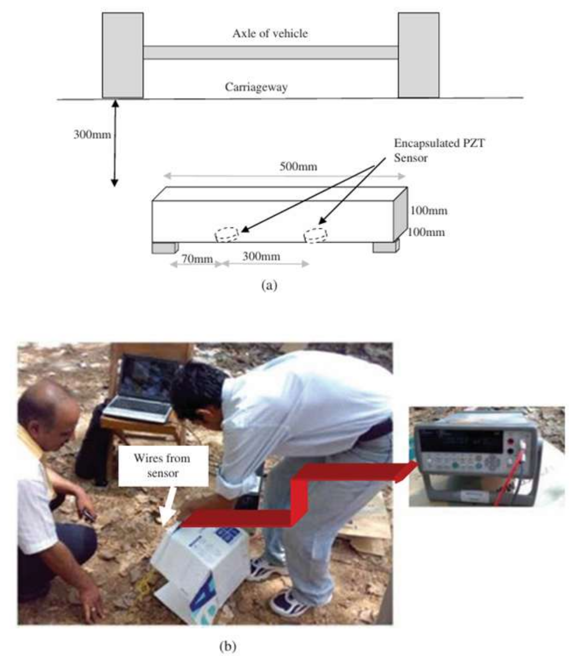

Fig. 4: (a) Placement of disk in concrete beam. (b) Embedding of beam below ground and connection to DMM

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Piezo-impedance based fatigue damage monitoring of restrengthened concrete frames

Moinul Haq [a], Suresh Bhalla [b,*], Tabassum Naqvi [a]

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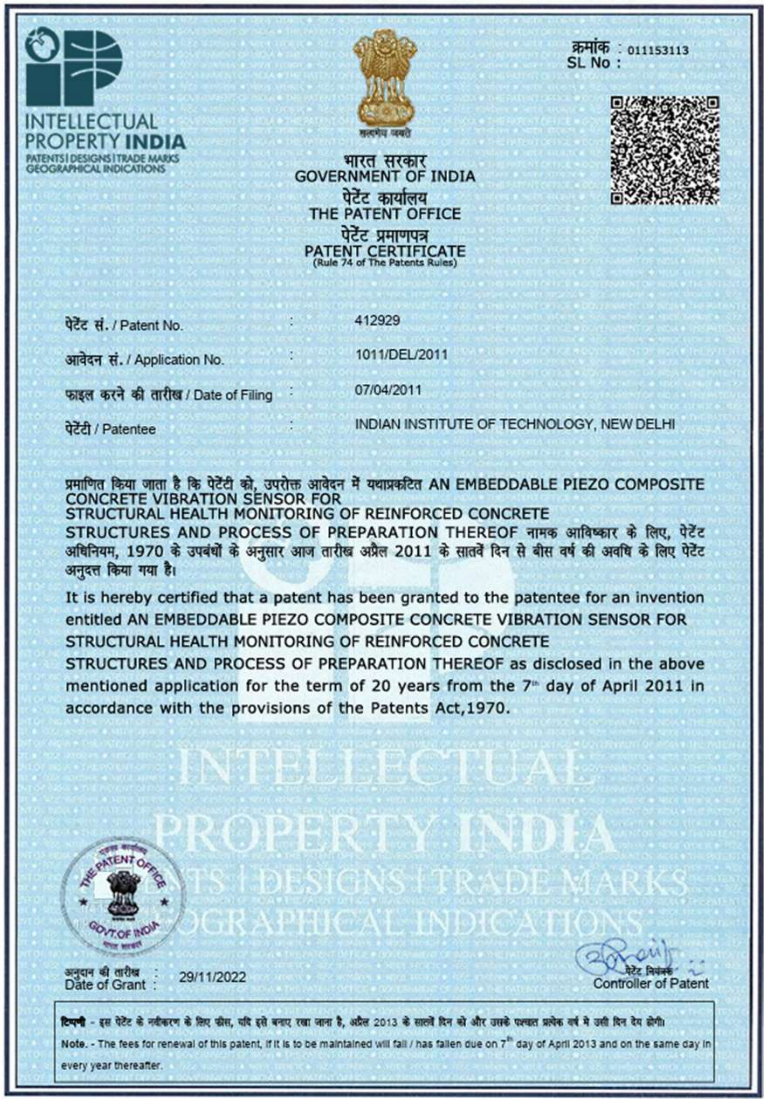

INTELLECTUAL PROPERTY INDIA
PATENTS | DESIGNS | TRADE MARKS
GEOGRAPHICAL INDICATIONS

क्रमांक : 011153113
SL No :

सत्यमेव जयते

भारत सरकार
GOVERNMENT OF INDIA
पेटेंट कार्यालय
THE PATENT OFFICE
पेटेंट प्रमाणपत्र
PATENT CERTIFICATE
(Rule 74 of The Patents Rules)

पेटेंट सं. / Patent No.	:	412929
आवेदन सं. / Application No.	:	1011/DEL/2011
फाइल करने की तारीख / Date of Filing	:	07/04/2011
पेटेंटी / Patentee	:	INDIAN INSTITUTE OF TECHNOLOGY, NEW DELHI

प्रमाणित किया जाता है कि पेटेंटी को, उपरोक्त आवेदन में यथाप्रकटित AN EMBEDDABLE PIEZO COMPOSITE CONCRETE VIBRATION SENSOR FOR STRUCTURAL HEALTH MONITORING OF REINFORCED CONCRETE STRUCTURES AND PROCESS OF PREPARATION THEREOF नामक आविष्कार के लिए, पेटेंट अधिनियम, 1970 के उपबंधों के अनुसार आज तारीख अप्रैल 2011 के सातवें दिन से बीस वर्ष की अवधि के लिए पेटेंट अनुदत्त किया गया है।

It is hereby certified that a patent has been granted to the patentee for an invention entitled AN EMBEDDABLE PIEZO COMPOSITE CONCRETE VIBRATION SENSOR FOR STRUCTURAL HEALTH MONITORING OF REINFORCED CONCRETE STRUCTURES AND PROCESS OF PREPARATION THEREOF as disclosed in the above mentioned application for the term of 20 years from the 7th day of April 2011 in accordance with the provisions of the Patents Act,1970.

THE PATENT OFFICE GOVT.OF INDIA

अनुदान की तारीख / Date of Grant : 29/11/2022

पेटेंट नियंत्रक
Controller of Patent

टिप्पणी - इस पेटेंट के नवीकरण के लिए फीस, यदि इसे बनाए रखा जाना है, अप्रैल 2013 के सातवें दिन को और उसके पश्चात प्रत्येक वर्ष मे उसी दिन देय होगी।

Note. - The fees for renewal of this patent, if it is to be maintained will fall / has fallen due on 7th day of April 2013 and on the same day in every year thereafter.

Statement of Patent Ownership and Protection

This is to notify that **Indian Patent No. 412929** titled **"An Embeddable Concrete Vibration Sensor for Structural Health Monitoring of Reinforced Concrete Structures and Process of Preparation Thereof"** is the intellectual property of the **Smart Structures and Dynamics Lab, IIT Delhi**. The patent is currently **not licensed to any organization or entity**.

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9. Col. Kunal Srivastava
10. Er Rajat Chabbra

OTHER INVENTIONS OF SSDL

1. Concrete Vibration Energy Harvester (Patent no. **477706), jointly with Dr. Naveet Kaur.**
2. **A Hybrid Passive Energy Dissipation Device for Multipurpose Vibration Control of Tall Buildings (**Patent no. **407996), jointly with Prof. Alok Madan**
3. **An Eco-Friendly High Capacity Bamboo Composite Structural Member Suitable for Seismic/Wind Resistant Modular Multistorey Construction and Process of Preparation (Patent application no 202211056213), jointly with Dr. Diwakar Bhagat.**
4. **Piezo-SMA Based Wearable Device For Electro-Mechano Gram (EMG) of Human Bones for Diagnostic Purposes (Patent application 202011041058), jointly with Dr. Shashank Srivastava and Prof. Alok Madan**
5. **A game changing passive energy dissipation device:** Jointly with **Prof. Alok Madan** (to be unveiled in 2026)
6. **A game changing structural prestressing and control strategy:** Jointly with **Prof. Alok Madan** (to be unveiled in 2026)
7. **Game changing new sensor:** Jointly with **Ms Shipra Prakash** (to be unveiled in 2027)
8. **SAPPHIRE:** Jointly with **Prof. Alok Madan** (to be unveiled in 2027)