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Research Article

Concrete Strength Evaluation Based on Non-Destructive Monitoring Technique using Piezoelectric Material

Yogita[†*] and R. D. Patel[†]

[†]Department of Civil Engineering, M.M.M.U.T Gorakhpur Uttar Pradesh, India

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Abstract

For the purpose of strength evaluation and damage evaluation the piezoelectric sensor based wave propagation technology is experimentally done in the laboratory using the specified equipment and experimental setups. The energy attenuation of stressed wave measured on the basis of relative index between output voltage of piezoelectric sensor and the excitation voltage at actuator (ZHU Jinsong ,et al, 2010)on the basis of experimental output of concrete cubes the effect of impedance amplitude, excitation frequency , path of propagated wave and curing time of the output signature of sensors are evaluated and Relative voltage attenuation coefficient RVAC is used as indicator for measuring the attenuation of stress waves of concrete cube as a result.

Keywords: *SHM, Pzt , RMSD, smart materials, EMI, RVAC*

1. Introduction

Reinforced concrete structure are widely used in civil engineering like as high rising building, bridges and dams etc. because of the low cost of construction and durable service under the various loading and environmental exposure conditions. Real time health monitoring of R.C.C. structure are very challenging task due to the complexity of nature of damage .

The integration of global and local damage identification strategies are consider as the effective methods for the purpose of finding out location and quantity of damage induced in the structure . The non-destructive evaluation technology are comparatively undeveloped (S. Park, *et al*, 2006).Due to the development of "smart materials " such as piezoelectric, magnetostructive , rheological the health monitoring of civil infrastructure becomes easy. Piezoelectric material are widely used for the purpose of structural health monitoring (ZHU Jinsong , S. Park ,*et al* ,2010). At the starting the piezoelectric patch based electro mechanical impedance (EMI) technology was introduced for field of structure. (Soh and Bhalla,*et al*, 2005) ,has proposed piezoelectric material based EMI technology for the investigation the strength of the concrete (C K Soh , *et al*, 2005).

This experiment proves a strong existing correction between the strength of concrete and resonance frequency of EMI. The practicability of EMI techniques was additionally investigated by (S W Shin , *et al*, 2008). Using cube specimens with different installation techniques of pzt and the conclusion was founded that (RMSD) Root Mean Square derivation index is an effective parameter for strength gain monitoring of concrete structure. Recently (R Tawie ,*et al*, 2010) To investigate the effect of the mix proportion parameter of concrete on the measured EMI resonance spectra in field monitoring of concrete by using the cost effective pzt patch and the relation between the concrete compressive strength and the indices of RMSD, correlation coefficient derivation (CCD) and mean absolute percentage deviation (MAPD) of EMI spectra were analyzed and comparative study made.

These developed techniques has the ability to continuously monitoring the integrity of civil infrastructure in real time can provide for increased safety to the public , the ability to detect damage at initial stage can reduce the costs and down time associated with repair of critical damage (Billie F. SPENCER, *et al* ,2004) .(H.Gu , *et al* , 2006) introduced a piezoelectric based strength monitoring techniques using embedded pzt into the concrete specimen at the stage of casting. (F Song, *et al* ,2008) have investigated the surface bonded wave propagation in beam element the process of surface bonded pzt element through numerically and experimentally.

However the generated stress waves excited by the actuator are very complex due to reflection, attenuation and transmitting when the propagate inside the concrete structure. The mix proportion materials, Size of structure, induced crakes, wave from, frequencies of excitation signals and amplitude

*Corresponding author **Yogita is a PG Scholar** and **R. D. Patel** is working as Associate Professor

signature all those affect the velocity of signal and attenuation output signal, Which are received by the sensors.

This paper presented a novel experimental study to monitor the attenuation of wave propagation along the two direction of concrete specimen. The experimental overcome of specimen are reported here in. RVAC is used to measure the attenuation of generated stress waves. The effects of amplified, excited frequency signal by the pzt actuator on the RVAC of sensor are evaluated.

2. Wave Propagation in Concrete Structure

2.1 PZT Patch Based Wave Propagation

Piezoelectric material that has been used in this experimental work is a smart material , smart material are defined as those material which are capable of altering their physical properties in a specific manner in "response" to a specific stress input piezoelectric generate the electric charge due the applying the mechanical stress . this effect is called the direct effect which has been used for various monitory purpose . Pzt available (5-50 mm wide) and (0.1 to 0.5 mm thick). They demonstrate the characteristics such as low cost, large frequency range , up to a 100 khz , low weight , durability and good dynamic performance (Suresh Bhalla , *et al* ,2004) .

Recently pzt materials have also employed as mechatronic transducers and as a actuator/ sensor for NDE of structure.

For small field consideration, the general equation pzt can be demonstrated –

$$D_i = E_{ik}^T E_k + d_{ip}{}^d{}_{tq} \qquad 1(a)$$

$$S_p = d_{kp}{}^c E_k + S_{pq}{}^E{}_{tq} \qquad 1(b)$$

D_t is electric displacement rector, S_p is strain vector , E_k is the applied electric field vector and T_q is the stress vector, piezoelectric constant are the dielectric permittivity $E_{jk}{}^T$, the piezoelectric strain coefficient $d_{ip}{}^c$ and $d_{kp}{}^c$ and elastic compliance ,$S_{pq}{}^E$. the superscripts 'd' and 'c' indicates the direct and converse piezoelectric effect respectively while 'T' and 'e' indicates the quanty.

In this presented application for NDE the pzt is bonded at the surface of host structure through epoxy adhesive. the pzt is emitted by high frequency range (10 khz to 50 khz) due to converse effect , the attached pzt act as actuator , transmits its vibration to the monitored structure.

Generated stress waves travels away from the pzt patch and the resultant vibration signature are recorded by other pzt patch and via direct piezoelectric effect voltage signals are developed across the terminals and other pzt patches acts as sensor.

2.2 Wave propagation in concrete structure

The stress waves that has been generated by piezoelectric actuators gives the information of the host structure and thus this signature can be used to evaluate the pressure and characteristics of damage. The propagation of stress waves in concrete structure can be viewed as one dimensional longitudinal wave propagation (G B Song ,*et al*,2008] .the equation of wave can be written as :-

$$(\partial^2 u / \partial x^2) = (1/ C_b^2) (\partial^2 u / \partial t^2) \qquad (2)$$

In this $C_b^2=E/P$, u is displacement of an element , E is young's modulus and ρ is density of concrete.

The average power ρ of the harmonic response over a period can be expressed as –

$$\rho = EA^2 w^2/2\, C_b = \sqrt{E\rho}\; A^2 w^2/ 2 \qquad (3)$$

Where A is the harmonic amplitude and w is the angular or circular frequency.
Equation 3 can be rewritten as –

$$A= 1/w\, (4\rho^2/ E\rho)^{1/4} \qquad (4)$$

As per equation 4 , the modulus of elasticity of the medium effect the harmonic amplitude during the early age development of concrete the Young's modulus also increase as the concrete gains strength during the hydration process. The harmonic amplitude will decrease with increasing the Young's modulus E as per given equation (4). Young's modulus is the major factor that effect the concrete strength evaluation thus we can say that harmonic amplitude is correlated with the Young's modulus and concrete strength by evaluating the amplitude change of harmonic stress wave, the strength development of specimen can be evaluated and monitored .

3. Experimental Work

To investigate the efficiency and applicability of the wave propagation technique for monitoring of concrete strength and damage, an experiment conducted on specimens are presented in this section. First the specimen preparation, experimental setup and test procedure are introduced and at last section result discussed.

3.1 Test Specimens

Table1 Details of the composition of the prepared specimen tasted and curies for the experiments

Component	Composition (kg/m)	Description
Water	191.6	Tap water
Cement	416	Opc-43 grade
Sand	659	Well graded
Coarse	1146	Size 20 mm

3 cubes are tested for compressive strength, 3 for wave propagation acquisition and young's modulus the design compressive strength of concrete mix is M25 and (content) of specimen was listed in table 1 . After the casting specimens were stored in moisture and temperature controlled curing room until the testing.

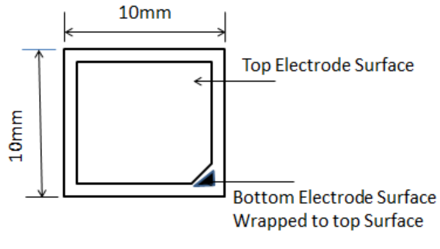
Four pzt patch with (10 * 10 * 0.2) mm were attached at each specimen after 1 day casting time and first test is conducted at age of 3 days to assure the full development of pzt bonding adhesive at the ages of 3, 7, 14 and 28 days compressive strength of cubes were tested these days are important in evaluating the compressive strength with respect to given codes the 3 specimens were tested for evaluating compressive strength and 3 other for Young's modulus.

3.2 Experimental Arrangement

3.2.1 Pzt Installation

The pzt patch that has selected for installation are 10mm in width 10mm in length and 0.2mm in thickness. Fig 1 (a) shows geometry of available commercial size of pzt patch

These pzt is surface bonded to all four side of cube specimen. in the table 2. The key characteristics of pzt patch is given below.



(a)

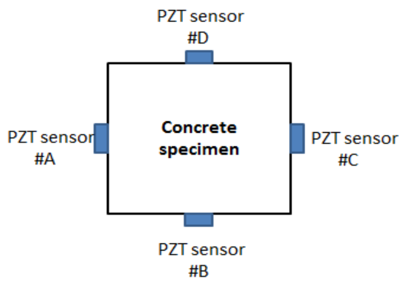


Fig.1 (a) A typical commercially available PZT patch (b) configuration of the PZT patches attached to the concrete specimens

Physical Parameters	Values
Density /kg*m^{-2}	7700
Young's modulus /N*m^{-2}	6.667*10^{-10}
Poission ratio υ	0.3
Dielectric matrix [ε]/ (c*v^{-1}*m^{-1})	$\begin{bmatrix} 6.45 & 0 & 0 \\ 0 & 6.45 & 0 \\ 0 & 0 & 5.62 \end{bmatrix}*10^{-9}$
Piezoelectric matrix [e]/(c*m^{-2})	$\begin{bmatrix} 0 & -6.5 & 0 \\ 0 & 23.3 & 0 \\ 0 & -6.5 & 0 \\ 0 & 0 & 0 \\ 17 & 0 & 0 \\ 0 & 0 & 17 \end{bmatrix}$
Stiffness matrix [c]/P_a	$\begin{bmatrix} 13.9 & 6.78 & 7.43 & 0 & 0 & 0 \\ & 13.9 & 7.43 & 0 & 0 & 0 \\ & & 11.45 & 0 & 0 & 0 \\ & & & 3.56 & 0 & 0 \\ & & & & 2.5 & 0 \\ \text{symmetry} & & & & & 2.56 \end{bmatrix}$

Fig 2: Key parameters for the PZT patch

3.2.2 Monitoring System

In this section the experiment system setup was made for the generation and recording of the signature and stress wave using piezoelectric sensor/ actuator the system introduce a digital oscilloscope, wave form generator and a personal computer.

The wave signals disappear very rapidly in concrete structure so the signal input on the actuator should be enough to produce output signal. Requirement of a power amplifier was also done to amplify the signals from the function generator this factor was set to 15 for the test procedure.

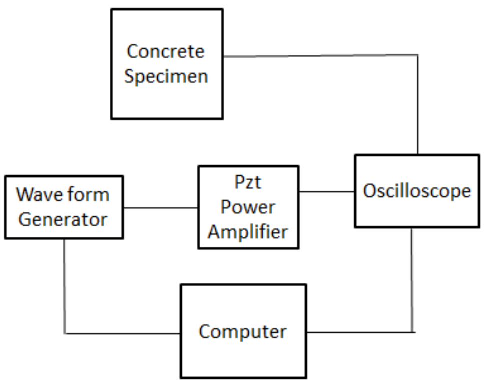


Fig.2 Typical Monitoring System

3.3. Test Procedure

In this presented investigation, the wave with amplitude of 2, 3, 4 and 5 v were generated by wave form generator and amplified by amplifier before exciting the pzt actuator . The resulting voltage amplitude excited on pzt patch was (15 to 75)volt. The excitation signal with frequency (1 to 50 kHz) was used for excitation source for bonded piezoelectric actuator for making comparison. The sinusoidal signals were restricted with frequency range (1 to 50 kHz) more than 50 kHz not applicable for concrete monitoring purpose.

At the curing age of 3, 7, 14 and 28 days the young's modulus and compressive strength were tested of cube specimen .At these (test) age intervals the wave propagation test was conducted pzt patch a was used a actuator and reaming B,C and D were act as sensor the signals were collected by digital oscilloscope from patch B,C,D by .software ultra-scope.

3.4 Experimental Results

The casted concrete cube specimen with surface bonded pzt sensor was tested using wave propagation technique. The results shows that the harmonic amplitude dropped with strength development of concrete cube specimen at early age which is the aim of this experimental research work to get pzt sensor output voltage RVAC can be defined

$RVAC = A_S/A_a$

A_s is output voltage amplitude of sensor A_a is amplitude of actuation voltage .according to conducted analysis (ZHU Jinsong , *et al* ,2010).

RVAC is a function of dimensions of the pzt patch and host structure. in this study three factor varied during wave propagation . Those are presented as following:-

3.4.1. Sensor output voltage

To verifying the wave based concrete specimen strength gain monitoring the compressive strength of specimen cubes were casted by universal compressive testing machine. To get the compressive strength and young's modulus values at 28 days age of curing the curves are respected in the fig (3).

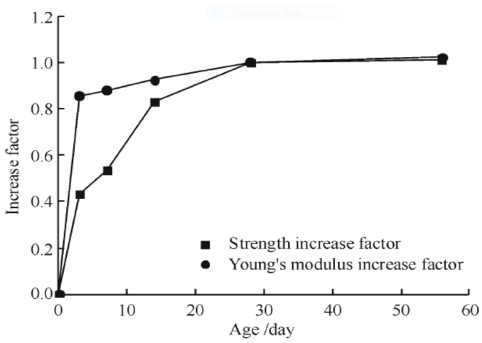
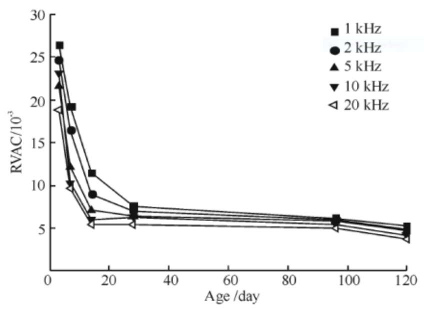
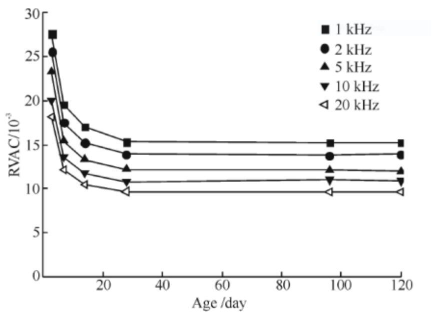


Fig.3 Increase of compressive and Young's modulus verses curing age

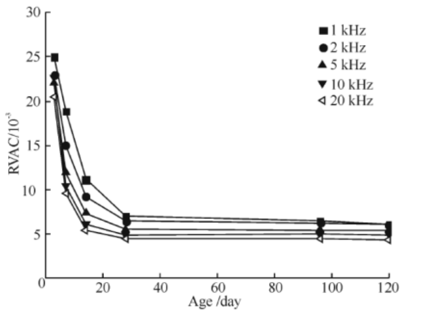
Fig 4: Shows measured RVAC at 5 different curing age for the different wave propagation path (A-B) and (A-C) and (A-D) direction respectively.



(a) A-B



(b) A-C



(c) A-D

Fig.4 Time –dependent RVAC of different propagate paths

3.4.2. Effect of Excitation Amplitude

RVAC of received sensor signal observed at actuator match of A-C with different frequency excitation. The amplitude of excitation voltage only effected the intensity of sensor signal development upon the displacement of actuator and thickness of pzt patch.

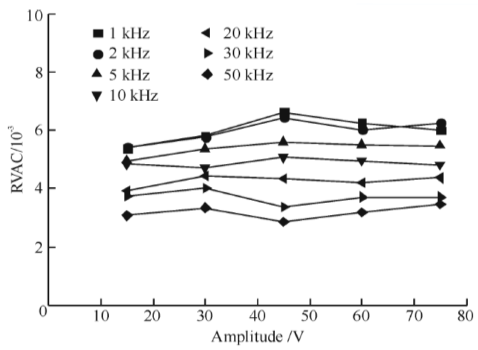
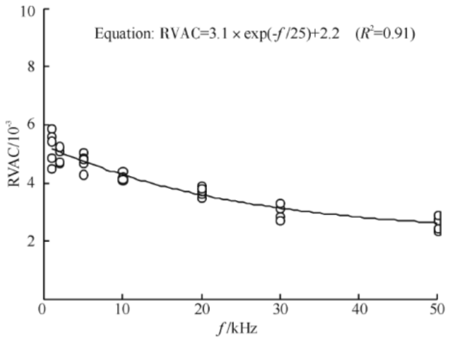


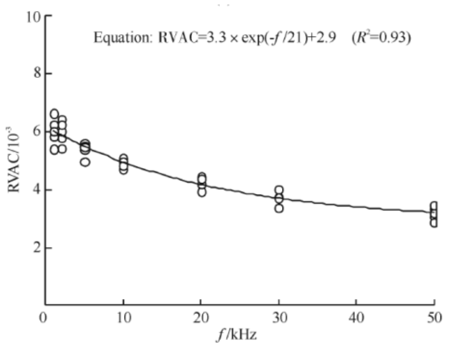
Fig.5 RVAC at different Amplitude of Excitation Voltage

3.4.3. Effect of Excitation Frequency

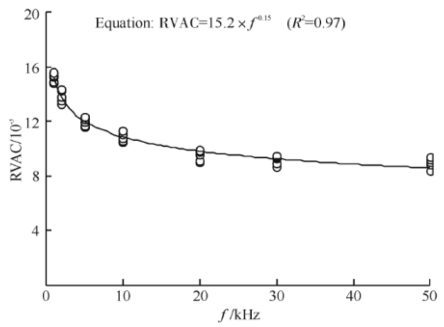
To observe the frequency of the input signals on the RVAC the frequency of input signal varies over range 1-50 khz. The (fig 5) the RVAC of measured output voltages of sensor at different –different impedance frequency. It can be concluded that RVAC decreases with increases in excitation frequency.



(a) A-B



(b) A-D



(C) A-C

Fig.5 RVAC of measured output voltages of sensor at different impedance frequency

Conclusion

This paper presents a novel method for monitoring of interior damage and mechanical properties of concrete which is based pzt wave propagation technology.

After the specimen tests the conclusion can be reached that RVAC of the output sensor is work as an indicator for measuring the attenuation of stress waves travelling through interior of concrete according to test the RVAC decreases to a relative steady level after the curing age of 28 days for all propagation paths.

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