

Defect Detection of Concrete Filled Steel Tubes with PZT based Technique

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ABSTRACT: In this paper, Piezo Electric Transducers (PZT) sensor is employed to detect the artificially mimicked debonding and compaction defect in a Concrete Filled Steel Tube (CFST) column specimen. Total four CFST columns were casted. Debonding was imparted with help of Styrofoam plates at predefined locations. All four columns are with different properties in terms of bonding and compaction. PZT sensors were excited with help of LCR meter and the output was detected with LCR only. Based on RMSD index Defect is identified.

KEYWORDS: Electromechanical Impedance (EMI); Structural Health Monitoring (SHM); Concrete Filled Steel Tube (CFST); Debonding & Compaction defects

I. INTRODUCTION

A Concrete Filled Steel Tubes (CFST) is a member in which concrete is poured inside Steel tube. CFST has enhanced ductility up to ultimate load. In CFST both Steel and Concrete resist external loading by interacting together by bond and friction. Major defect in CFST are debonding and poor compaction. Externally this defects cannot be detected and if this defects are present then that significantly reduce load bearing capacity of CFST member.

Xu et al. [1] carried worked on interface debonding detection in CFST. Two evaluation indices, an energy index and a damage index were defined based on the wavelet packet analysis. Based on this indices the debonding was detected. Ren et al. [2] elaborated on the design principles of health monitoring system, and introduced the layout proposal of all kinds of sensors on the bridge and the matching collection system and software system. Xu and Teng [3] monitored a column of large cross section from real life structure. The height of building was over 400 meter. Based on wavelet packet analysis result showed that no obvious damage and defect was detected and the interface of large cross section CFST are in good condition. Ning Hu et al. [4] worked on an identification technique for detecting delaminations in composite laminates. The distributed piezoelectric actuators/sensors were used and the conception of transfer function was employed. The study was carried out on cantilever beam. Xu and Teng [5] Laboratory tests were performed on CFST column where debonding was introduced by putting four styrofoam plates on four faces of square rectangular column. Embedded PZT patches were attached to rod passing through central axis of column. 48 PZT patches were attached on outer surface of CFST. Embedded PZT were used as actuators and those on outer surface were used as receivers. based on proposed damage index debonding was detected. Yan et al. [6] worked on detecting compactness of concrete in Concrete Filled Steel Tubes (CFST) columns. PZT based Smart Aggregate (SMAG) were embedded prior to the casting of concrete columns. 6 CFST columns with rectangular cross-section were deployed. To mimic incompactness such as cavities, cracks and debond ,

artificial defects during casting of concrete were induced. Two damage indices of Time Reversibility and Symmetry were applied based on time reversal theory. The results showed that the detected areas were satisfactorily in agreement with the predesigned damage conditions. Li [9] proposed an active interfacial debonding defect detection approach based on the wavelet package spectrum analysis on the PZT measurements. Wavelet packet energy spectrum (WPES) was proposed and based on it the debonding was detected. WPES of signals output from the PZT patches on debonding region showed variation which confirms debonding.

PZT sensors are used to detect this defect in CFST. PZT sensors are actuated with help of LCR meter. LCR meter simultaneously actuates and receive the vibrations through PZT. With reference to the signatures/output obtained, results are presented. Generally a healthy structure is considered as reference. In this case a fully compacted and perfectly bonded CFST is kept as reference.

II. SYSTEM DEVELOPMENT

The Tests were conducted on four CFST columns with the help of LCR meter. LCR meter is shown in Fig 1 (c) below. Steel tubes of same sizes were used and the grade of concrete was maintained same for all the CFST specimen. All four specimen though seems externally similar but they differ internally. To mimic artificial debonding Styrofoam patches which are shown in Fig 1 (b) were attached on inner side of 2 CFST specimen. All Steel tubes shown in Fig 1 (a) confirm to IS:4923.



Fig 1 : (a) Steel Tubes Specimen



(b) Styrofoam Plates



(c) LCR meter

CFST with varied compactness were named as A, B, C & D and positions of PZT were given as 1, 2, 3 & 4. Position of Styrofoam plates that is debonding is shown externally with square boxes in Fig 2 & 3 and PZT patches were placed exactly on outer side of CFST at centre of patch.



Fig 2 : Experimental setup of CFST

A - Fully compacted and bonded CFST, B - Fully compacted but debonded partially, C - Not compacted but bonded internally and D - Not compacted and debonded partially.

CFST column dimensions are 100x100x1000 mm. Thickness of steel tube is 3mm. Grade of Concrete adopted is M25. High frequency PZT were used of size 10x10x1 mm. PZT were pasted at 230mm from both top and bottom of all CFST for position 1 & 4. Additional PZT were attached externally where debonding was mimicked from inside. the location was numbered as 2 & 3. Fig shows CFST specimens with naming given on its surface.

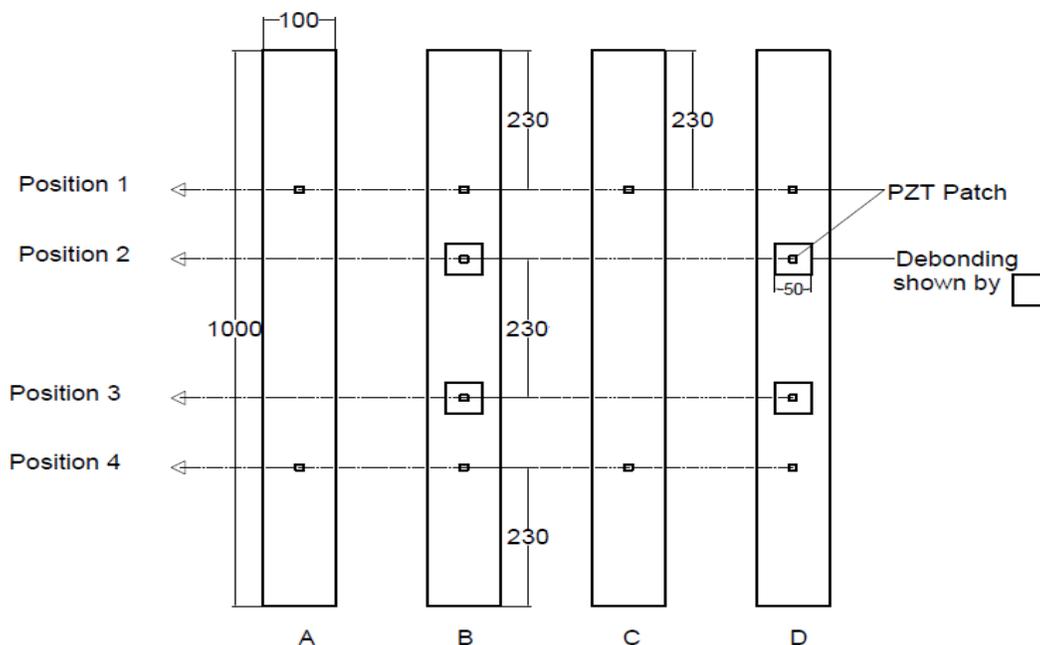


Fig 3 : Installation locations of PZT sensors and Styrofoam patches on CFST columns

The PZT patches attached to CFST were actuated with help of LCR meter. PZT sensors were actuated in frequency range 250Hz to 400 Hz. PZT itself behave as an actuator as well as receiver. The readings in terms of Conductance (G) and Susceptance (B) were obtained.

When compared to host structure it is that the PZT patch assumed is infinitesimally small and possess negligible mass. When an alternating electric field is applied to PZT patch it expands and contracts dynamically in the direction '1' as shown in Figure 4 (b). Hence two end points of the patch can be assumed to encounter equal mechanical impedance Z from the host structure.

The governing equilibrium equation for the system shown in Figure 4 (b) solved using impedance approach [7]. Using Liang's derivation following equation can be written for the complex electro mechanical admittance Y (inverse of electrical impedance), of the coupled system shown in Figure 4

$$Y = 2Gj \frac{wl}{h} \left[\epsilon_{33}^T + \frac{z_a}{z+z_a} d_{31}^2 \bar{Y}^E \frac{\tan kl}{kl} d_{31}^2 \bar{Y}^E \right] \dots \dots \dots (1)$$

Where,

- d_{31} = piezoelectric strain coefficient of the PZT material,
- Y^E = complex Young's modulus under constant electric field,
- (ϵ_{33}^T) = complex electric permittivity at constant stress,
- Z = mechanical impedance of the structural system,
- Z_a = mechanical impedance of the PZT patch,
- ω = angular frequency and
- kl = the wave number.

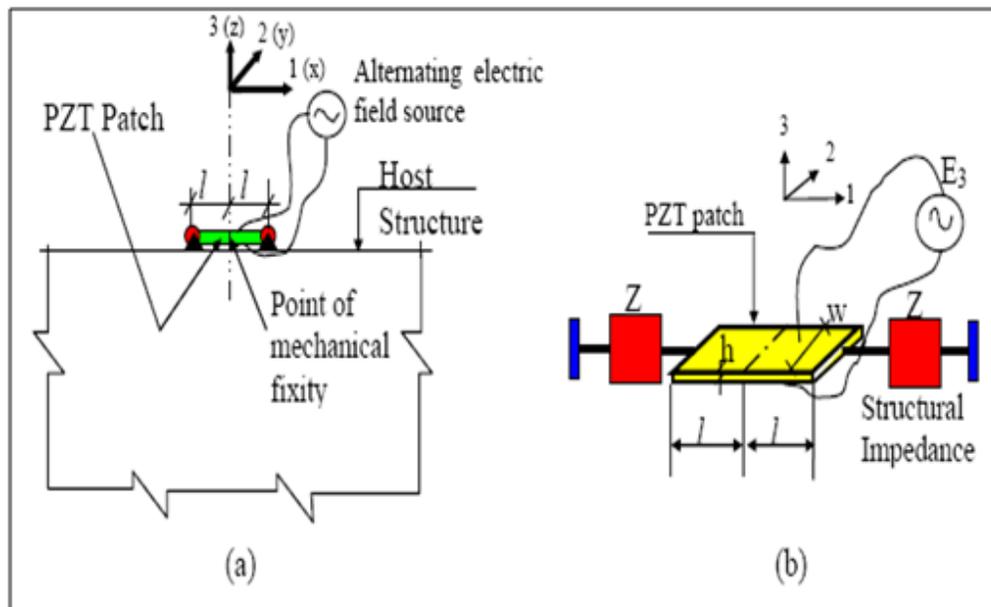


Fig 4 : (a) A PZT Bonded to the Structure (b) Interaction Model of One Half of PZT and Host Structure

Equation (1) is used in the damage detection in the EMI technique. The mechanical impedance Z in the equation is a function of structural parameters i.e. the stiffness, the damping and mass. Any damage to the structure will cause these parameters to change, and hence changes the mechanical impedance Z. Consequently, electro-mechanical

admittance \bar{y} , will undergo change, and serves as an indicator of state of health of the structure. Z cannot be measured easily but \bar{y} can be measured easily by using an electrical impedance analyzer.

RMSD is used as damage index to identify the defect. The readings obtained from LCR meter are used to calculate the index. Experimentally, when Conductance (G) and Susceptance (B) are calculated by impedance analyzer directly, then complex admittance can be expressed as $Y = G + Bj$. Since Susceptance is imaginary part of Admittance it is ignored and Conductance is used for calculations.

The RMSD index is calculated as below.

$$M = \sqrt{\left(\frac{\sum(G_2 - G_1)^2}{\sum G_1^2}\right)} * 100 \quad \dots\dots\dots(2)$$

Where,

M = Damage metric (Root Mean Square Deviation)

G₁ = Healthy Signature

G₂ = Signature of Specimen with defect.

III RESULTS AND DISCUSSION

The graph is plotted between conductance and frequency from data collected by response from PZT to LCR For position 1 of all the four columns the response is plotted and shown in fig 4 below. Where A1 denotes 1st position of PZT on column A similarly B1, C1 & D1 are plotted. This graph is plotted between Frequency and Conductance, frequency being the independent parameter.

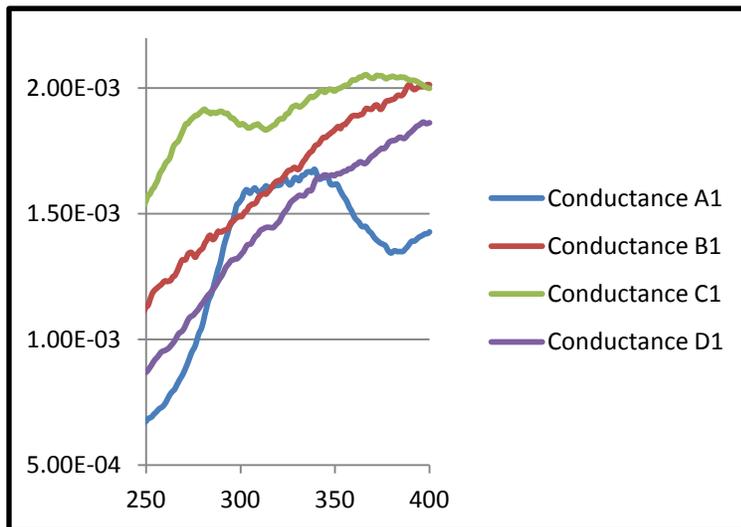


Fig 5 : Conductance variance at position 1 of all the CFST

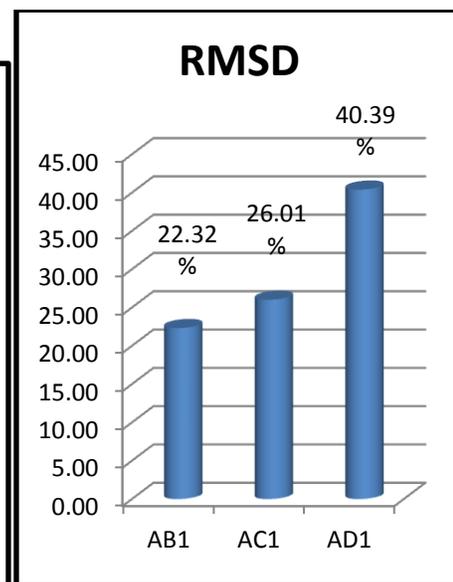


Fig 6 : RMSD index variation

Based on the RMSD index equation (1) different RMSD values are calculated and plotted as shown in fig 5. Here AB1 implies RMSD index between A & B at position 1 and similarly AC1 & AD1 implies RMSD index between A & C and A & D respectively at position 1. More the RMSD index better the sensitivity and greater the difference between two specimens. For e.g. for position 1 same column is considered twice (healthy & damaged)

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization

Volume 6, Special Issue 1, January 2017

International Conference on Recent Trends in Engineering and Science (ICRTES 2017)

20th-21st January 2017

Organized by

Research Development Cell, Government College of Engineering, Jalagon (M. S), India

then the RMSD index will be zero. The value will differ for two different specimen. Here AD1 has highest difference and this is in accordance with defect. Same is valid for other RMSD.

IV. CONCLUSIONS

The test were thus performed on four CFST specimen using PZT patches as actuator and itself as receiver. Defect was detected by change in output signatures obtained from LCR meter. Same position of all the four columns is compared for better analysis and detection. Defect was quantified with help of RMSD index.

- Defects and its extent in CFST are effectively detected with PZT sensors
- Higher RMSD index shows that D column is most damaged as compared to other 3 columns
- The horizontal and vertical shifting of peaks are quantified in RMSD index

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