IDENTIFICATION OF SHEAR DEFICIENCY AND SHEAR STRENGTH GAIN USING EMI TECHNIQUE

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ABSTRACT: Electro Mechanical Impedance (EMI) is a technique in which PZT sensors are used to monitor the health of the structure. These Sensors can be surface mounted or Embedded. In this paper Piezo Electric Transducers (PZT) sensors in form of Smart AGgregate (SMAG) are usedto monitor the shear deficiency and shear strength gain for Reinforced Concrete beam. The beams were rendered artificially deficient in shear by providing no shear reinforcement. Total four beams were cast. Beam 1 (C) is healthy/Control beam, beam 2 (0S 1) is maintained shear deficient, beam 3 (0S 2) is shear deficient and subsequently strengthened with steel bars and Beam 4 (0S 3) is also shear deficient but strengthened with CFRP bars using Embedded Through Section (ETS) technique. This study is aimed at identification and quantification of the shear strength gain and deficiency of Reinforced Concrete beam.

KEYWORDS: Reinforced Concrete Beam; Shear Strengthening; ETS(Embedded Through Section) Technique; Electro Mechanical Impedance (EMI); PZT sensors; Structural Health Monitoring (SHM).

1.INTRODUCTION

1.1 General

Shear failure of beam occurs when their shear capacity fall below their flexural capacity. Failure of beam in shear should be as such avoided due to brittle nature of beam. The behavior at failure of Reinforced concrete beam in shear is as such different from behavior at failure in flexure. They fail without any warning and daigonal cracks that develop are larger than flexural cracks. Hence to avoid these kind of failures shear strengthening and idendification of shear strength becomes important. There are many techniques used for Shear strengthening of Reinforced Concrete beam. The Embedded Through Section (ETS) Technique is a new and promising technique of Shear strengthening of Reinforced Concrete beam. In this technique holes are drilled in the section and bars of Steel or FRP materials are placed into these holes and bonded with adhesive.Carbon or Glass fibre reinforced polymer material are used for strengthening due to there high durability (not corrodible),ease of handling etc. The Electro-Mechanical Impedance (EMI) technique is as such a new technique for Structural Health Monitoring. In this technique Lead Zirconate Titanate (PZT) sensors are used. A PZT patch can be used as surface bonded or embedded. These PZT sensors are as such brittle in nature and should be protected from environmental conditions. Thus they are used in form of Smart AGreggate (SMAG) inside the structures to be monitored.

Khante and Gedam [1] experimentally investigated that embedded PZT in form of SMAG is more effective than surface mounted and damages are effectively detected. Khante and Chikte [2] studied the damage detection of CFST column and found that defect and its extent is effectively identified by PZT sensors. Negi et al. [3] studied three different configurations of PZT patches responses after embedding in Reinforced concrete beam. Feng et al. [4] detected the after-earthquake damage in concrete dams by using embedded sensors. Khante and Jain [5] studied the effectiveness of reusable PZT on Precast beams. Song et al. [6] studied the multifunctionality of SMAG for monitoring early-age concrete strength, impact detection and structural health monitoring. Khante and Gedam [7] studied the effectiveness of SMAG with varying orientation. Shanker [8] conducted experiment on concrete and steel beam and found out the possibility of embedded PZT as sensor. Annamdas et al. [9] monitored fresh concrete using EMI technique and suggested double protection wrap method with both metal and non-metal of embedding PZT sensors. M.Breveglieri et al. [10] studied the evaluation of ETS efficiency on Reinforced concrete beams.The effectiveness of different ETS configuration was also investigated. The present study focuses on monitoring the shear strength gain and deficiency of Reinforced Concrete beam using EMI technique.

1.2 Quantification of Damage:

Quantification of damage is done by RMSD index. The conductance response of SMAG which is placed in shear deficient beam is obtained. After shear strength gain conductance signature is recorded. Damage index is given by

$$M \qquad \sqrt{\Sigma}\ \frac{\qquad}{\Sigma}$$

Where

M = RMSD%.

G_1= Base line conductance signature.

G_2 = Conductance signature obtained after damage

1.3.Fabrication of SMAG

The experiment was done on reinforced concrete shear deficient beam. The PZT sensor was fabricated and placed at centre of beam. To fabricate the embedded sensor SMart AGgregate (SMAG), firstly top surface of naked PZT patch (10 mm × 10 mm × 0.2 mm) is soldered to coaxial cable wires. The plastic formwork of 30 mm diameter was first filled with cement mortar to the half depth. Then PZT patch was bonded on the top surface of that cement block using epoxy after curing it for 7 days. The form work was finally filled to full depth with the cement mortar. Then the formwork was removed. The SMAG was cured for 7 days and was ready to use in the experimental beam. The schematic diagram of typical SMAG is shown in fig

1

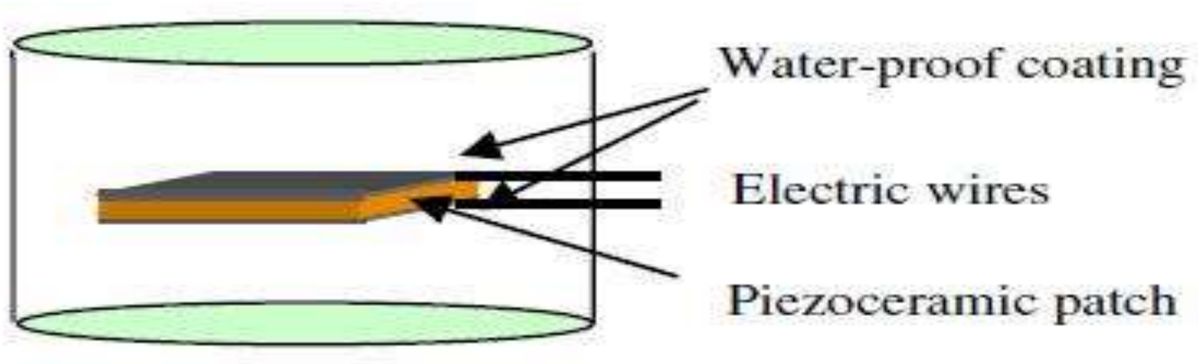

Fig 1. Typical Smart AGGregate (SMAG)

2.EXPERIMENTAL SETUP AND INVESTIGATION

2.1 Material and Specimen

In order to perform the experiment using EMI technique, three models of shear deficient Reinforced Concrete beams and one control beam were cast. The dimensions and properties of control beam are shown in table 1 and the details of other three shear deficient beams are shown in table 2. The materials used for shear strengthening of RC beam are steel bars and Carbon Fibre Reinforced Polymer (CFRP) bars as shown in fig 2.1. and SMart AGgregate was cast which was placed at centre of beam. The experiment is done to identify the shear strength gain and shear deficiency of RC beam. The instrument used is digital Impedance Analyzer (LCR meter E4980A) with frequency range 20 Hz to 2 MHz, a USB cable and VEE Pro 9.32 for data acquisition are its connecting fixtures.

Table 1. Material properties and dimensions of Control beam

Dimension /Properties	**Value**
Length (L)	1000 mm
Cross-Section	100mm x 125mm
Grade of cement(OPC)	53
Grade of Steel	Fe 500
Reinforcement Bars	2#10mm dia @ top and Bottom
Stirrups	6mm dia @ 90mm C/C

Table 2.Designation and Details of Shear Deficient beams

Designation	Details
0S 1	Shear deficient
0S 2	Shear deficient strengthen with Steel Bars
0S 3	Shear deficient strengthen with CFRP bars

a.) b.)

Fig 2.1: a.) Steel bars of 100mm length b.) CFRP bars of 100mm length

3 SETUP AND PROCEDURE

The experimental setup consisted of a RC beam which is shear deficient in form of no shear reinforcement in designated portion of beam. The span which is to be monitored (L1= 0.312 m) was 2.5 times the effective depth of the beam's cross section (L1/d = 2.5). In order to avoid shear failure in the L2 beam span, steel stirrups 6@90 mm were placed as shown in fig 3.2. The SMAG was placed in centre of beam and wired to LCR meter as shown in fig 3.1. The frequency of sensors was swept from 100kHz to 400kH. For strengthening the beam firstly holes of 12 mm diameter where drilled in the beam core in the span which is shear deficient. In order to avoid the adhesive to flow through the bottom part of the beam, an 25mm of intact cover was kept at the lower side of the beam. Then the holes were cleaned with the help of the blower untill the dust was completely removed and epoxy resin was poured into the holes. The bars were cut in the required length and were placed in the holes removing the resin which is in excess. These beams were then monitored after setting of Bars.

Fig 3.1: Set-up of RC beam connected to LCR meter

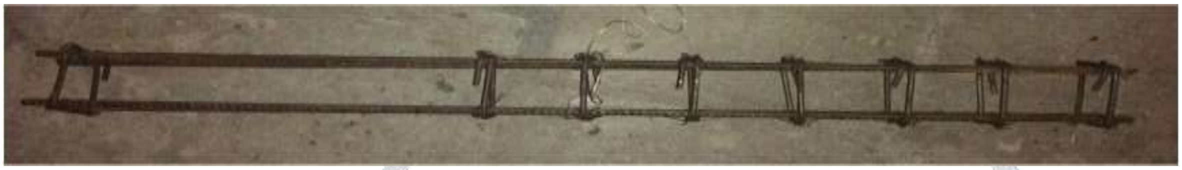

Fig 3.2:Reinforcement of Shear deficient beam

4 RESULTS AND DISCUSSIONS:

The SMAG which is placed in the structure is excited. The graphs between conductance and frequency are plotted from data collected by response from PZT as shown in fig 4.1, fig 4.2, fig 4.3

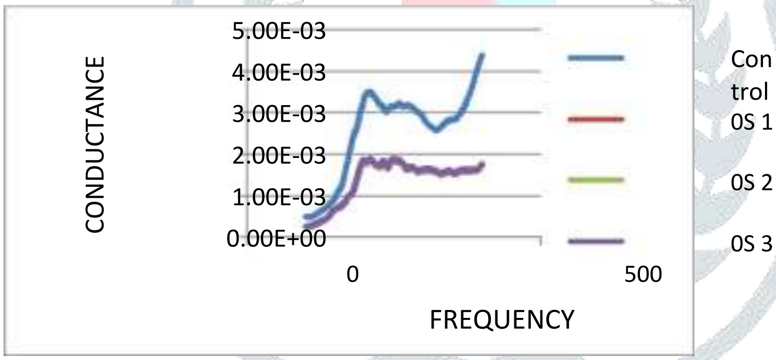

Fig 4.1: Conductance signature of Control Beam and Shear Deficient Beams Before Strengthening

From fig 4.1 comparing the signatures, lower peak of beam 2 (0S 1) shows that beam 2 (0S 1) is more shear deficient than beam 3 (0S 2) and beam 4 (0S 3). The difference between the signature of control beam 1 (C) and all other three beams indicate shear deficiency of beam 2 (0S 1), beam 3 (0S 2) and beam 4 (0S 3).

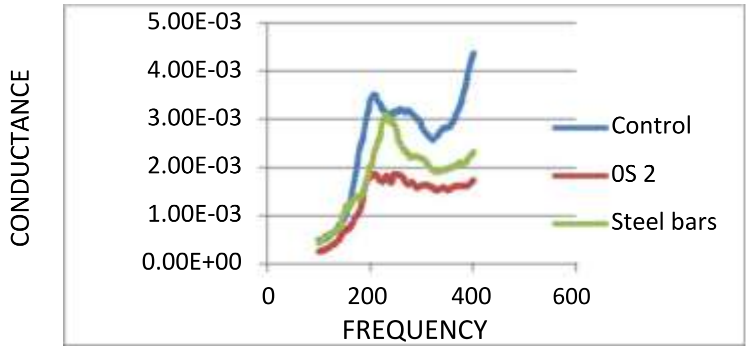

Fig 4.2:Conductance signature of Control Beam and Shear Deficient Beams after Strengthening with Steel Bars

From 4.2, higher peak of beam 3 (0S 2) signature after shear strengthening with steel bars than before shear strengthening signature shows the shear strength gain of beam 3 (0S 2) with steel bars.

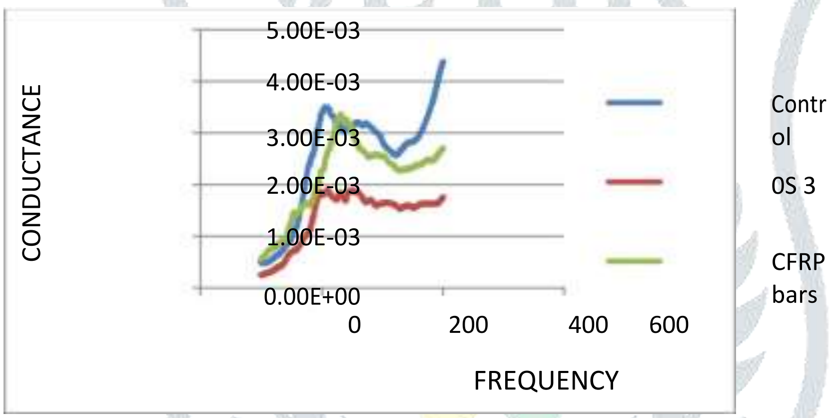

Fig 4.3: Conductance signature of Control Beam and Shear Deficient Beams after Strengthening with CFRP Bars

From 4.3, higher peak of beam 4 (0S 3) signature after shear strengthening with CFRP bars than before shear strengthening signature shows the shear strength gain of beam 4 (0S 3) with CFRP bars.

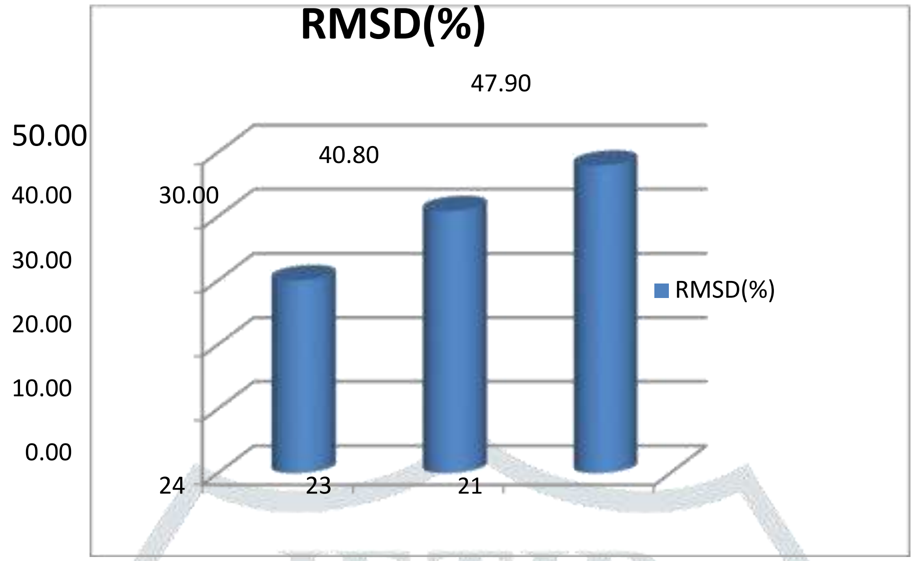

Fig 4.4 RMSD variation for Shear Strength Gain.

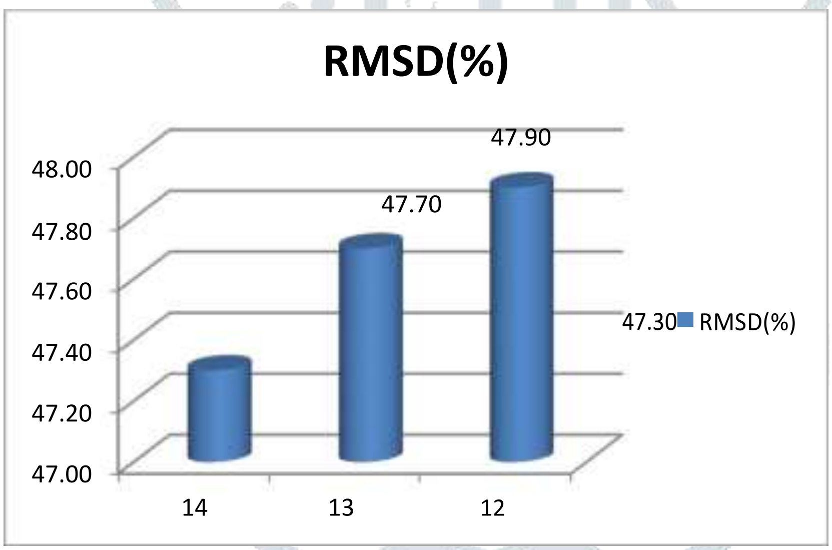

Fig 4.5 RMSD variation for Shear Deficiency

Based on conductance signature the RMSD index values are calculated and plotted as shown in fig 4.4 and fig 4.5. In fig 4.4, 21 implies RMSD index between 2 (0S 1) and 1 (C) beam and similarly 23 and 24 implies RMSD index between 2 (0S 1) and 3 (0S 2) and 2 and 4 respectively. More the RMSD index better the sensitivity and greater the difference between shear strength gain of two specimen. Here 21 has higher difference and this is according to maximum shear strength of beam 1(C) and similarly fig 4.5 shows that beam 2 (0S 1) is more shear deficient than beam 3 (0S 2) and beam 4 (0S 4) when compared with beam 1 (C).

5 CONCLUSION :

The test were thus performed on four beam specimen using PZT sensors which acts as actuator and itself as receiver. The Sensor was used in the form of SMart AGgregate. Deficiency and shear strength gain was detected by change in output signature from LCR meter and then quantified by RMSD index. By comparing the results obtained for both healthy and shear deficient specimen,

- Changes in the response are the indications of shear deficiency and shear strength gain.
- There is clear shift in vertical and lateral direction in the recorded conductance responses and from this effectiveness of embedded PZT can be specified.
- Higher RMSD index shows that Beam 2 (0S 1) is more shear deficient and Beam 1 (C) has maximum shear strength. The shear deficiency of beam 2 (0S 1) and shear strength gain of beam 3 (0S 2) and beam 4 (0S 3) is evident from respective RMSD index.

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