DAMAGE DETECTION OF REINFORCEMENT CONCRETE BEAM USING EMBEDDED PIEZOCERAMICS TRANSDUCERS

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Abstract - *Piezoelectric lead zirconate titanate (PZT) transducers are increasingly used for monitoring various engineering structures. The experimental effort for the damage assessment of concrete reinforcing beam using Embedded and surface bonded piezoelectric transducers based on the electromechanical admittance method. Test measurements of healthy and damaged reinforced concrete beams of span 1.3m have been conducted using the developed structural health monitoring system. The experimental program comprises data acquisition of current intensity curves for healthy and damaged RC beam as detected by the test instrumentation and implementation of the adopted admittance-based procedure to evaluate damages at different levels. Admittance signatures showed a clear gradation of the examined damage levels. The experimental results provide cogent evidence that piezoelectric lead zirconate titanate transducers are sensitive to damage detection in reinforced concrete (RC)beam from an early stage of the performed tests. Thus, the use of these sensors for monitoring and detecting concrete cracking by employing the electromechanical admittance approach can be considered as a highly promising structural health monitoring method.*

Key Words: Damage Assessment, Admittance Signatures, Health Monitoring, Damage Levels, Sensors

1.INTRODUCTION

Recent development of various experimental approaches that prevent catastrophic failures and reduce cost of inspection in Reinforced Concrete infrastructures has been emerged from the necessity of real-time damage detection and Structural Health Monitoring (SHM) techniques. SHM aims to develop efficient methods for the continuous inspection and detection of various defects in Civil Engineering structural members. Even more, SHM is becoming extremely important in RC structures that are governed by shear mechanisms which lead to fragile and abrupt failure modes. Even minor incipient shear damage to deficient shear-critical RC elements, such as beam–column joints, short columns and deep beams, could be the cause of catastrophic collapse. Inaccessibility of portions of structures, presence of unseen hair cracks, as well as material deterioration of some parts of the structure can lead to whole structure failure or some of its elements. Early prediction of this damage could help in increasing their life time and prevent unexpected modes of failure. Therefore, health monitoring of vital structures by means of reliable nondestructive damage detection tools is crucial to maintain safety and integrity of these structures.

In flexural beam members crack could develop under working load. Cracks occur in tensile zone because concrete is weak tension fibres exceeds. The concrete modulus of rupture the first of cracks occurs. A crack formed in concrete when narrow opening of concrete beam as results us internal tensile stress This internal stress should be induced by external force such as direct axial tension, shrinkage shear or flexure.

1.1 Structural Health Monitoring Technique

The process of implementing a damage detection and characterization strategy for Engineering structures is referred to as Structural health monitoring(SHM).Here, the damage is defined as change to the material and/or geometric properties of a structural system, including changes to the boundary conditions and system connectivity, which adversely affect the system's performance. The SHM process involves the observation of a system over time periodically sampled dynamic response measurements from an array of sensors, the extraction of damage sensitive features from these measurements, and the statistical analysis of these features to the current state of system health. For long term SHM, the output of this process is periodically updated information regarding the ability of the structure to perform its intended function in light of the inevitable aging and degradation resulting from operational environments. After extreme events, such as earthquake or blast loading, SHM is used for rapid condition screening and aims to provide, in near real time, reliable information regarding the integrity of the structure. The damage identification is the basic objectives of SHM. There are mainly four levels in damage identification

Level 1: Determination that damages is present in the structures.

Level 2: Level 1 plus determination of the geometric location of the damage.

Level 3: Level 2 plus quantification of the severity of the damage.

Level 4: Level 3 plus prediction of the remaining service life of the structures.

1.2 Vibration Based Damage Identification Techniques

Marjan dji drov et al(2014) worked on "vibration analysis of RC beam for damage detection " in this paper by using finite element analysis software vibration analysis and frequency response analysis RCC beam with bonded piezoelectric transducer were presented by location and depth of single transverse crack, vibration response of cantilever beam was analysed and numerical results of undamaged beam models was compared with damage presented in structure .Effect of different variables on beam model changes first three natural frequency and amplitude were also presented results obtained by ANSYS software of vibration like crack location crack depth and vibration modes. Kaustubha v.bhinge et al (2014) worked on "crack detection in beam by vibration technique. Thus study was related to measurement of natural frequency a global parameter that can be easily measured at any point conveniently on the structure to give the relationship between the stiffness and location of crack it is simulated by a spring in theoretical analysis connecting the two segmental of the beam using finite element method . The model of beam is generated. Dr.P.K.Sharma et al (2014) worked on "Alternative solution to the detection of crack location and crack depth in structure by using software analysis method Here in this study they used ANSYSsoftware package for finite element analysis of crack and uncrack RC beam taking input file as a CAD. Kaushar.H.Barad. et al (2013) worked on "Crack detection of damage of reinforced concrete beam by frequency based method "using natural frequency recognition of the damage exist on the surface of structural element was explained by authors for identification of damage parameters first two natural frequencies of the cracked beam was obtained by experimentally and selected crack location and size were compared with the actual results and found to be in good agreement. Also on the damage detection can be done with the help of natural frequency. The natural frequency was greatly affected by crack depth and crack location. From result it was observed that the crack of a particular present near the fit end minimize the natural frequency significantly greater .Than the crack of that size present closer to the end of the beam. Lede and Manti developed a method to asses crack prolongation using frequency measurement steel structure.

1.3. Impedance based method

Ayers et al(1998) utilized the electrical impedance of a bonded piezoelectric actuator/sensor as the means to qualitatively detect structural damage and activity monitor a structure's integrity. This technique is very sensitive to local damage in the sensing area. Soh et al(2000) applied the impedance based method to s concrete bridge. The piezoceramic transducer patches, which were electrically excited at high frequencies of the order of KHZ. By measuring the real part of (reciprocal of impedance0,the damage index was formed in non-parametric terms using the root mean square of the deviation in admittance signature with respect to the baseline signature of the healthy state. Saafi and sayyah(2001) attached an array of piezoelectric transducers to structure to detect and localize disbands and delamination of advanced composite reinforcement from concrete structure. In recent years this method has shown the potential of lamb waves in damage detection in metallic, composite structures and reinforced concrete structures. The lamb wave refers to the elastic perturbations propagating in a solid plate for(or layer)with free boundaries. Wang et al (2001) studied the Lamb-wave based method health monitoring of both fibre-reinforced composite and steel reinforced concrete. For health monitoring of the steel reinforced concrete, the piezoelectric sensor network was installed in selected rebar's in areas such as the deck, the columns of bridges, and footing area of columns. Experimental results showed that the cracks or deboning damage in reinforced concrete structures can be detected by the proposed built in active sensing system .Piezoelectric material can also be applied to health monitoring in order forms such as powder(Egusa and Iwasawa(1998))or film(Galea et al91993)).

The vibration characteristics based method are adopted for health monitoring purposes. Piezoelectric patches were embedded in the reinforced concrete beam at pre-determined spatial locations prior to casting and the piezoelectric patches are used as both actuator and sensor to detect possible cracks inside the reinforced concrete beam. This research can be continuation of an earlier work (Song et al 2004b), where four piezoelectric patches were embedded in planar locations near one end of the beam. One embedded piezoelectric patch is used as an actuator to generate waves and the other piezoelectric patches are used as sensor to receive vibration signals. Signal processing methods, such Fourier transform. One major advantage of the wavelet analysis is the ability to perform local analysis. In the sensor signal for the purpose of health monitoring of a reinforced concrete beam. The experimental result show that the damage index generated by the wavelet packet analysis is in accordance with measurement from conventional sensors such LVDTs and microscope this proves that the proposed wavelet packet analysis method is not only effective in identifying the existence of cracks inside the reinforced concrete bent cap but also monitoring the onset, the severity and the growth of the cracks within the reinforced concrete bent cap. The critical failure state obtained from the proposed method is earlier than that from LVDTs and microscope. The experimental results prove that the proposed method is more effective to predict the damage of reinforced concrete structures than the traditional methods.

1.4 Energy vector based on wavelet packet decomposition

Samuel and pines (2001) utilized a normalized energy metric based on wavelet packet analysis for the fault classification of helicopter gearboxes. The normalized of energy metric describes the distribution of energy on each frequency band. However, if the fault does not change the energy distribution, the normalized energy vector will not be affected even when the energy value on each frequency band changes. Therefore, the energy vector is directly applied in this paper instead of the normalized energy vector.

1.5 Damage index

Bhalla (2000) studied the detection and characterization of damage in concrete cubes and observed that the RMSD between the signatures was the most suitable damage index to characterize structure damage. soh et al (2000) successfully conducted RMSD between signatures of a PZT transducer to form the damage index for health monitoring of a reinforced concrete(RC) bridge. Tseng and Naidu (2002) presented the damage index by calculating the RMSD between the impedance of the PZT transducer mounted on aluminium specimens. In this paper, the damage index is formed by calculating the RMSD between the energy vectors of the healthy state and the damaged state. Ratcliffe introduced a finite difference approximation of Laplace's differential operator which can be applied tomode shape of damaged beam for the purpose of damage detection. Damage locations for plate-type structures were identified based on the strain modal analysis of a damaged plate.zArau´ jo dos Santos et al developed an algorithm based on the sensitivities of the orthogonality conditions of the mode shapes to identify damage of laminated plates. Moreover, the strain mode shapes were obtained by applying Rayleigh–Ritz approach, Li et al. Abdo and Hori carriedout study depend on comparison of the rotational mode shapes as a diagnostic tool in evaluating damage of plates. It was found that changes in the rotation of the mode shapes are more sensitive than the changes in the displacement mode shapes. Structural damages result in nonlinear dynamical signatures that can significantly enhance their detection, Marc Re´ billatn et al. Ndambi et al was Experimental study was applied on reinforced concrete beams aiming to detect the cracks and their locations using dynamic system characteristics Various damage detection methods based on mode shape changes and frequency response function were studied and compared. Maia et al. Kim et al The mode shape difference method was not successfully able to identify the damage precisely, formulated a damage index algorithm to estimate the severity of damage from monitoring changes in the modal strain energy. The sensitivity of mode shape to changes in mass or stiffness in structures was used as a base for damage assessment and localization. Parloo et althe operational deflectionshape and boundary effect evaluation method was used as a base for pinpointing crack location. The crack sizes were estimated by a local strain energy method Pai et al.

Arau´jo Dos Santos et al isDamage localization in laminated plates was determined based on mode shapes translation, rotation and curvature differences. The mode shapes translations are experimentally obtained using double pulse TV holography and an acoustic excitation. Mode shape derivatives were used to determine the location of damages due to presence of single crack and honeycombs.

2. PIEZOCERAMIC TRANSDUCER AS SENSORS

Piezoelectric transducers are a type of electro acoustic transducer that convert the electrical charges produced by some forms of solid materials into energy. The word "piezoelectric" literally means electricity caused by pressure. An early application of piezo transducer technology occurred during World War I with the use of sonar, which used echoes to detect the presence of enemy ships. Transducers are used in electronic communications systems to convert signals of various electronic signals, and vice versa.

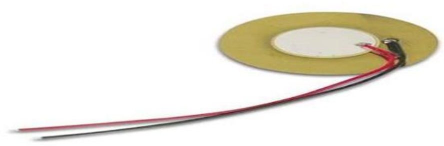


Fig.-1: Piezoceramic Transducer

The piezoceramic element expands or shrinks diametrically when an alternating voltages applied. This characteristic is used to bend the vibration plate which is generates sound. The acoustic generating's method can be subdivided roughly into the self-drive oscillation method . The former yields the lowest impedance on the acoustic generator produces sound through the oscillator circuits positive feedback .this allows the creation of sound pressure using a simple circuit. The external drive oscillation method uses a fixed frequency and produces sound through the oscillator.

2.1 Features of Transducers

Tone Type: piezo speaker
Operating Voltage: 30Vac
Rated Voltage: 15Vac
Current Consumption: 1.5mA
Resonant Frequency: 0.5-20 ± 0.5kHz
Sound Pressure Level: 75dB
Connector Type: leads
Body Color: metal
Weight: 0.11oz

Epoxy resins contain two substances namely resin and hardener that when combined form a material with incredible durability. They have several types which are used for adhesion, casting and coating. Epoxy resin is commonly used as adhesives. Epoxy resin adhesives are considered ered as very powerful bonding agent allowing two objects to unite inseparably. It can be applied in wood, glass, stone, metal and plastic.On the other hand, epoxy coating is applied to items that are severely damaged. Another type is epoxy resin castings. It is used to mould various objects of different forms and sizes.

Fig.-2: Fevitite Steel Epoxy Resin

3.DAMAGE DETECTION IN RC BEAM USING PZT

The implementation of active monitoring system to diagnose damage to reinforced concrete structures using piezoelectric smart aggregate, and based on wave propagation, rank among the world's most advanced research activities. Original models with parametric analysis of the damage index variation problem, depending on the size, position and orientation of cracks, are presented in this study.Piezoelectric based approaches hence provided an innovative approach for the structural health monitoring of civil structures with the advantages of structural simplicity, low cost, quick response and high reliability. The structure have embedded sensors and monitoring could be done due to the impact caused by outside. Thus it is called a passive monitoring system. This method requires the presence of trained staff that will monitor the reinforced concrete (RC) structures. However if the structure has sensors and actuator, then this system is called active monitoring system for structural damage detection development of the wireless system made possible the monitoring provides the ability. The monitor constructionat any moment of time, reducing the cost and increasing speed of the monitoring.

The piezoelectric smart aggregate wave propagating structural health monitoring is active monitoring system which has all the advantages mentioned above. In general, these are three major Piezoelectric based health monitoring approaches. The impedance based health monitoring approach which is a real time qualitative damage detection method. The working principle is based on the electromechanical compiling property of piezoelectric material.

The vibration characteristic approach utilizes piezoelectric actuators to generate certain waves which propagate with the structure, and compares with the structural vibration characteristic parameters (modal,shape,frequency),Vibration, characteristic response curves (sweep sine or tone burst response) or transfer function with those of the healthy state in order to detect damage.

3.1 Flexure Cracks in Reinforced Concrete Beams

Flexure word also means "Bending". Cracking in reinforced concrete beams subjected to bending usually starts in the tensile zone i.e. soffit of the beam. The width of flexural cracks in reinforced concrete beams for short-term may stay narrow from the surface to the steel. However, in long-term under continuous loading, the width of crack may get increased and become more uniform across the member. It Originates in maximum moment region (in above image this region is in center of the beam, it varies as per support Conditions of beam). It may be single or in groups and its Maximum width is at bottom/top of beam. The flexural cracks causes due to flexural capacity of the beam is inadequate, when Cross section of the beam or main reinforcement in beam is insufficient.

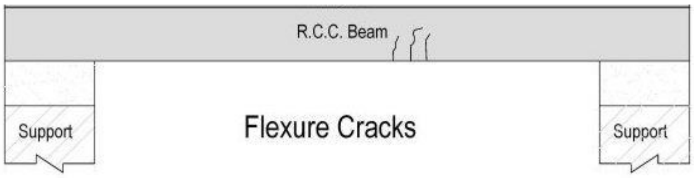
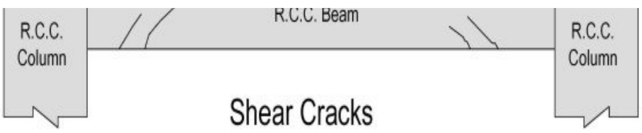


Fig.-3: The Flexure Cracks on Beam

3.2 Shear Cracks in Reinforced Concrete Beams

Shear cracks in reinforced concrete beams occurs in hardened stage and it is usually caused by structural (self-weight) loading or movement. These types of cracks are better illustrates as diagonal tension cracks due to combined effects of flexural (bending) & shearing action. Shear crack originates nearer to supports. It may be single or in groups and its maximum width is at neutral axis region or at bottom of beam. The shear cracks due to shear capacity of the beam is inadequate and cross section or torsional reinforcement insufficient.

Fig.- 4: The shear cracks on Beam



4.EXPERIMENTAL SETUP

The PZT transducers with sizes of 40 mm developed by PI Ceramic Co. were used in this experimental work. Four of them were fabricated as smart aggregates and embedded inside the concrete during casting shows the production process for the smart aggregates. The PZTs were coated with a layer of water proofing agent and were cast in mould with diameter of 50 mm and thickness of 30mm. A reinforced concrete(RC)beam with dimensions of 1300mm x 200mmx 250 mm was cast. The water/cement ratio was 0.55and concrete mix design was 350 kg/m^3 of ordinary Portland cement, 250kg/m^3 of water,1140.6 kg/m^3 of coarse aggregate with maximum aggregate size of 20mm and 814.015 kg/m^3 of sand. The mix design for production of smart aggregates was the same as the beam. However, coarse aggregates were placed by sand. The measured compressive strength of concrete was 40MPa.The beam was designed as a singly reinforced rectangular section under bending. Two #16 rebars with nominal area of 200 mm^2 were placed in the tension zone and two #10 rebar's were placed in the compression zone.

The beam was tested under the two loading points were 70 cm apart, the surface-bonded PZTs were attached at the center the beam aligned to two loading points and near that tends of the beam The three smart aggregates were installed inside the beam, tension bar's at 50 cm from the centre of the beam.

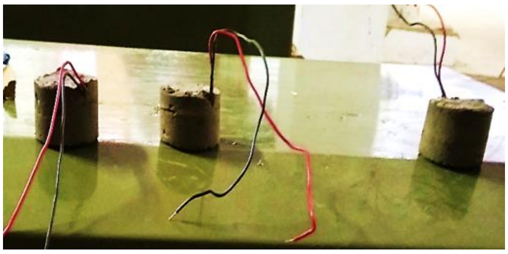


Fig.-5: shows the Resin coated PZTs and the PVCpipe moulds and Smart aggregates during hydration and after demoulding.

Fig:6 Digital Oscilloscope

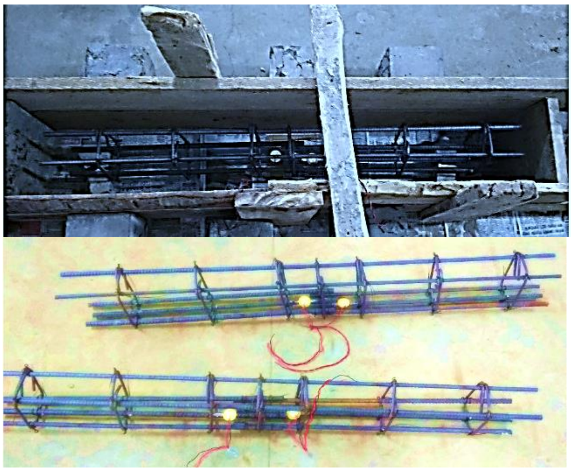


Fig.-7:shows the Installation of smart aggregate (Right) and whole formwork of RCC beams (Left).

4.1 Function Generator and Oscilloscope

A digital storage oscilloscope is an oscilloscope which stores and analyses the signal digitally rather than using analogy techniques. It is now the most common type of oscilloscope in use because of the advanced trigger, storage, display and measurement features which it typically provides. The input analogue signal is sampled and then converted into a digital record of the amplitude of the signal at each sample time. These digital values are then turned back into an analogue signal for display on a cathode ray tube (CRT), or transformed as needed for the various possible types of output liquid crystal display, chart recorder, plotter or network interface.

4.2 Test on RC beam and setup

The total length of A beam is 1.30 m, the shear span isa = 0.55 m, the width to the height ratio is b/h = 200/250, the effective depth is d = 200 mm and the span-to-depth ratio is a/d = 2.56. The bottom tensional longitudinal reinforcement of the beams comprises three steel bars of diameter 12 mm and the top compression reinforcement is two bars of diameter 10 mm (2Φ10). Both shear spans of the first beam (beam A0) have no transverse web reinforcement in order to control a typical shear failure of a beam without stirrups (design of a typical shear critical RC beam) and only a few closed stirrups of diameter 8 mm have been used just to hold longitudinal reinforcing bars in place. In order to examine thoroughly only the critical shear span of the beam in which final shear diagonal failure inevitable will occur .

Test setup and instrumentation of the shear-critical RC beams is also show in fig. Tested beams were simply supported on a rigid laboratory frame using two roller supports .The imposed loading was applied at two points 500 mm apart from each other in the mid-span of each beam using a steel spreader beam. The imposed load was consistently increased with low rate using actuator and was measured by a load cell with accuracy equal to 0.05 kN. The net mid-span deflections of the tested beams were recorded. One of them was placed at the middle of the beam span and the other two at the supports. Measurements for load and deflection were readand recorded continuously during the tests. Further, admittance measurements of the embedded piezoelectric transducers inside concrete mass as "smart aggregates" and the externally epoxy bonded PZTs were recorded at different levels of the applied loading using the SHM experimental setup shown in fig. Since PZTs transducers (embedded and surface bonded) have been installed in each tested beam, the devices were needed and used for the measurement of all four transducers simultaneously. Nevertheless, if the monitoring procedure requires more transducer than the available devices, the loading and therefore the corresponding damage should be kept on stand during the measurements of each transducer.

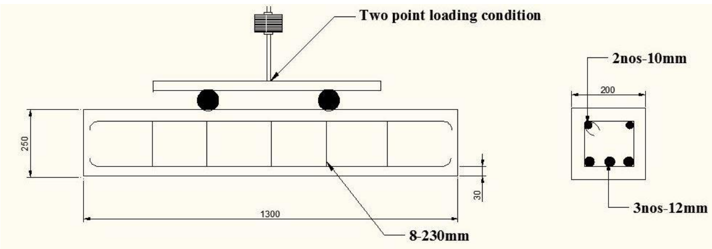
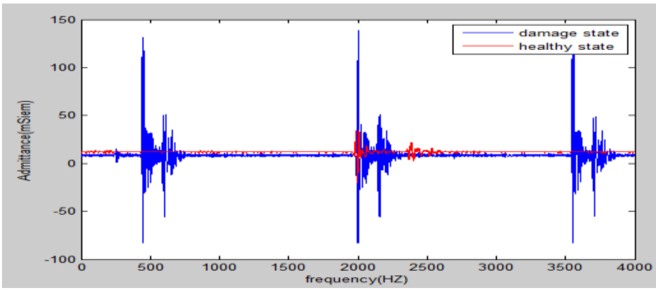


Fig.- 8: shows the Schematic presentation of the beam under loading

A typical two point bending scheme and setup is adopted for



the flexural test of the RC beams. The beam was simply edge-supported on roller supports apart from each other using a rigid laboratory frame. The imposed loading was applied at two points 300 mm apart from each other in the mid-span of the beam using a steel spreader beam. The imposed load was consistently increased with low rate using a pinned-end actuator and was measured by a load cell with accuracy equal to 0.05 kN. The net mid-span deflections of the tested beams were recorded the using venire scale to measure crack with 0.01 mm accuracy. One of them was placed at the middle of the beam span and the other two at the supports, as Measurements for load and deflection were read and depends on the successful frequency selection of the excitation rather than on the voltage of the excitation loading itself . This observation demonstrates that excitation loading sequence can have a voltage level low enough that the technique may be considered as easily applicable and effective for real structures. Thus, in this study analyses are performed for a frequency range of 1.3 kHz per step of 500Hz by using one cycle . This frequency range was chosen based on previous experience of the authors and researchers who investigated the suitable frequency range for RC beam.

`After undertaking the tests, the UTM was used to subject the increasing amplitudes and varying time duration. The loading frequency were of sinusoidal wave form with a frequency in embedded in the rc beam .The smaller amplitudes used in first two applications were specifically chosen to enable. During loading process in the beam smart aggregate as act sensor

` The recording the signals before crack like damages developed in the beam. In the process, the recorded signals were caused by background events like environmental noise, rubbing between the beam and supports, friction between the concrete and reinforcement, etc. A general view of the test setup, showing the close-up view of the crack and locations of beam, ages and sensors can be seen. Selection of the excitation frequencies of the mounted PZTs is an important parameter affecting the effectiveness of the method and therefore special attention. It has been proven that damage detection capability greatly

5. RESULTS AND DISCUSSION

The RC beams exhibited for typical flexural response, as it has been designed. First flexural cracks formed in the mid-span and if propagats perpendicular to the longitudinal axis of the beams. The increase of the applied load caused flexural cracks and spreads and inevitably tensional longitudinal bars to yield. The behavior of Beam-1 and

Admittance of the mounted PZTs embedded and surface bonded on the RC beams were measured at the beginning of the test healthy state of the beams and at damage levels . The experimentally measured time historiesof the current passing through PZT 1 of Beam-1 for frequency admittance equal to 1.3 KH .

5.1 Damage evaluation in shear-critical RC beams

Tested RC beams exhibited typical shear response and brittlediagonal failure, as they have been designed and expected. In general first flexural cracks formed in the mid-span and perpendicular to the longitudinal axis of the beams. The increase of the applied load caused further flexural cracks that spread and inevitably initialdiagonal cracks formed. Consequently, the formation of a critical shear crack on a shear span of RC beam caused its brittle failure. The present the behavior of RC beam in terms of experimental curve of shear admittance versus frequency . Further, the cracking patterns of the RC beams at different levels of loading and corresponding damage are also displayed in the photographs. The value of the applied load (shear force) in terms of ultimate shear strength percentage at each examined loading level in which PZT voltage signals have been measured for each beam.

A brief description of the corresponding damage at each loading level is also summarized .Voltage signals of the mounted PZT transducers were measured at the beginning of the test (''Healthy state'') and atthe damaged levels . This way, the examinedloading level corresponds to a specific damage level that also displayedin the cracking patterns of the beamsConcerning the measurements of the mounted PZTs,display the voltage signals of the embedded in the right shear span of beam ''smart aggregate'' transducers PZT3 . The comparisons of the curves in clearlyshowthat there are certain discrepancies between the healthy and the damaged levels that have been measured from the embedded.

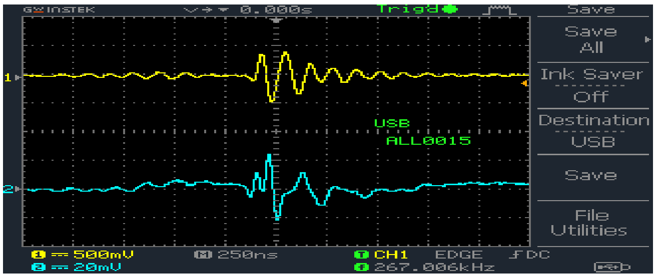


Fig.-11: shows the Input current flow frequency fromfunction generator at Healthy State of RC Beam in PZT1 and PZT2

6. CONCLUSION

The utilization of the EMA methodology for the crack detection and evaluation of the damage in the RC beam using PZTs has been presented. Experimental measurements of healthy, artificially damaged flexural RC beams have been carried out using an integrated experimental monitoring system and the signatures of mounted PZTs transducers. The proposed method has the ability not only to detect the existence of the cracks but also to monitor the growth of cracks.Based on experimental results, the following conclusions can be drawn. The experimental result shows that piezoceramic materials can be successfully applied to the health monitoring for RC beam .The transmission energy between the actuator and sensor will drop dramatically when a crack happens inside. The embedded PZT sensors are very sensitive in detecting the cracks.

Surface bonded PZTs using electro mechanical admittance technique are sensitive to localized damage. Thus, they can be useful for monitoring the important components or critical parts (e.g. beam-column joints) with potential localized damage in the structure. The sensitivity of the PZTs in damage detection, their influence locus and the determination of damage location is investigated using signature comparisons, and RC beams cracking patterns observations.

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