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STRUCTURAL HEALTH MONITORING SYSTEM AND IDENTIFICATION OF THE LOCATION OF THE DAMAGE

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ABSTRACT

In the field of monitoring the behaviour of structures, strain gauges are by far the most common type of sensor. Strains are created by the members of a structure deforming as a result of bending, torsion, shearing, or elongation and contraction on the surface of the structure. The purpose of this research was to develop a novel technique for correctly determining the experimental mode shapes of a structure by making use of a single surface-bonded PZT patch. This technique was developed as part of this investigation. The EMI approach is used to discover the beginning stages of damage, while the experimental mode shape technique is used to locate moderate to severe stages of damage. In the event of moderate to severe damage, the precise position may be pinpointed using a single piezo sensor to the appropriate degree of accuracy. Every nation's economy depends on the maintenance and expansion of its civil infrastructure. It has been brought to people's attention that if the nation's civil-infrastructure does not operate as expected, it might have a negative impact on the gross domestic product. Because the entire performance is dependent not only on the initial strength but also on post-construction degradation, it is of the utmost importance to undertake maintenance on these structures after the building phase has been completed. There are four components that make up comprehensive health monitoring of structures. These components include the existence, the location, the degree of the damage, and the remaining life of the building after the harm has occurred.

KEYWORDS: *structures, monitoring*

INTRODUCTION

As more advanced materials and technology become available, the designs of structures not only get more ambitious but also more complex. This is due to the fact that buildings are rising higher, bridges are having longer spans, and structural designs are getting more difficult. In light of these improvements, there is a rising need to provide not just cost savings in terms of maintenance but also a safer environment for by minimising structural failures. This should be done in order to meet the growing need for both of these things. This is a need that has become much more widespread.

India has kept up with structural improvements including new technical advances, despite the fact that it is still considered a developing nation. The various historical structures in India, each of which has its own distinct style, is a fair indication of the rich cultural and historical legacy of the country. These structures have been built to an exceptionally high level, and as a result, they have withstood the test of time. However, due of their historical value, it is of the utmost importance to analyse the present condition of health of these structures in order to guarantee that the right safeguards are taken before it is too late to do so.

In India, the construction of high-rise structures built of steel and concrete has recently begun, and these projects require considerable modelling, design details, and analysis both before and throughout the construction process. As a result of this, having knowledge about what has been created and how it is expected to act in the future is both advantageous and crucial. India is home to many historic structures, but it has also recently witnessed the construction of high-rise skyscrapers composed of steel and concrete.

Buildings that hold huge public meetings, such as sports arenas, stadiums, and commercial structures, are considered to be critical buildings. Critical buildings are often referred to as "Lifeline Structures." Examples of critical buildings include hospitals, schools, and power plants. These are the kinds of structures that, in the event that they were to sustain damage from a catastrophe of any sort, whether it natural or manufactured, might put a significant number of people in risk all at once. As a result, it is very necessary that they be regularly maintained and repaired.

In our country, state authorities are responsible for all aspects of dams, including research, planning, design, building, operation, and maintenance. The primary concern of these organisations is the safety of the dams that are located within their respective jurisdictions. There have been a few failures, despite the fact that the majority of the dams have performed properly. These failures, whether they are partial or total, bring to light the necessity of reviewing the processes and the criteria that are being established by the various states with the intention of establishing the best assurance of dam safety within the limitation of the current state of the art. This review is necessary because these failures bring to light the necessity of reviewing the processes and the criteria that are being established by the various states.

SHM is an abbreviation that refers to a practise known as "structural health monitoring," which attempts to offer accurate and up-to-date information on the state and performance of structures on a preventative basis. Recordings of representative parameters can be made in one of three ways: I in a manner that is permanently continuous, (ii) on a periodic basis, or (iii) in a manner that is periodically continuous over a short or extended amount of time. The information that is obtained via monitoring is often put to use in the following manners: to plan and design maintenance; to enhance safety; to verify hypotheses; to minimise uncertainty; and to widen one's understanding on the structure that is being monitored. In spite of the fact that it is of the utmost significance, the practise of structural monitoring is not yet generally practised across the country of India.

Civil infrastructures such as bridges and buildings start to deteriorate as soon as they are finished and placed into use when the construction process is complete. It is essential for all of our well-being to make certain that our civic infrastructures continue to be trustworthy and risk-free for day-to-day use. This is especially true for our transportation systems. It is essential and necessary to have knowledge about the structure's integrity in terms of its age and usage, as well as its level of safety in terms of its capacity to withstand infrequent but significant stresses, such as overweight loads, earthquakes, and fatigue. In addition, it is necessary to have knowledge about the structure's level of safety in terms of its ability to endure infrequent but significant stresses. The act of establishing and tracking a structure's structural integrity as well as determining the nature of damage within a structure is referred to as health monitoring, and the term "health monitoring" is widely used to refer to this process.

Monitoring the current condition of health of a structure and finding any damage that may already be there are becoming more significant tasks in the realm of civil engineering. SHM stands for "Structural Health Monitoring," which is the practise of conducting in-situ, non-destructive sensing and analysis of structural characteristics in order to determine whether or not a damage has been sustained, define its location and estimate its severity, and evaluate the impact that this damage will have on the structure's remaining useful life. The term "Structural Health Monitoring" (SHM) refers to the practise of conducting in-situ, non-destructive sensing and Even though structural health monitoring, often known as SHM, is a relatively new concept in the field of civil engineering, the practise of evaluating the condition of a structure's health by subjecting it to various tests and taking measurements is rather common. As a direct consequence of this, assessment and inspection suggestions have been at your disposal for a considerable amount of time. SHM seeks to accomplish objectives that are analogous to those of conventional methods; however, it does so by employing contemporary technology in the fields of sensing, instrumentation, communication, and modelling in order to bring together the individual elements of a problem and solve it using an intelligent approach. The information that is obtained from such systems may be useful for a variety of purposes, including the evaluation of the structural safety of existing structures, the rapid evaluation of the conditions of damaged structures after an earthquake, the estimation of the remaining life of structures, the repair and retrofitting of structures, the management, maintenance, or rehabilitation of historical structures, and the estimation of the remaining life of structures. These are just some of the potential applications of the information that is obtained from such systems.

OBJECTIVES:

(1) To develop a low cost experimental technique to extract the strain mode shapes of the structures directly using PZT sensors.

(2) To utilize artificial neural network for more efficient learning and data processing for reporting damage location and severity based on input data.

METHODOLOGY

Through this piece of study, the global dynamic technique and the EMI approach, both of which use the PZT patch as the central component, were effectively combined into a single method. Directly extracting the strain mode forms of the structures has been made possible by the development of an inexpensive experimental approach. This method utilises a single PZT sensor that is either surface bonded or implanted. Both the EMI and the global dynamic approaches are able to make use of the same PZT patch for their sensing needs. An embedded PZT sensor was also examined; this type of sensor may be included into a structure made of reinforced concrete (RC) at the time it is being built. It has been proven beyond a reasonable doubt that the lower modes can be generated by the utilisation of the PZT patches. Combining the EMI and global approaches into a single SHM strategy has been suggested as a way to facilitate its use in real-world scenarios. In comparison to more traditional methods, the suggested strategy is both more sensitive and more cost efficient. Utilizing this methodology, one may properly assess the presence of damage or a crack, as well as its degree and position. Both of these methods are complementary to one another. Using the combined method, one may also estimate how much longer a structure will continue to function after it has been damaged. Because of this, it offers a superior tool for SHM. The new method that has been suggested is one that is able to check the overall health of buildings.

DATA ANALYSIS

EXPERIMENTAL SET UP TO DETECT THE INITIAL DAMAGE

The fundamental flaw of the global approach is that it is unable to detect the initial stages of damage. Therefore, there is no debate over the precise position of these degree harm. The initial amount of damage might be catastrophic for certain buildings, such as those used in aircraft and nuclear power plants. The electromagnetic interference (EMI) method is utilised here in order to locate the initial damage.

Utilizing the EMI approach, one is able to extract the admittance signature of the PZT patch. The approach given in Section A is one that may be used to get equivalent values for damping and rigidity. These values for equivalent stiffness and damping are dependent of a number of characteristics, such as the thickness of the adhesive bonding layer, the kind of material, and the boundary conditions. It is impossible to control all of the governing parameters that have an effect on the signature of PZT patches, so even if two PZT patches were bonded on exactly the same type of specimen and all of the other parameters were the same, their signatures and the extracted equivalent parameters might still be different. This is because it is impossible to control all of the governing parameters. For instance, due to the fact that it is measured in micrometres, it is not possible to manage the thickness of the adhesive bond layer in a realistic setting. The percentage change of an analogous parameter with damage is nearly the same magnitude once PZT patches have been glued on the surface of the structure. These percentage shifts in equivalent parameters alter depending on the distance between the damage patches and the PZT patches. As a result, the damage may be centred on the areas that would see the greatest amount of change. Once the sensor with the biggest change and the one with the next highest change in equivalent stiffness have been selected, the site of the damage may be pinpointed. After the position of the damage has been tracked between two sensors, an approximation of its location may be determined using linear variations. Let it be known that the damage was done between the nth and the (n+1th) PZT sensors, and that the distance between these two PZT patches is "x." If the % change in equivalent stiffness on the nth sensor is y1, and the percentage change on the (n+1)th sensor is y2, then the formula below may be used to estimate the location of damage caused by the nth sensor.

$$d = \frac{y_2}{y_1 + y_2} x \qquad (1)$$

where, d = distance of damage from nth sensor

x = distance between sensors where damage located

A. EXPERIMENTAL SET UP TO DETECT THE INITIAL DAMAGE

As can be seen in Figure.1, the beam that is discussed in study was instrumented by placing 11 PZT patches at intervals of 33.33 cm apart. The artificial damages were induced in seven stages, as described and illustrated, and the first three damages were treated as incipient, where the first few frequencies changed negligibly. Artificial damages were induced in seven stages. The admittance characteristics of each PZT patch, including the conductance and the susceptance, were measured with an Agilent E4980A LCR metre (Agilent Technologies, 2009) across the frequency range of 100-160 kHz. This was done for the undamaged and the first three damage states.

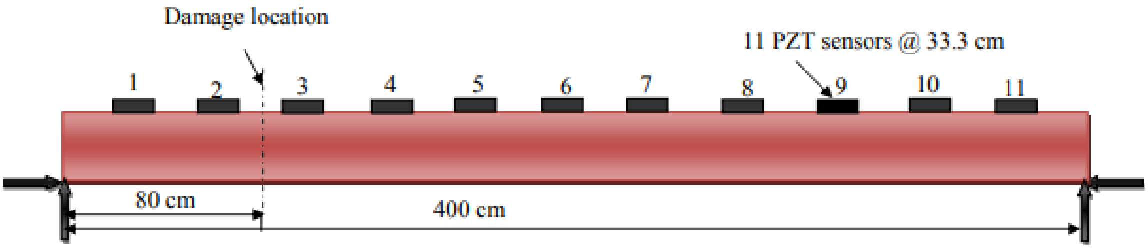

Fig.1 Experimental set up for incipient damage

Fig.2 depicts the plot between the conductances (G) for the undamaged stage of all eleven PZT sensors in the frequency range of 100 kHz to 120 kHz. This frequency range is shown for all eleven sensors. Conductance does not appear to follow any discernible pattern in response to changes in sensor distance, as was demonstrated here. The steel beam was conceptualised as an equivalent structure, which is a collection of fundamental elements arranged in either a series or a parallel, and the parameters of the equivalent system were calculated using equation.

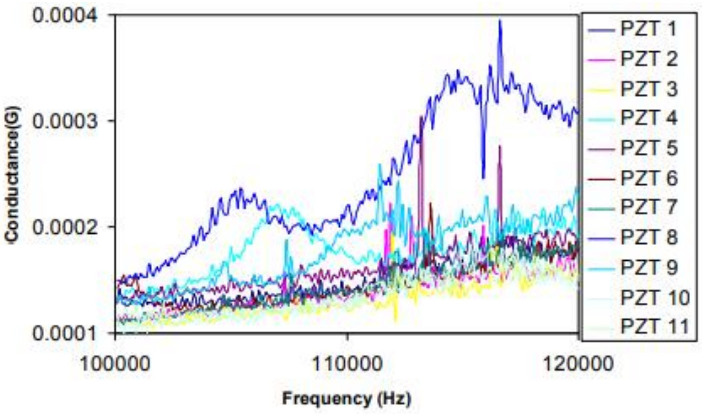

Fig.2 Signature of 11 PZT patches, Conductance vs frequency

Table.1 is an organised listing of these parameters for the first three damage stages. It is clear from looking at Table.1 that there are only little variations in the value of k for PZT no. 9, 10, and 11, all of which were situated in relatively remote areas. The percentage variations of k go up when there is more damage, but they go down when there is more distance between them and the PZT sensor. The plot of the change in k of various sensors for the three distinct damage states is displayed in Fig.3

Table.1 Percentage variation of Equivalent Stiffness of all PZT sensors

PZT No	Undamaged	Damage State 1		Damage State 2		Damage State 3	
	k(N/m) × 10^6	k(N/m) × 10^6	Change(%)	k(N/m) × 10^6	Change(%)	k(N/m) × 10^6	Change(%)
PZT 1	6.56	6.86	4.7	6.97	6.3	7.44	13.5
PZT 2	8.67	9.47	9.2	9.73	12.3	10.54	21.6
PZT 3	7.65	8.51	11.2	8.83	15.5	9.53	24.6
PZT 4	5.97	6.41	7.4	6.67	11.6	7.20	20.7
PZT 5	8.45	8.92	5.6	9.26	9.7	10.03	17.5
PZT 6	6.78	7.04	3.9	7.28	7.4	7.70	13.6
PZT 7	8.56	9.44	3.3	9.09	6.2	9.37	9.5
PZT 8	6.53	6.73	2.9	6.83	5.4	6.83	7.2
PZT 9	8.56	8.65	1.1	8.66	1.2	8.66	1.2
PZT 10	6.63	6.68	0.8	6.69	0.9	6.69	0.9
PZT 11	7.89	7.92	0.4	7.92	0.4	7.92	0.4

In order to pinpoint the location of the damage, the PZT patches that were going through the first two largest percentage shifts were selected. After damage state 1, it was discovered that PZT 2 and PZT 3 exhibited the greatest percentage alterations in their sensors. The same pattern was seen for the damage in state 2, which also occurred in state 3. As a result, it was determined that the site of the damage was in between sensors 2 and 3. With the help of Eq.1, the precise position of the damage detected by PZT sensor 3 was determined. It was discovered that the estimated value from the second PZT sensor was 18.3 centimetres, which compares favourably with the real value of 13.3 centimetres from the second PZT sensor. As a result, the damage appears to be rather localised.

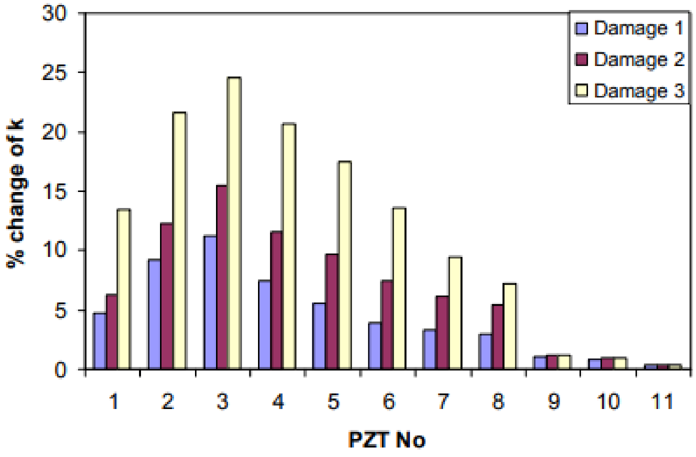

Fig. 3 Variation of percentage change of equivalent stiffness of different PZT sensor

In the same manner, the position of the damage after damage state 2 was determined to be 18.6 centimetres, and the location of the damage after damage state 3 was calculated to be 17.7 centimetres. These numbers compare favourably to their real locations of 13.3 centimetres each. As a result, using this method, incipient damage may be discovered, and utilising the global dynamic methodology, moderate to severe damage can be located. In the event that there is damage in the making, a sensor network that is dense will allow for more precision in the location of the harm.

EVALUATION OF EXPERIMENTAL MODE SHAPE

The general equation of motion for a dynamic system is (Chopra, 1996)

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F(t)\} \qquad (2)$$

where, [M] is the mass matrix, [C] the damping matrix, [K] the stiffness matrix , $\{\ddot{x}\}$, $\{\dot{x}\}$ and {x} the acceleration, the velocity and the displacement vectors respectively, and F{t} the force vector. For free vibration, {F(t)} is zero, hence

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=0 \qquad (3)$$

The solution of Eq. (3) yields the N natural frequencies ωn (n =1,2,3….N) of vibration. The roots ω_n^2 , of Eq. (3) are known as the eigen values. For every natural frequency ωn , there corresponds a mode shape vector Φ_n satisfying Eq. (3). The eigen value problem does not fix the absolute amplitude of the vector Φ_n but only provides the relative shape. Corresponding to the n^{th} natural frequency ωn, there are N independent displacements. The mode shape Φ_n is the profile of the structure's displacement (at the N places) at the particular frequency n. The total of the displacements caused by all modes is the displacement that may be measured at any point along the structure. If the movement of any point is monitored, then the FFT may be used to distinguish between the relative contributions of the different modes (Paz, 1999). Therefore, if the temporal history of each point is known, one may draw the mode shape by combining the displacement at the appropriate frequency n. This is only possible if there is complete knowledge of all the points. It is necessary to constantly apply displacement along the length of the structure in order to sketch the mode form accurately. However, it is not practical to place sensors at every location on the structure in the ideal situation. On the other hand, graphical interpolation will not provide the correct mode shape if the sensors were put at a substantial distance apart from one another.

In general, extremely tiny magnitude loads are necessary for excitation in order to satisfy the assumption that the structure would behave linearly. This is because in order to create free vibration in a structure, very small magnitude loads are required. Experiments are going to be done all throughout this chapter to determine the strain mode forms of the constructions. According to the reciprocal-displacement theorem, the amount of deflection that occurs at point 'n' as a result of a unit load operating at point'm' is mathematically equivalent to the amount of deflection that occurs at point'm' as a result of the unit load that occurs at position 'n'. (Reddy, 1996). Therefore, the strain response of every location on the structure may be determined by using a single sensor that is fixed at a particular point and then delivering a load that is either fixed in magnitude or has a unit magnitude at the site of interest. The temporal history of each of the N points may be obtained if the point of application of that fixed load is moved about. The natural frequency may be calculated using FFT based on the recorded time history, and the ordinate of the FFT curve that corresponds to that frequency reflects the relative maximum displacement at that instant. Figures 4, 6, and 8 depict the usual time histories of a PZT sensor in terms of output voltage, while Figures 5, 7, and 9 depict the FFT of these time histories.

The mode shape so derived will be the curvature mode shape, since the PZT patch measures surface strain, as given by,

$$\varepsilon = y''d \qquad (4)$$

where , y'' is the curvature, which is the second derivative of the displacement, and d is the distance from the neutral axis to the PZT patch. The minimum sample interval of the device by which time history is recorded, as well as the size of the frequency, are two factors that will determine the maximum number of mode shapes that may be retrieved.

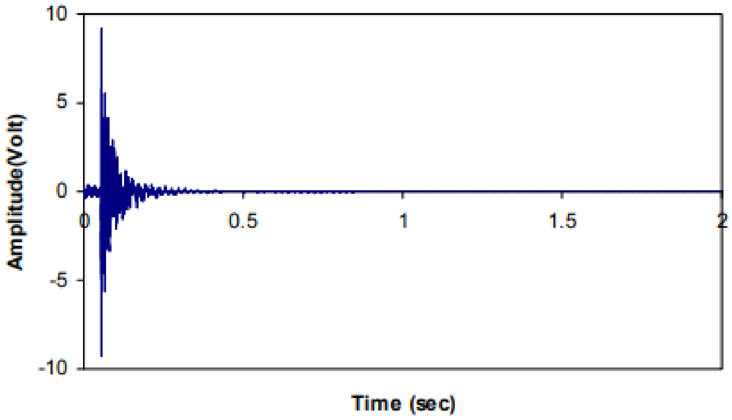

Fig. 4 Typical time history, measured by PZT sensor

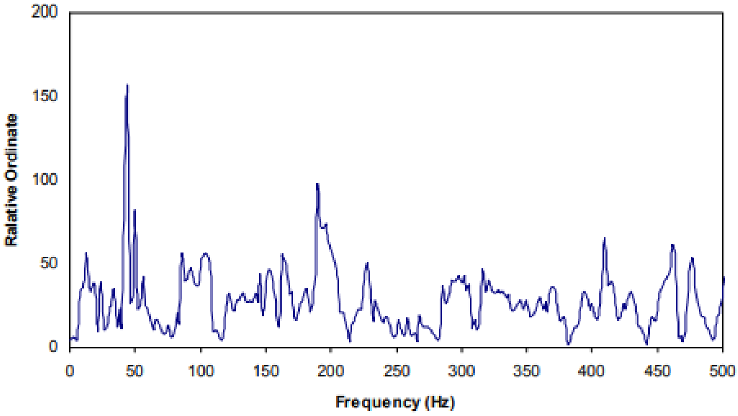

Fig.5 FFT of time history

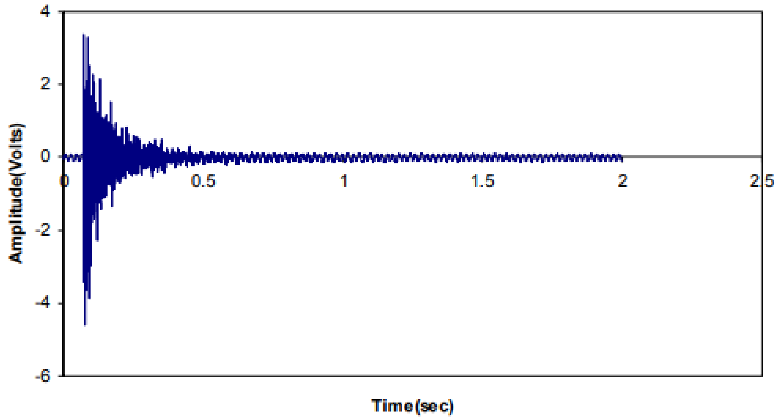

Fig.6 Typical time history, measured by PZT sensor

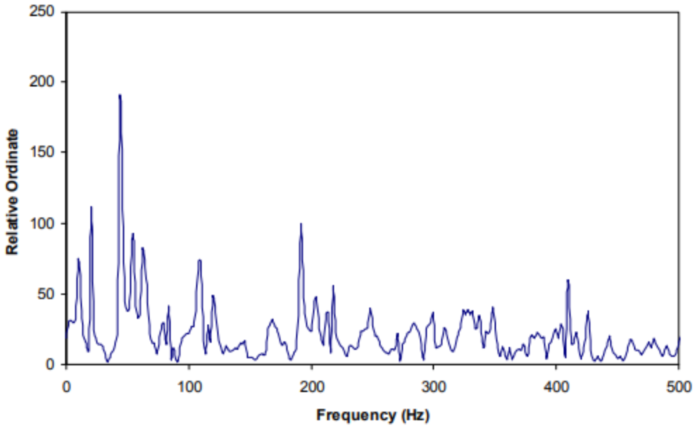

Fig.7 FFT of time history

If the first two or three mode shapes are precisely established, then it should be adequate to anticipate both the location of the damage and its severity. When more nodes are considered, there will be less interpolation error, which will result in better accuracy. Accuracy is directly proportional to the number of nodes into which the structure is split (Naidu and Soh, 2004).

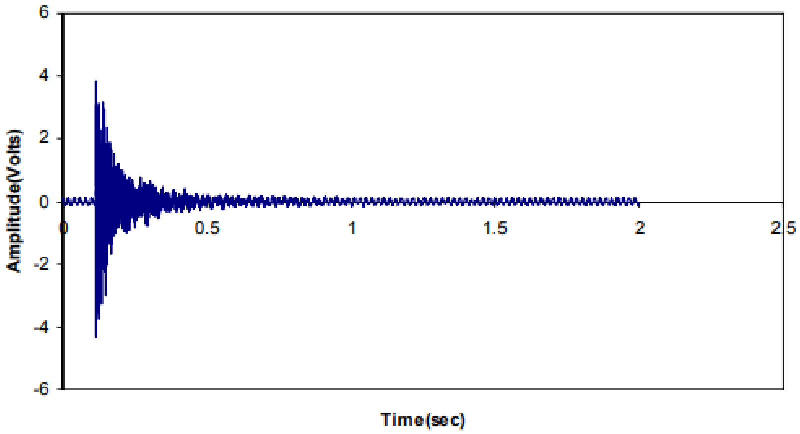

Fig.8 Typical time history, measured by PZT sensor

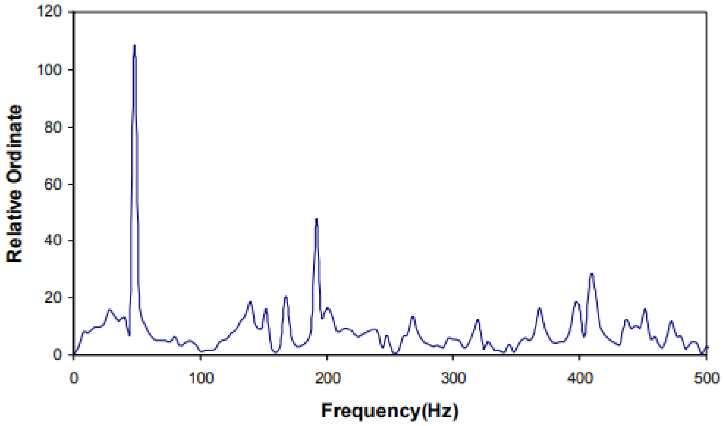

Fig.9 FFT of time history

CONCLUSION

There are four components that make up comprehensive health monitoring of structures. These components include the existence, the location, the degree of the damage, and the remaining life of the building after the harm has occurred. Conventionally, several methods, as well as various kinds of sensors and hardware, are utilised for each individual element. Surface bonded PZT patches have traditionally been utilised as a method for determining the overall health of buildings. This research works has successfully integrated the global dynamic technique with the local EMI technique utilizing the same PZT patch as the key element. Surface-bonded PZT patches come with a whole host of complications, including protection from unforgiving environments and external wiring, to name just a couple such challenges. In the course of this investigation, the feasibility of an embedded PZT sensor that may be included into a structure during the process of its construction was studied. It has been established beyond a reasonable doubt that the embedded sensor performs satisfactorily in both the global dynamic technique and the EMI approach. A straightforward and inexpensive digital multimeter is utilised for the purpose of measuring the response of the integrated sensor.

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