International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 04 | April - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Modelling And Analysis the Structures by Finite Element Methods

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--Abstract - Finite Element Method (FEM) has emerged as a powerful computational tool in the analysis and design of complex structures across various engineering disciplines. This study focuses on the modelling and analysis of finite element structures to evaluate their mechanical performance under different loading conditions. Utilizing advanced simulation tools, the project investigates stress distribution, deformation patterns, and failure mechanisms in structural components made from diverse materials. The primary objective is to develop accurate finite element models that replicate real-world behavior with high fidelity.

The research begins with geometric modeling, material property assignment, and meshing strategies, followed by the application of boundary conditions and loads. Several case studies are considered, including beams, trusses, and plates subjected to static and dynamic loads. The influence of mesh density, element type, and boundary conditions on the accuracy of results is also examined. Additionally, the study evaluates linear and nonlinear behavior, including material nonlinearity and large deformation analysis.

Validation is performed by comparing simulation outcomes with theoretical calculations and available experimental data. The results demonstrate that FEM provides reliable and precise predictions when appropriate modelling strategies are employed. This work underscores the importance of finite element analysis (FEA) in optimizing design, reducing material costs, and ensuring structural safety. The findings offer valuable insights for engineers, researchers, and designers involved in structural analysis and mechanical system development.

***Key Words*:** Finite Element Method (FEM), Structural Analysis, Modelling, Simulation, Stress Distribution, Deformation, Meshing, Boundary Conditions, Nonlinear Analysis, Validation, Structural Design, Engineering Structures

1. INTRODUCTION:

1.1 GENERAL

Health monitoring is the continuous measurement of the loading environment and the critical responses of a system or its components. Health monitoring is typically used to track and evaluate performance, symptoms of operational incidents, anomalies due to deterioration and damage as well as health during and after an extreme event (Aktan et al, 2000). Health monitoring has gained considerable attention in civil engineering over the last two decades. Although health monitoring is a maturing concept in the manufacturing, automotive and aerospace industries, there are a number of challenges for effective applications on civil infrastructure systems. While successful real-life studies on a new or an existing structure are critical for transforming health monitoring from research to practice, laboratory benchmark studies are also essential for addressing issues related to the main needs and challenges of structural health monitoring. Health monitoring offers great promise for civil infrastructure implementations. Although it is still mainly a research area in civil infrastructure application, it would be possible to develop successful real-life health monitoring systems if all components of a complete health monitoring design are recognized and integrated.

A successful health monitor design requires the recognition and integration of several components. Identification of health and performance metric is the first Component which is a fundamental knowledge need and should dictate the technology involved. Current status and future trends to determine health and performance in the context of damage prognosis are reported by Farrar et al. in a recent study (2003).

New advances in wireless communications, data acquisition systems and sensor technologies offer possibilities for health monitoring design and implementations (Lynch et al, 2001, Spencer, 2003). Development, evaluation and use of the new technologies are important but they have to be considered along with our "health" and "performance" expectations of the structure. Yao (1985) defined the term damage as a deficiency or deterioration in the strength of the structure, caused by external loading or environmental conditions or human errors. So far visual in spection has been the most common tool to identify the external signs of damage in buildings, bridges and industrial structures. These inspections are made by trained personnel. Once gross assessment ofthe damage location is made, localized techniques such as acoustic, ultrasonic, radiography, eddy currents, thermal, or magnetic field can be used for a more refined assessment of the damage location and severity. If necessary, test samples may extract from the structure and examined in the laboratory. One essential requirement of this approach is the accessibility of the location to be in spected. In many cases critical parts of the structure may not be accessible or may need removal of finishes. This procedure of health monitoring can therefore be very tedious and expensive. Also, the reliability of the visual inspection is dependent, to large extent, on the experience of the inspector. Over the last two decades number of studies have been reported which strive to replace the visual inspection by some automated method, which enable more reliable and quicker assessment of the health of the structure. Smart structures was found to be the alternative to the visual inspection methods from last two decades, because oftheir inherent 'smartness', the smart materials exhibit high sensitivity toany changes in environment.

1.2 NEEDS FOR HEALT HMONITERING

Appropriate maintenance prolongs the life span of a structure and can be used to prevent catastrophic failure. Higher operational loads, greater complexity of design and longer life time periods imposed to civil structures, make it increasingly important to monitor the health of these structures. Economy of a country depends on the transportation infrastructures like bridges, rails, roads etc., Any structural failure of buildings, bridges and roads causes severe damage to the life andeconomy of the nation. The U.S. economy is supported by a net work of transportation infrastructures like highways, railways, bridges etc., amounting to about US$ 2.5 trillion worth (Wang et al., 1998). Every government is spending many crore of rupees every year for the rehabilitation and maintenance of large civil engineering structures. Failure of civil infrastructure to perform may effect the gross domestic production of the country.
These facts underline the importance of an automated health monitoring system, which cannot only prevent an incipient damage included collapse, but can also make an assessment of structural health, as and desired, at a short notice. These automated systems

Hold the promise for improving the performance of the structure with an excellent benefit cost ratio, keeping in view the long term benefits.

1.3 OBJECTIVE AND SCOPE OF PROJECT

The objective of this project was to develop methodologies for finite element analysis of smart structures. In specific, the project attempted to compare experimental results obtained for health monitoring of lab sized Reinforced concrete (RC) frame with of numerical simulations, using finite element analysis.The study made use of high frequency dynamic response technique employing smart piezoceramic (PZT) actuators and sensors. They can excite the structure to vibrate at high frequencies, thus activating the local modes, which have higher sensitivity to incipient damage (Giurgiutiu and Rogers, 1997). Numerical results matched reasonably well with the experimental signatures, especially the peak frequencies. As second part of the project, appropriate damping constants were found by trial and error. Different damages were simulated into the numerical model and the effects of those damages on the conductance signature were studied and compared with the experimental results. Purpose of Numerical simulationwas to avoid tedious experimental work of subjecting the structure to numerous fractures in future research, thereby and saving time and money in future research.

2. LITERATURE REVIEW ON STRUCTURAL HEALTH MONITORING

2. 1 AN OVER VIEW

Increase in population necessitated the more civil infrastructural facilities in every country. Wealth of the nation can be represented by well conditioned infrastructure. Civil engineering structures under go damage and deterioration with age and due to natural calamities. Nearly all in-service structures require some form of maintenance for monitoring their integrity and health condition. Collapse of civil engineering structures leads to immense loss of life and property. Appropriate maintenance prolongs the life span of a structure and can be used to prevent catastrophic failure. Current schedule- driven inspection and maintenance techniques can be time consuming, labor-intensive, andexpensive. SHM, on the other hand, involves autonomous in-service in spection of the structures. The first instances of SHM date back to the late 1970s and early 1980s. The concept of SHM originally applied to aerospace and mechanical systems is now being extended to civil structures.

Objectives of health monitoring are as follows.

a) To ascertain that damage has occurred or to identify damage

b) To locate the damage

c) To determine the severity of damage.

d) To determine the remaining useful life of the structure.

SHM consists of both passive and active sensing and monitoring. Passive sensing and monitoring is used to identify the location and force–time–history of external sources, such as impacts or acoustic emissions. Active sensing and monitoring is used to localize and determine the magnitude of existing damages. An extensive literature review of damage identification and health monitoring of structural and mechanical systems from changes in their vibration characteristics is given by Doebling et al. (1996).

2.1.1 PASSIVE SENSING DIAGNOSTICS

For a passive sensing system, only sensors are installed on a structure. Sensor measurements are constantly taken in real time while the structure is in service, and this data is compared with a set of reference (healthy) data. The sensor-based system estimates the condition of a structure based on the data comparison. The system requires either a data base, which has a history of prestored data, or a structural simulator which could generate the required reference data.

Passive sensing diagnostics are primarily used to determine unknown inputs from changes in sensor measurements. Choi and Chang (1996) suggested an impact load identification technique using piezo electric sensors. They used a structural model and a response comparator for solving the inverse problem. The structural model characterised the relation between the input load and the sensor output. The response comparator compared the measured sensor signals with the predicted model.

2.1.2 ACTIVE SENSING DIAGNOSTICS

Active sensing techniques are based on the localized interrogation of the structures. They are used to localize and determine the magnitude of an existing damages. Local or wave propagation-based SHM is therefore advantageous since much smaller defects can be detected. Chang (2000) concentrates his research on wave- propagation-based SHM. He developed Lamb-wave-based techniques for impact localization /quantification and damage detection. Wilcox et al. (2000) examined the potential of specific Lamb modes for detection of discontinuities. They considered large, thick plate structures (e.g. oil tanks) and thin plate structures (e.g. aircraft skins). They showed that the most suitable Lamb mode is strongly dependent on what the plate is in contact with. Bhalla and Soh (2005) presented the technique using wave propagation approach for NDE using surface bonded piezo ceramics. They utilized simple, economical and commercially available hardware and sensors, which can be easily employed for real time and online monitoring of critical structures, such as machine parts and aircraft components. Lemistre and Balageas(2001)presented a robust technique for damage detection based on diffracted Lamb wave analysis by a multire solution wavelet transform. Bergeretal. (2004) employed fibre optic sensors in order to measure Lambwaves. Benz et al. (2003) and Hurlebaus et al.(2002) developed an automated, non- contact method for detecting discontinuities in plates. Laser ultrasonic techniques were used to generate and detect Lamb waves in a perfect plate and in a plate that contains a discontinuity. The measured signals were first transformed from the time–frequency domain using a short-time Fourier transform (STFT) and subsequently into the group– velocity–frequency domain. The discontinuity is then located through the use of a zz correlation in the group–velocity–frequency domain.The smart layer presented by Lin and Chang (1998) makes use of a PZT-sensing element, whereas the smart layer presented by Hurlebausetal. (2004) uses PVDF-sensing elements. Finally, in the study by Lin and Chang (2002) PZT transducers were placed at a few discrete points on the smart layer; and in the study by Hurlebaus et al. (2004), the PVDF polymer covers the entire surface of the smart layer.

2.1.3. SELF–HEALING & SELF–REPAIRING

Peairs et al. (2004) presented a method for the self-healing of bolted joints based on piezo electric & shape memory alloys . The loosening of a bolted joint connection is a common structural failure mode. They reported a real-time condition monitoring and active control methodology for bolted joints in civil structures and components. They used an impedance-based health-monitoring technique which utilizes the electro mechanical coupling property of piezoelectric materials to identify and detect bolt connection damage. When damage occured, temporary adjustments of the bolt tension could be achieved actively and remotely using shape memory alloy actuators. Specifically, when a bolt connection became loose, the bolted members can moved relative to each other. The heat produced by this motion caused a Nitinol washer to expand axially, thereby leading to a tighter, self-healed bolt connection.

Hagood and von Flotow (1991) established the analytical foundation for general systems with shunted piezo electrics. Their work characterised the electro mechanical interactions between a structure and the attached piezo network, and offers some experimental verification. Davis and Lesieutre (1995) extended previous studies by using the modal strain energy approach to predict the structural damping produced by a

network of resistively shunted piezoceramic elements. Using this approach, the amount of added damping per modecaused by an individual ceramic element can be computed. It was also demonstrated that increased damping could be achieved in several modes simultaneously via proper placement of the piezo ceramics. Demonstrates the effectiveness of shunted piezo electricity for three different resistance values. A structural vibration control concept using piezoelectric materials shunted with real-time adaptable electrical networks has also been investigated by Wang et al. (1994). Instead of using variable resistance only, they implemented variable resistance and inductance in an external RL circuit as control inputs. They created an energy-based parametric control scheme to reduce the total system energy while minimising the energy flowing into the main structure. Furthermore, they proved stability of the closed-loop system and examined the performance of the control method on an instrumented beam.Hagood and von Flotow presented a passive damping mechanism for structural systems in which piezoelectric materials are bonded to the structure of interest.

In previous days health monitoring concept was limited to electrical and mechanical systems. In present days, it is extended to large civil structures also. Civil engineering structures are huge, heavy, expensive and more complex than electrical and mechanical systems. The need for quick assessment of state of health of civil structures has necessitated research for the development of real time damage monitoring and diagnostic systems.

2.2 TECHNIQUES OF HEALTH MONITORING

2.2.1 Conventional Techniques for Structural Health Monitoring

(a) Static response based techniques

This technique was formulated by Banan et. al. (1994). In this method static forces applied on structure and corresponding displacements are measured. It is not necessary to select the entire set of forces and displacements. Any subset could be selected, but a number of load cases may be necessary in order to obtain sufficient information for computation. Computational method based on least scale error function between model and actual measurement is used. The resulting equations are to be solved to arrive at a set of structural parameters. Any change in the parameters from the base

line healthy structure is an indicator of damage. The short comings of this technique are measurement of displacements is not an easy task. It requires establishment of frame of reference. Employing a member of load cases can be very time consuming. Besides, the computational effort required by the method is enormous.

Sanayei and Saletnik (1996) proposed a technique based on static strain method. The advantage of this technique is strain measurement can be made accurately compared to displace measurement. Although the method has some advantages over the static displacement method, its application on real life structures remains tedious.

(b) Dynamic response based techniques

In this method structure is subjected to low frequency vibrations, and dynamic response of the structure are measuredand analysed. By this analysis a suitable set of parameters such as modal frequencies, and modal damping, and mode shapes associated with each modal frequency. changes also occur In structural parameters namely the stiffness matrix and damping matrix. In this method structure is exited by appropriated means and the response data processed to obtain a quantitative index or a set of indices representative of the condition of the structures.

These techniques have advantageous over static response since they are comparatively easier to implement. Few methods using low frequency dynamic technique are described below.

Casas and aparcio (1994) presented a method of localizing and quantifying cracks in bridges based on the first few natural frequencies and mode shapes extracted from the dynamic response measurements.

Zimmer man and kaouk (1994) developed this damage detection method based on changes in the stiffness matrix. The stiffness matrix is determined from mode shapes and modal frequencies derived from the measured dynamic response of the structure.

The stiffness matrix matrix [K] may be expressed in terms of mode shape matrix [□],

The mass matrix [M], and the modal stiffness matrix [□].

[K] = [M][□□][□□]^T[M]

3. METHODOLOGY:

3.1 PIEZOELECTRICITY AND PIEZOELECTRIC MATERIALS

The unique property of piezoelectric materials to play the dual roles of actuators and sensors is utilized in this particular application.

Piezo electricity is the effect of interaction between electrical and mechanical systems. it occurs in certain type of anisotropic crystals, in which electrical dipoles are generated upon applying mechanical deformations. The same crystals also exhibit the converse effect, that is, they undergo mechanical deformations when subjected to electric fields. This phenomena was discovered by Pierre and Paul-Jacques Curie in 1880.

Present research is "FINITE ELEMENT MODELLING OF SMART STRUCTURES". Particularly working of structure with piezo electric patch was studied. That's why these things were discussed in detailed manneras follows.

Theprinicipalcommerciallyavailablepiezoelectricmaterialsare

1. Piezoceramics,suchasLeadZirconate Titanate(PZT).
2. Piezopolymers,suchasPolyvinvylidene Fluoride(PVDF).

3.2 FUNDAMENTAL PIEZOELECTRIC RELATIONS

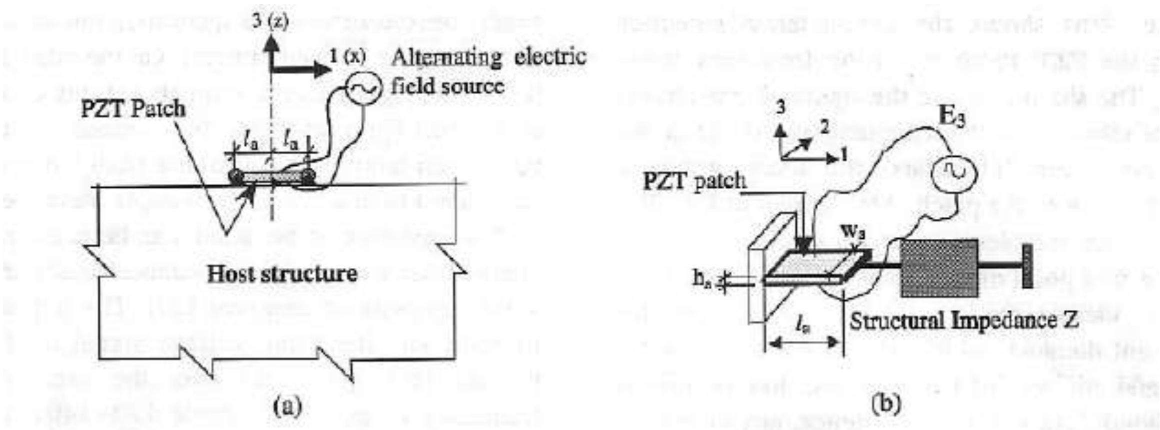


Fig 3.1 (a) APZT bonded to the structure (b) Interaction model of one half of PZT and host structure. (Bhalla and Soh (2002)).

Consider a piezoceramic actuator bondedto host structureas shown in fig 3.1 by means of high strength epoxy adhesive and electrically excited by means of impedance analyzer . It is assumed that the patch expands and contracts in direction 1only when the electric field is applied in direction 3. h_a, l_a and w_a are the thickness,length, andwidth respectively of the PZT patch. T is stress applied in direction 1, and E_3 is the electric field applied in direction 3.

Fundamental relationships of the PZT patch may be expressed as (Ikeda, 1990)

$S_1 = \frac{T_1}{Y_{11}^E} + d_{31} E_3$ (3.1)

$D = \varepsilon^T E + dT$ (3.2)

where

S_1 = strain

D_3= electric charge density over PZT

$Y = Y_{11}E\,(1+\eta j)$ is the Young's modulus of the PZT patch at zero electric field.

η = mechanical loss factor

ε_{33} = T ε (1-δj) is the complex permittivity of the PZT material at zero stress

δ = dielectric loss factoFor d_{31} first subscript signifies the direction of electric field and second subscript signifies the direction of the resulting stress or strain.

3.3 PRINCIPLE AND METHOD OF APPLICATION

As suggested by Sun et al(1995) by inducing an alternating current source, pzt patch Imposes a dynamic force on the structure it is bonded to. The structural response in turn modulates the current flowing through the PZT i.e. affects the electrical Admittance. The electrical admittance is therefore is a unique function of the mechanical impedance of the structure at the point of attachment. Any variation in mechanical impedance will alter the electrical admittance, which can be used as an indicator of damage. A frequency range is selected for extracting conductance as a function of frequency. This is called conductance signature. This frequency is kept typically high, in the order of kHz using an impedance analyzer. The conductance signature is recorded for the healthy structure as a bench mark. At any subsequent state, when structure health is required to be assessed, the procedure is repeated. If any change in signatures is found, it is an indication of damage.

The surface bonded piezoelectric patches, because of their inherent direct and converse mechatronic coupling, can be effectively utilized as mechatronic impedance transducers (MITs) for SHM. The MlT –based technique has evolved during the last 8 years and is commonly called the electro mechanical impedance (EMI) technique in the literature.

3.3.1 Description of EMI Technique

The PZT patch is assumed to be infinitesimally small and possessing negligible mass and stiffness as compared to host structure. When an alternating electric field is applied to PZT patch it expands and contracts dynamically in the direction '1'. As shown in fig 3.1 (b) Hence two end points of the patch can be assumed to encounter equal mechanical impedance Z from the host structure.

Liangetal. (1994) solved the governing equilibrium equation for the system shown in fig 3.1(b), using impedance approach. Using Liang's derivation following

Equation can be written for the complex electro mechanical admittance $\bar{Y}$ (inverse of electrical impedance), of the coupled system shown in figure 3.1.

$Y= 2\,\omega j.WL/h.[\in^{T}_{33}+Z_a/(Z+Z_a)\, d_{11}^2\, Y^{E}$

d_{11} = piezoelectric strain coefficient,

Y^{E} = complex Young's modulus of the PZT patch at constant electric field

$\in^{T}_{33}$ = complex electric permittivity of the PZT material at constant stress.

Z = mechanical impedance of the structural system

Z = mechanical impedance of the PZT patch

ω = angular frequency

k = wave number.

Equation (3.3) is used in the damage detection in the EMI technique .The mechanical impedance Z in the equation isa function of structural parameters i.e. the stiffness, the dampingand mass. Any damage to the structure will cause these parameters to change, and hence changes the mechanical impedance Z. consequently,

Electro mechanical admittance *Y*, will under go change, and servesas an indicator of state

of health ofthe structure. Z cannot be measured easily but *Y* can be measured easily by using an electrical impedance analyzer. The measured admittance is a complex quantity consists ofreal and imaginary parts, the conductance (*G*) and the suceptance (*B*), respectively. The real partactively interacts with the structure and is therefore preferred in SHM applications. A plot of G over frequency serves as a diagnostic signature of the structure and is called the conductance signature.

3.3.2 Damage quantification

Health of the structure can be known by visualizing the healthy signature and signature obtained after some period whenhealth monitoring is needed. But to quantify changes in signature due to damage, there are few techniques such as wave form chain code (WCC) technique, the signature assurance criteria (SAC), adaptive template matching (ATM), equivalent level of degradation system, root mean square deviation technique (RMSD) etc.

R.M.S. deviation of the signature was defined by Giurgiutu and Roger (1998a)

$$RMSD\,(\%) = \sqrt{\frac{\sum_{i=1}^{i=n}(w_i-u_i)^2}{\sum_{i=1}^{i=n}u_i^2}}\times 100 \qquad (3.4)$$

where,$i=1$

u_i i-1,2,3,….,N is a base line signature and

w_i i =1,2,3,….,N is the signature obtained after a period of time.

3.3.3. Improvements of EMI technique in recent years

Major developments and contributions made by various researchers in the field of EMI technique during last ten years are summarized as follows. (Park et al., 2003b)

(1) Application of EMI technique for SHM on a lab sized truss structure was first developed by Sun et

al.(1995). This study was then extended to a large scale prototype truss joints by Aryes et al.(1998).

(2) Lopes et al. (1999) trained neural networks using statistical damage quantifiers (Area under the conductance curve, root mean square (RMS)of the curve, rooy mean square deviation(RMSD) between damaged and undamaged curves and correlation coefficients) using experimental data from a bolted joint structure.

(3) Park et al.(2000a) reported significant proof of concept applications of EMI technique on civil structural components such as composites reinforced

massonary walls, steel bridge joints and pipe joints. The technique was found to be very tolerant to mechanical noise and also to small temperature fluctuations.

(4) Park et al. (2000a) extended the EMI technique to high temperature applications (typically>500^0c), such as steam pipes and boilers in power plants. Besides he also developed practical statistical cross section correlation based methodology for temperature compensation.

(5) Soh et al. (2000) established the damage detection and localization ability of piezo impedance transducers on real life RC structures by successfully monitoring a 5m span RC bridge during its destructive load testing.

(6) Park et al.(2000b) were integrated the EMI technique with wave propagation modeling for thin beams (1D structures) under ‘free-free’ bopundary conditions, by utilizing axial modes. The conventional statistical indices of the EMI technique were used for locating damage in the frequency range 70-90 KHz.

(7) After the year 2000, numerous papers appeared in the literature demonstrating successful extension of the technique on sophisticated structural components such as restrengthened concrete members and jet engine components under high temperature conditios (Winston et al., 2001).

(8) Inman et al. (2001) proposed a Novel techniqueto utilize a single PZT patch for health monitoring as well as for vibration control.

(9) Abe et al.(2002) developed a new stress monitoring technique for thin structural elements (such as springs, bars and plates) by applying wave propagation theory to the EMI measurement data in the moderate frequency range (1-10KHz).

(10) Giurgiutu et al.(2002) combined the EMI technique with wave propagation approachfor crack detection in aircraft components. While EMI technique was employed for near field damage detection, the guided ultrasonic wave propagation technique (pulse echo) was used for far field damage detection.

3.4 ADVANTAGES OF EMI TECHNIQUE

(1) EMI technique shows greater damage sensitivity than the global SHM techniques. It does not need expansive hard wares like the ultrasonic techniques.

(2) The PZT patches possess negligible weight can be bonded non-intrusively on the structure. No need to dismantle the structure.

(3) As PZT can be used both as actuator and sensor, reduces the number of transducers and eliminates complicated wiring .

(4) The PZT patches are available at very low costs, hence can be used at any number of locations.

(5) This technique does not need to interfere the functioning of structures.

(6) The method can be implemented at any time in the life of a structure.

(7) Since PZT patches are commercially available and portable, there are used in wide range of applications.

3.5 LIMITATIONS OF EMI TECHNIQUE

1. since the sensing zone PZT patch is limited to 0.4 to 2m only, thousands of PZT patches are required for real life monitoring of civil engineering structures like bridges and multi storied buildings.

2. This technique does not give the over all stability of structure. Since civil engineering structures are of indeterminate in nature, occurrence of cracks at some places may not affect the overall stability of structure.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 04 | April - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

RESULTS

The following results were obtained from numerical Analysis of Finite element model of RC Lab sized frame as part-1 of the project.

Fig. 4.5 shows the results of the numerical process when approached with 10mm, 5mm and 3 mm. sizes of the elements.

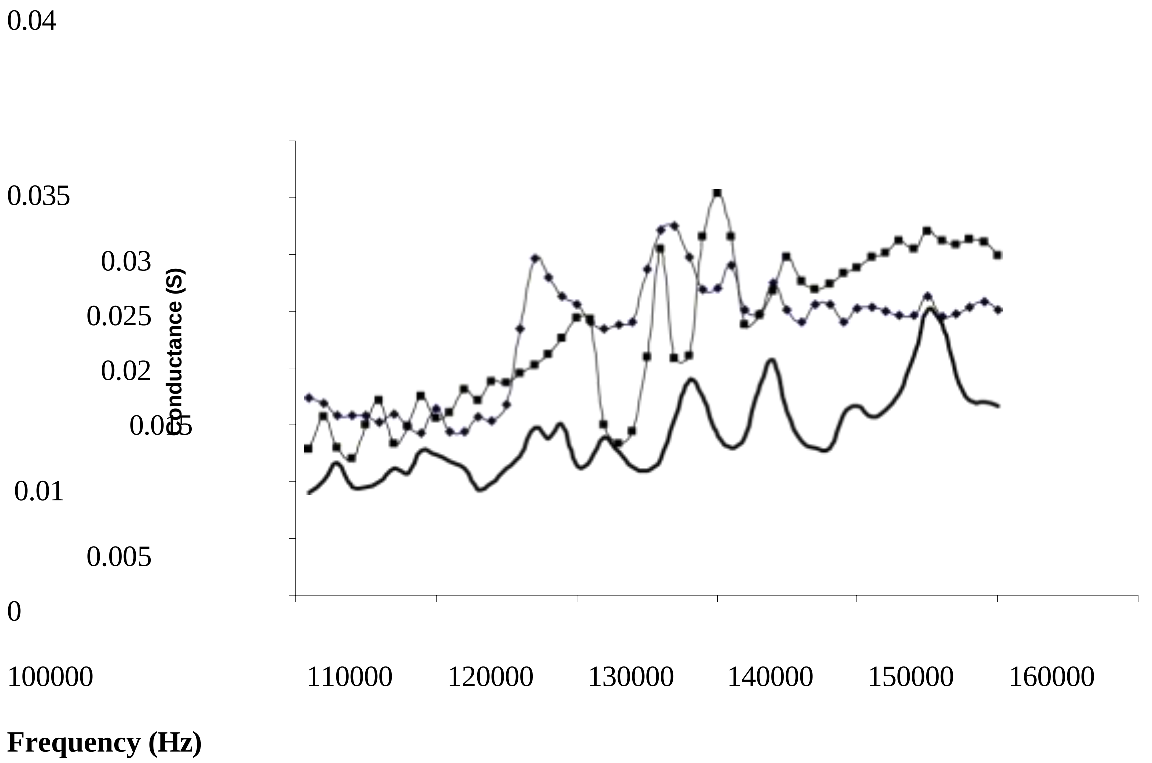
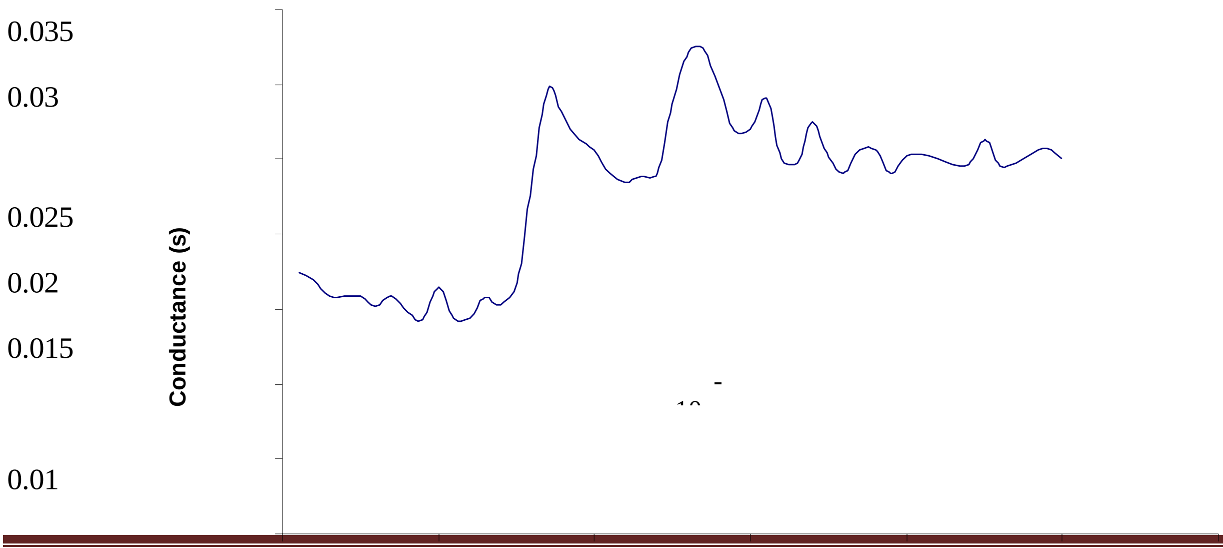


Fig 4.5 Conductance signatures using 10mm, 5mm and 3mm size of the elements.

From the figure 4.5 it is observed that pristine signature using 3mm elements converged with pristine signature corresponding to the 5mm elements. This is justified by the fact that most of the curve patterns are similar for these mesh sizes. Hence conductance signature obtained using 3mm element is considered as conductance signature of the RC model frame .This can be compared with the experimental signature shown in Fig 4.7 (Bhalla & Soh, 2004)



0.005

0

100000 110000 120000 130000 140000 150000 160000

Frequency (Hz)

Fig 4.6 Numerical conductance signature of the pristine frame model.

Experimental Healthy conductance signature

Signature obtained by Bhalla (2003) is shown in fig. 4.7.

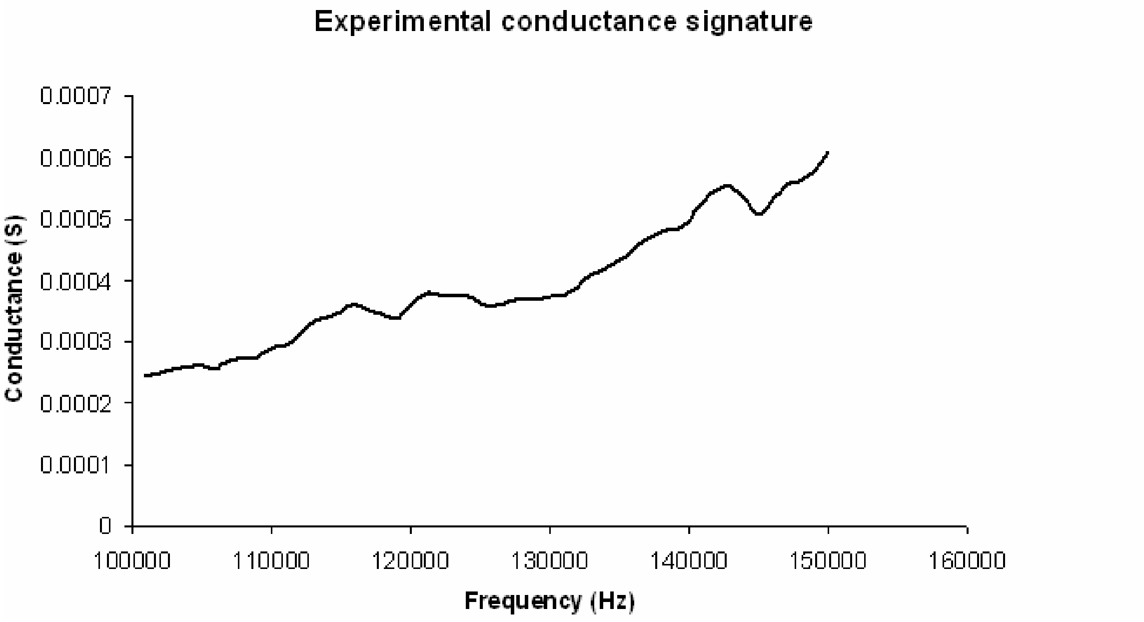


Fig 4.7 Experimental conductance signature of the pristine frame model. (Bhalla and Soh 2003).

4.4 COMPARATIVE STUDY

Discussions:

It is observed from the Fig 4.6 & 4.7 that simulated and experimental signatures are more are less similar in nature. Peak conductance in the both signatures occurs at quite close at same frequencies (117 and 127 kHz). Although the magnitudes are different, the results show much improvement than Tseng (2004) and Giurgiutiu & Zagrai (2002) results. In case of Tseng (2004), peak conductance in experimental and simulation curves did not coincide at same frequency. In the case of Giurgiutiu & Zagrai (2002), the conductance varied by nearly 100 times. But in the present study, conductance varied by 65 times only. The variation is due to high frequency effects which could not be included in the analysis and variation of damping of concrete. From dynamic analysis point of view, the damping of concrete might varied from 2% to 6%.

CONCLUSIONS:

(1) On this project, Finite element model for an RC lab sized frame was developed using ANSYS 9 software, for which experimental results are obtained by Bhalla and Soh (2004). Self equilibrium harmonic forces of 100 kN were applied at PZT location and Harmonic analysis was carried outat a frequency range of 100 kHz to 150 kHz. Translational displacements were obtained at PZT patches in the direction ofapplied forces at an interval of 1 kHz. Electrical admittance was obtained at each 1 kHz interval. Conductance signature for the PZT patch was drawn and compared with experimental signature. The patterns of both signatures was observed as same manner. Both signatures obtained the peak conductance at the identical frequencies. But there is a variation in magnitude. These variations are due to high frequency analysis, boundary effects and uncertainty of concrete damping.

(2). By reducing the young's modulus of elements in some locations the effect of different types of cracks was introduced. And again procedure was repeated and conductance signature of damaged state was obtained. Effect of different types of damages was clearly demarcated by the conductance signatures. Numerically obtained healthy and damaged signatures followed the same pattern as that of experimental results. Both experimental and numerical conductance signatures showed the peak conductance at identical frequencies. It is found that PZT patches can easily detect damages as far as 150mm. The results obtained by Giurgiutiu and Zagari (2002) are shown a variation of 100 times with the experimentals. But in the present research, the deviation t was around 20 times only. Hence, this is the better simulation compared to earlier researchs.

(3) This numerical simulation is useful in future researches in smart structures concept. Using these simulations tedious experimental works can be avoided. It leads to saving of time and economic resourcse. According to Tseng and Wang (2004) detection of damage by a PZT patch limited to 500mm from the PZT patch. Therefore for large

civil engineering structures require more number of PZT patches and impedance analyzers are required . This difficulty can be overcome by using numerical simulation method. Using simulation method, conductance signature for various damage patterns can be studied with out subjecting the structure to any cracks.

5.2 RECOMMENDATIONS

1. Research in area of smart structures can be handled at an ease with this numerical modelling.

2 The conductance signature patterns for various types of damages and for damages which cannot be studied in laboratory can obtained by numerical modeling.

3. Challenging tasks like modelling of piezo electric coupling in shell or plate structures can be performed in this manner.

4. Fracture analysis in the presence of coupled behavior is another critical aspect to be studied with help of numerical modeling

5. The modelling of full material nonlinearities and the modelling of full coupling between smart structures and liquids might be mentioned as possible examples for future research.

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