“Analysis of health monitoring system for different structures and its application”

B. TECH THESIS

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Analysis of Health monitoring system for different structure and its application.

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A Thesis submitted in partial fulfilment of the requirements for the degree of

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CERTIFICATE

This is to certify that the thesis entitled "Analysis of Health monitoring system for different structure and its application" submitted by Brijesh Kumar Yadav (Roll No: 1519200038) in the partial fulfilment of the requirements for the award of Bachelor of Technology degree in Civil Engineering at G.L Bajaj Institute of Technology and Management, Greater Noida is an authentic work carried out by them under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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ABSTRACT

Structural health monitoring (SHM) is a term increasingly used in the last decade to describe a range of systems implemented on full-scale civil infrastructures and whose purposes are to assist and inform operators about continued 'fitness for purpose' of structures under gradual or sudden changes to their state, to learn about either or both of the load and response mechanisms. Major structures like buildings, bridges, dams are subjected to severe loading and their performance is likely to change with time. It is, therefore, necessary to check the performance of a structure through continuous monitoring. If performance deviates from the design parameters, appropriate maintenance is required. The life of a structure depends on initial strength and the post construction maintenance. It is for this reason that the necessity of structural health monitoring (SHM) is emphasized worldwide. There are several techniques to monitor the health of structures. These can be divided broadly into two types, global and local.

This paper presents a system that can be used to measure or detect the parameter such as vibration, deflection etc. in order to monitors the health of structural elements such as beam. Such rapid and reliable detection of impairments enables the development of better risk management strategies to prevent casualties in case of earthquake and floods. There are different types of sensors which can be used for SHM. In general, the performance of PZT sensor is better than other sensors and is also very cost effective. In this study, PZT knock have been used as sensors for both global and local level damages. PZT knock sensor is made up of ceramic material which has been used to detect the vibration. A simple low-cost experimental technique has been developed to detect the physical parameter and the value obtained from sensor output has been verified with theoretical one. A case study has been done on the steel beam in the laboratory.

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List of symbols

V_i	input voltage
I_0	output current,
ε ̄33T	geometry constant
d3x2	complex dielectric constant of the PZT at zero stress
YxxE	piezoelectric coupling constant,Young's modulus
Z_I	reference impedance measurements taken in healthy state of the building
	the current impedance measurement
ω_i	frequency value

Chapter 1

Introduction

1.1 General

In civil engineering field, all design codes enforce the use of safety factors and various analysis and design procedures to make sure that the structure is safe and serve satisfactorily during its design period but the built structures may experience extreme loading conditions, like earthquakes, strong winds etc during its design period. The structure may be able to withstand them, suffering minor damages or, in the worst case, collapse but even if a structure manages to withstand the loading it becomes crucial to examine its strength and load carrying capabilities to make sure no substantial damages have occurred. On the other hand, even if a structure is not exposed to extreme loads, it can weaken over the years due to deterioration, which if left unnoticed can grow into a major problem.

Civil infrastructure provides the means for a society to function and includes buildings, pedestrian and vehicular bridges, tunnels, factories, conventional and nuclear power plants, heritage structures, port facilities and geotechnical structures, such as foundations and excavations. Depending on the significance of structure, such structures have inspection, monitoring and maintenance programmes. The effectiveness of maintenance and inspection programmes is only as good when it has ability to reveal any deterioration to structure by continuous, online, real-time and automated systems. SHM has been used in some areas like oil industry, large dams etc where it has achieved great attention and research for installation.. Residential and commercial structures have received relatively little attention due to potential obligations and consequences of owners knowing about poor structural health.

The sustainability of civil infrastructures can be achieved by periodic and continuous assessment that necessitates easy and effective Structural Health Monitoring (SHM) tools and techniques. The conventional SHM procedures were laborious, time consuming and capital intensive specially in the case of large span bridges, heritage structures, monuments and elevated buildings of national importance. Traditional methods are not effective for rapid full-field monitoring and hence a radical monitoring approach is most needed. Since the last few decades, the focus has been raised in non-destructive testing in reinforced concrete as its application doesn't affect the structure. Currently, certain amounts of large-scale infrastructures have reached their design life. For damage detection in large-scale and distributed systems, employing large number of sensors is a popular trend as the thorough information can be obtained by densely implementing sensors in the structures. Thus structures, especially important structures, need continuous monitoring and evaluation on a regular basis and for that, use of an economical, flexible and accurate sensor is required.

1.2 Different structure damages and failures

The different civil structures such as buildings, dams, bridges and sewerage tunnels consists of an assembly of various members like columns, beams, slabs etc. Detection of structural damages in such member poses a great importance on the prevention of casualties caused by unforeseen structure collapse. Structural deficiencies causing collapses may occur because of earthquakes, dead loads, live loads, floods or ageing. These factors exert external forces on structural elements causing fracture generation. Two of the most influential external effects are bending moments and shear forces that provoke bending cracks and shear cracks, respectively . In a concrete building, bending cracks signal an on-going deficiency progression within the element. Therefore, monitoring the visible crack over time enables taking precautions. However, such process cannot be applied on shear cracks since they are formed abruptly . Shear cracks are capable of causing building collapse solely although they are usually formed besides bending cracks. To prevent casualties resulting from abrupt building collapse, utilization of systems that enable forecasting bending and shear cracks are vital .

Damage is defined as a change to the material and/ or geometric properties of the structural system, including changes to the boundary conditions and system connectivity, which adversely affect the system's performance (Farrar and Warden, 20 07). In most general term, 'failure' refers to any action leading to an inability on the part of a structure or machine to function in the intended manner (Ugural and Fenster, 1995). Structural failure refers to loss of the load-carrying capacity of a component or member within a structure or of the structure as a whole beyond a threshold. The ultimate failure strength of the material, component or system is its maximum load-bearing capacity. When this limit is reached, damage in the materials occurs, and its load-bearing capacity is reduced permanently, significantly and quickly. To avoid collapse/ accident, localized damage should be detected timely for taking appropriate measure. Any civil structure may fail when a structural component deforms excessively. Some of the failure of structural component such as beam, column, etc. are discussed below

Mainly two types of failure occur in beam

I. Flexural failure
II. Shear failure

Flexural strength is the property of material which is defined as the stress just before it starts yielding in flexural test. This type of failure is generally seen in the mid span of the beam due to larger deflection of the beam at mid span. Flexural failure can be brittle flexural failure when concrete yield before rebar and ductile failure can take place when rebars yield before concrete crushing. Shear failure can take place due to insufficient of shear resistance available between the materials.

Figure 1.1 Image showing flexural failure in beam

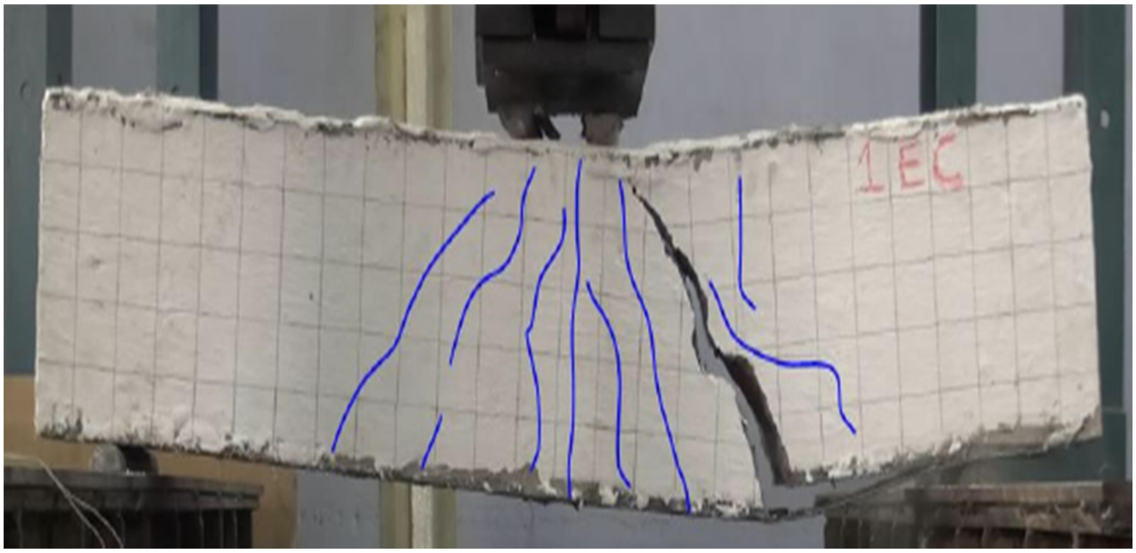


Figure 1.2 Image showing shear failure in beam

There are mainly two types of failure mechanism in column-

I. Buckling failure
II. Compression failure

Buckling failure can be seen in long column when slenderness ratio is more than 12. In such column for even small load, it becomes large enough to buckle the column in any side and more unstable structure. In compression failure, when applied load are high compared to cross sectional area of the column, the steel and concrete reach the yield stress and column is crushed without any lateral deformation.

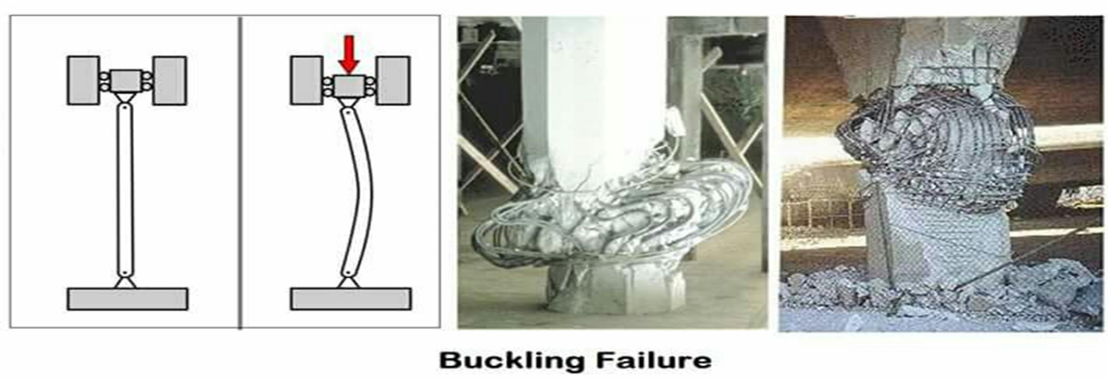


Figure 1.3 Image showing buckling failure in column

1.3 Recent structural damages and failure in India

1.3.1Kolkata-Majerhat-Bridge-collapse

A 50 year-old 66 foot deck bridge located adjacent to the Majherhat railway station in the Indian state of West Bengal collapsed on September 4, 2018 as shown in Figure no 1.4, resulting in the death of 3 people while injuring at least 25 others. Investigation committee found that the bridge lack regular monitoring, audit and maintenance.

Figure 1.4 Image showing Kolkata bridge collapse

1.3.2Bhagalpur-Flyover-collapse

A 150-year-old over bridge near the Bhagalpur railway station in the Indian state of Bihar was collapsed in December 2006 on the Howrah Jamalpur superfast express. The incident had led to the death of around 30 people. Investigation committee found that life of bridge was over and no monitoring was done about remaining strength and serviceability. It was also noted that the bridge was poorly maintained. Also as per "The Indian Express ",the Enterprises, which was awarded the contract to dismantle Ulta Pul and lay some roads near Bhagalpur railway station was responsible for it. One of the three span had been dismantled earlier, while another had collapsed on its own.

Figure 1.5 Image showing collapse of Bhagalpur flyover

1.3.3 Varanasi Bridge Collapsed

An under construction flyover bridge in Varanasi near cantonment railway station was collapsed in which 18 people were dead and several were injured. The investigating team said that the uninterrupted flow of traffic on the busy road was the main reason for vibrations that may have led to the collapse.

Figure 1.6 Image showing Varanasi flyover collapse

1.4 SHM-structural health monitoring

The process of implementing a damage detection and characterization strategy for engineering structures is called SHM.

SHM include following function:-

- ✓ Detection of Structural deficiencies using wireless sensor network.
- ✓ Send the data provided by the sensor mote to the data centre.
- ✓ Analyse the data collected and visualize the results.

SHM systems are used to monitor the physical status of critical structural elements, structure integrity and usually consist of multiple sensors placed on these locations, and microcontroller(s) responsible for environmental parameter measurement and data processing tasks. Statistical analysis of the measurement data gathered from sensors enables the assessment of current physical status of the structure. This way, structural problems can be detected earlier and thus, this provides better risk assessment. For monitoring tasks, the SHM systems may use various types of sensors depending on the parameters desired to be monitored. Moreover, the same kind of data may be measured using various types of sensors to increase reliability or availability. The performance within the target environment and the price of the sensor are the main criteria for sensor type evaluation.

Traditionally structural inspections, usually consisting of visual inspections, were carried out by trained or experienced individuals. In some special cases more advanced non-destructive methods such as eddy current, ultra sound, and other wave propagation based methods have also been used. The effectiveness of such inspections depends upon the accessibility of the structural location to be examined and to a large extent on the expertise of the individual conducting such inspections. Such approaches tend to be highly labour intensive and costly. The three key motivators to exploring an SHM strategy for a given infrastructure asset are to:

- increase user safety
- minimize cost (maintenance, replacement and/or downtime)
- maximize functionality (capacity, speed and service-life)

1.5 Structural health monitoring of railroad bridges

Railway is an important mode of transportation as it moves 8.26 billion passengers and transported 1.16 billion tons of freight daily. A key element of the rail network is bridges Extreme load events are a primary concern for bridges exposed to hazards. For example, bridges located in seismic regions are susceptible to ground motion which can lead to large lateral demands on bridges and residual displacements. This can be a serious issue for a number of reasons. Common damage mechanisms include vertical buckling, span displacements, and collapse of bridge piers. Undetected seismic induced damage can also render the bridge as unsafe for use by trains. The high live load-dead load ratio of rail bridges also leaves critical elements under an even greater risk of fatigue accumulation. The monitoring system is intended to be a permanent fixture on the bridge collecting data based on trigger events such as train loads and lateral motions. The monitoring system is interfaced to the Internet where data is pushed to an SQL data server for storage and data processing. An alert system is designed to alert bridge owners of extreme load events and excessive response of critical bridge components. In addition to notifying the bridge owner of potential safety issues, continuous monitoring of the bridge 68 response combined with traditional (visual) inspections will also assist in improving bridge 6 maintenance strategies.

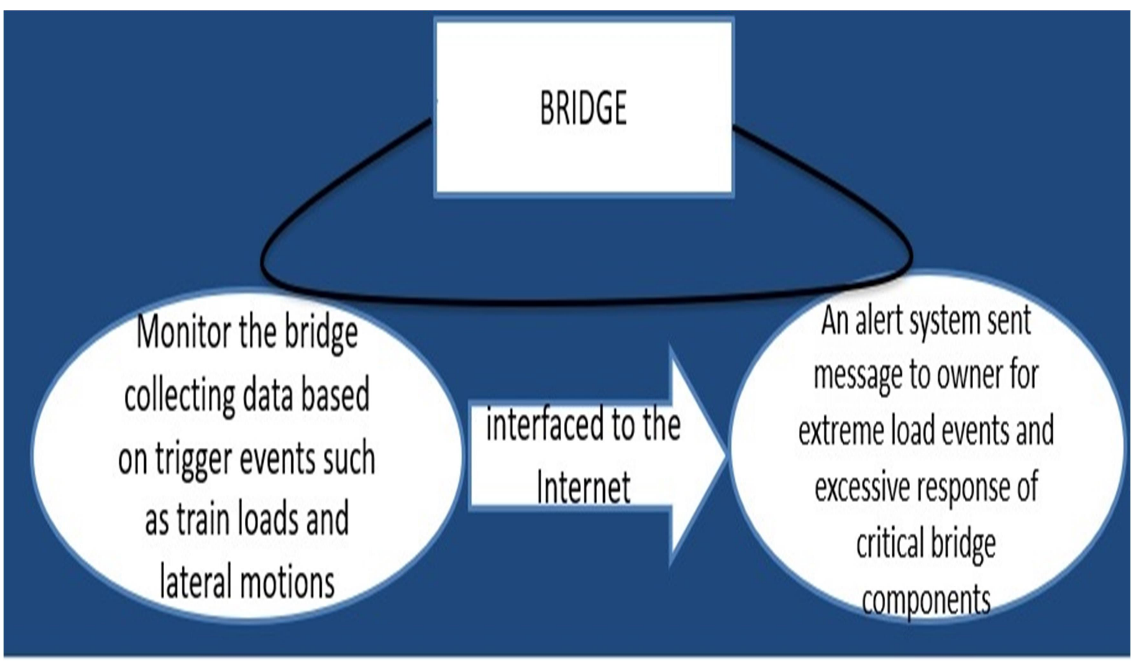


Figure 1.7 Block diagram for bridge monitoring

1.6 Need for SHM in India

Today India has been the developing country in terms of global market and more new structures are coming up in the field of civil engineering. Also India carries a burden of no of old structures which was built during British era and now which have been owned either by state or people. These old structures especially heritage building have known or unknown deficiencies which cannot be identified unless a disaster is experienced. However, it would be too late by then as the damage would have already happened. Apart from the old historic building like hospital, power, plant schools and commercial building may lead to loss of life of humans if the building suffers any damages due to calamity either natural or man-made.

Development of any nation largely depends on transportation facility. Huge amount is invested in transportation related infrastructure like construction of road, bridges, etc. The failure and damages of such structures which requires large investment may retard the development of any nation. Specially bridges can be monitored on regular basis to prevent damages.

1.7 Research gap

In this article, the various type of sensor used for health monitoring of different structural element have been discussed .Although, the above mentioned studies provide great effort to use SHM in civil engineering field but it has not provide any standard guidelines or data on the state of practice of SHM so that a structure can be classified as safe, unsafe or critical. Further it has not been discussed the optimum SHM methodology for rapid post –hazard assessment.

1.8 Objective

In view of above needs, this study aims to fulfill following objective:

- Optimize SHM methodologies for risk management, life-extension of aged structures and for rapid post-hazard assessment.
- Application of SHM
- To show the linear response of parameter used in beam using sensor system
- To measure the deflection of beam using sensor output and compares it with theoretical value.

Chapter 2

Review of Literature

2.1 General

This chapter presents a review of the investigations on SHM systems which are used to monitor the physical status of critical structural elements, structure integrity and usually consist of multiple sensors placed on these locations, and microcontroller responsible for environmental parameter measurement and data processing tasks. The performance within the target environment and the price of the sensor are the main criteria for sensor type evaluation. Integration of Wireless Sensor Network (WSN) technology into SHM applications provides many benefits in terms of cost, scalability, ease of deployment, and reliability. Besides these benefits, the migration from tethered to wireless systems require detailed consideration of battery lifetime. Therefore, the microcontroller to which sensor(s) attached are desired to have low power consumption.

A comprehensive review of the work done on structural health monitoring is presented in this chapter.

2.2 Methods of structural health monitoring

The methods can be grouped into two main categories, namely global and local structural health monitoring methods

Global structural health monitoring methods:-

This approach uses vibrational characteristics of the building to detect the presence of a structural problem. It is not capable of measuring small deficiencies, since it focuses on global vibrational characteristics

Local structural health monitoring methods:-

This uses propagation characteristics of a penetrating ultrasonic wave to locate the location of deficiency.it requires an extended network of sensors in large buildings.

There are two possible ways to realize WSN-based SHM applications.

Wireless communication:-This method requires sensor node to be directly connected to the data centre, which is usually provided via cellular networks.

Gateway:-This method requires the microcontroller to have only short distance communication with a gateway device responsible for forwarding data towards data centre. This method decreases the operational costs due to less number of SIM cards required. It also provides longer mote lifetime due to its low-power communication capability.

2.3 Sensor system

2.3.1 Ultrasonic waves or acoustic emission sensors

Ultrasonic sensor can be used to detect the deflection of beam. Fractures within a concrete structural element can be detected using ultrasonic waves or acoustic emission methods. However, such an approach requires trained personnel and takes a long time.

2.3.2 Strain gauge sensors

While there are several methods of measuring strain, the most common is with a strain gauge, a device whose electrical resistance varies in proportion to the amount of strain in the device. For example, the piezo-resistive strain gauge is a semiconductor device whose resistance varies nonlinearly with strain. The most widely used gauge, however, is the bonded metallic strain gauge. It is very important that the strain gauge be properly mounted onto the test specimen so that the strain is accurately transferred from the test specimen, though the adhesive and strain gauge backing, to the foil itself. Manufacturers of strain gauges are the best source of information on proper mounting of strain gauges.

A fundamental parameter of the strain gauge is its sensitivity to strain, expressed quantitatively as the gauge factor (GF). Gauge factor is defined as the ratio of fractional change in electrical resistance to the fractional change in length (strain). The Gauge Factor for metallic strain gauges is typically around 2. Ideally, we would like the resistance of the strain gauge to change only in response to applied strain. However, strain gauge material, as well as the specimen material to which the gauge is applied, will also respond to changes in temperature.

Working principle of strain gauge

It is based on the principle of Wheatstone bridge in which out of four resistance ,one is connected to strain gauge sensor. Initially the Wheatstone is balanced and hence there is any output in terms of voltage. When beam is subjected to load ,the upper surface of beam is in compression and the bottom portion is in tension. The tension in bottom portion of beam lead to elongation of metallic wire of strain gauge sensor . The more is the applied force, more is the increase in length of the wire .Further, as the length of the stretched wire increases, its diameter decreases. Now, we know that resistance of the conductor is the inverse function of the length. As the length of the conductor increases its resistance decreases. This change in resistance of the conductor can be measured easily and calibrated against the applied force. Thus strain gauges can be used to measure force and related parameters like displacement and stress. The input and output relationship of the strain gauges can be expressed by the term gauge factor or gauge gradient, which is defined as the change in resistance R for the given value of applied strain ε.

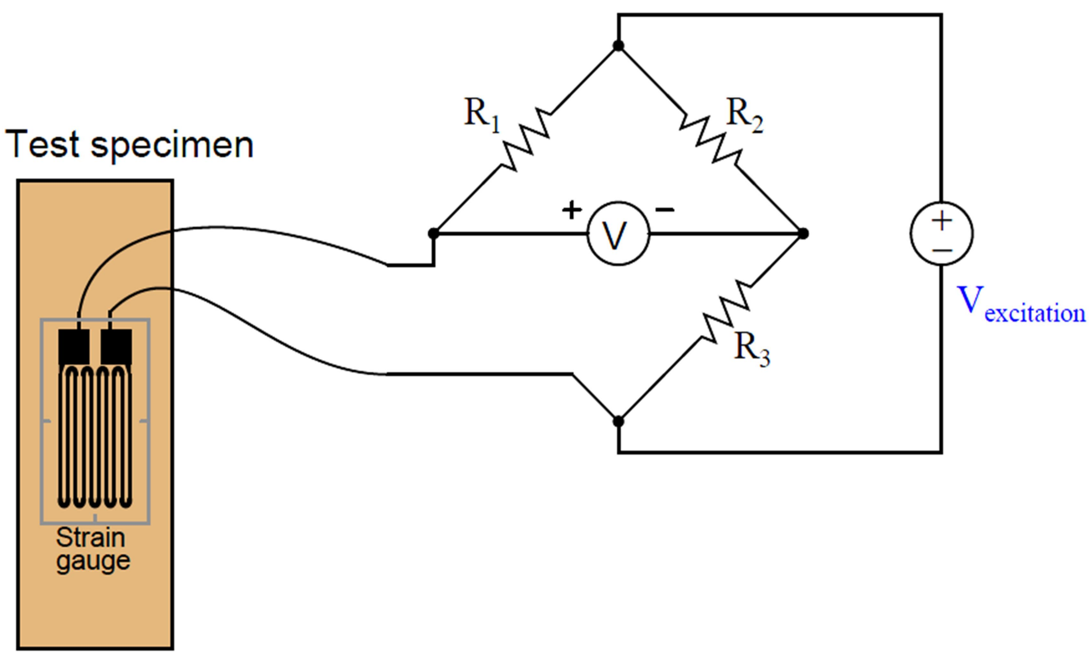


Figure 2.1 Image showing circuit diagram of strain gauge sensor

2.3.3 Piezoelectric (PZT) sensors

A piezoelectric sensor is a device that uses the piezoelectric effect, to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge. The prefix piezo- is Greek for 'press' or 'squeeze'. The piezo knock sensor can be used to detect the seismic vibration in the civil structure during earthquake.

2.3.4 Fiber optic sensors

It is of two types:

- Surface mounted optic sensors
- Embedded fiber optic sensor

Both surface mounted and embedded fiber optic sensors are utilized to monitor global and local health status of a high-rise building. According to the study, local and global behaviors of the building were successfully monitored. However, the study does not evaluate the detection reliability of the utilized method in case of an extreme situation since experiments are performed on actual buildings with residents.

In the authors test the feasibility of fiber optic sensor usage for SHM applications using a test bed that exerts variable levels of stress on a concrete block. As opposed to, the sensors are surface mounted. Results of the study show valuable findings including the validation of the capability of fiber optic sensor to successfully detect the cracks formed within the block.

2.3.5 Optical fibre sensors (OFS)

The use of optical fibre sensors (OFS) in RC structures for strain monitoring began in the 1980s, with several different implementations. Recent advances in sensors have provided alternative techniques for RC bond-slip monitoring some of them are an electromagnetic (EM) imaging technique, laser ultra-sonic waves, velocity dispersion analysis of ultra-sonic waves, Lamb waves, piezoelectric sensors and actuators embedded in RC.

FBG sensors can be used to measure the strain level and temperature strain inside RC. The present work details two OFS for RC bond-slip characterization and monitoring, one is incorporated into a silica optical fibre (SOF) and the other a polymer optical fibre (POF).

A FBG is a passive wavelength reflecting optical component, based on the modulation of the refractive index along the core of an optical fibre. Two prototypes of FBG optical sensors for bond-slip characterization of RC elements were developed and assigned as SOFBG (silica optical fibre Bragg grating) and POFBG (polymer optical fibre Bragg grating). FBGs are very interesting since it is possible to identify any changes in temperature and strain by analyzing the spectral shift of the reflected Bragg wavelength.

Components of sensors:-

- Each completed sensor unit is comprised of two metallic copper components (Fig. 3), with height of 32 mm, 5 mm thickness and 41 mm of total length.
- The superior component has an "L" shape with a hook placed at the center of the total length, whereas the inferior component has an "F" shape and a curvature (R = 5 mm) on the bottom surface.
- The superior and inferior surfaces are not in direct contact, and the minimum spacing between them is about 1 mm in the extremities. A transparent polyurethane resin (PU) layer was employed to fill the space between the two metallic surfaces and to embed the optical fibre sensor. Fig. 4

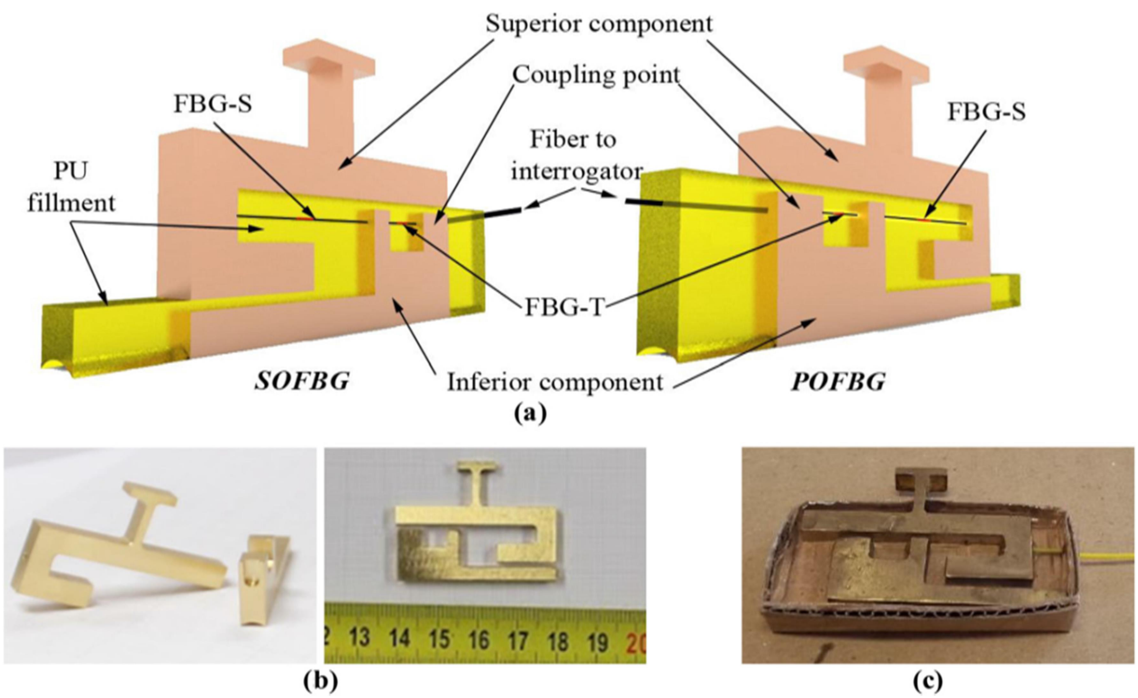


Figure 2.2 (a) Details of the bond-slip OFS; (b) image of the two parts (ruler for scale in cm) and (c) sensor after PU resin filling, inside a paper mould, without surfaces regularization.

Advantages of these sensors:-

The main advantages of the optical sensors are their high sensitivity and resolution, immunity to electromagnetic fields, passiveness (without electricity at the measuring point), small size and weight, resistance to harsh (basic or acidic) environments, and the possibility of real-time, bond-slip monitoring in RC structures.

- Polymer fibre sensor can stand up to higher strain values than the silica fibre sensor without yielding.
- Polymer fibre sensor is more suitable as bond-slip sensor than the silica fibre sensor, and in the future, more tests can be made to analyze the full potential of the other polymer fibres as bond-slip sensors.
- The structure surrounding the gratings was developed to be less intrusive as possible, making this sensor easy and practical to apply in RC constructions.

2.4 Different approach to SHM

There are different way to monitor the civil structure .Some of the way used by different person has been described below. Generally vibration based SHM have been used to detect the damages.

2.4.1 Column monitoring

Cem Ayyildiz et al. uses PZT sensor to monitor column and evaluate the data of sensor system to detect the structural deficiency. In this technique, the PZT sensor has been used to detect the fracture due to compressive load. The concrete column used in the tests incorporates Carbon Fiber Reinforced Polymer (CFRP) with 150 mm separation to increase the column performance and decrease the number of areas that are prone to fracture generation. This way, positioning of the sensors is made easier. Since the focus of this study is to evaluate the performance of the proposed method, using CFRP is crucial to diminish the time tests take enabling fracture generation close to the sensors.

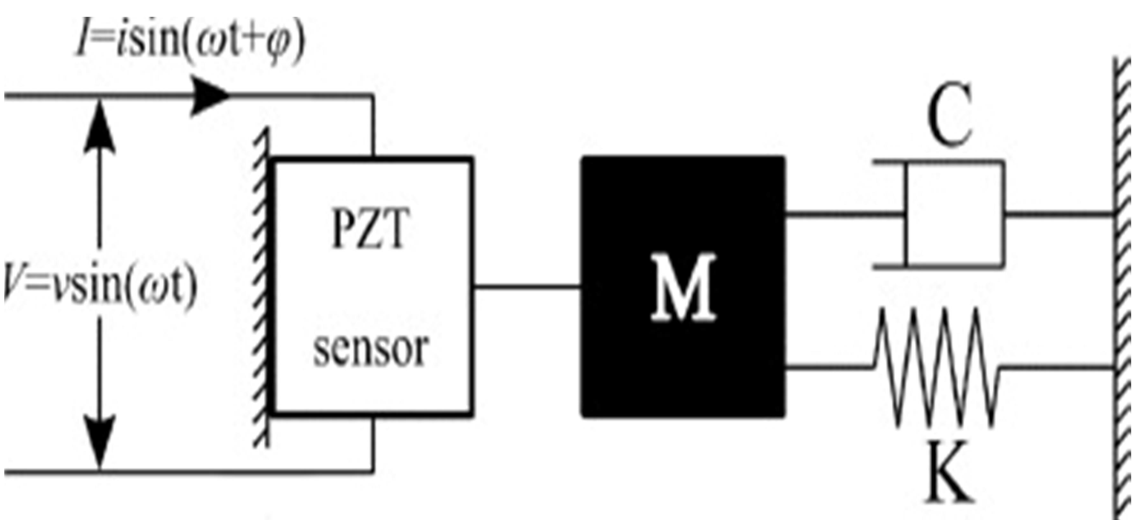


Figure 2.3 Image shows the model of the sensor

Using the model, the relation between the inverse of the PZT sensor impedance is formulated as:

$$Y(\omega) = \frac{I_0}{V_i} = j\omega a \left(\bar{\varepsilon}_{33}^{T} - \frac{Z_s(\omega)}{Z_s(\omega) + Z_a(\omega)} d_{3x}^{2} \hat{Y}_{xx}^{E} \right)$$

V_i and I_0 represent sensor input voltage and output current, respectively. Other parameters a, εε¯33T, d3x2, and YxxE represent geometry constant, complex dielectric constant of the PZT at zero stress, piezoelectric coupling constant,Young's modulus.

$$RMSD(\%) = \sqrt{\frac{\sum_{i=1}^{i=N} \left(Z(\omega_i) - Z_0(\omega_i)\right)^2}{\sum_{i=1}^{i=N} \left(Z_0(\omega_i)\right)^2}} \times 100$$

Z_0, Z_1 and ω_i represent the reference impedance measurements taken in healthy state of the building, the current impedance measurement and the frequency value, respectively.

The greater fluctuation in RMSD value will show that the column has undergone fracture. The back and forth movement of a Reinforced Concrete (RC) building during an earthquake may cause generation of fractures within its carrier elements. The fractures that do not result a collapse may still pose vital risks and should be detected and analyzed to decide the building's residual lifespan. In this study, a cyclic static force is applied to the short columns. To evaluate the detection results, PZT sensors are placed on positions both with and without fracture formation expectation. This way sensors detection capability at different distances to fractures is also evaluated.

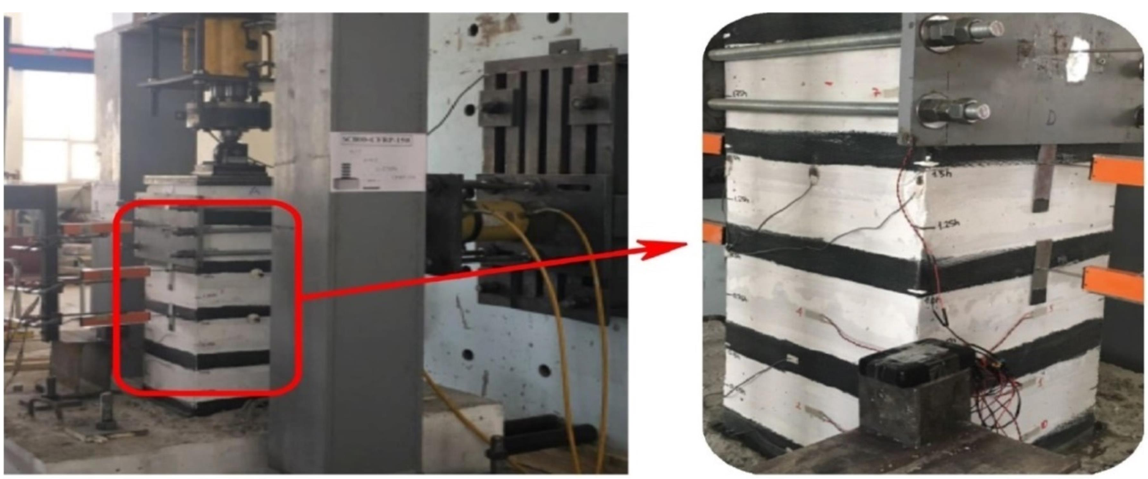


Figure 2.4 A view of crack development measured with PZT.

For measurements, 8 sensors attached to a single mote have been used. The sensors have been attached to the surface of the concrete block using a quick adhesive. The locations of the sensors have been selected near the areas that visible fractures would occur. While 4 of the sensors are attached to the front of the block that is compressed during pushing action, the rest is attached to the side of the block.

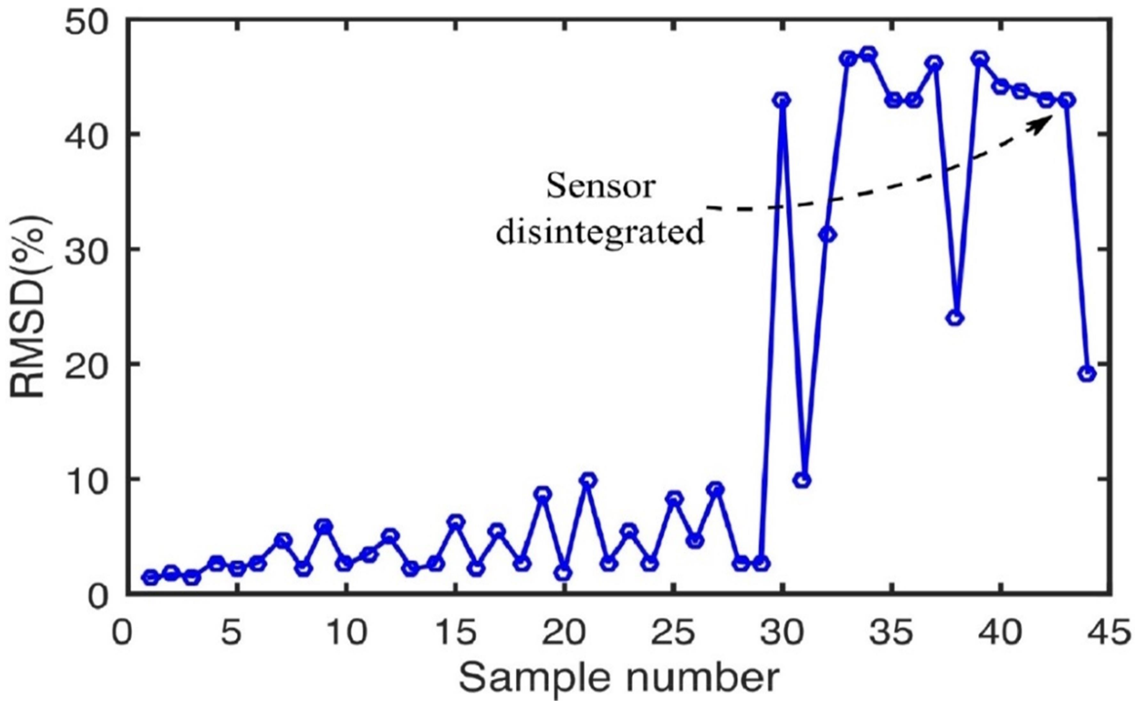


Figure 2.5 RMSD results for sensor

The results are shown in Figure 7 for single sensor. The main trend in all the resulting graphs shows fluctuations until 25th to 30th sample while the RMSD value increases abruptly beyond this point

The measurements taken from the front of the test column are focused on the fractures that are compressed during push forces. The compression causes fracture size to shrink thus lower RMSD values.

It has been shown that impedance measurement via PZT sensors provides an effective and cheap solution for fracture detection on RC buildings. To validate the method, forces have been applied on RC column to trigger fracture formation while taking impedance measurements via PZT sensors. Applying RMSD calculations on the collected data, the results show significant difference after the formation of visible fractures.

2.4.2 Bridge monitoring

D. Inaudi uses vibration characteristics to monitor the bridge. In this technique, accelerometer sensor along with pressure sensor and temperature sensor have been used to calculate the force such as static force as well as dynamic due to the movement of vehicle on bridge.

The Figure 12 shows the block diagram of the components of the Structural Health Monitoring System. The SHM system consists of a Microcontroller, Accelerometer, Pressure Sensor, Temperature Sensor, and Moisture Sensors which are placed at different places of an engineered structure.

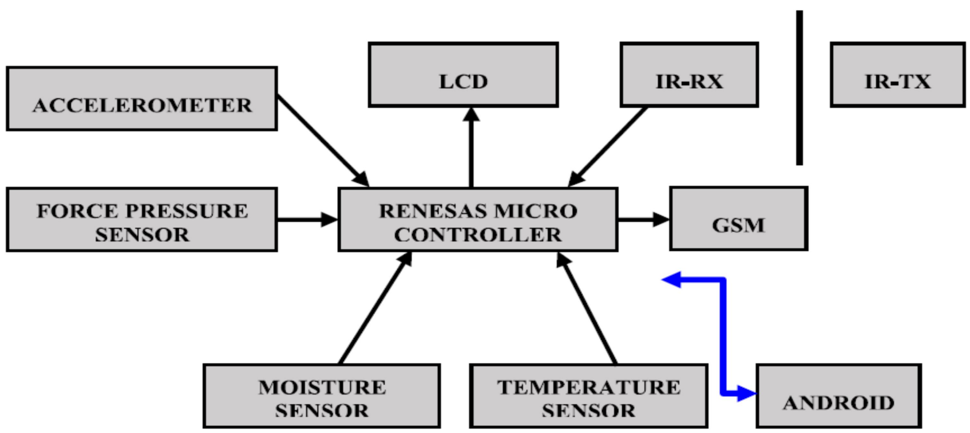


Figure 2.6 Block diagram for bridge monitoring

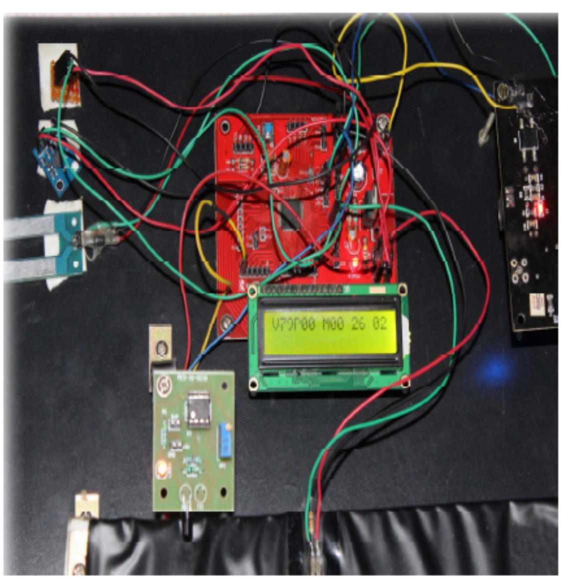
An Accelerometer sensor is used to measure acceleration forces. Such forces may be static, like the continuous force of gravity or, to sense movement or vibrations in bridge.

- The Moisture sensor U25 monitors the water absorption time of the road or wall.
- The Pressure sensor U33 senses the pressure or force applied on the bridges or walls of the building
- The Temperature sensor is mainly used to find temperature variations in an environment.
- The IR Obstacle LM358 is used to detect the obstacles and the temperature is sensed by the temperature sensor LM35.
- Renesas (RL78) is 16 bit architecture, it has 64I/O pin (R5F100LE). It has eleven I/O ports, 64KB ROM, 4KB RAM, watch dog timer,I2C protocol, three UART's, 10 bit ADC, eight Timers, on chip debug function, high speed on-chip oscillator.

- A liquid crystal display (LCD) is a flat panel display, electronic visual display, based on Liquid Crystal Technology liquid crystal display consists of an array of tiny segments (called pixels) that can be manipulated to present information
- IR (TX-RX) is mainly used to find the number of vehicles crossing the bridge.
- SIM900 is a Tri-band GSM/GPRS engine that works on frequencies EGSM 900 MHz, DCS 1800 MHz and PCS 1900 MHz SIM900 features GPRS multi-slot class 10/ class 8 (optional) and supports the GPRS coding schemes CS-1, CS-2, CS-3 and CS-4.
- AT Commands can be used to get information in SIM card. The SIM interface supports the functionality of the GSM.

Software Tools

- Cube Suite is an integrated development environment for microcontrollers, integrating the necessary tools for the development phase of software into a single platform. By providing an integrated environment, it helps to perform all development tasks, without the use of many different tools.
- Eclipse Kepler is an integrated development environment (IDE) used in computer programming. It contains a base workspace and an extensible plug-in system for customizing the environment..



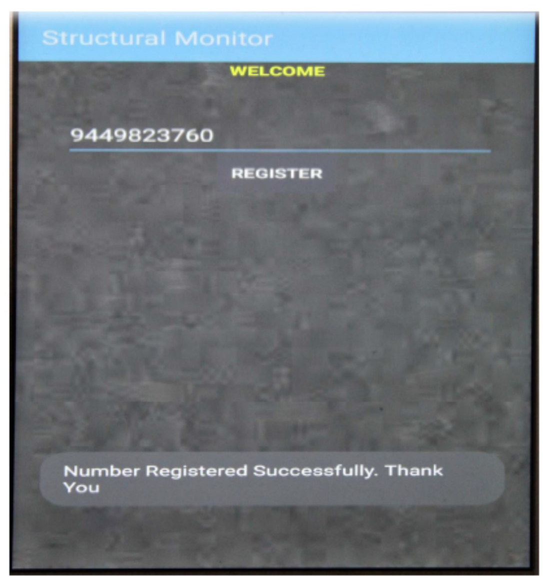


Figure 2.7 working model of SHM and Image showing the Registration process.

Initially, the microcontroller sends the command to all the sensors to start functioning. The microcontroller initiates the SIM for functioning of GSM. For every 30 seconds the sensor information is sent to the microcontroller. The Figure 9 shows the working model of SHM and shows the Registration process

The admin has to get registered to an android application. As soon as the verification of number is finished, the GSM sends the collected information to the admin through an android application. An android app contains a database called SQLite where the information will get updated for every 30seconds of duration. The Figure 9 shows the fetched measurement details from each sensor and the normal message sent to the registered phone number

The credentials used to represent the sensor parameters are - ‘V’ is used to represent vibrations, ’P’ is used for pressure, ‘M’ for moisture and ‘C’ for taking a count of number of vehicles. All the sensors in the system are provided with some threshold values. Once the threshold is reached a notification is sent to admin’s android device and the information will get updated in the SQLite database of an android application. The first data sensed from various sensor V78P00M00T26C02 indicates the sensors measurements as Vibration-78, Pressure-00, Moisture-00, Temperature- 26, count of Vehicle-02.

2.5.3 RC bond monitoring

Esequiel Mesquita et al. uses optical fibre sensor to examine the Bond-slip since it is an important interaction between steel and concrete in reinforced concrete (RC) structures and other civil engineering constructions. It is essential to understand and to characterize, at local level, this stress transference mechanism. In particular its behaviour for monotonic and cyclic demands, the parameters that influence this mechanism, and how it is affected by different deterioration factors. Therefore, characterizing and monitoring the bond-slip mechanism is essential for the safety assessment of RC structures, more specifically determining the reinforcing bars slippage inside the concrete, and therefore the stress and strain distribution in RC members.

In this work, two optical fibre sensors are presented, based on silica and polymer fibre Bragg gratings (FBGs), which were implanted inside a concrete block specimen and subjected to a pull-out test. After 6 days of curing, the pull-out test was recorded and the displacement incurred during the test was also monitored with a traditional electric sensor; for comparison with the data acquired with the two optical sensors. The results obtained confirm the viability and advantages of the optical sensors, evidenced by their higher resolution and far lower dimensions (allowing them to be embedded into the concrete) when compared with their electronic counterparts. The straight forward implementation and use of the optical sensors show very promising results when used in civil engineering structures. In this method, optical fibre sensor is to be used to measure the strain in reinforce rebar. A simple system was setup. A translational stage with a precision of 5 µm was used to apply controlled strain to the sensor, and the FBG response was recorded.

The experimental set up consisted of fixing the final sensor structure to two supports (Figure), one support used for strain characterization, was fixed and the other was attached to the translational stage.

The chamber's temperature and relative humidity precision is0.1◦C and 0.1%, respectively. The temperature was increased from 20.0◦C to 40.0◦C, in 5.0◦C steps, and at each step the stabilization time was 30 min.

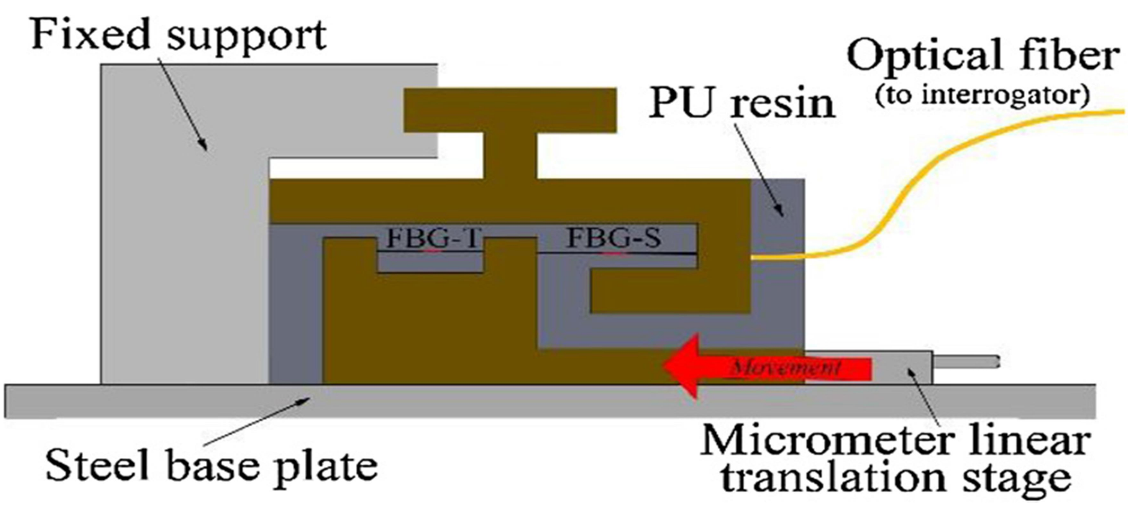


Figure 2.8 Set up used for strain characterization

The rebar was placed at the center of a formwork structure with dimensions of 0.2 × 0.2 × 0.4 m that was to be embedded in the concrete (Fig.) The distance between the sensors and the box's wall was about 0.10m. The box was filled with N35 concrete ("N35" is a parameter referring to the concrete curing type ("N" - normal) and its resistance to compression) and the cure process time was approximately 6 days.Linear variable differential trans-former (LVDT) was also placed at the bottom of the block to monitor the rebar displacement; this enabled comparisons between the different types of sensors. To perform the pull-out test, the reinforcing rebar was pulled vertically by a claw, with a displacement speed of 0.15 mm/s.

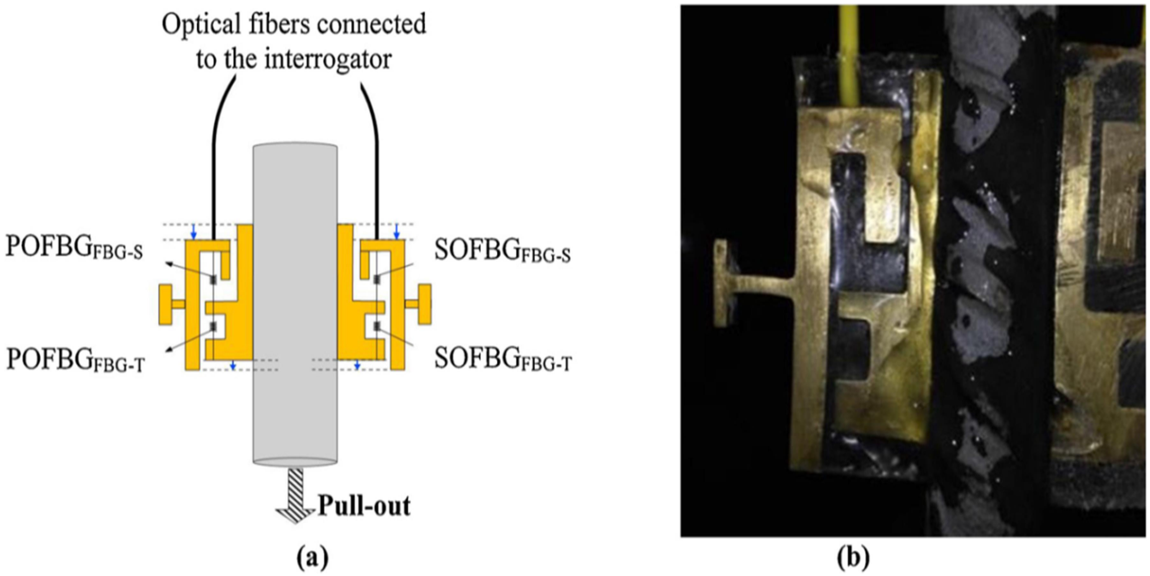


Figure 2.9 (a) Schematic of the sensors' position and (b) image of the sensors glued in opposite sides of the rebar.

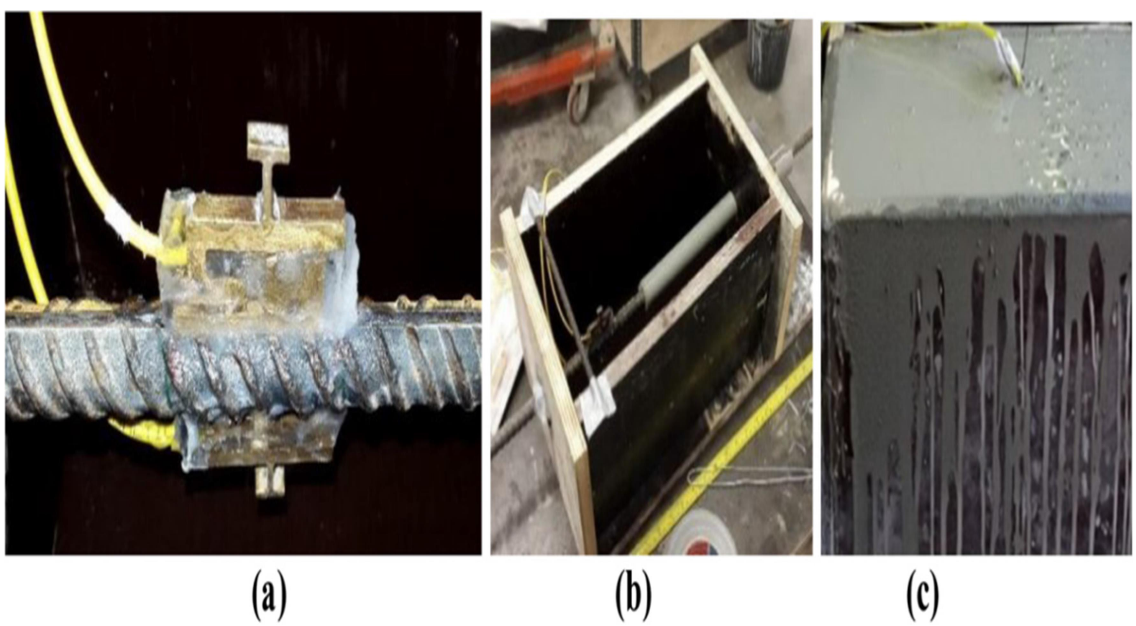
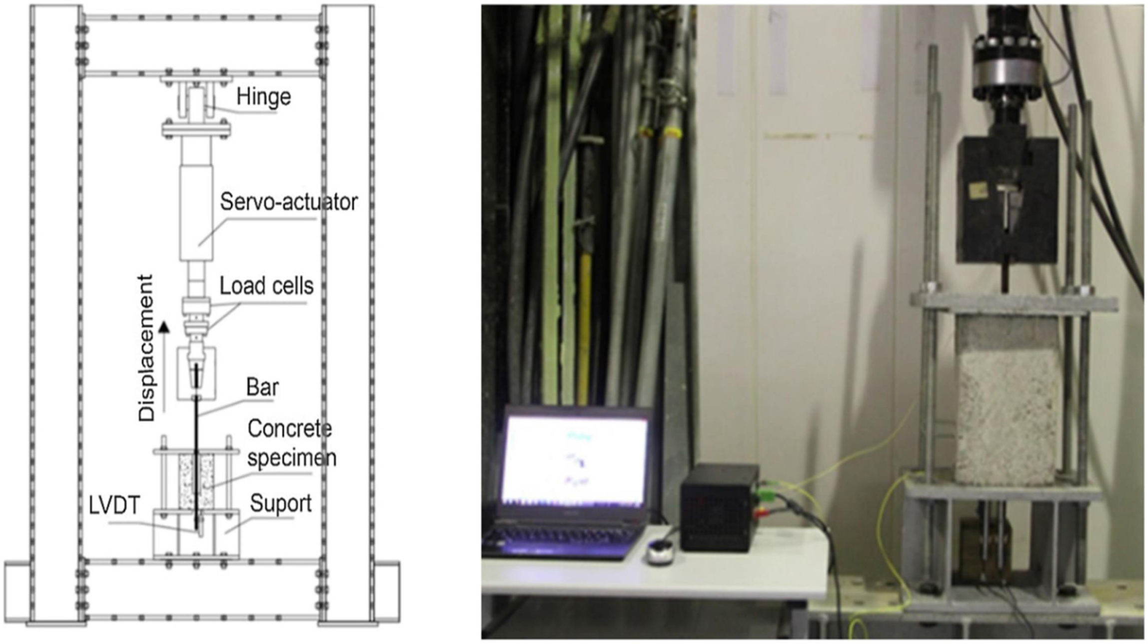


Figure 2.10 (a) Final aspect of the sensors fixed to the rebar; (b) formwork structure with the rebar and (c) formwork filled with concrete.



(a) (b)

Figure 2.11 Experimental setup of the pull-out testing: (a) details of the pull-out testing equipment and (b) system image.

Chapter 3

SHM System Overview

3.1. General

The SHM system developed in this work consists of PZT knock sensors to detect the vibration , temperature and humidity sensor to see the variation of temperature and humidity, ultrasonic sensor to measure deflection, an aurinido uno board for reading the sensor outputs, and USB device to forward the data provided by the sensor mote to the laptop.

3.2. PZT knock sensor connection

The black wire (the lower voltage) is connected to ground and the red wire (the higher voltage) is connected to analog pin 0. A 1-megohm resistor is connected in parallel to the Piezo element to limit the voltage and current produced by the piezo and to protect the analog input. Additonal ground is also provided. In order to connect more than two sensor ,a board was prepared

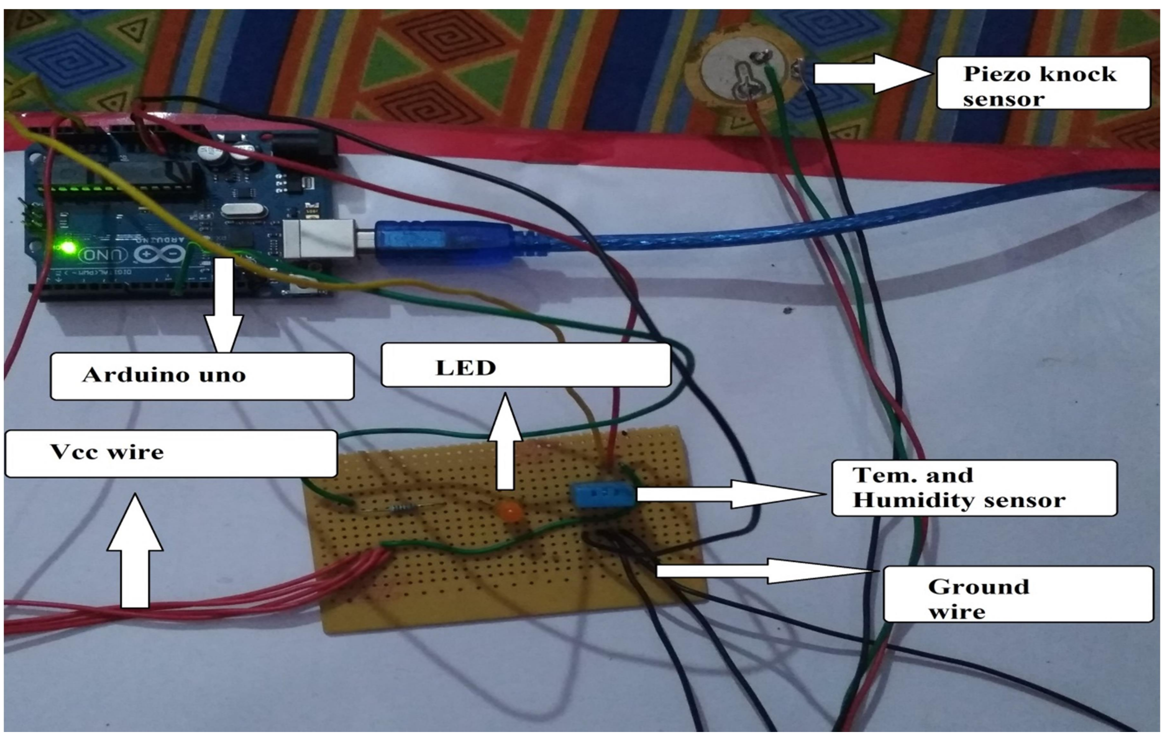


Figure 3.1 Image showing pzt knock sensor connection

Circuit Diagram

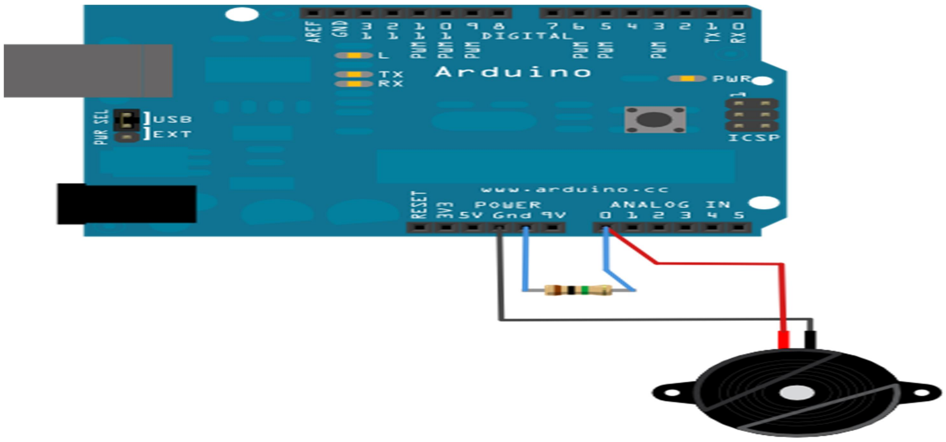


Figure 3.2 Circuit diagram of PZT sensor

Coding for Piezo-knock sensor

```
#include "dht.h"
#define dht_apin A0 // Analog Pin sensor is connected to
 int piezo_Pin= A1;
 int LED_Pin= 13;
dht DHT;
 int threshold=500;
void setup(){

  Serial.begin(9600);
  pinMode(LED_Pin, OUTPUT);
  delay(500);//Delay to let system boot
  Serial.println("DHT11 Humidity & temperature Sensor\n\n");
  Serial.println("Pressure value");
  delay(1000);//Wait before accessing Sensor

}//end "setup()"

void loop()
{
  //Start of Program

    DHT.read11(dht_apin);

    Serial.print("Current humidity = ");
    Serial.print(DHT.humidity);
    Serial.print("%  ");
    Serial.print("temperature = ");
    Serial.print(DHT.temperature);
    Serial.println("C  ");
    int reading= analogRead(piezo_Pin);
    Serial.print("Pressure Value:  ");
    Serial.println(reading);
    if (reading > threshold)
    {
      digitalWrite(LED_Pin, HIGH);
```

```
      digitalWrite(LED_Pin, LOW);
    }

    delay(1000);//Wait 5 seconds before accessing sensor again.

  //Fastest should be once every two seconds.

}// end loop()
```

3.3 Ultrasonic sensor connection

The HC-SR04 Ultrasonic Module has 4 pins, Ground, VCC, Trig and Echo. The Ground and the VCC pins of the module are connected to the Ground and the 5 volts pins on the Arduino Board respectively and the trig and echo pins to any Digital I/O pin on the Arduino Board.

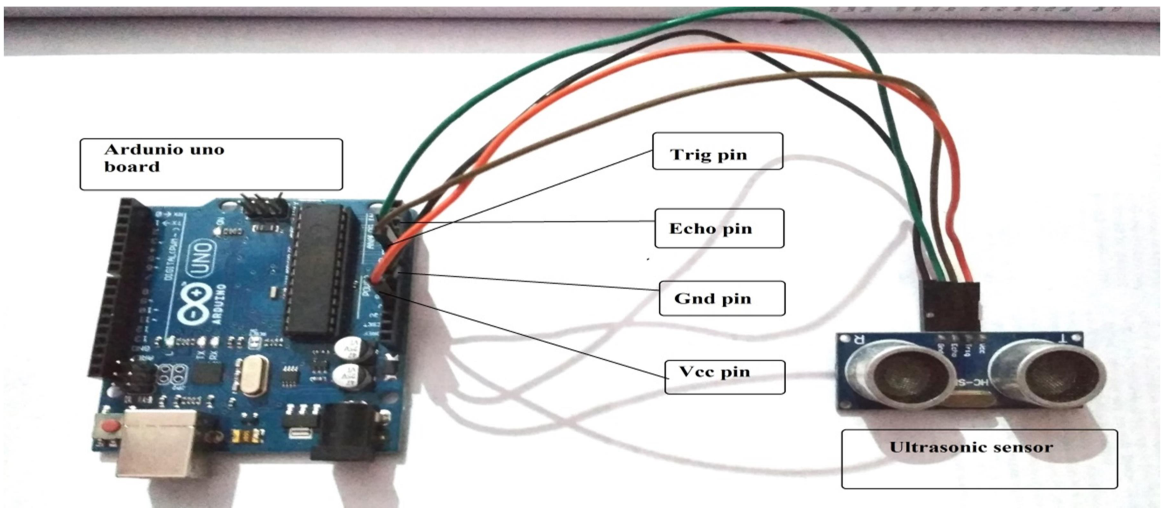


Figure 3.3 Image depicting connection for ultrasonic sensor

Circuit diagram

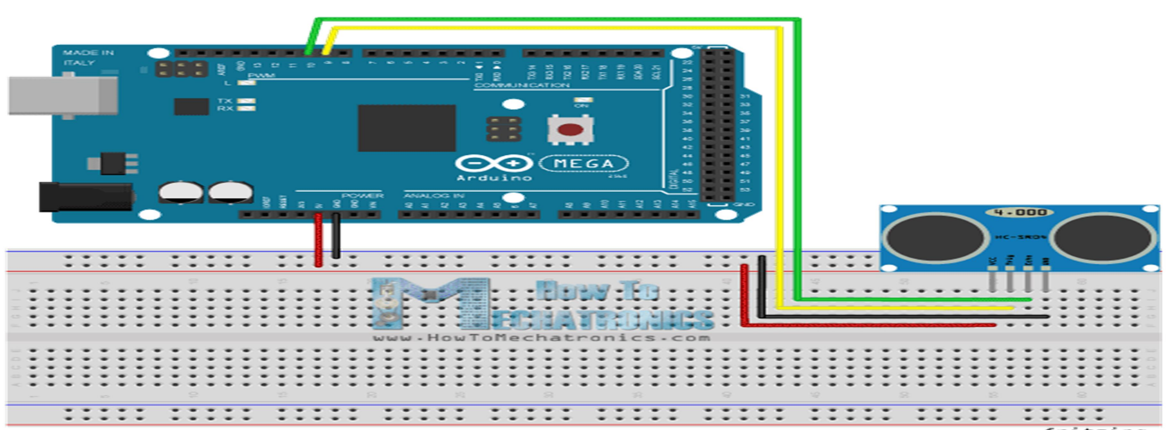


Figure 3.4 circuit diagram of ultrasonic sensor

Coding for Ultrasonic sensor

```
/*
* Ultrasonic Sensor HC-SR04
*
 */
 const int trigPin = 8;
const int echoPin = 9;
// defines variables
long duration;
int distance;
void setup() {
pinMode(trigPin, OUTPUT); // Sets the trigPin as an Output
pinMode(echoPin, INPUT); // Sets the echoPin as an Input
Serial.begin(9600); // Starts the serial communication
}
void loop() {
// Clears the trigPin
digitalWrite(trigPin, LOW);
delay(200);
// Sets the trigPin on HIGH state for 10 micro seconds
digitalWrite(trigPin, HIGH);
delay(500);
digitalWrite(trigPin, LOW);
// Reads the echoPin, returns the sound wave travel time in microseconds
duration = pulseIn(echoPin, HIGH);
// Calculating the distance
distance= duration*0.034/2;
// Prints the distance on the Serial Monitor
Serial.print("Distance: ");
Serial.println(distance);
}
```

Chapter- 4

Vibration measurement and applications

4.1 General

Ground vibrations arising from man-made sources including construction activities, blasting, and vehicle and rail traffic may interfere with surrounding residential and commercial activities. Ground-home vibrations can also cause cosmetic and structural damage to nearby structures. The problems may occur as a result of large amplitude vibrations, from repeated occurrences of smaller amplitude vibrations, or from differential settlement induced by particle rearrangement. Ground-borne vibrations are often accompanied by air-borne noise, annoying and heightening the sensitivity of humans. Their concerns often result in legal complaints alleging disruption with daily activities or damage to existing. To assess the impact of ground-borne vibrations on humans and to ensure the safety of existing structures, vibrations arising from construction activities, blasting, and vehicle and rail traffic are often monitored, especially in congested urban and suburban areas.

4.2 Vibration measurement using sensor

There are various sensor used to detect the vibration in civil structures. The sensor used for vibration measurement is piezoelectric sensor and accelerometer sensor. In our study we try to use the low cost piezo knock sensor to detect the vibration. Piezo knock sensor are made up of ceramic material which gives electric signal on application of vibration.

Case study

A steel simply supported beam of dimension (70x2.5x0.3 cm) was instrumented with PZT knock sensor at mid-point of beam , and tested under different loading . The beam was loaded at single point load. The hanger was at a distance of 30 cm from the left support on which different load was made to fall at a specific height. The initial output value was recorded just after load hanger is placed on the beam .First, the load 450 N was made to fall on hanger to produce vibration on the steel beam and then output value of aurnido was observed on the monitor. To increase the vibration, the 503 N load was further added to hanger and the output value was observed. This process is repeated to take at least 4 observation value. The output value of arduino shows the linear response as the vibration increases.

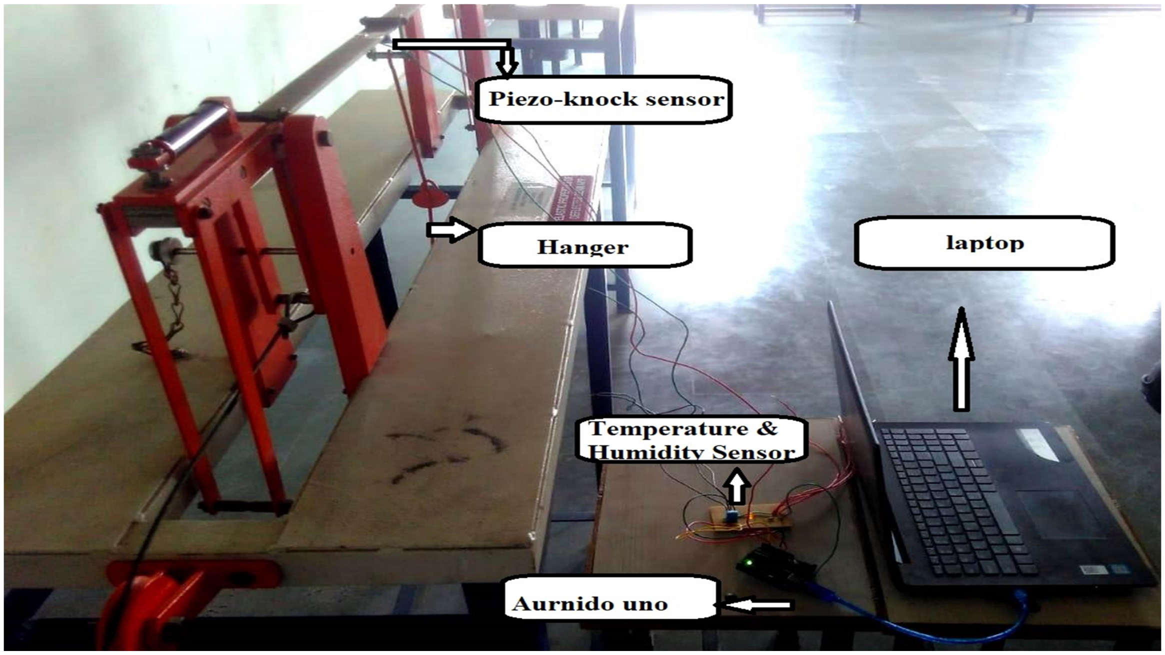


Figure 4.1 Experimental setup for vibration measurement\

The output value was just the sample number between 0 to 1023 having no unit. Whenever vibration was incorporated in the beam , it shows some number on the monitor which increases as the vibration increases. These sample number are given corresponding to the output voltage generated between 0 to 5V due to vibration in Beam.

Table 4.1 Sample value recorded by PZT sensor for steel beam under single point load

S.NO	LOAD (N) (applied on hanger from specific height)	TOTAL LOAD (N)	OUTPUT VALUE (Sample no)
1	450	450	23
2	505	955	36
3	505	1460	54
4	466	1926	69

Result

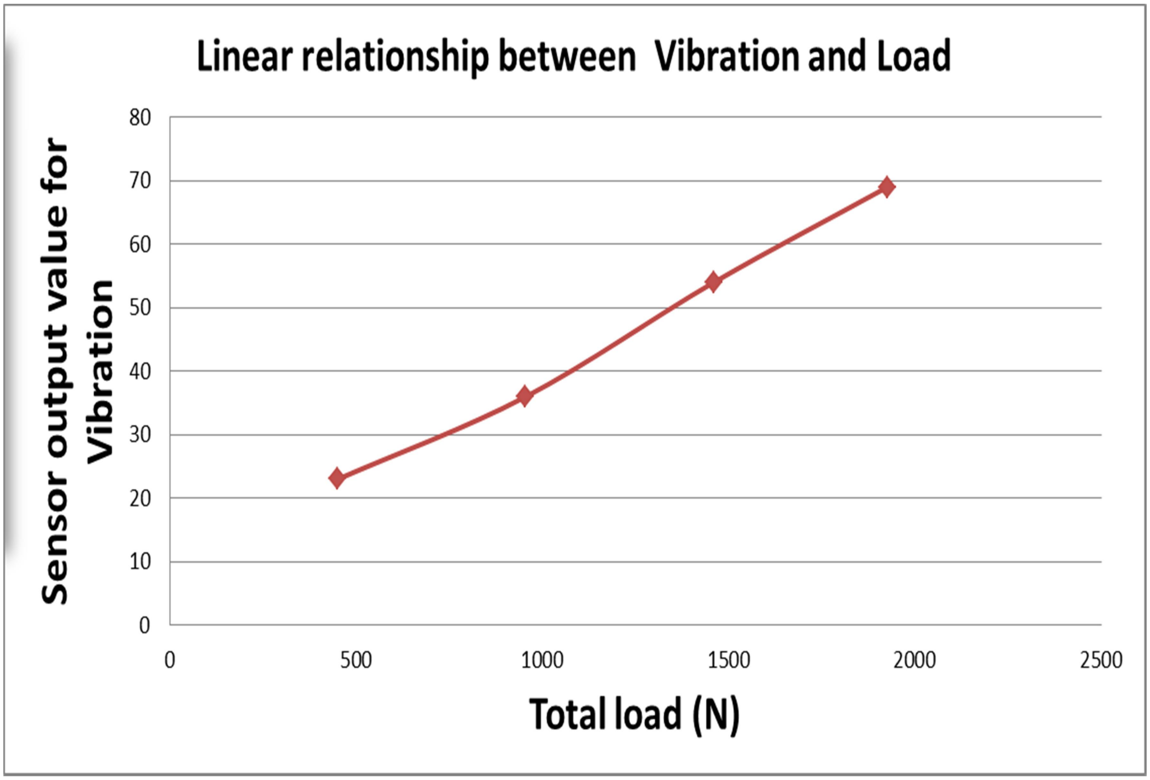


Figure 4.2 Graph showing linear response of vibration with load

It can be observed that the sensors have captured the natural frequencies of the experimental structures reasonably well and the vibration induced in experimental structure are directly proportional to the effect of load. From cost point of view, Piezo knock sensor are very cheap as compared to strain gauges and PZT patches.

Chapter 5

Deflection measurement of beam

5.1 General

In this chapter, the deflection has been calculated using sensor and it has been verified with the reading of dial gauge as well as it has been theoretically verified. Deflection is another important parameter of beam. When a beam is subjected to load, the beam deflects from its original shape. In other words, it is a distance or an angle to which the beam is displaced. It is often caused by internal loading such as bending moment and axial force.

5.2 Measurement of deflection using sensors

Deflection can be measured through accelerometer sensor by using the value of angle. Once an angle or slope is known at the particular point of beam, it can be used to calculate the deflection in the beam.

Another simple sensor for measuring the deflection of beam is ultrasonic sensor. This sensor is used to measure the distance of object by using the properties of wave. In our approach ultrasonic sensor was used to find the deflection of beam.

Case study

A simply supported steel beam of dimension (70*2.5*0.3 cm) was instrument with ultrasonic sensor at the midpoint of beam, and the sensor was fixed below the midpoint of the beam on the board. The dial gauge was set up from the top of the beam at its midpoint. In order to avoid the obstruction between bottom of beam and sensor, the two hangers were placed at a distance of 20cm from left support and right support respectively. The dial gauge was set to zero. Before applying the two point load on beam using two hangers, the initial output of ultrasonic sensors was recorded and it was verified using scale. Initially the distance shown by sensor was 17 cm which means the distance between the sensor and bottom of the beam is 17 cm. Firstly, 0.502 kg and 0.503 kg weight were applied on two hangers at 20 cm from left and right support respectively The output value of sensor and dial gauge readings were recorded. To increase the deflection in the beam the two weight were increased to 1.503 kg and the reading of dial gauge and the output of sensor was recorded.

Further, the two-point loads were increased to 2.470 kg and again the reading of dial gauge and output of sensor were recorded.

It was seen that, once the deflection of beam crossed or equal to 1cm the output of sensor was decreased from 17cm to 16cm.

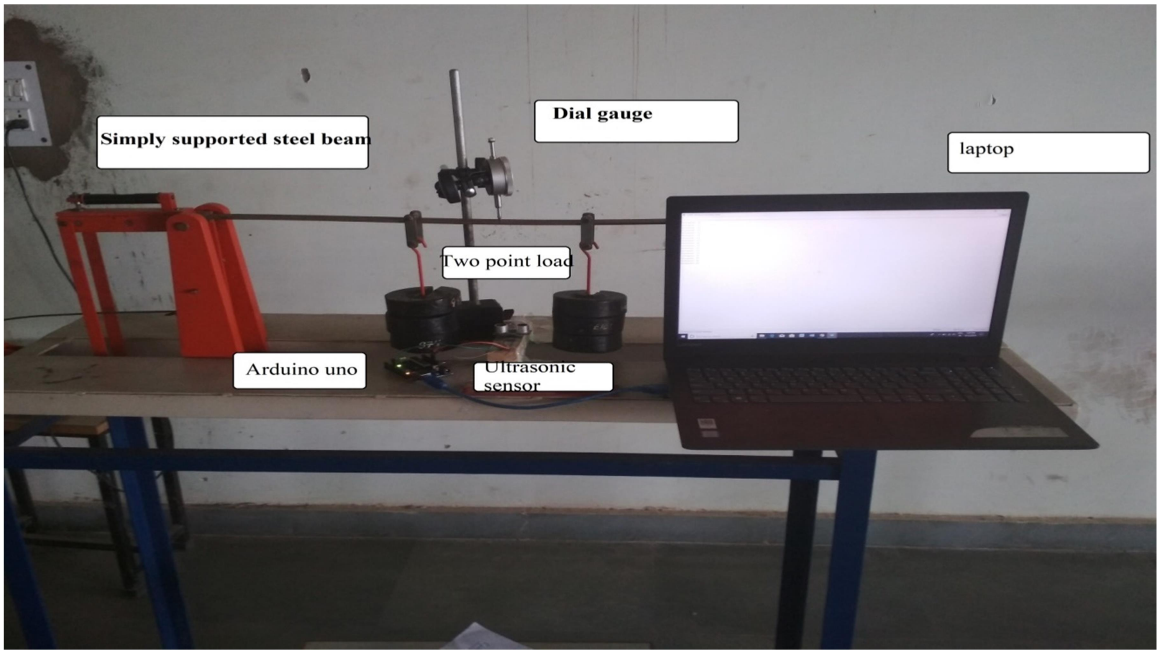


Figure 5.1 Experimental setup for deflection measurement

Table 5.1 Compare of deflection value of ultrasonic sensor and dial gauge reading for steel beam under two same point load

S.no	Load (Kg)		Sensor (Initial output in cm)	Sensor (Final output in cm)	Deflection value by sensor in cm	Dial gauge reading In cm
	P1	P2				
1	**0**	**0**	**17**	**17**	**0**	**0**
2	**0.502**	**0.502**	**17**	**17**	**0**	**0.48**
3	**1.503**	**1.503**	**17**	**16**	**1**	**1.45**
4	**2.470**	**2.470**	**17**	**15**	**2**	**2.40**

5.3 Theoretical calculation of beam deflection

For theoretical calculation of deflection of steel beam, following are the dimensions and properties of beam-

Width of beam = 2.5cm

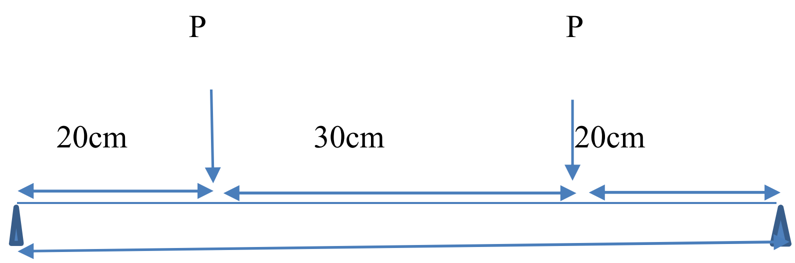
Depth of beam =0.3cm

Span length = 70cm

Young modulus of steel = 2*10^6 kg/cm^2

Moment of inertia = BD^3/12

I = (2.5*0.3^3)/12 = 5.625*10^-3cm^4



$$\sum Fy = 0,$$

$$Ra + Rb = 2P$$

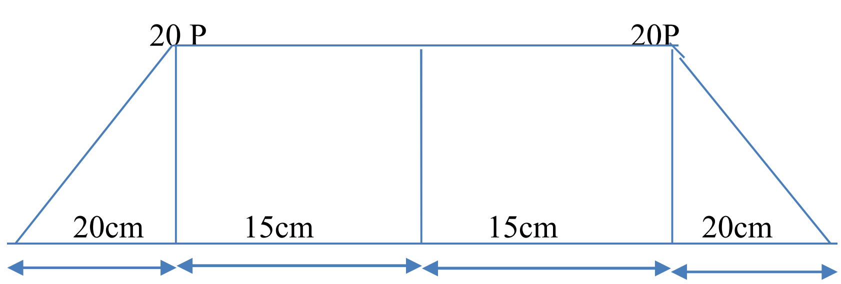
Taking moment about support b

$$Ra *70 = P*50 + P*20$$

$$Ra = P$$

$$Rb = P$$

BMD



Deflection at mid- point (35cm from left support)

$$\Delta mid = .5*20*20P*2*20/3EI$$

$$\Delta mid = 0.9703\ P$$

Table 5.2 Comparison of theoretical value of deflection with the value obtained from Ultrasonic sensor

S.no	Load (Kg) P	Theoretical deflection value in cm Δmid = 0.9703 P	Sensor value in cm
1	**0**	**0**	**0**
2	**0.502**	**0.46**	**0**
3	**1.503**	**1.38**	**1**
4	**2.470**	**2.28**	**2**

Result

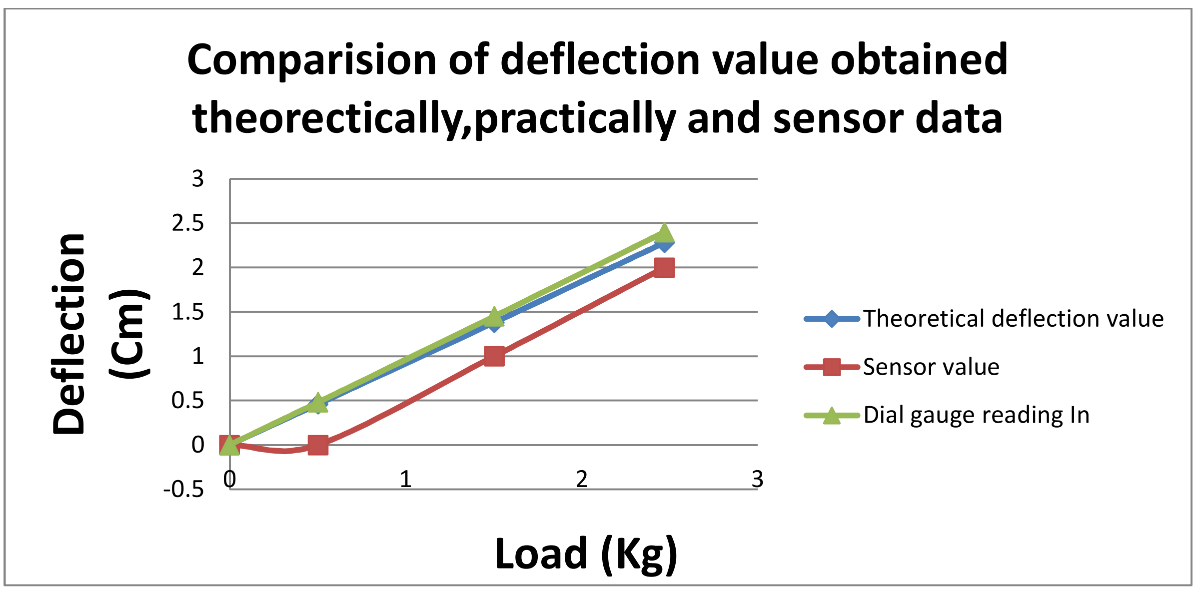


Figure 5.2 Graph showing linear response of deflection with load

The value of deflection obtained from sensor was verified with the dial gauge reading as well as theoretically. The graph have been plotted which shows the linear response between deflection and load. However, there were some instrument error in dial gauge which could be the possible reason for not matching the exact deflection value with those obtained from sensor

Chapter 6

Conclusions

There are various aspects for complete health monitoring of structures in which the severity of the damage and the post damage remaining life of the structure can be evaluated. Conventionally different techniques are used for each aspect and also different types of sensors and hardware. This thesis emphasizes only the parameter such as vibration and deflection of beam which can be evaluated out for structural health monitoring and non-destructive evaluation using PZT knock and ultrasonic sensors only. The conventional approach is not only costly and complex but also less sensitive and less accurate to predict the location of damages.

It has been shown that vibration measurement via PZT knock sensors provides an effective and cheap solution for gathering information at the time of earthquake in the building. To validate the method, impact load have been applied on Steel beam to trigger vibration while taking vibration measurements via PZT sensors. An ultrasonic sensor can be utilized to detect the deflection if any at the time of any unforeseen event. Also based on the deflection value ,the theoretical load can be calculated which should be less than the designed load of structural element in order to declare it safe.

Proposed approach can be implemented for on-line monitoring of structure on a small scale and can be further extended on large scale real life structures such as buildings and bridges.

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