# *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.

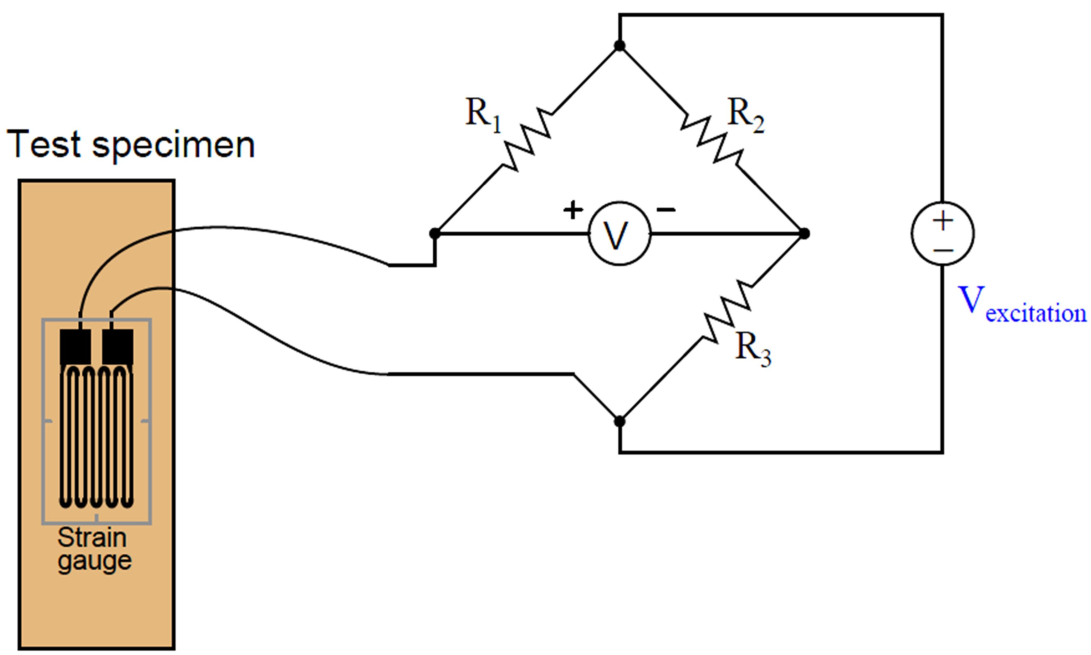



**Figure 2.1 Image showing circuit diagram of strain gauge sensor**

## 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

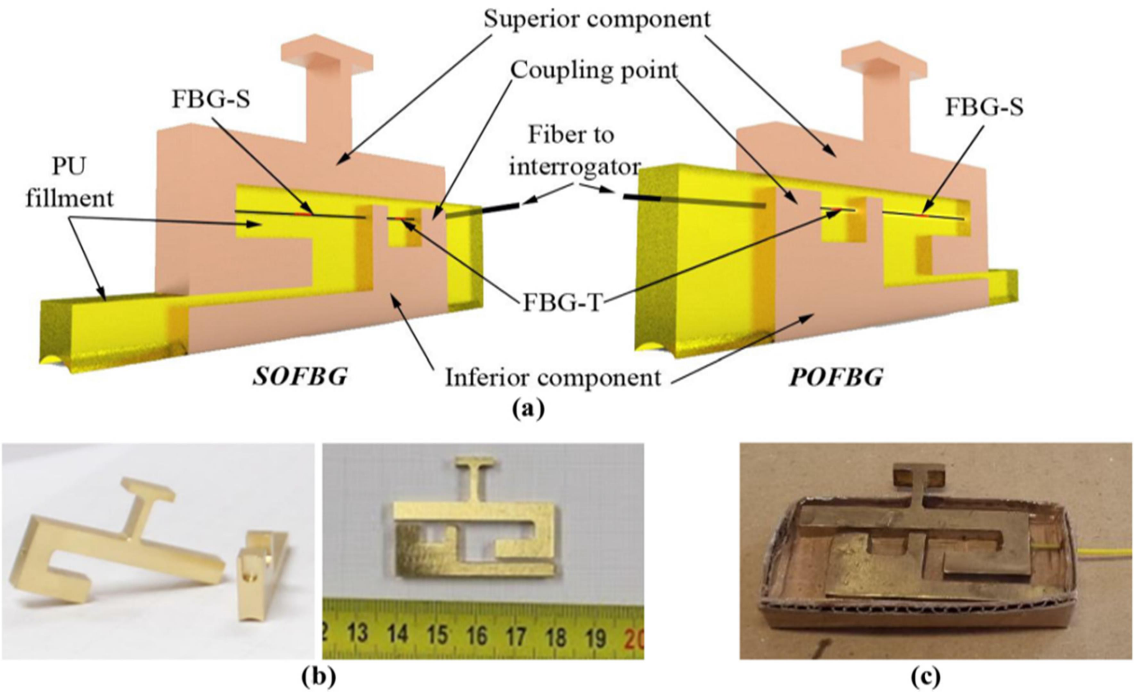



**Figure 2.2 (a) Details of the bond-slip OFS; (b) image of the two parts (ruler for scale in cm) and (c) sensor after PU resin filling, inside a paper mould, without surfaces regularization.**

**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.

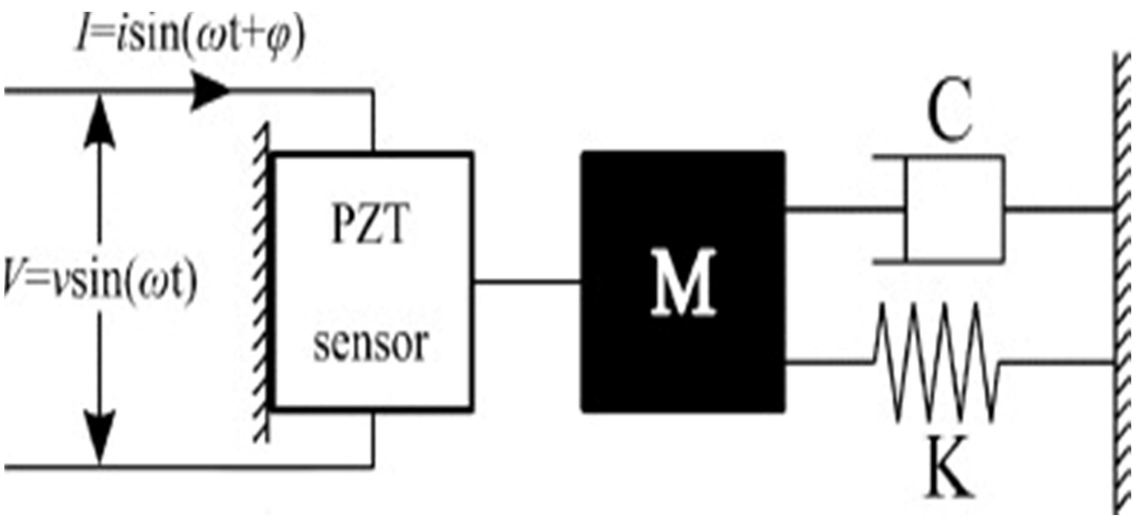



**Figure 2.3 Image shows the model of the sensor**

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 $\omega_i$ 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.

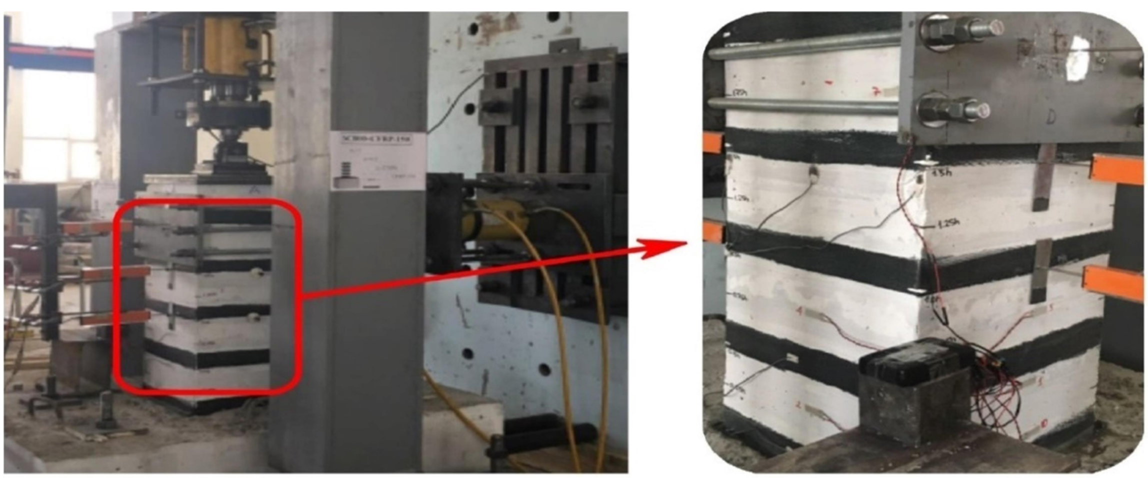


**Figure 2.4 A view of crack development measured with PZT.**

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.

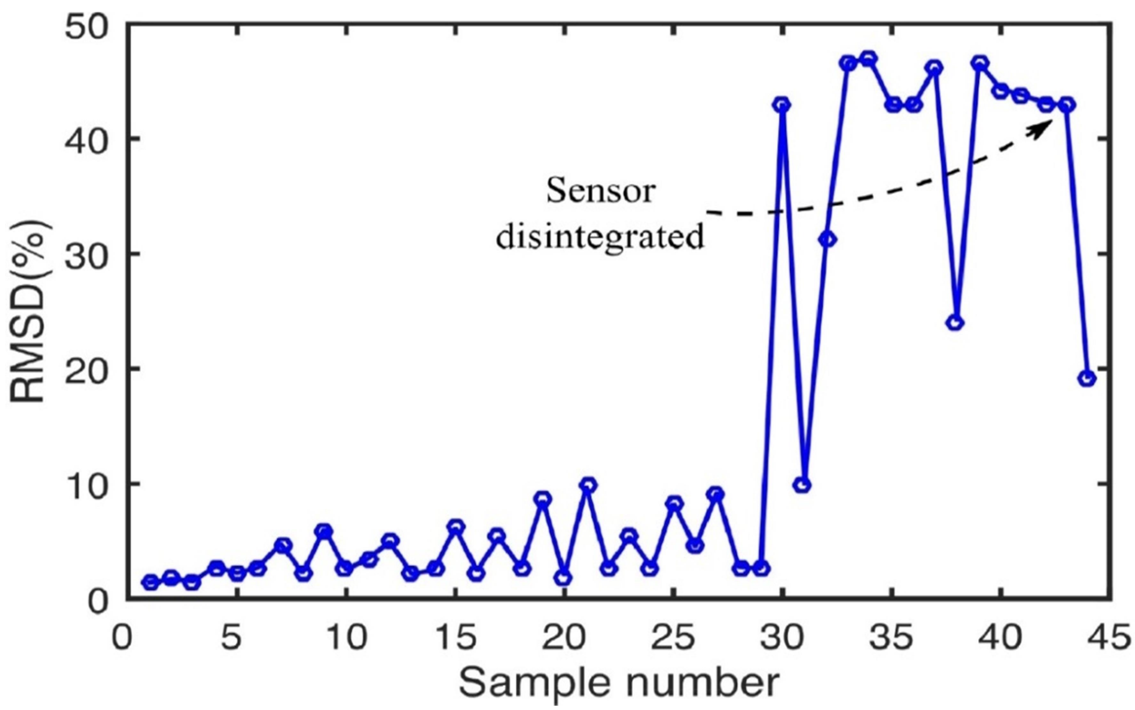



**Figure 2.5 RMSD results for sensor**

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.

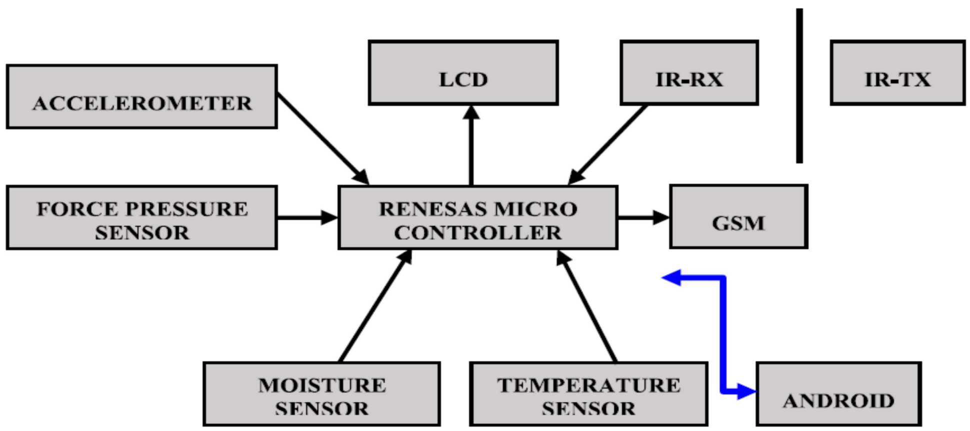



**Figure 2.6 Block diagram for bridge monitoring**

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..

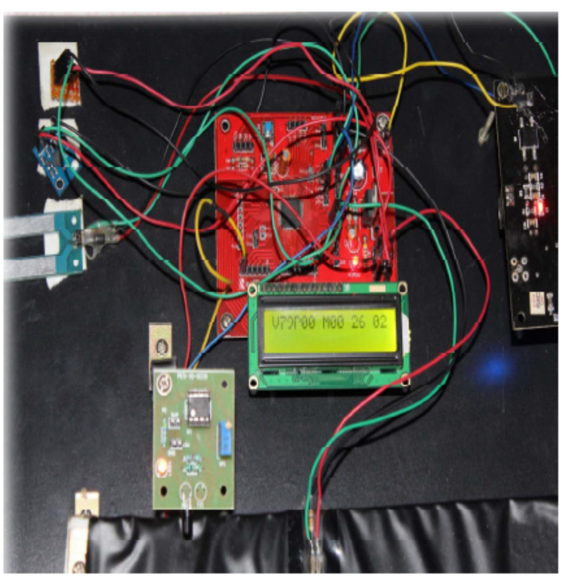




Figure 2.7 working model of SHM and Image showing the Registration process.

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.

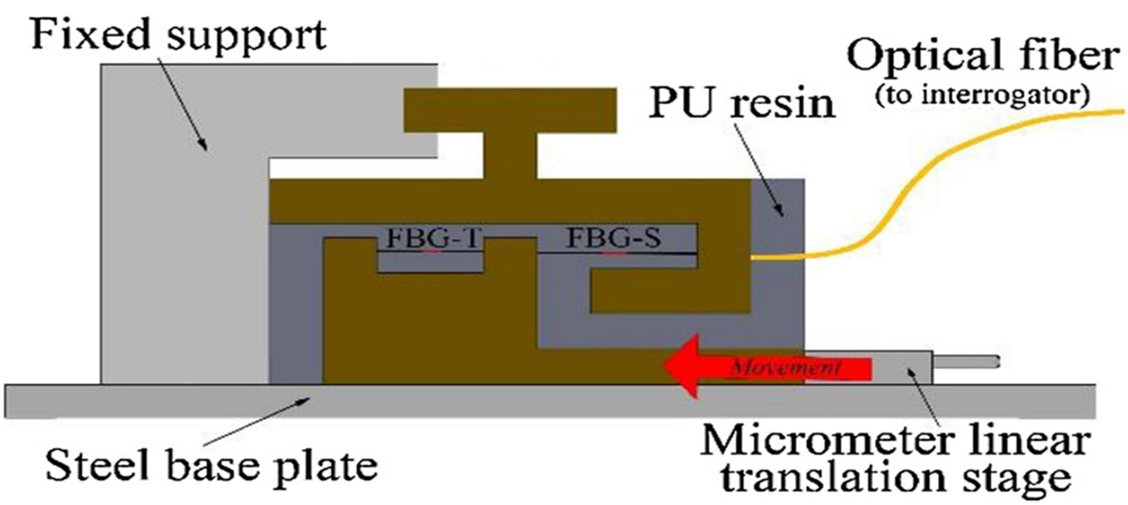



**Figure 2.8 Set up used for strain characterization**

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.

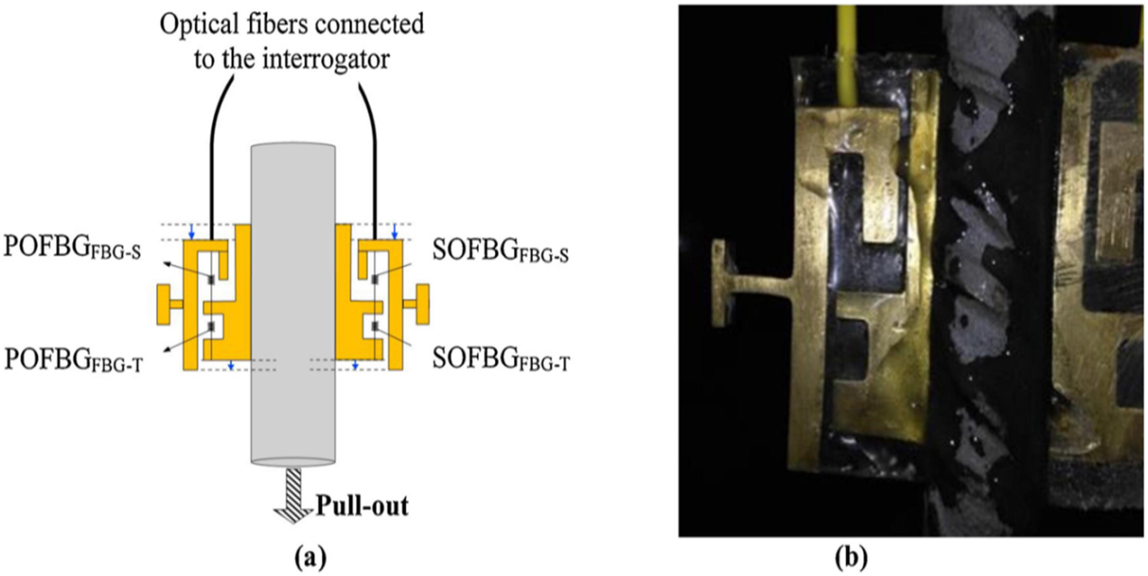



**Figure 2.9 (a) Schematic of the sensors' position and (b) image of the sensors glued in opposite sides of the rebar.**

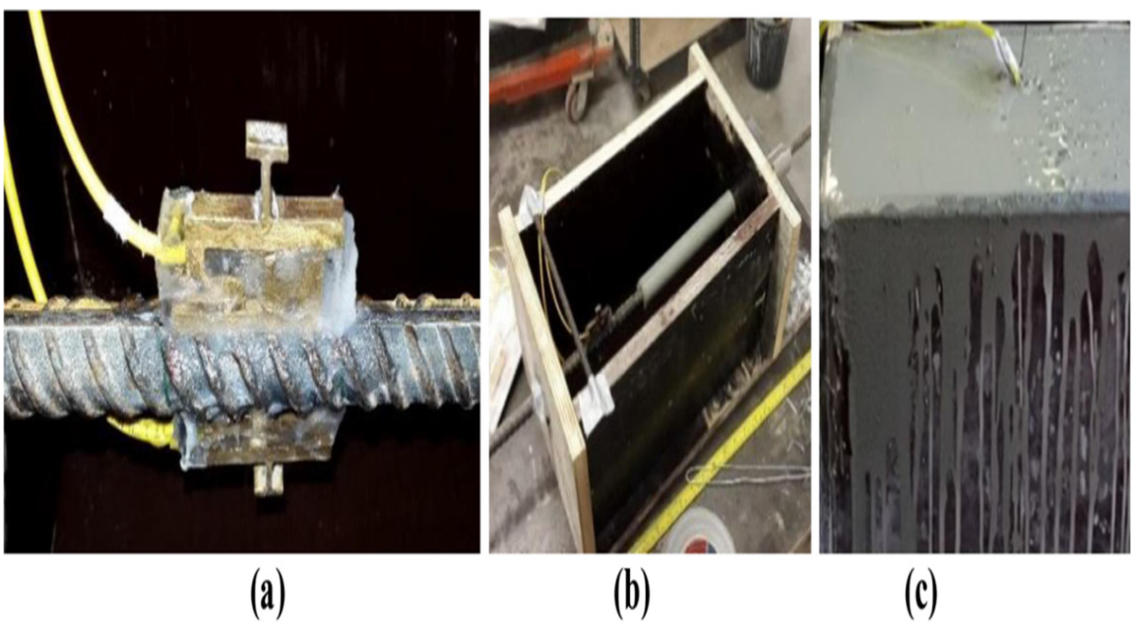
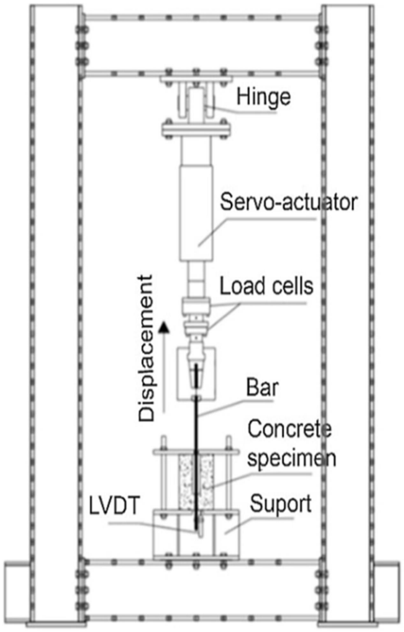
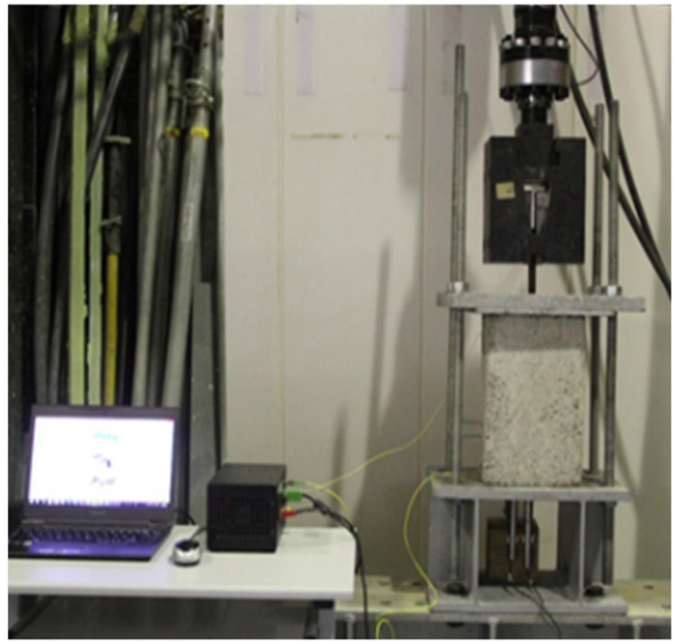



**Figure 2.10 (a) Final aspect of the sensors fixed to the rebar; (b) formwork structure with the rebar and (c) formwork filled with concrete.**




**(a)**



**(b)**

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