ENHANCING CONCRETE PERFORMANCE THROUGH ACCELEROMETER SENSOR-BASED INVESTIGATIONS

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Abstract

The term "Structural Health Monitoring" (SHM) refers to the application of a number of new and old technologies to track various internal and external conditions of contemporary civil engineering infrastructure. On both new and ongoing construction projects, SHM may be used. The act of gathering, interpreting, and analyzing data from structures to ascertain their health state and remaining life span is known as structural health monitoring (SHM). Usually, the Structures fails in early life span due to mismanagement in construction, Lack of quality control, Temperature conditions. Hence there is a need to structural health monitoring with suitable sensors in order to identify the damage in early stage and increase the life span of structure. Increased structural health monitoring (SHM) primarily aims to spot early-stage premature failure of structures. Additionally, SHM methods are eventually necessary for heritage structures to maintain and/or increase their life values. The use of sensors in SHM research is rather simple. Thus, the choice of sensor can affect how precisely structural components are made. In this project, the comparison to conventional concrete, the current experimental investigation study examines how accelerometer sensors can detect damage on fiber-reinforced concrete (RC) beams, cubes, and cylinders. Micro electromechanical systems (MEMS) accelerometer sensors are used to record the fundamental behavior of the RC beam under four-point bending. The experimental study supports the theoretical sensor.

Keywords: FRC (Fiber Reinforced Concrete)**,** Accelerometer sensors**,** Durability assessment**,** Crack propagation**,** Monitoring system**,** Strain measurement**,** Acceleration measurement**,** Structural health monitoring

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1. Introduction

The world's population depends on a complex network of roads, sewers, highways, and buildings. Hence durability of a structure plays an important role. The capacity of a structure to continue performing as intended over the course of its lifetime is known as durability. It is an essential component of sustainable building since poor durability can lead to unforeseen costs for repairs or reconstruction as well as negative environmental and social effects. Structural health monitoring (SHM) system is a method of evaluating and monitoring structural health. It has been widely applied in various engineering sectors due to its ability to respond to adverse structural changes, improving structural reliability and life cycle management.

"The process of implementing a damage detection and characterization strategy for engineering structures". Structural health monitoring (SHM) is an area of growing interest and worthy of new and innovative approaches. Structural Health Monitoring includes four major tools such as Health monitoring, Operational evaluation, Data feature extraction, Statistical models development.

Figure 1.1 Sensor based Structural Health Monitoring

1.1 Research Problem or Problem Formulation

Generally, a structure gets failure due to various aspects. The damages occur in the structure such as cracks, bulking, segregation, settlements etc. These damages are mainly caused due to temperature conditions, disasters such as landslides, earthquake, lack of quality in control, mismanagement in construction, water cement ratio, lack of maintenance. Due to these damages, Structures get failure suddenly and shows a lot of impact on the people life, which leads to the destroy of their hopes and livelihood, loss of property and life of people. Structural Health Monitoring is the only solution to solve these kinds of problems. Structural health monitoring can be done in two ways.

Non-Destructive Tests is the primary way, which specifies the strength of the structure. Nondestructive testing, or NDT, is the process of looking for flaws or changes in characteristics in materials, parts, or assemblies without harming the part's or system's ability to function. In other words, the part is still usable once the inspection or test has been performed. The secondary method is to determine the strength, cracks, life span and any kind of stresses and deformations of a structure with the help of "Sensors". Buildings, engineered structures, civil engineering structures, and historical monuments are all monitored for structural movements, deformations, stresses, and strains using structural sensors. Because of the variety of sensors available, structural monitoring solutions can be customized to meet specific needs and financial constraints. There are various types of sensors. Based on the study or investigation suitable sensors should be used. In this study, the experimental investigation is carried out based on the performance of Fiber Reinforced concrete in comparison with the conventional concrete with Micro-Electro Mechanical Systems (MEMS). Various challenges take place while monitoring a structure such as Infrastructure is expected to provide, develop wireless sensor networks, develop design-to- service solutions, develop smart control units.

1.2 Non-Destructive Tests

Concrete can be tested non-destructively to determine its compressive strength and other qualities from existing constructions. There are different types of NDT tests.

1. Penetration method.
2. Rebounds hammer method.
3. Pull out test method.
4. Ultrasonic pulse velocity method.
5. Radioactive methods.

1.3 Types of Sensors

A typical health monitoring system is composed of a network of sensors being responsible to measure different parameters relevant to the current state of the structure as well as its surrounding environment, such as stress, strain, vibration, inclination, humidity, and temperature.

1.3.1 Micro Electro Mechanical Systems (MEMS Accelerometer sensor)

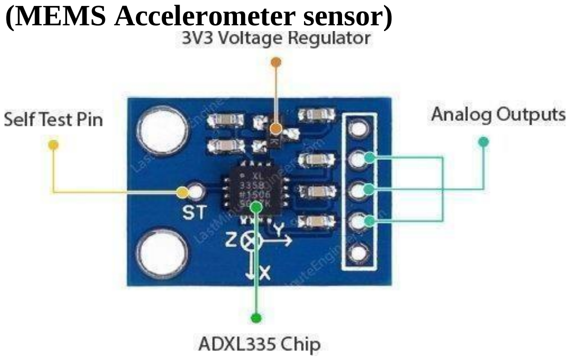

Fig 1.2 MEMS Accelerometer sensor

MEMS accelerometers measure the static/ dynamic force of acceleration in which it captures the frequency of the object in a precise manner than other sensors. MEMS accelerometer is much accurate in measuring the negligible amount of seismic excitement with low cost. Wherever linear motion must be measured without a stable reference, such as during movement, shock, or vibration, MEMS accelerometers are utilized. The object to which they are attached is measured for linear acceleration.

1.3.2 Fiber Optic sensors

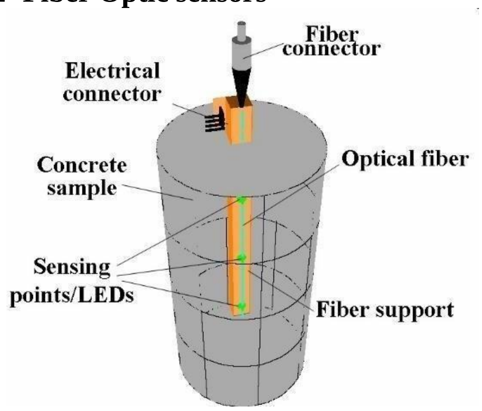

Fig 1.3 Fiber Optic sensor

In recent years, fiber optic sensors have seen significant advancement. These sensors can be used in civil engineering to measure various factors. The following are some examples: stresses, structural displacements, vibration frequencies, acceleration, pressure, temperature, and humidity. Both local and global monitoring options are available for the structure.

1.3.3 Piezo Electric sensors

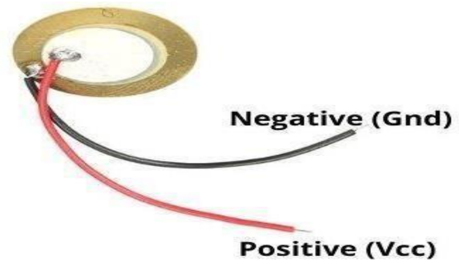

Fig 1.4 Piezo Electric sensors

A piezo sensor typically converts vibration, pressure, acceleration, temperature, strain, or force changes into an electrical charge using the piezoelectric effect to quantify these phenomena. Piezoelectric sensors can generate electrical charges when placed in a field of strain, and vice versa when placed in an electrical field. Researchers have established novel non-destructive evaluation and SHM approaches as a result of recent advancements in "smart" piezoelectric materials. To provide versatile, af1.4 fordable, reliable, wireless, and mobile software/hardware solutions, new sensors and PZT-based methodologies have been applied.

1.3.4 Strain Gauge sensors

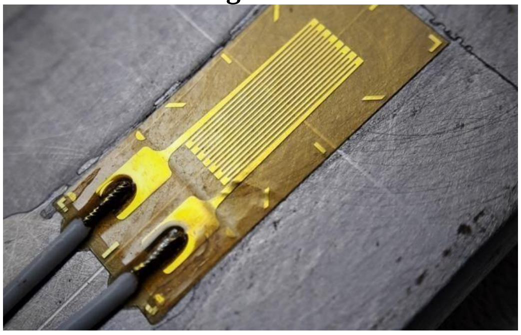

Fig 1.5 Strain Guage sensors

A strain gauge measures the strain that results from applying force to an item. The most popular strain gauge is made comprised of a metallic foil design supported by an insulating flexible backing. Using a suitable adhesive, the gauge is mounted to the item. Force causes the foil to distort, which changes its electrical resistance, which may then be measured. The most common application for these sensors is to measure strain in steel and reinforced concrete constructions.

1.3.5 Tilt meter

Fig 1.6 Tilt meter

A tiltmeter is a sensitive inclinometer used to keep track of even the slightest inclination changes in a structure. The collected data give a precise history of a structure's movement, which can be utilised to detect potential structural damage early on. The sensors can determine an object's elevation, depression, or angle of slope (or tilt) with relation to the direction of gravity. These sensors are appropriate for observing the rotation of buildings like retaining walls or concrete dams.

1.4 Objective of the Research

- An experimental examination using accelerometer sensors to compare the performance of fiber-reinforced concrete was conducted.
- Identifying possible damage and damage localization.
- Analyze the concrete blocks' damage in terms of severity.
- Monitoring of concrete affected by external factors.
- Parameters for predicting the future.

2. Literature review

This provides relevant information and a better understanding of the issues raised in this study by presenting several connected literatures and studies. The concepts, completed thesis, descriptions or conclusions, techniques, and other items are included in this chapter. Understanding the data that is important and related to the current study is made easier by those that were included in this chapter.

(Aravindan Sivasuryan Jan 2022) Increased structural health monitoring (SHM) primarily aims to spot early-stage premature failure of structures. Additionally, SHM methods are eventually necessary for heritage structures to maintain and/or increase their life values. The use of sensors in SHM research is rather simple. So, a sensor. Selection can affect how precisely structural elements are made. In the current work, a reinforced concrete (RC) beam that has been exposed to monotonic two-point loading is examined. Several sensors, including a force resisting sensor (FSR), a flex sensor (FLS), a piezoelectric sensor (PZS), and a micro electromechanical systems (MEMS) accelerometer sensor, are used to record the fundamental response of the RC beam under four-point bending. The experimental study supports the theoretical sensor suppositions. The MEMS accelerometer sensor thus performs better than other sensors on the RC.

(Ahad Javanmardi, 21 May 2022) Research and development are limited in developing nations because it is expensive to acquire vibration data using commercially available equipment. In this study, vibration data of a reinforced concrete beam at various damage levels was collected using micro- electromechanical systems (MEMS)accelerometers in conjunction with an Arduino-based data gathering system. The fundamental frequency of the beam was calculated using the recorded data, which had lower and variable sampling frequencies. The results demonstrated good agreement with accelerometers that are currently on the market. A finite element model with high agreement with the experiment was created to combine the computational and experimental efforts. Accelerometers have been found to be efficient and cost-effective for monitoring the ongoing condition of civil infrastructure that is already in place.

(Suyun Ham17 April 2015) This research examines the use of micro-electro-mechanical sensors (MEMS) for air- coupled (contactless or noncontact) sensing in Non-destructive testing (NDT) of concrete. First, a description of MEMS's basic properties and operation is provided. It is then shown how MEMS sensors can be used with well-known concrete test techniques including vibration resonance, impact-echo, ultrasonic surface wave, and multi-channel analysis of surface waves (MASW). MEMS performance is compared with traditional contactless and contact sensing technology in each test application. The MEMS sensors' successful performance highlights the technology's potential for use in contactless NDT initiatives. Goal: To show how air-coupled MEMS sensors are more useful for concrete NDT than traditional sensor technologies.

(Jeffri Ramli14 March 2021) Cracking in concrete structures can seriously impact their structural stability and eventually result in severe failure if undetected. New and improved sensors for real-time crack identification and monitoring have been developed as a result of recent advancements in sensor technology for structural health monitoring approaches. These applications range from laboratory experiments to huge constructions. The production of micro- and macrocracks in ordinary self-compacting concrete (SCC) and steel-fibre-reinforced (SFRSCC) beams during three-point bending has been detected and located in this study using triaxial accelerometers. On the surface of the beams, triaxial accelerometers were attached for the experiments. The experimental outcomes demonstrated that triaxial accelerometers might be utilised to locate cracks and provide a bigger volume of beneficial data for more precise assessment and include interpretation. The study provides information on the structural monitoring capabilities of triaxial acceleration measurements for SFRSCC structural elements that can serve as a structural failure system for early warning.

(Aftab MUFTI, August 1, 2004) Located in Victoria, BC, Canada, the Portage Creek Bridge is a 125m long, three-span structure with a reinforced concrete deck supported on two reinforced concrete piers, and abutments on piles. The bridge was designed prior to the introduction of current bridge seismic design codes and construction practices. Therefore, it was not designed to resist the earthquake forces that are required by today’s standards. The bridge is on a route classified as a Municipal Disaster Route scheduled to be retrofitted to prevent collapse during a design seismic event, with a return period of 475 years. The dynamic analysis of the bridge predicted the two tall columns of Pier No. 1 will form plastic hinges under an earthquake resulting in additional shear to the short columns of Pier No. 2. A non-linear static pushover analysis indicated that the short columns will not be able to form plastic hinges prior to failure in shear. The innovative solution of Fibre Reinforced Polymer Wraps was chosen to strengthen the short columns for shear without increasing the moment capacity. The FRP Wraps and the bridge were instrumented as one of 36 demonstration projects across Canada sponsored by ISIS Canada to assess the performance of FRP and the use of Fibre Optic Sensors for structural health monitoring.

(R. Joseph Daniel, January 2016) Accelerometers are used to monitor the health of big mechanical and civil structures. These sensors, which need to be highly sensitive and have a very low noise floor, are designed to measure changes in the natural frequency of the structures being monitored (about 100 Hz). Inversely proportional to frequency squared is accelerometer sensitivity. Commercial MEMS (Micro Electro-Mechanical System) accelerometers, which are typically designed for large bandwidth (e.g. 25 kHz in ADXL150), have poor sensor level sensitivity. As a result, these accelerometers use complex signal conditioning electronics to achieve large sensitivity and low noise floor, which raises the cost of the device. In this study, an effort has been made to develop MEMS capacitive and piezo resistive accelerometers for narrower bandwidth employing corresponding MEMS tools. The different performance measures were determined through simulated trials and the findings demonstrate that these sensors are even better than commercial MEMS accelerometers in terms of voltage sensitivity, noise performance, and high resolution at the sensor level.

(Arvindan Sivasuriyan, 20 June 2021) This research examined at damage assessments for building structures as well as operational and structural health monitoring (SHM). The study addressed scenarios of evaluation and self-monitoring, involving damage detection, and assessed buildings by installing sensors and assuming weak spots. From this angle, a building can be continuously monitored in real time using cutting-edge sensor technology and data collecting methods. In order to forecast the building damage, the structure's reaction and behaviour were also watched and recorded. In this work, real-time monitoring and reaction of buildings is covered, including static and dynamic assessments along with numerical simulation studies like finite element analysis (FEA), and suggestions for future SHM research and development are provided. The

SHM approach is extremely suitable for real- time monitoring if the methods are carried out comfortably by precisely applying all techniques. Ambient vibration methods range from measured dynamic responses to real- time monitoring such as mode shapes, modal damping ratios, and natural frequencies. Various types of sensors are used for structural health monitoring such as fiber optic sensors, piezoelectric sensors, microelectromechanical system sensors, accelerometer, temperature sensors, and accelerometers.

(Renan Rocha Ribeiro, 16 July 2019) One of the most researched and utilised sensing methods for identifying modal characteristics in civil constructions is the use of accelerometers. Low-cost MEMS accelerometers and open-source electrical platforms like Arduino have made it easier to create low-cost systems suited for modal identification, however there are still few studies comparing low-cost accelerometers that are now available on the market in real-world settings. The natural frequencies and damping ratios of a reinforced concrete slab and a three-story frame model are identified, together with their noise characteristics, using this work's experimental performance evaluation of six inexpensive MEMS accelerometers. It was done with a cheap Arduino-based data gathering system. The outcomes demonstrated the MEMS accelerometers' good overall performance, with the three-storey frame and concrete slab, respectively, had natural frequencies errors that were within 1.02% and 7.76% of reference values, and the noise density was as low as 108 g/Hz.

MEMS inertial sensors-(IEEE) With their incorporation into a wide range of consumer electronics goods, such as smart phones, tablets, gaming systems, TV remotes, toys, and even (more recently) power tools and wearable sensors, inertial sensors based on MEMS technology are quickly becoming commonplace. MEMS-based motion tracking, which is now a standard feature of the majority of smart phones, improves the user interface by enabling response to user motions, completes the GPS receiver by offering dead-on indoor navigation and supporting location- based services, and, thanks to its lower cost and small form factor, holds the promise of enabling handset optical image stabilisation in next-generation handsets. This tutorial gives a general introduction to MEMS technology and outlines the key characteristics of the mechanical systems that underlie the most popular sensors, gyroscopes and accelerometers. Additionally, it emphasises several crucial Mechanical system dynamics, force and charge transduction techniques, and their effects on the mixed-signal systems that handle the sensor outputs are all subject to trade-offs. A performance comparison of rival sensor technologies is possible thanks to the presentation of an energy-based statistic. The descriptions of the underlying mechanical theory, standard sensor topologies, and significant design issues are also included for each type of sensor. The tutorial concludes with a discussion of multi sensor silicon MEMS/CMOS monolithic integration, which is responsible for the current cost and form factor decrease of these devices.

(Jose Aguiar, 8 January 2021) PPF, or polypropylene fibre, is a type of polymer material that is lightweight, highly durable, and resistant to corrosion. PPFs can be added to concrete to increase its crack resistance. Concrete's pore size distribution can be improved via PPF. As a result, because PPF may prevent damaging ions or water from penetrating concrete, its durability is greatly increased. The impact of polypropylene fibre on concrete's resistance to cracking, shrinkage during drying, creep, water absorption, permeability, chloride ion penetration, sulphate corrosion, freeze-thaw cycle resistance, carbonation resistance, and fire resistance is discussed in this study. The impact of fibre content, fibre diameter, and fibre hybrid ratio on these durability indices were examined by the authors. Combining PPFs with steel fibres can significantly increase the durability of concrete. PPF's application in concrete suffers from poor dispersion and a tenuous connection with the cement matrix. Utilizing fibre that has been chemically or nano actively changed can help address these disadvantages. Finally, the authors discuss the potential for further study into PPF-made concrete. With its low weight, strong tensile strength, and exceptional toughness, PPF possesses remarkable qualities. Concrete with PPFs added has less porosity and more crack resistance than concrete without PPFs. As a result, it can lessen the transport of water and other damaging media through the concrete, increasing its durability. The PPF-reinforced concrete has superior impermeability, chloride resistance, sulphate resistance, carbonation resistance, and fire resistance, as well as decreased water absorption. The addition of PPF helps lessen drying shrinkage since PPF has a beneficial effect on avoiding deformation. However, because PPF has a lower elastic modulus than ordinary concrete, the creep of concrete was not decreased by applying PPF. Combining PPF-reinforced concrete with other fibres can increase its durability even more.

(Ashwini N nayak, Sanjana, 6 June 2017) Two significant disadvantages of conventional concrete include its poor tensile strength and brittle, destructive failure. There is now concrete (PFRC). Polypropylene fibre reinforced concrete is an attempt to increase the ductility and energy absorption of concrete. This study is a component of a larger investigation of the effectiveness of polypropylene fibre reinforced concrete. An experimental examination looked at the polypropylene fibre reinforced concrete's compressive strength, flexural strength, split tensile strength, shear strength, and shear strength. The fibre volume fraction, v, falls into the following ranges: 0%, 0.2%, 0.4%, 0.6%, 0.8%, 1%, and 2%. When compared to plain concrete, significant improvement is shown for compressive strength, flexural, split tensile, and shear. Compressive strength, Tensile strength, Flexural strength properties of polypropylene fibre reinforced concrete increase as the percentage of polypropylene fibre increase up to 0.8% increasing strength and therefore at 1.2% shows decreasing strength.

Conclusion

Hence by the reference of various literature reviews on the structural health monitoring, journals related to the sensors used for monitoring and the journals which specifies the strength and performance of polypropylene fibre reinforced concrete, it has been finally concluded that Structural Health Monitoring is the best method to examine the strength and durability of concrete, also known for quick detection of damage and increases the life span of structure. The SHM sensors relevant papers indicate MEMS accelerometer sensor is the best sensor which is also known as low-cost sensor. The MEMS accelerometer sensor thus performs better than other sensors. Polypropylene Fiber reinforced concrete. PPF, or polypropylene fibre, is a type of polymer material that is lightweight, highly durable, and resistant to corrosion. PPFs can be added to concrete to increase its crack resistance. Concrete's pore size distribution can be improved utilizing PPF. Hence the Experimental research is carried out for identification of performance between Polypropylene Fibre reinforced concrete and conventional concrete using MEMS accelerometer sensors.

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