

Sensors Based Structural Health Monitoring Of Rcc Structure

Mayuri G. Badwaik^{1*}, Arpita B. Wankhade², Assistant Prof. R.N.Puranik³

¹Student, Department of Civil Engineering, Jawaharlal Darda Institute of Engineering and Technology, Yavatmal.
mayuribadwaik73@gmail.com¹

²Student, Department of Civil Engineering, Jawaharlal Darda Institute of Engineering and Technology, Yavatmal.
wankhadearpita13@gmail.com²

³Assistant Professor, Department of Civil Engineering, Jawaharlal Darda Institute of Engineering and Technology, Yavatmal.
rujit_puranik@jdiet.ac.in³

ABSTRACT : Reinforced Cement Concrete (RCC) structures such as buildings, bridges, and dams can become weak over time due to heavy loads, weather conditions, and ageing of materials. Cracks may develop inside or on the surface of the concrete. If these cracks are not detected early, they can reduce the strength, safety, and service life of the structure. Structural Health Monitoring (SHM) is a useful method for detecting such damage at an early stage by using sensors to measure changes in vibration, strain, electrical resistance, and physical movement. However, many advanced SHM systems, such as fiber optic and impedance-based sensors, are expensive and difficult to install on a large number of structures. This review focuses on sensor-based SHM techniques for monitoring RCC structures, with special attention to low-cost and real-time crack detection. Different sensors, including fiber optic sensors, wireless strain sensors, MEMS accelerometers, ultrasonic sensors, and copper break-wire sensors, are studied. These sensors provide different levels of sensitivity, accuracy, and cost. The review shows that low-cost sensors combined with microcontrollers can provide useful real-time information about structural condition. Among these methods, copper break-wire sensors offer a simple and economical approach for detecting internal crack formation in concrete. Overall, sensor-based SHM can provide an effective and affordable method for early crack detection and structural safety.

KEYWORD: Structural Health Monitoring, RCC structures, internal crack detection, low-cost sensors, real-time monitoring

INTRODUCTION : Concrete is one of the most widely used materials in construction. Reinforced Cement Concrete (RCC) structures are commonly used in buildings, bridges, dams, and other important civil engineering structures. These structures are designed to carry heavy loads and remain safe for many years. However, over time, RCC structures can become weak due to repeated loading, changes in temperature, moisture, environmental conditions, and ageing of materials. These factors can cause cracks to develop in concrete. Some cracks may begin as very small defects and can develop inside the structure without being visible on the surface. Internal cracks are especially important because they may grow slowly and reduce the strength and safety of the structure without being noticed.

Traditional methods of structural inspection mainly depend on visual observation and manual testing. These methods require trained engineers and regular inspections. They can be time-consuming and costly, especially when large structures need to be checked. More importantly, visual inspection is mainly useful for detecting surface cracks and may not identify cracks that develop inside the concrete. Therefore, there is a need for better methods that can continuously monitor the condition of RCC structures and detect damage at an early stage.

Structural Health Monitoring (SHM) is an effective approach for checking the condition and performance of structures over time. SHM uses sensors to measure changes in important structural properties. Depending on the type of sensor, measurements can include vibration, strain, displacement, movement, electrical resistance, or changes in physical connections. When a crack develops, these properties can change. By observing these changes, it is possible to identify the formation and growth of cracks before they become serious. This can help engineers take suitable maintenance actions and reduce the possibility of sudden structural failure.

Different types of sensors have been studied for structural health monitoring. These include fiber optic sensors, ultrasonic sensors, MEMS accelerometers, piezoelectric sensors, strain sensors, and copper break-wire sensors. Advanced sensors can provide high accuracy, but they are often expensive and may require specialised equipment and installation. Low-cost sensors provide an alternative for applications where affordability and simple installation are important. Copper break-wire sensors are particularly useful for crack detection because a crack can break the wire and cause a clear change in the electrical circuit.

This review focuses on sensor-based Structural Health Monitoring of RCC structures, with particular attention to the detection of internal cracks. It compares different sensing methods based on their working principles, sensitivity, cost, and practical use. The main aim is to understand how simple and affordable sensor systems can be developed to detect internal cracks and provide reliable information about the condition and safety of RCC structures.

Literature Review

Richter et al. studied Distributed Fiber Optic Sensors (DFOS) for monitoring cracks in concrete structures. These sensors can measure strain continuously along the length of a structure. This makes it possible to identify the location and size of cracks more accurately than sensors that measure only at specific points. The researchers studied crack width using fiber optic sensors placed inside concrete or attached to steel reinforcement. A large amount of data was produced during monitoring, so the researchers developed Python software called “fosanalysis” to process the data automatically. The method was tested on a 4-metre-long reinforced concrete beam. The crack measurements from DFOS were compared with Digital Image Correlation (DIC) results. The results showed good agreement between both methods. The study concluded that DFOS can provide reliable crack detection and crack-width measurement for structural health monitoring.

Dhivya et al. developed a sensor-based system for monitoring buildings and bridges using wireless communication. The system had three main functions. The first function detected unusual vibrations during earthquakes and provided an alert. The second function monitored damage such as cracks and moisture in walls after earthquakes or heavy rainfall. The third function controlled lighting, ventilation, and audio systems in an auditorium according to the number of people present. The researchers also focused on keeping all sensor nodes properly synchronized in time. ZigBee wireless communication was used to transfer information from the sensors to a central server. This reduced the need for long wired connections. The study showed that combining different sensors into one wireless system can improve early damage detection and provide real-time information. It can also improve safety and help in planning future maintenance of buildings and bridges.

Kuang et al. developed a sensor system that could both detect and help repair cracks in concrete beams. The system used a copper wire that breaks when a crack develops. When the wire breaks, the electrical circuit changes, indicating that a crack has occurred. The sensor could be installed either on the surface or inside the concrete. An additional self-healing system was included using a tube filled with adhesive. When a crack damaged the tube, the adhesive was released into the crack and helped to repair it. The researchers tested the system on 2-metre-long concrete beams. The surface-mounted sensor detected cracks as small as 0.18 mm, while the embedded sensor detected cracks of about 0.96 mm. The study showed that copper wire sensors can be useful for crack detection. The self-healing feature also provides an interesting possibility for developing future smart structural monitoring systems.

Del Grosso et al. reviewed structural health monitoring (SHM) methods used in civil engineering. They explained that SHM combines structural engineering, sensors, electronics, and data processing to understand the condition of structures. The study discussed two main types of monitoring: permanent monitoring and periodic monitoring. Permanent monitoring collects structural information continuously, while periodic monitoring is carried out at selected times and is generally cheaper. The researchers also discussed different methods for detecting structural damage. They identified high equipment cost, sensor failures, and the lack of common SHM standards as major challenges. Reinforcement corrosion was also identified as an important cause of damage in concrete structures. The study showed that SHM can provide important information about structural condition and help detect damage at an early stage. However, high cost and reliability problems still limit its use. Therefore, there is a need for simple, affordable, and reliable monitoring systems.

Park et al. investigated crack detection in concrete using Lead Zirconate Titanate (PZT) piezoelectric sensors. The system was based on electromechanical impedance. When a crack develops in concrete, the structural behaviour changes, which also changes the electrical impedance measured by the PZT sensor. The researchers used the Root Mean Square Deviation (RMSD) value to identify these changes. Ten PZT sensors were installed on a reinforced concrete beam. The beam was then loaded gradually to produce shear and flexural cracks. The sensor readings were monitored during the loading process. The results showed that the PZT system could detect changes caused by crack formation and propagation. The method provided good sensitivity and allowed continuous monitoring of the structure. The study concluded that PZT-based impedance monitoring can be useful for detecting early structural damage, especially in places where visual inspection cannot easily identify internal or developing cracks.

Sun et al. reviewed three important structural health monitoring technologies: Wireless Sensor Networks (WSN), Global Navigation Satellite System (GNSS), and ultrasonic testing. WSN systems use small sensors placed at different locations to measure parameters such as strain, vibration, and pressure. The collected information is sent to a central system for analysis. GNSS technology uses satellite signals to measure structural movement, displacement, and settlement over long periods. Ultrasonic testing uses sound waves to identify internal

defects and corrosion without damaging the structure. The researchers explained that each method has advantages and limitations. GNSS requires a reliable satellite signal, which can be difficult in areas with obstructions. Wireless sensors can also be limited because one sensor may measure only one main parameter. The study showed that combining different monitoring technologies can provide better information about structural condition and improve the detection of internal damage.

Vasconcelos et al. reviewed structural health monitoring methods for checking the safety and condition of civil engineering structures. The study focused on Wireless Sensor Networks (WSN), Global Navigation Satellite System (GNSS), and ultrasonic testing. WSN systems can measure different parameters such as strain, displacement, pressure, acceleration, and temperature and can provide information in real time. However, communication becomes more difficult as the size of the structure increases. GNSS can accurately measure movement and settlement, but it depends on receiving reliable satellite signals. Ultrasonic testing can identify internal defects in concrete and steel without causing major damage to the structure. The researchers concluded that SHM is useful for detecting damage at an early stage and improving structural safety. They recommended developing monitoring systems that are simple, accurate, efficient, and suitable for long-term use. This study supports the development of low-cost sensor systems for continuous structural monitoring.

Taher et al. studied the detection of fatigue cracks in steel bridges caused by repeated traffic loads. The researchers developed a Wireless Large-Area Strain Sensor (WLASS) using a Soft Elastomeric Capacitor (SEC). The sensor could measure strain over a large area of the bridge surface. The collected data was stored and transmitted using a wireless monitoring system. The researchers also developed a data-processing method to identify traffic loading and changes in strain that could indicate crack growth. The system was first tested using computer-based analysis and was later installed on an operating steel highway bridge in Kansas City, USA. The results showed that the sensor and analysis method could be used for long-term monitoring of fatigue cracks. The study demonstrated that large-area strain sensors can help detect damage over a wider area than traditional point sensors. This approach can be useful for continuous monitoring of large structural elements.

Spencer et al. studied smart sensors for structural health monitoring. Smart sensors are small devices that can measure structural conditions, process information, and send data wirelessly. The researchers discussed the Berkeley Mote, which is a small, low-cost, battery-powered wireless sensor. These sensors can reduce the need for long wired connections and make installation easier. They can be placed at different locations on a structure to collect useful information about its condition. However, the study also identified some limitations. Battery life is limited, wireless communication may result in data loss, and the sensors have limited memory for storing information. Despite these problems, the researchers concluded that smart sensors have strong potential for future structural health monitoring. Their low cost, small size, wireless communication, and simple installation make them suitable for monitoring structures. The study provides useful information for developing low-cost embedded sensor systems using microcontrollers and wireless communication.

Bhatta et al. reviewed the use of Internet of Things (IoT) technology for structural health monitoring of buildings, bridges, and heritage structures. The study discussed different low-cost sensors, including MEMS accelerometers, smartphone sensors, and small wireless sensor nodes. These sensors can collect structural information and send it to cloud platforms for real-time monitoring. IoT systems can help identify problems such as cracks, corrosion, and unusual vibration. The researchers highlighted that low-cost IoT systems are easier to install and more affordable than many traditional monitoring systems. However, several challenges were identified, including limited battery power, poor network connectivity, data security, and the large amount of data produced by continuous monitoring. The study concluded that low-cost IoT sensor networks can provide a practical and scalable solution for structural health monitoring. The findings are useful for systems using ESP32 and wireless communication for real-time crack and damage detection.

Komary et al. studied low-cost IoT sensors, such as DHT22 sensors, for monitoring temperature and moisture in concrete during construction. The researchers explained that temperature and moisture have an important effect on concrete setting and curing. Monitoring these conditions can help identify situations that may contribute to early crack formation. Traditional monitoring equipment is often expensive and requires trained people to operate it. Therefore, low-cost sensors can provide a more affordable option, especially for small and medium-sized construction projects. The study showed that low-cost sensors can provide useful and reliable information when proper calibration and data-processing methods are used. This research is relevant to structural monitoring because it demonstrates that inexpensive sensors can be used for continuous monitoring of concrete conditions. It also supports the idea of using low-cost electronic systems to collect information about concrete behaviour and possible damage.

Komarizadehasl et al. investigated three different low-cost distance sensors connected to an Arduino microcontroller for structural monitoring. The main purpose was to detect small movements and deformation in structures that may occur because of crack formation. The researchers tested the sensors to determine whether inexpensive devices could identify small changes in structural position. The results showed that low-cost distance and motion sensors were able to detect small structural movements. The study demonstrated that expensive professional equipment is not always necessary for basic structural monitoring. Low-cost sensors can provide useful results when they are

correctly selected, installed, and connected to a suitable microcontroller. The researchers concluded that such systems can provide an affordable option for continuous structural monitoring. This study is relevant to the present project because it supports the use of low-cost sensors and microcontrollers for detecting structural changes caused by cracks.

Bagerzadeh Karim et al. proposed a low-cost structural health monitoring system using smartphone accelerometers and ESP32 microcontroller boards. The system focused on measuring vibration and damping behaviour in buildings. The researchers explained that the formation of cracks can change the vibration characteristics of a structure. By continuously measuring these changes, possible structural damage can be identified. The proposed system was much cheaper than conventional structural monitoring equipment and used easily available devices. The study showed that smartphones and ESP32 boards can provide useful information for real-time structural monitoring. The system can help identify unusual structural behaviour and provide information for early maintenance. The research is directly relevant to low-cost monitoring systems because it demonstrates the use of an ESP32 and accelerometer for structural assessment. It also supports the idea that affordable electronic components can be combined to create practical structural health monitoring systems.

METHODOLOGY: The proposed work will develop a low-cost sensor-based Structural Health Monitoring (SHM) system for detecting internal cracks in an RCC framed structure. Copper break-wire sensors will be embedded at selected locations in concrete members such as beams and columns during casting. An ESP32 microcontroller will be connected to the sensors to continuously monitor their electrical condition. An MPU6050 accelerometer will also be used to measure vibration and movement of the structure. Controlled loading will be applied to the RCC members to create and study crack formation. Changes in sensor signals, vibration, and movement will be recorded and analysed. The system will then be evaluated based on crack detection, sensitivity, response, and reliability.

CONCLUSION: Sensor-based Structural Health Monitoring provides a way to find damage in RCC structures before it becomes serious, resulting in safer and more cost-efficient maintenance. Across the reviewed studies, low-cost sensors, wireless communication, and IoT-based data handling are shown to make monitoring affordable and widely applicable. Kuang and Goh developed a copper wire-break sensor that can also self-heal small cracks in concrete beams (Available at: <https://doi.org/10.1016/j.conbuildmat.2016.12.007>). Simple approaches like this show that meaningful crack detection does not always need expensive equipment. Issues like sensor reliability and power supply still exist, but wireless real-time systems remain a practical solution.

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