

Internal Crack Detection Study In RCC Framed Structures

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Abstract

Reinforced cement concrete (RCC) framed structures are widely used in modern buildings, and their safety depends on the condition of the concrete and the reinforcement inside the frame. Cracks are one of the earliest signs of structural distress. Surface cracks can be seen through visual inspection, but internal cracks that form inside beams, columns, and joints often remain hidden until they grow large enough to cause serious damage. Relying only on visible signs allows internal deterioration to go unnoticed for a long time, which makes early detection difficult. This review paper studies methods used for internal crack detection in RCC framed structures, with a focus on approaches that are practical and low in cost. Literature on non-destructive sensing techniques, including ultrasonic, strain-based, fiber optic, capacitive, and GPS-based monitoring methods, was studied and compared for use in RCC framed construction. The review shows that embedded sensing methods can detect internal damage that visual inspection cannot, and that low-cost microcontroller-based systems, built using components such as Arduino and ESP32, can achieve this at a much lower cost than fiber optic or ground-penetrating radar systems. The review concludes that low-cost embedded sensor systems offer a practical and accessible direction for improving internal crack detection in RCC framed structures, and that such systems can be developed further for real building applications.

Keywords: Embedded sensors; Internal crack detection; Low-cost monitoring; Non-destructive testing; RCC framed structures; Structural health monitoring

Introduction

RCC framed structures form the skeleton of most modern buildings, and the safety of these structures depends directly on the condition of the concrete and the reinforcement inside them. Cracks are one of the first signs of distress in concrete. If cracks are not identified in time, they can grow further and reduce the load-carrying capacity of the structure. Cracks can be broadly divided into two types: surface cracks, which are visible on the outer face of a member, and internal cracks, which develop within the concrete and may not show any sign on the surface for a long time. Traditional crack detection has mostly depended on visual inspection. This method is simple, but it is also limited, since it can only catch cracks that have already reached the surface. To overcome this limitation, researchers have studied non-destructive testing methods that can sense damage without breaking or damaging the structure. These methods include acoustic emission, infrared thermography, ground-penetrating radar, fiber Bragg grating sensors, digital image correlation, and embedded sensor systems. Each method works on a different principle, such as sound wave reflection, strain change, light signal loss, or capacitance change, to identify the presence and location of a crack. Many of these methods, such as fiber optic and ground-penetrating radar-based systems, give accurate results, but they require expensive equipment and skilled handling. This makes them difficult to use for small-scale or student-level projects. On the other hand, several recent studies show that low-cost components, such as Arduino, ESP32, ultrasonic sensors, strain sensors, and GSM or GPS modules, can be combined to build affordable systems that can detect internal cracks with reasonable accuracy. This review paper

studies the findings from these different approaches and brings them together to understand which methods and components are most suitable for developing a low-cost internal crack detection system for RCC framed structures. The review focuses mainly on internal crack detection rather than surface-level methods, such as Comparative Vacuum Monitoring, which cannot sense damage hidden inside a structural member. The paper also aims to identify the sensing method and components best suited for a simple, low-cost prototype that a student-level project can build and test on a small concrete specimen.

Literature Review

Roach et al. explain that Comparative Vacuum Monitoring (CVM) detects surface cracks using small vacuum channels placed on a structure's surface. A steady vacuum pressure is maintained inside these channels, and if a crack forms, outside air leaks in and changes the pressure. This shift can be measured without the use of complex electrical parts, since the sensor only needs to sense a change in vacuum. However, CVM sensors must be in direct contact with the crack opening on the outer surface to detect the air leak, which means the method works only for surface cracks. If a crack starts deep inside a material and has not yet reached the surface, CVM cannot detect the resulting pressure change. Because of this limitation, internal flaws require other tools, such as ultrasonic testing, X-rays, or eddy current testing, which can sense damage that has not broken through to the surface. This study is relevant to internal crack detection research because it clearly shows the boundary between surface-based and internal-based sensing methods, and supports the case for using embedded sensors when the aim is to detect damage hidden within a structural member.

Wan et al. studied the use of a distributed fiber optic sensor for detecting and monitoring cracks in concrete structures. The main aim of the research was to develop a better method for finding cracks at an early stage, especially when the exact location of the crack is not known in advance. The sensor works using optical time-domain reflectometry (OTDR). When a crack opens, the optical fiber bends, which causes a loss of light, and this loss can be measured and related to the size of the crack. An important advantage of this approach is that a single optical fiber can detect and monitor several cracks at once, so many separate sensors are not required. The sensor was tested under different conditions, including static loading, multiple cracking, shrinkage cracking, and cyclic loading, and the results showed that it could successfully detect cracks and provide information about crack opening. The study concludes that distributed fiber optic sensors are a useful tool for structural health monitoring of concrete structures, since they can give early warning of cracking, allow remote monitoring, and reduce the need for frequent visual inspection, although further research is needed on installation and long-term durability.

Zhang et al. state that crack detection is important for maintaining the safety and durability of reinforced concrete structures, and that traditional methods such as visual inspection, strain gauges, ultrasonic testing, and X-ray CT have limitations for continuous and real-time monitoring. Recent research has therefore focused on optical fiber sensors, including distributed sensors such as BOTDR, BOTDA, BOFDA, and BOCDA, along with point-based Fiber Bragg Grating (FBG) sensors. Distributed sensors can locate cracks over a larger area, while FBG sensors provide sensitive local strain measurements at specific points. The study proposes combining BOFDA and FBG sensors to detect both internal and surface cracks together. The experiment showed that BOFDA could detect internal cracking while FBG could monitor surface cracks and estimate crack width, although the crack-width estimation showed about 50% error, indicating the need for further improvement in accuracy. Overall, the literature indicates that a combined BOFDA-FBG system can provide more comprehensive reinforced-concrete crack monitoring than either technique used alone, which is useful when both internal and surface damage need to be tracked together.

Chakraborty et al. state that cracks are a common problem in reinforced concrete structures, and if they are not detected at an early stage, they can grow and affect the strength and safety of the structure. Researchers have therefore studied different non-destructive testing (NDT) methods, such as acoustic emission, infrared thermography, ground-penetrating radar, FBG, digital image correlation, and ultrasonic testing, to find cracks without damaging the structure. Among these methods, ultrasonic sensors are useful for detecting changes inside concrete, since embedded ultrasonic sensors can be placed inside the concrete and used to monitor areas that are difficult to reach from the outside. When a crack develops, it changes the ultrasonic signal, and these changes can

be analyzed to identify damage. In this study, four embedded ultrasonic sensors were placed in a reinforced concrete beam to study early crack detection, and the signals were analyzed using different signal-processing methods. The results showed that the sensors could detect small cracks before they became visible on the surface, which supports the use of embedded ultrasonic sensing for early-stage internal crack detection in concrete members.

Yoon et al. developed a deep neural network-based structural health monitoring system for real-time crack detection and localization using strain gauge sensors. In this study, twelve strain gauge sensors were used to measure local strain from a CFRP composite structure subjected to cyclic loading. The strain near a crack changes because of stress concentration at the crack tip, and these changes can be used to identify structural damage. Principal Component Analysis (PCA) was used to reduce the large strain-field data, and a deep neural network (DNN) was used to predict the complete strain field from the readings of a small number of strain gauge sensors. The proposed system achieved an R^2 value of 0.96, and the predicted maximum-strain location showed more than 90% accuracy, with cracks as small as 3 mm detected in the tested specimens. This research is relevant because it demonstrates that strain sensors can detect changes caused by cracks and that deep learning can improve crack detection and localization. However, the study mainly focused on surface-mounted strain gauges and cracks at a fixed position, so further work is needed to extend the concept to sensors embedded within a structure for detecting internal or hidden cracks.

Komarizadehasl et al. describe a low-cost but highly efficient sensor system for detecting structural cracks. The system uses multiple MEMS sensors, five in total, placed at different points to improve measurement accuracy, with additional filtering used to reduce noise in the readings. Small movements of a structure are measured by these MEMS sensors and then transferred to other components for further filtering, which allows interior cracks in buildings to be detected with acceptable reliability. A notable feature of this study is that the complete system was built for only

140 Euros, showing that reliable structural monitoring does not always require expensive hardware. The paper also provides practical guidance on building a working prototype of a low-cost sensor system for structural assessment and crack detection. This approach is relevant to low-cost internal crack detection projects, since multiple MEMS sensors combined with a microcontroller, such as an Arduino or Raspberry Pi, can be used to take accurate measurements. Averaging the readings from several sensors can further reduce the margin of error and improve the overall reliability of the detection system.

Srivathsan et al. discuss the use of ultrasonic sensors for crack detection in concrete. Visual inspection alone only checks the surface of a member and can miss cracks that form internally, whereas an ultrasonic sensor system can detect such damage by sending high-frequency sound waves into the concrete. The sensor measures changes in the reflection of these waves to determine the crack's depth, height, and width. This approach is affordable and can be used by non-specialists without extensive training, which makes it easy, accurate, and less demanding in terms of time, effort, and labour. The system was also shown to work reliably in difficult weather conditions, such as high humidity and heat. The proposed idea can be applied in practice by building a system using an Arduino UNO R3, an LCD display, and three HC-SR04 ultrasonic sensors, with each sensor measuring the crack's depth, height, and width individually. The study reports that this system was built and tested successfully, confirming that low-cost ultrasonic sensing is a practical option for internal crack detection in concrete members.

Alshandah et al. present a method for detecting hidden cracks inside concrete using strain sensors. Discrete strain sensors were placed at the bottom of concrete specimens, and when a crack develops, the strain inside the concrete changes. By measuring these changes using two sensors, the researchers were able to estimate the crack's location, depth, and direction. Laboratory tests showed an average crack detection accuracy of about 82.4%, which indicates that a small number of strain sensors can provide useful information about internal damage that is not visible from the outside. The method is described as easier and less expensive to implement than several other sensing approaches, and it can be extended to buildings and other concrete structures. For internal crack detection projects, the same basic idea can be applied to beams or other concrete members by placing low-cost strain sensors at

suitable locations. Changes in strain readings can indicate the formation or growth of an internal crack, and a simple microcontroller can be used to collect the sensor data and raise an alert when unusual changes are detected, supporting early assessment of structural damage.

Wu et al. present a method for detecting cracks in concrete using an optical fiber network. Common methods, such as tapping, acoustic emission, and thermal imaging, often check only one location or require manual work, which means early signs of damage can be missed. In this study, an optical fiber network is used for continuous monitoring, so that when a concrete crack forms, it bends the fiber and this microbending changes the light signal passing through it. An optical time-domain reflectometer (OTDR) is used to identify information about the crack from this signal change. The sensor can work without prior knowledge of the exact crack location or angle, and it is able to detect cracks as small as 0.05 mm. This method is useful because it can monitor a wide area at the same time and does not damage the concrete, although OTDR equipment can be costly and may need skilled operation. For a low-cost internal crack detection system, optical fiber can be placed inside or near beams and columns along with a simple light source, detector, and controller to record changes in the light signal, giving an early warning of internal cracking.

Henault et al. studied the use of fiber optic sensors for monitoring cracks in reinforced concrete (RC) structures. A reinforced concrete beam was tested under bending, with fiber optic sensors placed both on the surface and inside the concrete. The sensors measured strain along the beam with high sensitivity and centimeter-level spatial resolution, and the results were similar to those from conventional sensors and theoretical calculations. The system was also able to detect and locate cracks earlier than normal visual inspection. This method is useful because it can continuously monitor a large area instead of checking only one point, and it can detect small changes in strain before a crack becomes clearly visible. However, the fiber optic system requires special equipment, such as a Rayleigh interrogator, which increases its cost. For a low-cost internal crack detection project, the main idea of this research can be applied in a simpler and cheaper form by using low-cost strain sensors at selected locations inside or on concrete beams, with sensor readings collected using a microcontroller. A sudden change in strain can then indicate a possible internal crack and provide an early warning of damage.

Parashuram et al. studied the early detection of cracks in reinforced concrete (RC) beams using non-destructive testing (NDT) methods, focusing mainly on Ultrasonic Pulse Velocity (UPV) and piezoelectric sensors. UPV was used to assess the quality of concrete and identify the position or depth of internal cracks, while the output signal from a piezoelectric sensor provided information about the behaviour of the beam and its cracked portion. ANSYS software was used to study the structural behaviour of the beam under loading. The study shows that cracks do not always need to be detected through visual inspection, since sensors can provide useful information about damage inside a concrete member, which is important for maintaining structural safety. The paper also discusses sensor systems suited for cost-effective structural health monitoring. This work supports the idea of sensing changes inside an RC member using a low-cost piezoelectric or ultrasonic-based system, which can be tested on a small RC beam by comparing sensor data between healthy and cracked conditions to identify internal damage.

Yan et al. present a low-cost method for detecting and monitoring cracks in concrete structures using Soft Elastomeric Capacitors (SECs) arranged as a dense sensor network. These sensors detect changes in strain by measuring changes in capacitance, and they were tested on small reinforced concrete beams as well as a full-scale post-tensioned concrete beam. The results showed that the sensor system could detect, locate, and estimate the growth of cracks, with sensor readings showing good agreement with the cracks observed during physical testing. This method is useful because it allows continuous monitoring of cracks instead of relying only on periodic visual inspections, and SECs are described as low-cost, durable, and suitable for covering larger surface areas. This idea can serve as a basic concept for developing a low-cost sensor system for internal crack detection, where sensors are placed at important locations on a beam or structural member to monitor changes in electrical readings that may indicate crack formation. However, since this study mainly demonstrates sensors placed on the surface of concrete beams, further testing would be needed to adapt the approach for detecting cracks inside a structural member.

Chakraborty et al. conducted an experiment to evaluate a method using embedded ultrasonic sensors for crack detection, installing sensors in beams, a large-scale reference structure, and a real bridge in Gliwice. The study examined the maximum distance between two sensors that still allows reliable crack detection, and found that the most accurate results were obtained when sensors were placed no more than 1.5 to 2 metres apart. The ultrasonic signal became less clear when the distance between sensors was increased beyond this range. Cross-correlation and wavelet transform methods were used to process the sensor data and identify signs of damage. This paper provides useful insight into the role of sensor placement in an embedded monitoring system, showing that the distance between sensors directly affects their ability to detect cracks reliably. The same principle is relevant when planning the placement of copper break-wire sensors inside an RCC column, since keeping sensors within an appropriate distance of each other helps ensure accurate crack detection without additional cost.

Im et al. explain how GPS technology can be used to check the health of structures such as bridges, towers, dams, and tall buildings. The study examines how GPS receivers can measure changes in the position of these structures when they are affected by wind, traffic, temperature, and other loading conditions, showing that GPS can track both slow movement over time and faster structural motion. The paper also discusses problems associated with GPS use, such as the multipath effect, which occurs when signals bounce off buildings, trees, or cables and reduce accuracy. To address this, the study looks at combining GPS with accelerometers, since GPS is better suited to long-term movement while accelerometers are more effective for fast movements. The results show that GPS is a useful tool for checking the condition of large structures without direct contact, but that a single sensor type is not enough to capture all the required information. The study concludes that using GPS and accelerometers together can provide a clearer picture of a structure's health and help engineers identify problems at an early stage, which is important for keeping structures safe over time.

Salazar-Lopez et al. discuss the use of GPS modules, specifically the u-blox Neo-6M, for structural health monitoring, with a focus on time synchronization rather than direct movement measurement. The system uses a Pulse Per Second (PPS) signal generated from satellite atomic clocks, which allows all wireless sensors in a network to begin recording data at exactly the same time without the need for long connecting cables. This approach to timing is described as a low-cost solution, since it removes the need for expensive wiring across a large structure. However, the study notes that clouds and walls can block the GPS signal, which is an important consideration when sensors are used inside a building. For an internal crack detection project, low-cost GPS modules can be used to synchronize sensor readings and improve data accuracy. Since sensors are placed inside a building in such projects, a small GPS antenna can be positioned near a window or on the roof, keeping the overall system low-cost while maintaining precise timing for detecting cracks.

Methodology

The proposed study will develop a sensor-based Structural Health Monitoring (SHM) approach for detecting internal cracks in RCC framed structures. Based on the methods studied, suitable sensors will be placed inside or at selected locations of RCC members to monitor changes caused by loading and crack formation. Strain, vibration, displacement, and ultrasonic responses will be considered for identifying internal damage. Accelerometers will be used to monitor structural movement and vibration, while GPS-based methods can support displacement monitoring and sensor time synchronization. Sensor location and spacing will be studied to improve detection. The collected data will be compared between healthy and damaged conditions to evaluate crack detection and structural response.

Conclusion

Internal cracks in RCC framed structures can remain hidden and may reduce structural safety before becoming visible. The reviewed studies show that sensor-based Structural Health Monitoring can detect internal damage using strain, vibration, displacement, ultrasonic, and fiber optic methods. Advanced systems can provide accurate results but may be expensive and difficult to install. Low-cost sensors provide a more practical option for regular monitoring. GPS-based studies also show that structural movement can be measured over time, while accelerometers can detect faster movements and vibrations. Future work should focus on testing suitable sensors in

RCC beams, columns, and joints under controlled and realistic loading conditions. Sensor placement, data processing, and crack-location detection should also be improved. Embedded ultrasonic sensing provides useful guidance for future development: "Chakraborty et al. (2022), Acoustics" (<https://reference-url-citation.invalid/0>).

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