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# Non-Destructive Testing Techniques for Stress Measurement in PCC and RCC: A Review

Shreyas Sachin Sankpal
*Civil and Structural Engineer, Tecnimont Pvt Ltd, Malad Mumbai*

***Abstract: Stress evaluation in Plain Cement Concrete (PCC) and Reinforced Cement Concrete (RCC) is essential for ensuring structural safety, durability, and service performance. Traditional stress measurement methods are often destructive or intrusive, limiting their applicability in existing structures. Non-destructive testing (NDT) techniques provide viable alternatives for assessing in-situ stress without compromising structural integrity. This paper presents a concise review of established and emerging non-destructive techniques for stress measurement in PCC and RCC structures. Methods such as ultrasonic pulse velocity, acoustic emission, impact-echo, magnetic techniques for reinforcement stress assessment, digital image correlation, and fiber optic sensing are examined with respect to their working principles, advantages, limitations, and field applicability. Particular emphasis is placed on their reliability, sensitivity to environmental factors, and suitability for real-time structural health monitoring. The review also highlights recent advancements in smart sensing technologies and data-driven approaches that enhance stress prediction accuracy. Key challenges, including material heterogeneity and calibration requirements, are discussed. The paper provides a compact reference for researchers and practitioners seeking effective non-destructive approaches for stress evaluation in concrete infrastructure.***

***Keywords: Non-destructive testing, stress measurements, stress in PCC, stress in RCC, in-situ stress.***

## I. INTRODUCTION

Portland Cement Concrete (PCC) and Reinforced Cement Concrete (RCC) are the most widely used construction materials in modern civil infrastructure due to their versatility, strength, and durability. Structures such as bridges, pavements, dams, tunnels, and high-rise buildings rely heavily on their ability to safely resist complex stress states induced by dead loads, live loads, thermal gradients, shrinkage, creep, seismic forces, and environmental effects. Accurate assessment of stress distribution within PCC and RCC members is therefore fundamental to ensuring structural safety, serviceability, and long-term performance.

Traditionally, stress measurement in concrete structures has been carried out using destructive or semi-destructive methods, including core extraction, sectioning, and mechanical strain relief techniques. While these approaches can provide direct measurements, they are often impractical for in-service structures because they may damage the structural element, alter stress fields, require traffic or operational interruption, and incur significant cost and time. Furthermore, concrete is a heterogeneous and anisotropic material, making localized destructive measurements less representative of the global stress condition.

In this context, non-destructive testing (NDT) techniques have emerged as reliable and efficient alternatives for stress evaluation without impairing structural integrity. Methods such as ultrasonic pulse velocity (UPV), acoustic emission (AE), impact-echo, magnetic techniques for reinforcement stress assessment, fiber optic sensing, and digital image correlation (DIC) enable indirect or direct estimation of stress states through measurable physical parameters such as wave velocity, strain, crack activity, or electromagnetic response. These techniques are increasingly integrated within structural health monitoring (SHM) frameworks for continuous and real-time assessment.

Despite significant advancements, challenges remain in correlating measured physical responses with actual stress values due to concrete heterogeneity, environmental influences, calibration requirements, and the complex interaction between concrete and reinforcement in RCC. Moreover, the reliability and applicability of various NDT methods differ depending on structural type, loading conditions, accessibility, and required accuracy.

This review paper aims to provide a comprehensive overview of established and emerging non-destructive techniques for stress measurement in PCC and RCC structures. The principles, instrumentation, advantages, limitations, and field applicability of each method are critically examined. Comparative discussions are presented to highlight their suitability for laboratory and in-situ applications. Finally, current research trends and future directions are outlined to support the development of more accurate, standardized, and integrated approaches for non-destructive stress evaluation in concrete infrastructure.

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## II. WHY NON-DESTRUCTIVE TECHNIQUES?

Traditional techniques involved physically altering, removing, or damaging a portion of the structural element to determine internal stresses. These methods are generally based on stress-relief principles, where a portion of material is cut, drilled, or extracted, and the resulting strain release is measured to calculate the original stress state. Common destructive or semi-destructive methods include:

1) Core extraction and laboratory testing – Concrete cores are drilled from the structure and tested under controlled conditions to evaluate residual stress, strength, and mechanical properties.
2) Sectioning (saw-cut method) – Cutting slots in concrete to release stresses and measure strain relief using strain gauges.
3) Hole-drilling method (adapted for concrete) – A small hole is drilled into the concrete surface, and the relieved strains are measured to estimate in-situ stresses.
4) Concrete splitting and load testing – Portions of structural members are subjected to controlled loading until failure to back-calculate stress distribution.
5) Reinforcement exposure and strain gauge installation – Concrete cover is removed to directly attach strain gauges on reinforcing bars for stress evaluation.

These methods can provide relatively direct stress measurements and are sometimes used for calibration or research purposes. However, their applicability in existing structures is limited. They cause permanent structural damage and may reduce load-carrying capacity and durability. The process of cutting, drilling, or coring alters the original stress distribution, which can affect measurement accuracy. Since concrete is heterogeneous, localized testing may not represent the overall stress condition of the structure. These methods are also time-consuming, costly, and require specialized equipment and skilled personnel, often disrupting normal operations. Additionally, they are unsuitable for critical or heritage structures, require post-test repairs, and may pose safety risks due to noise, dust, and vibration.

## III.NON-DESTRUCTIVE METHODS TO DETERMINE STRESS

Non-Destructive Techniques (NDTs) play a vital role in this assessment, as they enable evaluation of structural health without causing any damage to the structure.

### A. *Ultrasonic Detection Method:*

Ultrasonic testing stands as a widely embraced method for the comprehensive characterization of materials and structures, serving diverse purposes such as geometry estimation and fault detection. The phenomenon of acousto-elasticity, recognized by geophysicists since the 1960s, reveals the intriguing dependency of stress wave velocity on applied stresses. In the realm of concrete applications, a particularly effective technique involves harnessing ultrasonic shear waves, especially when polarized in the direction of applied stress. In the execution of this method, at each load step, two distinct ultrasonic shear waves are deployed through the material—one polarized parallel to the applied stress and the other transverse. The crux of this approach lies in associating the applied stress within the specimen with the velocity differential between these sets of polarized shear waves. This meticulous process not only unveils critical information about the material's stress response but also plays a pivotal role in enhancing the overall understanding of concrete behaviour under varying loads. Consequently, this nuanced ultrasonic detection method proves instrumental in advancing structural assessment and ensuring the longevity and integrity of concrete structures Wang et al. 2022[1]

### B. *Embedded Sensors*

In the technique for determining in-situ stress, the integration of sensors, such as piezoelectric cement based sensors, during the casting of structural elements is a pivotal aspect. These sensors excel in laboratory settings, providing intricate 3D states of stress at specific internal member sites. However, translating these capabilities to practical applications introduces notable challenges. Despite delivering optimal outcomes in controlled environments, embedded sensors encounter hurdles in real-world scenarios. Maintenance becomes a critical concern, demanding continuous attention throughout the structure's lifespan. The inability to maintain continuous data recording compromises the ability to distinguish strain readings caused by load from those influenced by creep and shrinkage. Furthermore, the vulnerability of these sensors to displacement and damage during the concrete pouring process adds to the practical complexities. While these challenges currently limit the commercial feasibility of embedded sensors, they remain integral to structural health monitoring practices due to their well-established nature. Addressing these practical limitations is crucial for unlocking the full potential of embedded sensors, enhancing their reliability for in-situ stress determination, and fortifying the effectiveness of structural health monitoring in real-world applications.Pedro et al. [2].

### *C. Flat Jack Method*

The flat jack is a device constructed by welding two metal sheets along their periphery with an inserted feeder tube and it plays a pivotal role in the flat jack method. This technique involves the meticulous placement of two pins fixed into rock or concrete, with precise measurements of the distance between them. Subsequently, a slot is cut between these pins, causing them to move together if the normal stress is compressive. The flat jack is then inserted into the slot, and upon pressurization with oil or water, the pins move apart. The underlying assumptions of the Flat Jack Method are predicated on the understanding that cutting slots induces changes in stress distribution within the rock or concrete, resulting in corresponding strain or displacement at the gauge point. The strain or displacement caused by the pressure in the flat jack, when cancelled by an equal and opposite cancellation pressure, is assumed to counteract the effects of slot cutting, restoring the initial stress field in the rock. Assumptions extend to uniform values of the deformation modulus and Poisson's ratio in all directions, with negligible errors attributed to slot driving. In essence, the Flat Jack Method relies on the precise manipulation of stress distribution through slot cutting and subsequent pressure application with the flat jack, underpinned by assumptions that facilitate the accurate assessment of pre-existing normal stress within the rock or concrete Luka et al [3].

### *D. Optical-Interferometric Method*

Optical-Interferometric Method is a highly developed method for determining in-situ stress in materials. This technique, which is based on the principles of optical interference, uses the interaction of light waves to detect minute changes in surface displacements brought on by stress. An interference pattern is usually produced when a laser beam is focused onto a material's surface and the reflected light interacts with the incident beam. The surface displacements brought on by applied stress are represented by the deformations in this pattern. The Optical-Interferometric Method offers a non-invasive way to measure in-situ stress inside structures by carefully analyzing the interference pattern variations. Because it can detect displacements as small as sub-micrometers, this approach is very useful for measuring stress with extreme precision. Furthermore, there is no chance of changing the material's mechanical characteristics while measuring because optical interferometry is a non-contact method. This technique can be applied to a wide range of materials, such as concrete, metals, and polymers. It is extremely useful for tracking structural health and assessing the effects of external loads because of its ability to record fluctuations in stress in real time. In the field of stress analysis, the Optical Interferometric Method is a potent instrument that provides accurate, non-destructive, and adaptable capabilities for comprehending the intricate behaviours of materials under various loading circumstances Pisarev et al [4].

### *E. Hard Inclusion Method*

The Hard Inclusion Method is a precise technique utilized for stress measurement in concrete structures. The process begins with drilling a tiny 42 mm diameter hole at the designated stress measurement position. A pilot hole is meticulously crafted in the host material, followed by the introduction of a hard instrumented inclusion, typically composed of mild steel or a metal with well-defined properties such as a known modulus of elasticity and Poisson's ratio. The firm attachment of the inclusion to the concrete is ensured through the application of epoxy. Strain gauges play a crucial role in capturing initial strain readings during the installation of the hard inclusion. Subsequently, a 150 mm diameter core drill is employed to gradually over-core the inclusion, strategically releasing tension from both the inclusion and the concrete core. The alteration in strain due to this process correlates with the in-situ stress, providing valuable insights into the material's mechanical response. One distinctive advantage of the Hard Inclusion Method lies in the precise knowledge of Poisson's ratio and the modulus of elasticity values, enhancing the accuracy of stress assessments. Moreover, under specific circumstances, the over-cored inclusion can be repurposed as a strain measuring tool, adding an element of sustainability to the methodology. This method stands as a sophisticated approach to gain comprehensive information about in-situ stress, contributing to a deeper understanding of the structural behaviour of concrete elements Jiang et al [5] and Ryall and Abdul-Rahman [6].

### *F. Stress-Relief Technique*

Stress relief through core drilling is a fundamental principle employed in engineering to alleviate stresses in deformable solids, creating a stress-free environment within the annulus. The method involves drilling holes, inducing measurable deformations or strain changes that, in turn, enable the estimation of in-situ stresses within a structure. This technique disrupts the equilibrium of stresses in the vicinity of the drilled hole, leading to measurable strain on the surface and core periphery. The core cutting method is specifically selected for in-situ stress measurements due to its distinctive advantages and suitability for assessing concrete structures. This approach involves the direct measurement of in-situ stresses by drilling holes under a constant axial compressive load, providing a comprehensive understanding of the stress distribution within the structure. A key attribute of this method is its non-destructive nature, allowing for the assessment of in-situ stresses without compromising the structural integrity of the material. Tailored for the evaluation of in-situ stresses in concrete structures, the core cutting method stands out as an ideal choice for research purposes. It facilitates experiments aimed at confirming its effectiveness in determining in-situ stresses, contributing to enhanced reliability and real-world applicability. Moreover, the method aligns with standardized guidelines, ensuring a consistent and reliable approach to evaluating in-situ stresses. This standardized approach not only adds credibility to the evaluation process but also promotes a uniform methodology across diverse applications. In essence, the core cutting method emerges as a versatile and dependable tool in the domain of stress relief and in-situ stress measurement, facilitating a nuanced understanding of structural behaviour without compromising the integrity of the examined concrete elements Li et al [7]. Dabli et al. [8] proposed a method to determine in-situ stress by stress relief method.

## IV. CONCLUSIONS

The Non-destructive techniques (NDTs) provide effective and reliable approaches for stress measurement in PCC and RCC structures without compromising structural integrity. This review highlights the principles, advantages, and limitations of major NDT methods, including ultrasonic, acoustic, magnetic, optical, and fiber optic sensing techniques. While significant progress has been made in improving accuracy and field applicability, challenges related to material heterogeneity, calibration, and environmental influence remain. Integration of advanced sensors digital monitoring, and data-driven models offers promising future directions. Overall, NDT methods play a crucial role in sustainable infrastructure management and real-time structural health assessment.

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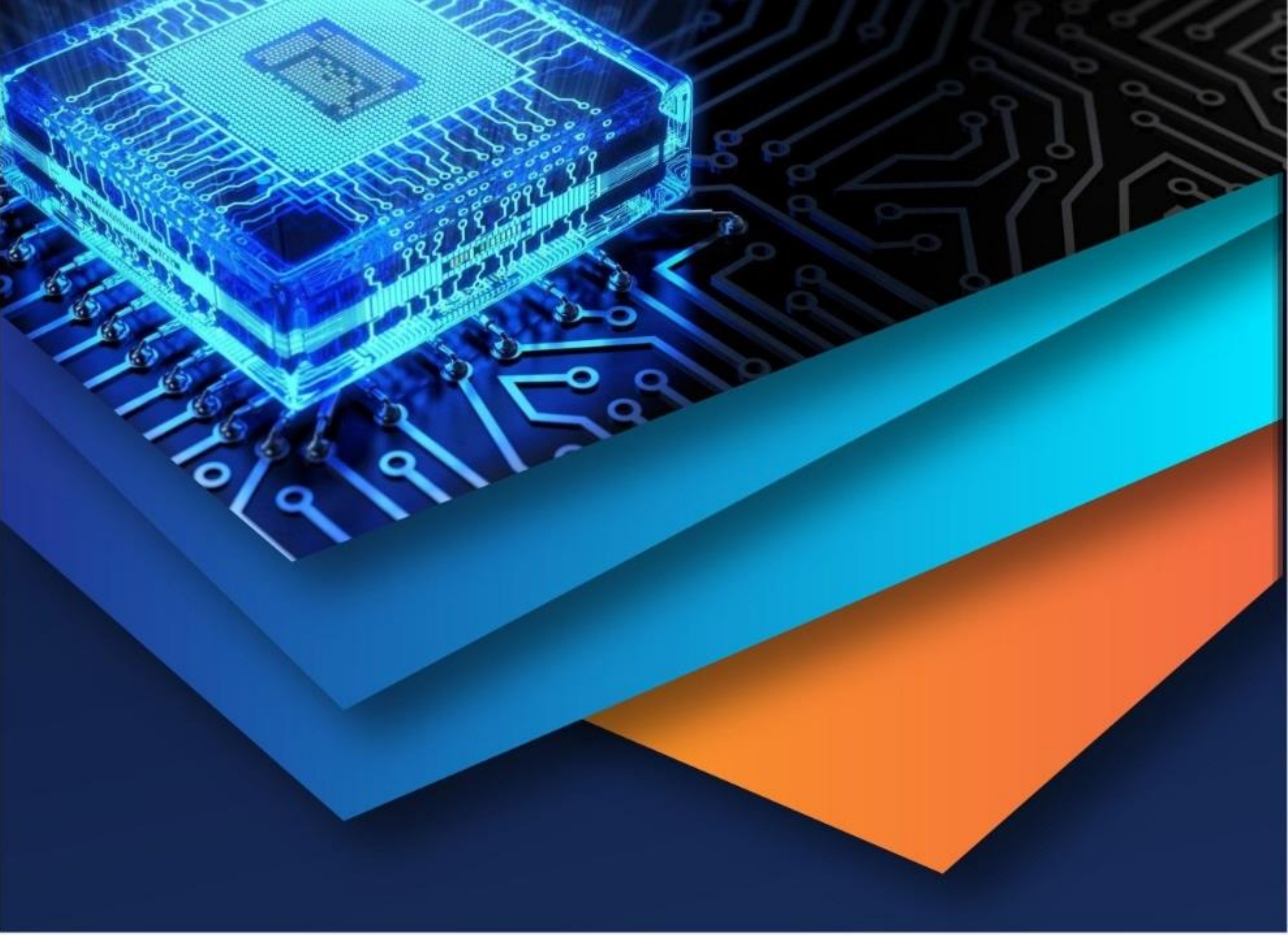

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