Cracks Evaluation of Reinforced Concrete Structure: A Review

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Abstract. Many reports state how serious the problems associated with cracking in reinforced concrete (RC) structures worldwide. The cracking can cause damage and destruction to RC structures. The cracks are the damage to RC structures that require repair or replacement. Analysis of the damage level as early as possible on the RC structure cracks can reduce the greater impact and streamline the cost of repairing the concrete structure. Therefore, non-destructive testing (NDT) method is needed on the RC structure, namely: visual inspection technique. The image obtained from the visual inspection is then analyzed using image processing. After that, the concrete structure with cracks is tested for quality (compressive strength) using the rebound hammer technique with a rebound index. From the image processing and rebound index results, the damage from the cracks that occurred can be concluded so that the repairs become more effective and efficient.

Keywords: Concrete, Aggregate, Agricultural waste, Lightweight Concrete, Mechanical Behaviour, Corroded LWC

1. Introduction

The deterioration of reinforced concrete (RC) structures caused by inadequate planning, poor estimation, poor workmanship, environmental conditions, and lack of maintenance. Damage that occurs will affect service and maintenance costs on RC structures. Therefore, the RC structure needs to be improved at an early damage stage of the RC structure [1]. The cost of repairing damaged RC structures reaches billions of dollars annually worldwide [2, 3]. Cracks are the most common type of damage to RC structures such as floors, beams, columns, and walls. The cracks in the RC structure are considered a sign of the deteriorating process of the concrete structure. Cracks in the RC structure physically occur due to the load experienced and corroded steel reinforcement [4, 5].

The RC structure cracks do not always represent the structure's actual condition and the damage's degree. Therefore, the cracks must be carefully detected, inspected, and analyzed at an early stage or a stage before the structure's function is severely damaged due to the damage that has occurred [6]. Non-destructive testing (NDT) method is a method of the accurate detection and inspection of the RC structures that are generally damaged, namely: visual inspection techniques (visual inspection), half-cell potential (HCP), ultrasonic pulse velocity (UPV), ground penetrating radar (GPR), acoustic emission
(AE), infrared thermography (IRT), rebound hammer, and others [7-13]. The NDT methods can provide objective information in the damage identification of RC structures [14].

Visual inspection is one of the NDT methods widely used to assess the cracks and the damage RC structures' surface. Visual inspection in the form of observations made directly or by using optical instruments (camera) [15]. Visual inspection is a technique that has been used in general to assess cracks and conditions of damage to RC structures [16]. Visual inspection is performed in general with the help of a measuring device, either using a measuring device in the form of a magnifying glass (Figure 1 (a)) or a ruler to measure the width of the crack (Figure 1 (b)).

![Figure 1. Cracking width device: (a) magnifying glass and (b) crack width ruler](image)

However, these manual visual inspections are ineffective, time-consuming, subjective, and often lead to errors in measuring the cracks examined [17, 18]. To an effective, fast, and objective crack inspection, an optical device (camera) is needed to obtain the crack's image that occurred in the RC structure. The obtained image needs to be processed again with image processing techniques to analyze the cracks that occur. The main advantage of visual inspection based on image processing from crack detection is accurate results compared to manual visual inspection. Therefore, this paper addresses the most important developments in the crack detection of the cracked RC structure. The review aims better to understand the crack evaluation of the cracked RC structures to emphasize certain potential research requirements in this area.

2. Crack Inspection Method

The crack inspection method is a method in analyzing cracks in RC structures using any technique. In general, the crack inspection can be done in two methods, namely: manual inspection and automatic inspection. The manual inspection of the cracked structures is shown in Figure 1. It is very difficult to assess damage objectively, effectively, and quickly using manual inspection [17, 19]. On the other hand, automatic crack inspection is very effective for inspecting damage due to cracks on the RC structures' surface. The automatic inspection of cracks on concrete structures' surface uses a non-image NDT testing method and image-based testing methods.

2.1. Non-image NDT method

The non-image NDT methods for crack inspection are acoustic emission [20], piezoceramic transducers [21], ultrasonic testing [22-24], laser testing [25], and radiographic testing [26]. The research of Shahidan et al. [20] focused on utilizing statistical b-value and RA value of acoustic emission data in evaluating concrete beam specimens. The specimens were tested by cyclic loading with the AE monitoring device in a four-point load testing. The findings show that the acoustic emission technique is promising for micro- and macro-cracking beam specimens. On the other hand, In et al. [22] designed the reinforced beam specimens under four-point bending to create vertical cracks on the beams' top surface for ultrasonic testing. Ultrasonic measurements are performed using the instrumentation of the
previous research on these cracks. The diffuse ultrasonic method tests crack depths that vary by approximately 1 cm compared to the core results. For laser testing, Buyukozturk et al. [25] proposed an acoustic-laser system as remote detection of cracking and debonding in FRP-strengthened concrete structures. The difference between the intact and deteriorating regions' dynamically reactive response to acoustic arousal in the concrete structures is calculated by laser vibrometry. The acoustic laser testing device has shown the difference in dynamic response and is ideal for simple computations of cracking and debonding of the concrete structure.

Non-image-based testing method, such as ultrasonic testing, is a signal processing-based testing, and its very complex analysis is performed using signal processing techniques. For laser and radiographic testing, the testing is done using expensive equipment so that the application and research conducted is very limited. So far, research using limited laser testing has been conducted to analyze the damage caused by the strength of FRP on the concrete structures [25], and radiographic testing in the literature was conducted three decades ago by Najjar and Hover [26].

2.2. Image-based testing methods

There are two cracked concrete structure inspection methods based on image testing methods, i.e., infrared thermography [27-29] and visual inspection based on the image processing method [17, 18, 30-34]. In the study of Aggelis et al. [27], infrared thermography scans the beam specimen to indicate the crack's position. The temperature field shows a substantial difference in the cracked beam specimen's defect region, as shown in Figure 2(a). The cracks in this result equal to 2 mm from the middle specimen deflection. On the other hand, in Valenca et al. [18] research, the image processing technique aims to remove the disadvantages of conventional visual inspection methods by proposing a new method for cracking the concrete structure's characterization. The image processing technique identifies, maps, and measures the concrete specimen cracking easily to be monitored, as shown in Figure 2 (b).

![Figure 2](image-url)

**Figure 2.** The results of image-based testing methods: (a) image from infrared thermography [27] and (b) image from image processing technique [18]

The infrared thermography is based on temperature variations (thermal) occurring on the surfaces' imaging-converted concrete structures. However, this technical limitation is that environmental temperature will influence the crack calculation and other damage to concrete structures such that the image obtained is ambiguous and imprecise [29]. Image inspection testing based on image processing of concrete structure is expected to be an objective, efficient and effective crack inspection technique measured from testing techniques, costless, and test results obtained with the above visual inspection techniques' various limitations and weaknesses.
3. Image Processing for Crack Evaluation

Image processing techniques have become a highly developed technique of application and application in various fields. Many researchers have applied image processing techniques, such as: to analyze the image of medical data [35-38], astronomical data [39, 40], geoscience and remote sensing data [41, 42], and biological data [43]. The image processing technique is a technique that is also a very significant development in the inspection of damage that occurs on the surface of reinforced concrete structures, namely: cracks, honeycomb, AAR, steel reinforcement corrosion, and any other concrete damages [33, 44]. This technique has also been widely applied in reinforced concrete structure testing, such as bridge structure [45, 46], post-earthquake buildings [47], tunnel [48], columns [49], beams [50], and on the road [51]. However, the implementation of this technique on the concrete structures also presents many challenges because the concrete structures are non-homogeneous materials, the damage that can occur randomly and irregularly, and various disturbances that occur during testing, such as lack of illumination and others concrete fragments on the obtained imagery [14, 44]. Another limitation is the various techniques developed for image processing with different success rates but with different failure degrees.

Various image processing techniques are available in the literature, such as: using gradient-based edge detection techniques, namely: Roberts, Sobel, Laplace, Prewitt, and Canny, to analyze the image of the cracks on concrete surfaces [18, 30, 32, 33, 48]. The percolation method analyzes cracks as objects with a thinner shape than non-cracked objects [52, 53]. In addition, visual inspection for automatic monitoring of cracks in concrete structures using an image processing system called MCRACK has been developed by Valenca et al. [17, 18]. On the other hand, image processing techniques have been combined with other NDT methods, such as acoustic emission (AE) [54] and terrestrial laser screening (TLS) [17], to analyze the damage levels of image processing results effectively. Therefore, the authors suggest that the image processing analysis study be combined with other NDT methods such as the rebound hammer technique, which increasingly improves performance. The image is taken perpendicular to the field from the cracked concrete structure. The concrete structure surface that suffered cracks is tested using a rebound hammer technique on both sides for quality analysis (strong pressure) based on the ASTM C805 standard [55].

4. Conclusions

This paper has reviewed the methods of crack evaluation of concrete structures. Two main crack evaluation methods for concrete structure: i.e., non-image NDT methods and image-based testing methods. The concepts, basic implementations, and limits for each method have been briefly reviewed. Therefore, image-based testing methods are supposed to be objective, reliable, and effective crack evaluation techniques of concrete structures based on image processing compared with visual inspection techniques and other methods. Although more research may be required to exploit the proposed methods and devices fully, the future performance of image processing and combined with other NDT methods in the crack evaluation of RC structures seems promising.

5. References

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