EVALUATION OF THE MASONRY CONCRETE ARCH STRUCTURAL RESPONSE AND PREDICTION OF CRACK USING NON-CONTACT AND CONTACT TECHNIQUE

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ABSTRAK

Keretakan konkrit tidak dapat diramalkan dan sukar untuk diramalkan kerana ciri konkrit tidak linear. Atas sebab ini, kajian tentang tindak balas struktur gerbang konkrit batu adalah sangat penting. Kajian ini bertujuan untuk menilai tindak balas struktur di bawah beban menggunakan teknik bukan sentuhan dan sentuhan dan meramalkan laluan retak. Teknik analisis peranti bukan kenalan dan kenalan digunakan untuk mengesan keadaan struktur, dengan taburan terikan pada permukaan konkrit diukur dengan Perisian GOM. Adalah mungkin untuk meramalkan laluan keretakan dalam sampel menggunakan analisis imej perisian GOM medan terikan. Menggunakan kamera telefon pintar, drone, dan DemEC Gauge, kajian ini menganalisis bagaimana teknik bukan hubungan dan hubungan boleh digunakan untuk meramalkan keretakan struktur dan menilai tindak balas struktur gerbang konkrit batu. Beban yang diagihkan secara seragam digunakan pada pertengahan sampel. Untuk setiap peringkat beban, hasil teknik bukan hubungan dan hubungan dibandingkan. Untuk peringkat pemuatan menegak mendatar, bawah, dan kiri atas, bacaan tolok DEMEC diambil. Data dari DemEC Gauge dibandingkan dengan nilai yang diperolehi daripada GOM Correlate. Hasilnya dianalisis secara serentak menggunakan kaedah hubungan dan kaedah bukan hubungan. Dengan mengukur ketegangan pada permukaan sampel, telefon pintar terbukti 50% lebih tepat daripada drone dalam eksperimen ini. Masalahnya berlaku apabila menggunakan drone untuk menilai ketegangan menggunakan DIC. Ini kerana dron menjana banyak pergerakan yang disebabkan oleh angin sekeliling dan juga bunyi yang dihasilkan daripada bilahnya sendiri semasa penerbangan. Akibatnya, data dalam video drone lebih tidak dapat diramalkan. Pengagihan ketegangan struktur, yang menunjukkan di mana ketegangan tertinggi terkumpul semasa proses ubah bentuk, boleh digunakan untuk mengetahui di mana laluan retak berlaku.

ABSTRACT

Concrete cracking is unpredictable and difficult to predict due to the nonlinear characteristics of concrete. For this reason, studies on the structural response of masonry concrete arches are very essential. The study aims to evaluate the response of the arch structure under loading using non-contact and contact techniques and predict the crack path. Non-contact and contact device analysis techniques are used to track the structure's condition, with strain distribution on the concrete surface being measured with GOM Software. It is possible to predict the path of cracks in a sample using GOM software's image analysis of the strain field. Using a smartphone camera, a drone, and the DEMEC Gauge, this study analyses how non-contact and contact techniques can be used to predict structural cracks and evaluate the structural response of masonry concrete arches. A uniformly distributed load is applied at the midspan of the sample. For each load stage, the results of the non-contact and contact techniques were compared. For the upper horizontal, lower horizontal, and left vertical loading stages, the DEMEC gauge reading is taken. Data from DEMEC Gauge is compared with the values obtained from GOM Correlate. The results were analysed simultaneously using the contact method and the non-contact method. By measuring the strain on the sample surface, the smartphone was proven to be 50% more accurate than the drone in this experiment. The problem occurs when using a drone to evaluate strain using DIC. It is because drones generate a lot of movement caused by surrounding wind and also noise generated from its own blades during flight. As a result, the data in the drone video is more unpredictable. The structure's strain distribution, which shows where the highest strain is accumulated during the deformation process, was used to figure out where the crack path occurred.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DIC	Digital Image Correlation
SHM	Structural Health Monitoring
DEMEC	Demountable Mechanical Strain Gauge
RC	Reinforced Concrete
UDL	Uniformly Distributed Load

CHAPTER 1

INTRODUCTION

1.1 Background

Large-scale structures would require an evaluation of their structural integrity, which cannot be ignored. Structural integrity is an engineering field that ensures that either a structure or structural member functions properly and safely under normal conditions. Long-term monitoring and long-term effectiveness of concrete structures depend on their performance, reliability, and overall efficiency. Because of this, it's important to make sure the structures are strong and to reduce public risk from weak structures. Bridge monitoring using conventional sensors, such as DEMEC gauges, has recently been carried out successfully. DEMEC Gauges have been designed to provide a cost-effective strain measurement system that can be used to take measurements at multiple locations on a structure. Furthermore, the purpose of digital image correlation technique is to investigate the feasibility of employing DIC for real-time concrete strain monitoring and to compare the suggested technique's accuracy with conventional methods (Mohammad & Huang, 2010). With 0.001mm accuracy, the DEMEC Gauge can be used for strain and fracture monitoring on a wide range of structures, as well as a variety of other applications. Bridges have been monitored for a long time with conventional sensors like DEMEC gauges and displacement sensors. A DEMEC gauge is a good way to measure strain because it is inexpensive, reliable, and accurate as long as the changes in strain are not too small. There is no effect on the gauge readings due to temperature and moisture variations. However, since these gather readings in a straight line, this makes it more difficult to detect damage Chen et al. (2018). Also, it’s not always possible to choose a comfortable position because it can affect how well you read.

The structural integrity and dynamic conditions of the building's systems are very important for both the safety of the building and its lifespan. It's important to check the condition of old buildings to make sure they are safe, will last a long time, and need to be fixed or replaced. According to a study, over 500 bridges in the United States cracked over a period of 52.5 years. Due to that, steel bridges accounted for 59% of those that cracked. 13% of failed bridges were made of concrete, 10% of failed bridges were made of wood, and 17% of failed bridges were made of another material. Arch bridges are usually known as structures that use masonry as their load-carrying system. Since they are still in use, it is clear that masonry arch bridges are very strong and can retain a significant amount of load. Visual inspections of masonry arch bridges are ineffective because of their limitations and ability to provide sufficient details on their mechanical properties. Because of this, a full research study is required to find out how well and reliably masonry arch bridges work. Yazdani & Azimi (2020) stated that a masonry arch bridge is classified into three types based on the material used in its construction: brickwork, stone, and plain concrete arch bridge. In addition, various materials such as cast iron, steel, and concrete were progressively used in the construction of arch bridges. Concrete arches, which are relatively easy to build, lasting for a long time, easy to maintain, and have a low total cost of ownership but might be difficult to evaluate because of their complex geometry and the materials involved.

Because of these advantages, various structural health monitoring systems have fully integrated acceleration devices to detect full-scale structures. Hasheminejad et al., (2018) stated that the non-contact method was first used to measure surface deformation during experimental testing. The results were the same as the numerical ones, which proved that it could be used in construction. The DIC method can also be used to make a 2-D strain profile when strain gauges cannot be used because they are too expensive.

Concrete degradation is a progressive process that includes fracture creation and propagation, aggregation, and destabilising elongation. When exposed to extreme weather and loading conditions, concrete fractures readily. Furthermore, these minor cracks have the potential to grow into major ones, causing serious structural damage to the building. Zhang et al. (2016) found that crack monitoring of concrete buildings, particularly arch structures, has grown in importance. Concrete cracking is unpredictable and difficult to predict due to the nonlinear characteristics of concrete. However, by using the Digital Image Correlation (DIC) technique, we can evaluate and model the crack propagation by measuring surface displacement of the arch structure. DIC can also be performed to analyse the surface strain map of the arch structure and determine the location of crack formation. This technique can easily measure the displacements and strains on large structures such as arch bridges with high accuracy to monitor and evaluate their structural condition.

1.2 Problem Statement

According to studies in the literature, the geometry and behaviour of masonry arch bridges are so complex that there is no reliable way to determine whether they are still functional. Niu et al., (2019) had studied on non-contact, efficient structural health monitoring and analysing crack behaviour in concrete. Even though these systems can only use stationary sensors, it is hard to find a place where the images have a wide enough field of view to effectively monitor structures like bridges that are always moving. According to the National Bridge Inventory, there were approximately 1700 masonry bridges in the United States in 2013. Like most bridges over 100 years, they may experience serious deterioration, lack of maintenance, and high traffic volume through the years (Pulatsu et al., 2019). But traditional methods of measuring sight motion assume that the camera is still, which limits the drone's ability to get around the problem of finding good places to put cameras. Instead of getting a precise displacement, these methods give displacements that are proportional to the movement of the camera.

Because of the nonhomogeneity of the concrete in masonry arch bridges, fractures occur and spread at random. One of the reasons for building collapse is crack formation and growth in concrete structures (Faron & Rombach, 2020). Therefore, a method to study and model the crack development in concrete arch structure is crucial to predict crack failure at an early stage. Due to an inaccessible location like a bridge or a tall building, conventional method such as DEMEC Gauge are unable to provide full-field measurements and physical contact is needed between the specimen and the equipment. There are not many load samples that are subjected to strict uniformity deformation in real-world engineering. Instead, there are more examples of heterogeneous deformation. In this case, it may be hard to figure out how the DEMEC gauge works in relation to the area of interest. To solve this problem and not damage the sample itself, the need for full-field non-contact approaches is becoming more important. Digital image correlation cameras can be attached to a drone, which can quickly and easily reach any part of a structure. For this study, a digital image correlation method with a fixed camera and a non-fixed camera is made. The method is designed to measure deformation in the field.

1.3 Objectives

The main objectives of this study are:

- To evaluate the response of the arch structure under loading using non-contact and contact techniques.
- To predict the location of the first crack in the arch structure under different loading conditions using the Digital Image Correlation technique.

1.4 Scope of Study

In this project, a load test was done on the sample masonry arch. The non-contact method employs a smartphone camera and drone, while the contact method employs the DEMEC Gauge. The DIC technique is used for the non-contact technique to measure strain, cracks, and crack opening under increasing loads. Using the DIC analysis concept, there are several steps involved are (i) pre-processing, which consists of elements like preparing samples and capturing images; (ii) image analysis using GOM Correlate; and (iii) post-processing (extracting analysed images from GOM Correlate).

1.5 Layout of Dissertation

This dissertation is divided into five chapters, which are Introduction, Literature Review, Methodology, Results and Discussions, and Conclusions. In the first chapter of this dissertation, the following topics are covered: an overview of the history of the study; problem statements; the objectives of the study; the scope of the work; and the outline of the dissertation.

Next, Chapter 2 divides the research topic into a few components, which includes the literature review, which summarises the findings of previous studies related to the topic of this project. The literature review discusses the related reviews or research articles done by previous researchers, such as masonry arch bridges, vision-based structural health monitoring, and the basic principle of DIC. Moreover, previous research studies on the use of the DIC Technique in monitoring structures and cracks are compiled and discussed.

Furthermore, Chapter 3 consists of the methodology of the project, which describes procedures and detailed steps, experimental calibration, and software analysis procedures such as obtaining full-field surface displacements using GOM correlate Software to achieve the objectives of this research.

Chapter 4 covers the results and findings of research while discussion is made accordingly. Result obtained must satisfied the research outcomes that shows the success in this study.

Chapter 5 is the conclusion chapter which concludes the achievement of this project based on the main objectives. Suggestions and recommendations for further study are also described.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The goal of this Chapter 2 was to do a literature review of recent works that are related to this dissertation. Researches and information from thesis papers, reports, articles and journal are taken for study purposes in order to improve the recent researches for future knowledges. Digital Image Correlation (DIC) is an innovative, simple to use, cost-effective, and non-contact optical method for measuring the deformation of crack behaviour. The technique known as digital image correlation (DIC) detects deformations and stress by analysing a sample under tension in 2D or 3D in a digital picture. This technique is discussed in this section. Furthermore, this section explains and discusses Drone DIC, with a focus on experimental validation in field work.

2.2 Definition of Structural Health Monitoring (SHM)

Structural health monitoring is a simple and effective way to ensure the long-term stability of concrete structures. Health monitoring measurement systems are becoming increasingly important in engineering structural areas since they analyse service conditions and identify degradation. Sankarasrinivasan et al., (2015) demonstrate that SHM techniques are critical to the security requirements of major civil structures over their specified lifespans and beyond. It also has structural sensing capabilities that are reliable and stable over the long term. Over the last decade, long-term monitoring systems have been installed on bridges in the United States, Canada, Europe, China, Japan, Korea, and other countries (Ko & Ni, 2005). Bridges, high-rise buildings, electricity utilities, nuclear power plants, and hydropower are among the most important structures. According to Sun et al., (2010), buildings are facing plenty of problems, including huge scale, complicated structural form, and the environment. In the event that these structures fall down, there are significant economic and human consequences. While a bridge is being constructed or maintained, monitoring devices can track the stress level and damage evolution. This lets building problems be found, diagnosed, and fixed before they happen. Knowing the history, current state, and performance of these structures helps a lot when it comes to figuring out what to do first and making sure the structure is safe.

To determine the current state of engineering structures like buildings and bridges, non-destructive testing must be implemented. When determining the extent of a structure's damage, there are four steps involved: identifying the damage, locating it, determining its type, and calculating its severity level. On the other hand, health monitoring relies heavily on crack and damage detection. Every building project should be carried out in a way that has minimal negative effects on the environment and maximum positive effects on the local population. This facilitates the identification of bridge abnormalities, the introduction of appropriate traffic control measures, and the coordination of trained workers to inspect, analyse, and repair the structures. The three main parts of bridge structural early warning system are real-time abnormal early warning, disaster early warning, and flood early warning. Real-time abnormal early warning includes early warning of bridge temperature, wind speed, load, and other real-time changing state variables. Disaster early warning includes early warning of flooding, earthquakes, and other natural and man-made disasters (Miao et al., 2015). It is possible to do SHM on large bridges by taking simultaneous measurements of the forces that are acting on the bridge and the effect that these loads have. It involves keeping an eye on the wind and the weather, as well as the traffic, prestressing, stay cables, deck, and ground (Sharma & Mehta, 2016). The results of dynamic load tests done concurrently at various times to examine the structural stability of a medium-length prestressed reinforced concrete bridge built and tested in the 1960s were compared in terms of structural reactions, performance, and costs. SHM refers to the process of developing a civil engineering infrastructure damage identification plan. It can be divided into four levels: anticipating the presence of damage in structures; detecting the geometric location of the damage; calculating the degree of damage; and evaluating the structure's remaining service life. As a result, it is important that damage is assessed as quickly as possible in order to ensure the structure's safety. This means that the stiffness and other mechanical parameters of essential members should be properly documented. This is because deterioration above a certain level presents a safety risk, resulting in a decrease in the structure's use or perhaps its destruction.

2.3 Historical Background of Masonry Arch Bridges

A masonry arch bridge is a compact and durable structure that can withstand floods and the consequences of time. For this reason, stone arch bridges deteriorate with time as a result of their having been exposed to traffic conditions as well as high vibrations, base settlement, and weather conditions, including the effects of wind, frost assault, and high heat cycles (Modena et al., 2015). Steel, masonry, and reinforced-concrete bridges were all constructed for past few years. Lund et al. (2016) carried out comprehensive experimental testing to explore the structural reaction of brickwork under compression in both directions of the material to find constitutive models for both unconfined and confined clay brick masonry prisms. Controlled displacement experiments were done on stone and brick masonry as well as their parts to measure their strength, stiffness, brittleness, energy loss, and degradation. Also Roberts et al. (2006) studied the cyclic behavior of masonry under axial load to learn more about the stress state of the material when it is subjected to traffic and earthquakes. The typical structure of a masonry arch bridge is shown in Figure 2.1.

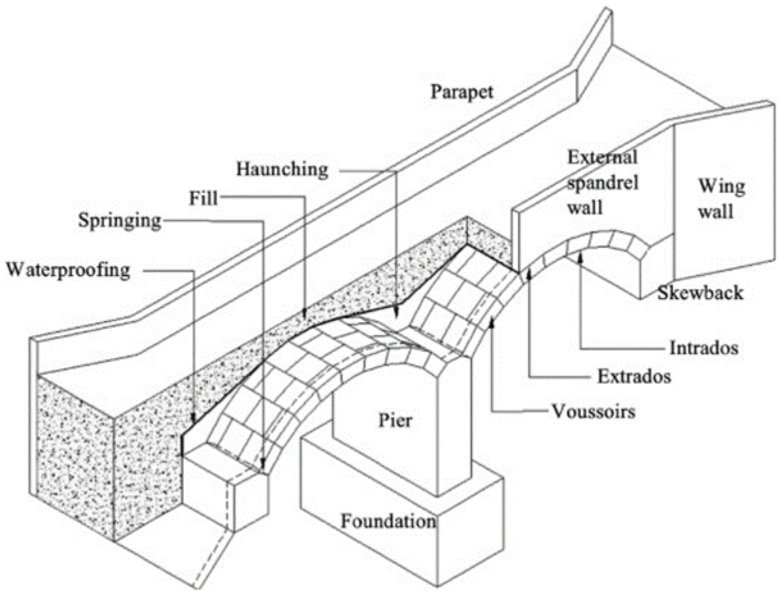

Figure 2.1: Typical Structure of Masonry Arch Bridge (Sarhosis et al., 2016)

Masonry arch bridges carry loads in two directions that are perpendicular to each other: longitudinally and transversally. Figure 2.2 illustrates the three-dimensional layout of cracks in masonry arch bridges. For longitudinal load transfer, the behaviour of the masonry arch bridge is the most essential aspect. The bridge's structural behaviours are predicted using a computer model created for static and dynamic construction studies. It is also critical for establishing the reasons for deformations along the structure, such as the causes of longitudinal cracks in the bridge's arch (Sokolovi et al, 2021).

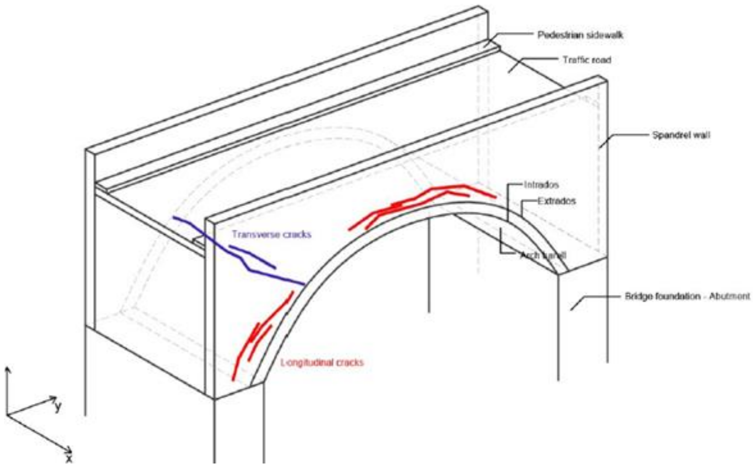

Figure 2.2: Three-dimensional layout of cracks in masonry arch bridges (Sokolović et al., 2021)

2.4 Application of Digital Image Correlation

The non-contact method, also known as the digital image correlation technique (DIC), is an image analysis procedure that analyses digital images of a deformed field using mathematical correlation functions to determine the capabilities of two devices which is smartphone and drone that are used to monitor the surface of sample arch. The Digital Image Correlation (DIC) approach is a commonly used method for detecting surface strains. It was originally utilised in experimental tests for surface deformation and displacement measurements supporting its usage in construction. DIC is a non-contact and precise tool for fracture measurements (Fayyad & Lees, 2014). The concept of DIC is simply based on determining deformation by comparing the changes in the images of the tested object before and after deformation. Digital pictures are captured at various loading stages, and compared by images, the deformation of an object subjected to external stresses may be determined (Fayyad & Lees, 2014).

Liang, Yin, Mo, et al., (2015) proposed out the methods track the changes in texture of a small region that called the reference image and the subsequent images by comparing the similarity between the reference subset and the target subset. The concept of DIC is to compare the speckle of digital images before and after they have been distorted. Figure 2.3 shows the Pixels in a reference subset and the corresponding pixels in the deformed subset. The initial image is without loads, while the subsequent images are with loads. It requires speckling the points of interest on the smooth bridge surface. To be able to complete this task, the speckles must have attributes such as contrast, unpredictability, uniform distribution, and durability. When the images of undeformed and deformed structures are compared, the surface strains can be obtained.

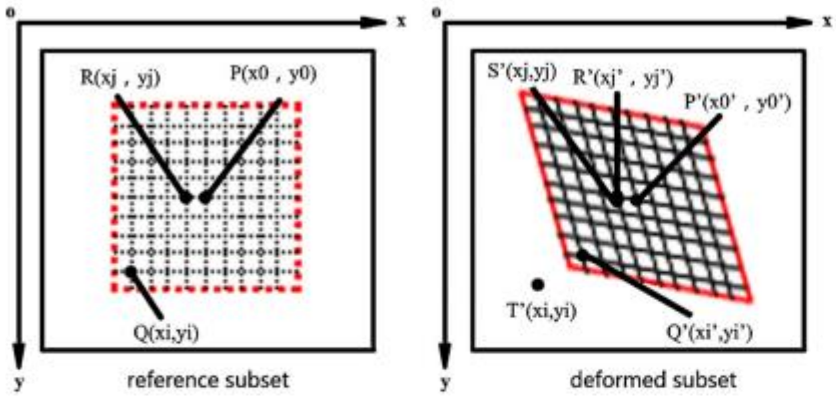

Figure 2.3: Pixels in a reference subset and the corresponding pixels in the deformed subset (Liang, Yin, Mo, et al., 2015)

The use of DIC in research and industrial applications, particularly in civil engineering, is becoming increasingly important for displacement and strain investigations in two- and three-dimensional surfaces. Furthermore, the approach gains popularity when technology, such as computing performance and camera quality, improves, as does the continued development of assessment strategies. The existence of a randomly dispersed greyscale pattern, often known as a speckle pattern, on the surface of the subject being evaluated is a basic condition for using the DIC approach (Peretzki et al, 2019). However, changes in lighting conditions during consecutive photographs, issues recognising the precise location of the subset, video motions, vibration, and so on can all affect the method's accuracy. The correlation function may also cause mistakes in the region of rough spots, for example, the intersection of the specimen with the background. Figure 2.4 shows the image acquisition of a DIC process. A fixed camera, a light source, and a sprayed pattern of speckles on the surface of the sample are all that are needed to calibrate the camera for DIC processes that are fast, easy, and cheap.

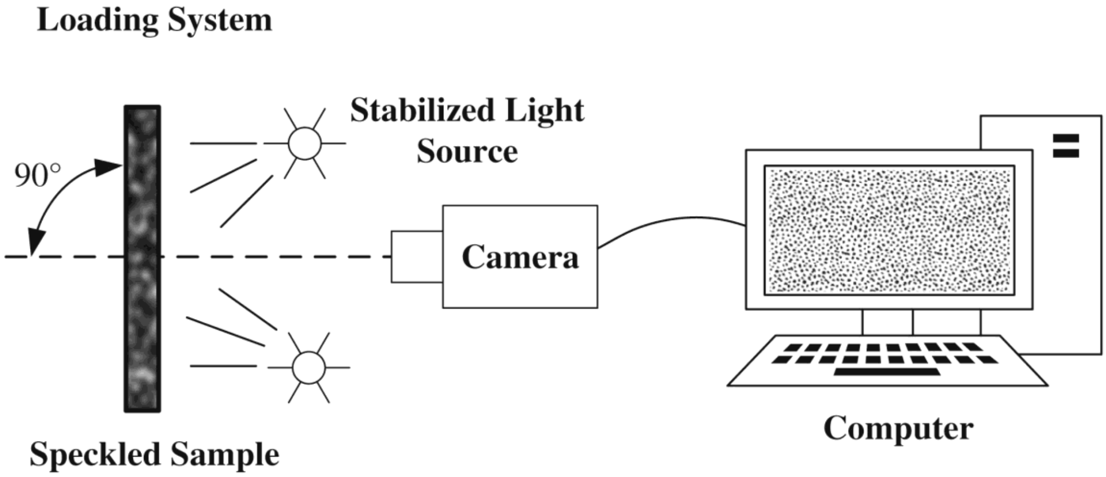

Figure 2.4: Image acquisition of DIC process (Zhao et al., 2019)

Structural evaluation is performed using optical technology in this Digital Image Corelation method. A pixel can be moved by correlating images taken at various intervals to achieve this effect. By comparing images of structures that have changed and those that have not, the surface strains can be found. When it comes to the investigation of internal forces within a structural member under operating loads, this technique is relatively new. There are several advantages to using this approach in the future because of its ease of use, low cost, and technical development. The areas of interest on the smooth bridge surface are dotted with paint. In an experimental investigation of the railhead, Bandula-Heva et al. (2012), strongly recommended that the camera position should be firm to avoid any disturbances in pixel movements. He also used the DIC technique to measure shear strain in thin walls.

According to Tong (2018), the non-contact technique, namely DIC obtains full-field surface displacements on a specimen surface by matching subsets of images taken before and after deformation using random speckle patterns. For DIC to function effectively, the sample surface must have a random grey intensity distribution as a carrier of deformation information that deforms along with the specimen surface. In general, a natural or white light source is adequate since DIC does not require laser sources, which are usually required by other optical methods (Liang et al., 2015). Liu et al. (2015) have found that the calculation accuracy is influenced by many factors such as the correlation criteria and the quality of the speckle images. Figure 2.5 shows the comparison between speckle patterns with different densities.

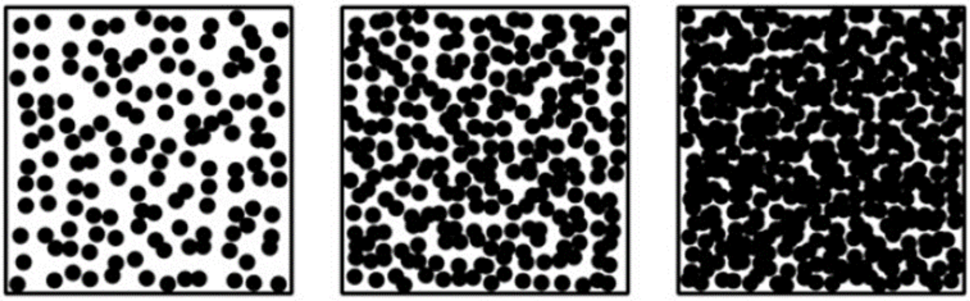

Figure 2.5: Comparison Between Speckles Pattern with Different Density (Lecompte et al., 2006)

2.4.1 Fundamental Concept of Two-dimensional (2D) and Three-Dimensional 3(D) Digital Image Correlation

Two-dimensional DIC (2D DIC) is the original DIC method for tracking speckles in 2D pictures. The DIC method is roughly classified into two types: two-dimensional DIC and three-dimensional DIC, as shown in Figures 2.6 and 2.7, respectively. It only employs one camera and is only applicable to in-plane deformation. For 2D DIC to operate, the optical camera axis must be perpendicular to the specimen, and there must be no significant out-of-plane movements during specimen deformation (Lv et al, 2018). Sutton et al. (2008) claim that the measurement accuracy of 2D DIC is inadequate because out-of-plane vibrations have a major influence on the observed results in real-world tests. The correlation process is done in the software. DIC assists in locating the damage on the sample, determining the type of damage, its location, severity, and intensity. A 3D-DIC approach that uses two synchronised cameras, or a single camera supported by light-splitting devices (Pan, 2018). Stereo-DIC is based on the idea of binocular stereovision and can accurately measure the three-dimensional shape and deformation of both flat and curved surfaces. This makes it more useful and practical in real-world applications.

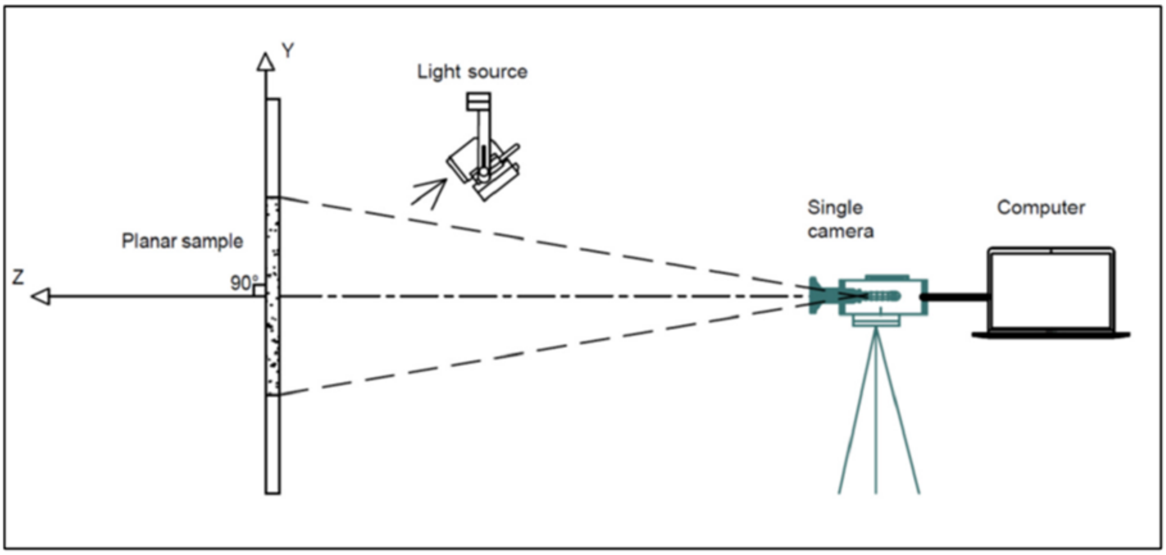

Figure 2.6: 2D-DIC surface deformation on a smooth surface (Mousa et al., 2021)

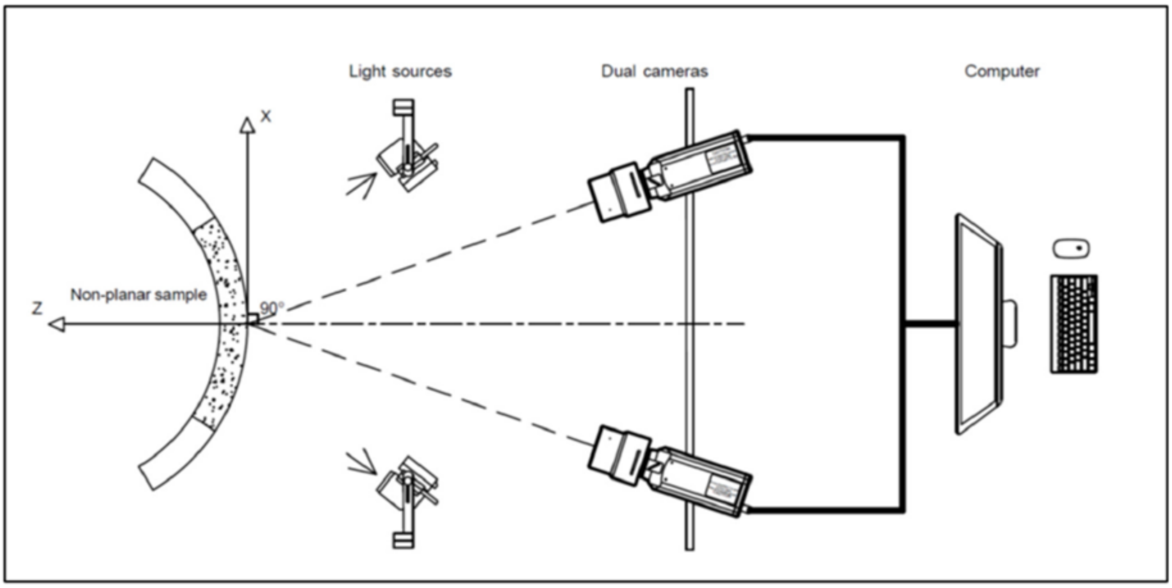

Figure 2.7: 3D-DIC surface deformation on a smooth surface (Mousa et al., 2021)

2.5 Visual Inspection of Bridges Using DIC Enabled Drone

New technologies like drones have the potential to be used in a wide variety of ways within the subject of civil engineering. The drone may provide an opportunity to take videos of civil infrastructure more effectively by allowing the camera to get closer to the structure. An increasingly pressing problem facing society is the ageing and degradation of physical infrastructure, such as bridges. In fact, ageing processes can occur in buildings because of both internal and external factors, including wear and tear on the materials, natural degradation, and environmental factors such as weather conditions, heavy use, and growing loads. Commercial drone markets are growing dramatically, which results in improved performance in terms of stability and mobility. Using drones to inspect structures for damage and fractures during maintenance is becoming more common, and the results are remarkable. Dams, commercial and historic buildings, bridges, and other infrastructure must be inspected (Duque et al, 2018). The camera mount rigging must be capable of reducing vibration enough to allow stable image capturing (Catt et al, 2019). Reagan et al. (2017) was one of the earliest studies that concerned the use of drones and digital image correlation. In that study, it was proposed that a drone that was mounted with a camera system could monitor the development of cracks on a bridge. Recent investigations have been carried out by research into vision-based methods for monitoring the health of structures. For better accuracy, Digital Image Correlation (DIC) was applied by Murray et al. (2020), whereas an optical flow-based motion magnification approach was utilised by Anthwal & Ganotra, (2019) and rise cross correlation (UCC) and orientation code matching (OCM) were utilised by Feng et al. (2017) for better accuracy. Using optical flow-based tracking, Jo et al. (2018) devised a method to quantify the dynamic motion of a structure and developed a way to quantify the dynamic movement of a structure. This technique did not necessitate the attachment of a target. Yoon et al. (2018) presented a phase-based method that magnifies motion even when rigid body motion is present. Some of the recent case study examples for the past 10 years will be listed in Table 2.1.

Table 2.1: Research conducted in the past 10 years on visual enabled drone

Author	**Research Description**
Gordan et al., 2021	A Brief Overview and Future Perspective of Unmanned Aerial Systems for In-Service Structural Health Monitoring (2021)
Khadka et al., 2020	Strain monitoring of wind turbines using a semi-autonomous drone (2020) that quantify the level of strain and loading conditions that rotating structures such as wind turbines
Flammini et al., 2016	Railway infrastructure monitoring by drones (2016) that evaluate structural faults and security threat detection.
Mousa et al., 2021	Application of Digital image correlation in Structural Health Monitoring of Bridge Infrastructure (2021) of DIC to detect damage such as cracks, spalling, and structural parameters such as deformation, strains, vibration, deflection, and rotation

2.6 Study of Crack Formation and Growth

Construction materials such as concrete are frequently employed in bridge construction. It is a quasi-brittle material with a relatively weak tensile strength compared to its compressive strength. As a result, it is prone to cracking. According to Kim et al. (2019), concrete cracking is often used as the main indicator for evaluating the degree of deterioration in reinforced concrete (RC). The Table 2.2 shows several research that rise concern about analysed crack growth.

Table 2.2: Research conducted in the past 10 years of fatigue crack

Author	**Research Description**
Zhu, 2016	Mechanism of Fatigue Crack Growth of Bridge Steel Structures (2016) in Sutong Bridge Project by doing research on the mechanism behind the propagation of fatigue cracks in a bridge
Beams, 2020	Analysis of Crack Width Development in Reinforced Concrete Beams (2020) study of 10 single span reinforced concrete beams to follow the process of crack formation and changes in their width
Accornero & Lacidogna, 2020	Safety Assessment of Masonry Arch Bridges Considering the Fracturing Benefit (2020) which provides an accurate and effective whole service life assessment of masonry arch bridges

2.7 Durability and Functionality of Masonry Arch Bridges

Masonry arch has previously been a popular material for building arch bridges on highways and railroads due to its low cost, high durability, and readily available skilled labor. According to a study performed in the United States, over 500 failures occurred at bridges having an average age of 52.5 years. The failures involved steel bridges for 59% of the cases, concrete bridges for 13% of the cases, timber bridges for 10%, and bridges made with miscellaneous materials for 17% of the cases.

2.8 Previous Studied Using Non-Contact Technique to Evaluate Displacement Measurement of Bending Tests

Numerous studies have also been conducted over the last few decades to further enhance the capability of the DIC technique. A lot of testing has been done to find the minimum bending radius takes time and costs money. Using online DIC as the emphasis of his work in this area, Pan, (2018) studied the bendability of structural steels with sheet thicknesses of more than 6 mm. Air-bending tests were done at room temperature with special instruments made for this kind of testing. A bending test setup and placement of a camera using two digital cameras with high resolution was used to perform a non-contact measurement of the deformation, as shown in Figure 2.8. When bending, optical 3D strain measurement systems are used to monitor the structure's outer surface for deformation.

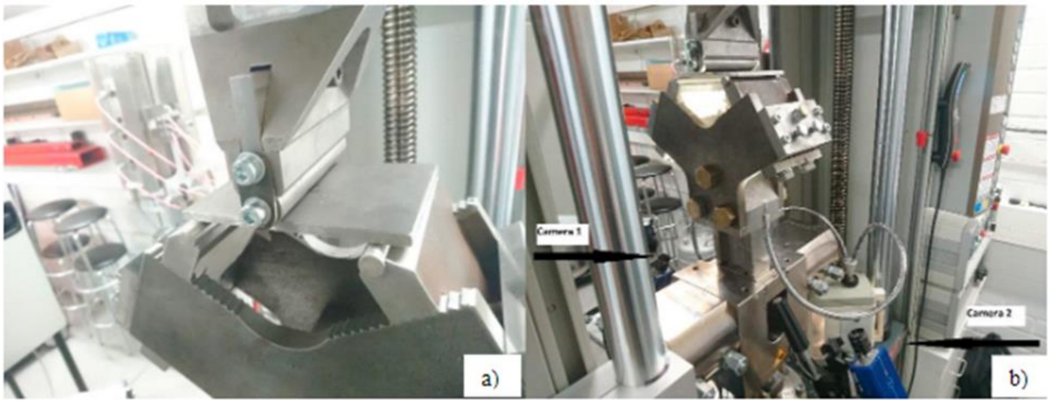

Figure 2.8: (a) Bending Test Setup (b)Placement of Camera (Pan, 2018)

2.9 Previous Research Using the Digital Image Correlation Technique to Predict Cracks

In a study conducted by Mousa et al., (2021), the digital image correlation (DIC) approach was used to detect damage such as cracks, spalling, and structural parameters such as deformation, strains, vibration, deflection, and rotation. Using DIC, as shown in Figure 2.9, the overall size and number of cracks inside the speckled zone can be detected from a single recorded snapshot taken before cracking emerged and a second captured afterwards. Cracks that form without physical contact can be detected with this method. If a targeted component was to undertake load crack checks like in the reinforced concrete beam, the position of the major vertical crack would be quickly identified.

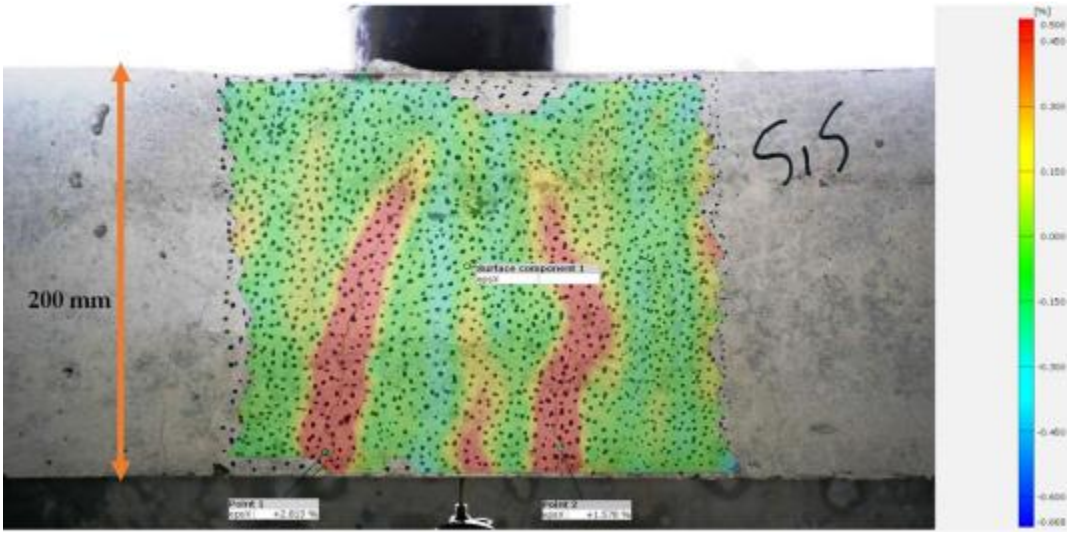

Figure 2.9: Digital image correlation deformation map between two major cracks (Mousa et al., 2021)

2.10 Video Features Cracking for Fatigue Crack Detection in Steel Structures with DIC Questionnaire Design

In Catt et al., (2019), deformational measurements are taken using a DIC system. Vision-based Structural Health Monitoring (SHM) systems, like Point Tracking and Digital Image Correlation, can be used on a drone because the process does not involve touching the structure and does not require any special equipment or instruments other than a camera. The study was conducted by Ellenberg et al. (2014) on quantitative infrastructure evaluations using a professional drone that is an affordable drone (Parrot AR Drone 2.0). The platform was not provided with any additional sensors, and the experiments were conducted only on the camera. Figure 2.10 shows the overview of the experimental setup DIC enabled drone.

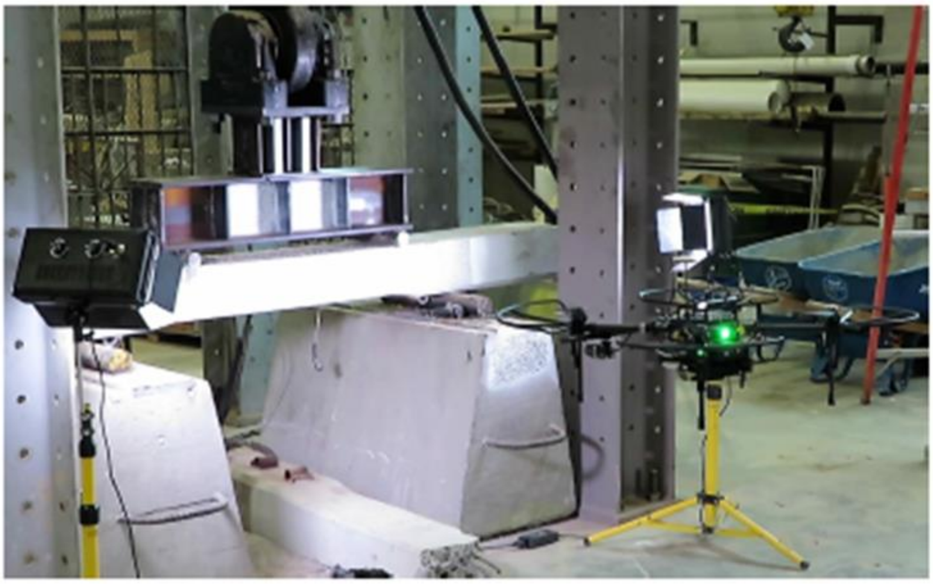

Figure 2.10: Overview of the Experimental Setup DIC Enabled Drone (Ellenberg et al., 2014)

2.11 Conventional Techniques Used in Evaluating Cracks on Structures

Cracks are the most significant shortcomings in concrete structures, impacting not only their design and durability but also their structural stability. Huang et al. (2010) studied that concrete’s fracture stability is now monitored using classic monitoring techniques such as crack gauges, strain gauges, and displacement metres. These classic monitoring methods can be used to monitor major deformations or the macroscopic failure of concrete structures, but they cannot effectively monitor micro-cracks in the deep layers prior to the concrete's macroscopic breaking. As a result, traditional methodologies are unable to provide predictive and warning signals in advance. Many dams’ failure stories, such as the Malpasset arch dam in France and the Plum Blossom arch dam in China, demonstrate that there were no obvious macro-abnormal indicators prior to the catastrophe.

CHAPTER 3

METHODOLOGY

3.1 Overview

In this Chapter 3, the overall flow of the method created to conduct the study to evaluate the response of the structure under loading using non-contact and contact methods applies Digital Image Correlation (DIC) is presented. Figure 3.1 below shows the flowchart of the research methodology that has been adopted in this study. The specimens are then subjected to manual experimental testing of concrete arch samples, and the DIC technique is used to capture images before and after deformation for analysis using GOM Correlate. The objective of Digital Image Correlation is to evaluate the capabilities of two devices that are used to monitor the sample bridge. The DIC technique is used for the non-contact technique to measure strain, cracks, and crack opening under increasing loads. The approaches compare the similarity of the reference subset and the target subset to track the variations in a specific region known as a subset during deformation. There are two devices that use smartphone cameras, and the DJI Mavic Pro 2. Five stages of loading are distributed to obtain the results of both methods. At five load stages of 0.75 kN, 1.52 kN, 2.29 kN, 3.08 kN, and 3.86 kN, experimental materials were considered and analysed using both contact and non-contact methods The team in the USM concrete laboratory first made a test sample of a structure made of concrete.