Case Report

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Implementation of Nonlinear Waves for Ceramic Plank Degradation Analysis

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Abstract

The purpose of this study is to monitor the condition of GFRP-reinforced concrete structural members through the use of elastic wave propagation. A deck slab is selected as an illustration. The deck slab is constructed of concrete of the targeted C30/37 class under three-point bending. The strain field can be calculated by observing the specimen during loading cycles with a digital image correlation (DIC) system. The Q400 system from Dantec Dynamics GmbH includes two 12.3 Mpx Baumer cameras with VS-1220HV lenses. Signals recorded by PZT (lead-zirconate-titanate) sensors are utilized to gauge flexible waves also. In addition, the usual crack opening measurements are taken. The crack's appearance and expansion alter the registered signals' shape and amplitude. But the changes are hard to see and depend on where the sensors are. Because it is impossible to determine simple parameters for disturbingly wide cracks, damage detection employs an artificial neural network (ANN). A 100% correctly classified pattern and perfect determination of the specimen's condition are possible depending on whether the element is under loading.

Keywords: Elastic waves • Digital image correlation • Concrete slabs • GFRP reinforcement • Cracks

Introduction

Concrete is a common building material that is used in a lot of structural parts and holds up well under a variety of loading conditions. This material transfers compression better than tension because of its properties, so reinforcement is required in elements with tensile zones (though not always). Due to the material's irregular internal structure, it is also impossible to accurately predict when a crack will appear and how it will spread. Cracks remain in concrete structures despite reinforcement; But most of the time, they don't mean that office activities become risky. For the construction to keep being utilized in a protected way, it is expected that it will have a specific satisfactory degree of breaks [1].

Controlling cracking in reinforced concrete is important for water leakage prevention as well as aesthetics. Break requirements take creep breaking and shear influences into account [2]. Breaks in a building's load-bearing components should be carefully examined on a regular basis. If the structure has significant cracks of a significant width and height, its condition may be deteriorating and becoming useless [3].

Break opening estimations are typically performed physically with a crack width estimating instrument or sensor during impromptu or intermittent reviews [4]. Like any manual control, it only provides a view of the structure during the inspection and requires an experienced and skilled operator to participate. The situation might change until the next inspection because of exploitation. A growing number of scientists are looking into alternative methods for detecting and evaluating cracks in concrete components in construction projects where damage would have severe consequences [5].

Crack detection employs the following non-destructive testing (NDT) methods: Measurements of elastic wave propagation, ultrasonic coda wave interferometry, digital image correlation, X-ray tomography, and acoustic emission are all utilized in this investigation. These techniques include elastic wave propagation and DIC, two examples [6].

The movement of an elastic wave through a material is very similar to the movement of a wave through water. Waves can move within a material or along its surface. They think about a problem that changes how propagation works. Material and/or structural changes can be identified through the observation of wave propagation. Contact measurement with PZT transducers, which can be glued onto the surface of the element being examined or embedded within the element being examined, is the most common method for measuring elastic waves in concrete structures.

In addition to cracks in concrete structural members, elastic waves are used to detect damage in connections and a variety of materials, such as metal and composite. In addition, a number of applications make use of this peculiarity, including the estimation of support bar jetty length.

Simultaneous measurements at multiple points are highly desirable in concrete specimens where the exact location of failure and its propagation are difficult to predict. DIC provides this opportunity. This estimation procedure depends principally on looking at the enrollment request of photographs taken with aligned cameras. After the calibration data have been taken into consideration, it is possible to link changes in the pictures to changes in the areas that were observed (in terms of displacements and deformations). This makes it possible to obtain information about strain/displacement fields across the entire observed region without requiring the element's mass or surface properties [7].

The following are some examples of DIC applications: to observe the propagation of cracks in concrete cube samples during the wedge splitting test; for determining the break mouth opening in supported, bowed-at-three locations cement footers; for determining the three-dimensional displacement of reinforced concrete beams under torsion; and for looking for fatigue cracks in mild steel specimens. It's essential to take note of that break estimation is being tried for other computerized picture handling techniques also. For some of these methods, which do not require any additional equipment, a smartphone is sufficient [8].

This investigation aims to determine whether elastic wave propagation can be used to determine the alarm level of a crack opening. This is a continuation of the exploration that was introduced in, yet this time we incorporate DIC estimations and utilize a deck piece as an example. The development of cracks and the effect of crack depth on wave propagation are examined using DIC in this study.

Several tasks in the literature are comparable to those in this paper. Kee and Nam looked into the possibility of creating and receiving the elastic wave in the crack detection problem using beam-mounted PZT disk sensors. They demonstrated that cracks deeper than about 80% of the wavelength affect the surface wave. However, their choices regarding the type, location, and distance between the sensors differ greatly from ours.

They measured crack penetration using DIC in a similar manner, but their sample was smaller (500 mm x 150 mm x 150 mm) and bent at four points. Additionally, the study intends to use signals gathered by PZT sensors to pinpoint concrete cracks. They also looked into how the system's impedance was affected by the crack. They claim that stress-wave propagation techniques and electromagnetic impedance influence the discontinuities in concrete cracks [9].

During a three-point bending test, an identically sized small concrete specimen (500 mm x 150 mm x 150 mm) was the subject of the investigation. The authors monitored the formation and opening of cracks using embedded PZT sensors. DIC was also used to observe the procedure. They concluded that the signal amplitude decreases when there is a material discontinuity. Wave flight time also gets longer.

Spiral-ribbed solid GFRP (glass fiber reinforced polymer) bars with a diameter of 10 millimeters were used to reinforce the concrete slab. Using the ISO 10406-1 standard, the mechanical properties of five GFRP bar samples were examined. The GFRP rebars had an average tensile strength of 1000 MPa and a modulus of elasticity of 55 GPa, respectively.

Top and base support were provided by means of bidirectional matrices made of GFRP bars measuring 10 mm in diameter. The bar spacing was 80 millimeters apart in the longitudinal and transverse directions. The slab's cross-section featured 11 longitudinal bars and 30 millimeter-thick concrete covers.

The slab specimen was manufactured and delivered to the laboratory by a precast concrete plant nearby. Prior to testing, the slab was examined, and two initial cracks with widths of less than 0.1 mm were determined to be irrelevant due to shrinkage, transportation, or handling.

The sample would be loaded and unloaded, according to the exam plan. Various load rates were used to define eight cycles. Displacement was the method of loading control. For the first three cycles, the increment was 0.5 mm/min, and for the subsequent five cycles, it was 2 mm/min. In subsequent cycles, the following load values were achieved: 10 kN, 20 kN, 30 kN, 50 kN, 80 kN, 100 kN, 135 kN, and 150 kN. Since the slab was destroyed after the scheduled cycles, this examination does not take this stage into account.

The Dantec Dynamics GmbH, Ulm, Germany, DIC system Q-400 recorded the shape shifts of the observed area as the loading increased. In accordance with the guidelines for 3D DIC measurement, the area was painted with irregular black speckles using two high-resolution cameras with a resolution of 12 Mpx. The specimen was 150 centimeters and 82 centimeters away from the two cameras, respectively. Utilizing DIC made it possible to observe crack propagation during loading and estimate the degree of permanent deformation after the load had been removed. Because a portion of the material is chipped when the crack appears, the pattern around it may be lost. The crack opening cannot be accurately measured after that point. Consequently, the conventional measurement of crack propagation was used to validate the experiment. This measurement, on the other hand, was taken on the slab's opposite side.

Results and Discussion

Throughout the course of the experiment, the receivers recorded signals with varying amplitudes and shapes. The observed changes were connected to the cracks' appearance and the force applied to the slab. It was possible to compare signals because all signals were normalized using the C2 signal, which had the largest amplitude of all measurements. When compared to State 0 (before the first loading cycle, without loading and cracks), the normalized signals for alarm states C2–C4

When GFRP reinforcement bars are utilized, corrosion-related crack limitations are not required because of the bars; properties that are resistant to corrosion, making it possible to tolerate cracks with wider widths than steel-reinforced concrete elements. Standards recommend crack widths of 0.5 to 0.7 millimeters. In this study, we defined an alarm state as when the crack width reaches 0.7 mm.

Crack widths were recorded and measured at each load step to assess the formation of cracks. Between the 30 kN and 50 kN load steps, the tested slab showed the first crack, according to the conventional method, at about 35 kN. The example of break movement that was seen in the tests for two burden levels: 50 and 80 kN, respectively. There were only flexural cracks and no shear cracks at either load level.

The views captured by the left camera are examples of views recorded by two cameras; however, the von Misses formula-compliant maps of Lagrange effective strain fields presented here were derived from images taken with both cameras. All DIC calculations were carried out with commercial software called ISTRA 4D. The strain fields were calculated using the first image that was recorded during a suitable loading cycle as a reference. The strain increases in these figures reflect the permanent deformation left over from previous loading cycles. The permanent strain field following 80 kN loading in the analyzed region and the reference image for State 0 (before any load). The average accuracy of strain measurement was 0.02%.

Conclusions

The phenomenon of elastic wave propagation can be utilized to ascertain the bending state of concrete components. Due to the effect of strain fields on wave propagation and crack-induced discontinuities in materials, information gathered in both the tensile and compressive zones must be included simultaneously. The proposed method makes it possible to determine the state of a slab when the structure's initial state is "healthy," which indicates that there are no significant cracks at the beginning of monitoring.

It is important to note that the signals generated and recorded by PZT transducers are influenced by their glue; Errors may occur during the production of reinforced components due to the heterogeneity of concrete. Impact wave spread is influenced by the aforementioned factors as well as the type of applied support or cement. We believe that developing a universal tool for monitoring the structural health of concrete components will be difficult, if not impossible. However, after reducing the number of variables and increasing the number of patterns (for statistical analysis), it appears that artificial intelligence can be used to automate damage detection in concrete elements.

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