Computer vision-based stress estimation of concrete structures

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ABSTRACT

Losing tension forces of tendons is a critical issue in pre- and post-tensioned structures. The decreasing tension force can be considered as an initial step of structural damage, as it can further cause concrete cracks, reduced load carrying capacity, and even structural instability. Indeed, it is a serious threat to structural soundness while difficult to identify. Several approaches for estimating current tension forces have been developed, including ultrasonic wave-based methods, vibration-based methods, and impedance of the piezoelectric material. Although these methods in the literature have made certain progress in this field, practical use is still limited. Instead of measuring the tension force, this study presents a method that can directly measures the static stress level of concrete by combining the stress relaxation method (SRM) and digital image correlation (DIC). By drilling a small hole, a part of the current static stress can be released, inducing stress field change around the hole. DIC can identify the deformation due to the stress field change using two images taken before and after drilling the hold. This deformation is subsequently compared to one that is calculated using finite element model to finally estimate the current static stress level in concrete. The proposed strategy is validated using concrete specimen loaded by the universal testing machine.

1. INTRODUCTION

As increasing the number of pre- and post-tensioned structures, it is important to know how much tensile force is given in the tendon to prevent structural damage. The losing tensile force of tendon can cause the significant structural damage and even collapse and it may lead to the serious social loss including human loss and economic loss. Identifying the degree of losing tension in tendon becomes a critical issue and several approaches to identify current stress condition in the tendon have been developed. Some of the existing methods for evaluating current tensile forces are stress calculating using standardized formulas, ultrasonic wave-based methods, vibration-based methods, and impedance of the piezoelectric material. These methods have some limitations in being applied to real structures even though they have made some contribution in this field.

In this study, the static stress in the concrete could be estimated using both stress relaxation method (SRM) technique and computer vision based digital image correlation (DIC). SRM is a semi-destructive stress releasing method and DIC is a non-contact displacement measurement method based on image processing. By making a small hole, the current static stress in concrete can be released and the released displacement near a hole can be identified by DIC technique. In the DIC, two images can be taken to compare before and after drilling and the displacement field near hole can be identified. This displacement field is finally used to estimate the current static stress in concrete by comparing to finite element model of concrete. The proposed method is validated through laboratory-scale experiments on concrete specimens.

2. BACKGROUND

2.1. Stress Relaxation Method (SRM)

A stress relaxation method (SRM) is a semi-destructive technique that estimates current stress by applying a small damage. It can estimate the current stress condition by measuring the deformation near applied damage. The SRM was first developed in 1930s (Mathar, 1934) and Owens (1993) firstly introduced the SRM using strain gauges to estimate the static stress in concrete.

There are several different SRM techniques: hold-drilling method and core-drilling method. The hole-drilling method is an effective way to evaluate stress condition with relatively less destructive and low cost (Beghini & Bertini, 2000). The core-drilling method needs a relatively larger diameter core than that of the hole-drilling method. In this study, hole-drilling method have been adopted as SRM method because the damaged part can be easily recovered after the stress evaluation testing.

2.2. Digital Image Correlation (DIC)

Computer vision-based approaches provide a convenient and effective means of measuring structural deformation: digital image correlation (DIC) is one of the most widely used methods. DIC uses at least two images, of which correlation is examined to identify deformation between them. DIC has been used in various fields ranging from microscopic deformation measurement to deformation measurement of large structure by tracking optical patterns on the surface of object and measuring the change of images using correlation of digital image.

To conduct DIC, small and irregular speckles are densely painted on the objective surface and DIC can implement full-field measurement on the objective surface by calculating correlation between before and after images. In this paper, 'Ncorr' MATLAB software developed by Georgia Institute of Technology has been used as a DIC software (Blaber et al., 2015).

3. STRESS EVALUATION OF CONCRETE SPECIMENS

3.1. Experimental Setup

The combination of SRM and DIC is used to estimate static stress levels of concrete specimen. The concrete specimens have 24.4GPa of elastic modulus and 0.17 of Poisson's ratio. The specimen size is 100mm×100mm×400mm. Diameter of hole which was used in SRM technique was 20 mm and random speckle pattern was made in concrete surface to measure deformation by using DIC. It is better that the speckle pattern has more randomness to calculate correlation of each pattern. The concrete specimen was under 15MPa loading by universal testing machine (UTM) and computer vision was used to perform DIC. Experimental condition is represented in Table 1.

Table 1. Compressive test condition on concrete specimen.

Specimen size	100mm×100mm×400mm
Elastic modulus	24.4GPa
Hole diameter	20mm
Hole depth	30mm
Loading stress	15MPa

3.2. Experimental Results

Figure 1 shows experimental result after hole-drilling and DIC image processing. Displacement near hole was considered as a measured region and the measured data was compared to FEM data. As comparing experimental measurement and FEM data, the static stress level which has the smallest error can be obtained. The estimated stress is shown in Table 2. Error of each experiment is less than 5% and therefore, the proposed method can be considered as an effective and practical methods for estimating the static stress condition inside concrete structures.

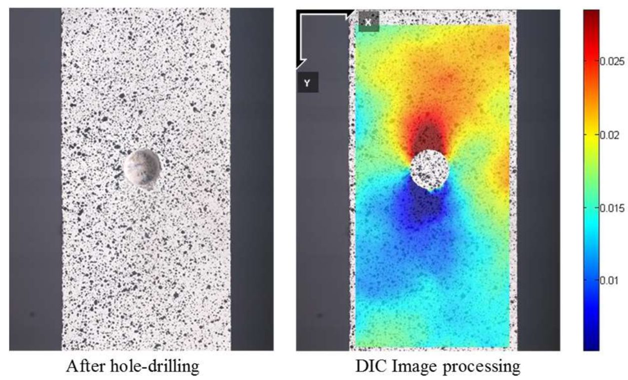

Figure 1. Experimental result.

Table 2. Experimental results.

Test	1	2
Reference (MPa)	14.1	14.2
Estimation (MPa)	14.5	14.4
Error (%)	2.9	1.5

4. CONCLUSION

This study presented the semi-destructive static stress evaluation technique by combining the stress relaxation method (SRM) and computer vision-based digital image correlation (DIC). The existed static stress condition in concrete was released by hole-drilling method which is one of the SRM techniques. Deformed shape by stress relaxation was captured by DIC and static stress could be estimated based on the relaxed displacement. A finite element model of concrete specimens was modeled as a reference using commercial software and the proposed method was validated through laboratory-scale experiment. Tests were conducted on concrete specimens loaded by the universal testing machine. This technique will be expected to investigate a safety assessment of the concrete structures.

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