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Stress estimation using digital image correlation for prestressed bridge monitoring

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ABSTRACT

Stress distribution of full-scale civil engineering structures is an important information for reliable structural management, while the distribution is difficult to acquire. For example, comparing current stress levels at crucial structural members to the design values or yield stress can provide a direct measure of structural safety. In particular, decreasing tendon forces of aging prestress concrete bridges is a critical threat to the structural health, whereas the measurement is challenging. The compressive stress of concrete is a more direct health indicator than the tendon force. Despite the advantages of measuring the stress distribution for infrastructure monitoring purposes, available measurement methods are quite limited and relevant research to develop such methods has been rarely found in the literature. This study proposes a stress estimation approach for concrete structures using digital image correlation (DIC) in conjunction with the hole drilling method. A small hole with a diameter of 20 mm is drilled on the target concrete specimen to induce changes in the displacement field around the hole. Images before and after drilling the hole are used to determine the displacement field using DIC. The stress level of the specimen is then estimated by comparing the measured displacement field to that obtained from the finite element model. The performance of the proposed method is experimentally validated using two types of concrete specimens loaded by a universal testing machine. In addition, an optimal hole size is evaluated ranging from 10mm to 30mm through the experiments conducted with various condition.

1. INTRODUCTION

Concrete is the most commonly used construction material in the world. Concrete has a

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number of advantages such as low price and simple use with various shapes and sizes. Most civil structures consist of concrete and thus, identification of current concrete state in structures is essential information for maintaining safe society. One of significant information in structures is to recognize current stress level in concrete. The current stress state in concrete is essential factors to check the deterioration and current load distribution of structures in service. Technique to evaluate the stress condition in concrete becomes a critical issue and various field areas require to develop this technique involved in tensile force measurement in tendon of PSC bridges and architectural building remodeling [1-3]. However, once the structures have been built with concrete, verification of the stress distribution and how much loading is given in structural elements is challenging. In other words, load distribution and stress condition inside concrete remains a challenging task even though this information is a significant issue to monitor safety of concrete structures.

This study presents that the static stress in the concrete can be estimated using both stress SRM technique and computer vision-based digital image processing. Static stress estimation algorithm has been developed to identify the optimal static stress in concrete. Parametric analysis is conducted to determine the optimal measured field which has the minimum error. By using the algorithm and parametric analysis, the experimental errors can be calibrated which may include non-uniform and inhomogeneous loading distribution and the abnormal state of concrete specimen. The proposed method including the developed optimization algorithm is validated through laboratory-scale experiments on several concrete specimens and demonstrations its performance within 5% error.

2. STATIC STRESS ESTIMATION

To measure static stress of a concrete structure, this study combines the stress relaxation method (SRM) and computer vision approach using digital image correlation (DIC). As the proposed approach requires a small hole with a diameter of about 20 mm on the concrete surface, the effect of the induced damage on the structural health must be negligible. After drilling a hole on the concrete surface, the change in the displacement field around the hole is measured using DIC, and utilized in estimating the static stress of the concrete.

A stress relaxation method (SRM) is a semi-destructive technique that releases current stress condition by applying small damage and measure the deformation. The SRM was first developed in 1930s (Mathar 1934) and efforts to apply the SRM to concrete have been conducted. Owens (1993) introduced the SRM with strain gauges to estimate the static stress in concrete. This study selects hole-drilling method as SRM method because the damaged part can be simply recovered after experiment.

Vision-based approaches provide a convenient and effective means to measure deformation. Among several vision-based techniques, digital image correlation (DIC) is one of the most widely used methods. DIC is a non-contact deformation measurement technique using several images which are before and after deformation and it can track the movement of each subset pixel by calculating the correlation which has the maximum value. In this paper, Ncorr, MATLAB software developed by Georgia Institute of Technology, has been used as a DIC software (Blaber et al. 2015).

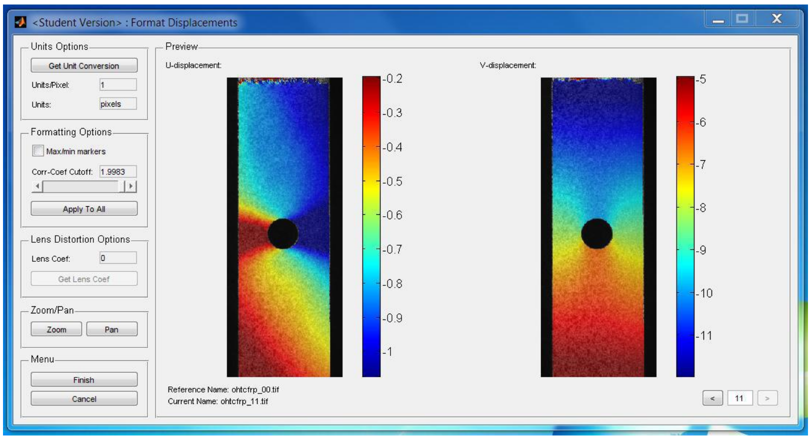

Fig. 1 User interface of Ncorr

After measuring the deformation using DIC, the static stress can be determined to have the smallest error between the reference and experimental data. The reference displacement field is obtained from finite element analysis of concrete specimens with holes.

3. EXPERIMENTAL VALIDATION

A series of experiments are conducted to validate the stress estimation method in the laboratory environment. Prepared are concrete specimens (100mm×100mm×400mm), on which irregular speckle patterns are painted for DIC. 20 mm diameter holes are drilled on the concrete specimens under the stress of 15 MPa.

Figure 1 shows experimental result after hole-drilling and DIC result. Displacement near the hole is measured and compared to reference data. Then, the static stress level which has the smallest error can be determined. The estimated results are shown in Table 1. Error of each experiment is less than 5% and therefore, the proposed method can be considered as an effective method for evaluating the static stress condition inside concrete structures.

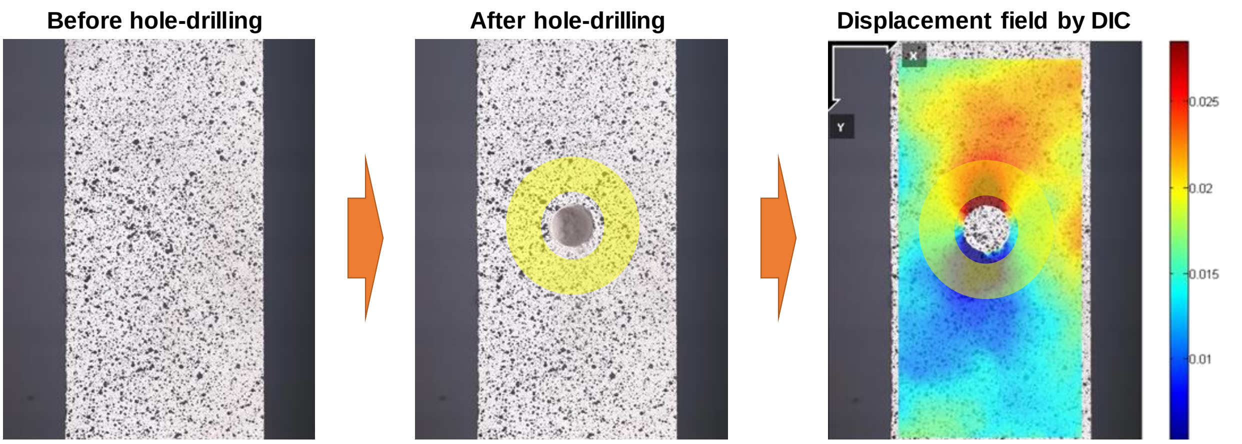

Fig. 2 Displacement field measurement using DIC and hole drilling

Table 1. Estimation result

Test	1		2	
Reference (MPa)	13.8	13.8	13.5	14.0
Estimation (MPa)	14	15.1	12.7	13.7
Difference (%)	1.5	9.4	5.9	1.8

4. CONCLUSIONS

This study presented the static stress evaluation technique for concrete by combining SRM and DIC. The existing stresses in the concrete specimens were released by drilling holes on the surface and the resulting deformation field was captured by DIC. The static stress level could be estimated based on the measured displacement difference between the concrete surface images before and after drilling the holes. The stress estimation method was successfully validated through the laboratory-scale experiments within 10% errors.

REFERENCES

Blaber, J., Adair, B., and Antoniou, A. (2015), “Ncorr: Open-Source 2D Digital Image Correlation Matlab Software,” *Experimental Mechanics* **55**, 1105–1122.

Cadappa, D.C., Sanjayan, J.G. and Setunge, S. (2001), “Complete triaxial stress-strain curves of high-strength concrete,” *J. Mat. Civil Eng., ASCE,* **13**(3), 209-215.

Chern, J.C., Yang, H.J. and Chen, H.W. (1992), “Behavior of steel fiber reinforced concrete in multi axial loading”, *ACI Mat. J.,* **89**(1), 32-40.

Mathar, J. (1924), “Determination of Initial Stresses by Measuring the Deformation around Drilled Holes,” *Transactions ASME* **56**, 249–254.

Owens, A., “In-Situ Stress Determination Used in Structural Assessment of Concrete Structures,” *Strain* **29**, 115-124.

Trautner, C., McGinnis, M.J., and Pessiki, S. (2010), “Analytical and Numerical Development of the Incremental Core-Drilling Method of Non-Destructive Determination of in-Situ Stresses in Concrete Structures,” *The Journal of Strain Analysis for Engineering Design* **45**, 647–658.