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Use of digital image correlation technique in full-scale testing of prestressed concrete structures

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ABSTRACT

This paper reports the advantages and limitations of the digital image correlation (DIC)-based non-contact measurement technique through full-scale testing of prestressed concrete (PC) structures. Specifically, two ultimate load tests were conducted on a full-scale pre-stressed I-shaped beam and measurements were collected from both conventional instruments (displacement transducers) and a pair of high definition cameras. Stereographic images were processed using the DIC technique to obtain full field 3-D displacement (and strain) fields. The results were compared with those from conventional instruments. It was observed that the DIC technique could provide very accurate and detailed information, which is not possible to obtain using conventional techniques, including the in-plane and out-of-plane strains and their spatial variations, and the locations of high tensile and compressive strains which at later stages of loading result in cracking or crushing of concrete. Nevertheless, certain limitations of the DIC technique exist when used in testing of concrete structures such as the sensitivity to external light sources and preparation of the measurement surface, loss of data points after spalling of cover concrete, and the inability of the used algorithm to identify cracks and report crack widths. Currently, research is being conducted to address these limitations. Although providing useful information on the pros and cons of the DIC-based non-contact measurements for PC structures, it is noted that the results presented in this paper are based on a limited number of tests. Future research is needed to draw general conclusions.

1. Introduction

It is a challenging task to identify and understand the governing modes of failure in large, complex structures that are subjected to extreme loads. Well thought-out experiments can be extremely valuable in understanding material/structural behavior. However, the data that can be gathered from a single test is limited mainly due to conventional point-based sensor technology, which only allows measurements at a limited number of discrete points. This can be particularly restrictive when considering unique, complex and costly experiments in which collecting the maximum amount of relevant data is desirable. Additionally, various aspects of structural behavior are difficult to identify even experimentally, such as the load path in components with complex geometries, effect of boundary conditions, and load transfer through contact surfaces. For these reasons, advanced non-contact measurement techniques became very valuable in studying the behavior of structures.

One of these measurement approaches is based on digital image correlation (DIC) technique. In DIC-based non-contact measurements, two digital images, taken before and after the deformation, represent the positions of an object at these moments. A small subset in the reference image (taken before deformation) is matched to a similar

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subset in the target image (taken after deformation). This process is called DIC and it is repeated for the entire region of interest to retrieve the 3-D shape of the object, 3-D displacements and the plane strain tensor. More information regarding the underlying theory of this technique is provided in the next section. The DIC technique overcomes several limitations of point-based sensors by providing detailed information on complex deformation states that lead to the initiation of damage as well as its progression until complete failure.

Yamaguchi [41] and Peters and Ranson [30] are amongst the first to introduce the DIC method. This technique later on extended by others to measure surface profiles of objects [23] and 3-D displacements [22]. Other optical deformation measurement techniques such as Electronic and Temporal Speckle Pattern Interferometry (ESPI and TSPI) and moiré interferometry were also developed [7,33,12]; however, these approaches have not been widely adopted due to reasons including the limited measurement range and high vibration isolation requirements. The DIC technique, on the other hand, is insensitive to massive rigid body motions, uses ordinary light rather than coherent laser light (in the case of ESPI), and can capture large deformations in a single measurement as long as the object remains in the field of view of the cameras [36,35,27].

The DIC technique has been successfully used to study textile deformability [21], cyclic/fatigue performance of polymer materials [38], 3-D damage in concrete prisms [18], crack variation in masonry walls [39], strengthening of RC specimens with composite plates [25], crack behavior in a RC beam [14], multiple growing cracks in RC slabs [11], crack detection in a concrete beam [20], amongst many others. Additionally, the use of full-field measurements to identify material mechanical properties has been extensively studied [9,24,6,19]. However, these studies and others mainly focused on material tests rather than on structural scale experiments [13,38,34]. Various parameter identification methods such as the finite element model updating method [26], constitutive equation gap method [15], and virtual fields method [1] have also been leveraged with DIC-based non-contact measurements for finding the material properties. One other use of full-field measurements has been related to finding the actual (rather than assumed) boundary conditions during experiments [31,10]. Studies to evaluate the measurement errors on the accuracy of full-field displacements have also been performed [3,16,17].

This paper studies the advantages and limitations of DIC-based non-contact measurement technique for full-scale testing of prestressed concrete (PC) structures. Specifically, the local response of a pre-stressed I-beam for bridges failing in shear is measured and the results are compared to those from conventional instrumentation. The value of this paper is due to the fact that, to our knowledge, only one study in literature (i.e., [20]) assessed the use of DIC technique for investigating the complex response of full-scale PC elements. In the following sections, first the underlying theory and working principles of the DIC-based non-contact measurements are provided followed by a description of the conducted full-scale experiments. Second, the expected structural behavior is described and the non-contact measurements are validated using data from conventional sensors. The paper is concluded with a discussion on the benefits and drawbacks of using DIC technique on concrete structures.

2. Digital image correlation-based non-contact measurement technique

Through DIC-based non-contact measurements, 3-D displacements and deformations of an object are measured. The technique requires that a stochastic pattern exists (or applied) on the surface of the measuring object similar to the example shown in Fig. 1. For a 3-D measurement, two cameras are needed to capture a stereographic image of the test object. The size and location of measuring volume with respect to the cameras, and the position of the two cameras with respect to each other are first determined by taking a set of pictures of the so-called "calibrating objects" which have targets mounted on them with known sizes and distances to each other.

Digital images of the specimen are collected at predetermined time intervals (fixed or variable) throughout the test. The first (or another selected) image represents the undeformed (reference) configuration. By processing the digital images, the software [8] recognizes the structure of the stochastic pattern and allocates coordinates to image pixels. The deformation of the object is measured through overlapping image details (or facets)

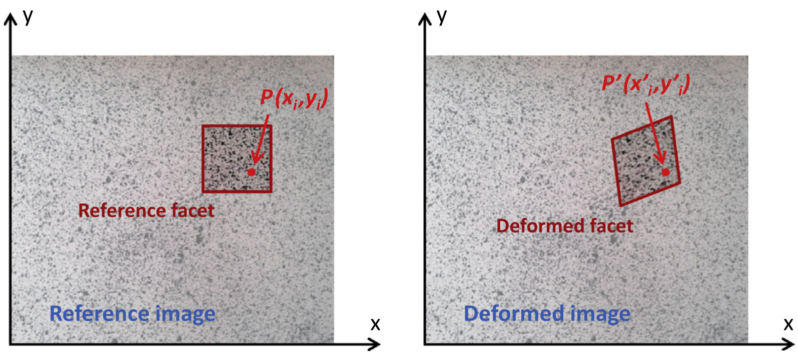

Fig. 1. Stochastic pattern on the surface of a concrete specimen and facets assigned to image details to track deformation.