Measurement 44 (2011) 527–538

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

# Laboratorial test monitoring applying photogrammetric post-processing procedures to surface displacements

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ARTICLE INFO

*Article history:*
Received 7 July 2010
Received in revised form 4 November 2010
Accepted 17 November 2010
Available online 23 November 2010

*Keywords:*
Photogrammetry
Post-processing
Strain field
Crack
Test monitoring

ABSTRACT

Most of the traditional laboratorial methods for monitoring displacements and strains at the surface of the specimen present several constraints, namely: (i) limitations in hardware positioning; (ii) costly equipment and human resources; and (iii) time-consuming data processing. Consequently, the development of new methods capable of eliminating these drawbacks is of utmost interest.

Herein, a new technique for laboratorial test monitoring is presented. By using photogrammetry and image post-processing, all the above mentioned drawbacks are overcome. Furthermore: (i) both displacement and strain fields can be monitored at a practically unlimited number of target points at any stage; (ii) it is a cost effective method, since data is acquired with non-professional digital cameras; and (iii) it is a fast procedure since data is automatically processed. Additionally, high precision is reached allowing an accurate characterisation of the fracture localisation process, including the establishment of a correlation between the latter and the localisation of cracks and their evolution in time.



## 1. Introduction

Monitoring of most common civil engineering laboratorial tests is still performed with traditional methods and devices, namely: (i) LVDTs to measure displacements; and (ii) strain gages to measure the strain field. These devices present several limitations related to: (i) positioning, due to a reduced number of devices usually available and/or due to lack of space in critical zones of the specimens; (ii) high cost, normally further increased by the need of costly hardware, such as data loggers; and (iii) time-consuming procedures. Moreover, and as a consequence, in most tests only a reduced number of points are thoroughly monitored.

More recently, new techniques have been developed. Optical fibre sensors, for instance, are experiencing a growing interest [1]. Although allowing for high precision measurements, all the above mentioned drawbacks found on traditional devices and methods are still present. Furthermore, complex and burdensome cable connections are needed for full-field strain monitoring.

Other techniques recently developed include: shearography, digital image correlation, laser speckle analysis, thermal imaging and laser scanning vibrometry [1,2]. With these, positioning is no longer a drawback. However, these equipments are expensive and their usage has been limited due to the need for technical expertise.

In this paper, a new technique, using photogrammetry and post-processing tools, herein designated by '*visual*-DSC' – 'Visualisation of Displacements, Strains and Cracks', is presented. The *visual*-DSC method was developed aiming at the following: (i) monitor a virtually unlimited set of pre-defined points identified by small painted

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doi:10.1016/j.measurement.2010.11.014

**Nomenclature**

| | | | |
|---|---|---|---|
| $E_{cm}$ | Young's modulus | $f_{ctm}$ | average tensile strength |
| $f_{cm,cube}$ | average compressive strength evaluated from cubes | $\varepsilon_1$ | first principal strain |
| | | $\varepsilon_3$ | third principal strain |

targets, thus avoiding the limitation of having a reduced number of LVDTs at the laboratorial facilities and overcoming placement restrictions in small areas of test specimens; (ii) obtain a cost-effective technique by using a low cost digital camera and a laptop, avoiding the use of any other type of costly hardware, such as a data logger; (iii) obtain both displacement and strain fields at any stage in a fast and reliable way by automatically storing and processing data.

Some authors have already dealt with displacement monitoring using photogrammetry [3–8]. For instance Sachtleber et al. [9] evaluated the displacement field and the corresponding plastic strains, whereas Thomas and Cantré [10] aimed at evaluating the strain field of cracked soils. However, the strain field was still constrained to narrow areas and good results were achieved using metric cameras [11,12]. *Visual*-DSC is capable of avoiding all these drawbacks.

In order to calibrate *visual*-DSC, namely to adequately characterise both displacement and strain fields and also to correlate the latter with cracking, the new method was used in a vast campaign of push-off tests. Herein, one of these push-off specimens, monitored until failure with *visual*-DSC, is presented. All capabilities of *visual*-DSC are fully illustrated and a complete understanding of the structural behaviour of the specimen can be obtained.

First, in Section 2, the *visual*-DSC method is described regarding both set-up and data processing. In Section 3, details concerning the experimental set-up and the validation method are provided. In Section 4, results are analysed and discussed. Finally, in Section 5, the most relevant conclusions are presented.

## 2. Photogrammetric procedure

### 2.1. Set-up

Photogrammetric data was obtained with a Nikon D200 installed on a tripod, using 28 mm focal length lens. Self-calibration based on the conventional bundle adjustments method [13] was used to estimate the internal parameters of the camera. Images were acquired at maximum resolution, corresponding to an image size of $3872 \times 2592$ pixels. Conditions were created to insure a homogeneous and diffused light pattern with natural light sources.

A rigid frame was designed to be placed in front of the specimen, containing 32 static targets, assumed as the ground-truth reference (see Fig. 1). The specimen was marked with a $25 \times 28\ \mathrm{mm}^2$ grid of 194 high-contrast circular targets which are represented in Fig. 1b. The diameter of the targets, 10 mm, was defined considering the maximum distance between the camera and the target, the dimensions of the CCD sensor of the camera, the number of pixels in the image, the focal length, and also taking into account the following constraints: (i) the Least Squares Matching (LSM) algorithm must be capable of automatic identification of the central point of each target with sub-pixel accuracy; (ii) the diameter of the targets should be small enough to avoid interference with visual crack identification. This led to an average diameter of 26 pixels per target. For direct comparison with the LVDTs, four additional targets were installed (see Fig. 1a).

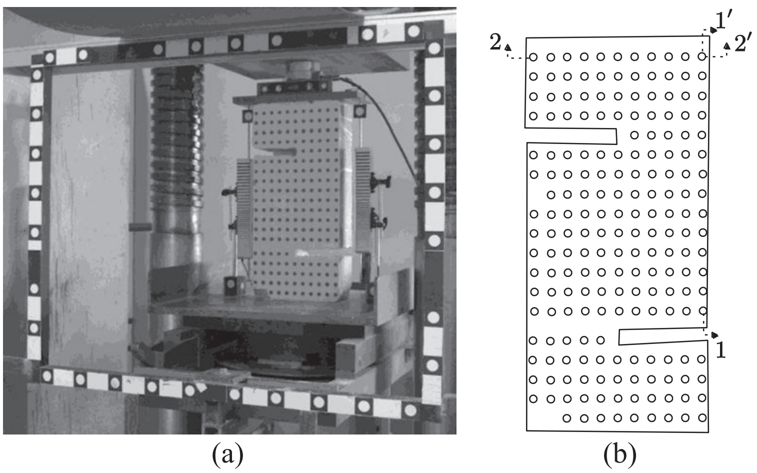


**Fig. 1.** Photogrammetric set-up: (a) photo; and (b) scheme showing the targets of the specimen and location of profiles.