Dawie Marx
Jones & Wagener Engineering and
Environmental Consultants
marx@jaws.co.za

Prof S W Jacobsz Pr Eng
Department of Civil Engineering
University of Pretoria
sw.jacobsz@up.ac.za

Stephan van Eeden
Department of Civil Engineering
University of Cambridge
sjv29@cam.ac.uk

Pile displacement measurement using digital image correlation

INTRODUCTION

Digital image correlation (DIC) is a non-intrusive measurement technique whereby the relative displacement of a target object between successive digital images is measured. In geotechnical research the technique is typically used to measure the deformation of a soil mass while it is being loaded. Alternatively, the technique can be used to track the movement of a synthetic target between successive images. For this article DIC was used to measure the displacement of a target attached to a driven tubular pile during vertical and horizontal load tests.

This study formed part of a 'Greener Cities in South Africa' research project funded by the Green Fund. The aim of this section of the work was to determine whether it is feasible to erect solar voltaic facilities on dormant tailings storage facilities, founded on micro-piles. Accordingly, horizontal and vertical capacity tests were done on micro-piles installed in the basin of a gold tailings storage facility in Johannesburg that has been dormant for a number of years.

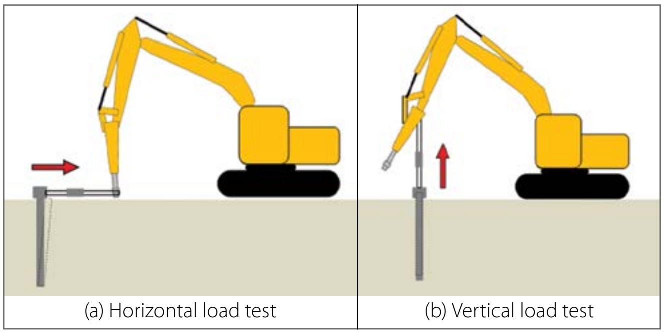

Figure 1 Testing setup for horizontal and vertical pile load tests

METHODOLOGY

Driven tubular piles with a diameter of 118 mm were installed in a dormant tailings storage facility to depths ranging from 2 to 5 m. The piles, made from tubular sections of ductile cast iron, were installed using an excavator fitted with a hydraulic hammer. However, since the tailings was relatively soft, most of the piles were simply pushed into the tailings by the excavator, with little need for engaging the hammer.

Previous testing of this type of pile in South African soil conditions was discussed by Jacobsz *et al* (2012). For both the horizontal and vertical capacity tests a sling was attached to the top of the pile. This sling was connected to a load cell that was in turn fastened to the excavator arm. The excavator arm was used to apply the load, as illustrated in Figure 1.

A digital camera was set up to capture images of the pile at six-second intervals as it was loaded. In Figure 2 the target attached to the top of the pile, as well as static control markers are

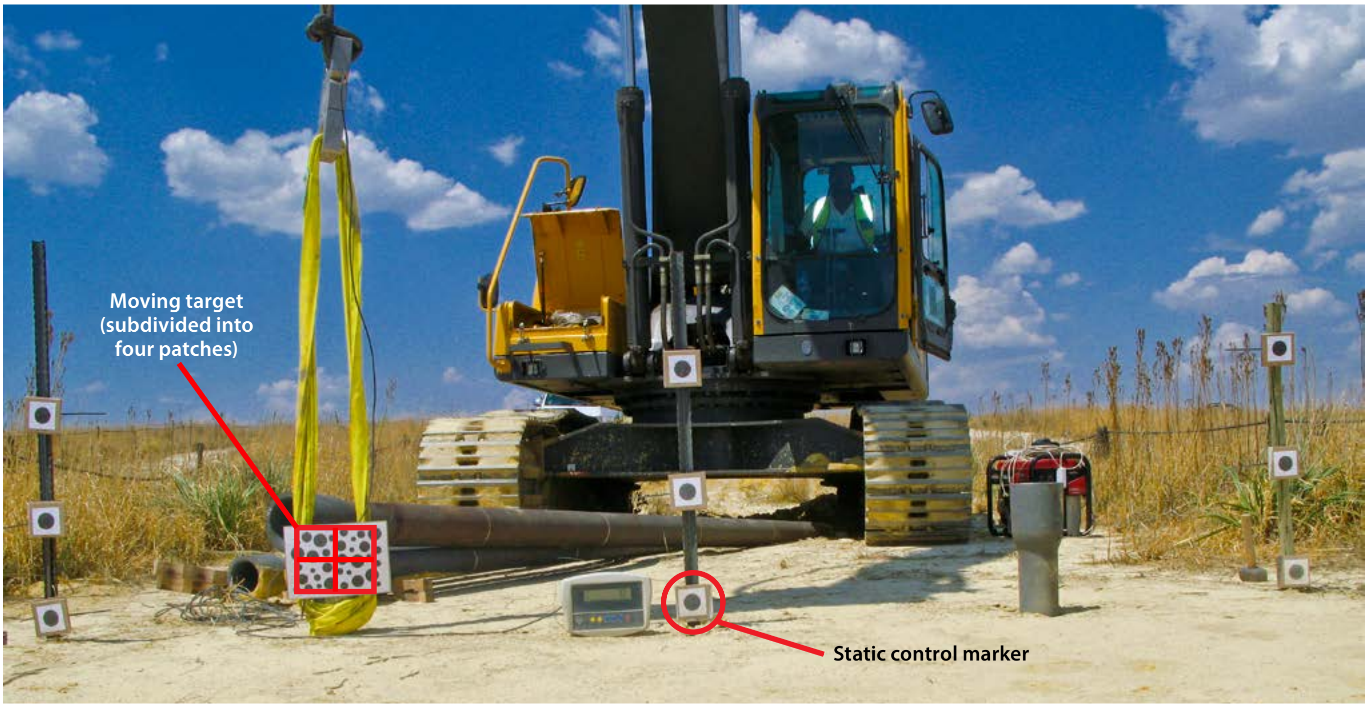

Figure 2 Typical image used for tracking pile displacement

highlighted on one of the images used for the analysis. In addition to the digital images, a conventional dial gauge was used to verify the pile displacement measurements calculated with DIC.

After the tests, the digital images were processed using the GeoPIV-8 software by White *et al* (2003). The software divides each photo into a number of patches or blocks. Subsequently the relative movement of any given patch between two succeeding photographs is calculated in units of pixels.

A white target with randomly spaced black dots was attached to the top of the pile being tested to ensure that there is sufficient contrast for the software to track the pile in an uncontrolled environment. The section of the photo containing the marker was subdivided into four patches (or blocks, see Figure 2), each of which was tracked between successive digital images.

Displacement of the patches is calculated by the software in units of pixels. Consequently, to convert from pixel displacement to metres or millimetres, static control markers (see Figure 2) were required. The exact position of each static control marker was surveyed before each test. By referencing the movement of the pile target relative to the static control markers, the software can calculate the actual movement of the target (in metres or millimetres), taking scale and camera lens distortion into account.

For the horizontal load tests the dial gauge did not measure displacement at the same height as the DIC target. Consequently, the displacement measurements from both the dial gauge and the DIC were first translated to the ground level for comparison. The point of rotation, as calculated using the method of Prasad and Chari (1999), was used as reference point for the translation.

RESULTS

The results of one of the horizontal load tests are shown in Figure 3. The displacement measurements from both the dial gauge and the digital image correlation are shown. In addition, lines of best fit through the data sets are shown. It was found that the load-displacement behaviour of the piles was best approximated with a bilinear curve. The bilinear curves were fitted using least square regression. The measurements from the dial gauge and DIC followed each other closely until the slope of the DIC load-displacement curve changed. This point can possibly coincide with the yielding of the soil.

The DIC displacement measurements for five of the horizontal load tests are plotted in Figure 4 against the equivalent dial gauge displacements. Wherever the measurements fall on the reference line the dial gauge and DIC measurements were equivalent. Initially there was good agreement between the DIC and dial gauge measurements. However, as the tests progressed the difference between the DIC and dial gauge readings increased until the DIC measurements deviated completely from the dial gauges. The pile displacement at the deviation coincided with the change in slope observed in Figure 3. It is postulated that the deviation, or change in slope, coincided with the soil yielding during the test. Once the soil yielded, a greater displacement increment occurred for a given load increment, i.e. a flatter slope. While the

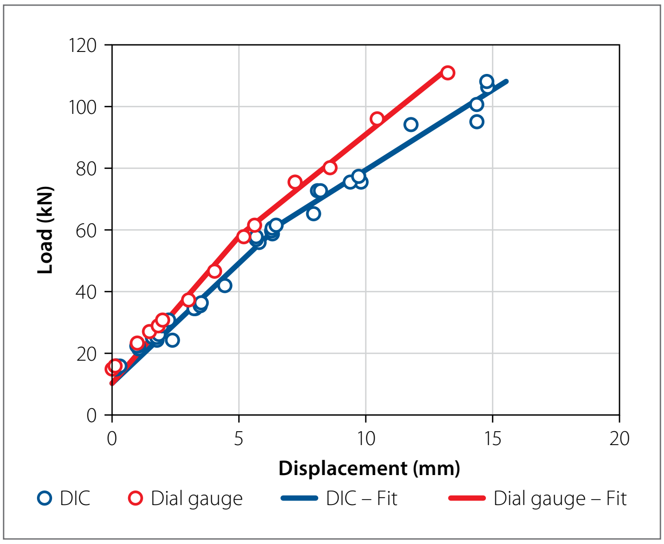

Figure 3 Load displacement curve for a horizontal load test (Test 10) using dial gauge and DIC displacement measurements

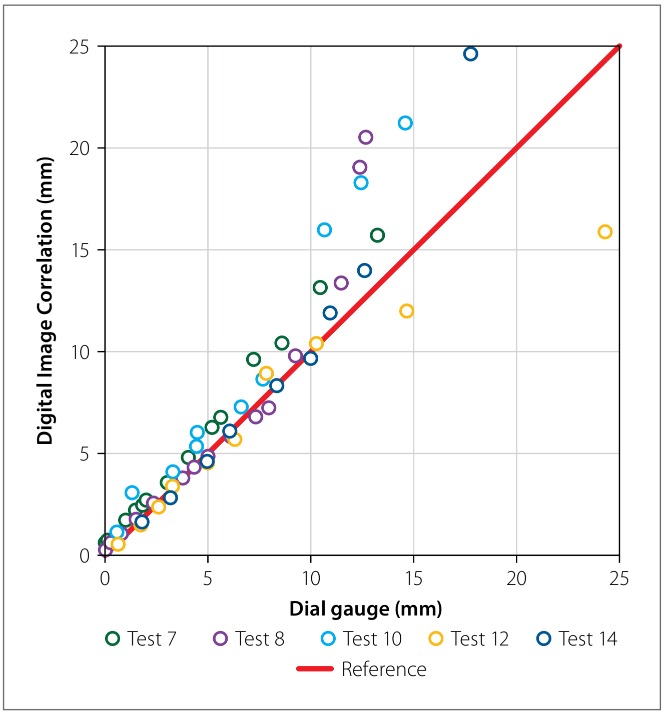

Figure 4 Load displacement curve for a horizontal load test (Test 7) using dial gauge and DIC displacement measurements

camera was isolated from the pile, the pile could move the dial gauge frame. Consequently it is assumed that the DIC measurements reflect the true behaviour of the piles. However, further testing is required to validate this statement.

The bilinear load-displacement curves for the five horizontal load tests are shown in Figure 5. These curves were subsequently used to calculate design loads for the micro-piles. Only three of the five horizontal curves have a similar initial slope, illustrating the influence of inherent variation of tailings properties on the capacity of the micro-piles.

Load-displacement curves for two vertical load tests are shown in Figure 6. In contrast to the horizontal load tests these load-displacement curves were initially linear, then distinctly non-linear and finally the soil yielded. Due to the piles failing too quickly for dial gauge measurements to be recorded, it was not possible to validate the DIC results for the vertical load tests.

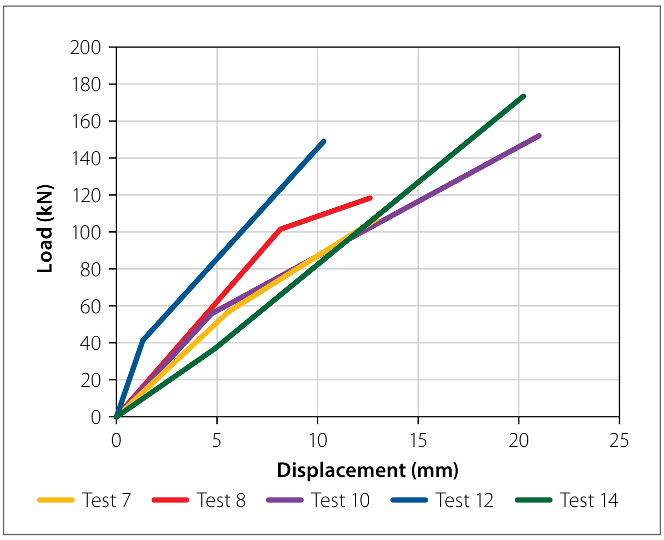

Figure 5 Summary of the horizontal load displacement curves using DIC displacement measurements

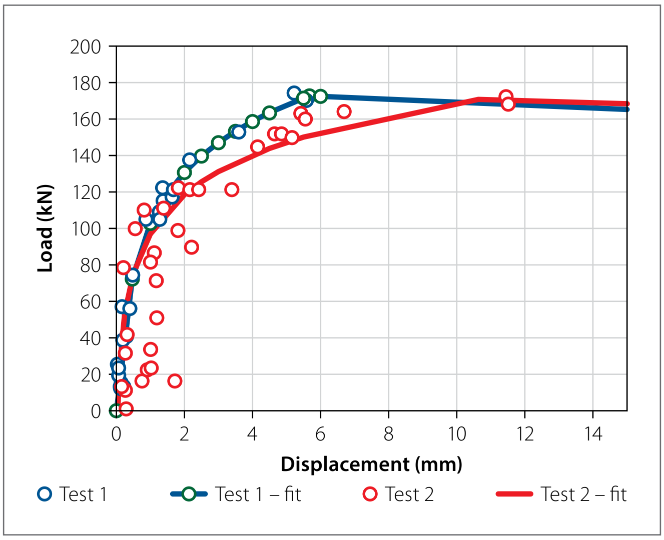

Figure 6 DIC load displacement curves for vertical load tests

CONCLUSION

This article presents a broad overview of the use of digital image correlation (DIC) to measure pile displacement during relatively crude horizontal and vertical load tests. Good correlation was achieved between the dial gauge and DIC measurements, with the DIC possibly outperforming the dial gauge once the soil yielded. Furthermore, the DIC measurements have the advantage of providing more continuous data without interfering with the loading of the piles. The loading technique for the vertical tests has to be improved, as some of the tests failed too quickly for either the DIC or the dial gauges to provide useful measurements. By using more recent processing software (e.g. GeoPIV-RG by Stanier *et al* 2016), better load control and more accurate validation measurements for digital image correlation can potentially be used to provide non-intrusive displacement measurements of piles during load tests with the same, or better, quality than conventional methods.

ACKNOWLEDGEMENTS

This article forms part of a research project, 'Greener Cities in South Africa', funded by the Green Fund, an environmental finance mechanism implemented by the Development Bank of Southern Africa (DBSA) on behalf of the Department of Environmental Affairs (DEA). Opinions expressed and conclusions arrived at are those of the authors and are not necessarily to be attributed to the Green Fund, DBSA or DEA. The authors also wish to acknowledge Geopile Africa for the installation and testing of the micro-piles. □

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