Available online at www.eccomasproceedia.org
Eccomas Proceedia SMART (2023) 1885-1893

ECCOMAS
Proceedia

X ECCOMAS Thematic Conference on Smart Structures and Materials
SMART 2023
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DISPLACEMENT MONITORING BASED ON IMAGE TRACKING WITH RANDOM IRREGULAR AND SPECIAL REGULAR PATTERNS: AN APPLICATION FOR TESTING OF PIPELINES

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Abstract. The paper discusses two the cases of displacement monitoring based on image tracking. In the first case, an image of a random irregular shape is selected for tracking. In the second case, an image of a special planar shape, the so-called target, was selected for displacement tracking. Both cases were used in testing of a pipeline with a joint. In both cases, displacements of pipelines in four-point bending tests were monitored. Two tests are discussed here. In the first one, an iPVC pipe with a joint was tested. In the second test, a ductile iron pipeline with a joint was tested. The experimental setup and the test specimen were extensively instrumented with conventional strain gages and position transducers. In addition, fiber-optic sensors were installed on the test specimen. The tests were documented by a high-resolution video recording. Individual frames were extracted from the video file and each of them was used for image tracking in time. A specific shape was identified in each frame and its movement from frame to frame was monitored. The advantages and shortcomings of each approach are discussed. The displacements obtained by the image-tracking approaches were compared to those obtained from conventional position transducers. The results of the displacement monitoring approaches for this relatively simple type of pipeline loading were evaluated to assess their feasibility for use in future more complex loading, for example, bi-axial testing.

Keywords: Image tracking, displacement monitoring, four-point bending, pipeline, iPVC pipe, ductile iron pipe, joint's moment capacity, joint's rotation capacity.

1 INTRODUCTION

Monitoring the deformation of a test specimen is very important for any kind of testing or field assessment. This paper is focused on the application of two image-based approaches to track the displacement of a pipe with a joint in a four-point bending testing. The approaches

doi: 10.7712/150123.9958.445566

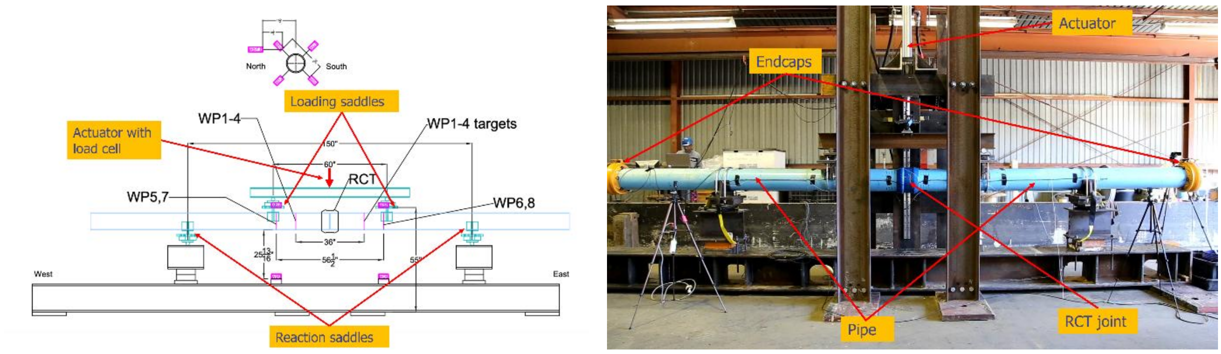
were applied to two different cases of pipe testing. The first test was conducted on an iPVC pipe with a joint. In the second test, a ductile iron pipe with a joint was experimentally studied. It is worth noting that in both cases the pipe was tested up to the joint's failure. Because of the flexibility of a polymer pipe, the ultimate displacement of the pipe was much larger for the iPVC pipe than that for the ductile iron pipe.

2 TESTING OF IPVC PIPE

This section describes some results of the experimental study conducted on an iPVC pipe meeting the American Water Works Association (AWWA) requirements [1] with an RCT Flex-Tite joint [2]. This pipe was experimentally studied in a four-point bending configuration. This section presents only some relevant results of the experimental study [3].

2.1 Instrumentation

The pipe was pressurized by water to 0.345 Mpa (50-psi) and the water pressure was maintained throughout the test. To enable the pressurization the pipe ends were closed by an endcap installed at each end of the pipe. The pipe and the joint were extensively instrumented by fiber-optic sensors and strain gages. In addition, a number of position transducers were installed into the experimental setup to capture the joint rotation and deflections of the pipe as presented in Figure 1a (WP stands for Wire Pot, a position transducer). The actuator was installed in the vertical orientation as presented in Figure 1b. A load cell installed in line with the actuator was monitoring the load.



a) Simplified drawing (1 in = 25.4 mm) b) Photo of the setup and major components

Figure 1: Experimental setup for four-point bending of plastic pipes.

2.2 Non-contact measurements

In addition to the instrumentation described above, a DSLR camera (Canon 6D) was installed in front of the experimental setup to monitor and record the deformation of the pipe. It monitored the deformation by recording a test movie.

After completion of the experimental program, the individual frames were extracted from the test movie. Each frame has 1920 pixels along the horizontal axis and 1080 pixels along the vertical axis. A typical example is presented in Figure 2a.

A few pieces of black duct tape were installed along the centerline of the pipe as presented in Figure 2b. They were used for tracking the displacement of the pipe in the plane of loading. They were called markers for the purpose of this paper.

A normalized 2D cross-correlation procedure (2DCC) [4,5] was used for tracking these markers in the plane. An implementation of this procedure offered by Matlab [6] is utilized herein.

a) Example of marker selection

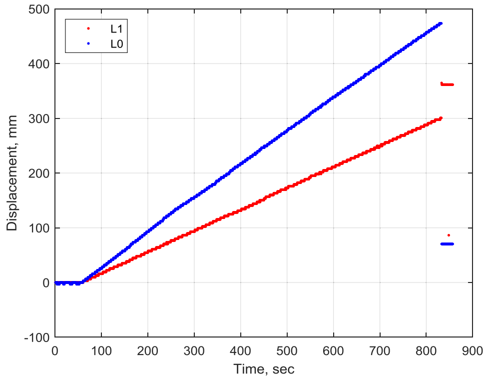
b) Markers used in this paper

Figure 2: Example of marker selection and markers discussed in this paper.

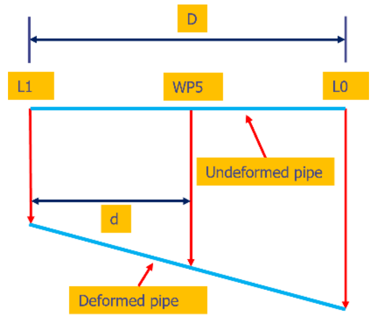
2.3 Results

The locations of the markers shown in Figure 2b were monitored in each movie frame. The analysis showed that the Matlab implementation of the 2DCC procedure works reasonably well until the rotation of the marker exceeds a certain threshold. To overcome this shortcoming the target image of the marker (to be located in the overall image) was changed a few times. When the rotation of the marker's image was excessive and impossible to find, the target image was replaced by the one with the current rotation.

The results for the vertical displacement of the pipe are presented in Figure 3a. It is worth noting that WP5 was monitoring the pipe's vertical displacement at a different location between markers L1 and L0.



a) Displacements of selected markers



b) Diagram for displacement estimation at WP5 location

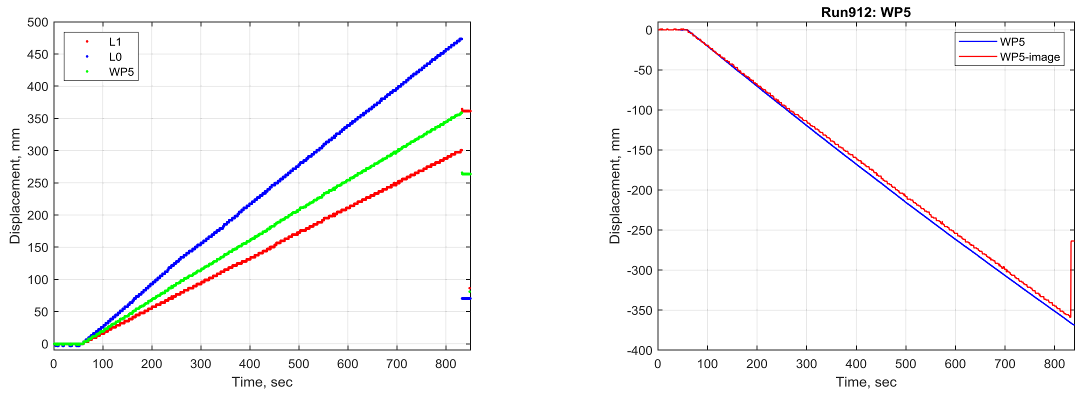
Figure 3: Markers' vertical displacements and WP5 estimation diagram.

In the overall image shown in Figure 2b, WP5 is not visible because it was installed behind the channel on the left side of the experimental setup. To compare the displacements obtained from the image tracking and the data recorded by the position transducer, it was assumed that the pipe remains straight between L1 and L0, and the placement at the WP5 location can be obtained as a linear interpolation as shown in Figure 3b.

To generate the plot shown in Figure 3a, the displacements estimated in pixels were converted to mm. The estimation of the WP5 displacement was based on the following:

$$WP5 = (L0\text{-}L1)d/D+L1. \tag{1}$$

The actual displacement of the pipe recorded by WP5 is shown by green dots in Figure 4a. The plot also shows the displacements of markers L1 (red dots) and L0 (blue dots). Figure 4b shows the final comparison between the displacements recorded by the position transducer (blue line) and those estimated from image tracking of two markers L1 and L0 (red line). The latter is a computational result based on (1) and the diagram shown in Figure 3b. As presented in Figure 4b the displacements measured by the WP5 and those estimated from the image tracking correlate relatively well. The difference between the measurement and the estimation can be related to a few factors. First, the deformed shape of the pipe is not a straight line as assumed in Figure 3b and instead has a downward curved shape. Second, the markers are located along the centerline of the pipe, whereas the position transducer is monitoring the displacement of the bottom point of the pipe. Hence some error associated with the rotation of the cross-section needs to be taken into consideration to achieve a better correlation. These shortcomings will be addressed in the next phases of the study.



a) Displacement at WP5 location (green): estimation from image tracking

b) WP5 measurements vs. estimation from image tracking

Figure 4: Measurements and estimations of vertical displacement at WP5 location.

It is worth noting that the 2DCC procedure tracks the location of the marker with an accuracy of one pixel. The procedure that was used below for the second test can achieve a sub-pixel accuracy [7].

The distances *d* and *D* (shown in Figure 3b) were obtained by measuring the tested pipe as presented in Figure 5.

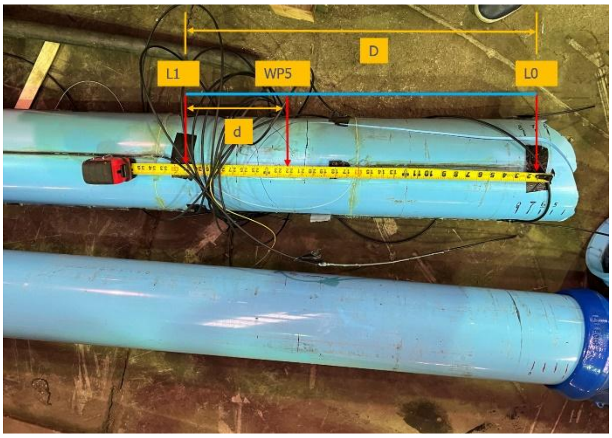


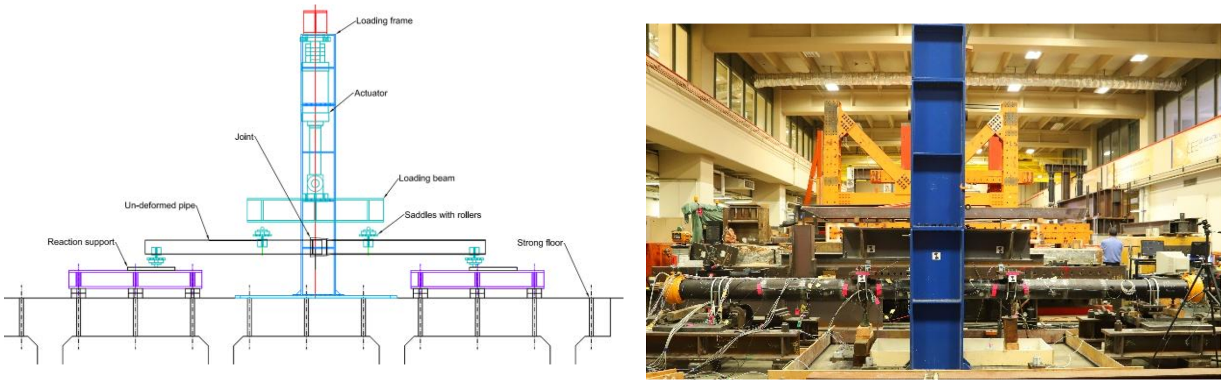
Figure 5: Measurements of *d* and *D*.

3 TESTING OF DUCTILE IRON PIPE

This section describes an application for tracking images of the so-called targets [7]. The targets are based on the utilization of black and white zones and they are commonly used as reference points for stitching point clouds. The targets were used in a point-bending test of 203 mm (8-in) TR-XTREME™ ductile iron pipe [8]. This paper discusses only the portion of the project related to non-contact measurements. More details on the rest of the project are provided in an extensive technical report [9].

3.1 Experimental setup

The drawing of the experimental setup is presented in Figure 6a. It utilizes a 2050-kN (460-kip) actuator with a stroke capacity of 508 mm (20-in). The setup's photo is shown in Figure 6b.



a) Drawing b) Photo

Figure 6: A drawing and a photo of four-point bending experimental setup with a large capacity.

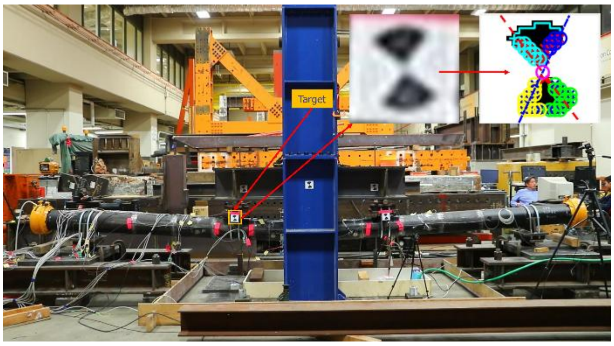
Similar to the previously described testing, the setup and the pipe were extensively instrumented by the fiber-optic strain gages, regular strain gages, and position transducers. Similar to the previous case, a DSLR camera was added to capture the overall deformation of the pipe. A few targets were installed onto the setup and the pipe in order to monitor the displacements at the critical locations as presented in Figure 6b.

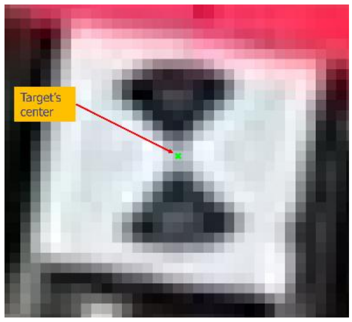
3.2 Target monitoring

The targets were placed on the loading elements and the pipe itself. In addition, one target was installed on the face of the loading column (blue in Figure 6b) which was used as a reference point. An example of one target is discussed in this paper.

The procedure of monitoring the targets is based on the utilization of the target's specific pattern consisting of black and white zones. The borderlines separating these zones are obtained from the target's image. Finally, the points at the borderline are best fit to straight lines as presented in Figure 7a. The intersection of these lines will produce a location of the target's center in a plane, as presented in Figure 7b.

This procedure was discussed and evaluated earlier [7] in a specially designed experimental setup with a high-accuracy position transducer. It was shown that this approach can deliver a sub-pixel accuracy in image tracking.



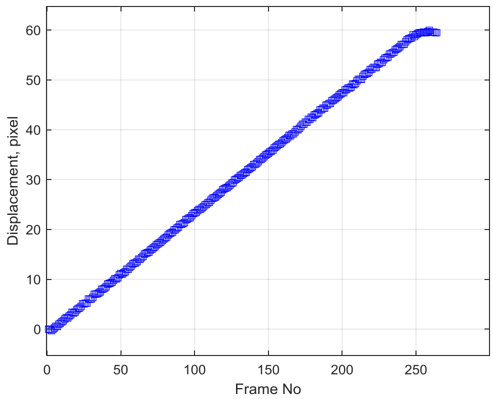


a) Selection and computations b) Result

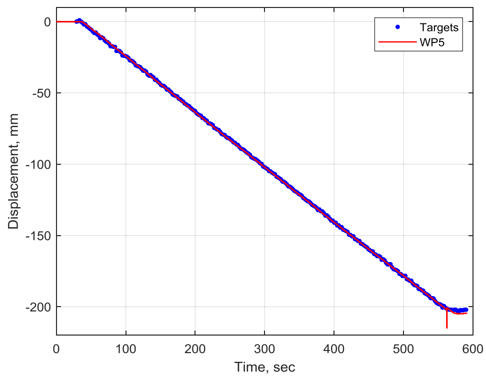
Figure 7: Procedure for computing center of the target.

3.3 Results

The results of the target tracking are presented in Figure 8. The displacements of the target's centers in pixels are shown in Figure 8a. The pixels were converted into engineering units and the sign of the target displacements was corrected to ensure that the up direction corresponds to positive vertical displacement. The results are presented in Figure 8b where they were compared to the WP5 displacement monitoring the vertical displacement of the pipe at the same cross-section.



c) Displacements in pixels



d) Displacements of recorded (red) vs. estimated by the target tracking (blue)

Figure 8: Displacement based on target tracking compared to that of position transducers.

Figure 8b shows an excellent correlation between the displacement estimated by tracking the target and that measured by a position transducer.

4 CONCLUSIONS

Two approaches based on image tracking were used in the testing of a pipe with a joint. The first approach was based on a normalized 2D cross-correlation procedure (2DCC) [4,5] and was used to monitor large displacements of a polymer pipe in four-point testing. The second approach was based on tracking targets with a regular pattern [7]. Since the second approach was proven to deliver a sub-pixel accuracy [7] this approach was used in the ductile iron pipe testing, in which smaller displacements were expected. It was demonstrated that the second approach can deliver high accuracy in displacement estimation by tracking images of targets. Due to the size limitations of the paper, only limited results are discussed herein. All results of the study will be published in an expanded version of the paper.

5 ACKNOWLEDGMENTS

The funding for this project was provided by the East Bay Municipal Utility District (EBMUD). The completion of the work would not be possible without the support of Llyr Griffith, John Kochan, Irik Larson, and Phillip Wong of the University of California, Berkeley. Active involvement and guidance from David Katzev of EBMUD are greatly appreciated. The authors would like to acknowledge Holly Halligan of UC Berkeley for editing the paper.

REFERENCES

[1] American Water Works Association (AWWA). 2016. AWWA C900-16: Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 60 In. (100 mm Through 1,500 mm). Denver, CO, USA.

[2] http://www.rctfittings.com/products/index.php.

[3] Shih-Hung Chiu, Shakhzod Takhirov, Kenichi Soga (2023) Four-Point Bending Testing of 8-in. (200-mm) Diameter AWWA C900 DR14 iPVC Pipe. CSI Report 2023/03, Center for Smart Infrastructure (CSI), Department of Civil and Environmental Engineering, University of California, Berkeley January 2023.

[4] Lewis, J. P. "Fast Normalized Cross-Correlation." Industrial Light & Magic, 1995. http://scribblethink.org/Work/nvisionInterface/nip.pdf.

[5] Haralick, Robert M., and Linda G. Shapiro, Computer and Robot Vision, Volume II, Addison-Wesley, 1992, pp. 316-317.

[6] MathWorks. Matlab Version R2020a; 2020.

[7] Takhirov, S. (2021). Measuring Centers of Special Targets in Digital Still Images and Movie Frames: Approach and Evaluation. In Proceedings of the 9th International Conference on Photonics, Optics and Laser Technology - PHOTOPTICS, ISBN 978-989-758-492-3; ISSN 2184-4364, pages 136-142. DOI: 10.5220/0010392901360142.

[8] U.S. Pipe. (2020). TR XTREME [Brochure]. https://www.uspipe.com/wp-content/uploads/2020/12/USP_TR_XTREME_Brochure_03-03-2020-for-web.pdf?fbclid=IwAR2n950mDSY8OQ39WFCoVzV8WWoNmk_ae88eCPNjQym1okpuRK7mLp6absE.

[9] Shih-Hung Chiu, Qinglai Zhang, Shakhzod Takhirov, Kenichi Soga (2023). Four-point Bending Testing of 8-in. (200-mm) Diameter TR-XTREMETM Ductile Iron Pipe, Center for Smart Infrastructure (CSI) Report 2023/02, University of California, Berkeley,

February 2023.