Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 17 (2019) 806–811

Structural Integrity Procedia

www.elsevier.com/locate/procedia

ICSI 2019 The 3rd International Conference on Structural Integrity

Experimental measurement of bridge deflection using Digital Image Correlation

Pedro J. Sousa[a,b,*], Francisco Barros[b], Paulo Lobo[c,d], Paulo J. Tavares[b], Pedro M. G. P. Moreira[b]

[a]*Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, s/n, 4200-465 Porto, Portugal*
[b]*INEGI – Institute of Science and Innovation in Mechanical and Industrial Engineering, Rua Dr. Roberto Frias, 400, 4200-465 Porto, Portugal*
[c]*CERIS, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal*
[d]*Departamento de Engenharia Civil e Geologia, Universidade da Madeira, Campus Universitário da Penteada, 9000-390, Funchal, Portugal*

Abstract

Civil engineering bridges usually face a multitude of loads, ranging from strong winds to intense traffic. Thus, it is important to understand their behaviour for adequate maintenance design and prevention of catastrophic failure.
The present work reports an image sensing methodology for deflection measurement that was successfully employed on the Entre-Águas bridge in Caniçal, Madeira, Portugal. For the application of two-dimensional Digital Image Correlation, it was necessary to build and deploy a patterned target onto the bridge in the monitored area and a camera setup in stable ground on a plane orthogonal to the target. Two different 2D DIC software packages were used for calculations, one commercial and one self-developed, enabling their comparison and increasing the confidence in the experimental results.
The developed system was applied in order to analyze the effects of the passage of 30-ton trucks in the bridge, with promising results.

Peer-review under responsibility of the ICSI 2019 organizers.

Keywords: Structural monitoring, Structural Integrity, Digital Image Correlation, Displacement measurement

* Corresponding author.
E-mail address: ppsousa@fe.up.pt

2452-3216 © 2019 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the ICSI 2019 organizers.
10.1016/j.prostr.2019.08.107

1. Introduction

Civil engineering structures such as bridges usually face a multitude of loads, ranging from strong winds to intense traffic. In order to maintain them in operating conditions, it is important to understand their behaviour in face of these loads and perform extraordinary maintenance operations if an issue is detected.

The analysis of these structures usually includes a combination of finite element modelling and experimental measurements. Among the latter, typical solutions include strain gauges, fibre optics and ultrasound sensors [1]. Besides, imaging technologies have been demonstrated to be applicable for the measurement of displacement and strain fields in civil engineering works [1–4]. In particular, digital image correlation (DIC) is capable of giving valuable insight into the behaviour of a structure, as it can provide continuous full-field measurements while being of simple implementation and, because it is a non-contact technique, having minimal impact on the structure itself during testing.

The presented work describes an image-based monitoring system to monitor the displacement of the Entre-Águas bridge in Caniçal (Madeira, Portugal). This includes the setup of a two-dimensional DIC system that monitors a speckle pattern mounted on a section of a bridge in order to measure the vertical deflection of the bridge at that section, and analyse its evolution through time as vehicles travel across the bridge. The obtained data could then be used for validation of numerical models.

2. Methodology

As it is not possible to measure the whole span of the bridge at once, the most interesting point to measure would be exactly at half-length of the bridge's central span, as the maximum displacements are to be found there. It was also verified that there was a street at an approximate height to the bridge and 70 meters northwest of the point where the target was to be located. As such, it was deemed possible to measure the displacement using a simple 2D system, as the measured vertical displacements are primarily influenced by differences in height and not as much by differences in horizontal positioning. This avoided the need to create a calibration pattern for a stereo vision system and move it around the target area.

With these considerations, and taking into account that the expected displacements would be in the millimeter range, it was possible to calculate the requirements for a suitable camera and lens. A four-megapixel iDS UI-3370CP camera was selected with a 70 – 300 mm zoom lens and a 1.4× teleconverter, equivalent to a 420 mm focal distance lens. The expected resolution with this imaging system was 0.9 mm/px, although the actual value depends on the final distance and exact zoom factor. Ideally, resolution should be as high as possible although, in practice, limitations of the optics and the specific measurement conditions impose the use of subpixel registration in the acquired images to accurately measure displacement values in the expected range.

To track the movement of the bridge, a target speckle pattern was designed in 1189 x 1682 mm A0 size paper, with 50% fill ratio and speckles of 3.5 mm diameter. The target, depicted in Fig. 1, contains six markings along the edges at known distances to enable scale calibration. A0 size was a compromise between the occupied area and the maximum distances at which these markings could be placed, before deformation of the markings significantly influenced scaling calculation.

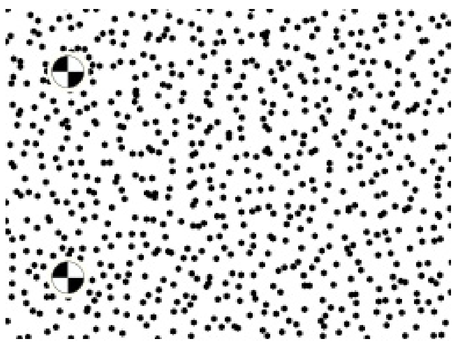

Fig. 1. Bottom left corner of pattern, highlighting two of the distance calibration markings.

Retroreflective markings or unique structural features, such as straight lines or corners can also be used as alternatives to scaling marks for image gauging, although measurement accuracy can be compromised. The expected resolution of a controlled Digital Image Correlation experiment in laboratory premises with a well-designed target is estimated as high as 1/50th to 1/100th of a pixel, although in fieldwork, such as reported here, 1/20th of a pixel is already an acceptable estimate.

The camera and lens were assembled in a sturdy tripod, in order to withstand the effects of vibration from side wind or road movement. The camera assembly was leveled so the resulting target image was as parallel to the image frame as possible and adjusted so the pattern rigidly attached to the bridge occupied most of the image. The simplicity of this assembly enables safeguarding the controlling hardware inside the support vehicle, partially seen in Fig. 2.

Fig. 2. Camera setup for deflection measurement

The printed pattern was attached to a polymeric board and held onto a rigid structure, which was in turn fastened to the bridge. This enabled an easy positioning of the pattern outside the bridge protection rails at approximately half-length of the bridge's central span, Fig. 3. Nonetheless, care must be applied to these attachment procedures, as any movements due to the wind can create excessive measurement noise.

Fig. 3. Placement of the speckle pattern on the bridge

The valley where the bridge is located is well known for high temperatures and wind speeds during the summer, when the measurements were taken. A short image exposure was thus deemed necessary to avoid motion blur that could be caused by external factors such as wind or heat wave induced distortions. Additionally, higher framerates also enable better filtering of the measurement noise and the measurement of dynamic loadings such as the passage of a truck without stopping.

The camera, based on the CMOSIS CMV4000-3E5M sensor, is capable of achieving 80 frames per second (fps) at maximum resolution using USB3 [5]. However, recording at such framerates is also dependent on the capacity of the controlling computer. Due to this limit, and since the resulting field of view was not entirely filled with the pattern, a region of interest was defined in order to increase the recordable framerate.

3. Results

During the experiment, an image sequence containing 3078 frames was recorded at 36 fps, the maximum possible framerate due to hardware limitations. A set of reference images was acquired beforehand to define the unloaded state of the bridge. The actual resolution of the acquisition system was calculated from the acquired images with the calibration markings included on the speckle pattern, at approximately 0.89 mm/px.

The image sequence was captured during the consecutive passage of two trucks through the bridge, both weighing 30 tons. The first truck stopped upon arrival at the measured section of the bridge and then moved to a 2nd position, until its middle section was aligned with the pattern, leaving the bridge after a few seconds. The second truck moved through the bridge without stopping. The individual frames of the video were used as input for both a commercial digital image correlation solution and a proprietary algorithm developed at INEGI.

During the experiments, the environmental conditions were not ideal, with sustained winds of approximately 26 to 33 km/h, gusts up to 55.6 km/h and temperatures around 25°C in the closest available monitoring point, the airport of Madeira [6]. The measurements noise due to the changing environmental conditions demanded the application of a filter, which was applied to both algorithms. The results are shown in Fig. 4 for INEGI's digital image correlation and in Fig. 5 for the commercial digital image correlation. For both, the average displacement of the pattern was the considered parameter.

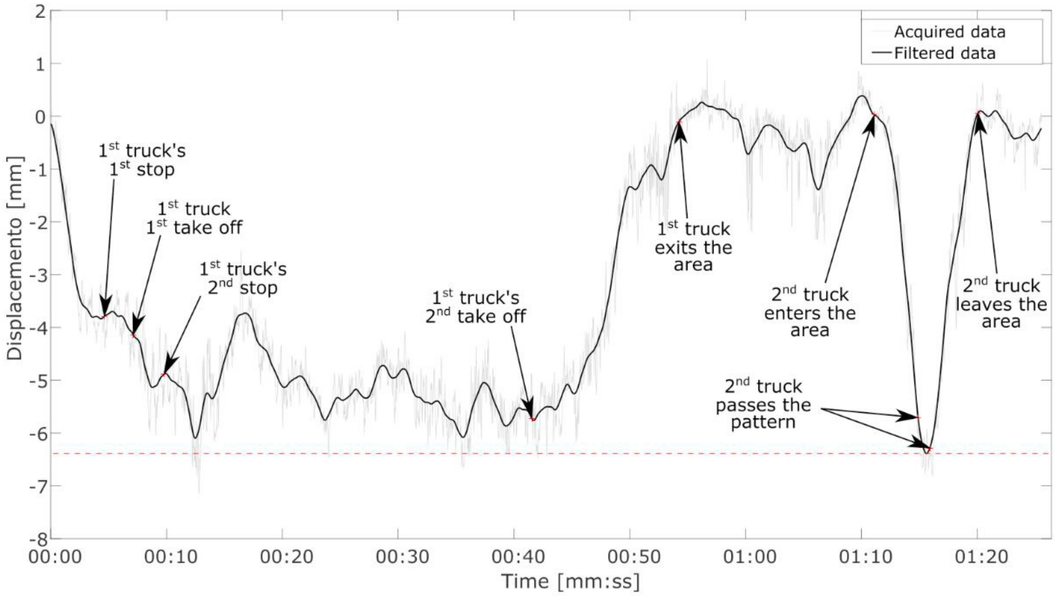

Fig. 4. Average displacement of the speckle pattern obtained using the developed digital image correlation system

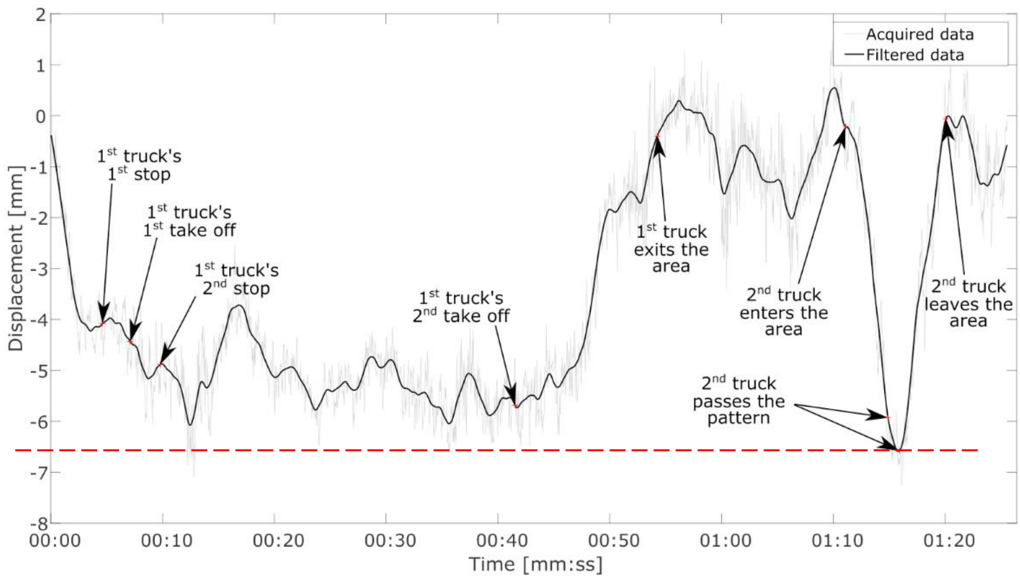

Fig. 5. Average displacement of the speckle pattern obtained with the commercial system

4. Conclusions

The presented results confirm the applicability of Digital Image Correlation to these measurements and validate the quality of the developed DIC algorithms in INEGI. It was possible to clearly identify the different effects caused by static loads in different positions, by comparing the bridge's response to the two stops of the first truck, and by a dynamic load, by comparing those previous responses to the second truck's passage.

The wind gusts caused some instability of the speckle pattern, which generates measurement noise, and this was made worse by distortions caused by the effect of the heat in the tarmac. Some of these problems could be mitigated by using heavier or painted targets and positioning them closer to the edge of the bridge. Nonetheless, after filtering and considering these unfavourable weather conditions, the obtained results are promising.

Acknowledgements

The authors gratefully acknowledge the funding of Project NORTE-01-0145-FEDER-000022 - SciTech - Science and Technology for Competitive and Sustainable Industries, co-financed by Programa Operacional Regional do Norte (NORTE2020) through Fundo Europeu de Desenvolvimento Regional (FEDER). Pedro J. Sousa gratefully acknowledges the FCT ("Fundação para a Ciência e a Tecnologia") for the funding of the PhD scholarship SFRH/BD/129398/2017.

Pedro Moreira and Paulo Tavares further acknowledge FEDER through Programa Operacional Competitividade e Internacionalização – Compete2020 and Fundos Nacionais through FCT – Fundação para a Ciência e a Tecnologia through project PTDC/EME-EME/29339/2017 - Monitorização Multiescala de Fendas.

References

[1] M. Malesa, D. Szczepanek, M. Kujawińska, A. Świercz, P. Kołakowski, Monitoring of civil engineering structures using Digital Image Correlation technique, in: EPJ Web Conf., EDP Sciences, 2010: p. 31014.

[2] T. Ramos, A. Furtado, S. Eslami, S. Alves, H. Rodrigues, A. Arêde, P.J. Tavares, P.M.G.P. Moreira, 2D and 3D Digital Image Correlation in Civil Engineering – Measurements in a Masonry Wall, Procedia Eng. 114 (2015) 215–222. doi:http://dx.doi.org/10.1016/j.proeng.2015.08.061.
[3] C.A. Murray, W.A. Take, N.A. Hoult, Measurement of vertical and longitudinal rail displacements using digital image correlation, Can. Geotech. J. 52 (2014) 141–155. doi:10.1139/cgj-2013-0403.
[4] M. Kujawinska, M. Bukalska, G. Dymny, Hybrid Digital Image Correlation/Thermovision system for monitoring of civil engineering structures, Proc. 10th Int. Conf. Quant. InfraRed Termography QIRT10. (2010) 173–178.
[5] IDS Imaging Development Systems GmbH, Frame rate calculator, (n.d.). https://en.ids-imaging.com/fpscalc.html (accessed February 23, 2018).
[6] Meteored, Histórico do tempo para Funchal 2017-07-12, (n.d.). https://www.tempo.pt/funchal-sactual.htm (accessed February 23, 2018).