Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 37 (2022) 159–166

Structural Integrity Procedia

www.elsevier.com/locate/procedia

ICSI 2021 The 4th International Conference on Structural Integrity

Displacement monitoring of crossbeams in an airport runway extension using digital image correlation

Francisco Barros[a]*, Susana Aguiar[a], Pedro J. Sousa[a], António Cachaço[a], Nuno V. Ramos[a], Paulo J. Tavares[a], Pedro M. G. P. Moreira[a], Min Xu[b], L. Oliveira Santos[b], Elsa Franco[c]

[a] *INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal*
[b] *LNEC, National Laboratory for Civil Engineering, Av. Brasil 101, 1700 066, Lisboa, Portugal*
[c] *ANA- Aeroportos de Portugal, SA, 9100-105 Santa Cruz, Madeira, Portugal*

Abstract

The structure of the Madeira Airport runway extension was built above the sea and is composed by a slab supported by frames at heights above 60 m. When landing in the E-W direction, aircraft touch this structure, which results in bending of the support beams. A vision system was installed under the runway in order to evaluate the deflection of the two support beams more directly involved with impact loads upon landing, but otherwise also involved in take-off or taxiing operations. Each system consists of a camera mounted on a beam, directed at the midspan of the following beam, whose displacement is set to be measured. The section captured by the camera has been prepared with a 2 m by 1 m speckle pattern target for displacement tracking using digital image correlation (DIC). A trigger mechanism was developed in order to save only the images obtained upon clear operational events. The camera acquires images continuously onto a circular buffer and compares them with a reference using DIC. When a displacement is detected, the images on the buffer, along with the frames taken in the next few seconds, are saved for posterior image processing. This system was successful at obtaining measurements for the monitored areas' displacement fields and the evolution of deflection through time for each event. Significant values for strain are yet to be obtained, as they were, most likely, too small for the system's resolution, for the events captured to this date.

---

* Corresponding author.
E-mail address: fbarros@inegi.up.pt

Peer-review under responsibility of Pedro Miguel Guimaraes Pires Moreira
10.1016/j.prostr.2022.01.072

Keywords: digital image correlation; beam deflection; structural monitoring

1. Introduction

The runway at Madeira Airport has the unique feature of including a section, built as an extension of the original runway. The runway extension is a high bridge, 1000 m length and 178 m width, composed by a succession of 32 m spaced frames which support a platform at 60 m high above mean sea-level (Fig. 1). The reinforced concrete slab, bi-directionally prestressed, has a thickness varying from 1.70 m, near frames, to 1.00 m, at its span centre. Each frame is made up a succession of 6 columns, 32 m distant from each other. The beams of each frame are 5.60 m high near columns, 3.60 m at the span centre. The column section is circular with a constant diameter of 3.0 m (Tavares & Vaz, 1997).

Fig. 1. Madeira Airport runway extension and its supporting structure.

When landings take place in the east-west direction, the aircraft's contact with the runway occurs in this extension, exerting a load on the supporting infrastructure.

The objective of the presented work was to implement a monitoring system based on digital image correlation (DIC), a computer vision method which measures the displacement and strain fields of a surface, to evaluate the displacement of an area around the midspan of the crossbeams of the supporting frames caused by the impact of a landing aircraft. The DIC technique has been successfully applied in a variety of structural monitoring scenarios, both as a means of assessing permanent displacements of structures (Tung, et al., 2013), but also to measure responses to dynamic loads (Niezrecki, et al., 2010). The presented work can, more specifically, be seen as closely related to the application of DIC to the measurement of the deflection and strain fields of bridges under loads which are part of their normal operation (Sousa, et al., 2019; Winkler & Hendy, 2017).

2. Setup

2.1. System components and layout

Two systems were installed monitoring two adjacent beams, namely those on frames P18 and P19. These frames are the closest to the most likely landing location and as such, they are expected to be subjected to the highest loads.

Fig. 2 shows the general configuration of the two systems. The main components of each system were a speckle pattern applied on the monitored area, a camera capturing this pattern on an adjacent beam (P17 and P18, respectively) above a pillar, and a computer for image acquisition control and data storage. The cameras were installed above pillars since the beam will have negligible deflection at those locations.

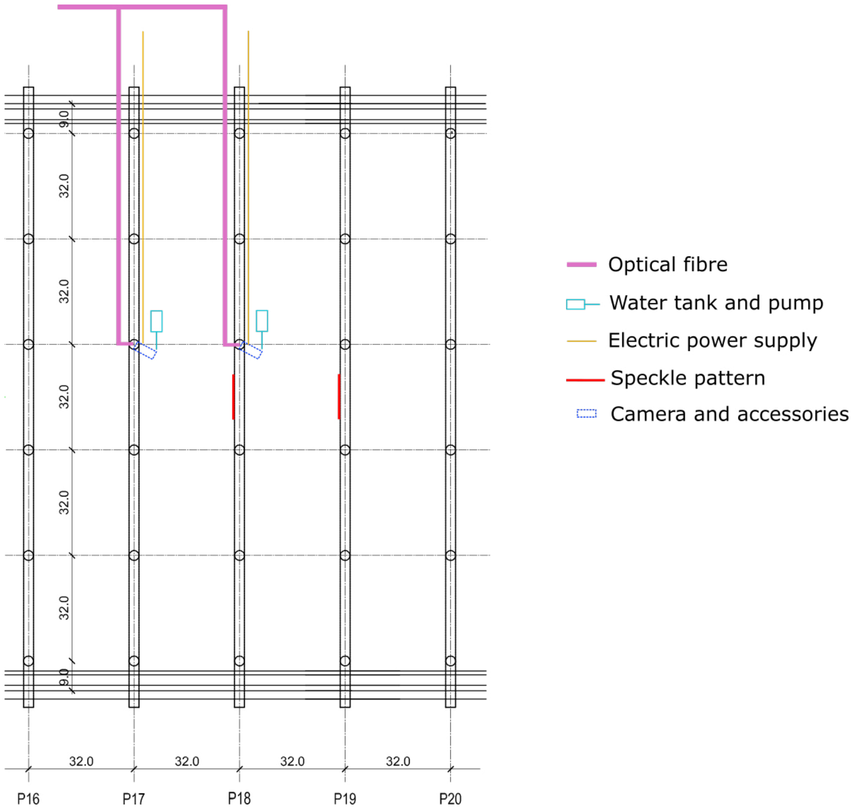

Fig. 2. Schematic of the setup of the two DIC monitoring systems.

2.2. Camera assembly

The central element in each camera assembly is the ImperX Cheetah C4180 camera with CoaXPress connections (4096 × 3072 px, 90 fps), equipped with a 300 mm lens. The distance to the monitored area is around 33 m, which by the camera’s specifications results in an average spatial resolution of around 0.5 mm/px. The camera was connected to a range extender, which powers the camera and serves as an interface between the coaxial cables from the camera and the optical fibre connections which connect the system to a computer.

These components were mounted on an IP68 steel housing which was fastened to the concrete structure, with some freedom to rotate and tilt. A wiper system for the housing’s glass cover, controlled by the same computer over an optical fibre connection, was mounted in order to clean the glass in case particles accumulate over time and affect the visibility conditions. A water tank with a pump was fastened to the structure and connected to the wiper system. Fig. 3 shows the fully assembled setup on one of the beams.

After all connections were completed and the speckle pattern was completely applied, the housing was rotated and tilted such that the pattern was completely inside the image and the lens was focused such that the pattern was as clear as possible.

Fig. 3. Camera assembly on one of the beams.

2.3. Speckle pattern

Speckle patterns were painted on the two beam sections being captured by the cameras. The patterns had a speckle size of 5 mm, a width of 2 m and a height of 1 m, roughly filling the cameras' horizontal field of view and spanning most of the height of the beam surface being monitored. Targets for geometric reference were included in the pattern, for calibration and perspective correction purposes. An image of the pattern obtained using one of the installed cameras can be seen in Fig. 4. Because precise positioning of the targets could not be guaranteed, a calibration procedure was performed, with a checkerboard pattern leaning on the surface, so that the real positions of the targets could be known.

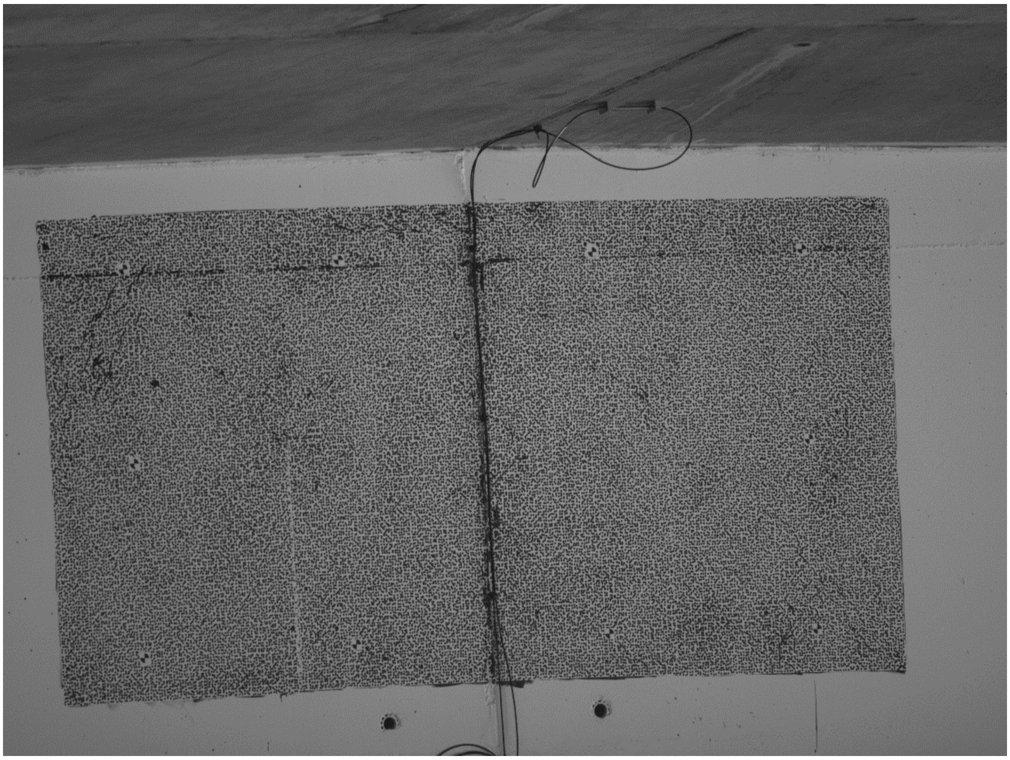

Fig. 4. Speckle pattern as seen by one of the cameras.

2.4. Control and processing hardware

The cameras are accessed and controlled by two computers placed in an outpost located next to the runway, this being the closest sheltered place to the camera assemblies. These workstations are equipped with the appropriate frame grabbers, which are connected to the cameras through roughly 600 m of optical fibre. They continuously run the automated scripts which control the image acquisition, retrieve the images from the cameras and, after some initial processing, send them to a server. The server, which stores all of the relevant data and allows for its consultation, is inside the airport building and accessed by the workstations through a local network.

3. Software

3.1. Image acquisition

During daytime, a script was set to run on each workstation to continuously acquire images at 90 fps. When the script starts, a reference is taken and all subsequent frames are compared to it using a rough DIC algorithm. This algorithm only evaluates a small area and does not perform any subpixel interpolation, making it computationally less intensive, but lacking in accuracy. A memory buffer is kept with the last 60 frames that have been acquired.

When a displacement is detected relative to the reference, the buffer is saved, along with all the frames acquired in the next 4 seconds. This way, it is possible to capture the start of the event, including information from before it was detected, and its further development. Afterwards, the entire process is repeated, with a new reference being taken and acquisition being restarted.

3.2. Initial processing

A script which obtains some results from the acquired images and sends data to the server was set to run on the workstations during the night, when there are few flights and no sunlight. These are operations that cannot be performed when images are being acquired, since they are too computationally demanding to be compatible with the simultaneous acquisition of images from the camera at 90 fps.

For each recorded event, the rigid displacement is calculated for all frames, now with subpixel resolution (Guizar-Sicairos, et al., 2008), and converted to millimetres. After verifying that, by this more rigorous computation, the event did not correspond to a false detection (e.g. a very small displacement or a sudden jump due to a camera error), all values are saved into a text file and this file is sent to the server, along with the reference image and the frames where the displacement magnitude was the highest. This is because keeping all of the images would take a prohibitively large amount of disk space.

3.3. Further processing and visualisation

A program was developed to be used in the server with the main objective of computing the full displacement and strain fields and providing visual feedback for all computed data. The results for displacement and strain fields obtained using this software, such as the ones presented in this article, were obtained with a 2D DIC computation over the entirety of the speckle pattern. This was preceded by a perspective correction of the image, taking into account the known locations of the targets on the speckle pattern. This correction is necessary because, even though the surface and its displacement are contained within a plane, that plane is not parallel to the camera sensor.

4. Results

4.1. Rigid displacement over time

Fig. 5 shows the rigid displacement over time of one of the beams in an event which was identified, by means independent from the monitoring system, as the landing of an aeroplane in the east-west direction, with a maximum deflection of 0.85 mm. All registered events had deflection peaks below 1 mm. Fig. 6 shows the displacement over time of events other than landings which were nonetheless detected by the system, namely a take-off and a taxiing operation, with slightly smaller maximum beam deflections.

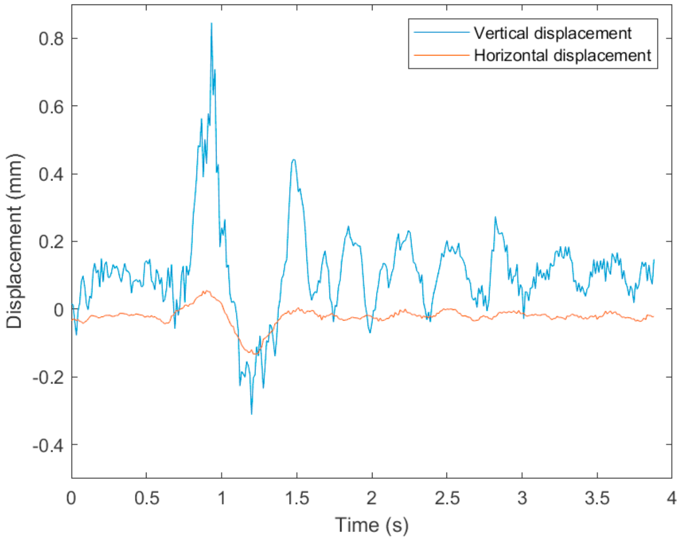

Fig. 5. Displacement over time on frame P18 for an east-west landing (positive displacement downwards/to the right).

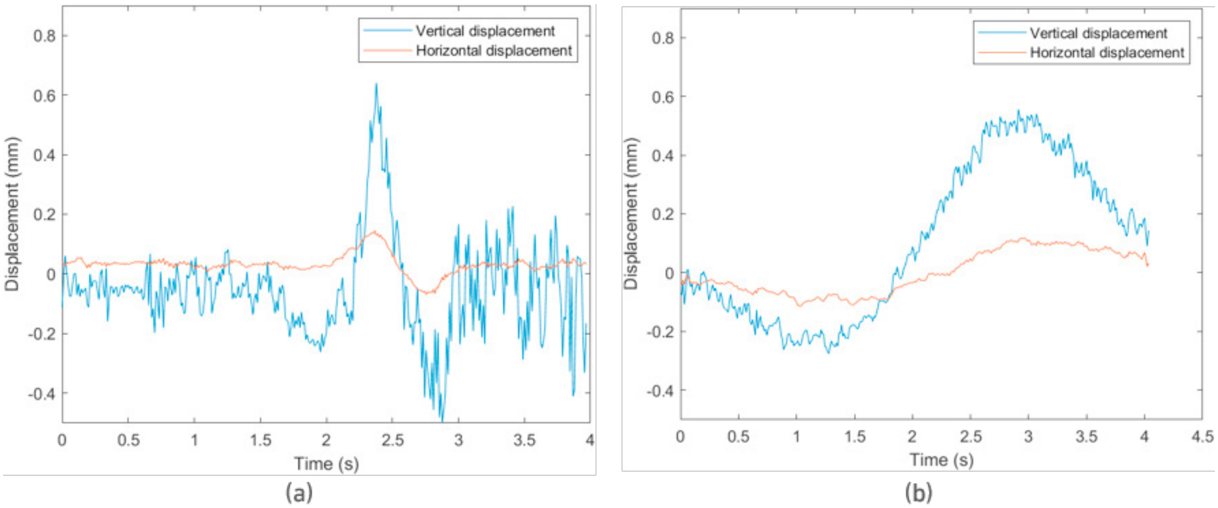

Fig. 6. Displacement over time on frame P18 for events other than landings: (a) take-off; (b) taxiing (positive displacement downwards/to the right).

4.2. Displacement and strain fields

Examples of a vertical displacement field and a strain field in *xx* (horizontal direction) are shown in Fig. 7 and Fig. 8, respectively. The displacement field seems to mostly describe a rigid displacement, since the variation of the values does follow any clear pattern.

The strain field fluctuates around zero, which is expected for an approximately rigid displacement. The areas with extreme values occur near the middle of the pattern, where a high correlation error was verified. Adding the knowledge that the speckle pattern is not as well defined in this area and there is a cable going through the pattern, we can conclude that these values may not correspond to any real phenomenon.

We can conclude that all recorded events so far have had a displacement field with little variation, being approximately rigid within the 2 m long monitored section, and consequently, strain values have been too small to be measured by the installed system. It remains to be seen whether more extreme events causing higher deflections will show clear displacement or strain patterns.

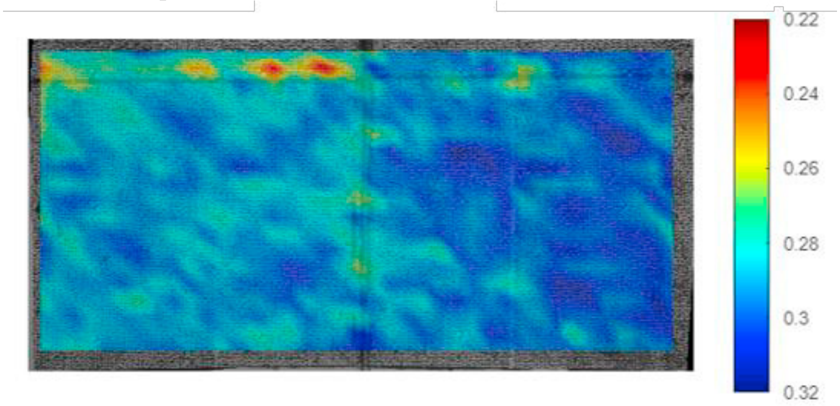

Fig. 7. Vertical displacement field obtained for a displacement peak (in mm).

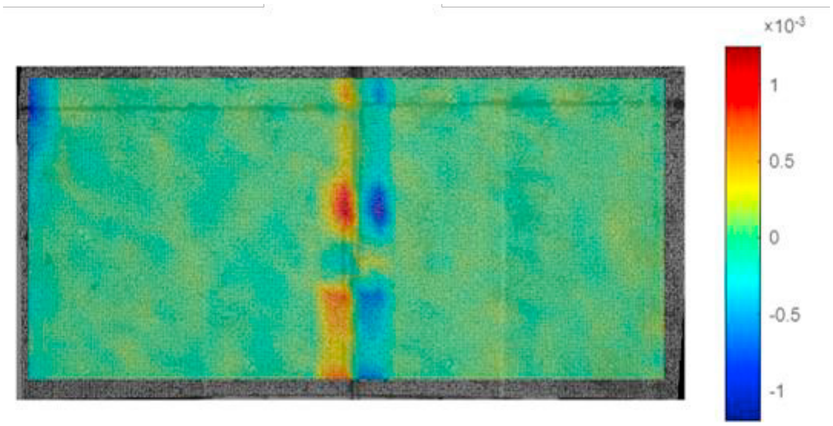

Fig. 8. Strain field in *xx* obtained for a displacement peak.

5. Conclusions

A computer vision system for the measurement of the deflection of the Madeira Airport runway extension beams was successfully developed and installed. This included a permanent camera assembly at a location with difficult access, the infrastructure for communication and control and the software for automatic acquisition control and data processing.

The system was able to detect and measure events on the runway that are part of the airport's daily operation, including landings, take-offs and taxiing, with image acquisition, processing and storage done automatically with minimal human interaction. Displacements and their evolution through time for each event were successfully quantified, while strain values so far have been too small to be measured.

Acknowledgements

This work was developed in the frame of project MEGE – Monitorização Estrutural de Grandes Estruturas, with reference number M1420-01-0247-FEDER-000030, funded by operational Program Madeira 14-20, PROCiência 2020, Sistema de Incentivos à Produção de Conhecimento Científico e Tecnológico da Região Autónoma da Madeira.

References

Guizar-Sicairos, M., Thurman, S. T. & Fienup, J. R., 2008. Efficient subpixel image registration algorithms. *Optics Letters,* 33(2), pp. 156-158.

Niezrecki, C. et al., 2010. A Review of Digital Image Correlation Applied to Structura Dynamics. *9th International Conference on Vibration Measurements by Laser and Non-Contact Techniques and Short Course,* Volume 1253, pp. 219-232.

Sousa, P. J. et al., 2019. Experimental measurement of bridge deflection using Digital Image Correlation. *Procedia Structural Integrity,* Volume 17, pp. 806-811.

Tavares, A. S. & Vaz, J., 1997. *Funchal Airport. The Structural Solution.* Lisbon, s.n.

Tung, S.-H., Weng, M.-C. & Shih, M.-H., 2013. Measuring the in situ deformation of retaining walls by the digital image correlation method. *Engineering Geology,* Volume 166, pp. 116-126.

Winkler, J. & Hendy, C., 2017. Improved Structural Health Monitoring of London's Docklands Light Railway Bridges Using Digital Image Correlation. *Structural Engineering International,* 27(3), pp. 435-440.