DIGITAL IMAGE CORRELATION ANALYSIS FOR DISPLACEMENT MEASUREMENTS IN CANTILEVER BEAMS

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Abstract: Digital Image Correlation (DIC) uses digital images processing techniques, which allows the acquisition of displacement fields of an object in regions of interest. The difference between DIC and other conventional measurement techniques is that DIC allows measurement of non-invasive mode, resulting in a low cost benefit. DIC is a technique applied in civil engineering, mechanical engineering, materials science and biomedical engineering, among others. Thus, it can also be adapted and used in many different measurement conditions, allowing a quick and accurate processing of a large number of images. This work is aimed to measure displacements in a cantilever beam by using DIC technique. To this end, different configurations of markings in ASTM A36 steel beams were analyzed, which obtained displacement fields along the beams. Commercial software for images processing, based on DIC technique was used. The procedure was applied to loads of 0.05 N, 0.1 N, 0.2 N, 0.5 N, 10 N, 20 N and 50 N. Satisfactory results were found when compared to analytical values and the Finite Elements Method. Results for loads of 10 N presented a difference around 0.3 mm between analytical results and DIC. This demonstrated the potential of DIC for displacement measurements in cantilever beams.

Keywords: DIC technique; Finite Element Method; Steel beams.

Resumo: A correlação digital de imagens (DIC) usa técnicas de processamento digital de imagens, o que permite a aquisição de campos de deslocamento de um objeto em regiões de interesse. A diferença entre DIC e as outras técnicas de medição convencionais é que DIC permite a medição de modo não-invasivo, resultando em uma técnica de baixo custo. DIC pode ser aplicada em engenharia civil, engenharia mecânica, ciência dos materiais e engenharia biomédica, entre outras. Também pode ser adaptada e utilizada em diferentes condições de medição, permitindo um processamento rápido e preciso de um número elevado de imagens. Este trabalho teve como objetivo medir deslocamentos em uma viga em balanço por meio da técnica DIC. Para este fim, foram analisados diferentes configurações de marcas em vigas de aço ASTM A36, que obteve campos de deslocamento ao longo das vigas. Foi utilizado um software comercial para o processamento das imagens, baseada na técnica DIC. O procedimento foi aplicado para cargas de 0,05 N, 0,1 N, 0,2 N, 0,5 N, 10 N, 20 N e 50 N. Os resultados mostraram-se satisfatórios quando comparados com valores analíticos e com o Método dos Elementos Finitos. Valores para cargas de 10 N apresentaram diferença em torno de 0,3 mm entre os resultados analíticos e DIC. Isso demonstra o potencial da técnica DIC para medições de deslocamento em vigas em balanço.

Palavras-chave: Técnica DIC; Método dos Elementos Finitos; Vigas de aço.

INTRODUCTION

Digital imaging emerged from the image transmission systems in the 1920s. The introduction of personal computers, mass storage, display systems and the development of new algorithms used for artificial vision, between the decades 1960 and 1970 was the starting point for the digital image processing and applications (GONZALEZ E WOODS, 2009).

Hobrough (2003) designed a high-resolution photography tool toward to correlation recognition for accurate measurements. It is considered one of the first researches for developing a digital image correlation in order to extract the information of location.

Experimentally, several other optical techniques have been used to measure displacements field and stresses by using Digital Image Correlation (DIC). This technique uses digital image processing to capture the object displacement field in regions of interest. Displacement may occur in a bi-dimensional plane or three-dimensional space.

One advantage of image process techniques is that most of them are considered a non-invasive technique and has a low cost-benefit when compared to other conventional measurement techniques (BRAGA JR et al., 2015; MAGALHAES et al., 2015, BRAGA JR et al., 2016).

Optical methods are used in experimental mechanics to obtain access to the kinematic data, meanwhile DIC works using a nondestructive testing, which calculates the displacements field without damage of the structure. Also, DIC can be adapted for many different measurement situations, allowing a quick and accurate processing of a large number of images (ZHOU et al., 2014).

Based on that, this paper is aimed to measure displacements in cantilever beams by using DIC, considering different configurations of the marks in the beam. Results of displacements field were compared with analytical data from cantilever beams theory - Equation 1 (TIMOSHENKO AND GOODIER, 1970). In addition, Finite Element Method (VALLEJO et al., 2014) was used to verify the potential of new applications for the DIC technique.

$$v = \frac{PL}{EI}\left(\frac{x^2}{2} - \frac{x^3}{6L}\right) \tag{1}$$

where v is the vertical displacement of the beam free end, P is the load applied to the beam free end, L is the length of the beam, I is the moment of inertia of the beam cross section, E is the modulus of elasticity of the material and x is the distance between the point of displacement measurement and the point of the load application in the beam.

MATERIAL AND METHODS

Experimental procedures based on DIC

The first step was setting the experimental procedures which were divided into three experiments. The first experiment consisted of random black ink dots placed at a distance of 250 mm, on a white paper. Similarly, in the second test, five ASTM A36 steel beams were white-painted and marked with random black dots. Beams had a length of 150 mm with cross-section dimensions of 3.2 mm x 25 mm. In the third test, black ink dots were spread randomly on the white-painted steel beam. The beam had a length of 215 mm and a cross-section 3 mm x 30 mm. Finally, a 5 mm-diameter hole was drilled on the left side of all beams in order to attach the support for the loads.

Figure 1 shows the experimental scheme considering the clamping position of the ASTM A36 steel beam as well as the image capturing setup. For this, it was used a Dino-Lite Digital Microscope Camera Premier Rp 116819. USB 2.0 interface with a resolution of 5 Megapixel and focus expansion on the lens to 50x, which can vary between 10x ~ 50x and 200x, with 145 mm of distance between the camera and the beam.

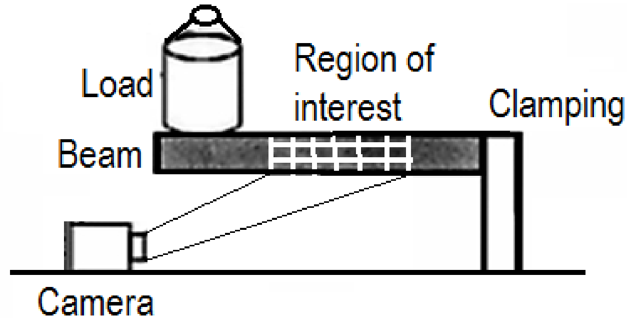

Figure 1: Experimental setup for the use of DIC technique

Different markings on the samples

In the second step, DIC technique was used for performing different markings in the object of study. It was performed by the three different experiments, which are: Random black points in white paper, random points on the beam and random dispersion points on the beam, as proposed by TANG et al. (2012). In all cases, an image was captured with no displacement (reference image, Figure 2a) and after a vertical up-down load applied, a new image was captured (distorted image, Figure 2b).

Figure 2a: Reference image in white paper

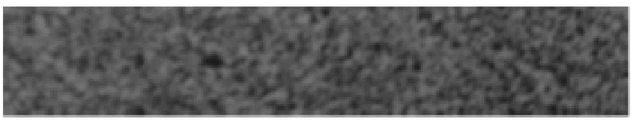

Figure 2b: Deformed image in white paper

Black dots were randomly outlined using a fine-tip marker (1 mm) to draw small points and a medium-tip marker (2 mm) for medium dots, scattered on five A36 steel beams.

Different patterns were employed: (a) small, adjacent dots (1 mm); (b) small, sparse dots (5 mm); (c) large, adjacent dots (3 mm); and (d) large, sparse dots (5 mm).

After drawing the random points in the five steel beams, the following weights were applied: 10 N, 20 N and 50 N at its free end of the beam. The other side of the beam was clamped at a distance of 20 mm from the edge. The camera captured 38 mm, starting at a distance of 5 mm right after the clamping position according to Figure 3.

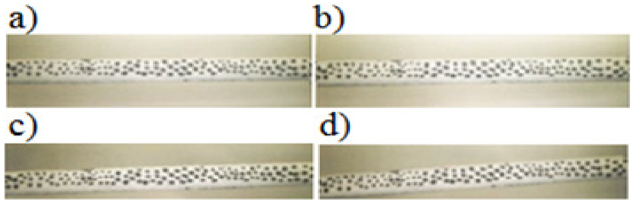

Figure 3: Steel beam a) reference image; b) load of 1 N; c) load of 2 N; d) load of 5 N

Finally, random points on the body surface of the test sample were generated on the ASTM A36 steel beam in order to achieve pictures with grayscale intensity. The applied loads were 0.05 N, 0.1 N, 0.2 N, 0.5 N, 10 N, 20 N and 50 N at the free end side of the beam (Figure 4). The camera captured a length of 36 mm as suggested by ANTONIU (2015).

Figure 4: Random points on the steel surface under a load of 0.05 N

DIC versus FEM and analytical values

The results obtained by DIC were compared to analytical results (Equation 1) and the Finite Element Method in order to evaluate the potential of DIC applications. For the FEM validation, ASTM A36 steel beam was modeled through the commercial software ANSYS with a mesh of 231387 nodes and 51843 hexahedral elements type. Clamping position of the beam and the region where the loads were applied can be observed in Figure 5a. The generated Finite Element mesh is shown in Figure 5b.

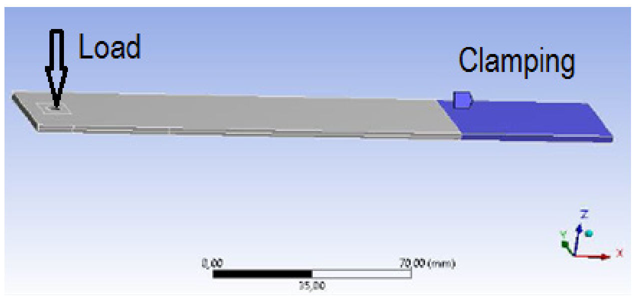

Figure 5a: Clamping and load position applied to the beam Finite Element model

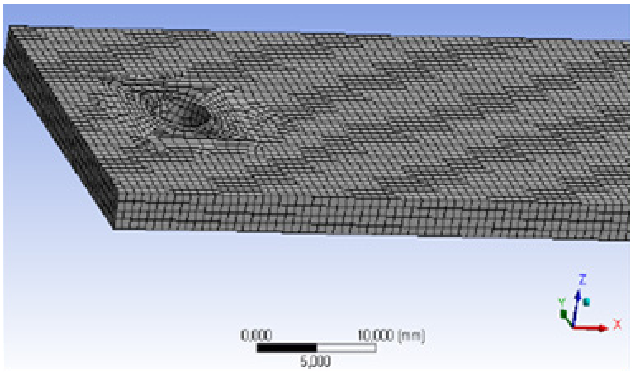

Figure 5b: Cantilever beam Finite Element mesh

RESULTS AND DISCUSSION

Random points on paper

Figure 6 shows the results from the images processing for the black dots drawn on the white paper by Ncorr software based on DIC. Previously threshold from the open source software ImageJ was applied which did not showed a satisfactory result.

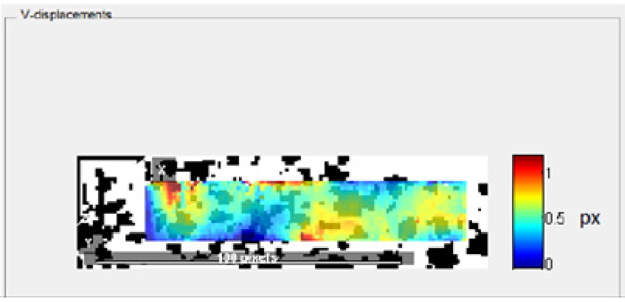

Figure 6: Processed image via DIC using threshold in a white paper

In order to improve the results of processing original images in white papers, the reference and deformed image were processed by Ncorr software without any treatment. Results identified the maximum (20 pixels) and minimum displacement (10 pixels), according to Figure 7.

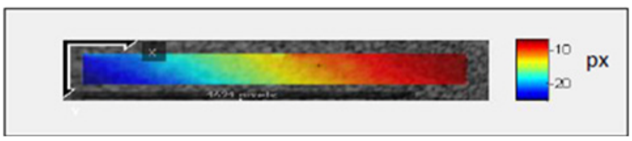

Figure 7: Processed image via DIC without threshold in white paper.

Figures 6 and 7 demonstrated that processing images using threshold gets results with no correlation while processing the original images without threshold gets satisfactory results. For this reason, images without threshold were used for DIC analysis in the cantilever beam.

Random painted dots in the cantilever beam

DIC technique by means of random dots painted in the ASTM A36 steel beam under loads of 10 N, 20 N and 50 N was processed using images without threshold. Figure 8 illustrates the distorted image for small and adjacent dots by using Ncorr software under a load of 10 N.

Results from DIC (Figure 8) presented displacements values in y-axis and it was observed minimum values (~ 6 pixels) close to the clamping position and maximum values (14 pixels) close to the load of 10 N.

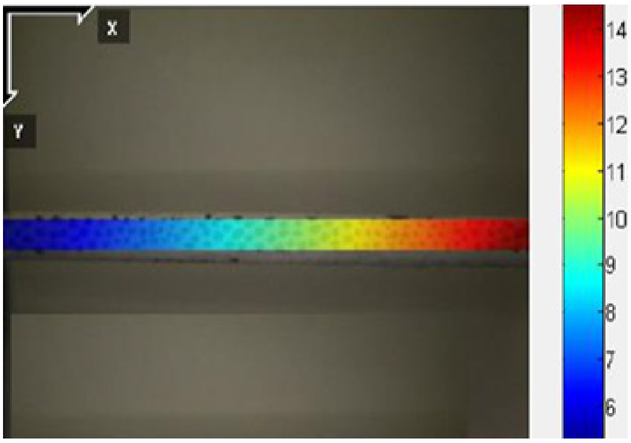

Figure 8: Beam displacements under a load of 10 N at Ncorr (painted dots)

In order to certify the DIC technique, results were compared to analytical values (Equation 1) and significant difference between values was found. Figure 9 shows analytical displacements curve compared to DIC under a load of 10 N applied to the free end of the beam, where the x-axis (analyzed portion of the beam length) is represented in pixels and the y-axis (displacements) is represented in millimeters.

Figure 9 showed that curves' behavior did not follow linearity. It was generated results considering loads of 20 N and 50 N and curves' behavior kept similar. For this reason, the same procedure was performed considering random dispersion points in the beam in order to improve the results.

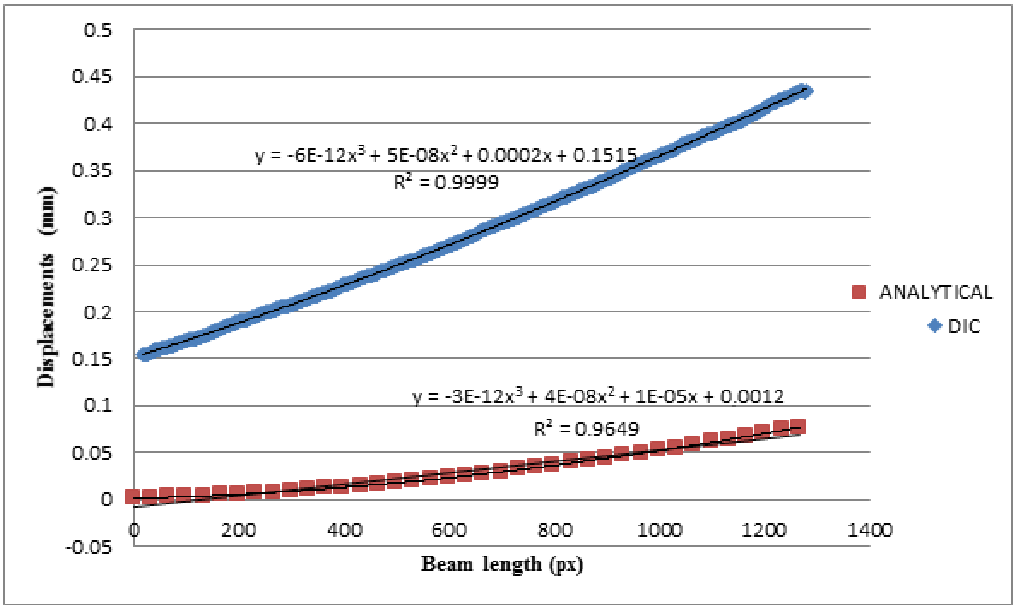

Figure 9: DIC vs. analytical displacements for a load of 10 N

Random dispersion dots in the cantilever beam

In order to try improvements on the DIC results a different assessment was performed for DIC by applying random dispersion black dots in the ASTM A36 steel beam. In this case, loads of 0.05 N, 0.1 N, 0.2 N, 0.5 N, 10 N, 20 N and 50 N were applied in the beam free end and results were obtained. Figure 10 shows displacement in the y-axis direction for the load of 10 N.

Figure 10: Beam displacements under a load of 10 N at Ncorr (dispersion dots)

It is observed in Figure 10 the minimum values (~ 32 pixels) close to the clamping position and maximum values (~ 42 pixels) close to the load of 10 N. In order to compare DIC results with analytical values, Equation 1 was used and results are shown in Figure 11.

It is noted in the Figure 11 that, in the analyzed stretch in the beam, both curves presented constant offset along the beam length, showing an average difference around 0.3 mm between them. The same experimental procedures were applied for loads of 0.05 N, 0.1 N, 0.2 N, 0.5 N, 2 N, 10 N and 50 N and satisfactory results were obtained by using 10 N. This can be explained as result of the marks configuration with higher amounts of black dots and, consequently, larger information. Figure 12 shows displacement results from loads of 0.05 N, 0.1 N, 0.2 N, 0.5 N, 10 N, 20 N and 50 N, obtained from DIC technique by using random dispersion dots in the beam.

It is noted in the Figure 12 that higher displacement occurs when load values were increased and also that higher displacements is observed when the distance from the clamping position is increasing for all loads. It demonstrates DIC coherence with cantilever beam theory. In order to certify this, Finite Element simulations were performed. Figure 13 shows simulated displacement in the ASTM A36 steel beam when 10 N was applied in the beam.

It is noted in the Figure 13 that the maximum displacement value obtained by FEM simulations is around 0.89 mm and DIC presented maximum displacement of 1.2 mm (Figure 11) for a load of 10 N, showing an average difference around 0.36 mm between them (FEM and DIC).

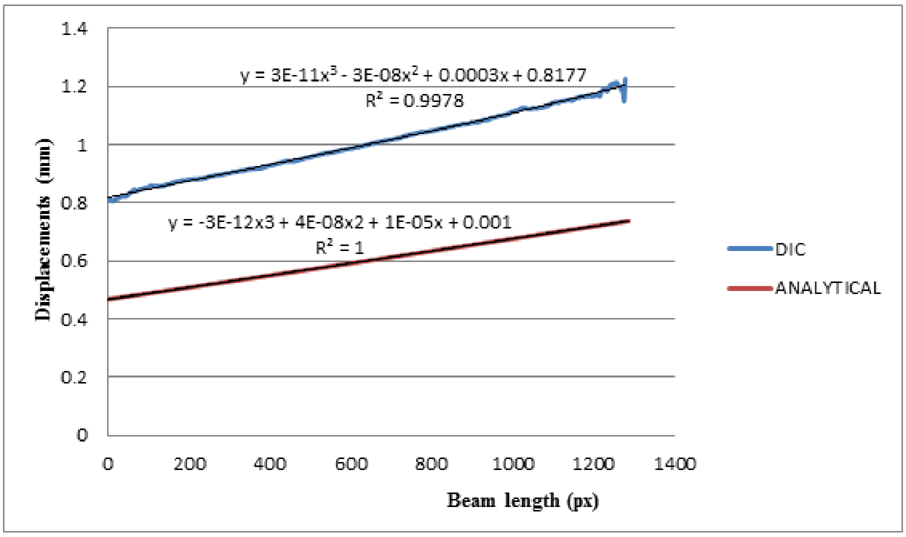

Figure 11: DIC vs. analytical displacements for a load of 10 N (Random dispersion dots)

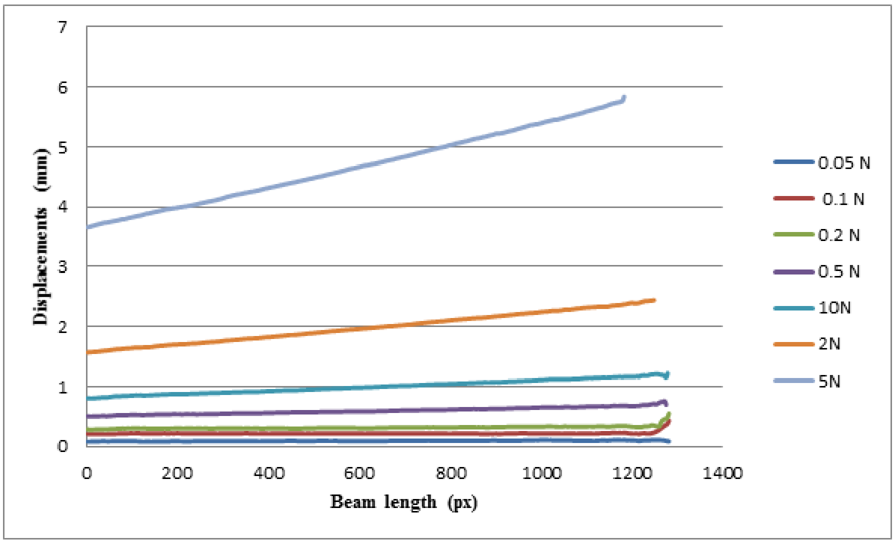

Figure 12: DIC displacements for loads of 0.05 N, 0.1 N, 0.2 N, 0.5 N, 2 N, 5 N and 10 N

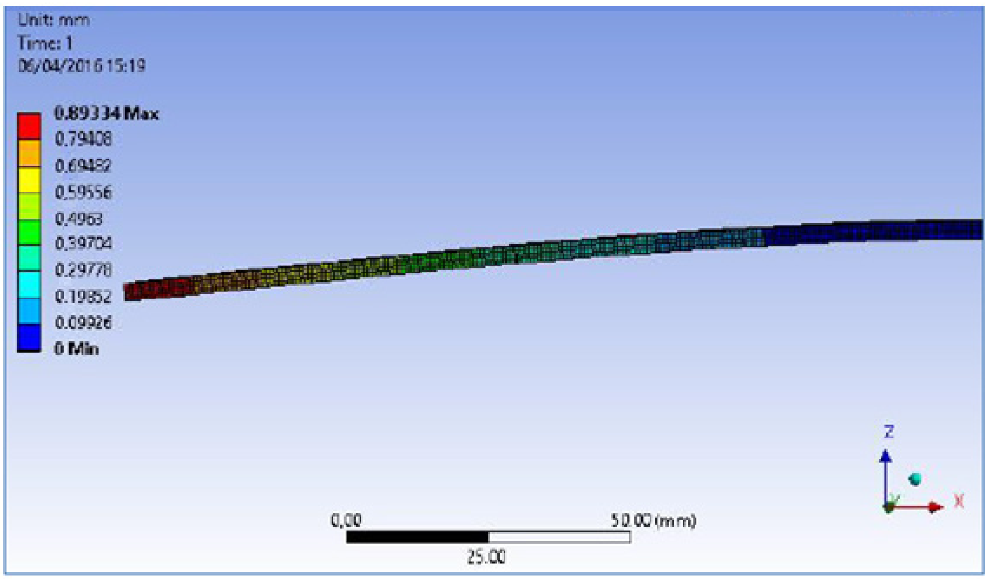

Figure 13: FEM simulations on the A36 steel beam under a load of 10N.

CONCLUSIONS

Digital image correlation technique was used for identifying displacements on ASTM A36 steel beam, showing the possibility to work with different kinds of markings, including painted and random dispersion dots. Better results were obtained under random black dots dispersion on the beam surface by applying a load of 10 N.

Even though an average difference around 0.3 mm between analytical results and DIC was found, both curves showed a constant offset along the beam length. In addition, simulations were performed showing an average difference around 0.36 mm between FEM and DIC.

Considering the results obtained, it can be concluded that DIC has potential for measuring vertical deformations of cantilever beams by using only one camera for bi-dimensional estimations, showing low-cost benefit. Moreover, it can be quickly applied in a large number of images in many engineering areas and also adapted for different measurement situations. As a suggestion for future works, it is proposed to carry out application on other kinds of materials and perform comparisons between other measurement techniques.

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