DAMAGE IDENTIFICATION USING DIGITAL IMAGE CORRELATION METHOD

Tiago de Melo Trindade (T.M. Trindade)
Luiz Carlos da Silva Nunes (L.C.S. Nunes)
Laboratory of Opto-Mechanics (LOM/LMTA), Department of Mechanical Engineering (TEM/PGMEC), Universidade Federal Fluminense – UFF, Rua Passo da Pátria, 156, Bloco E, Sala 216, Niterói, RJ CEP 24210-240, Brazil
tiago.m.trindade@gmail.com
luizcsn@id.uff.br

Abstract. *This paper aims to investigate the mechanical behavior of cantilever beams with different cracks near to the fixed end. A damage variable was introduced and the evolution of damage was obtained. In the experimental procedure, cracked cantilever beams were submitted to applied load at the free end. Horizontal and vertical displacement fields of whole specimen were attained using the Digital Image Correlation method. The values of vertical displacement of the free end together with applied loads were used to achieve force-displacement responses for distinct crack configurations. From these data, the relationship between the stiffness and crack length was evaluated, as well as damage variable and crack length relation. Also, full-field strains near to the defect were calculated and values of the mean of principal strain as a function of damage variable were investigated.*

Keywords: *Digital Image Correlation, Damage, Defect*

1. INTRODUCTION

Several methods based on the structural damage detection using dynamic measurement data have been employed in many different areas such as mechanical, civil, and aerospace engineering. The basic idea of dynamic methods is to associate modal parameters with physical properties of the analyzed structure, such as mass, volume, and stiffness (Hu, M., Tu, S., *et al.*, 2012). Therefore, changes in the physical properties leads to changes in the modal parameters. For instance, Dixit and Hanagud (2011) proposed an analytical expression and a new damage measurement method that associates the strain energy with the location and magnitude of damage. This method can be applied to beams with notch, considering arbitrary boundary conditions.

A computationally attractive damage index method was proposed (Hu, M., Tu, S., *et al*. 2012) for structural damage detection of cylindrical shell. It provides an insight to the extent of structural damage. The algorithm was applied to two numerical examples and its efficiency was demonstrated through damage simulations.

Optical methods, such as shearography, laser speckle interferometry, and moiré were developed for measuring surface displacements and deformations (Bendek, E., Lira, I., François, *et al*., 2006) (Ruzek, R., Lohonka, R., *et al.*, 2006) (Cárdenas-García, J. F. & Preidikman, S., 2006). Recently, with the development of high-resolution Charge Coupled Device (CCD) cameras the use of the Digital Image Correlation (DIC) method (McGinnis, M. J., Pessiki, *et al*., 2005) (Corr, D., Accardi, M., *et al*., 2007) has been increased considerably.

The basic principle of Digital Image Correlation is to correlate two images of the same specimen in two different states, namely before and after applying a load, via a correlation function. The term “digital image correlation” refers to the class of non-contacting methods that acquire images of an object, store images in digital form and perform image analysis to extract full-field shape, deformation and/or motion measurements (Sutton, M. A., Orteu, J. J, *et al*., 2009). The determination of displacement and deformation fields using the DIC method can be done directly on a structure, independent of material: metal, polymer, composite materials, among others. The specimen only needs to be prepared by creating a speckle pattern on the specimen surface.

A recent study (Alam, S. Y., Kotronis, *et al*., 2013) presented experimental and numerical investigations of the influence of size effect on crack opening, crack length and crack propagation applied to a concrete bending beam, using the DIC method. In this way, the aim of the present paper is to propose an approach based on experimental method using Digital image correlation combined with damage analysis. The DIC method is employed to obtain displacement and strain fields of cracked cantilever beams under bending.

2. EXPERIMENTAL PROCEDURE

An experimental procedure was developed to investigate the mechanical behavior of cantilever beams with different cracks near to the fixed end. The cracked cantilever beams were submitted to quasi-static monotonic loading at the free end. Specimen beams with dimension of 100 x 20 x 5 mm^3 were made of acrylic. Three cases were tested and each case used one single beam specimen. For each case, a crack was produced at a specified position d_1 (and d_2 in Case III) along the longitudinal axis of the specimen beam, near to the fixed end, as shown in Fig. 1. The crack lengths (a) of beam specimens were carefully controlled considering steps of 2 mm in the range of $0 < a < 12$ mm for the Case I and II and, from 0 to 16mm for the Case III. Table 1 shows the specifications of the three cases.

Figure 2 illustrates the experimental arrangement that involves a cantilever beam with loading support, a CCD camera set perpendicularly to the specimen, light source and a computer. All beam specimens were covered with painted speckles (random black and white pattern) and the CCD, used to record images of the specimen before and after load, had a resolution of 1280x960 pixels.

Table 1. Experimental parameters of the beam specimens and crack information.

Case	L (mm)	w (mm)	t (mm)	d_1 (mm)	d_2 (mm)	a (mm)
Case I	100	20	5	7	0	0 to 12 (2 by 2mm)
Case II	100	20	5	7	0	0 to 12 (2 by 2mm)
Case III	100	20	5	7	7	0 to 16 (4 by 4mm)

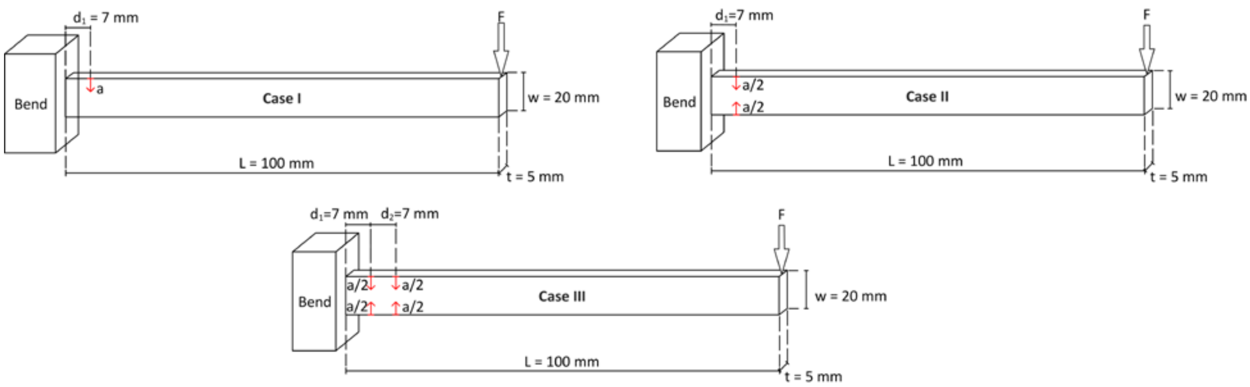


Figure 1. Scheme of cracked cantilever beams for the three cases (I, II and III).

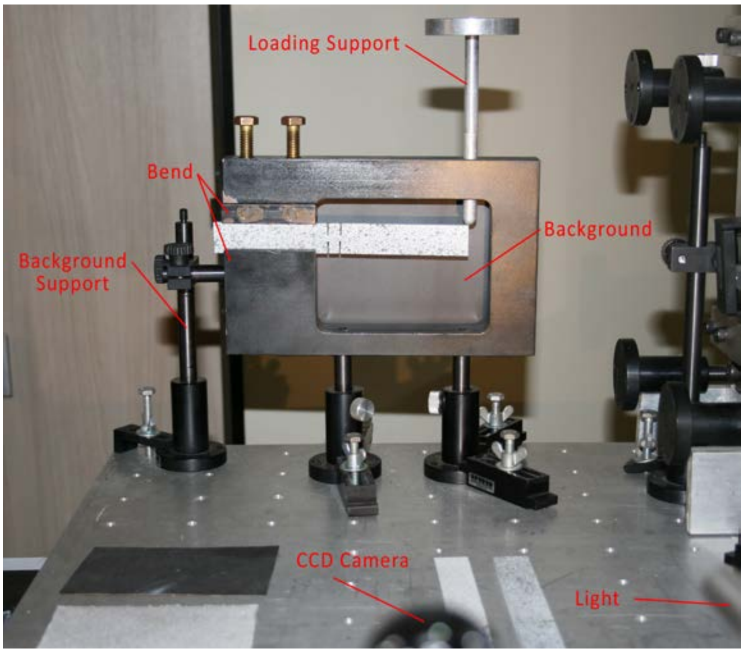


Figure 2. Experimental arrangement.

3. RESULTS AND DISCUSSION

For each crack length "a" of a cracked cantilever beam, two analyses were performed. Full-field displacements of whole beam specimen were determined and, strain map from a selected region near to the crack was calculated. The results of three cases are now presented.

Figure 3 shows examples of cantilever beams with different crack configurations, i.e., the three cases previously presented. It is important to remark that these results are associated with crack length of 12mm for Case I, 14mm for the Case II and 16mm for the Case III. DIC analyses were carried out in the 20 x 100 mm^2 area (First selected area) of whole the specimen and in approximately 20 x 20 mm^2 area (Second selected area) near to the crack, which are marked with a white and red boxes, respectively.

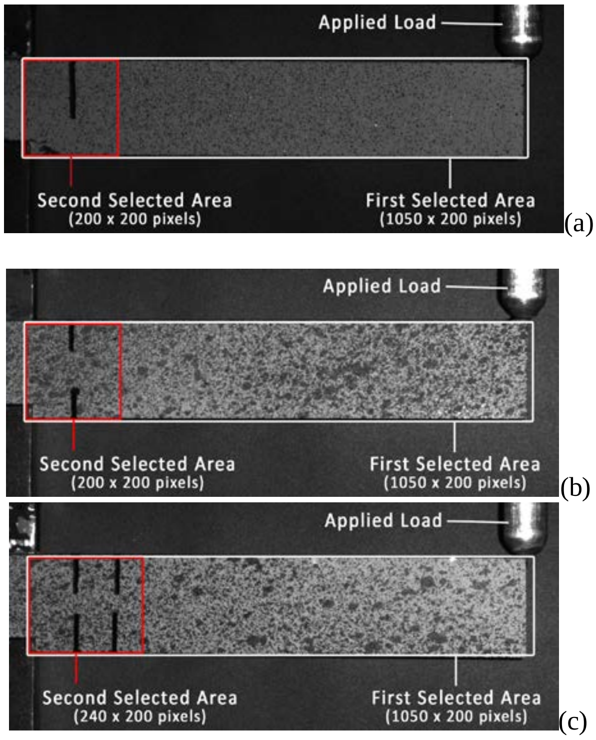
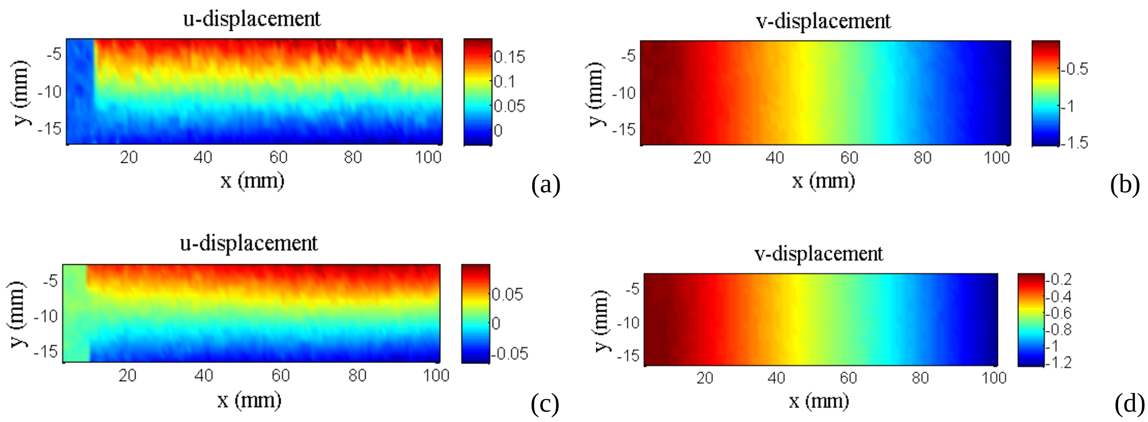


Figure 3. Cracked cantilever beam for three cases: (a) Case I, (b) Case II and (c) Case III.

Horizontal and vertical displacement fields, denoted by u(x,y) and v(x,y), are illustrated in Fig 4. The Case I, II and III associated with an applied load of 5.21N are shown in Fig4 (a-b), Fig4 (c-d) and Fig4 (e-f), respectively. These results were obtained from first selected area in Fig 3 using DIC program. In all cases, discontinuities of u-displacement fields on the crack region near to fixed end are easily observed. From these data, the crack can be identified. On the other hand, there is no additional information of crack in vertical displacement. The results of v-displacement can be used to determine the vertical displacements at free end of the cantilever beam.



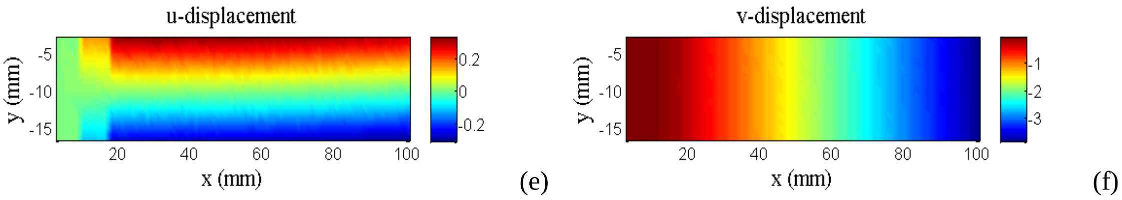


Figure 4. Horizontal (a-c-e) and vertical (b-d-f) displacement fields for Cases I (a-b), II (c-d) and III (e-f).

An alternative way to identify discontinuity, or crack, is evaluated the principal strain (maximum). The values of strain were calculated using full-field displacements that are associated with second selected area, near to fixed end, as shown in Fig 3. The maps of strain for Case I, II and III are presented in Fig 5(a), (b) and (c), respectively. The defects that are related to maximum values of strain can easily be identified in all cases when cracks open; however, this observation is not possible when cracks tend to close. In fact, a crack growth condition should receive particular attention.

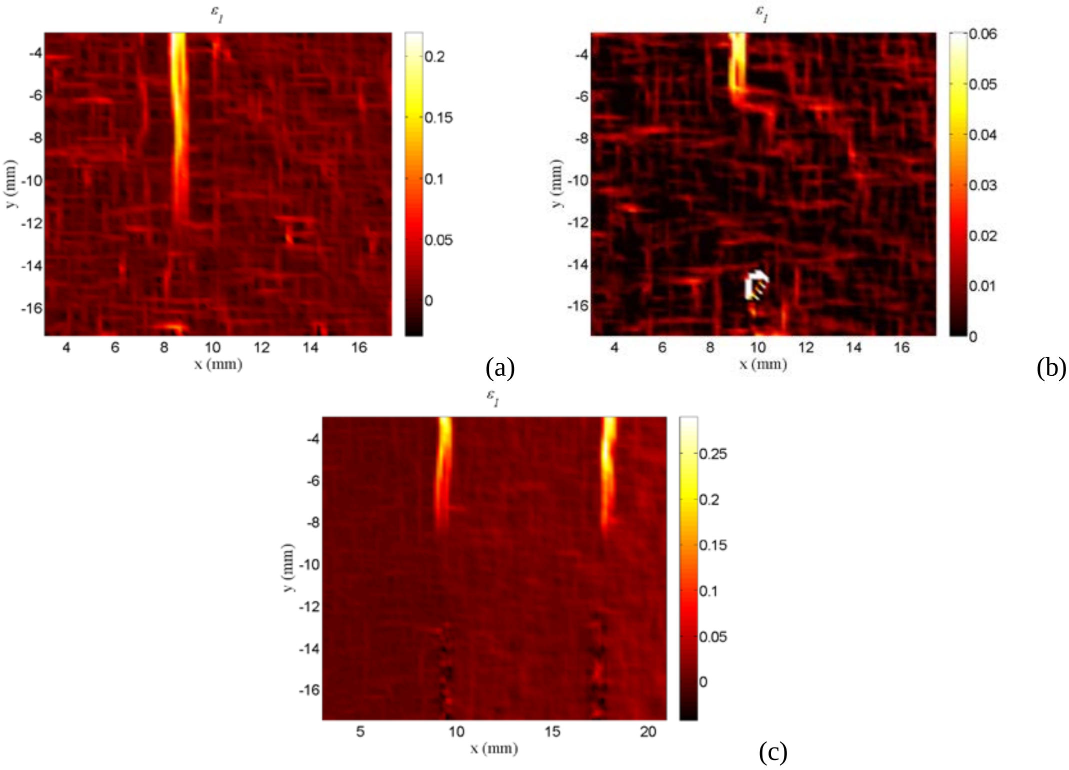
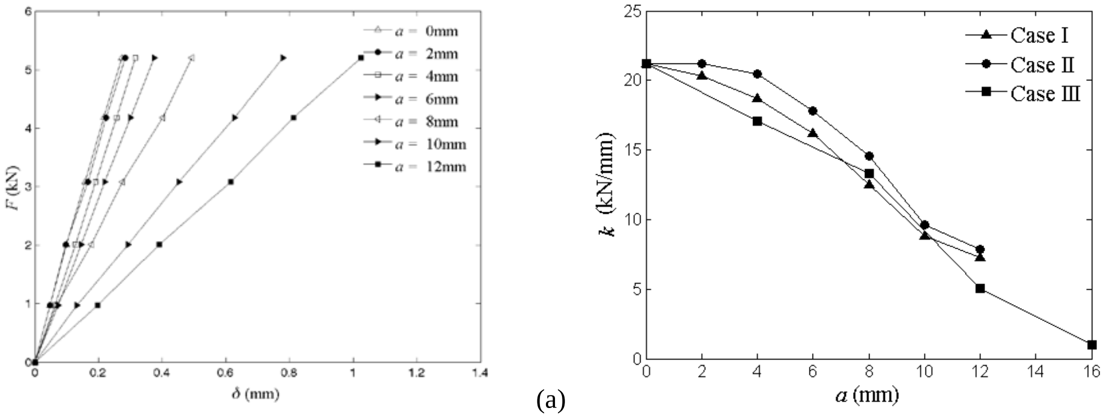


Figure 5. Maps of principal strain for Cases I (a), II (b) and III (c).

It is of interest to understand the relation between applied loads F and vertical displacements of free end δ of the cracked cantilever beams. For instance, F-δ responses for Case I considering different crack lengths are illustrated in Fig 6(a). It can be notice that the load-displacement slopes decrease with increasing crack lengths, as expected. Assuming a linear behavior, F-δ relation can be given as

$$F = k\,\delta \tag{1}$$

Where the slope of F-δ curve is k, denoted by stiffness of the cracked beam. Fig 6(b) shows the behavior of the stiffness as a function of crack lengths for all three cases. Overall, the results indicate that the k-a response is nonlinear and present the same behavior for all cases.

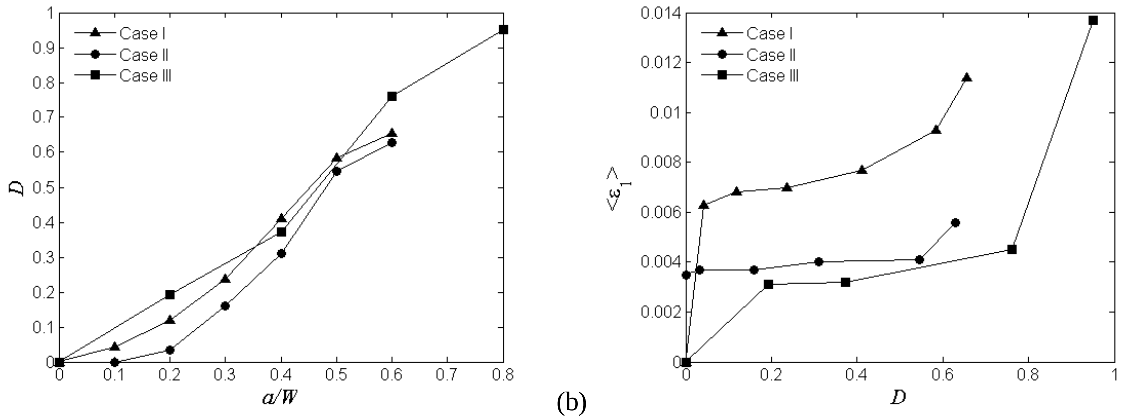


(a) (b)

Figure 6. (a) Applied loads versus vertical displacements of free end (b) and stiffness versus crack length.

To investigate the evolution of damage, the values stiffness of cracked beams is considered assuming that (k-k_0/(1-D)), where k_0 and D are defined by stiffness of beam without defect and damage variable ($0 < D < 1$), respectively. Fig 7(a) shows the damage variable (D=1-k/k_0) against crack length divided by width (*a/W*). Note that, in the Cases I and II, obtained responses are clearly nonlinear, while an linear behavior is observed in Case III.

The mean value of the principal strain was calculated to find a relationship between the measured parameter and damage variable. From the results presented in Fig 7(b), it is possible to observe that there is a nonproportional response between the proposed values of strain and damage variable. The same behavior is observed in all cases. These results indicate that the mean value of the principal strain can be used to evaluate evolution of damage.



(b) (c)

Figure 7. (a) Stifness behavior versus damage size “a” produced on each beam case. (b) Damage factor “D” versus a/w ratio. (c) Mean of principal strain of each test within each case analysed versus damage factor “D”.

4. CONCLUSION

In this work, Digital Image Correlation method is employed to analyze the evolution of damage in cracked cantilever beams with different crack configurations. With this method, displacement and strain fields were obtained and used for identification of damage. The relationship between a damage variable and crack length were achieved. In addition, an alternative way to estimate the damage variable was proposed using the mean values of the principal strain.

It is important to remark that this is a preliminary work and additional experimental tests will be performed in order to improve the obtained results. Moreover, a constitutive model will be proposed to predict the evolution of damage.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support provided by the Brazilian Government funding agencies FAPERJ, Capes and CNPq.

6. REFERENCES

Alam, S. Y., Kotronis, P. & Loukili, A., 2013. “Crack propagation and size effect in concrete using a non-local damage model”. *Engineering Fracture Mechanics,* 109, pp. 246-261.

Bendek, E., Lira, I., François, M. & Vial, C., 2006. “Uncertainty of residual stresses measurement by layer removal”. *International Journal of Mechanical Sciences*, 48, pp. 1429-1438.

Cárdenas-García, J. F. & Preidikman, S., 2006. “Solution of the moire´ hole drilling method using a finite-element-method-based approach”. *International Journal of Solids and Structures,* 43, pp. 6751-6766.

Corr, D., Accardi, M., Grahan-Brady, L. & Shah, S., 2007. “Digital image correlation analysis of interfacial debonding properties and fracture behavior in concrete”. *Engineering Fracture Mechanics*, 74, pp. 109-121.

Dixit, A. & Hanagud, S., 2011. “Single beam analysis of damaged beams verified using a strain energy based damage measure”. *International Journal of Solids and Structures*, 48, pp. 592-602.

Dixit, A. & Hodges, D. H., 2011. “A general damage theory: Solution of nth-order equations using Unified Framework”. *Mechanics Research Communications*, 38, pp. 486-493.

Hu, M., Tu, S., Xuan, F., Xia, C. & Shao, H., 2012. “Strain energy numerical technique for structural damage detection”. *Applied Mathematics and Computation*, 219, pp. 2424-2431.

McGinnis, M. J., Pessiki, S. & Turker, R., 2005. “Application of Three-dimensional Digital Image Correlation to the Core-drilling Method”. *Society for Exper/mental Mechanics*, Vol. 45, No. 4., pp. 359-367.

Ruzek, R., Lohonka, R. & Jirone, J., 2006. “Ultrasonic C-Scan and shearography NDI techniques evaluation of impact defects identification”. *NDT&E International*, 39, pp. 132-142.

Sutton, M. A., Orteu, J. J. & Schreier, H. W., 2009. “Image Correlation for Shape, Motion and Deformation Measurements - Basic Concepts, Theory and Applications”.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.