International Journal of Solids and Structures 48 (2011) 1644–1657

Contents lists available at ScienceDirect

International Journal of Solids and Structures

journal homepage: www.elsevier.com/locate/ijsolstr

Shape features and finite element model updating from full-field strain data

Weizhuo Wang [a,*], John E. Mottershead [a], Christopher M. Sebastian [b,c], Eann A. Patterson [b,c,d]

[a] Centre for Engineering Dynamics, School of Engineering, University of Liverpool, L69 3GH, UK
[b] Composite Vehicle Research Center, Michigan State University, Lansing, MI, USA
[c] Department of Mechanical Engineering, Michigan State University, East Lansing, MI, USA
[d] Department of Chemical Engineering & Materials Science, Michigan State University, East Lansing, MI, USA

ARTICLE INFO

Article history:
Received 14 October 2010
Received in revised form 18 January 2011
Available online 15 February 2011

Keywords:
Full-field strain pattern
Shape features
Zernike moment descriptor
Model updating

ABSTRACT

Finite element model updating is an inverse problem based on measured structural outputs, in this case maximum principal strain measured using digital image correlation. Full-field responses in the form of strain maps contain valuable information for model updating but within large volumes of highly-redundant data. In this paper, shape descriptors based on Zernike polynomials having the properties of orthogonality and rotational invariance are shown to be powerful decomposition kernels for defining the shape or map of the strain distribution. A square plate with a circular hole subject to a uniaxial tensile load is considered and effective shape features are constructed using a set of modified Zernike polynomials. The modification includes the application of a decaying weighting function to the Zernike polynomials so that high strain magnitudes around the hole are well-represented. The Gram–Schmidt process is then used to ensure orthogonality for the obtained decomposition kernels over the domain of the specimen, i.e. excluding the hole. Results show that only a very small number of Zernike moment descriptors are necessary and sufficient to represent the full-field data. The onset of yielding may be quantified using the descriptors. Furthermore, model updating of nonlinear elasto-plastic material properties is carried out using the Zernike moment descriptors derived from full-field strain measurements.

1. Introduction

Traditionally validation of numerical models using data from experiments has relied on strain values obtained at a point or collection of isolated points using electrical strain gauges. Occasionally techniques such as photoelasticity, Moiré or holographic interferometry were used and data obtained along sections. Validation procedures were unsophisticated and largely consisted of qualitative assessment of the correlation between the data from experiments and the numerical model for 'hot spots' in the data where the stress in the model was observed to reach a maximum. In general, strain gauges were only placed at the 'hot-spots' indicated by the numerical model thus providing the possibility that other 'hot-spots' not found by the model could exist and be ignored. In addition, in lightweight structures, there is the possibility, that to save weight, material could be removed from a design in an area where the model indicates low or zero stress, has not been validated and is potentially incorrect. These circumstances could be characterised by an insufficiency of experimental data which fails to place sufficient demands upon the method of comparison of the experimental and simulated data. Recent advances in optical methods Sharpe (2008) permit full-field maps of surface strain to be obtained relatively easily using a variety of techniques, including digital image correlation, automated photoelasticity, electronic speckle pattern interferometry and thermoelastic stress analysis. These maps provide a level of redundancy in the data and require more sophisticated approaches to data comparison between experiments and numerical models Ravichandran et al. (2007), which is the focus of this work. The conceptual framework for verification and validation of computational models in solid mechanics is provided in a set of ASME guidelines (2006), and Schwer (2007). In this context verification refers to ascertaining that the computational model employed accurately reproduces the underlying mathematical model whereas validation refers to checking the extent to which the model is an accurate representation of the real world. From an experimentalist's perspective, the guidelines provide a sequence of steps starting from designing the experiment for the purpose of performing the validation through to quantifying the uncertainty in the data measured in the experiment. Earlier work Whelan et al. (2008), and Patterson et al. (2007) focused on calibration of the optical system of strain measurement in order to allow the measurement uncertainties to be quantified. Once data have been obtained from specifically-

* Corresponding author. Tel.: +44 151 7944838.
E-mail address: wangweizhuo@gmail.com (W. Wang).

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doi:10.1016/j.ijsolstr.2011.02.010