Establishing a one-to-one relationship between FEA and DIC: pitfalls and solutions

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Abstract. In this contribution a methodology is presented that relies on the use of synthetic speckle image deformation to produce validation maps of finite element (FE) models from Digital Image Correlation (DIC) data. The underpinning novelty is the fact that it takes into account the filtering effects of DIC, which according to the authors, is a compulsory step to obtain robust validation. As such, it is less dependent on the choice of the DIC parameters. Initial results are presented for a double-notched specimen and a comparison is made to other available approaches based on interpolation and image decomposition.

Introduction

The experimental validation of numerical simulations in the development of load-bearing structures is an important step in the design process. It enables to detect any potential issues with the design before the structure is put in service. For many years, the experimental tools have been limited to point measurements through strain gauges or extensometers, which requires reliable *a priori* knowledge of the location of hotspots. 3D photoelastic models have also been used but they were expensive, unrepresentative (because they were not made of the same material as the structure of interest) and inconvenient, though photoelastic coatings have been employed with some success. Thanks to phenomenal progress in computing power and digital camera technology, full-field deformation measurements based on image processing have grown spectacularly over the last decade. In particular, the technique called Digital Image Correlation (DIC) is now widely used both in academia and industry, thanks to its apparent simplicity and the wealth of information it can provide. Therefore, there is a drive towards introducing DIC as a tool for quantitative validation of finite element (FE) model of structures. However, DIC acts as a low pass filter with noise. Indeed, using numerically deformed speckle images with a sine displacement of increasing frequency, studies have shown that only spatial frequencies above a certain threshold can be correctly reconstructed [1,2] and that this was strongly dependent on subset size, shape functions and speckle size, among others. As such one should not directly compare FE strain maps with experimental ones as any difference can be attributed either to the model or to the DIC low pass filtering effect. It is therefore essential to push the FE data through the same experimental filter as the experimental ones. Only in this case can model errors be reliably established.

Procedure

The flowchart in Fig. 1 gives an overview of the proposed validation process implemented in MatchID [3]. On one side, the finite element model, which should have been checked for convergence. On the other side, the experimental configuration, with a given speckle pattern. Before starting the test, the DIC performance is evaluated using either stationary images or rigid body movements simulated from a shift of the cameras. Also, for stereo-DIC, the calibration parameters are recorded to feed into the image deformation tool. Then, the FE-DIC map is created from the FE displacement data using the procedure described in Ref. [4]. From the simulated deformed images, DIC is performed with exactly the same parameters as for the experiments and strain maps are obtained. It should be noted that in dynamics, acceleration maps may also be used as validation output. The experimental and FE-DIC maps can then be combined together (subtracted) to produce the FE-DIC - DIC maps. Finally, the validation maps are produced by comparing the residuals in the FE-DIC - DIC maps to the DIC uncertainty as evaluated before the test. In practice, any residual within the range of +-2 or 3 times the DIC noise standard deviation will be considered as zero and the validation map then consists of zeros (areas where the model is validated and areas where is above the uncertainty (areas where the model is not validated). At this stage, engineering expertise has to be employed to understand where these significant differences come from. The examples in the lecture will give more information about how the patterns in the validation maps can be used to separate typical sources of errors (material parameters, material model, boundary conditions) but this will be highly application specific and will require combined input from the test and simulation engineers.

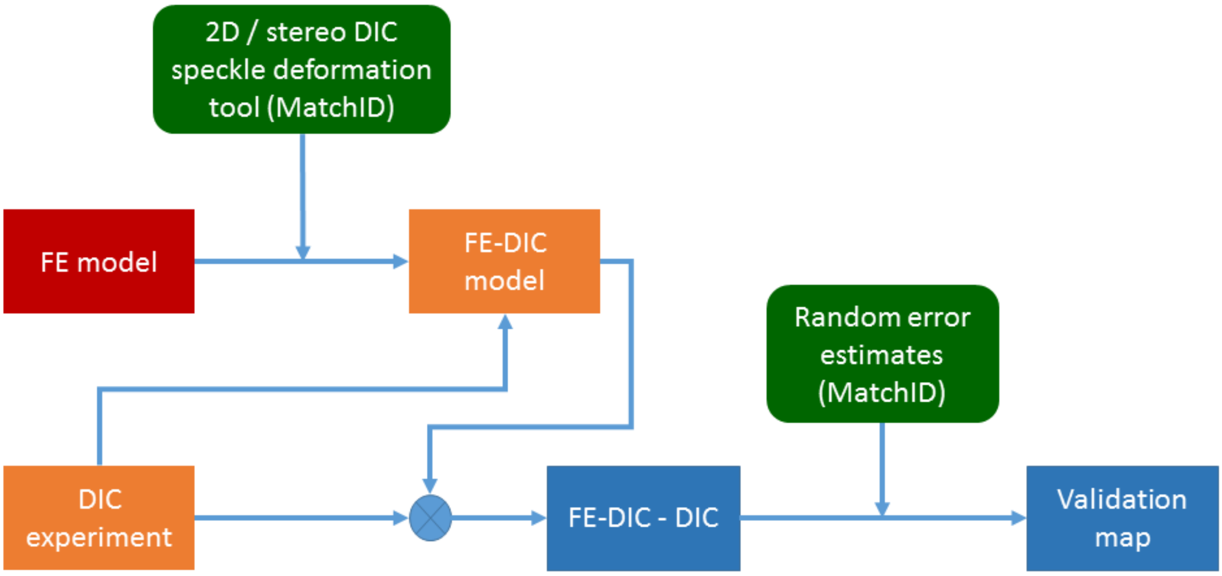

Figure 1: Flowchart of the proposed FE model validation process

Example

The cover plate of a pressure vessel (diameter of 100mm, thickness of 1mm) with a central tube connector of 10mm diameter is studied. The cover plate is clamped via bolt connections along the plate circumference. Both the bolt and the central tube connection result in local strain concentrations. The following model parameters are assumed for isotropic bilinear hardening: Young's modulus: 210 GPa, Poisson's ratio: 0.3, yield stress: 500 MPa, hardening modulus: 3 GPa (linear isotropic hardening), loading pressure: 10 MPa. Hereby, it is important that the modelling yield stress (500 MPa) considerably differs from the experimental true yield stress (450 MPa). As a result deformations for DIC are larger at the same force. This is clearly picked up by the FEA validation process as indicated in Figure 2. Not imposing an identical filtering might have masked out the larger DIC deformations (smoothing effect) and resulted into the prediction of a false positive.

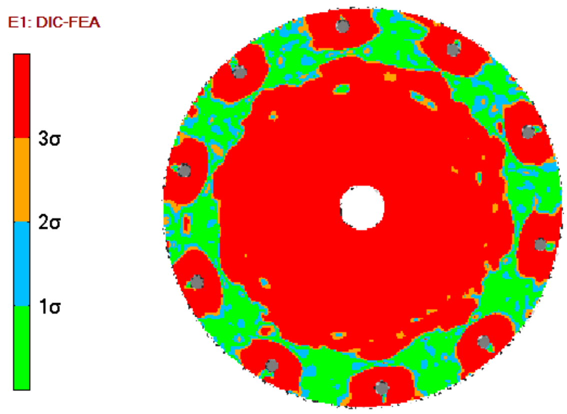

Figure 2. E1: DIC - FEA validation map. Difference is the Yield Stress (450 MPa (DIC) vs 500 MPa (FEA)). As a result deformations for DIC are larger at the same force. Red areas indicate errors that fall beyond the noise floor.

References

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