APPLICATION NOTE

DANTEC DYNAMICS

Experimental Finite Element Method (FEM) validation

Using Digital Image Correlation (DIC)

FEM simulations

A variety of mechanical engineering disciplines, such as aeronautical, biomechanical, and automotive industries rely on Finite Element Method (FEM) in the design, development and testing of their products. State of the art FEM software packages include specific modules to simulate and investigate, among others, thermal, electromagnetic, fluid, and structural behaviors and phenomena. Structural FEM simulations are commonly performed to predict stiffness and strength of CAD models providing not only information on localized stresses and displacements but also visualizing dynamic deformations such bending or twisting structures.
FEM has significantly improved both the standard of engineering designs and the methodology of the design process in many industrial applications. The introduction of FEM has substantially decreased the process timeline from concept to production.

In summary, benefits of FEM include increased accuracy, enhanced design and better insight into critical design parameters, virtual prototyping, fewer hardware prototypes, a faster and less expensive design cycle, increased productivity, and increased revenue[1].
In spite of the significant advances that have been made in FEM, the results obtained of any FEM study are purely theoretic and must be carefully examined before they can be used. Qualifying the outcome of a FEM simulation typically raises questions or issues such as:

- Is the level of modeling and simplification sufficient for the required application?
- What are the most critical parameters in the simulation?
- Up to which degree do the simulation results reflect reality?

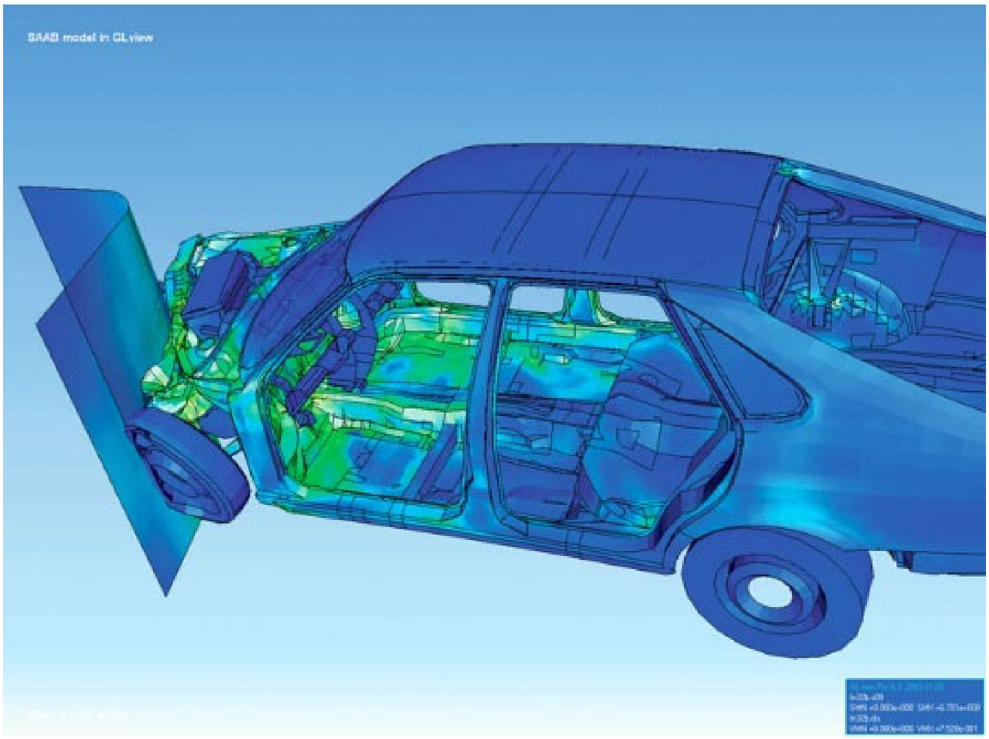

Figure 1 - Visualization of how a car deforms in an asymmetrical crash using finite element analysis

[1] https://en.wikipedia.org/wiki/Finite_element_method

Finding answers to these questions involves a thorough validation of FEM results. A common way of validating the quality and correctness of the computational models is the comparison with experimental data. Most of the commonly used experimental set-ups deliver one-dimensional point information only, like unidirectional displacement or strain information. FEM results can be verified on the surface point the experimental data are collected on by comparison of both data sets. The decision maker needs to qualify the results and make the final judgement or repeat the experiment in a different surface point if the first location is esteemed not representative. While this validation method might be suitable for small sized models with simple geometries, it has inherent limitations in validating more complex, large scale FEM models.

DIC for measuring 3D deformation data

Such limitations are eliminated by comparing FEM results to experimental full-field deformation data gained from a 3D Digital Image Correlation (DIC) system. DIC is a 3D, full-field, non-contact optical technique that measures shape, deformation, vibration and determines strain fields on almost any material and shape.

Dantec Dynamics' DIC solution incorporates a flexible design which opens a wide range of applications from microscopic investigations to large scale civil engineering measurements, with resolutions down to µ-meters. The multi-camera DIC system provides, in particular, the ability to measure extreme shaped components that are not possible with conventional methods. DIC is based on pattern recognition of the object to be measured, the so-called "speckles". The speckles provide an optical "fingerprint" that is identifiable in 3D space and is tracked by the DIC system as long as the surface is in view of the DIC cameras. Dantec Dynamics' Digital Image Correlation system has been especially designed to match the experimental validation needs for FEM:

- 3D measurements of components with complex shapes and a 360 degree all-round-view
- Component testing is available as a holistic system with measurement results in one coordinate system, independent of the number and setup of cameras
- Experimental measurement results comparable with simulation results by standardized multidimensional data exchange formats and interfaces to FEM tools

DIC for experimental FEM validation

The advantage of DIC 3D full-field data is the reduced uncertainty of localization mismatch next to additional information like gradients and distribution of values and increased number of data points. The number of data points renders a meaningful comparison-by-values ineffective. Therefore a visual comparison of the images of the experimental and computational results is most-widely used. A process of quantitative and objective validation of computational models, based on image results, is developed within the EU founded project VANESSA[2]. The result leads to the development of a CEN workshop agreement[3]. In this methodology the image results from both, the experiment and simulation are taken and compared using an external process. Taking the data uncertainties into account, a decision if the computational model is valid or not, can be made.

Dantec Dynamics' DIC Results Integration into Simulation Tool

Dantec provides a fully integrated experimental validation tool for the ANSYS simulation framework. The ANSYS Validation Workbench was developed together with the Scientific Computing Centre in Ulm (www.uni-ulm.de/uzwr). The workbench is based on the above visual comparison principle. Once the experimental data from the DIC measurements are available, the relevant measure and contour data are imported into the ANSYS Framework. A static structural model is created with the measured contour and the imported displacements measure as its result. Now the experimental data are in exactly the same format as in the FEM simulation, meaning experimental validations with different computational models can be performed in a standardized framework using the existing and proven tools.

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[2] Validation of Numerical Engineering Simulations: Standardization Actions; http://www.engineeringvalidation.org

[3] CEN/WS 71 - Validation of computational solid mechanics models using strain fields from calibrated measurement

Example DIC FEM Validation - Compact Tension Sample

Figure 2 shows a screen shot of the Dantec Dynamics' ANSYS Validation Workbench tool, with the result of an imported DIC measurement (Block D). The results are compared with the simulated data (Block E) and build the validation (Block F). All information is part of the ANSYS Workbench and so all tools and feature can be used for visualization and further post-processing of the outcome.

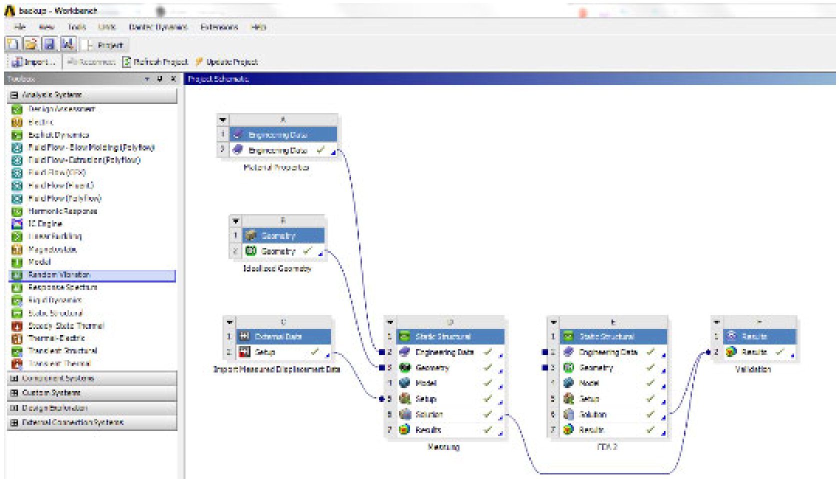


Figure 2 – Dantec Dynamics' ANSYS Validation Workbench

Figure 3 illustrates the process on a simple compact tension sample. The dimensions of the sample are indicated on the live image of the sample as seen by one camera of the DIC setup. The load is applied by opening a slit at the opening.

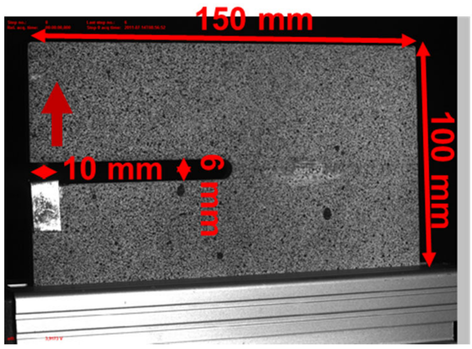


Figure 3 - Compact Tension Sample

The images of the sample at different load steps are captured by Dantec Dynamics' DIC system. From these images the displacements can be calculated. The results are imported into the ANSYS Workbench. The results of the experimental data in ANSYS are shown in Figure 4, where the displacement in loading direction is mapped as color coded texture on the contour.

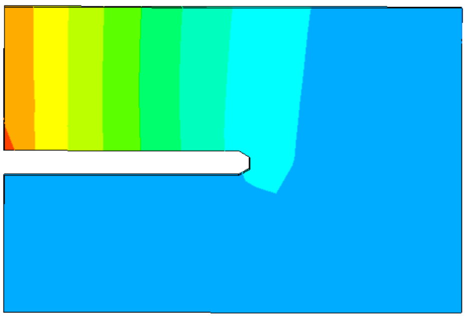


Figure 4 – DIC experimental result

Both figures show very similar displacements. The simulation data are more smooth and regular. The load in the experiment is applied using a screw. This does not produce a pure one-dimensional movement, as assumed in the simulation, but a torsion, as well. This causes deviations with the DIC data. Looking at the differences between the two results the major deviations are located in the loading area. A map of the differences is shown in Figure 6. From this the operator can decide if the match of the experimental and simulated data is sufficient to validate the model or if additional adaptations of the computational model are required in order to get a better agreement of the results.

Using the object geometry and material properties the deformation of the object can be simulated easily. The calculated displacements in loading direction are shown in Figure 5. The scaling of displacements are identical with the imported DIC data in the previous figure.

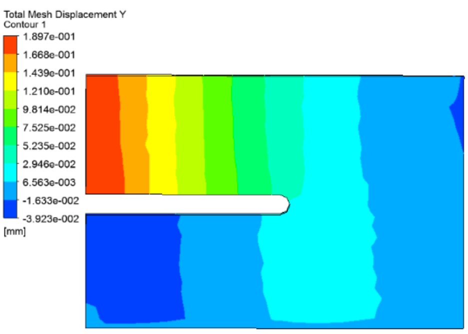


Figure 5 - FEM simulation result

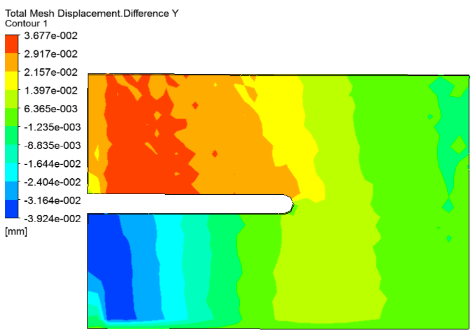
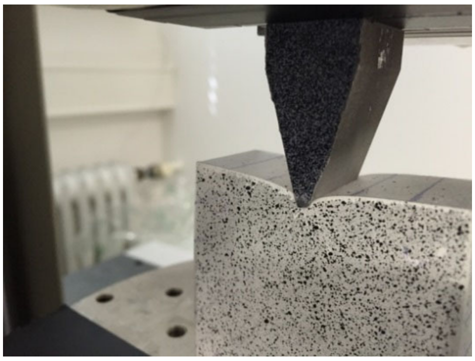


Figure 6 - Comparison simulation / DIC

Example DIC FEM Validation - Block of Rubber Material

The next example compares the indent of a wedge in a block of rubber material. An image of the experimental setup of the wedge and the rubber block in a material test machine is shown in the left figure. The right figure is a sketch of the model for the simulation. This situation is more challenging than the one before, because of the large displacement, the contact problem and uncertianties in knowing the material properties of the rubber.



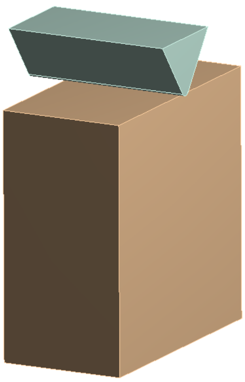


Figure 7 - Block of Rubber Material / Sketch of model for simulation

The experimental results for the displacement of the sample in loading direction are display-ed in Figure 8.

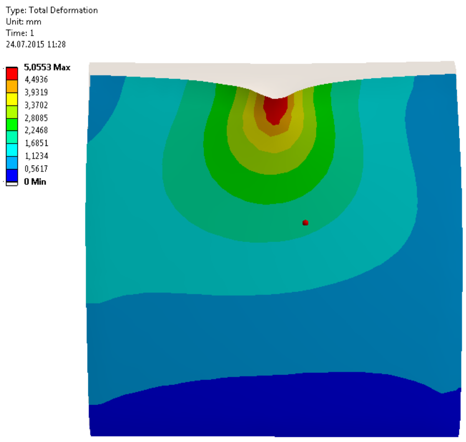


Figure 8 - DIC Experimental Results

The simulation in Figure 9 shows a more symmetrical and smoother variation of the displacement. Both figures use the same scaling and the maximum displacement is lower compared to the experimental data.

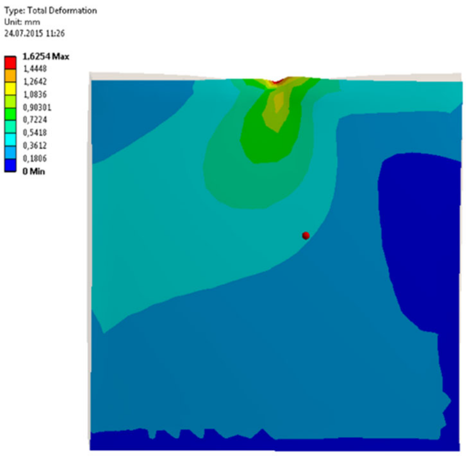


Figure 9 - FEM Simulation Result

The difference in the displacement is shown in Figure 10. The pattern is very similar to the simulation pattern, indicating a possible mismatch in the applied forces, transfer of the force in the material or material properties.

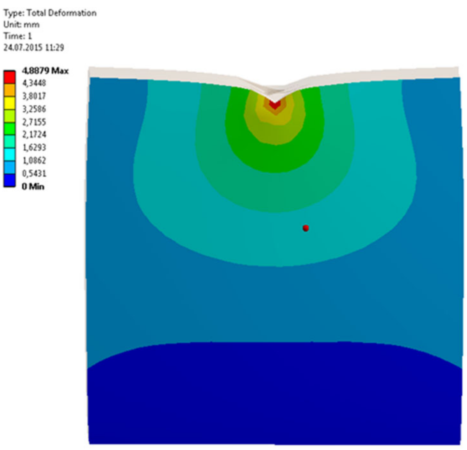


Figure 10 - Comparison Simulation / DIC

It is now again up to the FEM simulation expert to decide, if his model is accurate enough to match the experimental results.

Benefits of the Digital Image Correlation measurement solution

Save time/money

- Full-field, 3D quantitative analysis on displacements and strain, insensitive to sample alignment and rigid body movements.
- Non-contact measurement. Quick and easy setup.
- Fast and easy real-time calibration for all cameras in one step.

Explore innovative measurement techniques

- Measurement of any material/component with smooth or uneven surfaces in one coordinate system.
- Increased accuracy with multi-camera setups.
- Multi-camera setup also working for high-speed and vibration analysis applications.
- Investigate anisotropic material behavior.
- Explore advanced materials and structural testing areas with DIC, such as:
  - Strain measurement
  - Fatigue Testing
  - FEM validation
  - Vibration Analysis
- Stress determination by measurement of sample necking.
- Flexible measurement areas: from mm² to m² dimensions.
- Indication of measurement accuracy always available.
- Accuracies down below 1µm displacement for smaller areas.

Easy to use – Built-in "Sensor intelligence"

- Deformation, Displacements (x, y, z), Strains (exx, eyy, exy, e1, e2), etc.
- Material parameters: Poisson ratio and Young's Modulus.
- Vibration analysis and modal shape analysis modules are available.
- Various export formats to support post processing for simulation validation or country and company specific procedures are provided (e.g. HDF5).
- End user customizable procedures for complex calculations are supported and can be initiated with a single keystroke.

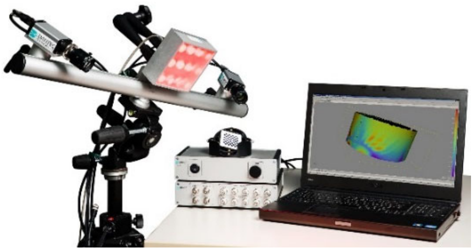


Figure 11 - DIC System with two cameras and illumination option

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