Comparison of Laser-Scanned Test Results and Stochastic Simulation Results in Scatter Mode Space

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Abstract

Recent years, CAE plays more important roles in product development than ever. Good CAE models require validation works with various test data. However, the way of comparison needs to be improved in order to meet the market expectations. Usually a set of test data is given to CAE engineers after all specimen are tested, and test machines are cleaned up. In case CAE engineers find out remarkable differences between simulation results and test results are too great due to mistakes in test laboratories, validation process becomes quite difficult in many cases.
In this study, quasi static compression of a crash box is used as an example in order to illustrate the proposed process. A preliminary stochastic simulation and a set of tests is conducted, and the deformation of the crash boxes are transformed into the common modal space. This process makes it possible to assess similarity of deformation modes from multiple simulation results and test results at a glance. This analysis can be conducted at test lab, and fundamental difference between test and simulation can be detected every time specimen are tested. In case an issue is detected, CAE engineers and test engineers can start discussion how to improve the test set up and simulation model in the laboratory.

1 Introduction

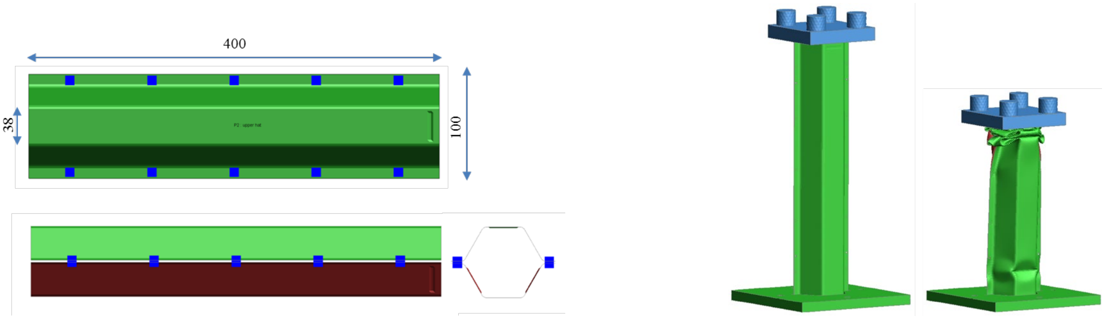
Recent years, CAE plays more important roles in product development than ever. Reliable CAE models require validation works with various test data, and the way of comparison needs to be improved in order to meet continuously increasing market expectations.
Usually input from tests are curves, pictures, and videos. Simulation results and test results used to have been compared only by overlaying or putting side by side on slides. Laser scanning of objects is becoming common in production engineering. However, not so many applications in structural testing are reported. Besides, comparing simulation results and laser scanned image tend to be subjective so that more objective comparison methods need to be developed.
There is another issue about comparing tests and simulations. In many cases, test data is given to CAE engineers after all specimen are tested, and test machines are cleaned up. In case CAE engineers find out remarkable differences between simulation results and test results are too great, there are two possibilities.

- Simulation model has problems, and it does not represent reality. In this case, CAE engineers need to figure out what are missing or wrong in their models. However, it is difficult only from pictures and movies in many cases.
- Test setup has problems, and the test has not run as planned. In some cases, the mistakes are captured by pictures or video, but there is no guarantee. CAE model needs to take the mistake into account with assumption in order to make reasonable comparison with the test results.

In both cases, it is better to find out problems before all test specimen are consumed.
This paper presents a process of comparing deformation between test and simulation in an objective way in order to detect errors in test laboratories.

2 Preliminary stochastic simulation

In order to illustrate the process work flow, a quasi-static compression test of a crash box is used as an example. Fig.1 shows the specimen and the set up. Two stamped steel plates are connected by spot welds on both sides. 3 trigger grooves are stamped on the top end in order to stabilize the deformation. The crash box is fixed to the base which is fixed to the reference space.



(a) Crash box dimensions (b) Quasi static compression test simulation

Fig.1: Quasi static compression simulation of a crash box

A stochastic simulation is conducted with LS-DYNA® and LS-OPT[1]. Table 1 shows the range of parameters. 25 runs are made. Sheet metal thickness have been varied from -3% to +1%, and spot weld failure criteria and yield curve have been scaled +-10%. Spot weld positions in longitudinal and lateral position is individually varied +-1.0mm.

Parameter	**Nominal**	**Range**
Sheet metal thickness	0.75 [mm]	-3% to +1%
Material curve scaling factor	1.0	+-0.1
Spotweld position		+-1.0mm
Spotweld failure scaling factor	1.0	+-0.1

Table 1: Parameter range for stochastic simulation

3 Principal Component Analysis of deformation modes with DIFFCRASH

In order to compare deformations of multiple results from stochastic simulation in an objective way, DIFFCRASH developed by SIDACT GmbH has been used for visualization. For robustness analysis, dozens of non-linear simulations are conducted with slightly different conditions, and results are superposed so that the “scatter modes” are extracted. Although crash box is a highly non-linear structure, by focusing only on the coordinate of a node in 1 direction at a point of time, results from several calculations can be described as a cloud on the number line so that statistical values such as mean and variance can be calculated to form a covariance matrix for entire structure. Covariance matrix is known as semidefinite so that eigenvalues are equal or greater than 0, and eigenvalue analysis of the covariance matrix yields eigenvalues and eigenvectors[2]. Eigen values represent the level of scatter, and eigenvectors represent trends of scatter in terms of deformation at the point of time.
PCA (Principal Component Analysis) for the 25 simulation results at 120mm has been conducted. Fig. 2 indicates the cloud plot of the contribution factors in mode-1 and mode-2 direction. Each plot represents a simulation run.

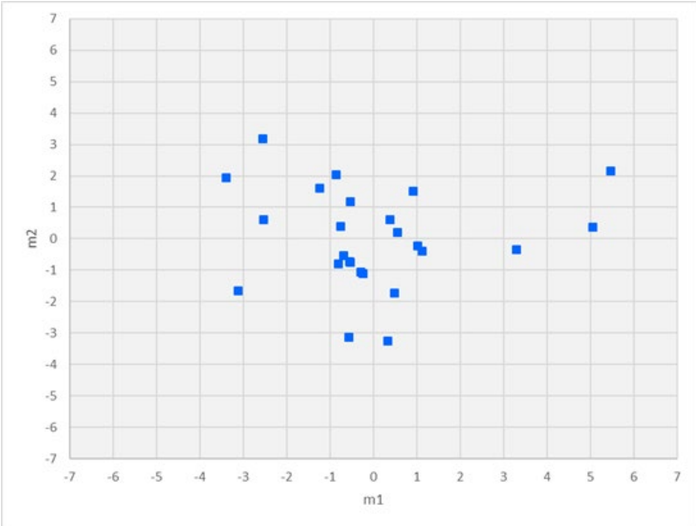


Fig.2: Result of Principal Component Analysis

4 Quasi static compression test

A set of quasi static compression test is conducted with Zwick Z250 quasi-static universal testing machine by Fraunhofer EMI. The test is repeated 8 times. Fig. 3 shows a crash box compressed. After the test is complete, full laser scan is conducted. Fig.3 also shows the laser scanned result of the final status. It captures details of the buckling and opening on the side.

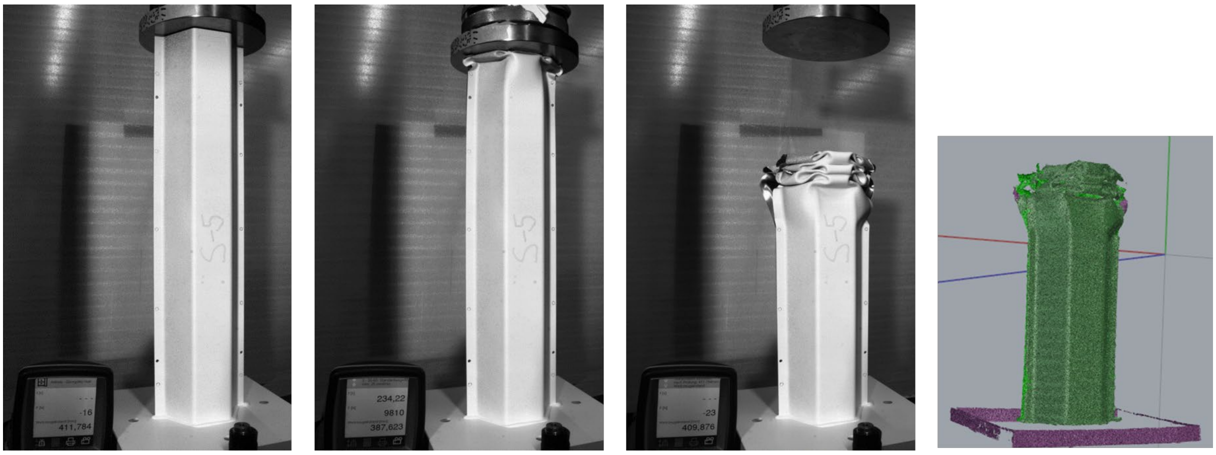


Fig.3: Quasi static compression test and the laser scanned result after test

5 Test data plot in modal space

DIFFCRASH version 6 has a feature of combining laser scanned test data with stochastic simulation results in modal space [3]. By using this feature, the test STL data is semi-automatically aligned to the simulation results with a few steps and contribution factors to the 1st mode and the 2nd mode are calculated. Fig. 4 shows the test results combined with simulation results in modal space. In this case, cloud plot from test data and the cloud from simulation results shows good match.

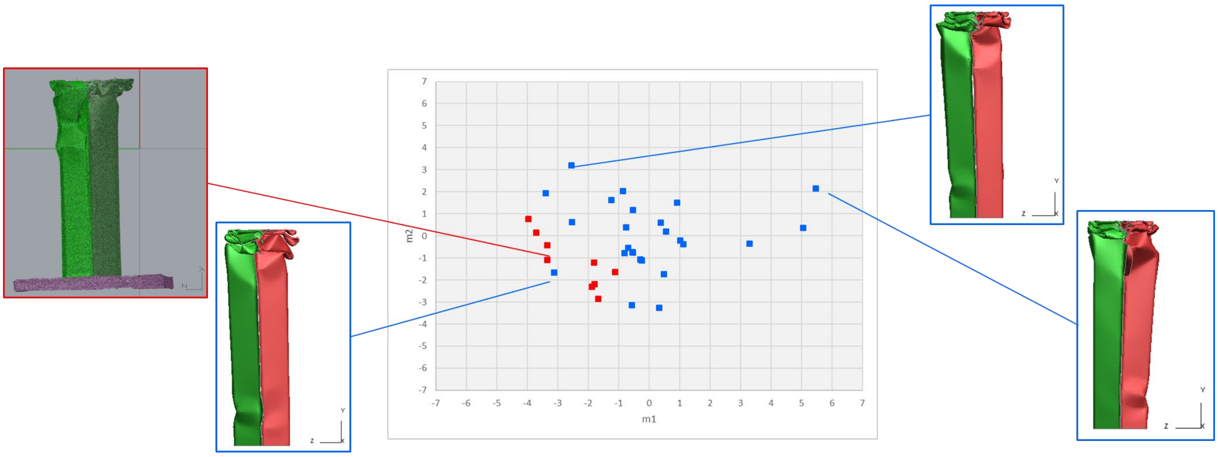


Fig.4: 25 simulation results in modal space

6 A numerical study on bifurcation

A numerical study is conducted in order to verify the function. Fig. 5 shows two configurations. A group of simulations are with trigger grooves on the top, and another set of simulations are with grooves on the bottom. In addition to that, the scatter in material and spot weld position is increased. 25 simulation runs for each configuration are conducted.

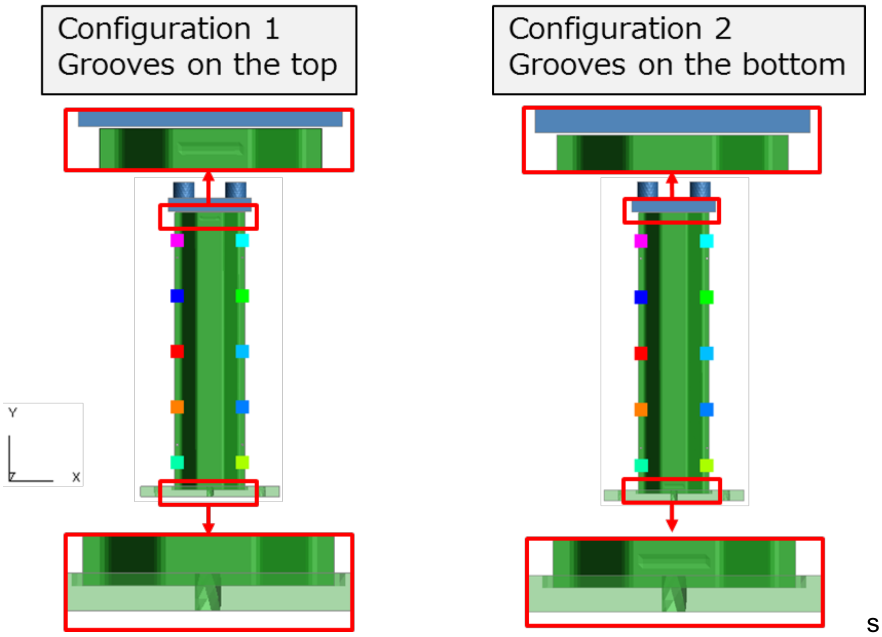


Fig.5: Modification to the simulation model in order to induce instability

Fig. 6 shows the plot generated by the same process with DIFFCRASH version 6, and it shows 2 clusters. The one on the left shows collapse on the top, and the other one shows collapse on the bottom. The test results indicated by red points on the plot are on the same position as the simulation cluster with the same deformation mode.

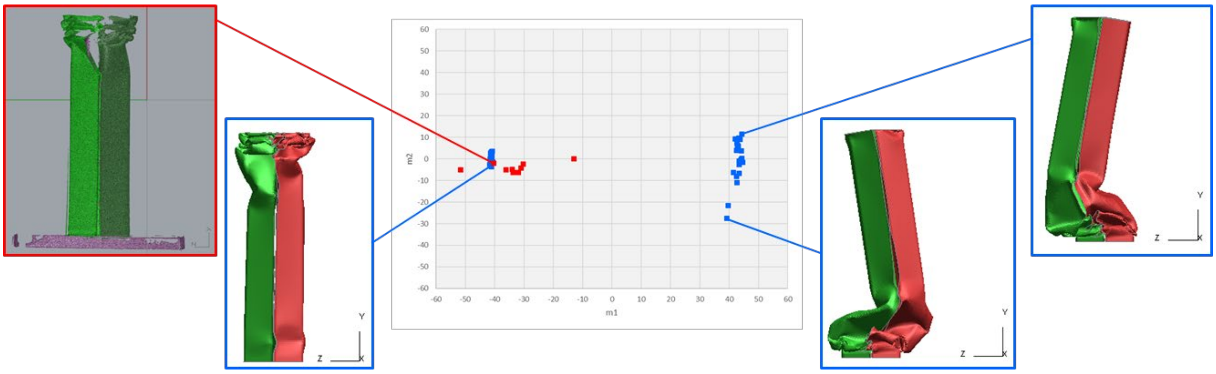


Fig.6: Modal plot of simulation results with instability and test results

7 Summary

In this study, quasi static compression of a crash box is used as an example in order to illustrate the concept of the proposed process as shown in Fig. 7.

Firstly, a preliminary stochastic simulation is conducted, and the deformation of the crash box are transformed into modal space. Secondary, a set of quasi static compression tests are conducted, and the results are also transformed into the same modal space by using DIFFCRASH version 6. The cloud in the modal space showed good match. This indicates the simulation represents reality, and the test is conducted as planned by the preliminary simulation. A numerical study is conducted in order to simulate the case of a structure with instability. The result showed that test cloud is in the same position to the simulation cloud with the same deformation mode.

Once stochastic simulation results are ready, this analysis can be conducted at test lab, and fundamental difference between test and simulation can be detected every time specimen are tested. In case an issue is detected, CAE engineers and test engineers can start discussion how to improve the test set up and simulation models in the laboratory. With repetitive practice of this process will reduce risk of wasting test specimen in tests and defining unrealistic settings in simulation models, increase the quality of tests and simulation runs, and accelerate product development process as the result.

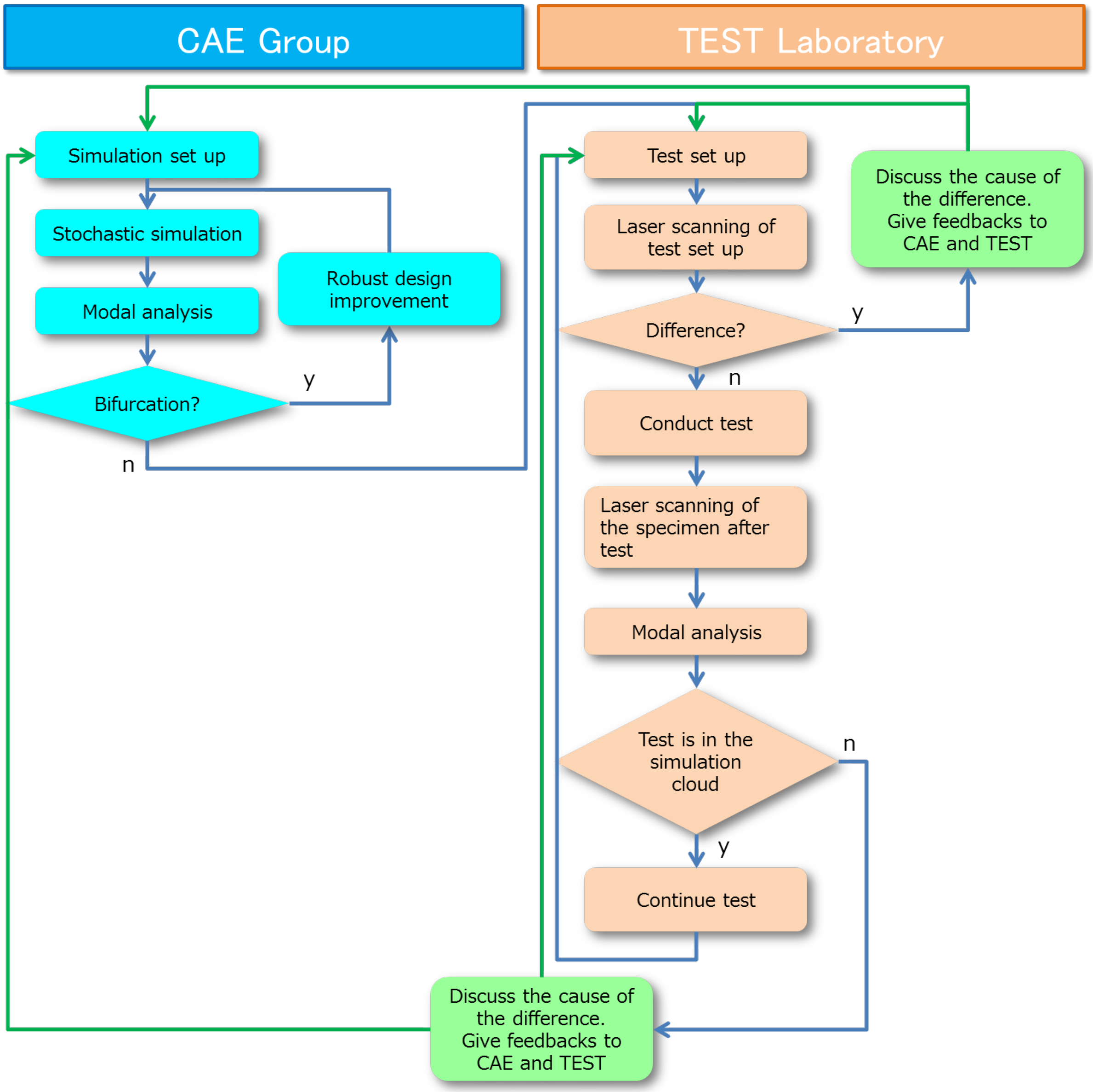


Fig.7: Proposed workflow with DIFFCRASH and laser scanning

8 Acknowledgment

The author would like to acknowledge DIFFCRASH license for this study to Mr. Clemens-Augst Thole of SIDACT GmbH.

9 Literature

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