Research Report

First Order Analysis for Automotive Body Structure Design Using Excel

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Abstract

CAE numerically estimates the performance of automobiles and proposes alternative ideas that lead to higher performance. However, most automotive designers cannot directly utilize CAE since specific well-trained engineers are required to achieve sophisticated operations. Moreover, CAE requires a huge amount of time and many modelers to construct an analysis model. In this paper, we propose a new CAE concept, First Order Analysis (FOA), in order to overcome these problems and to quickly obtain optimal designs. The basic ideas include (1) graphic interfaces using Microsoft/Excel, (2) use of sophisticated formulations based on the theory of mechanics of material, and (3) the topology optimization method. Further more, some software prototypes are presented to confirm the FOA method. Moreover, the cross-section generation tool is added to easily create the FOA model from FEM data and to easily evaluate the yielding state. Also a trial study of interaction between FOA and CAE is performed.

Keywords CAE, Automotive, Design, Topology optimization, Finite element method

1. Introduction

Because of the spread of Computer Aided Engineering (CAE)[1)] and the improvement of its functions over the last few years, it has become possible to quantitatively estimate the performance of automobiles to some degree before actually building prototypes and, therefore, to propose structures that offer better performance. At present, however, CAE has advanced to such a degree that it is difficult for body design engineers, who must handle many other tasks, to deal with it as part of their daily work. Furthermore, CAE requires a huge amount of time, many modelers, and also special knowledge to construct the analysis model, thereby it becomes a situation in which we are obliged to entrust CAE to analysis experts.

As a technique for complementing such conventional, detailed CAE, we are advocating a new type of CAE, called First Order Analysis (FOA),[2)] that body design engineers can easily use themselves at the concept design stage (**Fig. 1**).

The basic concepts of FOA are described below:

(1) To provide a graphical user interface using Microsoft Excel[3)] as its front end so that body design engineers can easily manipulate it without any special training.

(2) To use techniques that can be understood with only a basic knowledge of the mechanics of materials (elements:beam and panel elements), because the purpose is to examine the validity of a conceived design in a convenient manner.

(3) To provide topology optimization functions using beam elements to provide hints on the new

structures and suggestions on reinforcement member placement.

Needless to say, quantitative evaluation must be done by conventional, detailed CAE.

Due to the development and infiltration of CAD/CAE tools, each manufacturer has accumulated a large amount of mesh data for finite element models. It is thought, therefore, that data for old models can be easily accessed within one's company.

If it is easy to construct FOA models from the finite element mesh data for old models, design engineers can obtain tools for understanding the paths by which forces and moments are transferred to structural members, their generation mechanisms, yield function values, etc. and for carrying out considerations with structural changes.

Thus, a function which creates a cross-sectional shape used in FOA from the mesh data of a finite element model is also prepared. Through comparison with the finite element analysis results, guidelines for setting boundary conditions can be obtained. FOA can be used to easily obtain not only the approximate force and moment distributions but also the cross-sectional property values and yield function values. It is, therefore, capable of suggesting new measures to be introduced. In addition, because it enables design engineers to easily make shape and thickness changes while viewing the stress state and yield function values, FOA is particularly effective in the preliminary design studies that are done before the execution of detailed CAE.

When we think of the efficiency of geometric data creation and of the reflection of FOA examination results in a design, we can see that links such as data conversion with CAD and CAE emerge as important items that are required for FOA. It is thought that commercially available, detailed CAE can become an effective analysis engine for expanding FOA to a variety of objects because it provides many analysis functions and elements.

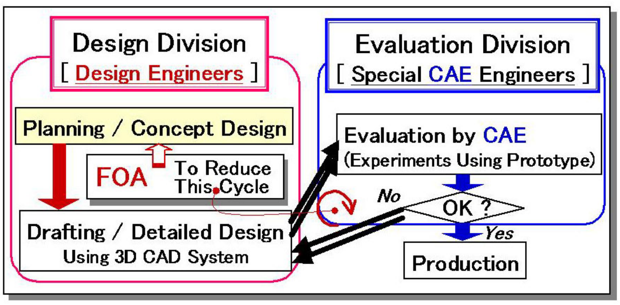


Fig. 1 Flow diagram of structure development.

ANSYS, for example, provides a macro language called ANSYS Parametric Design Language (APDL) and, therefore, can be used to automate operations. The model construction, analysis, and result output of general-purpose CAE can be automated by automatically generating APDL commands from FOA. This makes it possible to use advanced functions while maintaining the easy operability of FOA.

In this paper, we first describe the analysis tools that constitute FOA and which use Microsoft Excel as their interface.

Second, we introduce sample programs that are based on the concepts of FOA to demonstrate the applicability of automotive design in concept design stage.

Third, we present a function that takes the mesh data for a finite element model and uses it to create a cross-sectional shape for use in FOA. We go on to explain that it can be used to easily obtain not only the force and moment distributions but also the yield function values, cross-sectional stress distributions, and the like.

Finally, we demonstrate that, by automatically generating ANSYS APDL commands from the FOA, we can access the analysis functions of general-purpose CAE while maintaining the easy operability of FOA.

2. Static and eigen-value analyses using beam and panel elements

We focus on linear static analysis and eigen-value analysis using beam and panel elements because the purpose of FOA is to provide a convenient means of examining the validity of a conceived design.

A beam element follows the formulation of an ordinary, linear elastic beam, but to represent the joint stiffness of the joints that are essential to the analysis of an automotive structure, it is possible to provide a rotational spring with three degrees of freedom at one end (with the translational components of the residual three degrees of freedom being rigid stiffness) (**Fig. 2**).

If detailed joint stiffness is required, it is possible to use a stiffness matrix that is obtained by reducing the degrees of freedom of a finite element model in which original joint part are represented in detail by shell elements, using Guyan Reduction[4] technique (**Fig. 3**).

For panel elements, formulation[5] based on stress assumed that is resistant to distortion and accurate is used because it is assumed that the elements may be twisted due to rough modeling (**Fig. 4**).

3. Topology optimization using beam elements

Topology optimization using beam elements provides hints on the new structures, and assists in determining the placement of reinforcement members.

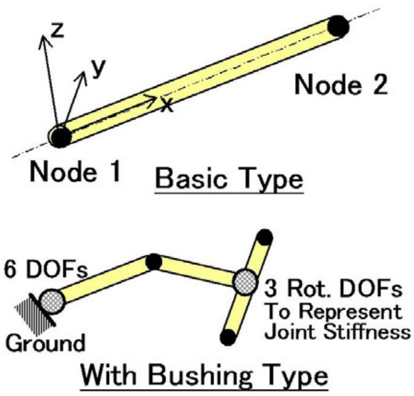


Fig. 2 Beam element.

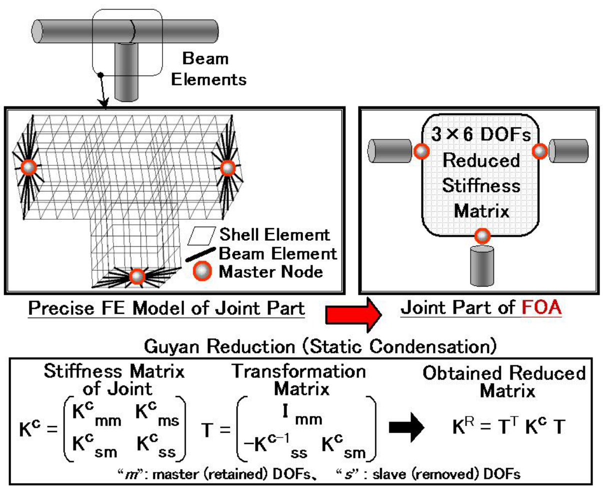


Fig. 3 Modeling of flexible joint.

The key concepts for maximizing the stiffness of a structure are (a) the ground structure approach and (b) mean compliance minimization.[6]

(a) With the ground structure approach, a number of fixed nodes are first preset, and for all combinations of nodes, beam elements are placed, as shown in **Fig. 5**. Then, using an optimization technique, the design variable (diameter of the cross section of the solid cylinder in this case) is updated to remove any unnecessary beam elements. Thus, an optimal beam structure state can be determined.

(b) The mean compliance L is defined by Eq. (1)[6], and is equivalent to the strain energy ($u^T K u$).

$$L = F^T u \quad \cdots\cdots (1)$$

where F denotes the load, u the displacement, and K the global stiffness matrix. Stiffness maximization is achieved by minimizing the mean compliance L with the total mass of the beam structure as a constraint. To handle multi-objective problems, an objective function based on the min-max approach, given by Eq. (2), is adopted:

$$\text{minimize max } L^k \quad \cdots\cdots (2)$$

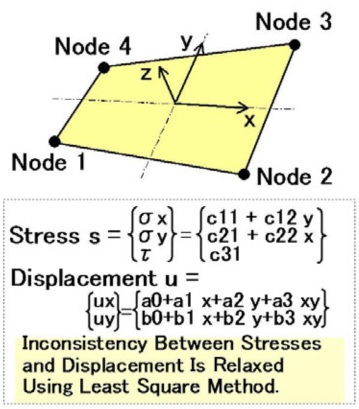


Fig. 4 Panel element (stress assumed).

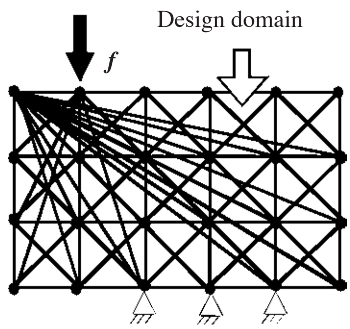


Fig. 5 Ground structure approach.

4. Program samples based on the concepts of FOA

Microsoft Excel[3)] incorporates a macro language called Visual Basic for Application (VBA). By using the functions of VBA, we can perform operations through simple mouse clicks, such as (a) reading and writing cell data, (b) transfer to other sheets, (c) numerical calculation, (d) input from and output to external files, and (e) start of external programs.

Figures 6 to **8** show very simple FOA examples in which the object is the entire automobile. For example, clicking the button that indicates the passenger compartment of the automobile in an Excel sheet moves the focus to the passenger compartment sheet. By manipulating the slider bars on the passenger compartment sheet, the shape of the passenger compartment can be changed instantaneously. Clicking a member causes a window showing a cross-sectional shape to appear, in which the shape can be easily revised. As the static analysis results, strain energy and member force distributions can be displayed at the size of circle and the like, together with deformed shape. Cross-sectional stress distributions of member can also be displayed.

Figure 9 shows a simple topology optimization example for a problem involving the optimal placement of reinforcement members for a plate structure with a hole. Figure 9 (a) shows the design domain and its initial shape. The white lines indicate the beam elements subject to optimization, whereas the light white parts indicate the panel elements to be excluded from the optimization. When we perform the above-mentioned topology optimization using beam elements by supplying the boundary and loading conditions shown in Fig. 9 (b), we obtain the shape shown in the figure.

We can see that the unnecessary beam elements are so thin that they are negligible. The required elements are represented by thick lines. Thus, it can be confirmed that merely by setting the design domain and the boundary and loading conditions conceived by design engineers, guidelines for framework layouts can be obtained easily.

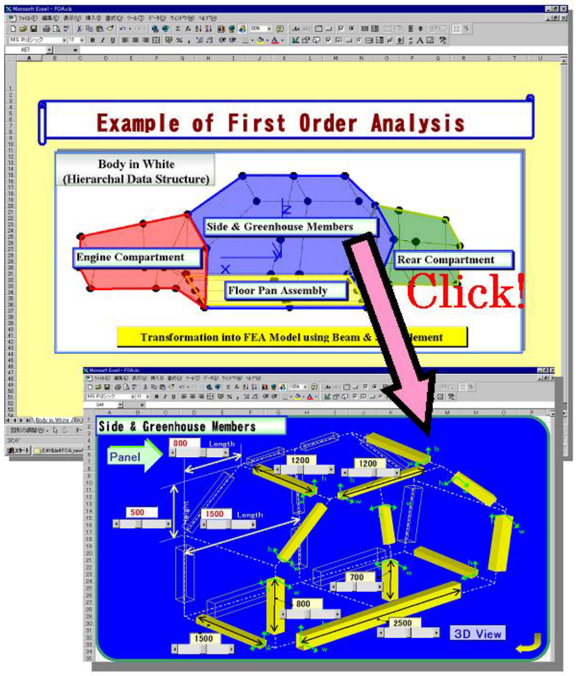


Fig. 6 Simple example_1 of FOA.

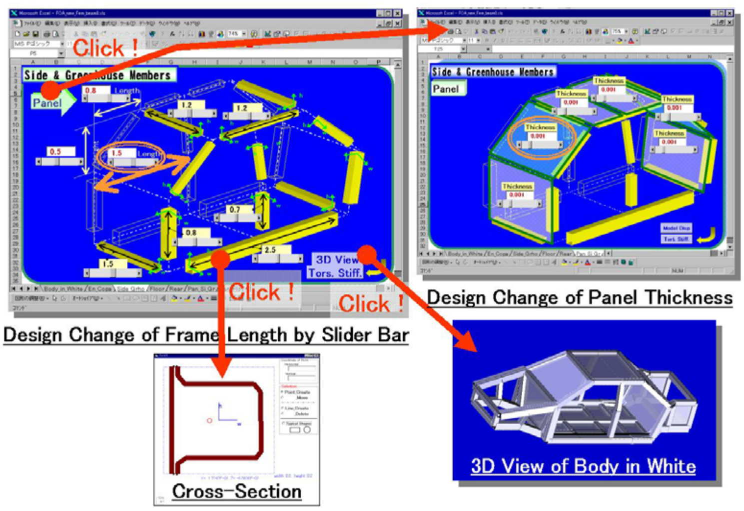


Fig. 7 Simple example_2 of FOA.

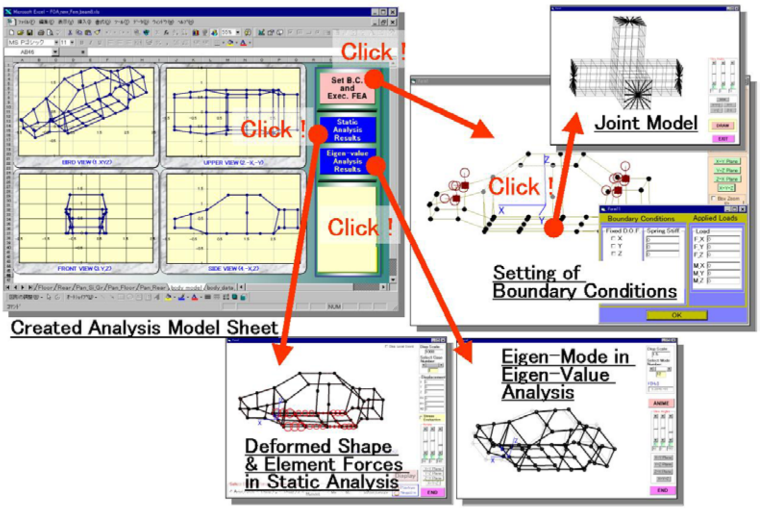
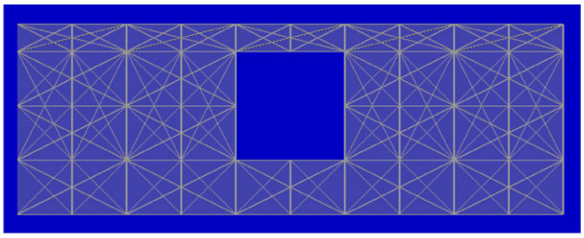
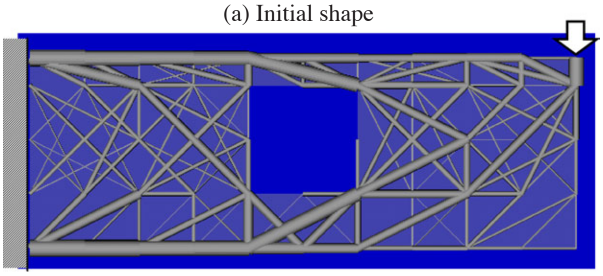


Fig. 8 Simple example_3 of FOA.



(a) Initial shape



(b) Boundary condition & optimal design

Fig. 9 Simple example of topology optimization.

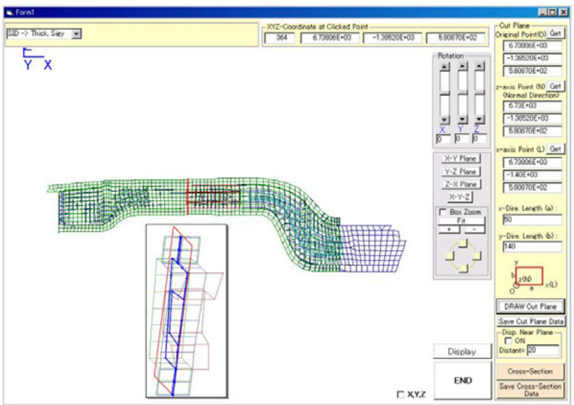


Fig. 10 Cross-section generation tool from FEM data.

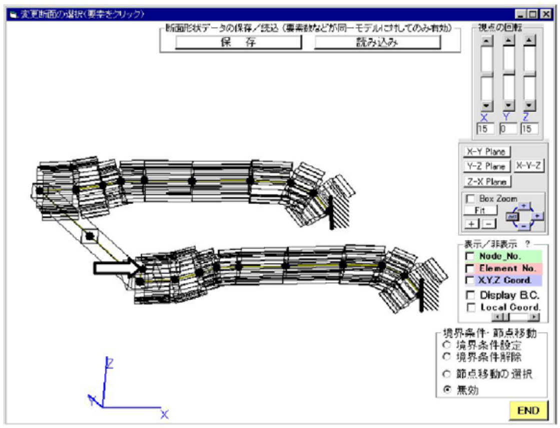


Fig. 11 Example of generated FOA model from FEM data.

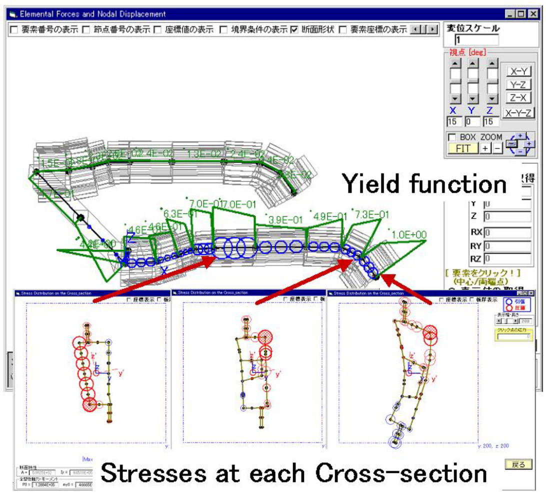


Fig. 12 Obtained yield function distribution and stresses at each cross-section from FOA.

5. Function for creating cross-sectional shapes from finite element models

Figure 10 shows a program that takes the mesh data for a finite element model and uses it to create a cross-sectional shape for use in FOA. When coordinate and other information for a cut cross section is entered, this program automatically creates a cross-sectional shape for use in FOA, like that shown in the bottom half of the figure.

Figure 11 shows an example FOA model that was obtained as described above. In this figure, the cross-sectional shape of a beam element that is obtained by the above technique is overlaid. The coordinates of the nodes are those obtained from the centroid of the cross-sectional shape determined with the same above technique.

Figure 12 shows the distribution of yield function and the cross-sectional stress distribution at typical positions as determined using the forces and moments obtained by stiffness analysis under the boundary conditions shown in Fig. 11, and using the cross-sectional property values obtained from the cross-sectional shape. In this figure, the yield function values were obtained by normalizing the forces and moments with their corresponding fully plastic axial forces and moments and overlapping the squares of the force components and the absolute

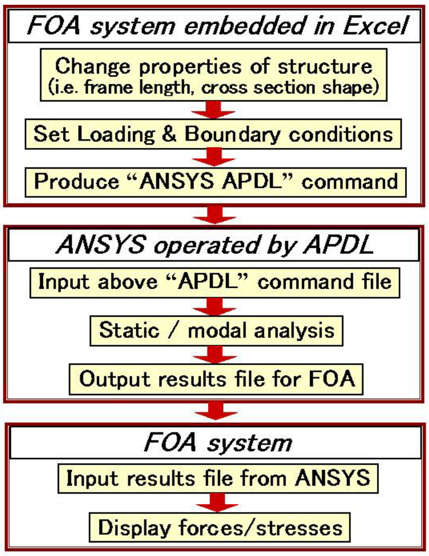


Fig. 13 Flow diagram of interaction between FOA and CAE (ANSYS).

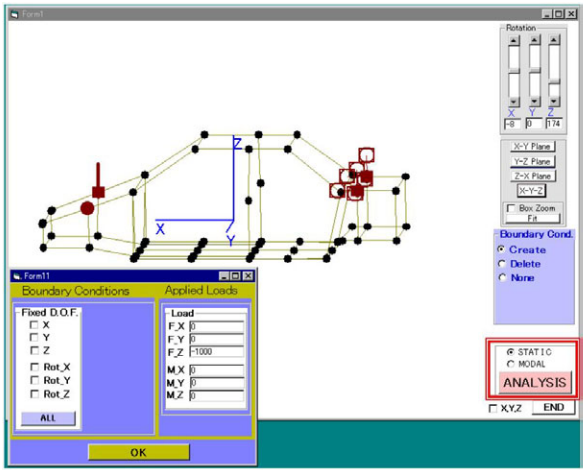


Fig. 14 Boundary condition setting frame.

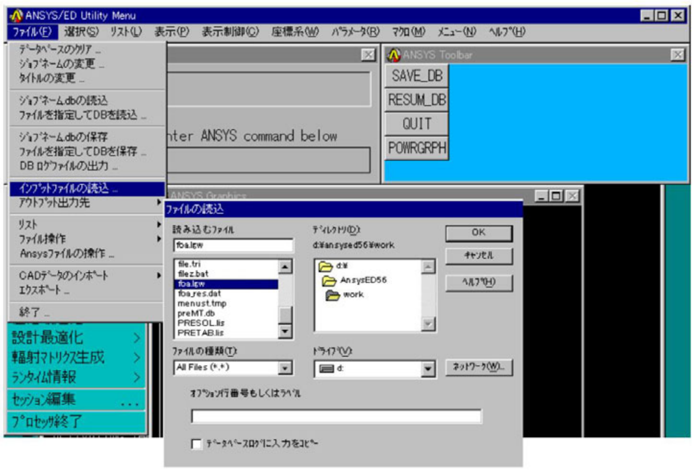


Fig. 15 Input APDL command file.

values of the moment components. The cross-sectional stresses result from combining the axial stresses caused by the axial forces and the bending stresses caused by bending moments.

6. Links with general-purpose CAE

We believe that, as FOA is expanded, a need will arise to transfer data to and from CAD/CAE. It will also be necessary to transfer any elements and analysis functions that have not yet been incorporated in FOA to general-purpose CAE. Of the conventional FOA functions, we attempt to transfer the solving processes of linear, static analysis and eigen-value analysis to general-purpose CAE (**Fig. 13**).

This new attempt of FOA is assumed to be exactly the same as conventional FOA up to the boundary condition setting frame shown in **Fig. 14**.

By first selecting either linear static analysis or eigen-value analysis and then clicking the "ANALYSIS" button, APDL commands coded in the ANSYS macro language are automatically produced.

Then, by inputting the macro language file into general-purpose CAE (**Fig. 15**), model construction, analysis, and result output are performed automatically (**Fig. 16**).

It is then possible to view the calculated member force distributions and cross-sectional stresses in the same way as with conventional FOA (**Fig. 17**).

Thus, it has been confirmed that we can use the analysis functions of general-purpose CAE while maintaining the easy operability of FOA.

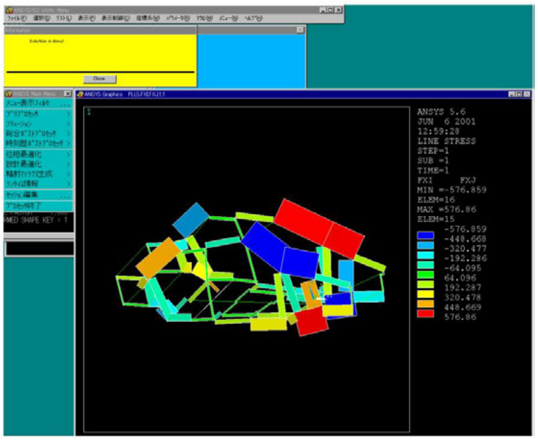


Fig. 16 Result of analysis.

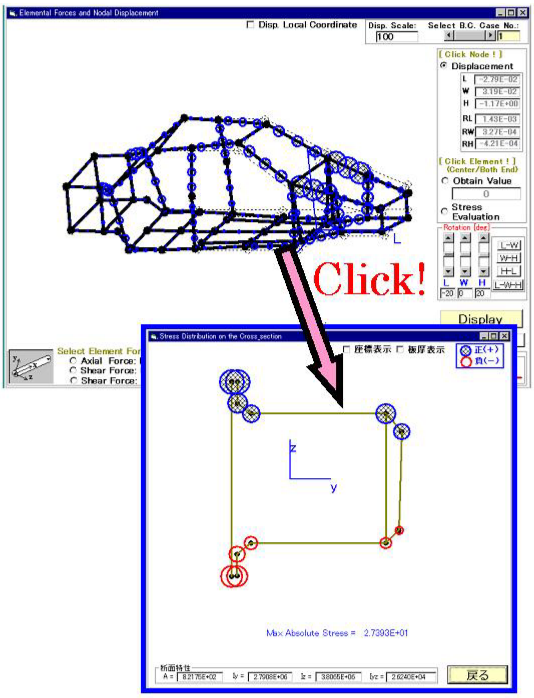


Fig. 17 Post process at FOA.

7. Conclusions

In this paper, we have advocated a new type of CAE that is known as First Order Analysis (FOA). Body design engineers can easily use this tool themselves at the concept design stage, as a complement to detailed CAE.

We first described the analysis tools that constitute FOA and which are run using Microsoft Excel as the interface.

Secondly, we presented example programs that are based on the concepts of FOA to demonstrate the applicability of automotive design to concept design.

Thirdly, we presented a function that takes the mesh data for a finite element model and uses it to create a cross-sectional shape for use in FOA. We explained how it can be used to easily obtained not only the force and moment distributions but also yield function values, cross-sectional stress distributions, and the like.

Finally, we demonstrated that it is possible to use the analysis functions of general-purpose CAE while maintaining the easy operability of FOA, by automatically generating ANSYS APDL commands from FOA.

References

1) Lemon, J. R., Tolani, S. K. and Klosterman, A. L. : "Integration and Implementation of Computer Aided Engineering and Related Manufacturing Capabilities into Mechanical Product Development Process", Gi-Jahrestagung, (1980)
2) Nishigaki, H., Nishiwaki, S., Amago, T. and Kikuchi, N. : "First Order Analysis for Automotive Body Structure Design", ASME DETC, 2000/DAC-14533, (2000)
3) Microsoft Corporation : Microsoft Excel/Visual Basic Reference Second Edition, (1998), Microsoft Press
4) Guyan, R. J. : "Reduction of Stiffness and Mass Matrics", AIAA Journal, **3**-2(1965)
5) Sekiguchi, M. and Kikuchi, N. : "Remark on the Mixed Formulation of a Finite Element Stiffness Matrix Based on Clough's Paper in 1960", Proc. of the Conf. on Comput. Eng. and Sci., JSCES, Tokyo, Japan, **4**-1(1999), 131-134
6) Suzuki, K. and Kikuchi, N. : "A Homogenization Method for Shape and Topology Optimization", Compt. Methods Appl. Mech. Eng., **93**(1991), 291-318

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