Intelligent Support to Structural Design Analyses

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Abstract: - Intelligent analytical aids for design capture the expertise of a specialist in the application of a design analysis technique – for instance in the development of an analytical model, in the forming of assumptions or in the interpretation of results. Such intelligent computer aids that have been developed for decision support within pre-processing and post-processing phase of the structural design analysis, using well known and widely used finite element method, are discussed in this paper.

Key-Words: - knowledge based systems, computer aided design, finite element analysis, decision support

1 Introduction

It is hard to imagine a modern structural analysis-based design optimisation without using a computer. Computer aided numerical analyses are so extensively applied within design process that analysts are no longer the only specialists dealing with this issue. Designers have to carry out different types of analyses very frequently by themselves.

However, the existing conventional computer aided design (CAD) tools are not adequate as a proper aid to be used by designer in the process of analysing a new product. Instead of being oriented particularly in mathematical aspects of the analysis, they should provide a continual stream of advice and information to assist in decision making. For example, CAD system can be used as a powerful computer graphic tool for developing an idealised model for the analysis, but it would give no advice on what type or density of idealisation is appropriate for the particular design case. For this reason, the quality, effectiveness and reliability of the structural analysis-based design optimisation still depends mostly on the level of designers' knowledge and experience.

The way in which it is hoped to get more intelligent computer support to structural analyses-based design optimisation is to increase the intelligence of the existing CAD systems. In order to do that, some intelligent modules need to be developed and integrated into the analysis process.

This paper presents some basic ideas and development strategies for three intelligent modules to be applied within structural design analysis process with finite element method in order to make analysis-based design optimisation process more intelligent and less experience-dependent.

2 Structural design analysis

The purpose of structural design analysis is to simulate and verify the conditions in the structure, as they will appear during its operational life. Physical and mathematical modelling simulations are computationally intensive but offer immense insight into developing product. The results of engineering analysis are often basic parameters for design optimisation process.

Optimal design performed at the first attempt is rare in engineering. Design is an iterative process. The number of iterations/cycles needed directly depends on the quality of the initial design and appropriateness of the later design changes. If the structure does not satisfy given criteria, it needs to be improved by applying certain optimisation steps, such as design changes, use of another material, etc.

A lot of knowledge and experience is needed, first to prepare the correct idealised model for numerical analysis, and second to be able to understand the results of the analysis and to choose necessary design optimisation steps. Young inexperienced engineers often do not understand basic principles of the structural design analysis and make wrong conclusions quite frequently. They even have problem to see whether the results are within expected limits considering the original problem. In most of such cases the existing software can not help them. Thus, very extensive, time consuming and expensive analysis often become meaningless. Moreover, as a consequence of wrong problem definition or miss-interpretation of the results of the analysis, the structure may even break down during its exploitation. Needless to say, there exists a great motivation to improve pre- and post-processing phase of the structural design analysis.

3 Finite element method

Finite element method (FEM) is the most frequently used numerical method to analyse stresses and deformations in physical structures [1].

Finite element analysis is divided into three phases. Each phase of the analysis is important and has to be performed carefully and consistently.

First of all, in the pre-processing phase of the analysis the real structure has to be idealised with the appropriate mesh model that ensures low approximation errors and avoids unnecessary computational overheads. For that purpose, the correct finite elements need to be selected for the analysis and the appropriate density of the mesh needs to be defined.

Whilst many FEM pre-processors will automatically create the finite element mesh, such automatic creation still requires data, such as the type of the elements, the mesh density and the position and type of loads and boundary conditions to be applied.

The selection of finite elements is strongly related with the meshing task. The quality of the results derived by using inadequate type of element for a certain problem is usually very poor. There are also differences looking at the basic polynomial approach (linear or parabolic) and the geometry of an element (tetrahedral or hexahedral) [2].

After setting up the loads and boundary conditions, the second phase of the analysis – matrix computation is performed to solve a system of linear algebraic equations. This phase of the analysis is the most optimised and user independent.

In the third, post-processing phase of the analysis, numerical results in terms of displacements (and stresses) in the nodal points of the computational model have to be examined and correctly interpreted. Post-processing phase represents a synthesis of the whole analysis and is therefore of special importance. It concludes with the final report of the analysis, where the results are quantified and evaluated with respect to the next design steps that have to follow finite element analysis in order to find an optimal design solution.

The sources for post-processing are numerical results of matrix computation, performed in the previous phase of the analysis. In spite the fact that the results are pretty well ordered, the numerical figures are hard to be followed in case of complex real-life problem, when the data file is usually both, complex and extensive. Nowadays FEM software is very helpful at this point, as it offers an adequate computer graphics support in terms of reasonably clear pictures showing a distribution of unknown parameters inside the body of the structure. However, the user still has to answer a lot of questions and solve many dilemmas in order to conclude the analysis and compose the report.

4 Intelligent systems in design

The application of artificial intelligence (AI) to design is generally concerned with studying how designers apply human intelligence to design, and with trying to make computer aids to design more knowledgeable. The AI applications in design are specially interesting for the representation of heuristic knowledge that is less easy to express using traditional mathematical approaches. The part of AI that is particularly concerned with the development of such representations is known as expert systems, or more generally knowledge–based systems, often also intelligent computer systems [3].

Although the AI technology is still a subject of extensive research, many successful AI applications in real–life domains already proved the usefulness of these technologies when dealing with nondeterministic problems that cannot be treated adequately by using conventional approaches, unless the user is possessed of special skills and experience.

It is becoming increasingly evident that adding the intelligence to the existing computer aids, such as CAD systems, leads to significant improvements of the effectiveness and reliability in performing various engineering tasks, including design. Actually, AI applications to design are reality and subject of intensive development and implementations. Proceedings of the international scientific conferences "AI in Design", edited by J.S. Gero, constitute a good collection of papers related to this area [4].

Intelligent computer support to design may be classified into four broad groups, as follows:

(1) Intelligent consultative systems for guiding inexperienced users;
(2) Intelligent systems for 'automated' design of particular type of products;
(3) Intelligent analytical aids;
(4) Intelligent systems for product design optimisation considering specific manufacturing or application aspects.

In continuation of this paper, three different knowledge based (KB) computer systems that belong to the third group listed above are presented as the examples of intelligent analytical aids to support structural design analysis using FEM.

5 Intelligent analytical aids for FEM

It order to support the designer in overcoming three major bottlenecks within structural analysis process using FEM (finite elements selection, finite element mesh design, and results interpretation) separate stand-alone intelligent analytical aids (one for each task) are being developed in our laboratory.

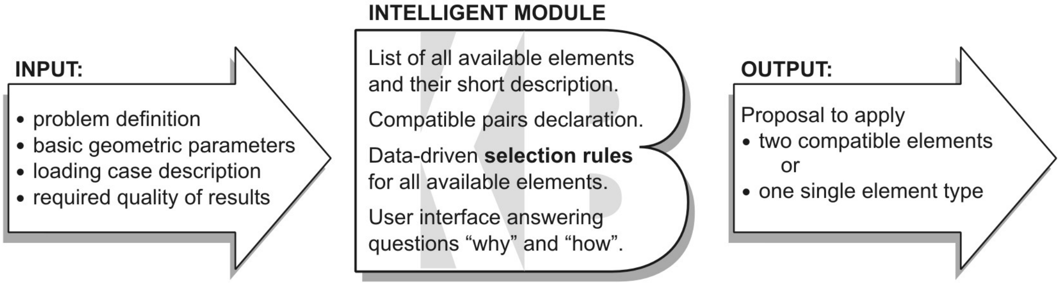

Fig.1. Knowledge based finite elements selection.

5.1 KB finite elements selection

Nowadays FEM software tools offer to the user a wide range of different, but often also very similar elements. Even the elements that are meant to be used for the same generic type of analysis may have different geometric shape and polynomial function. Thus, selection of the most appropriate type of the elements to be used for certain analysis became a complex task that requires a lot of knowledge and experience. Most of novice finite element users need advice which type of finite elements should be used for the analysis to get satisfactory results at reasonable consumption of computing resources.

Figure 1 presents basic idea for the KB approach to support this initial pre-processing phase of the analysis. Actually, the proposed scheme has been realised in our laboratory by development of the KB system named Z88FESES, which is adjusted to the freeware finite element analysis program Z88 [5].

The knowledge base consists of 24 data-driven production rules that are applied to select the appropriate finite element type out of the list of 20 different types that are available in the current version of the Z88 program. The most appropriate type of finite elements is proposed by the system considering problem description given by the user, who needs to answer some questions interactively.

In current version of the system the selection of the most appropriate finite elements type to be used for the analysis is based on the following selection criteria: space dimension, dimension of the structure, cross-section (only for beams), the expected quality of the results, geometry and loading case complexity.

5.2 KB finite element mesh design

Within finite element analysis usually a few different mesh models need to be created until the right one is found. The trouble is that each mesh has to be analysed, since the next mesh is generated with respect to the results derived from the previous one.

There is no clear and satisfactory formalisation of the mesh design know-how. Finite element design is still a mixture of art and experience, which is hard to describe explicitly. Defining the appropriate geometric mesh model that ensures low approximation errors and avoids unnecessary computational overheads is still very difficult and time-consuming task.

As the alternative to the conventional “trial-and-fail” approach to this problem, we have developed the intelligent computer system named FEMDES [6]. The system was designed to help the user to define the most appropriate density and pattern for the finite element mesh model. The system application enables the designer to conduct the finite element mesh model easier, faster, and more experience independent.

Figure 2 shows how KB system is meant to be applied within the pre-processing phase of the analysis. In any case, the user has to define the problem (geometry, loads, and supports). The data about the problem need to be converted from the FEM pre-processor format into the symbolic qualitative description to be used by the KB module. The task of the intelligent system is to determine the appropriate mesh resolution values. A command file for the mesh generator can be constructed according to the results obtained by the intelligent system.

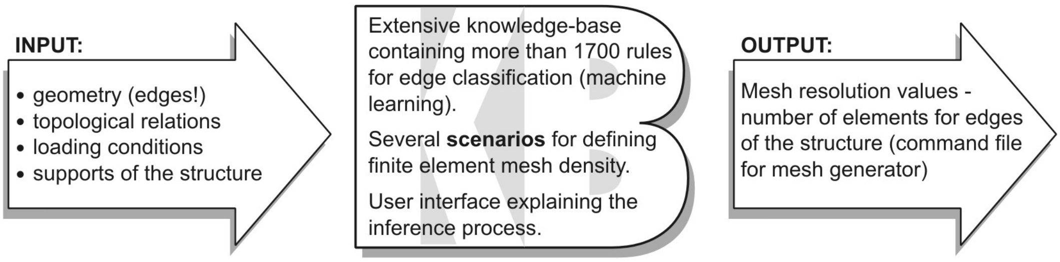

Fig.2. Knowledge based finite element mesh design.

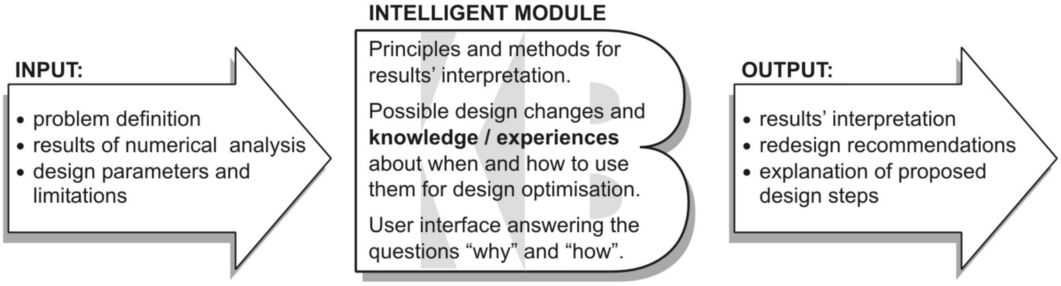

Fig.3. Knowledge based results interpretation.

5.3 KB results interpretation

After the numerical part of the engineering analysis is finished, designer has to be able to judge, whether the results of the analysis are correct and reliable, and also to decide what kind of design changes are needed, if any. Most of the users need "intelligent" advice to perform the results interpretation adequately. Unfortunately, this kind of help cannot be expected from the present software. The traditional systems are rather concentrated on numerical aspects of the analysis and are not successful in integrating the numerical parts with human expertise.

In order to support this crucial phase of the analysis-based design optimisation, a prototype of the intelligent consultative system PROPOSE has been developed [7]. PROPOSE provides a list of redesign recommendations that should be considered to optimise a certain critical area within the structure considering the results of a prior stress/strain or thermal analysis. As a rule, there are several redesign steps possible for design improvement. The selection of one or more redesign steps that should be performed in a certain case depends on the requirements, possibilities and on wishes.

Figure 3 presents a basic idea for the KB analysis results interpretation. The user has to define design problem and present the results of the engineering analysis. In addition, critical areas within the structure need to be qualitatively described to the system. These input data are then compared with the rules in the knowledge base and the most appropriate redesign changes are determined and recommended to the user.

The abstract description of the problem area should be as common as possible to cover the majority of the problem areas, instead of addressing only very specific products. In cases when the problem area can be described to the system in different ways, it is advisable to run the system several times, every time with different description. Thus, the system will be able to propose more design actions, at the expense of only a few more minutes at the console.

At the end, the user can get the explanation how the proposed redesign changes were selected and also some more precise information how to implement a certain redesign proposal including some pictorial explanations.

6 Conclusion

Structural analysis-based design optimisation is a part of development process for almost every new product. It has very important role in nowadays high-tech world, where only optimal solutions can win the game on the market. However, development of the optimal design solutions is very complex domain that cannot be treated adequately by using the conventional CAD tools, unless the user is possessed of special skills and experience.

Thus, many research activities are oriented in making analysis-based design optimisation process more intelligent and less experience-dependent. Many experts share the opinion that it can be done by supplementing the existing CAD systems with some intelligent modules that will provide advice when needed. The intelligent modules discussed in this paper represent some important parts of the overall intelligent design optimisation cycle.

References:

[1] Zienkiewicz O.C., Taylor R.L., Shu J.Z., *The Finite Element Method: Its Basis and Fundamentals*, 6th edition, Butterworth-Heinemann, 2005.

[2] Rieg F, Koch F., *Selection of Finite Elements Considering Loadcases and Geometry*, International Conference on Engineering Design, Glasgow, 2001, pp.107-114.

[3] Turban E., Aronson J.E., Liang T.P., *Decision Support Systems and Intelligent Systems*, 7th edition, Prentice Hall, 2004.

[4] Gero J.S. (Ed.), *Artificial Intelligence in Design '02*, Springer, 2002.

[5] Novak M., Rieg F., Dolšak, B., Hackenschmidt R., Intelligent support to finite element type selection, *WSEAS transactions on information science and applications*, 3 (9), 2006, pp. 1617-1624.

[6] Dolšak B., Finite element mesh design expert system, *Knowledge-based systems*, 15 (5/6), 2002, pp. 315-322.

[7] Novak M., Dolšak, B., Intelligent computer-aided structural analysis-based design optimisation, *WSEAS transactions on information science and applications*, 3 (2), 2006, pp. 307-314.