Proceedings of the 7th WSEAS International Conference on Automation & Information, Cavtat, Croatia, June 13-15, 2006 (pp44-47)

Intelligent Finite Element Type Selection

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Abstract: - The paper presents a prototype of the consultative knowledge-based system that was developed to support the initial pre-processing phase of the engineering finite element analysis. 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. The present knowledge base is quite modest and is adjusted to the freeware finite element analysis program Z88. It consists of 24 data-driven production rules 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. Several examples confirm that the shell of the system written in Prolog enables efficient use of the knowledge base and adequate communication between the system and the user. The results of experimental use of the system are encouraging and can be used as guidelines for further developments.

Key-Words: - computer-aided engineering analyses, finite element method, decision support, intelligent system

1 Introduction

Finite Element Analysis (FEA) is one of the most popular numerical methods that are used to check, how the part being designed in the virtual environment of the computer geometric modeller will behave in the real-life environment under specific working conditions. The quality of the idealised model, which is also known as a *mesh model*, directly affects the quality of the results. Despite the fact that designers have at disposal a wide range of modern computer software for FEA, the preparation of the idealised model is still based mostly on user's experience and some rules of thumb.

The preparation of the mesh model is often the most time-consuming and costly part of undertaking the FEA. Many FEA pre-processors will automatically create the mesh. However, the “automatic” pre-processors still require many input data, such as type of the elements, density of the mesh, and position and type of boundary conditions to be applied. Selection of the adequate finite elements is strongly related with meshing task during the FEA. The use of inadequate type of finite elements leads to poor quality of the results, which therefore cannot serve as a reliable basis for further design decisions.

Many different, more or less intelligent systems were developed in the last two decades to improve the pre-processing phase of the analysis. Most of the systems deal with geometry simplification and finite element mesh design, from determining the resolution values for the mesh [1] to re-meshing algorithms [2].

Finite element type selection was considered as relatively easy task. However, nowadays FEA 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 [3,4]. 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. In this paper, we are presenting a prototype of the consultative intelligent system that was developed to provide this kind of advice.

2 FEA Program Z88

Z88 is a compact FEA program for PC with Linux or Windows operating systems and for workstations and number crunchers with the UNIX operating system [5]. The system comes with the graphical user interface based on OpenGL technology, mesh generator, DXF and COSMOS converter, plot program and several powerful solvers. The program is distributed under the GNU General Public License and can be downloaded from internet site *http://www.z88.de*.

The element library is not as extensive as in commercial FEA software. Yet, development of the Z88 system is primarily focused on research. Nevertheless, many problems can be solved with the current element library. Only for very special applications, one has to switch to other commercial FEA packages. The present version 11 of the Z88 program features 20 finite element types covering plane stress, plate bending, axial symmetric structures and special structures, up to 20-node Serendipity hexahedrons.

For simple structures, Z88 offers truss, beam and cam elements. Truss and beam are available for 2D and for 3D problems. The cam element is a simplification of the general beam element with a circular cross-cut. Two-dimensional elements are very common in Z88. These elements are usually focused on special purposes. Solving axial-symmetric problems, torus elements are the best solution. Special elements are also provided for plane stress problems and plate problems. All three classes consist of elements with quadratic and cubic shape functions. The elements differ also according to their shape, which is triangular or rectangular. In addition, a very simple torus element with linear shape function is offered, while the most complex element is very accurate plate element based on Reissner-Mindlin and Lagrange approach. Like most of the two-dimensional elements, three-dimensional elements are all based on isoparametric transformation. Tetrahedrons and hexahedrons are offered. Both shapes are based on either linear or quadratic shape function.

3 Intelligent system Z88FESES

The intelligent system presented in this paper is named Z88FESES, which stands for Z88 Finite Element Selection Expert System. English and German versions of the program for MS Windows and Linux are available to be downloaded following the links from internet site *http://licads.fs.uni-mb.si/FESES.htm*.

Z88FESES is a consultative system, which means that the user is asked to answer some questions interactively. The running time is short and depends on:

- the number of questions to be answered (2 - 5),
- the amount of help requested by the user, and
- the frequency of the user amendments.

3.1 Selection criteria

The selection of the FE type is based on several selection criteria. The number of criteria needed to select the appropriate type of FE is case-dependent and range from two for truss structures to five for some three-dimensional analyses. By answering questions stated by the system, the user gives input values for all criteria needed in certain case.

Here is the list of selection criteria and their possible values (italic):

Criterion 1: Dimension of the structure can be 1D (*truss* or *beam*), *2D* or *3D*.

Criterion 2: Cross-section (only for beams) can be *circular* or *symmetric*.

Criterion 3: Space dimension is not applicable for 2D structures and can be *space* or *plane* in case of 1D structure, while 3D structures can be *general*, *axial-symmetric* or *plates*.

Criterion 4: The expected quality of the results can be *approximate* when user wants to perform a quick and simple analysis for qualitative evaluation only, while *accurate* results are required for exact quantitative evaluation.

Criterion 5: Geometry complexity can be *low* or *high*.

Criterion 6: Loading case complexity can be described as *simple* (e.g. only single force is applied) or *complex*.

Table 1 shows how these criteria and their values determine the most appropriate FE type for two-dimensional structures. Only those criteria that are applicable for a certain case are shown in the table. Grey cells in the table denote special cases when certain criterion is not needed to select the element type. In these cases, the user should not be asked to give the value for such a criterion.

TABLE 1: FE SELECTION CRITERIA FOR 2D STRUCTURES.

Required results	Geometry complexity	Loading case	Element type
approx	low		No.3
	high	simple	No.3
		complex	No.7 & No.14
accurate	low		No.7 & No.14
	high	simple	No.7 & No.14
		complex	No.11

As it can be seen in the last column of the Table 1, the elements are numbered. All FE available in the present version of the Z88 system are presented in Figure 3.

3.2 Knowledge base

The knowledge base was developed manually, according to our own experiences and good acquaintance with Z88 program. The knowledge is encoded in Prolog syntax [6]. Production rules were chosen as the most appropriate formalism to present the knowledge at maximum possible clarity and transparency [7].

Three different procedures are used in the knowledge base to present the knowledge needed to select the appropriate type of finite elements. First, all available elements are presented to the system by 20 facts, each describing one finite element, as for example:

```
available( no1," No.1 - Hexahedron (8 nodes)").
```

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The second procedure in the knowledge base is used to present pairs of differently shaped compatible elements that can be used for the same type of analysis and can be combined within the same FE mesh, as for example, elements No.1 and No.17:

```
compatible(no1,no17).
```

The rules for element selection are the most important part of the knowledge base. Each row in the Table 1 is represented with exactly one rule. To cover all types of the structures, the present knowledge base consists of 24 data driven rules. All the conditions that lead to selection of certain type of element are arguments in the head of the rule, while the body contains the list of selection criteria values, needed for inference process explanation (*how*). Proposed FE types are the first two arguments in the head of the rule. In case only one element type is proposed, both two arguments have the same value. For example, the rule:

```
chose_element(no3,no3,
        2,_,_,sym,approx,low,_,How) :-
                How = [2,approx,'&',low].
```

is proposing element No.3 for beams with symmetric cross-section in plane (see the first row in the Table 1).

3.3 Shell of the system

The shell of the system is also written in Prolog syntax. It makes feasible the proper use of the knowledge base for FE type selection as well as communication between the user and the system The shell consists of 120 rules and 28 facts, which are used to define 36 procedures – 2 for inference engine, 30 for user interface, and 4 assistant procedures, mainly for operations on lists. The most complex part of the shell is the user interface, while the inference engine is quite modest.

4 Z88FESES application

At the start of application of the system the user is asked to answer the questions that are necessary in certain case. The values for the selection criteria are being set. Figure 1 presents the example of communication between the system and the user, while specifying the first criterion – a dimension of the structure.

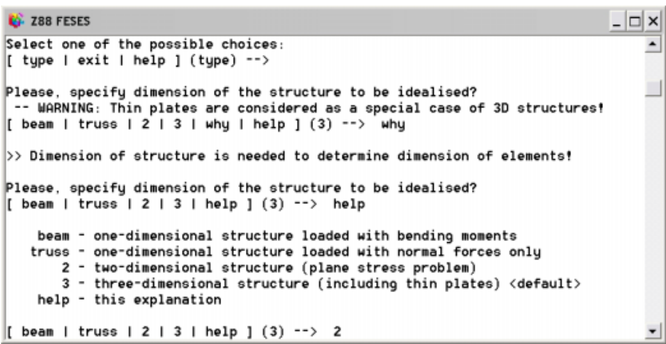

Fig. 1. Specification of the selection criterion.

As in all consecutive figures depicting the application of the system, user input is presented just after the prompt sign (-->).

For every question stated by the system, the user can ask *why* the answer is needed. The user can always ask for *help* to get the explanation for all the available options. Every user input has also a default value, which is presented in the brackets after the list of available options.

The system always proposes at least one finite element type. If possible, a pair of two differently shaped compatible finite elements is proposed. Secondary elements are usually not as accurate as primary ones. They are meant to be used to increase or reduce the number of nodes in particular direction/area.

After the proposal is presented on the screen, the user can ask the system *how* the selection was made. As it is shown in Figure 2, the inference process explanation consists of the selection criteria values, the actual proposal and the short description of the proposed finite elements to enable the user to evaluate the proposal.

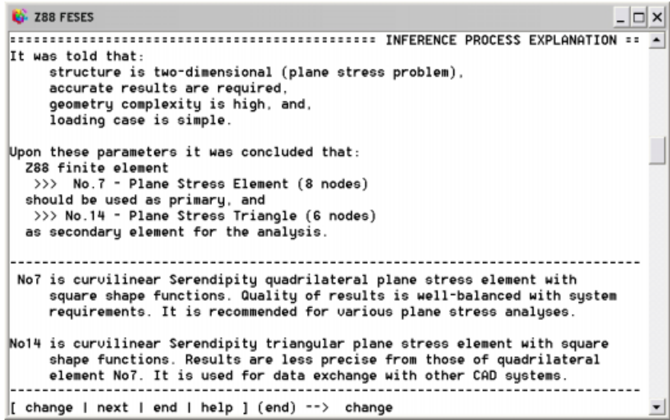

Fig. 2. Example of the inference process explanation.

The user can *change* the element types proposed by the system. In the example presented in Figure 2, this option was chosen after the inference process explanation. As it can be seen in Figure 3, the system supports the user in changing the proposed element type by presenting the list off all available elements. The user just needs to make the selection by specifying the number of element that should replace the proposed one.

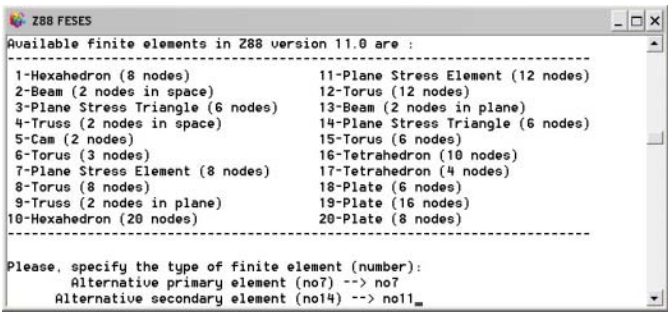

Fig. 3. The user is changing the proposal of the system.

In case the user changes the proposed type of finite elements, the system checks the compatibility of the elements selected by the user. Figure 4 shows the warning message, which appears on the screen if the finite element types specified by the user are not compatible. In that case, the user has to make another change to avoid incompatibility. Again, the system provides some advice by presenting the information which elements can be combined with the selected ones, if any.

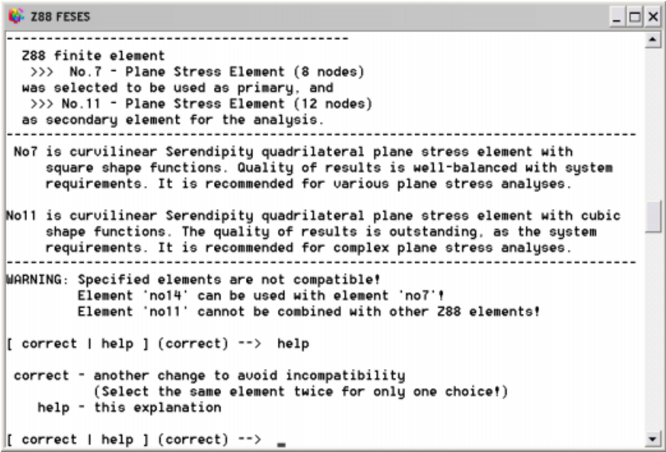

Fig. 4. Incompatibility warning after user FE type selection.

4 Conclusion

The system presented in this paper is a part of the global intelligent system for overall support to the key decisions within the whole process of the FEA [8]. It is a typical representative of a new approach to deal with a common engineering problem. We believe our approach to the FE type selection is quite novel, not so much because of techniques used, but because of application domain. In the last two decades, development of intelligent systems for FE mesh design almost exclusively supported a definition of the mesh density, while selection of the appropriate elements type was mainly set aside.

Z88FESES is easy to use and user friendly. It is also robust, as the user's errors do not end with interrupt but with system warning, usually accompanied with advice how to correct the error. The system is able to explain possible options (*help*), the reason for question (*why*) as well as the inference process (*how*). The user can also *change* the results. In spite of all that, time and memory requirements of the system are negligible. The proposal is also explained with short description of the proposed element type. We believe this description can be very useful, not only because it informs the user with basic numerical data about the proposed element, but also, more important, as it presents some performance experience and the application recommendations.

All this explanations gives to the system a great potential to be used as a teaching tool. In fact, it has already been used at Universities in Maribor and Bayreuth as a part of the education process. Within this process, the system was applied many times to compare the proposal from the system with the type of the finite elements that were actually used for certain analyses. The results of this experimental use of the system are encouraging and can be used as guidelines for further developments..

The architecture of the knowledge base, which is based on production rules, enables that new element types (e.g. shell elements) can be added to the system easily. Presumably, in this case we would also need to introduce additional selection criteria. Adding new elements to the system is not the only possibility for its further improvements. Currently, the way of adding the relation between the element type and the mesh density into finite element type selection process is being investigated.

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