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GDE IN GRAPHICAL MODELLING OF PLATE SYSTEMS

Summary. Graphic Data Editor (**GDE**) has been implemented into graphical modelling of plate systems and applied in ARTIF Plate Module CAD software. Fuzzy expert system has been used to control the process of problem description and computation. The simple language of graphic symbols enables to define the problem and carry out computations to any engineer, even if he is not conversant with the finite element method (**FEM**).

1. Introduction

In this article a fuzzy intelligent CAD system (ARTIF Plate Module) for static analysis of plate systems based on a modelling method called the Graphic Data Editor [2] is presented. Numerical methods used for the analysis of structures (such as the **FEM**) are relatively less popular in the engineering practice. Such is the case in view of the very poor knowledge of the theory and techniques to use the finite element methods, and the merely sporadic use of computer-aided systems for the analysis of structures in engineering practice. The process of structural analysis using the finite element method can be divided into several stages:

- building up a real-structure model:
    - finite element mesh formation,
    - numerical description of boundary conditions,
    - numerical description of material constants,
- carrying out computations,
- presentation and analysis of results.

The construction of a structure model is labor-consuming and complicated, even for those who are experts of the job. Apart from the precious time loss, subtle errors in description are liable to occur. Errors originating at the model construction stage may give rise to a number of problems. Part of them will involve errors in the results, rather easily detected, such as the output falling outside of the variation interval. Unfortunately, in a number of cases errors would escape easy detection or even be undetectable at all. These difficulties are not the only reasons why **FEM** is relatively rarely in use in the designing practice. Closer examination of the designing processes by means of CAD systems will demonstrate another practical difficulty, accounting for the lack of **FEM** popularity among engineers: the mode of structure description in terms of the **FEM** method appears unnatural from the point of view of engineering practice. Conventionally, an engineer would be using some technical drawing for his designing job - a drawing composed of a strictly defined number of graphic symbols reproducing the real structure. Now **FEM** requires that structure description to be converted into an abstract model.

The study presents the ARTIF Plate Module for the examining of 2D plate systems. With ARTIF, structures can be evaluated in a technical drawing direct, while the constructional session lasts. It constitutes one whole entity with the drafting system. The defining of a computational task is simplicity itself and it does not require any intrinsic knowledge of the Finite Element Method.

2. Formulation of the numerical problem

ARTIF Plate Module analyzes plate stress problems in the elastic range. If a body is subjected to set of body forces **b** then by the Virtual Work Principle we can write:

$$\int_{\Omega}[\delta\epsilon]^{T}\,\sigma\, d\Omega \;-\; \int_{\Omega}[\delta u]^{T}\, b\, d\Omega \;-\; \int_{I'_t}[\delta u]^{T}\, t\, d\Gamma \;=\; 0 \qquad (1)$$

where $\boldsymbol{\sigma}$ is the vector of stresses, **t** is the vector of boundary traction, $\boldsymbol{\delta u}$ is the vector of virtual displacements, $\boldsymbol{\delta\epsilon}$ is the vector of associated virtual strains, $\boldsymbol{\Omega}$ is the domain of interest, I'_t is that part of the boundary on which boundary traction are prescribed and I'_u is that part of the boundary on which displacements are prescribed.

Mindlin plate theory was applied to solve above formulated problem. The main assumptions are that:

- displacements are small compared with the plate thickness,
- the stress normal to the midsurface of the plate is negligible,
- normals to the midsurface before deformation remain straight but not necessarily normal to the midsurface after deformation.

3. Construction of ARTIF Plate Module System

The construction of the ARTIF Plate Module system is based on the Graphic Data Editor [2]. The **GDE** method has been extended to include a 2D Modeller. **GDE** in the ARTIF system is responsible for the recognition and modelling of the shape of a plate system to obtain the form of a collection of mono-connected and multi-connected regions. An interactive mechanism based on the language of graphic symbols has been used to describe constraints and loads. In the effect, the process of computational task definition is similar to drawing a sketch on a paper sheet, where the technical drawing is the substrate on which the sketch is made. To be able to interpret such an unequivocal description Fuzzy Expert System has been developed, with the purpose in view to identify the computational task, generate a mathematically equivocal numerical description, carry out computations and present the results. The ARTIF system is composed of several integrated modules, being:

- User Interface **(UI)**;
- Drawing Recognition Module **(DRM)**;
- Modeller Module **(MM)**;
- Mesh Generator **(MG)**;
- Solver Module **(SM)**;
- Task Interpretation Module **(TIM)**.

TIM is the Fuzzy Expert System that plays an important role in the ARTIF system where it monitors the whole computational task defining process. **TIM** controls, by medium of **UI**, the interactive process of task description, of the computations and presentation of results. The process of computational task description falls into the following stages:

- either transporting the shape of a structural member from a technical drawing or its independent definition (done by **UI**),
- modelling of areas (done by **MM**),
- definition of loads, constraints and material constants (done by **UI**),
- identification of shapes, constraints and loads (done by **TIM**),
- generating mesh of finite elements (done by **MG**),
- generating and optimizing the numerical description (done by **TIM**),
- performing computations (done by **SM**),
- presentation of graphic results (done by **UI**).

4. Modeler

The adopted concept to construct the ARTIF system involves the need to apply a 2D modeller of non-standard design. The modeller is expected to meet the following requirements:

- give access to shape description through a set of lines defined as LINE (x1, y1, x2, y2),

- present the effect of modelling as a set of mono-connected and multi-connected regions;
- necessarily provide for automatic identification of regions, without User interference.

The above requirements follow from the assumption that technical drawing (Fig. 1a) is the basis to identify regions while user interference is to be restricted to transporting the lines bounding the regions straight from the technical drawing. **MM** closely co-operates with the **DRM** module and sources drawing recognition from its knowledge base. **DRM** does the recognition of a mathematically non-equivocal drawing of the structure model (Fig. 1b) basing on the Theory of Fuzzy Sets [4] and generates a list of non-intersected objects, **Op**$_i$ [2]. **Op** List is a mathematically equivocal shape interpretation, as generated by the system.

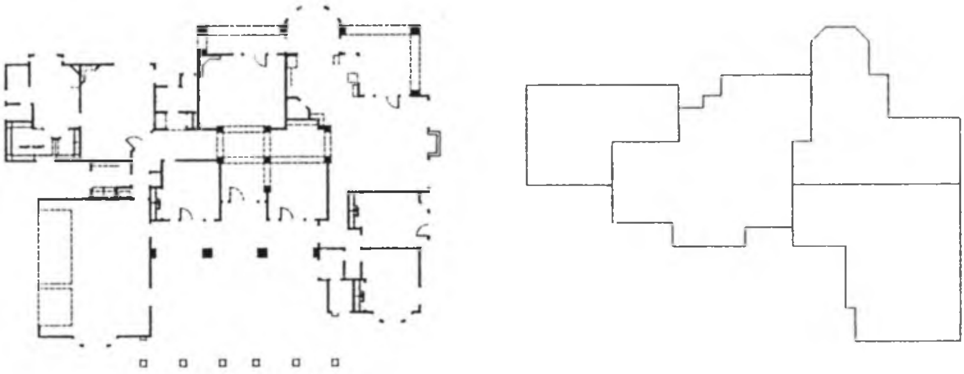

Fig. 1. Apartment building floor structure, modelled as a plate system: (a) technical drawing, (b) mathematically non-equivocal model of structure, prior to its recognition.

Unlike the standard 2D and 3D modellers, **MM** does not conform with the Boolean algebra by its function or design. **MM** compares the relationships between and among non-intersected objects, **Op**$_i$, recognizing those that are boundaries of mono- or multi-connected regions. Whilst searching for the relations among objects on the **Op** list, **MM** is able to identify them by the mere statement, which of them are those that form mono- or multi-connected regions (Fig. 2a). This is how complete automation of the modelling process has been achieved. **MM** can also distinguish between region-forming objects and those that must be treated as bars, all within the Op List. This capability renders **MM** a valuable asset for the modelling of plate-and-bar systems.

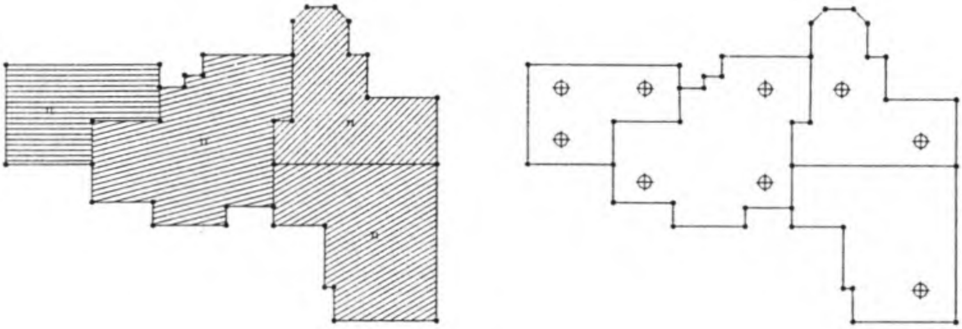

Fig. 2. Shape of the examined plate system after its recognition and identification: (a) identified regions, (b) description of constraints.

5. TIM Fuzzy Expert System

TIM is the Fuzzy Expert System that controls the entire system operating. **TIM** starts the particular subsystems (modules) by generating their input data and examining the results of their operation. The functioning mode of the **TIM** module has been determined from the application domain of the ARTIF system. ARTIF has been assumed to be used predominantly by engineers knowing next to nothing of the finite element method. In this context two significant theses are assumed:

- **TIM** may allow User interference in the course of analysis and computation to a restricted degree only;
- **TIM** may not accept any User statements on the mode of generating the mesh of finite elements, interpreting constraints or results as being 100 percent sure.

5.1. Knowledge representation

TIM is a rule-based system. The knowledge of **TIM** is represented in two ways:

- as the fundamental-knowledge base, consisting of the rules of inference,
- as the dynamic base of facts (hereinafter called the context), individually generated by **UI** for any computational example and modified by the Inference Engine during the inference process.

Two following groups of rules can be distinguished in the base of inference rules:

- classical rules of the type:

  IF *smth* **THEN** *action*,

- fuzzy rules, where a specific action is taken after a fuzzy condition has been satisfied.

Classical rules are decisive for the interpretation of regions, constraints and loads. Fuzzy rules can decide, e.g., on the mode to generate finite element meshes. The rule to interpret slab corners is a good example for a fuzzy rule. The corner of a plate having any of its edges fixed (or unsupported) may give rise to stress concentrations. To enhance the accuracy of results **TIM** condenses the mesh of finite elements in the plate corner area, guided by the simple rule connected with the magnitude of the angle between edges having one common vertex. Further deliberations introduce the term of the object angle defined as two edges of an area having a vertex in common and an angle that they are forming. The purpose of the rule is to identify a perfectly acute and perfectly obtuse angle. Any conclusion related to a given object **(angle)** is naturally associated with the certainty factor α, $0 \leq \alpha \leq 1$. An *acute angle fuzzy function* then is proposed, i.e.:

$$\chi_A(x) = \frac{1}{1 + K \sin(\frac{\varphi}{2})^2}, \quad K > 1 \tag{2}$$

If $\phi = 0$, then x is a perfect *acute angle*. Otherwise, it is an angle with certainty $\alpha = X_A(x)$. Thus *angle fuzzy set* has been constructed:

$$R = \{(x, X_A(x)) \mid x \ \text{ is an acute angle } \} \tag{3}$$

There is a rule to determine the condensation area, connected with the object angle; thus:

Rule. If the object is *acute angle* and is *small area angle* then condense the mesh in all area formed by this object.

Similarly area fuzzy set can be defined:

$$AR = \{(x, \chi_{AR}(x)) \mid x \text{ is a small angle area}\} \tag{4}$$

Now, it is possible to determine whether an *angle* is *acute and small area angle.* Third fuzzy set **RAR** - the intersection of **R** and **AR** can be defined:

$$RAR \triangleq R \cap AR = \{(x, \chi_{RAR}(x)) \mid x - \text{acute and small area angle}\} \tag{5}$$

where

$$\chi_{RAR}(x) = \min\{\chi_R(x), \chi_{AR}(x)\} \tag{6}$$

5.2. Inference engine

TIM has a mixed conclusion-drawing mechanism. The basic mechanism to draw conclusions is forward chaining. The system, basing on data grouped into context and its accessible rules, progressingly performs the inference process, until it reaches the final conclusion in the form of a numerical description of the computational task. **TIM**, having reached that stage, starts **SM** to operate and presents the results. The presentation of results, however, does not yet complete the process of inference. **TIM** verifies the results. The mechanism of the described system version is very simple and it consists in verifying the results for correctness. The mechanism is based on testing the stress gradient in way of the node. If **TIM** finds the presence of unjustified stress peaks, it will attempt, by means of the mechanism of backward chaining, either to modify the mesh of finite elements or the description of loads and constraints.

6. Mesh generator

The ARTIF system has a built-in finite-element mesh generator based on a deterministic algorithm. The system structure would rather suggest a fuzzy intelligent mesh generator [1] to be used. However, this mesh generator type would require higher power main frames to be used. So the ARTIF system applies GEN2 Generator [3] using the OC-tree method for its operating.

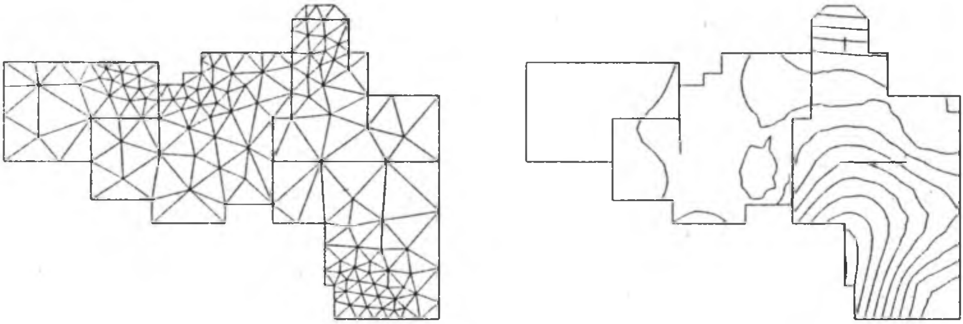

Fig. 3.Generated mesh of finite elements and computation results: (a) mesh generated by GEN2, (b) results of analysis.

Mesh generation runs in three stages:

- preparing a mesh of squares,
- dividing the squares into triangles,
- fitting the triangle mesh into the topology of an object, either by means of node traction or the Delounay's division method.

GEN2 is generated by **TIM** and the mesh generating mode depends on the inference process. The generator allows to originate finite element meshes of preset density; it can enforce node formation at the preset point, provide for mesh compaction within the preset area and optimize allocation of numbers to the nodes. **TIM**, while matching some or all of the above parameters, optimizes the mesh it generates, according to its accessible knowledge and task under review (Fig. 3a).

7. Conclusions

By means of applying the AI and Fuzzy Expert System techniques ARTIF enables any engineer to carry out numerical computations of plate systems, where the User must not necessarily possess a thorough knowledge of the numerical method applied. The User can verify the structure in the natural environment of the drafting system. The entire scope of task modelling and defining is done with the use of simple graphic symbols and in the technical drawing direct. The terms an engineer has to learn are few and uncomplicated, and rendered even more simple by their graphic symbols language presentation. The defining speed has been upgraded by resorting to the **GDE** method for the plate model drawing recognition. The commercial version of the ARTIF system can be linked into any drafting system running in the AutoCAD (R.12 for Windows) environment.

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