Alternative concept in structural analysis education
-AxisVM® X6 FEM software -

Dušan Kovačević
Department for Civil Engineering and Geodesy
Laboratory for Testing of Structures
Faculty of Technical Sciences, University of Novi Sad
Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia
E-mail: dusan@uns.ac.rs

Abstract. One short review on the preferable concept in Structural Analysis education by use of finite element method (FEM) software is given. It is generally accepted that good "educationally aided" FEM software includes a pre-processor with intuitive graphically user interface that enable simple and efficient geometrical modelling of structural topology, powerful solver-processor with sophisticated numerical modelling possibilities, post-processor with various types of analysis results presentation, as well as benefit of fast, easy training and satisfaction of use.

Hungarian software company "InterCAD" developed FEM software AxisVM® that satisfies mentioned conditions and much more performances in professional and scientific area. Therefore AxisVM® is embedded in a curriculum of subject "FEM Modelling in Structural Analysis" on Department of Civil Engineering and Geodesy, Faculty of Technical Sciences, University in Novi Sad, Serbia.

1. Introduction
New concept of education in structural analysis field and, especially, examination of the knowledge, should be implemented for achievement of complete understanding of the essence of structural behavior. "Old fashion" learning, intended to the "encyclopedic knowledge", by understanding of many "good old" methods, possibly provide wider "quiz-like knowing of lessons" and contribute to some of "technical culture", but it ruins enthusiasm of students in reaching of so-called "functional knowledge". "Functional knowledge" is not only ability of practical use of studying results, but situation what make possible establishing of new knowledge by "full life self-studying". In this regard is one alternative definition of intelligence as "possibility of obtaining of new knowledge by learning". Here is important to make difference between "high school learning" and "college studying" according to need of research on student's level in college, see [1].

Therefore, teaching and studying focused to one dominant method give the results that establish a structural modeling as the most important step in structural analysis and design. In this way, numerical modeling, as a mathematical realization of structural modeling system and FEM as the prevailing concept in the numerical modeling, become "sine qua non" of modern structural analysis education.

The software implementation quality decides how much the advantages of FEM would be realized and presented. Thus, as the key one, is imposed the questions and dilemmas of choice of the FEM software in education.
In connection to this, arises the problem of educational concept. In addition to high knowledge in the primary profession (structural analysis and design) also is needed:

- basic knowledge in FEM software development (numerical mathematics, software design and programming),
- certain knowledge in FEM software distribution (computer technology knowledge at the advanced user level, sense for marketing and public relations) and
- high level knowledge in FEM software competent use (basics of numerical mathematics, advanced use of computer technology).

The key thing is that every technically oriented faculty should make possible this concept in education.

2. Actual circumstances in FEM education
Learning of the principles of FEM is initial step in strategy of FEM education according to fact that FEM is widely accepted concept in structural modeling, analysis and design. It is completely justified for education in engineering area, but need one approach that is more practical. For engineers, dilemma what is FEM does not exist: FEM is not the only one of numerical methods for solving of differential equations, but a technology for modeling, analysis and design in many engineering fields, see [2].

Although the dilemma disappeared in the last century (after the Hrenikoff and Courant works), is still going the old joke about how things can be analyzed (different professions differently observe one simple scene), figure 1.

![Figure 1](image_url)

**Figure 1.** Different views about same thing

The old joke illustrates education of FEM that is sometimes overloaded by information that are unnecessary and sometimes hide the essence of FEM. Reason for that is the fact that well educated structural engineers do not practice so-called "dry theoretical approach", but only trainers/educators of other vocation. This circumstance is particularly noticeable in well-established university environments, but, fortunately, things become well, by time, see [3].

3. AxisVM® X6 - training tool in desired FEM education concept
AxisVM® ver. X6 is a Microsoft Windows® based FEM software which, because of its extensive analysis capabilities (developed by civil engineers for civil engineers), has verified for successful application in design of projects from large complex structures to small and simple buildings, [4].

AxisVM® performance satisfy needs of everyday design practice, scientific work and education in structural analysis domain. Therefore AxisVM® is embedded in program of following subjects: Theory of plates and Shells, Structural Stability and Dynamics, FEM Modelling in Structural Analysis and
Testing of Structures in our Department for Civil Engineering and Geodesy on Faculty of Technical Sciences, University in Novi Sad, Serbia.

The software performs linear and nonlinear, static and dynamic analysis of beam, membrane, plate, and shell structures. It enables use of an unlimited number of nodes and unlimited number of FEs freely combined in models by use of: plane/space frames/truss FEs, elastically embedded beams, plane stress/strain membranes, bended plates, spatial shells and any combination of mentioned structural parts.

There are three AxisVM® main versions: Professional (fully functional and limitless version with all modelling and computation abilities), Mini (limited version for educational purposes) and Viewer (for review and analysis of results obtained by Professional version). Typical working environment of this software is shown by figure 2.

3.1. AxisVM® X6 Pre-processor (Editor)

Why pre-processor of FEM software is so important for educational purposes? Probably because of possibility of fast and easy understanding of use of software and taking the information by visual approach. In initial steps of education, students accept the FEM on the best way if the presentation starts from the geometrical topics. Figure 3 shows different method of the geometrical discretization for the same domain. There are examples of good "✓", very good "✓✓", not so good "✓✗" or bad "✗✗" FE mesh.
Pre-processor of AxisVM® performs geometrical discretization by which user can to influence on the result in substantial amount. However, it is necessary to draw attention to the advantages and disadvantages of some FE mesh in terms of influencing the result of numerical analysis. Additionally, this pre-processor offers many geometry generation commands (translate, rotate, mirror, scale, with multiple copy or move), powerful selection tools (filtered selection, for example), working with structural parts what allows easy editing of most complex 3D geometries and includes advanced part management. It is included cross-section and material libraries and fully integrated graphical cross-section editor for complex cross-section (all cross-sectional properties are automatically calculated), what is very attractive for educational and design office use, figure 4.

![Graphically aided cross-section editor](image)

**Figure 4.** Graphically aided cross-section editor

3.2 *AxisVM X6® Processor (Solver)*

AxisVM X6® implements an "object-oriented FE architecture" that inherits more reliability than the classical systems. It provides a variety of FEs for modeling line and surface structures, special elements for modeling boundary conditions and connections and elements with nonlinear capabilities. Line FEs are truss, beam (6- and 7-DOF) and rib. The rib FE is a 3-node isoparametric with quadratic displacement interpolation that can be used taking into account the shear deformations) or in conjunction with surface elements. 7-DOF beam makes possible modeling of warping effects.

Surface FEs are: membrane, plate and shell (these elements are isoparametric quadrilateral (8/9-node) or triangular (6-node) elements, that use quadratic shape functions to interpolate displacements. Plate and shell use Mindlin's plate assumptions in a Heterosis formulation. Example of structural part with shell FEs are given on figure 5.

![AxisVM X6® shell FEs modeling example](image)

**Figure 5.** AxisVM X6® shell FEs modeling example

Additionally AxisVM® offers Winkler-Pasternak (additionally includes shear layer) type elastic supports for line and surface elements with nonlinear characteristics (tension or compression only, limited resistance) what is excellent for explanation of a real work of foundations for students.
Joint support elements are with arbitrary orientation and stiffness can have nonlinear characteristics (tension or compression only, limited resistance) what gives opportunities for understanding the essence of nonlinear behavior of structures, what is sometimes "mystery" for students and engineers, [5, 6].

There are gap, spring, link and rigid special FEs for modeling of particular phenomena in boundary/interface conditions, see [7].

Various loads can be applied on the nodes and the finite elements, as well as number of load combinations from load cases. Load cases can be classified in load groups for automatic critical internal force calculations.

AxisVM X6® performs most of the analyses, typical in the practical design of civil engineering structures: linear static analysis, buckling analysis with critical force and shape computation, nonlinear static analysis (displacement/force controlled incremental-iterative solution), free vibration analysis, figure 6, dynamic and earthquake analysis (response spectrum, time history and pushover analysis).

This part of FEM software as well as this area of structural design are subject of many dilemmas, questions and misunderstandings among students and civil engineers.

Here it is necessary to point out that the type and shape are not the same thing. FE type is determined in numerical manner, but a shape is derived from FE geometry. In that sense it is necessary to discuss about some circumstances when type structural systems require dense mesh of FE and discussion about inadequate shapes of FE (left and right side of the figure 7).

In the first case (areas with the stress concentration) it is necessary to obtain FE with corresponding geometry (triangle) and sufficiently small. In this matter, it is not allowed that shape of FE be distorted over the acceptable limit (too big length/width ratio, sharp angle corner, shape which tend to disappearing of some joints, etc.).
Reducing the size of FE can cause problems not only with the time of computation, but also problems with the convergence and stability of the FE solution, figure 8.

![Figure 8. Convergence of FE solution](image)

Clearly, in application of FEM software, it is not sufficient to know only the basic problem and the essence of the applied method, but also to know the software performances (in sense of possibilities and limits) and possibilities of numerical methods.

Last, but not least it is important to present various strategies of formation of structural matrices in FEM. Illustrative example is given on figure 9.

![Figure 9. Composition-assembling of matrices in FEM](image)
Here is essential to emphasize band shape, symmetric, diagonally dominant, positive definite and sparse structure of FEM matrices and technology of solving systems of algebraic equations that are strongly developed by expansion of multiprocessor/multithread PC systems and corresponding algorithms for parallel computation.

3.3 AxisVM X6® Post-processor (Viewer)

After AxisVM® Pre-processor, as the most attractive for FEM introduction lessons and its Processor, as more educative for understanding of FEM essence, follows a description of Post-processor as most interesting for viewing of results of FEM computation and analysis of possible problems, difficulties, traps and surprises.

AxisVM X6® provides multi-window model analysis results display and design capabilities:

- results display by different types of diagrams with user defined color legend, figure 10,
- multi window presentation of the different numerical quantities with ability of animation view of results what is very useful in studying of structural behavior,
- integrated Report Generator for create of report templates,
- detailed documentation of strength and stability checks using formulas and substituted values,
- 3D PDF file export of the graphical content, which can be rotated and zoomed in and out within the PDF reader, etc.

4. Conclusions

Application of FEM software as specific training tool in the educational process is the area where the professional competence is essential, but together with solid knowledge in the field of computer technology and numerical mathematics. Similar relations are justified in FEM software development and distribution. Fortunately, InterCAD follows that route and therefore AxisVM® is developed "by engineers for engineers" as well as for students and researchers.

Second important thing is the question of technical regulations that should be harmonized regards to strong development of personal computers hardware and FEM software. Progress in FEM education could be motivating in desired trend of innovation of technical rules.

Acknowledgements

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