THE METHODS OF TEACHING AND LEARNING STRUCTURAL MECHANICS

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Abstract

Structural mechanics is a key issue to study for engineers. A high rank and high social responsibility profession require both a high graded and intuitive approach. The evolution of learning / teaching methodology follows the novel technical achievements of every decade. The aim remains the same: to produce a professional to perform advanced relevant analysis and safe, optimal structural design.

Keywords: *structural design, civil engineering, structural mechanics, structural reliability*

1. INTRODUCTION

Structural mechanics is a discipline to be possibly located between the distinct milestones of fundamental and applied science. The former comes from highly advanced cases of shells and shell-framed systems making the engineer an expert of non-Cartesian tensors and curvilinear system analysis. There are two paths a civil engineer can go by in her/his prior high-school period but in the long run the aim remains the same: proficiency in structural performance assessment.

2. PATHS OF ENGINEERING EDUCATION

In a general educational course, a high-school aged student may follow one of two major routines.

The first - the routine of a general education school, the General-Education Lyceum (such a name in the Polish system). The theoretical courses of mathematics and physics provide the student with wide-tailored skills to find a mathematical model for a problem and solve it, but not oriented to a specific branch of technology. Such a student enrolling in the University of Technology is ready to launch any branch: civil, mechanical, automotive, marine, aerospace and military engineering, or technical physics and applied mathematics.

The second way directs the further profession of a student just in the high-school stage of education. The choice of a dedicated lifelong discipline is the choice of a Technical Education School oriented to a specific discipline. The Polish expression Technikum stands for this variant. Just the first-class syllabus defines a group of the so-called directional or professional subjects to pave the future professional path of engineering. These subjects, despite their inherent theoretical background, are covered with the links o to engineering practice, even a contact with the companies, manufacturing plants and facilities. At graduation the student becomes the technician, ready to start work with a pack of relevant tools to go. This is one of the variants regular technical education may be completed. The other way finds the student continuing professional education at the University of Technology.

My personal teaching experience started in the early nineties of the 20th century. My study course was located in the eighties. These were the in-between days (better say, years). To announce the upcoming paragraph: the descriptive methodology was about to decline but this time a computer meant a large room filled with extra heavy cupboards full of advanced equipment and devices. The PCs largely the public domain ten years later.

3. HISTORIC OUTLINE, STAGES OF DEVELOPMENT

3.1 The descriptive routine

The past centuries of construction brought a worldwide legacy of multi-purpose structures, including the eminent and outstanding pieces of historic technology development. Just to simplify the issue and make it brief, the methodology is thought to be mostly intuitive, transferred by tradition, the written evidence complies with the descriptive, visual routines, no analytical procedures are detected according to those historic times.

The descriptive solution methods in mechanics have survived as the most popular ones until the last decades of the 20th century, they have been relatively popular in the middle of the 70s. Fig. 1 presents a Structural mechanics textbook of 1974, much attention is paid to the descriptive solution for support reactions in beams and frames, the so-called force polygon to find constraint forces and the so-called wired polygon to find cross-sectional forces in structural members. My parents have been studying at the same faculty I am affiliated with now. The collection at our home includes fine technical drawings of a sole descriptive mode. The entire precision of such computations was controlled by precision of the hand in the course of drawing

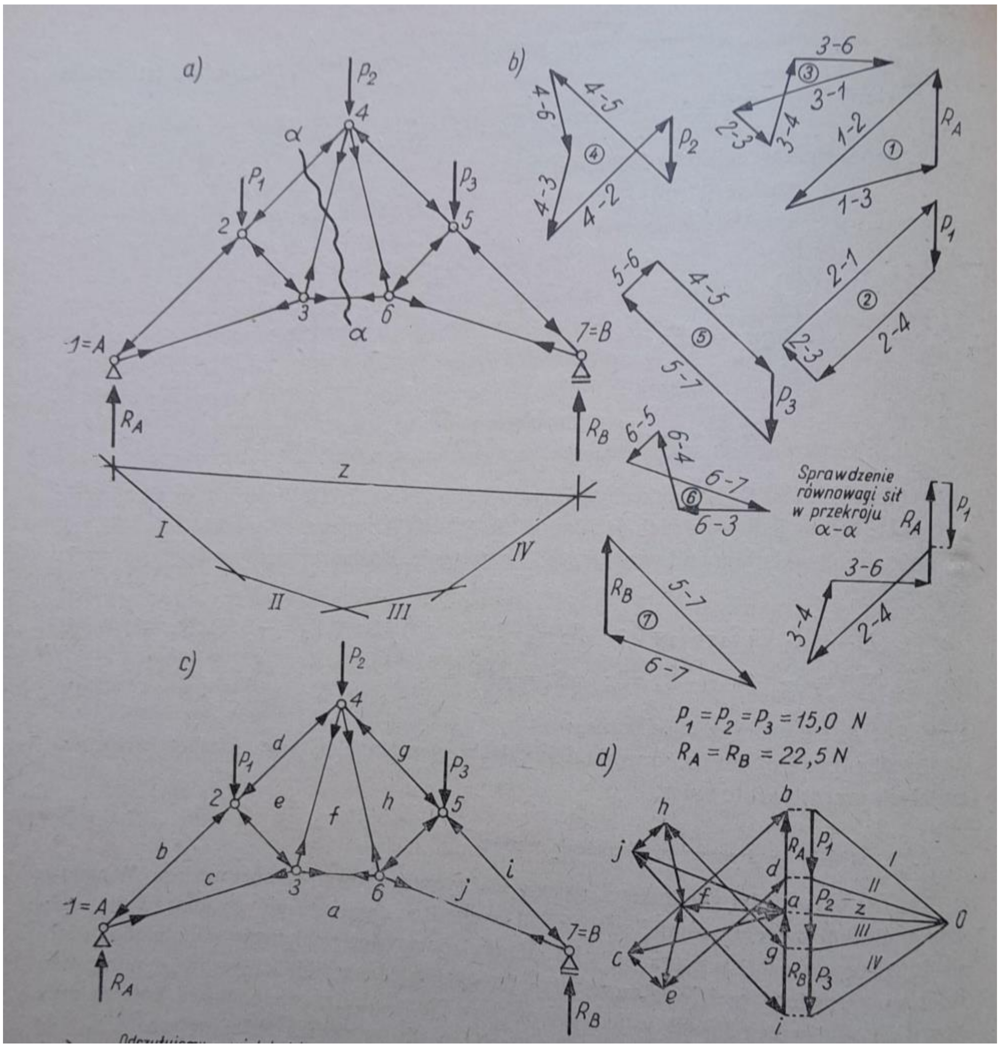


Fig. 1. The descriptive solution of a truss

Source: Z. Dyląg, E. Krzemińska-Niemiec, F. Filip: Structural mechanics (in Polish), PWN, 1974

3.2 The advent of analytical methods

The disadvantage of descriptive methods is a low precision. The resolution of results is strictly controlled by hand drawing precision. Thus, the methods could not be applied extensively to analyse and design structures of high responsibility, whose failure was about to bring catastrophic outcomes to humans and property. In the middle of the 20th century the analytical methods in civil engineering were highly developed. In the domain of bar structures the elementary relations were derived on the basis of simplified linearly elastic models, the assumptions to be further called geometric and material linearity. The basic relations of bars restricted the governing functions to bar axis only, thus, common differential equations were enough to solve the problems. The Euler's equation of a beam at bending or the load / shear force / bending moment relations stood for a basic set. Moreover, in engineer's design computations this mathematical base brought about simplified algebraic routines, easy to handle for a large community of designers not acquainted to analytically solve the problems of practice. Figs 2 and 3 shows the educational version of analytical approach to structural analysis, still active in current syllabuses of Structural Mechanics. The Force Method and Slope and Deflection Method were the most popular to solve statically redundant systems.

In the domain of 2D systems the analytical solutions were apparently handicapped by the need to directly use tensor algebra and analysis to compute stress, strain and deflection fields of the problem. The solution strategies, like the complex method routine of the application of stress function (e.g., the Airy stress function for 2D problems of plane stress and plane strain) represented the simplified analytical approach in this domain.

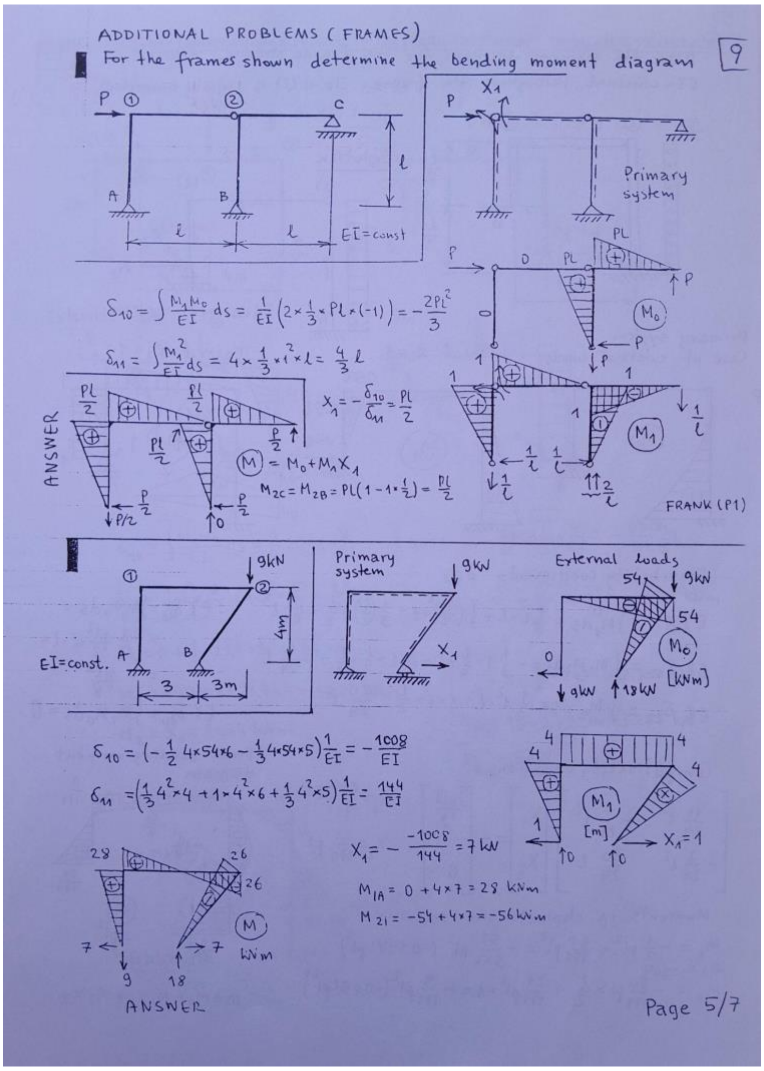


Fig. 2. The force method applied to solve the 2D frame (author: dr. Czesław Jacek Branicki)

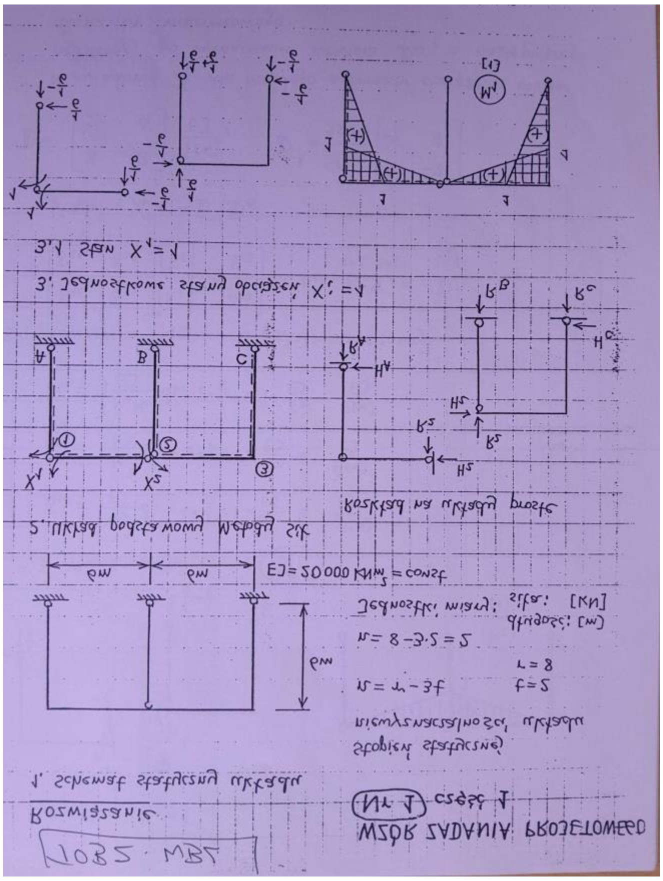


Fig. 3. The force method applied to solve the 2D frame (author: dr. Czesław Jacek Branicki)

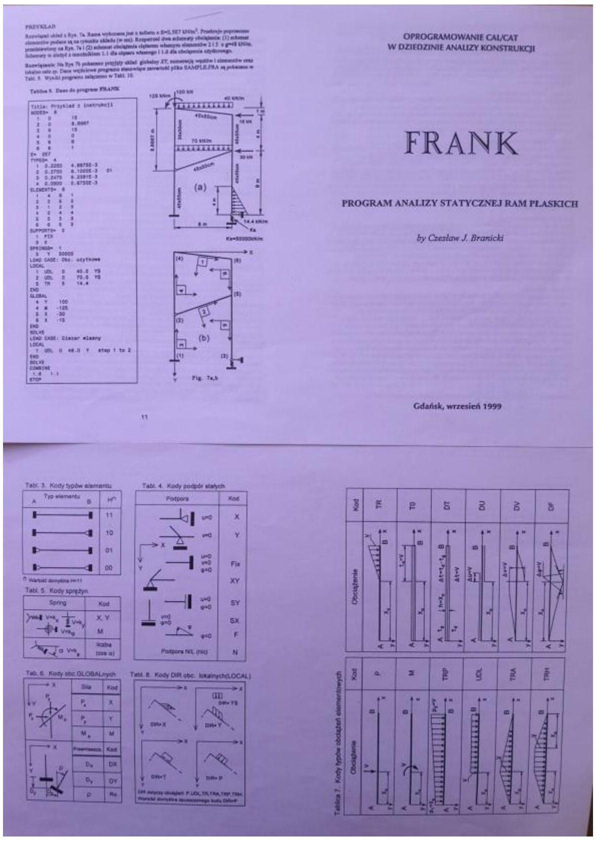
3.3 The pioneering IT tools in education

The late 80s brought about the pioneering devices to support structural analysis. The 70s and early 80s defined computers as a collection of heavily packed cupboards filling in a large operational room; their operation procedure was highly complicated. The situation was about to be clarified with the pioneering, prototype IMB PCc at the end of the eighties. Fig. 4. presents such a device. The DOS operating system was the most popular in this computational standard.

Fig. 4. The pioneering IBM XT personal computer of the eighties of 20th century. An exhibition at the Faculty of Electronics, Telecommunications and Informatics, Gdansk University of Technology

The IBM PC standard made it possible to launch students' computational laboratories and to enrol the computational approach to the process of learning mechanics. My native Department made a pioneering work, in our native domain only, to promote the computational approach in teaching and learning mechanics - the CAL-CAT philosophy (Computer-Aided Learning - Computer-Aided Teaching). Dr. Czesław Branicki from my native Department applied his experiences from the scholarships all over the world to launch a collection of CAL-CAT software dedicated to students. The major packages were: FRANK - a system to analyse plane frames under static and non-static actions DSM - Direct Stiffness Method - a computational variant of the Slope and Deflection Method, explicit in enlisting the procedure elements, stressing the following stages: preparation of input data, launching the subroutines and result visualization.

Figs. 5, 6 and 7 show the use of DOS packages to analyse structures



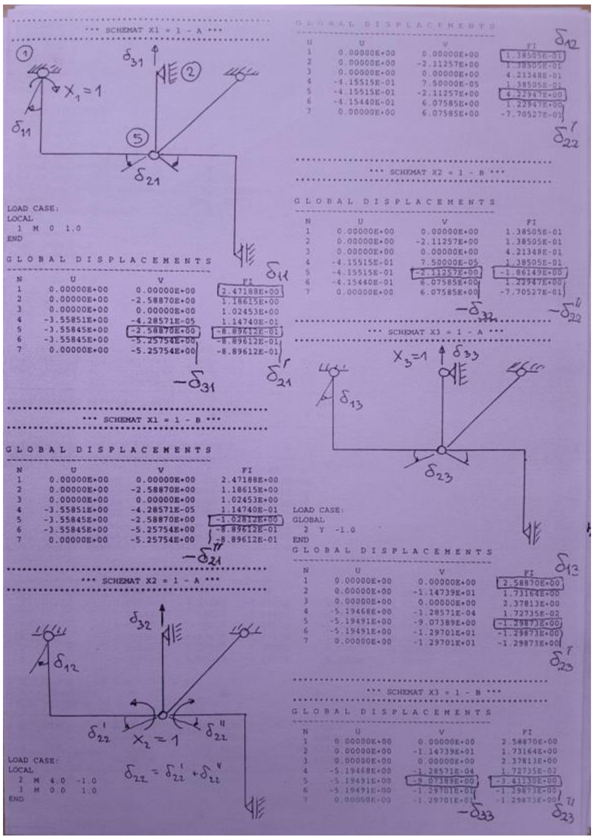
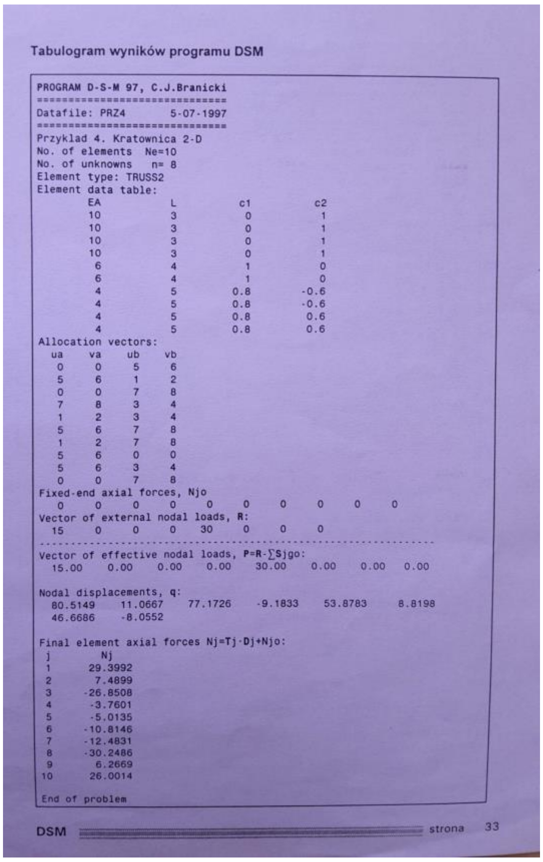


Fig. 5. The FRANK package - user's manual (author: dr. Czesław Jacek Branicki)

Fig. 6. The FRANK results (author: dr. Czesław Jacek Branicki)



Tabulogram wyników programu DSM

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PROGRAM D-S-M 97, C.J.Branicki
==============================
Datafile: PRZ4        5-07-1997
==============================
Przyklad 4. Kratownica 2-D
No. of elements  Ne=10
No. of unknowns   n= 8
Element type: TRUSS2
Element data table:
        EA          L         c1         c2
        10          3          0          1
        10          3          0          1
        10          3          0          1
        10          3          0          1
         6          4          1          0
         6          4          1          0
         4          5        0.8       -0.6
         4          5        0.8       -0.6
         4          5        0.8        0.6
         4          5        0.8        0.6
Allocation vectors:
  ua    va    ub    vb
   0     0     5     6
   5     6     1     2
   0     0     7     8
   7     8     3     4
   1     2     3     4
   5     6     7     8
   1     2     7     8
   5     6     0     0
   5     6     3     4
   0     0     7     8
Fixed-end axial forces, Njo
   0     0     0     0     0     0     0     0     0     0
Vector of external nodal loads, R:
  15     0     0     0    30     0     0     0
------------------------------------------------------------
Vector of effective nodal loads, P=R-∑Sjgo:
  15.00    0.00    0.00    0.00   30.00    0.00    0.00    0.00

Nodal displacements, q:
  80.5149    11.0667    77.1726    -9.1833    53.8783    8.8198
  46.6686    -8.0552

Final element axial forces Nj=Tj·Dj+Njo:
 j        Nj
 1      29.3992
 2       7.4899
 3     -26.8508
 4      -3.7601
 5      -5.0135
 6     -10.8146
 7     -12.4831
 8     -30.2486
 9       6.2669
10      26.0014

End of problem
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DSM strona 33

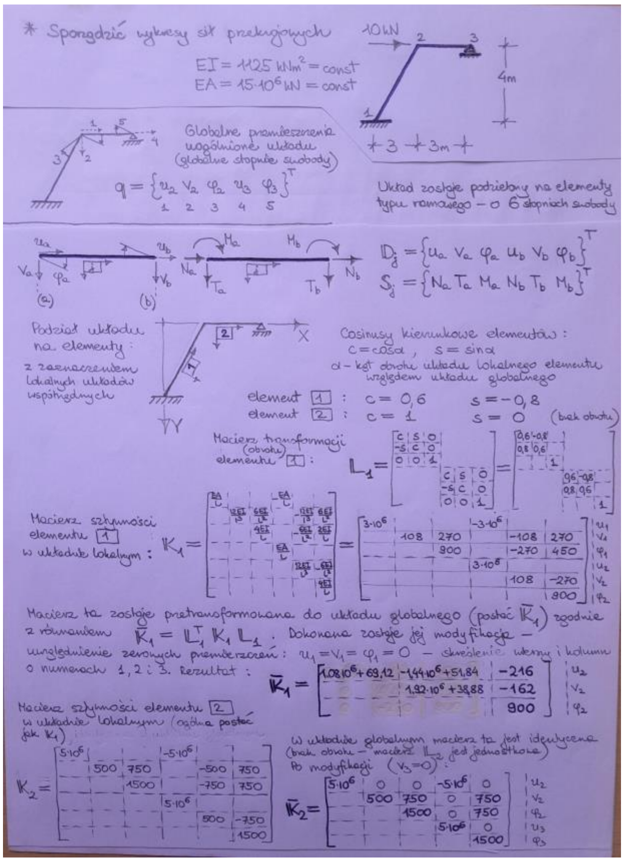

Fig. 7. The DSM course report (author: dr. Czesław Jacek Branicki)

Fig. 8. The DSM insert, resolved manually (dr Marek Skowronek, the 90s, notes for the tutorials)

This was the pioneering stage, an attempt to include the computer-aided procedures into regular courses of mechanics. Such a routine was practised about 5 years in regular B.Sc. courses. The real achievement of this approach is apparent: at this time there were no ready-to-use software to lend the engineer a helping hand. This approach was not regular at all Universities, not included in a state syllabus. It was an eminent outburst of educational innovation, dedicated thoroughly to the students.

There is a specific and major advantage of incorporating computational methods in teaching / learning Mechanics. Such an approach serves as a young person's guide to FEM. The DSM represents an isolated application of FEM in the simplified case: bar systems of linear response under simplifying assumptions (Euler-Bernulli beams). Here the FE shape functions majorly coincide with the Euler's deflection lines, leading to exact solutions in the prescribed framework. A student familiar with CAL / CAT procedures in the stage of bar analysis, approaches the FEM as the upgrade of the simple version, focusing on the novel components. The FEM is the most widespread tool in structural analysis all over the world, so the computational routines priorly taught make a significant contribution.

4. A NEED FOR VITAL LIFELONG LEARNING

A real professional in any field of activity never restricts the educational process to school / university years only. The work, which often encounters non-standard, extraordinary cases, requires an ability to learn more, to complement the educational reservoir with new elements or simply to update and upgrade the former skills with novel ones due to technological progress, especially in the IT branch. Therefore, the prior education of every worker in the field of education is given a kind of starting device and tools to develop them in the ongoing working routine. This is a major idea of the engineering branch training, in fact, enhanced to numerous professions of various sorts and species.

5. CONCLUSIONS

The course of teaching mechanics has evolved throughout the decades of the post-war period. The descriptive methods of engineering intuition have been continuously updated by analytical tools, to finally direct the routine into the computational course. It has to be kept in mind that structural engineer's intuition, which served as a design basis for centuries, is an everlasting advantage to be preserved, despite an overwhelming progress in technology. The emerging machine-controlled routines, CAL-CAT philosophy provide a powerful and often a unique tool to solve complex problems of engineering. However, these innovations, finally, remain a means only, to never come a methodology. The issue is given a more serious consequence while the AI procedures enter the arena.

ACKNOWLEDGMENTS

I would like to acknowledge the great Lecturers who made their highest effort to make the students understand the major idea behind Mechanics, what is the essence of advanced, isolated procedures of mathematics, the real language expressing what it really serves for. I have made a direction in my own teaching: once a number of classes provide the students with a clear understanding of the issues, without a single mathematical formula. My special words of gratitude to the everlasting educational spirit of the late dr Czesław Jacek Branicki, the friend of my Family, reviewer of my M.Sc thesis, co-operator in Structural Mechanics teaching, who extensively promoted the CAL-CAT education by means of the DOS-based software package, very popular among the Students. His lecture and tutorial notes cover the paper.

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