A METHODOLOGY FOR COMPUTER-AIDED LEARNING IN STRUCTURAL MECHANICS

Application to Continuous Beams, Plane Frames and Finite Elements.

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ABSTRACT.

In this paper a general methodology for Computer-Aided Learning (CAL) in structural mechanics is presented. An application of this methodology for the linear analysis of continuous beams with matrix methods is presented. Moreover, other applications to the elastic analysis of plane frames and continuous structures using triangular finite elements (in development stage) are presented. These applications were developed for the IBM PC, XT, AT, PS/2 and compatibles.

RESUMEN.

En éste artículo se plantea una metodología general para la Enseñanza Asistida por Ordenador (EAO) en Mecánica Estructural. Se presenta una aplicación de ésta metodología al Análisis Elástico de Vigas Continuas por Métodos Matriciales. Además, se presentan otras aplicaciones al Análisis Elástico de Pórticos Planos y Estructuras Contínuas utilizando Elementos Finitos Triángulares (En etapa de desarrollo). Estas aplicaciones se están desarrollando para ordenadores IBM PC, XT, AT, PS/2 y compatibles.

INTRODUCTION.

The overall objective of this work lies in the development of an integral methodology for Computer-Aided Learning (CAL) in topics related to structural analysis. This methodology should be useful both for students of engineering schools as well as for the retraining of technicians of companies involved in this area. Firstly, the educational programs will confront basic problems like the linear analysis of continuous beams, trusses and frames. Following this, more complex problems like the dynamic analysis of frames and the linear and non-linear analysis of continuous structures using the finite elements method are solved.

In the development of these programs for CAL, the use of the IBM PC, XT, AT family of micro-computers and compatibles has been adopted. This decision was taken on the grounds that most of the equipment in use at institutions of middle and higher education are computers of this kind. Moreover, the practical use of these kind of programs requires low cost computers in order to permit the use of them for courses with a large quota of students. All these facts are even more relevant in educational institutions of developing countries for which the training programs developed will be particularly useful.

GENERAL METHODOLOGY.

The methodology that is proposed for CAL of structural mechanics problems integrates in a coordinated manner three essential areas of education in the scientific/technical subjects. These areas are: THEORY, EXAMPLES and EXERCISES, and each is outlined below.
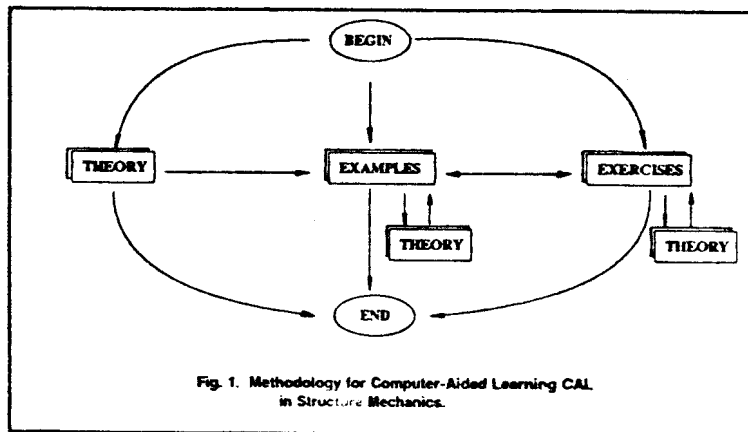

Fig. 1. Methodology for Computer-Aided Learning CAL in Structure Mechanics.

The **THEORY** area provides basic information about the structural analysis method that is to be taught. The student should be able to access this information whenever he/she requires.

In the area of **EXAMPLES**, the computer constructs the complete and detailed solution of some structural analysis examples. These examples should range from the most basic to the more complex. During the development of the examples, the program must emphasize any important aspects of the solution process and give a suitable interpretation of the results.

In the area of **EXERCISES**, the student (possibly with the help of the computer) attempts the partial or total solution of some applied exercises in the field of structural analysis.

The interaction of these three areas is shown in Fig.1.

CAL PROGRAM 'BEAMS' FOR THE MATRIX ANALYSIS OF CONTINUOUS BEAMS.

The integrated methodology outlined above has been applied in a pilot stage to the simple problem of matrix analysis of continuous beams. The resulting program, **'BEAMS'**, is described below.

The program **'BEAMS'** was developed on an IBM PS/2 - 80, under the MS-DOS operating system. It is written in the programming language 'C' and compiled using the MICROSOFT C COMPILER version 4.0. This program was developed for use within the MICROSOFT WINDOWS environment version 2.03

or higher. This environment was developed to emulate the convenient user-machine interface of the APPLE MACINTOSH computer. For the development of programs that can be run under WINDOWS, the libraries available in the MICROSOFT WINDOWS SOFTWARE DEVELOPMENT KIT version 2.0 must be used. 'BEAMS' is available in both an English and a Spanish version.

As outlined for the CAL methodology described previously, the program 'BEAMS' consists of three independent modules that together make up the integrated learning program for the analysis of continuous beams by matrix method. These modules are: THEORY, EXAMPLES and EXERCISES. The general structure of the program 'BEAMS' is shown in Fig.2.
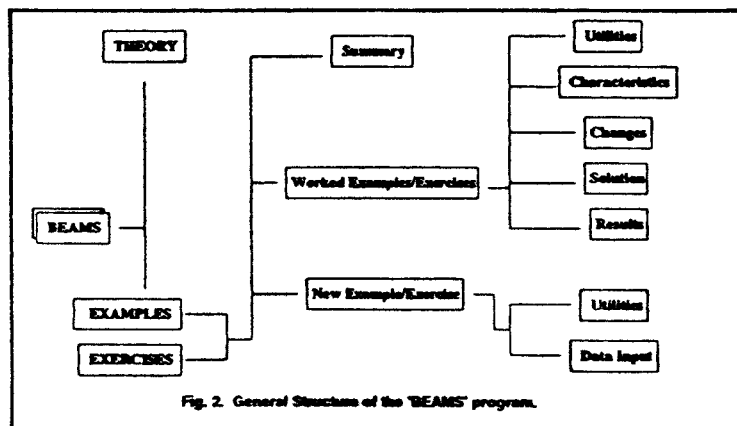

Fig. 2. General Structure of the 'BEAMS' program.

THEORY.

The THEORY module displays information concerning:

1. Stiffness Matrix of the Beam Element.
2. Equivalent Forces. (Uniform Load).
3. Equivalent Forces. (Concentrated Load).
4. Assembly of the Beam Stiffness Matrix.
5. Assembly of the Beam Loads Vector.
6. Solution of the Linear System of Equations.
7. Calculation of the Internal Forces in the Joints.
8. Calculation of the Reactions in the supports.
9. Deformed Shape, Shear Forces and Bending Moment Diagrams.

This information may be accessed whenever the student requires it during the execution of any example/exercise. The development of the example/exercise may then be continued with.

EXAMPLES.

The EXAMPLES module illustrates the working through of an example and its results, and allows changes to be made to existing examples and the creation of completely new ones.

Some utilities of the program 'BEAMS' that give the characteristic of CAL program are:

a) There is a library of examples (teacher's examples) with beams of different level of difficulty.

b) In order to completely define the problem chosen by the student, it is possible to display only the characteristics of the example that the student needs and not all the information at the same time. For example, it is possible to display the beam with the node and element numbering, the dimension of the elements and the properties of the section but not showing the applied loads.

c) The program allows modifications to be made to the original example for different educational objectives. The most important options are:

      - Add, Remove and Move Joints.
      - Change the Supports.
      - Add, Remove and Change Sections.
      - Change a Section in the Beam.
      - Add, Remove and Change the Joint or Element Loads.

The change of the Element Loads for a particular beam example is shown in Fig.3.
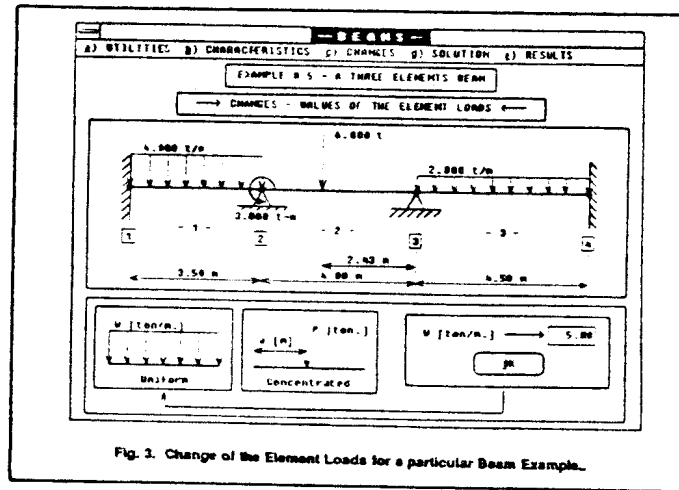

Fig. 3. Change of the Element Loads for a particular Beam Example.

d) The structural solution of the beam could be achieved in three different ways:

      - Step by Step.
      - Interactive.
      - Final.

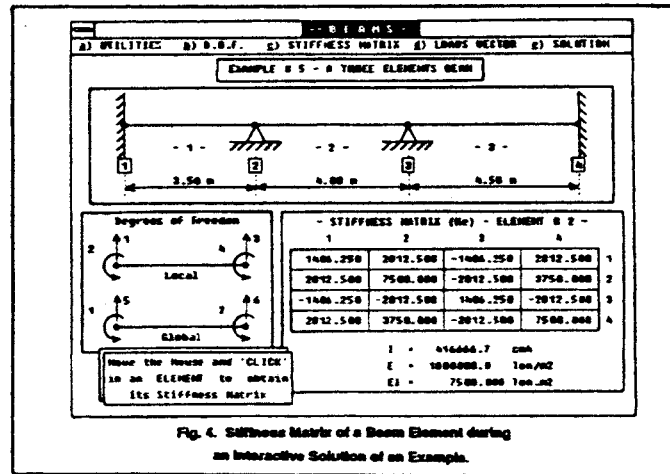The stiffness matrix $[k_e]$ of an element during an interactive solution of an example is shown in Fig.4.

Fig. 4. Stiffness Matrix of a Beam Element during
an Interactive Solution of an Example.

e) The results of the examples are displayed in different ways, showing important items of each one of them. The options for display the results are:

- Joint Movements.
- Internal Forces.
- Supports Reactions.
- Load + Deformed Shape.
- Load + Shear Forces.
- Load + Bending Moment.
- + Last Example.
- Shear Forces + Bending Moment.
- Deformed Shape in detail.
- Shear Forces in detail.
- Bending Moment in detail.

The results of " Shear Forces + Bending Moment. " and " Deformed Shape in detail. " for a particular beam example, are shown in Fig.5. and Fig.6. respectively.

f) The program allows the generation of a completely new example in a graphical and interactive way. The use of the 'mouse' for the selection of different choices makes for a quick and easy generation process.

The input of the supports data for a generated example is shown in Fig.7.

EXERCISES.

The EXERCISES module allows the student practice in the solution of beam problems. The solution of the exercise is carried out jointly by the computer and the student.

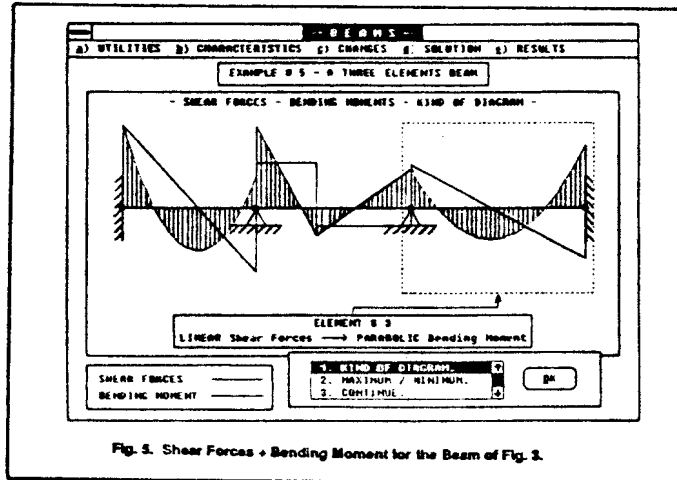Some utilities of the program 'BEAMS' concerning exercises are:

Fig. 5. Shear Forces + Bending Moment for the Beam of Fig. 3.

a) The student builds up the structural solution of the beam interactively, numbering the degrees of freedom and piecewise assembling the element stiffness matrix and the element loads vector.

The assembly of the stiffness matrix of an element for an exercise is shown in Fig.8.

b) Once the results of the matrix analysis are obtained, the student can build up a qualitative shear forces or bending moments diagrams by her/his self. It means that only the shape of the diagram is relevant and not the exact values.

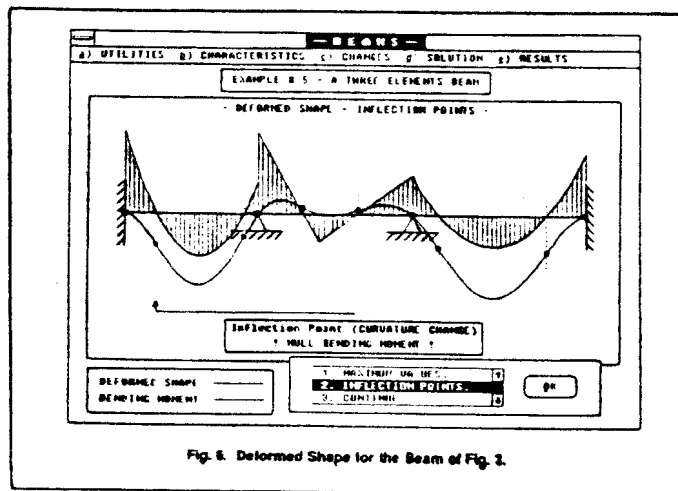The construction of the bending moments diagram for an exercise is shown in Fig.9.

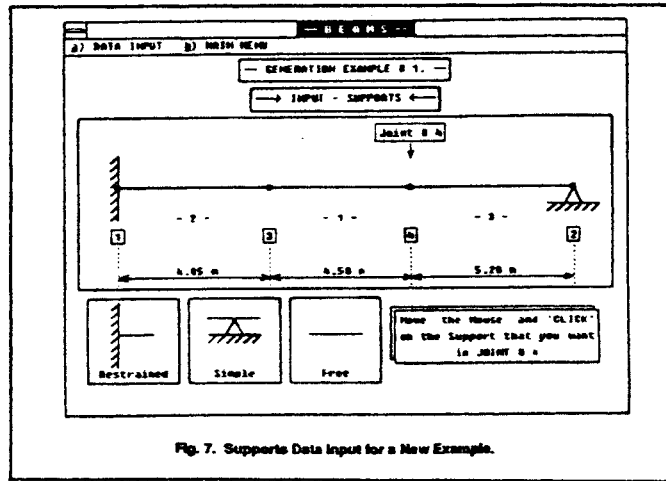Fig. 6. Deformed Shape for the Beam of Fig. 3.

Fig. 7. Supports Data Input for a New Example.

c) The computer (the program) always controls the development of the exercise. It means that when the student makes a mistake, the computer remarks it and shows where and why it occured.
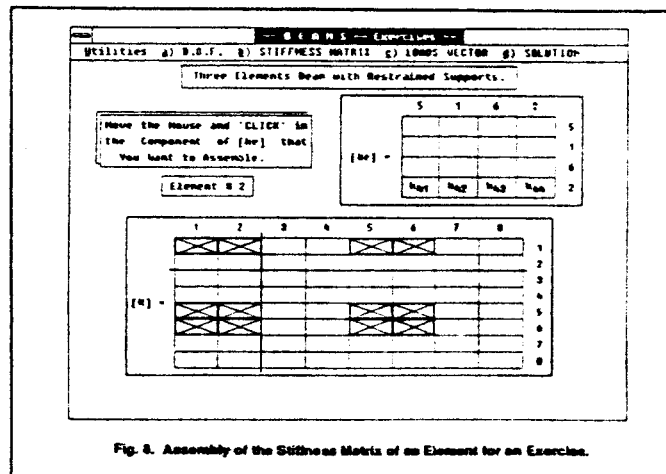

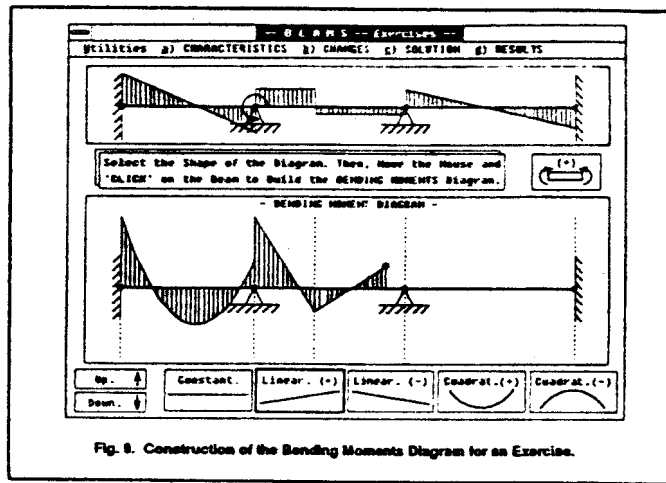Fig. 8. Assembly of the Stiffness Matrix of an Element for an Exercise.

Fig. 9. Construction of the Bending Moments Diagram for an Exercise.

CAL PROGRAM 'FRAMES' FOR THE MATRIX
ANALYSIS OF PLANE FRAMES.

The program 'FRAMES' aims to be used as a complement of the learning of the structural analysis of plane frames using matrix methods. This program follows the same philosophy explained above for the program 'BEAMS'. At the time of writing, this program still at the development stage.

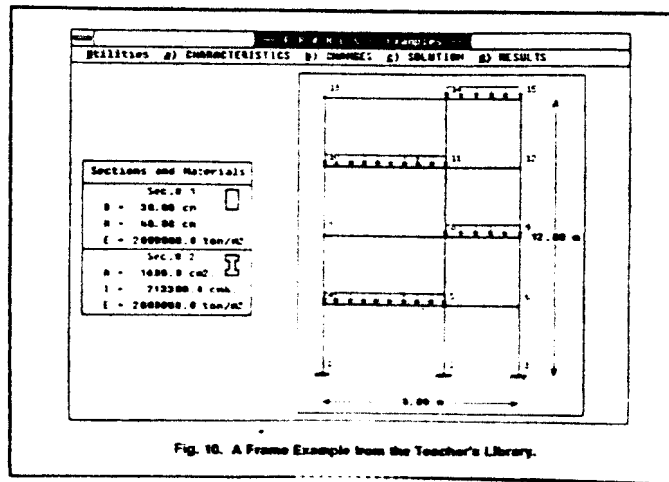A frame example from the teacher's library is shown in Fig.10.

Fig. 10. A Frame Example from the Teacher's Library.

CAL PROGRAM 'F.E.M.' FOR THE ANALYSIS OF CONTINUOUS STRUCTURES USING TRIANGULAR FINITE ELEMENTS.

The program 'F.E.M.' aims to be used as a complement of the learning of the analysis of continuous structures using isoparametric triangular finite elements (T3). This program follows the same philosophy explained above for the program 'BEAMS'. At the time of writing, this program still at the development stage.

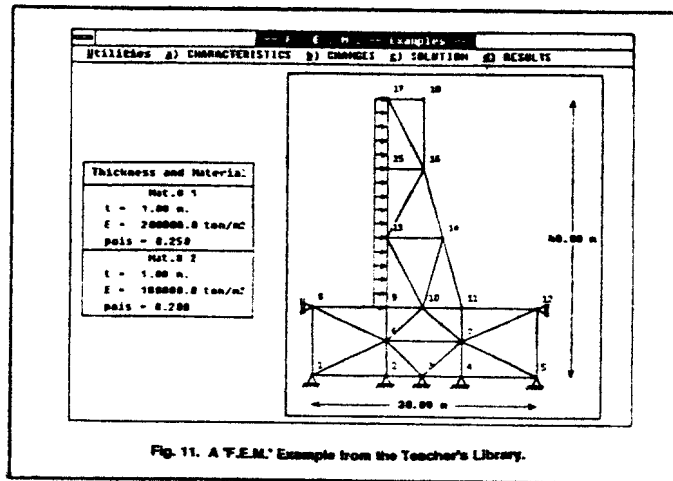A F.E.M. example from the teacher's library is shown in Fig.11.

Fig. 11. A 'F.E.M.' Example from the Teacher's Library.

CONCLUSIONS.

A general methodology for CAL programs in Structural Mechanics has been established. The program 'BEAMS' for the Matrix Analysis of Continuous Beams has been developed as an application of this methodology. In Addition, the programs 'FRAMES' and 'F.E.M.' are being developed for 2D problems. It is suggested that the MICROSOFT WINDOWS environment is an appropriate tool for the development of CAL programs on the IBM PC, XT, AT, PS/2 and compatibles.

For the development of CAL programs, the use of additional equipment such as a 'mouse' and a colour monitor, etc, is necessary. These improve the presentation, make the use of the program more convenient and increase the user-machine interactivity. Moreover, all of these facilities are obtainable at only a small overcost.

The CAL programs in Structural Mechanics should be used as a complement of the usual studies and not as an instrument to eliminate the lecturer. All the programs developed under this project are based on this philosophy.

ACKNOWLEDGEMENTS.

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