Session 3649

Teaching and Learning Structural Analysis Using Mathcad

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Abstract

The students taking Structural Analysis (required) in the ABET-accredited 4-year Civil Engineering Technology program at Georgia Southern University learn two classical methods for analysis of statically indeterminate continuous beams and frames - the moment distribution method and the slope-deflection method. The moment distribution method operates by successive approximations approaching the exact solution. Learning this method provides an unique perspective of how the internal reactions (moments) and the associated structural deformations are interrelated, an understanding of which is essential in structural analysis. However, the traditional teaching method (lecturing and having the students work on related assignments) does not always prove to be effective.

An approach to teaching this important classical method of structural analysis that complements the traditional lecturing through inclusion of a powerful, versatile and user-friendly computational tool, is discussed in this paper. Students will learn how to utilize *Mathcad* to perform a variety of calculations in a sequence and to verify the accuracy of their manual solutions. A *Mathcad* program is developed for this purpose and examples to illustrate the computer program are also included in this paper. The integration of *Mathcad* will enhance students' problem-solving skills, as it will allow them to focus on analysis while the software performs routine calculations. Thus it will promote learning by discovery, instead of leaving the student in the role of passive observer.

I. Introduction

The moment distribution method was published by late professor Hardy Cross in 1930, and was the most widely used method for analysis of statically indeterminate continuous beams and frames for the next 40 years. The primary reason for the popularity of this classical method was the fact that unlike other classical methods such as the slope-deflection method, it does not require solution of simultaneous equations. Even though the use of the moment distribution method has declined as computers have become increasingly available, the method is still preferred by some engineers, especially for analysis of smaller structures, as it provides a better insight into the load-deformation relationship. The elegance of the method lies in its simplicity in theory and application.

The moment distribution method takes into account the flexural deformations of structural members (i.e., rotations and settlements), but neglects shear and axial deformations. It is possible to deal with beams under any degree of restraints at the ends, and with any settlement of the supports. All members of a structure are assumed to be prismatic (i.e.,uniform cross-section).

In this method, moment equilibrium equations of the joints are solved by *iterations*, considering the moment equilibrium of one joint at a time, while the remaining joints are assumed to be fixed. To begin with the analysis by the moment distribution method, it is assumed that all joints are initially clamped, i.e., moment equilibrium is non-existent at the joints due to difference in fixed-end moments under applied loadings on members. Obviously, this condition can only occur if artificial restraints are provided at the joints. Now, if each artificially restrained joint is released, one at a time, it will rotate under the unbalanced moment to reach moment equilibrium. In the process, the following occur: (1) the unbalanced moment is shared by the members framing into the joint in proportion to their stiffness (this is called "balancing" or "distribution" step) and (2) one-half of the distributed moment is carried over to the other end of the member (this is called "carry-over" step) . Once these two steps are completed for one joint, it is assumed to be clamped back and the same process is repeated for other joints. The "balancing" and "carry-over" steps are repeated until the unbalanced moment at each joint becomes negligible.

II. Why use *Mathcad*?

Mathcad, which is an industry standard calculation software, is used because it is as versatile and powerful as programming languages, yet it is as easy to learn as a spreadsheet. Additionally, it is linked to the Internet and other applications one uses everyday.

In *Mathcad*, an expression or an equation looks the same way as one would see it in a textbook, and there is no difficult syntax to learn. Aside from looking the usual way, the expressions can be evaluated or the equations can be used to solve just about any mathematics problem one can think of. Text can be placed anywhere around the equations to document one's work. *Mathcad*'s two- and three-dimensional plots can be used to represent equations graphically. In addition, graphics taken from another Windows application can also be used for illustration purpose. *Mathcad* incorporates Microsoft's OLE 2 object linking and embedding standard to work with other applications. Through a combination of equations, text, and graphics in a single worksheet, keeping track of the most complex calculations becomes easy . An actual record of one's work is obtained by printing the worksheet exactly as it appears on the screen.

III. Program Features

The program developed will require input data pertaining to the geometry of the problem, material property and the loading. More specifically, the following information is required as input data: number of joints, number of members, type of end supports, length, moment of inertia and modulus of elasticity of each member, support settlements, magnitudes of distributed loads on members, and magnitudes and locations of concentrated loads. Based on the input data, calculations are carried out in the following steps:

1. Calculate the member stiffness for all members framing into each joint.
2. Calculate the joint stiffness for each joint.
3. Calculate the moment distribution factors for members framing into each joint..
4. Calculate the fixed-end moments for each member due to applied loadings and support settlements, if any.
5. Balance each joint by distributing the unbalanced moment (algebraic sum of the moments at each joint) with the sign changed, in proportion to the moment distribution factors. The results of this step are "distribution moments."
6. For each member, carry over one-half of the balancing moment from one end (except for the very end of a continuous beam or frame) to the other, provided the other end is not a simple support nor the free end of an overhang. The results of this step are "carry-over moments."
7. Repeat steps 5 and 6, until the carry-over moments become negligible.
8. Add, for each member end, the fixed-end moment and the results of steps 5 and 6 to obtain the final results (member-end moments).

IV. Results

The solutions obtained through use of this program for two example problems are shown in the following pages. Figure 1 shows the variables used in the program. Figures 2 through 4 pertain to Example 1, and Figures 5 through 7 relate to Example 2. For any of these problems, one or more input data change would translate to change in the member-end moments. Any number of combinations of input data is possible and students can see the effects of these changes instantaneously. Furthermore, with further additions to the program, it would be feasible to use computationally linked plots of shear and moment diagrams to provide additional graphical representation of results.

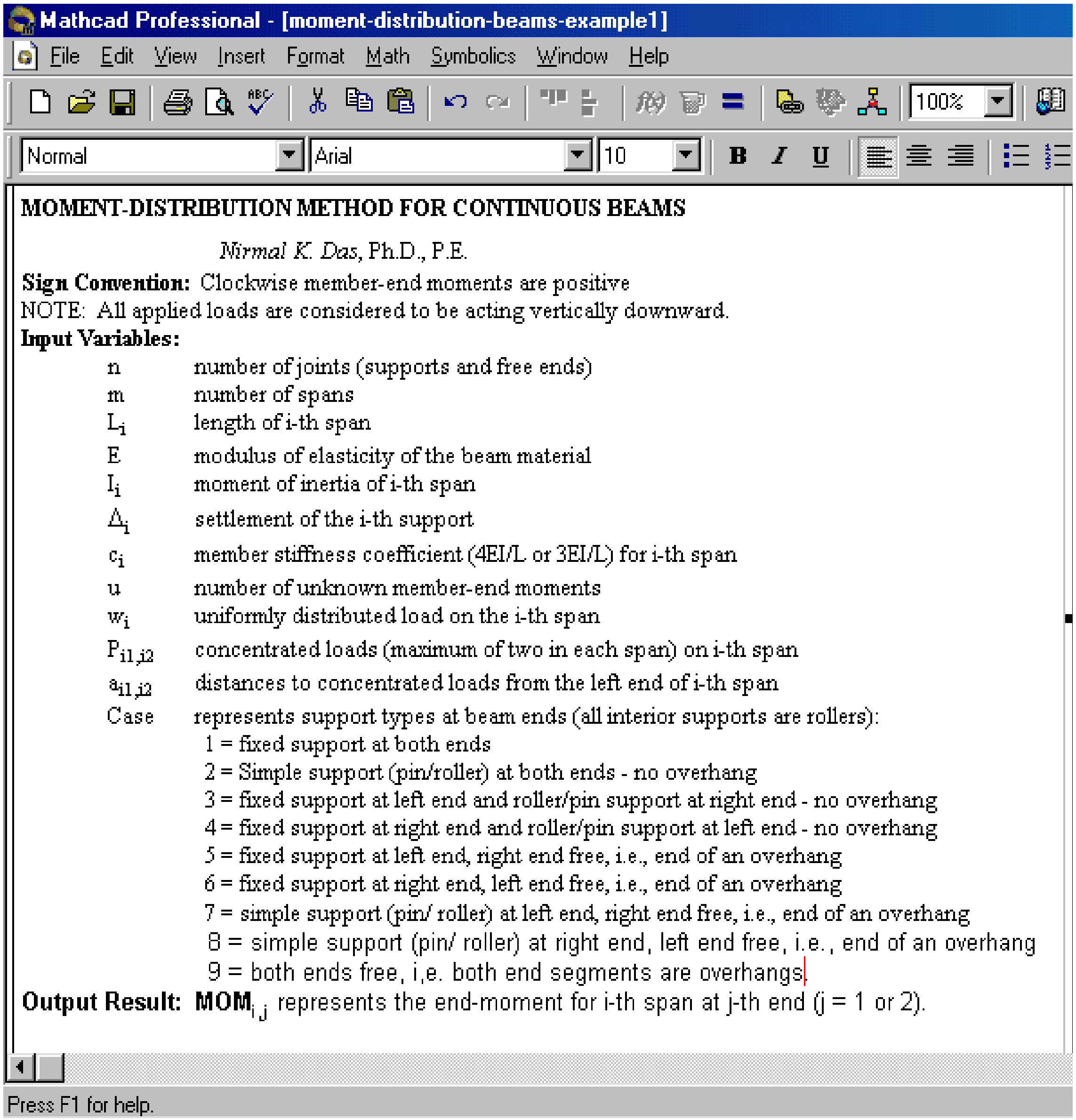

Figure 1. Nomenclature of variables

Example 1: Determine the member-end moments for the three-span continuous beam shown in Figure 2, due to the uniformly distributed load and due to the support settlements of 5/8 in. at B, 1½ in. at C, and ¾ in. at D. (Reference 2, Example 16.4)

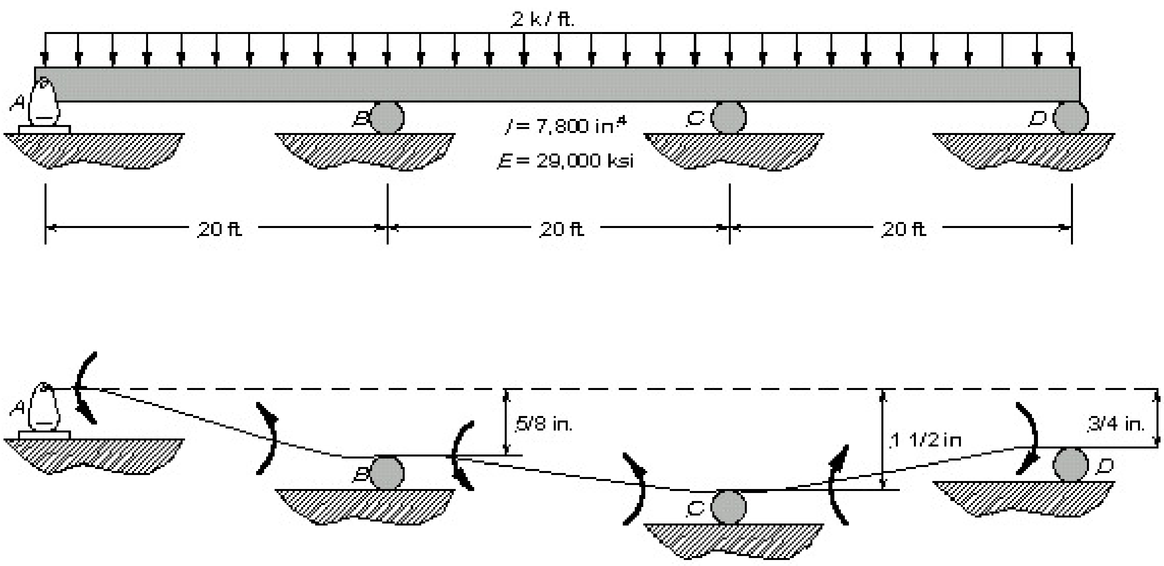

Figure 2. Continuous beam and support settlements of Example 1

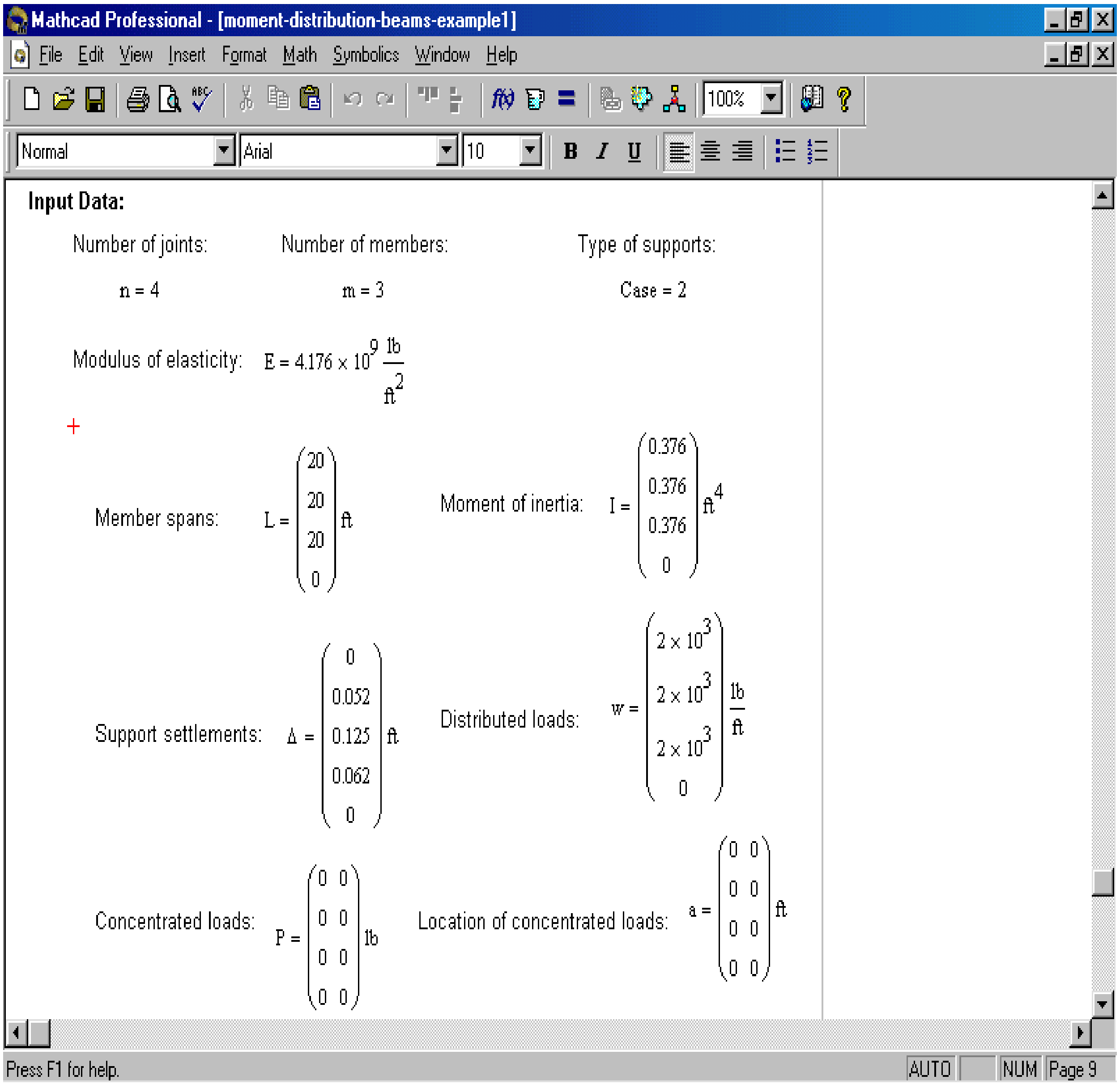

Figure 3. Input data for Example 1

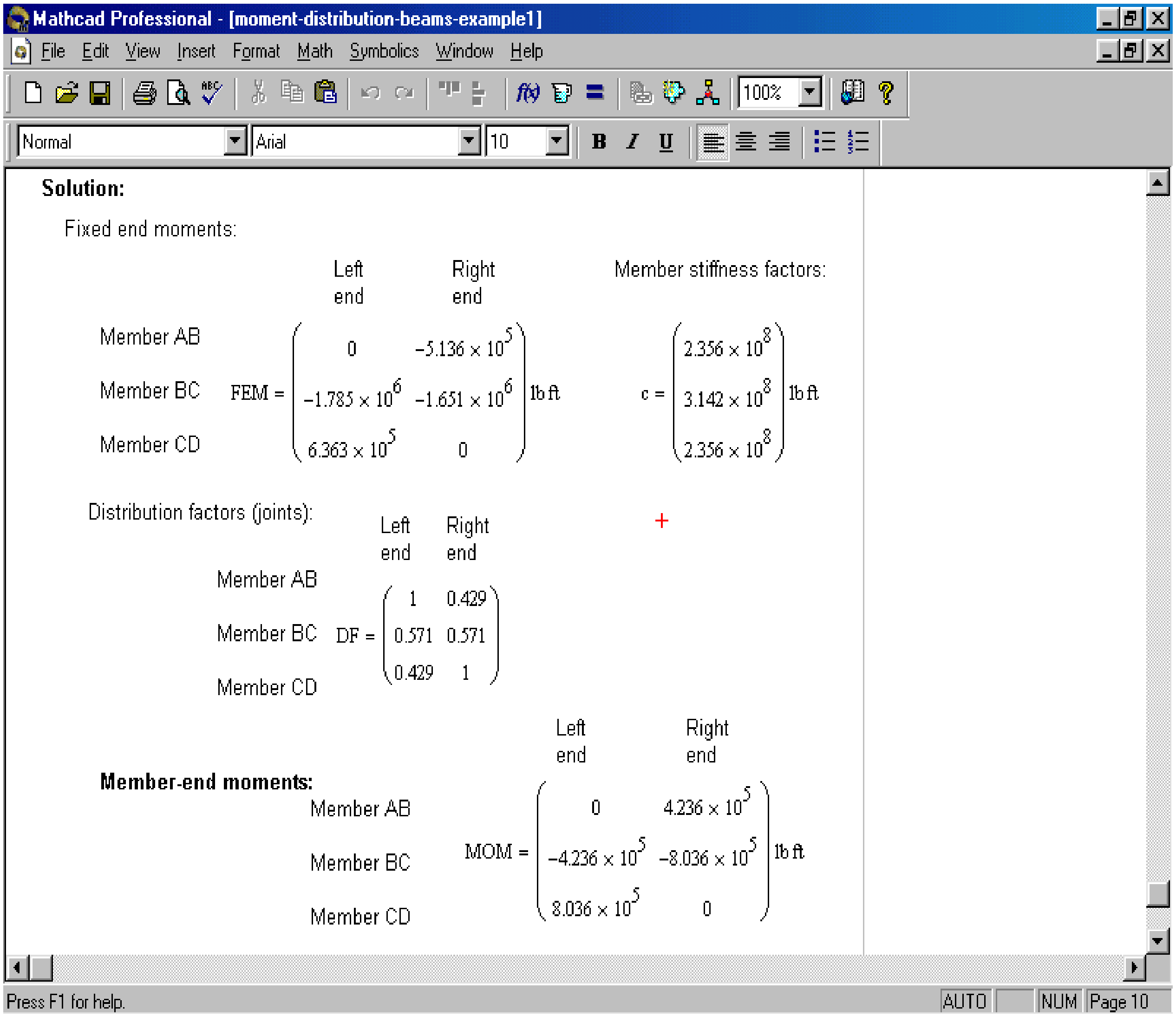

Figure 4. Solution to Example 1

Example 2: Determine the internal moment at each support of the beam shown in Figure 5. The moment of inertia of each span is as indicated. (Reference 1, Example 11-2)

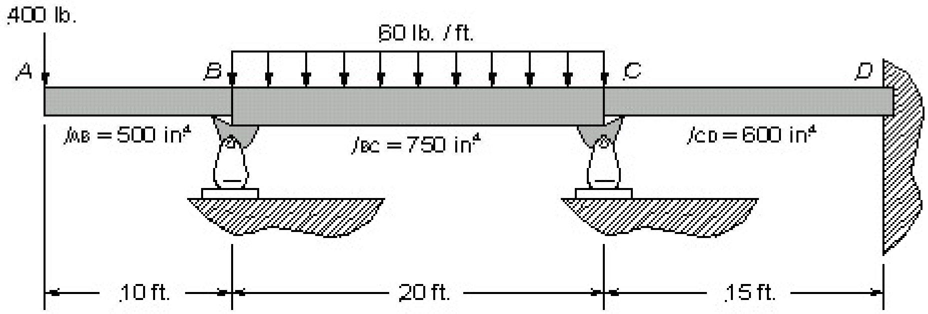

Figure 5. Continuous beam of Example 2

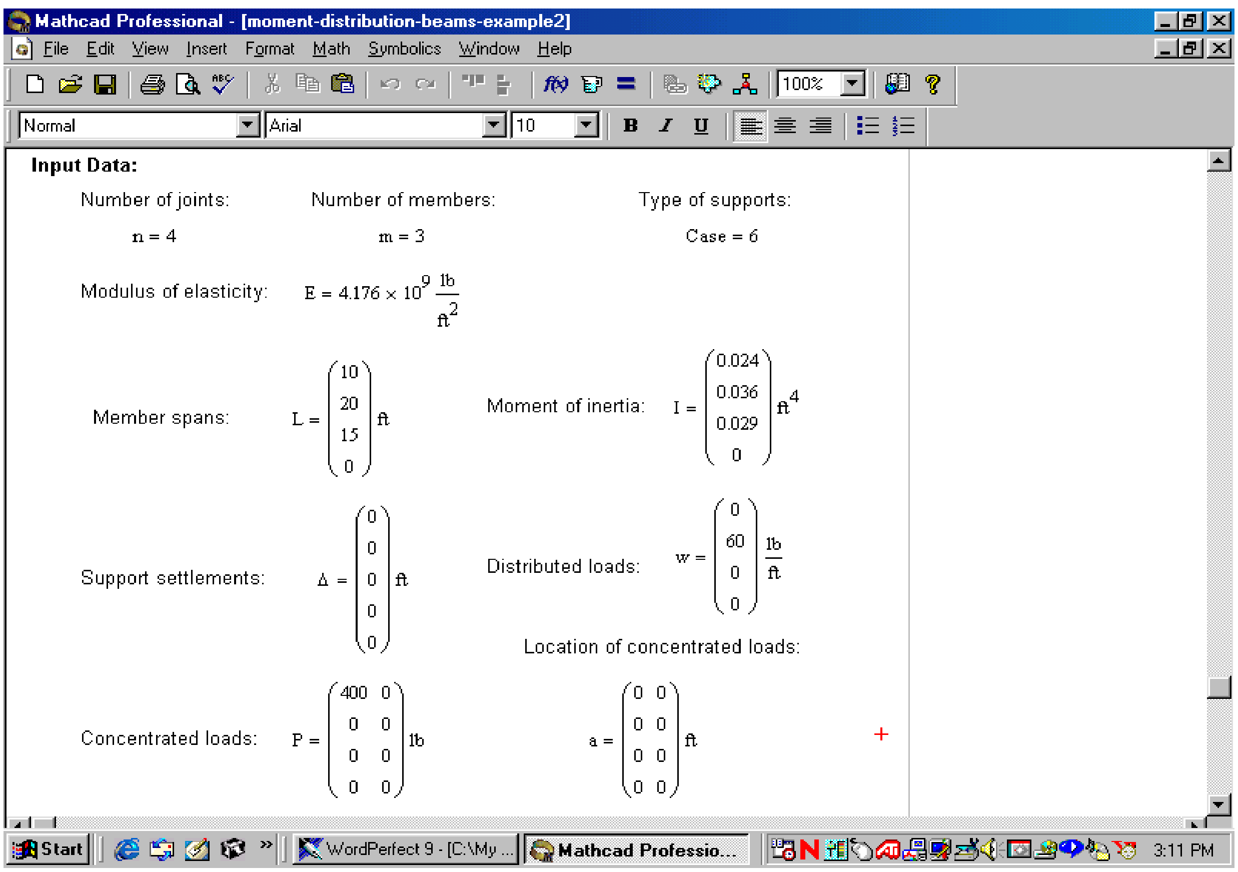

Figure 6. Input data for Example 2

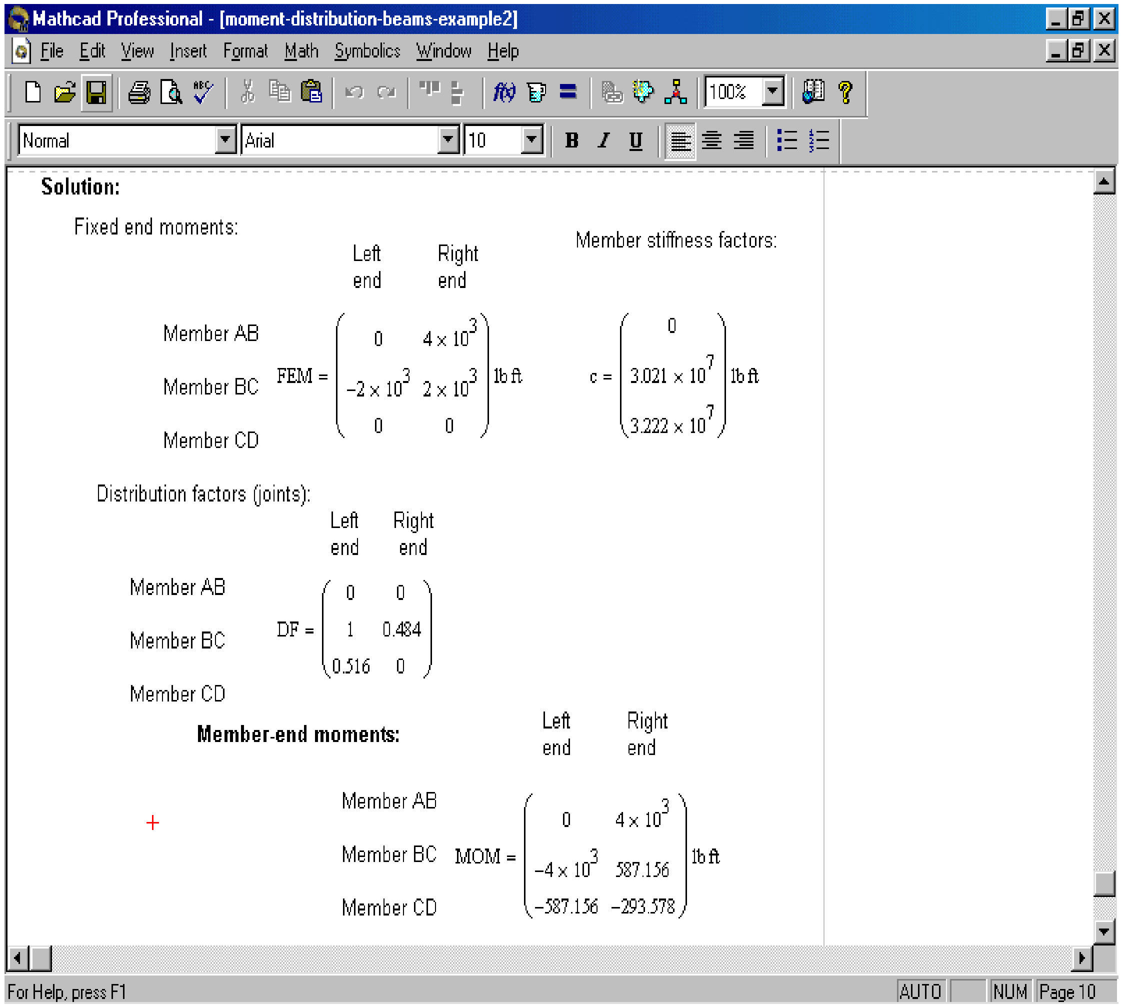

Figure 7. Solution to Example 2

V. Summary

The suggested approach to complement the traditional lecturing would likely provide a better insight in the subject matter, in addition to making a convenient checking procedure readily available. The students can easily verify the accuracy of their manual solutions for the member-end moments and support reactions of a continuous beam.

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