

# Teaching Structural Engineering Using a State-of-the-Art Computer Program

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## Abstract

Structural engineering computer programs are used extensively in the industry in order to analyze and design structures. Several classical methods of analysis that are still presented in textbooks on Structural Analysis have not been used in the industry for many years. Code checks are done using the computer and reports generated automatically now complement the engineer's hand calculations. In order to reflect the current engineering practices, the teaching of structural engineering should include computer programs. Basic concepts specific to computer modeling of structures include the definitions of nodes and members, degrees of freedom, connections, types of analysis, etc. State-of-the-art computer programs have wide applications and can be presented in several structural engineering courses such as Structural Analysis, Steel Design, Concrete Design, etc. By freeing students from sometimes tedious hand calculations, attention can be better focused on the behavior of structures. The present paper will briefly review the evolution of structural engineering computer programs and will present examples that show how a state-of-the-art computer program can be used effectively in teaching several courses in structural engineering.

## The Advent of Structural Engineering Computer Programs

It is generally recognized that one of the first uses of computers has been the analysis of structures. The finite element method, which works effectively only with computers, was developed by structural engineers in the early forties (Hrennikoff, A. 1941, McHenry, D. 1943, Courant, R. 1943). Nowadays, the finite element method is used also in other fields of engineering such as foundation engineering, stress analysis, heat transfer, fluid mechanics, electrical engineering, etc.

Structural analysis programs were used by practicing engineers as soon as they became commercially available. In the late sixties and early seventies, that is, before the era of the PC's, input data had to be prepared painstakingly on punched cards and the results were available several hours later, sometimes the following day, printed on large computer sheets with no graphics. As few engineering companies owned their own computer, jobs had to be brought to the companies specialized in providing such services for structural analysis.

## **The Use of Structural Engineering Programs in the Industry**

Today, structural engineering programs run on ordinary PC's under Microsoft Windows, as well as other computers and operating systems. There exist a large number of commercially available programs such as, from Canada: SAFI (SAFI Quality Software Inc. 2002); SFrame (Softek Services Ltd. 2002); from the U.S.A.: GT Strudl (Georgia Tech Research Corporation 2002); Staad (Research Engineers Inc. 2002); SAP2000 (Computers and Structures Inc. 2002); RAM Structural System (RAM International 2002); Larsa (Larsa Inc. 2002); and from Europe: Robot Millennium (RoboBAT 2002); etc. Some programs are used for special applications, such as TOWER (Power Line Systems Inc. 2002) for the analysis and design of electric power transportation and telecommunications towers.

Most engineering and construction companies, utilities, DOT's and professional engineers use one computer program or another on a daily basis. Complex projects, for example the construction of the new roof for the Montreal Olympic Stadium, the Experience Music Project in Seattle, just to name a few, would have been almost impossible to realize without the use of modern computer programs.

Structural engineering programs are improving rapidly and are becoming surprisingly powerful and user friendly. The following points are worth mentioning: graphical interfaces allow easy modeling of complex 3-D structures; data files containing material and cross-section properties allow quick definition of all elements in a model; loads and load combinations can be defined easily; advanced types of analysis, in addition to linear static analysis, can be done readily such as dynamic and seismic analyses, non linear large displacement as well as material non linear analyses; results, which include deformed shapes, support reactions, internal forces and stresses, modes of vibration, etc. can be displayed graphically on the computer screen or printed in full details.

Most structural engineering programs include complete design checks for structures made of steel, reinforced concrete, wood or aluminum, according to the relevant National Standards. Design checks of members are presented either graphically on the screen or printed in reports with full details. Member sizes can be optimized automatically. Programs also include routines for the design of shallow and deep foundations, shear walls, bridges, utility towers, etc., as well as routines for cost estimates of the modeled structures. The term "Structural Analysis Program", which was adequate 20 years ago, has become too restrictive. The authors suggest the term "Structural Engineering Program" for describing software now available to engineers for analyzing as well as designing complete structures.

## **Teaching Structural Engineering With State-of-the-Art Computer Programs**

Computer programs can complement classical teaching since they include most elementary and advanced concepts of structural engineering and hence can be used for many demonstrations. They can be introduced to some extent in the teaching of most courses, which include Strength of Material, Structural Analysis, Steel Design, Reinforced Concrete Design, Wood Design, Structural Design Project, Seismic Design, Dynamics of Structures, High-rise Structures, Bridges and Towers, Stability of Structures, Plates and Shells, Foundations, etc.

The particular choice of a computer program used in the courses is not restrictive. By learning how to use a given program, students acquire the basic concepts of computer modeling

of structures common to most programs. Later, they will be able to learn easily other programs as required.

Most computer programs perform more or less the same tasks. However, some programs have certain convenient features. The first author has evaluated different commercially available programs for teaching structural engineering courses. The following recommendations for the selection of a program can be made:

- The program should be complete enough so that it can be used in different courses such as Structural Analysis, Steel Design and Reinforced Concrete Design. Hence, students will be able to concentrate on the subjects taught rather than on learning new programs.
- The program should be used in the industry. Students will learn how to use the program and will be able to use it later on real engineering jobs. Programs provided at the back of textbooks on Structural Analysis are usually very basic because they are meant simply as an introduction to the matrix method of structural analysis.
- The program should be easy to learn and to use, and it should be user friendly and efficient.
- The program should be well documented with reference manuals available at low cost to students.
- The program should have a demo version available for free or at low cost so that students can practice and solve simple problems at home.
- The program must be very robust and performing well in a student computer laboratory, which can be at times a very harsh environment.

Teaching structural engineering should reflect the reality of the industry, that is, structural engineering has become a high tech field of engineering. Engineers face ever-increasing challenges such as designing taller skyscrapers, longer span bridges and buildings with larger open spaces. They are often required to design more economical structures. Design schedules are usually very tight. In addition, Standards now require that P-delta (non-linear) and seismic analyses be carried out for most types of structures. Such requirements can only be met with the help of modern computer programs and hence most structural engineers are now relying extensively on their use. The tendency for analyzing and designing structures using the computer is also reinforced by the fact that drafting, design and fabrication of structures are becoming an integrated process.

Structural engineers, including engineers in training, are requested to use computer programs. Proper training is required and there is a need for teaching, at an early stage, the basic concepts of modeling and designing structures using state-of-the-art structural engineering programs.

In the **Structural Analysis course**, students spend a few weeks studying the matrix method of analysis. Then, they are introduced to the concepts of structural modeling and learn the following basic definitions: nodes; members; degrees of freedom; types of connection: pinned, rigid, semi-rigid (Figure 1); support conditions: roller, fixed (Figure 2); global and local coordinate systems. Students model simple structures using a computer program (SAFI) and are able to experiment with the following topics: internal force and stress diagrams; deflection diagrams; behavior of trusses, beams and frames; instability; support conditions; types of connection; tributary areas; projected loads on inclined members; support settlements; inclined supports; thermal loads; moving loads; loads due to earthquakes, P-delta and non linear analysis, etc. Computer programs allow the study of structures in 2-D as well as in 3-D, and quick

comparison between different structures, for example statically determinate and indeterminate structures under thermal loads or with support settlements.

Students with technical background, familiar with drafting programs such as AutoCAD, learn quickly structural engineering programs that use graphics extensively. Students are soon able to solve simple problems as well as more complicated ones. By getting rid of sometimes tedious calculations, students can spend more time in studying the behavior of structures under various support and loading conditions.

Student's evaluation can be done through homework problems and examinations to be completed on the computer. Figure 3 shows an example of a homework problem in which the students are required to study different arrangements of a structure. The solution by hand calculations would be very long, but is achieved easily by using the computer. A problem of this type is meant to enhance understanding of structural behavior, here the effect of having different support and framing arrangements. Figure 4 shows an examination question in which the students are asked to model a simple structure.

The same structural engineering program (SAFI) is used in the **Steel Design course**. Students are generally enthusiastic about using the program. The following topics are first covered in the traditional way, by using hand calculations, and then are treated using the computer program: beams; columns; beam-columns; composite beams; P- $\Delta$  analysis of frames; roof diaphragms.

The **Structural Analysis and Design Project course** uses extensively still the same computer program. Students are required to design an existing two-story building. They are given the architectural drawings and have to compute the loads due to use and occupancy, wind, snow and earthquakes according to the National Building Code. They select structural systems for vertical resistance and lateral resistance, and model the entire structure on the computer (Figure 5). They find the forces in all structural members and design a number of beams, columns and bracings in either steel or reinforced concrete. Technological tools such as the Steel Calculator™ and the Concrete Calculator™ (SAFI Quality Software Inc. 2002) have proven to be very effective in design and are ideally suited for educational purposes.

Such a case study is similar to what the students will be asked to do when they become engineers. Students apply what they have learned in Structural Analysis, Steel Design and Reinforced Concrete Design. Motivation is high because they realize that the project is close to real engineering.

## **Conclusions**

State-of-the-art structural engineering computer programs are widely used in the industry. Teaching structural engineering should include these computer programs and present them in several courses in order to demonstrate concepts of structural engineering and complement classical teaching. SAFI Quality Software Inc. collaborates with technical schools and universities in order to help them achieve their goals by acquiring such modern technologies for educational purposes. Students introduced early on to state-of-the-art structural engineering computer programs will be better prepared for today's challenges.

## Acknowledgments

This work was supported by an Educational and Research Grant, PSIRE-ENS 2000-2001, from the School of High Technology, Montréal, Canada.

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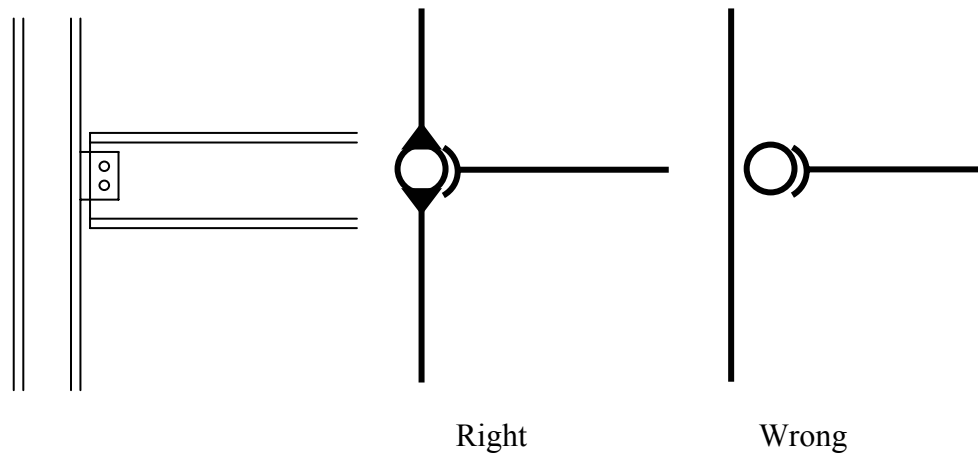
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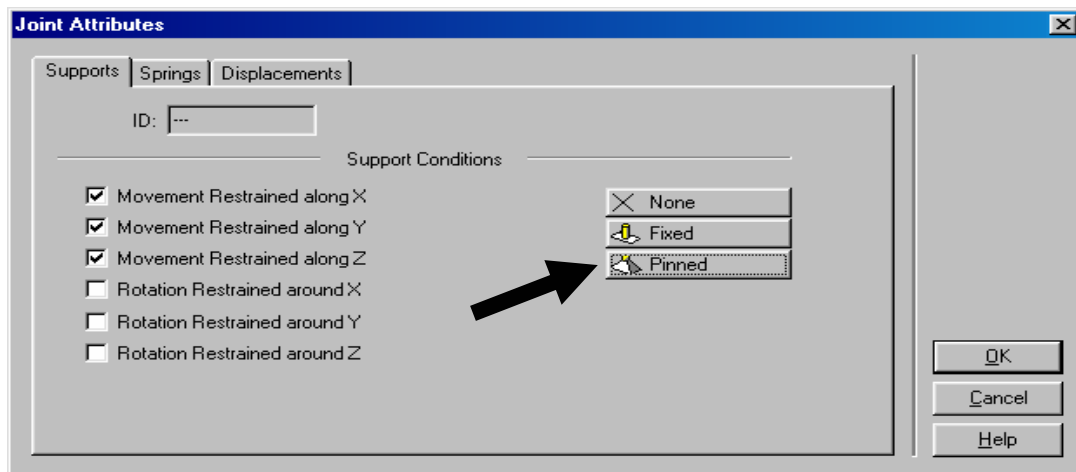
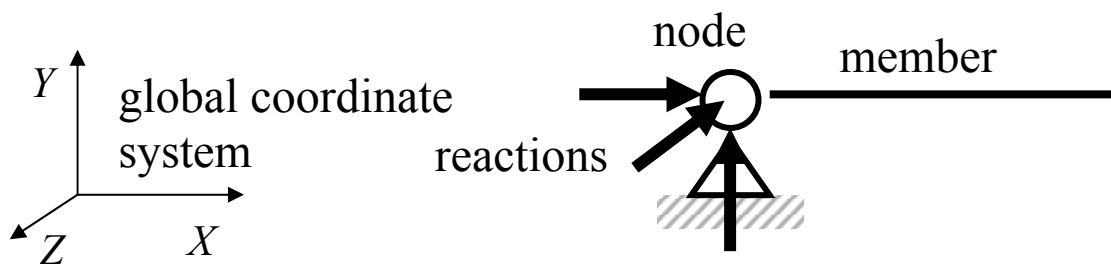
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**Figure 1. Basic concepts of structural modeling in the Structural Analysis course. Connecting members to nodes. Example: Beam to column simple connection.**



**Figure 2. Basic concepts of structural modeling in the Structural Analysis course. Modeling supports (3-D analysis): Pinned support.**

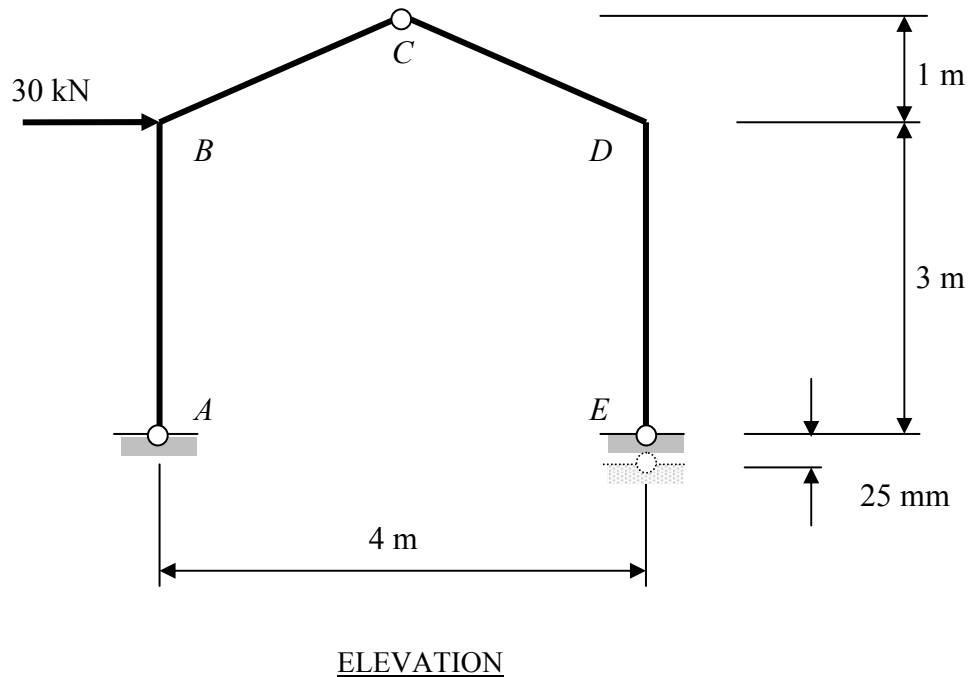
Analyze the frame shown in the Figure below. All members of the frame are made of 350W steel W310x45 sections oriented in such a way as to act about the strong axis. Consider the self-weight of the members and compare the following types of construction:

- Three-hinged arch: pinned supports at  $A$  and  $E$ , pinned connection at point  $C$
- Rigid frame with fixed supports: fixed supports at  $A$  and  $E$ , rigid connection at point  $C$
- Rigid frame with simple supports: pinned supports at  $A$  and  $E$ , rigid connection at point  $C$

Consider the following two distinct load cases:

- Lateral static 30 kN load applied at point  $B$
- 25 mm settlement at support  $E$

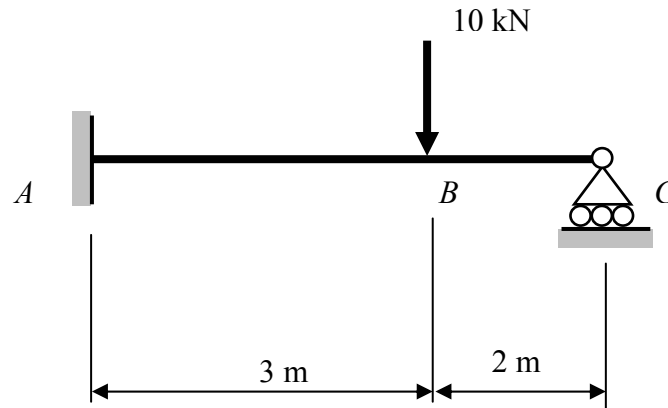
For each model, generate the deformed structure and bending moment diagrams showing numerical values. Compare the values of the horizontal displacement at point  $B$  and the maximum bending moment in the structure. Present the results in a Table and comment on the flexibility of the structure and bending moments that developed in the structures for the different types of construction.



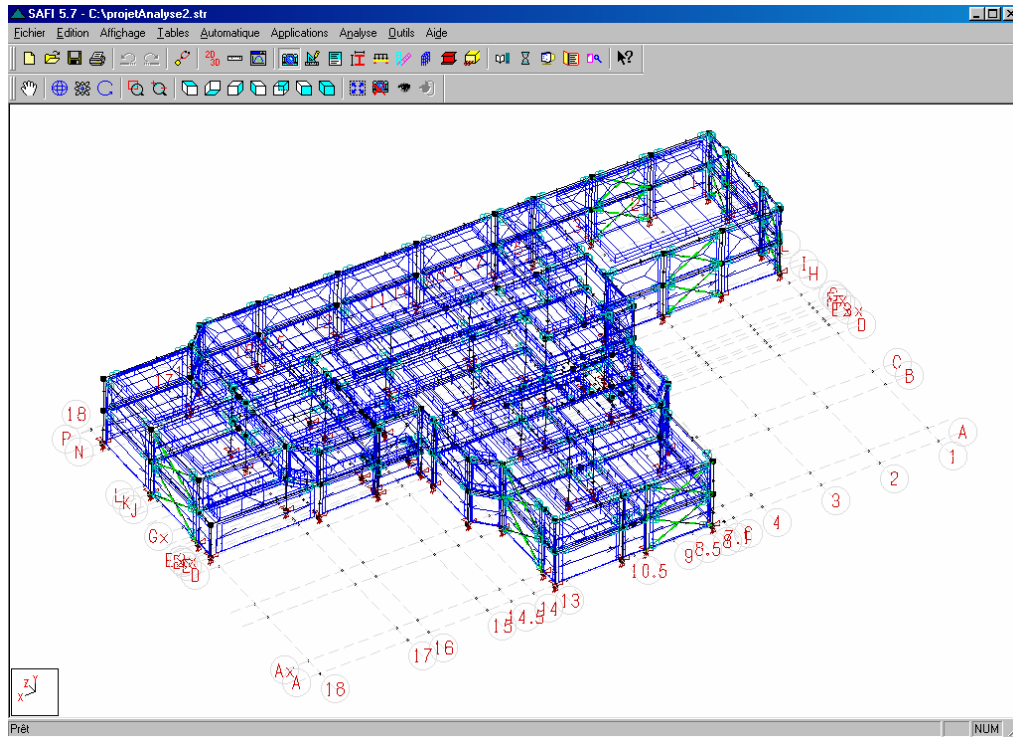
**Figure 3. Homework problem in the Structural Analysis course.**

Analyze the statically indeterminate fixed-end beam shown in the Figure below. The beam is 5 m long and is made of a W460x67 section oriented in such a way as to act about the strong axis. Consider the self-weight of the beam. Perform a linear static analysis and calculate:

- the maximum shear force (absolute value) along the beam,
- the maximum positive bending moment along the beam,
- the maximum deflection along the beam.



**Figure 4. Examination question in the Structural Analysis course.**



**Figure 5. Structural Design Project Course: Design of a Two-Story Building.**