Teaching Structural Engineering with SAFI Software

Dominique Bauer, Eng., Ph.D.
Department of Construction Engineering
École de Technologie Supérieure
Montréal, Québec

ABSTRACT

A brief review is presented of the evolution of structural engineering computer programs and their current use in the industry. The reasons justifying the teaching of these programs in the structural engineering courses are presented. The choice of SAFI software is explained and a few applications of structural engineering concepts are briefly addressed.

HISTORICAL REVIEW

Since the beginning of the computer science, construction engineers have used computers to solve complex problems in the analysis of structures. The finite element method was developed by structural engineers at the beginning of the nineteen-forties (Hrennikoff 1941, McHenry 1943, Courant 1943). Today, this method is widely used beyond the field of structural analysis, that is, in stress analysis, heat transfer, fluid mechanics and electricity.

In structural engineering, computer programs are used for the study of all kinds of structures including residential, commercial, institutional and industrial. These structures are most often built from steel or reinforced concrete, but also from wood, masonry and aluminum.

Structural analysis programs have been developed and used very early by construction engineers. Before the advent of the PC's, data was carefully prepared on punched cards and the results were available several hours later, printed on huge accordion-folded sheets of paper. It was the good old times.

THE USE OF STRUCTURAL ENGINEERING SOFTWARE IN THE INDUSTRY

Today, structural engineering computer programs are used on personal computers under the Windows platform. Several commercial programs exist and some of the best known are SAFI, VisualDesign, SFrame, Staad, Etabs, etc. Specialised programs also exist, for example the Tower program which was developed for the study of telecommunication and power line towers.

The vast majority of engineering firms and departments, for example at Hydro Quebec and the Quebec Ministry of Transportation, now use one computer programs or another. The achievement of special projects, for example the construction of the new roof for the Montreal Olympic Stadium (Bauer et al. 1998) would have been impossible without modern structural engineering software.

The power and user-friendliness of structural engineering software are outstanding. Graphical interfaces allow for easy modeling of complex structures, databases for material properties and standard sections allow for quick definition of members. Loads and load combinations can be quickly established, and linear elastic analyses as well as dynamic, large displacements and material non linear analyses can easily be carried out. Results, i.e. deformations, support reactions, axial forces, shear forces, bending moments, corresponding stresses, modes of vibration, etc. can all be graphically displayed on screen, printed or transferred to spreadsheets.

Moreover, structural engineering software nowadays includes design code requirements for steel structures (CSA 1994a), reinforced concrete (CSA 1994b), aluminum (CSA 1983), etc., which permits the design of members. Design results are presented in color graphics and detailed reports. Some programs, for example SAFI (2001), offer additional modules for the design of special structures such as bridges and towers.

The author believes that the expression "structural analysis programs" has become too restrictive. He proposes instead the expression "structural engineering software" in order to reflect the fact that computer programs now perform both structural analysis and design.

TEACHING WITH STRUCTURAL ENGINEERING SOFTWARE

In order to reflect the industry practice and educate the students up to modern structural calculation techniques, the author believes that it is essential to teach structural engineering software in courses such as Structural Analysis, Reinforced Concrete, Steel Structures, and Structural Design. The reasons are simple as explained below.

As soon as the young engineer enters the work market, he will have to use structural engineering computer programs, since traditional methods such as Moment Distribution (Samikian 1994) have become obsolete for a while. By getting familiar with structural engineering software, the student receives an education adapted to the needs of the industry.

Concerning the course on Structural Analysis (Bauer 2001a), several concepts exist specific to structural modeling that must be mastered when using a structural engineering computer program. The elementary definitions of nodes, members, degrees of freedom, supports, rigid and pinned joints, local and global coordinates systems, etc. all have to be well understood by the future engineer in order to prevent potentially serious errors in structural calculations.

It is important to note that most elementary principles of structural analysis can be well explained with structural engineering software, often in a more illustrative way than with traditional hand calculations. For example, the following points taken from a course on Structural Analysis are taught by the author using SAFI:

- types of supports and joints;
- tributary areas and load distributions on floors (one-way and two-way actions, with joists);
- distributed loads on an inclined member;
- support settlements;
- behaviour of structures, for example the internal forces and lateral stiffness of a three-hinge frame compared to those of a rigid frame (Figure 1);
- etc.

As soon as the student masters a structural engineering computer program, he is in possession of an outstanding tool for the solution and checking of all problems he will have to solve in his homeworks and laboratories, not only in Structural Analysis but also in other structural engineering courses.

CHOOSING AND USING SAFI

The specific computer program selected for teaching structural engineering is not restrictive for the student. By learning his first software, the future engineer acquires the basic principles related to computer modeling of structures common to all structural engineering software. Later, he will be able to switch easily to another program as required in his work.

Because commercial programs are based on matrix calculations and have reached a high level of maturity, all programs perform more or less the same tasks, yet each one has its own strengths and weaknesses. Among several available programs, SAFI (2001) was chosen by the author for teaching courses in Structural Analysis, Steel Structures, and Structural Design. SAFI software has the following advantages:

- developed in Quebec and available in English and French;
- widely used in the construction industry by consulting engineers, Hydro-Quebec, the Ministry of Transportation, etc.;
- simple to learn and to use, user-friendly, efficient and complete;
- ranks among the best structural engineering computer programs regarding tools for modeling, analysis and result processing;
- complete set of manuals, written in English and French, containing clear explanations on how to use the software. Manuals are available at an affordable cost to the students;
- SAFI is robust and behaves very well in the sometimes difficult environment of computer laboratories;
- free download of the software demo version limited to the analysing structures with 50 nodes and 50 members. This demo is quite sufficient for learning the main features of the program used in the courses on Structural Analysis, Reinforced Concrete and Steel Structures. Students can use the demo at home or on a laptop computer.
- retained by STEEL Plus Network, sponsored by Canam-Manac, as the recommended software for structural engineering calculations;

- won the Hot Products Award for the Steel Calculator™, conferred by the American Institute of Steel Construction (AISC 2000).

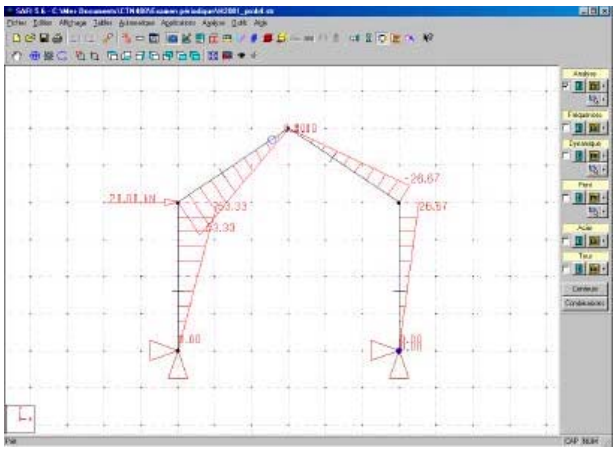

Figure 1. Modeling a Three-Hinge Frame with SAFI - Structural Analysis Course

Regarding the course on Steel Structures (Bauer 2001c), the author uses SAFI to illustrate the design of tension members, columns, beams, beam-columns, composite beams, diaphragms, global stability or P-Δ analysis, etc.

SAFI has become an essential part of the course on Structural Design (Bauer 2001b) in which the students design a two-storey building. Based on architectural plans, the students have to design the structural system, compute loads according to the National Building Code, and then model the entire structure using SAFI (Figure 3). The model is then used to determine the internal forces in the main members of the structure, i.e. columns, beams and bracings, and to design them in steel or reinforced concrete. This assignment closely corresponds to the work performed by practicing structural engineers.

The author believes that it would be very useful to use SAFI software also for the course on Reinforced Concrete, as well as graduate courses in Rehabilitation of Civil Engineering Works and Rehabilitation of Buildings.

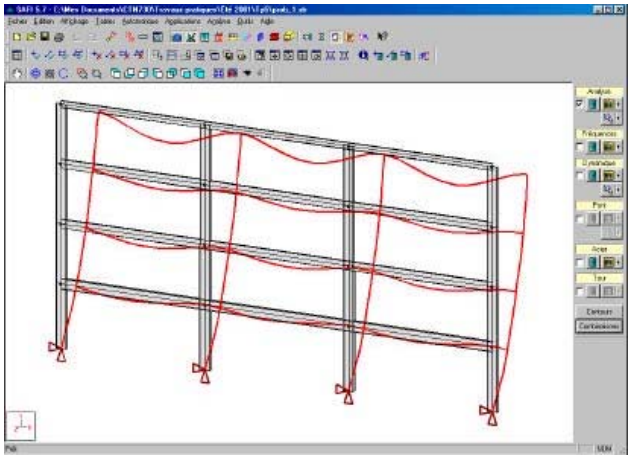

Figure 2. Global Stability Analysis (P-Δ Effect) of a Steel Frame with SAFI - Steel Structures Course

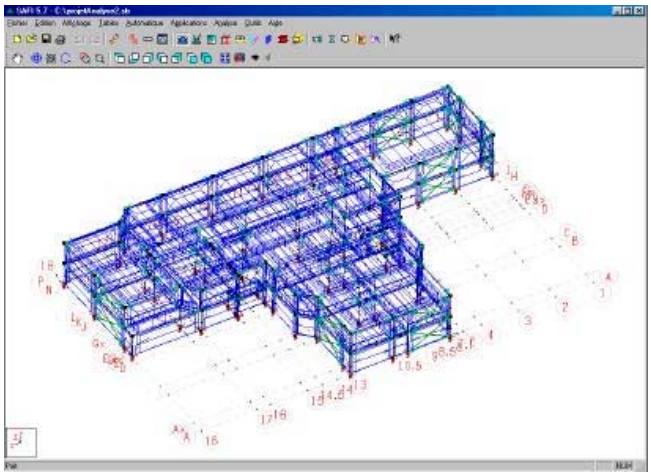

Figure 3. Modeling of a Two-Storey Building with SAFI - Structural Design Course

CONCLUSION

Structural engineering software is widely used in the construction industry and should be taught in structural engineering courses. The author successfully used SAFI software to illustrate several structural engineering principles in the courses on Structural Analysis, Structural Design and Steel Structures.

ACKNOWLEDGEMENTS

This educational development project was made possible thanks to a grant from the Institutional Support Program for Research and Teaching PSIRE-Teaching 2000-2001 of the École de Technologie Supérieure.

REFERENCES

AISC 2000. Modern Steel Construction. American Institute of Steel Construction, August.

Bauer D. 2001a. CTN408 Structural Analysis – Lecture Notes. Construction Engineering Department, École de technologie supérieure.

Bauer D. 2001b. CTN605 Structural Design – Lecture Notes. Construction Engineering Department, École de technologie supérieure.

Bauer D. 2001c. CTN730 Steel Structures – Lecture Notes. Construction Engineering Department, École de technologie supérieure.

Bauer D., Bouzaiene H., Gauthier Y. 1998. Design of the Montreal Olympic Stadium Roof. Report RSW/LMB. Presented to the Olympic Installations Authority (RIO).

Courant R. 1943. Variational Methods for the Solution of Problems of Equilibrium and Vibrations. Bulletin of the American Mathematical Society, Vol. 49, pp. 1-23.

CSA 1994a. Limit States Design of Steel Structures CAN/CSA-S16.1-94, Canadian Standard Association.

CSA 1994b. Design of Concrete Structures A23.3-94, Canadian Standard Association.

CSA 1983. Strength Design in Aluminum CAN3-S157-M83, Canadian Standard Association.

Hrennikoff A. 1941. Solution of Problems in Elasticity by the Frame Work Method. Journal of Applied Mechanics, Vol. 8, No. 4, pp. 169-175.

Mc Henry D. 1943. A Lattice Analogy for the Solution of Plane Stress Problems. Journal of Institution of Civil Engineers, Vol. 21, pp. 59-82.

SAFI 2001. User's Manual SAFI 5.7. SAFI Quality Software Inc. Ste-Foy, Quebec.

Samikian A. 1994. Analyse et calcul des structures. Gaëtan Morin éditeur, 580 pages.