Incorporating Software Usage in Teaching Structural Analysis Courses in Civil Engineering

Chiara Silvestri, Worcester Polytechnic Institute, Worcester
Adriana Hera, Worcester Polytechnic Institute, Worcester
Malcolm H. Ray, Worcester Polytechnic Institute, Worcester
Siamak Najafi, Worcester Polytechnic Institute, Worcester

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Abstract

This paper illustrates an approach of software integration in teaching structural analysis courses in civil engineering. The authors describe key facets of their methodology to enhance the students understanding of the engineering notions and to motivate them exploring alternative solutions to practical problems. Two particular cases, involving instruction of undergraduate and graduate level classes, are here depicted. Software packages for technical computing (MATLAB) and finite element analysis (ANSYS) served for development of classroom demonstrations and assignments in a matrix analysis of structures undergraduate course. Transient dynamic finite element program (LS-DYNA) and pre and post-processor (LsPrePost) were employed for illustration of wave propagation concepts taught in an impact strength of materials and crashworthiness graduate class.

To help students acquiring the necessary skills to effectively use these software applications and to understand the process by which commercial software is correctly used, Matlab training sessions, ANSYS invited lectures and LS-DYNA tutorials were incorporated in the development of the courses. These approaches helped students to interactively become acquainted with the engineering concepts and to go beyond the information presented during class. Furthermore, the necessity to validate the assignments results obtained using the software packages stimulated students to reconsider and deepen the understanding of the theoretical concepts.

Introduction

The new generation of students has been raised in a digital world, as multimedia, technology and social networking can testify. Instructors of engineering courses should take advantage of this revolution and include technology into their courses as a tool to improve the learning process and enhance the curiosity of the students. Technology could be used for self-directed learning, especially in learn-distance classes, and would require the student to interactively become acquainted with the engineering concepts and to go beyond the information presented during class. Moreover, especially in classes that are predominantly theoretical, technology can be used for visualization of abstract notions, raising the interest of the students and facilitating their understanding for a more complete and competitive preparation for their stepping into the work-world. This paper illustrates an approach of integrating software in teaching structural analysis courses in civil engineering to enhance the students understanding of engineering notions and to stimulate them exploring alternative solutions to practical problems. Two cases are here depicted: an undergraduate class where MATLAB and ANSYS software are employed to assist in teaching matrix analysis concepts and a graduate class in impact and crashworthiness for which FE LS-DYNA and pre and post-processor LsPrePost were used for illustration of wave propagation concepts.

MATLAB is a high-performance programming language for technical computing that integrates computation, visualization and programming in an easy-to-use environment [1]. It can be used for numeric computation, data analysis, data visualization and algorithm development for a wide range of applications. Since, as its name suggests (MATrix LABoratory), Matlab is especially designed for matrix operations, we found this software as the appropriate tool for numeric computation to be integrated in a "Matrix Analysis of Structures" course.

ANSYS is a family of products used to numerically solve, by using finite element (FE) method, a wide variety of engineering problem in the field of structural mechanics, heat transfer, fluid dynamics, as well as acoustic and electromagnetic and coupled field analyses [2]. ANSYS is one of the standard Finite Element Analysis (FEA) teaching tools in many universities. In "Matrix Analysis of Structures" course, we used the application ANSYS Classic which provides a graphical user interface and, at the same time, challenges the students to understand and explore the underlying theory and concepts of finite element analysis.

LS-DYNA, developed by the Livermore Software Technology Corporation (LSTC), is an advanced simulation software package designed for non-linear transient dynamic finite element analysis [3]. Both options for explicit and implicit time integration calculation are feasible. LS-DYNA is used in a wide range of areas which include automobile, aerospace and military use, but also bioengineering, manufacturing, explosions, etc… Ls-PrePost (developed by the Livermore Software Technology Corporation (LSTC)), is a mesh generator and is employed as pre-processors for FE analysis [4]. Also, Ls-PrePost can be used as post-processor to process the results from FE solvers.

Envisioning the increased integration of technology in the classroom and software usage in the courses, in March 2006, WPI initiated a new information technology (IT) program, intended to support the academic undergraduate and graduate curriculum by providing training sessions on main scientific and engineering software applications (SESA) and technical expertise to assist the research efforts of students and faculty.

This program proved to become very popular and highly appreciated by students and is considered a valuable resource by faculty. At the end of the academic year 2008-2009, 24% (over 1000 students) of currently enrolled students (approx. 4500) attended an average of 5 hours of training. As a result of this program and other similar activities, most of WPI students incorporate numerical solutions and simulations in their projects and HW assignments. Finite element and computational fluid dynamics analyses are included in undergraduate students major qualifying projects (MQP) and more realistic solutions are developed.

Scientific and Engineering Software Applications (SESA) Training at WPI

The SESA training program started with training sessions and technical support on software applications such as Matlab, ANSYS, and Fluent. At the request of students and faculty members, over the last three years, the offer was expanded to training sessions on MathCAD, CES EduPack, Labview and Comsol. For each supported software application training sessions and office hours were offered, as well as one-to-one consultations and assistance by email and phone. Most of the training sessions are hands-on and last two-three hours. They can either be of general interest (open to all WPI students), or customized, geared towards a specific course or project. Each training session presents the basics concepts and is problem solving oriented. The main goal is to help the students to acquire the necessary skills and knowledge to use software in their projects and for various simulations. The interest on these training sessions increased over years, as summarized in Table 1, and a clear shift of the interest from general sessions to more specialized sessions, customized according to class curriculum can be observed.

Table 1. Distribution of SESA training sessions over years.

	# Training Sessions			# Attendees	Average # of training hours per student
	Total	Customized sessions	General sessions		
Mar 06-Aug 06	56	3	53	255	4.2
Aug 06 - Aug 07	97	40	57	468	3.7
Aug 07 - Aug 08	111	63	48	561	3.4
Aug 08 - Aug 09	150	92	58	750	4.2

As part of this program, during last academic year 2008-2009, over 150 SESA Training sessions were conducted, with 750 attendees, including 540 engineering students which represent 26% of the enrolled engineering students at WPI. Each student took an average of 4.2 hours of training. We worked together with 22 faculty members from seven academic departments, and conducted 92 training sessions tailored to a specific course's needs and assignments.

Objectives

Following are listed the main objectives the authors aimed to reach by incorporating software into civil engineering courses:

- Introducing the students to numerical computing programs and finite element (FE) software, which are nowadays widely used for solving real-world problems in various areas of engineering field;
- Developing tutorials at different levels on FE and pre-processors/post-processors software to be electronically uploaded on the information portal available for members of the WPI community;
- Using software for faster learning of concepts that are generally too abstract and tedious to visualize, enhancing the curiosity of the students to the subject considered and motivating them for self-directed learning, creativity, and empowerment.

The methodology used to accomplish these objectives is next illustrated for two civil engineering courses: the undergraduate course CE 4007 “Matrix Analysis of Structures” and the graduate class CE 527 “Impact Strength of Materials and Structural Crashworthiness”.

Examples of Software Incorporation in Civil Engineering Courses

CE 4007. "Matrix Analysis of Structures". The undergraduate class CE 4007 "Matrix Analysis of Structures" offered at the Civil and Environmental Engineering (CEE) department at WPI is taught during one spring term, for a total period of seven weeks, with a capacity of less than 30 students. It is held four times a week for 50 minutes. Summary of the relevant course topics/assignments is as follows.

Contents. This course presents the principles of matrix analysis of structural elements and systems. Analysis of structures subjected to point loads, distributed loads, temperature change, member fabrication error, pre-stressed members and support displacement is discussed. Topics include displacement method, principle of virtual work, analysis of continuous beams, analysis of plane frames, plane trusses, analysis of building frames and bridges. Homework is directed to analyze structures using different methodologies. In the very first weeks of course, assignments are asked to be solved by hand, to let the student familiarize with the main concepts and increase his/her ability in approaching the problems. With the increase in the complexity of the problems, software packages for technical computing (MATLAB) and finite element analysis (ANSYS) are employed in the following weeks in order to lead students to understand the potentials of using numerical tools for solution and result visualization.

Use of Software. Once the students became familiar with the main theoretical concepts of the course, as part of SESA Training, two Matlab hands-on training sessions were offered. The first two-hour session included topics such as Matlab basics with emphasis on matrix manipulation, writing a script, plotting data and user defined functions. At the end of this session, Matlab homework exercises were assigned and additional help was offered to the students with no previous Matlab experience. The second lecture was geared towards matrix analysis of structures. Students learned how to write a Matlab program to analyze a planar truss. The problem used as example was part of previous assignment that required the student to solve by hand for the unknown displacements, reactions and member forces in a planar truss. At the end of the second training session, the students were able to write under guidance the code to solve the problem and to develop a set of templates to be used and expended in the subsequent assignments. At the request of students, SESA Training program scheduled few more Matlab help sessions to assist students acquiring the necessary skills to write, debug and evaluate code for correctness.

The second software application used in this course was ANSYS. Two ANSYS invited lectures were offered. In the first lecture, students became familiar with the ANSYS environment and the stages of FEA. The second lecture was focused on using ANSYS to analyze the planar truss included in a previous homework assignment and the second Matlab training session. After completing these two ANSYS sessions, students were able to use ANSYS Graphical User Interface efficiently, and incorporate ANSYS solution along with Matlab solution and hand calculations in their final project. An example of employment of Matlab and ANSYS in this class is shown in Fig.1.

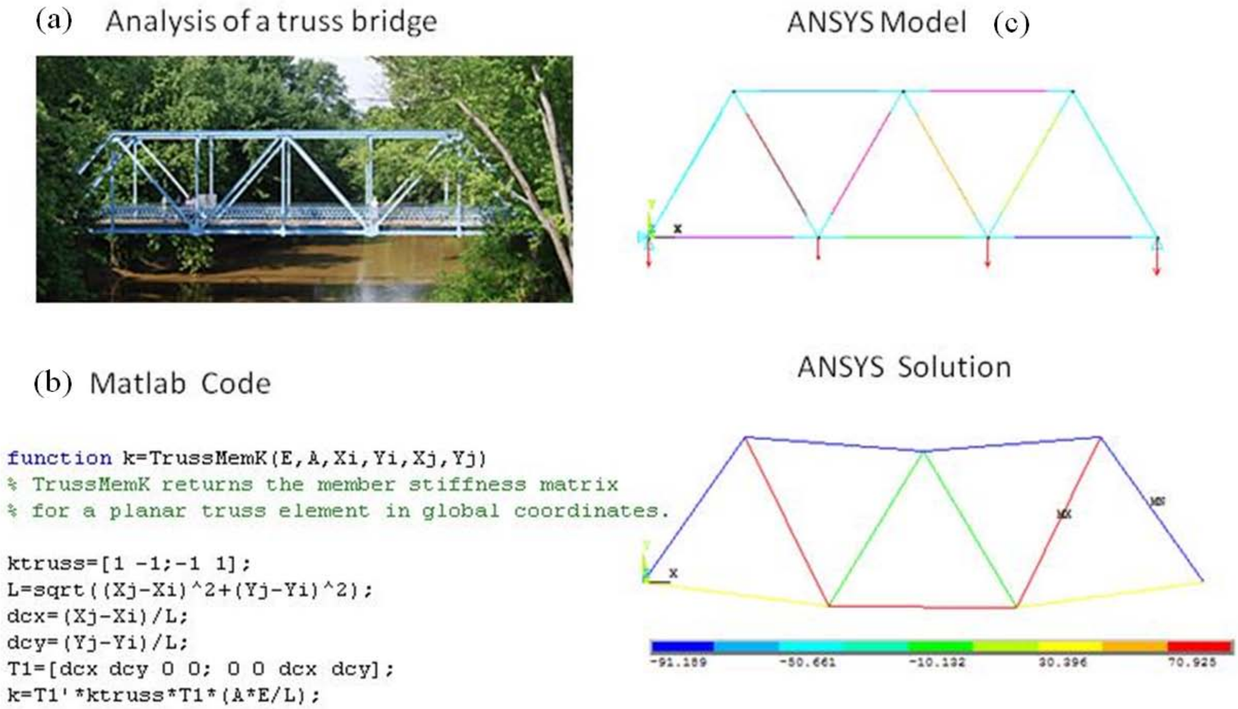

Figure 1. Example of employment of Matlab and ANSYS software applications in CE-4007 undergraduate course: (a) problem definition (analysis of truss bridge), (b) Matlab programming and (c) ANSYS FE modeling.

CE 527 "Impact Strength of Materials and Structural Crashworthiness". The graduate class CE 527 "Impact Strength of Materials and Structural Crashworthiness" is taught during fall semester, for a total period of 14 weeks. Its capacity is between 10 and 15 graduate students. It is held for three hours, one day a week. Summary of the relevant course topics/assignments is as follows.

Contents. With this course, the basic mechanics of impact is taught and attention is given to the behavior of materials subjected to dynamic loadings. Elastic and plastic stress wave theory is introduced, as well as the behaviour of colliding bodies. In the first part of the course, homework is assigned on a weekly basis and requires the student to solve wave propagation conceptual problems by hand. In the second part of the course, students are requested to develop and solve a project based on an impact and crashworthiness concept of their interest. For this final project, students need to use the FE software introduced in class, to allow for a complete and easier solution of the problem chosen.

Use of Software. This course includes an introduction to the use of LS-DYNA and LsPrePost software, which are mainly employed to allow for visualization of abstract wave propagation concepts. Besides, these FE packages supported numerical replication of impact experiments which were conducted during laboratory hours. The students were also required to pro-actively use the software for completion of a final team-project in the area of impact and structural crashworthiness of their interest.

Tutorials on use of the software were prepared by the instructor and made available on the information portal available for members of the WPI community. Given the multiple capabilities of the software, these tutorials were formulated as small demonstrations, no longer than five minutes, with the intention of addressing specific software features and being used according to the needs of the students.

An example of employment of LS-DYNA FE program in this class is reported in Fig.2. In this case, LS-DYNA was used to solve for propagation of elastic waves after collision of two steel rod bars.

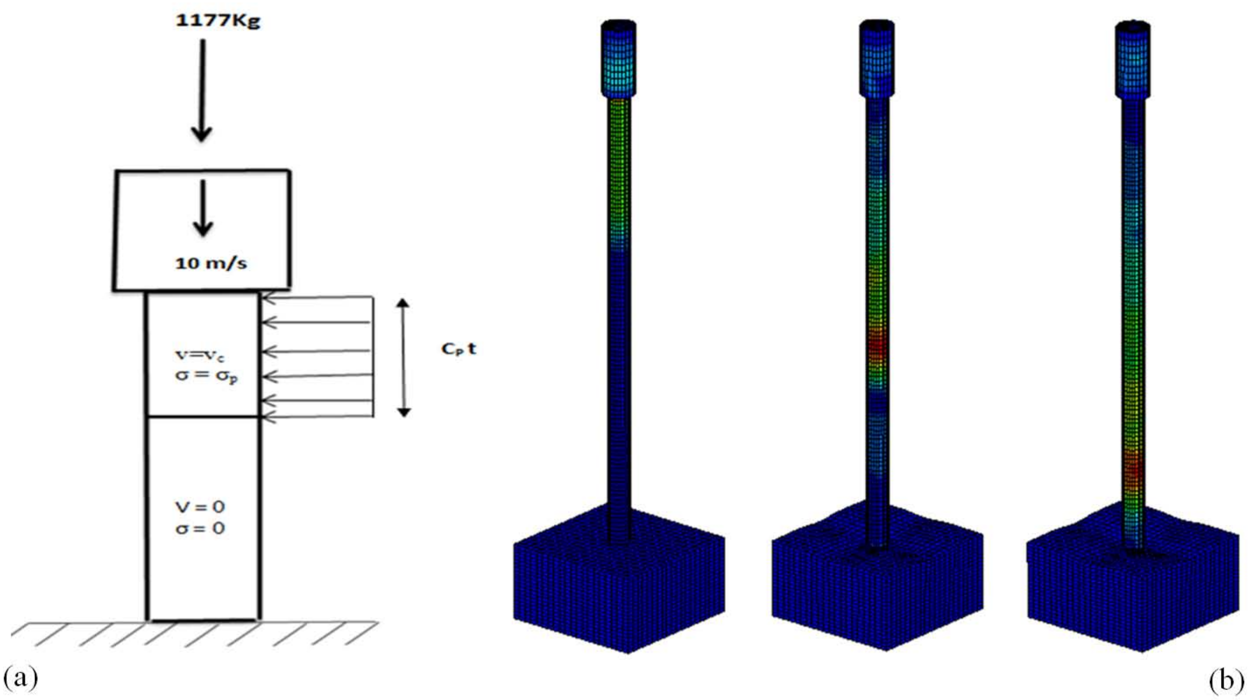

Figure 2. Example of employment of LS-DYNA FE software applications in CE-527 graduate course: (a) physical model and (b) visualization of elastic stress propagation for a model of a pile driving into soil.

Conclusion

In this paper, the authors presented an example of incorporating numeric computing and FE software in certain civil engineering classes, as a tool to support theoretical aspects and numerically replicate experiments conducted during laboratory hours. Matlab training sessions, ANSYS invited lectures and LS-DYNA tutorials were offered to students. These sessions were tailored to address tasks and topics from the class syllabus.

The students had the opportunity to familiarize with different software options and to become able to conduct independent valuable research and studies by employing these numerical tools. As result, students were able to understand the process by which commercial software is correctly used and the results are wisely critiqued. In addition, incorporating the software in class benefited the students by facilitating the understanding and visualization of theoretical concepts that are generally of an abstract nature.

With inclusion of SESA training, the instructors were relieved from the time-consuming task of teaching software during the class time, while the students had access to one more resource of direct help and support. Considering the high success the SESA training sessions had among students and faculty at WPI, the authors are oriented to continue supporting this activity by developing more training sessions, lecture notes and animated tutorials in the near future.

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Biographies

Chiara Silvestri

Chiara Silvestri is an Adjunct Assistant Professor in Civil Engineering at Worcester Polytechnic Institute, USA. After receiving her Master degree in Aerospace Engineering at Politecnico of Milan, Italy, she obtained her Ph.D. in Civil Engineering at WPI, where she has been working in the area of computation mechanics since six years. Her research interests include linear and nonlinear computational mechanics, impact, crashworthiness, roadside safety and biomechanics.

Adjunct Assistant Professor, Department of Civil and Environmental Engineering, Worcester Polytechnic Institute, 100 Institute Road, Worcester, MA, 01609 - USA -
Phone: +1-508-831-6671; Fax: +1-508-831-5808; E-mail: chiara@wpi.edu

Adriana Hera

Adriana Hera is an Academic Computing Applications Scientist in the Computing & Communication Center at Worcester Polytechnic Institute, USA. She is in charge of developing training sessions on scientific/engineering software applications to support the core academic undergraduate and graduate curriculum, and research activity. Her research interests include system identification, structural health monitoring, structural vibrations, stochastic dynamic systems, and wavelets. She holds a Ph.D. degree in Mechanical Engineering from WPI.

Academic Computing Applications Scientist, Computing and Communications Center, Worcester Polytechnic Institute, 100 Institute Road, Worcester, MA, 01609 - USA -
Phone: +1-508-831-5323; Fax: +1-508-831-5680; E-mail: ahera@wpi.edu

Malcolm H. Ray

Malcolm H. Ray directs WPI's Impact Engineering Program and the Structural Mechanics Impact Laboratory. He is a professor of civil and environmental engineering at WPI, USA. His research interests include using FE methods to evaluate the crashworthiness of structures, in-service performance of roadside features, verification and validation methods in computational impact mechanics, and side-impact crash testing and evaluation methods. He holds degrees from University of Vermont (BS), Carnegie Mellon (MS), and Vanderbilt University (PhD).

Professor, Department of Civil and Environmental Engineering, Worcester Polytechnic Institute
100 Institute Road, Worcester, MA, 01609 - USA -
Phone: +1-508-831-6671; Fax: +1-508-831-5808; E-mail: mhray@wpi.edu

Siamak M. Z. Najafi

Mr. Najafi is responsible for assuring that the Information Technology needs of each academic department at WPI are met. In addition to the departmental needs, he is leading the effort to improve the research computing facilities available to the faculty, laboratories and research centers including oversight of the development of WPI's High Performance Computing tools.

Director of Research Computing and Academic Departmental Support, Computing and Communications Center, Worcester Polytechnic Institute, 100 Institute Road, Worcester, MA, 01609 - USA -, Phone: +1-508-831-5752; Fax: +1-508-831-5680; E-mail: snajafi@wpi.edu