Understanding 2D Structural Analysis: Learning Modules in the Modeling and Analysis of Structures

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ABSTRACT. Civil Engineering schools may integrate the use of commercial computer software in the civil engineering curriculum to enhance the teaching and learning process. A one-unit (three-hour laboratory) computer-oriented course on “Computer Methods in Structural Engineering” is introduced in the undergraduate civil engineering curriculum at De La Salle University, Manila. This computer laboratory course aims to introduce the students on the use of state-of-the-art civil engineering software in solving both routine and complicated problems in the analysis and design of structures. One of the software that will be used is GRASP, a user-friendly software for two-dimensional analysis of framed structures. This paper describes the development of learning and instructional materials using a commercial software to deepen the students’ understanding of the modeling, analysis and behavior of structures in 2D.

1. INTRODUCTION

The rapid development of fast, powerful and affordable microcomputers has resulted in the professional engineers’ extensive use of sophisticated computer software in the solution of large, complex and sometimes even common problems. Specialized software for various civil engineering applications have now become a useful and necessary tool in the industry these days. The increasing reliance of engineers on computer software in the performance of their tasks requires that civil engineering students, the future professional engineers, must be knowledgeable of sound engineering concepts, updated on the latest computer technology used in the industry and aware of the limitations and capabilities of the computer in solving engineering problems. To address these issues, the Civil Engineering (CE) Department of De La Salle University - Manila will offer a new computer-oriented course in the undergraduate program starting with the incoming freshmen SY2003-04. This course is a one unit computer laboratory for all CE students.

The course is a supplement to the structural analysis and design subjects in the BSCE program. The main objective of the course is to enhance the understanding of the students in structural modeling, analysis and behavior by exposing them to the use of state-of-the-art software. The course is basically a “hands-on, learning-by-doing” class where students will be required to perform computer exercises and by analyzing the graphical and numerical results, they will understand the effects of various parameters on structural behavior.

Depending on the available software, the course may be divided into phases such as (a) 2D analysis; (b) 3D analysis; (c) Structural Design. The first part of the course is modeling and analysis of structures in 2D. The computer exercises for this phase may be completed during the first half of the term.

DLSU-Manila presently has a strong linkage with the Asian Center for Computations and Software (ACECOMS) of AIT, Thailand with the Department of Civil Engineering designated as an ACECOMS Satellite Center. The department has acquired and received state-of-the-art software on structural engineering. One of them is GRASP – a 2D structural analysis software.

The present project aims to develop instructional and learning materials for understanding structural modeling, analysis and behavior of framed structures in 2D with the aid of the software GRASP.

2. A COMPUTER-ORIENTED COURSE IN STRUCTURAL ENGINEERING

2.1. Rationale and Objectives

Civil Engineering schools may integrate the use of software in the civil engineering curriculum to enhance the teaching and learning process. The computer software may be introduced to students in specialized courses in Structural Analysis, Reinforced Concrete Design and Steel Design and/or a separate computer-oriented course may be offered. A separate computer-oriented course is introduced in the civil engineering curriculum at DLSU-Manila. This course is a one-unit computer laboratory subject (three hours per week) with a course title of “Computer Methods in Structural Engineering”. The course is a supplement to the structural analysis and design subjects in the BSCE program. The main objective of the course is to deepen the understanding of the students in structural modeling, analysis, design and behavior by exposing them to the use of state-of-the-art software. An advantage of using software in the classroom is that more complex and larger structures may be analyzed and designed by the students, which is not possible by manual calculations or a calculator. This increases the student’s “feel” to real life problems. Another advantage of using these software, especially those with graphics, is that students can visualize the behavior of complex systems. By using a software, a student may follow a “cause and effect” type of activity wherein parameters are varied and the
effect on the system is observed. By interpreting the graphical results visually and comparing numerical results, the student learns new insights and discovers new knowledge which will expand his understanding on the implications of various parameters to structural analysis and design.

The danger of using sophisticated software, however, should also be recognized. Students using powerful software can suffer from the “black box” syndrome. As the program becomes more complex, it becomes increasingly likely that the student will not understand the internal workings of the program and the possibility of “garbage in, garbage out” becomes most likely where the student can not detect the errors. Engineers should understand the logic, algorithm, capability and limitations of the computer software. The saying that “knowing how to run a program is not the same as knowing how a program runs” must be emphasized. The engineer, as the design professional, has the responsibility for the design of the civil engineering systems, which were derived using computer software. Although commercial software developers have a moral and ethical responsibility to produce software reasonably free of programming and technical errors, they have no control over how or by whom the software is used. It is thus imperative that users of computer software must be equipped with the proper background of engineering concepts and tools and must use sound engineering judgement and common sense. It is thus important that before exposing the students to specialized software, they should have a solid background on the theory of structures. Learning to use the software is not the end and main objective of the course. But what must be developed in the students is their ability to make sound judgement based on results obtained from the software 1.

2.2. Prerequisite Subjects

The prerequisite subjects for this course are basic computer programming and the structural analysis subjects. A three-unit programming course is usually taken by the students in their third year. Students who have completed the programming course are expected to be familiar with the basic operation of the computer and related hardware and the Windows operating system. Since this course focuses on the use of state-of-the-art CE software on structural analysis and design, the students must have completed the basic structural analysis subjects. In the CE curriculum, there are two structural analysis subjects: (a) STRUCT1 – a four unit course on advanced topics in mechanics of materials and introduction to theory of structures; and (b) STRUCT2 – a three unit course on the structural analysis of statically determinate and indeterminate structures. During this term also, the students have already completed RCPRINS, a reinforced concrete design subject and are enrolled in STELDES, a steel design subject.

2.3. Learning Strategy

To achieve the learning objectives, the author decided to adopt an active learning approach where students “learn by doing”. The basic responsibility of the faculty in a “learning by doing” strategy is to design an appropriate learning environment wherein (a) the students are personally involved in the learning task, and b) knowledge or information must be discovered by the students themselves. The objectives may be accomplished by assigning computer exercises which the students accomplish during the laboratory class. To achieve these objectives, teaching and learning materials must be developed.

This paper describes the development of learning and instructional materials using a commercial structural analysis software to deepen the students’ understanding of the modeling, analysis and behavior of framed structures in 2D.

3. UNDERSTANDING STRUCTURAL ANALYSIS

Structural analysis is an integral part of any structural engineering project. Its main objective is to determine the stresses or stress resultants in the members and the deflections at various points of the structure. The results of the structural analysis are used in the structural design of members, which must satisfy the safety and serviceability requirements of the design codes. If the code requirements are not satisfied, then the member sizes are revised and a re-analysis of the model of the structure is carried out until all safety and serviceability requirements are satisfied.

Recognizing the importance of structural analysis in the tasks of a civil engineer, the undergraduate civil engineering curriculum requires subjects related to structural analysis which includes Engineering Mechanics - Statics (3 units) and Dynamics (3 units), Strength of Materials (3 units), Structural Analysis I (4 units) and Structural Analysis II (3 units). In these courses, the student learns the fundamentals of modeling and analyzing structures usually two-dimensional or plane trusses, and beams from the determination of support reactions, computation of internal forces to prediction of displacements using various methods such as double integration method, moment-area method, Castigliano’s method, method of virtual work or conjugate beam method. Classical methods of analysis of statically determinate and indeterminate structures such as Moment Distribution Method, Slope Deflection Method, Method of Consistent Deformation and the Direct Stiffness Method are discussed. A student who understands the theory and techniques discussed in these courses is equipped with the tools and background needed in structural design.

There is still room for improvement in the teaching of structural analysis by introducing the computer and commercial software in the classroom. The rapid development of computer technologies, which include powerful and affordable microcomputers and reliable and user-friendly software in structural analysis has started to change the delivery of instruction in higher education. Computers have greatly increased the ability of students to perform calculations and to process large amount of data. As a result, the type and nature of problems and mathematical techniques taught in school should adopt to new technology and maximize the usefulness of the computer in the teaching-learning process. In what way can computer usage be introduced in the curriculum? How can we increase the awareness of students on the importance of computers in the solution of
various problems in civil engineering? Through this one-unit computer laboratory course, the computer and appropriate software in structural analysis are used as tools to improve the teaching-learning process. An advantage of using a structural analysis software in the classroom is that more complex and larger structures may be analyzed and designed by the students, which is not possible in the regular class in structural analysis where the calculator or general math solvers (e.g. spreadsheets) are used by students in their calculations. Another advantage of using these software, especially those with graphics, is that students can visualize the behavior of complex systems. The software can be used to simulate a variety of structural and loading configurations and to determine cause and effect relationships between loading and various structural parameters, thereby enhancing the students’ understanding on the behavior of structures. This increases the student’s “feel” to real life problems.

Software for structural analysis are now available commercially – from simple to more sophisticated software and affordable to expensive ones (e.g. MicroFEAP, GRASP, BATS, STAAD, ETABS, SAP2000). Some textbooks in structural analysis (e.g., Kassimali 2, Hibbeler 3) also contain CD-ROM with software. In this course, GRASP, a user-friendly software is introduced for two-dimensional analysis of framed structures due to several reasons: (a) it is affordable; (b) it uses the Windows operating system which is common in most microcomputers; and (c) it uses a graphics user interface (GUI).

4. INTRODUCING GRASP

GRASP, which stands for Graphical Rapid Analysis of Structures Program, is a user-friendly software for two dimensional analysis of framed structures which includes beams, trusses and rigid frames. Especially developed for the Windows, GRASP provides an interactive, easy to use, graphical environment for modeling and analysis (Fig. 1). The major features of GRASP include:

- Modeling and analysis of multiple models in one file
- Presetting of default load cases and load factors
- Internal and automatic tracking of node numbers and member incidences
- Display the structural model at all times on the screen during analysis and superimposition of the analysis results on the model after analysis
- A Structure Wizard provides a step-by-step guideline for the generation of multistory structural models (Fig. 2)
- Supports SI, US and metric units and use of mixed units (Fig. 3)
- Apply loads on nodes and on members in multiple load cases (Fig. 4)
- Various restraint conditions including spring supports (Fig. 5)
GRASP allows the user to select different member cross-sections, material properties, and restraint conditions from its library. Member cross-sections may be any of the eight pre-defined types. Material properties are defined by the user. Support restraints can be specified by on-screen selection from several pre-defined cross-sections and restraint identification in GRASP is in a graphical manner.

GRASP is ideally suited for rapid and easy analysis of simple structures and can also be used as an educational tool. GRASP is primarily based on a graphical means of interaction with the user and can provide direct feedback and effect of modifications.

5. LEARNING MODULES USING GRASP

An exploratory-type of instructional and learning material consisting of a set of modules is proposed. Each module focuses on a structural analysis issue which is presented through a case study. Included in the modules are hands-on exercises and problems on two-dimensional analysis of framed structures (beams, trusses, and rigid frames). Using the set of learning modules, the student with the aid of GRASP discovers the behavior of structures due to variations in the parameters of the model and configurations of the structure, changes in member and material properties, and also changes in the restraint and loading conditions. Through the graphical results, students can visualize the phenomena and this would accelerate their understanding of concepts through the experience of seeing and interpreting solutions to many different problems.
The set of learning modules is not a substitute to a textbook on structural analysis. The theory will not be presented. No derivations or equations can be found. The student must refer to the textbooks for definitions, equations and techniques. Each module will focus on a specific issue. A case study on the issue will be presented and walk through. The student by observing the graphical results and by interpreting the numerical output discovers important insight and can make conclusions. The implication and relevance of the structural analysis issue to the safe and reliable design of structures is also discussed. The module ends with a similar or related problem which the student has to solve using GRASP. Since GRASP provides direct feedback graphically and numerically, the student can explore and have fun by simple modification of the configuration of the structural model or loading condition and will discover new knowledge related to the structural analysis issue of the module.

Among the issues that may be addressed by the learning modules are:

(a) **Pattern Loading**: How should the live loads be placed so that the maximum internal forces at critical points of the frame can be determined? The individual members of a building frame must be designed for the worst combination of loads that can be expected to occur during its useful life. Live loads such as floor loads from human occupancy can be placed in various ways, some of which will result in larger effects than others. For this issue, the live loading can be placed on the frame in a great variety of different schemes (e.g. Fig. 8).

(b) **Lateral Loads in Plane Frames**: What is the effect of lateral loads due to earthquake or wind on the internal forces of a building frame? A case study where two frames, one without lateral loads and another frame with lateral loads can be presented and their internal forces compared (e.g., Fig. 9).

(c) **Restraint Conditions**: How do support conditions affect the behavior of a structure? Support restraints can be specified by on-screen selection easily in GRASP. The use of spring elements to model footings resting in soft soil can also be done. Fig. 10 compares the axial forces in the columns and beams of similar building frames with different support conditions.

(d) **Wind Loads on Roof Trusses**: How does wind direction affect the member axial forces and deflection of a roof truss? Wind pressures acting on the windward and leeward sides of the roof of a frame can be applied. Wind pressures acting towards the surfaces are positive, while negative pressures, called suctions, act away from the surfaces of the structures. Fig. 11 shows an example of the deflection of a truss.
Other modules addressing issues on modeling of structures such as strengthening of frames using diagonal braces, modeling of shear walls, hinges at connections, semi-rigid connections, offset connections, symmetric structures, modeling of foundations etc. can be also be developed. These issues are not discussed in detail in a regular structural analysis class due to time constraints and limitations in the size and complexity of structures that can be solved in class.

6. CONCLUSION

The university has a role in properly training engineering students to become competent professional engineers – updating them on the latest computer tools and technology used in the industry and providing them the necessary background and skills about engineering. The author believes that through the use of a computer software in structural analysis like GRASP in the one-unit computer laboratory course in structural engineering, students will deepen their understanding of structural analysis of two-dimensional structures and will discover the implications of various parameters in carrying-out the safe design of structures. Using a user-friendly software in structural analysis increases the process of learning new insights which is not possible in a regular structural analysis class. Learning the use of the software is not the end and main objective of the course. By adapting a “learning by doing” approach through hands-on computer exercises, students will develop their analytical and self-teaching skills, and will sharpen their judgement in interpreting computer output.

REFERENCES


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