GP133/abs053

Role of commercial software in teaching finite element analysis at undergraduate level: a case study

Faiz Uddin Ahmed Shaikh (s.ahmed@curtin.edu.au)

Curtin University, Perth, Australia.

Abstract: *Finite element analysis (FEA) is an advanced analysis method in structural engineering. In most universities around the world, it is still offering at postgraduate level due to vast amount of complex theoretical contents which are beyond the capacity of undergraduate students. In the past, FEA was mostly used in research and specialized jobs through the use of in-house computer program. However, with the advancement of computer technology and numerical solution techniques, specialized FEA software in structural analysis and design are now commercially available and are used widely in the industry. The FEA results provide the insight of the stress and strain distributions of a structure to the engineer/designer, which is not possible or time consuming using the conventional/classical analytical methods. The user friendly nature of new generation FEA software can stimulate the teaching and learning experience of advanced structural analysis and can provide the students with satisfaction of learning by discovery and deep understanding. This paper presents author's observation and experience on the use of general purpose FEA software "Strand7" in the teaching and learning of finite element analysis of structural problems in the undergraduate final year class at Curtin University. A brief description on theoretical course contents on FEA and the strategic use of Strand7 software to supplement student's understanding of FEA theory and its use in the problem based FEA assignment is provided. It is observed that the use of Strand7 greatly helped students understanding of FEA of structures. The feedback from students show that the exposure of Strand7 in their tutorial and assignment project helped their development in the advanced analysis of structures using finite element method and increased their preparedness for engineering practice or graduate school after graduation.*

Introduction

Rapid development in computer aided structural analysis and design can be seen in the past decades. The advancement of computer technology especially the processing speed and powerful language such as C, C++, etc. accelerated this development and as a result various commercial software packages are readily available to assist with all phases of design process from ideation to analysis and design (Oreta, 2005). Computer-aided analysis and design tools have become an essential part of the modern design environment and engineering curricula has evolved to include instruction in this field. Virtually all engineering schools include instruction in computer-aided analysis and design to some extent. Analysis and design software has become so powerful that a novice can conduct sophisticated analyses without knowing very much about the details or limitations of the analysis process.

Engineering analysis has always faced the challenge of modeling complex real problems by replacing the real problems with carefully designed, yet easily manipulated simpler problems which obey the same fundamental principles. The finite element method is a numerical technique that simulates physical behavior by means of a numerical process based on piecewise polynomial interpolation applied to the controlling fundamental equations. The finite element analysis (FEA) is a mathematical technique and computer based procedure that can be used to analyse structures and continua. This method has been used extensively during the past thirty years in industry due to advancement of computer technology and is now a standard engineering tool for both analysis and design of structures in many branches of engineering. FEA is probably the most widely used form of computer based engineering analysis and design now-a-days due to the availability of commercial software packages that have significantly reduced the complexities of the actual application of FEA.

It is also important to emphasize, however, that the reliability of the FEA results is highly dependent on the skills and the basic theoretical knowledge of the engineer in the application of the method. Modern finite element developments have become very sophisticated, and the available software developed for the user has become very easy and user friendly to use. It has become more important than ever to insure that the analyst, in his/her search for the best modeling method, correctly uses the tools available. It is more usual to teach FEA at the postgraduate level due to the complicated theories behind the method. However, there is also a benefit in introducing students to the application of FEA at undergraduate level (Zhuge and Mills, 2009).

Type of Education Required To Carry Out a Proper Finite Element Analysis

When FEA first appeared in the 1960's, it was introduced into the engineering curriculum at the graduate level. Because of the complexity of the FEA method and complex pre- and post-processing requirements of the FEA programs, only specialists did a majority of FEM analyses, mostly educated at the masters or doctoral level. As the method and computer technology matured over the decades, FEA is introduced at the undergraduate level in engineering (Miners and Link, 2000). Graphical user-friendly interfaces (GUI) have significantly reduced the complexities of the actual application of FEA software such that engineers with education equal to or less than the bachelor degree are using the technique today.

Finite element analysis (FEA) courses in academia at the undergraduate and graduate levels in engineering programs are mainly theoretical in nature (Reneis et al., 2007). Although some students and practitioners have taken an FEA course at the undergraduate and/or graduate level, many individuals have only been introduced to FEA in a short *training* course. These training courses enable an individual to 'build a model' and have the program run successfully to yield some output. However, these software-training courses fall short of teaching the supporting theory. This led to misuse of finite element technology where, new users tend to believe that any results that look good are probably right. Therefore, a person eager to use newly acquired software skills and lacking a good grasp of fundamental FEA theory and mechanics of materials is the most dangerous user (Ural, 2010). It is important that students and practicing engineers learn to be critical of their results and not get into the bad habit of accepting computer-generated answers on faith. Therefore, it is essential for students and practitioners to be *well-educated*, not well trained, in applied fundamental finite element theory and mechanics of materials.

The finite element method is closely related to theory because the method is largely a way of implementing theory. The assumptions and restrictions underlining analysis tools that are incorporated in finite elements must also be understood! For students and practitioners, the main reason to study finite elements is that assumptions and restrictions are revealed enabling individuals to decide when and *when not* to use a particular theory or procedure. Only then one can correctly address questions that must be answered. What physical actions are important? Is the problem time independent? Are there nonlinearities? What are the boundary conditions? How will the results be checked?, etc. Finite element analysis is much more than geometric modeling, pre-processing, and running an analysis.

This paper presents the method used to educate the final year civil engineering students in the fundaments of finite element theory and practices. First the undergraduate course outline is discussed and then proposed educational learning objectives are presented.

Undergraduate Finite Element Course

Finite element method is taught as part of structural engineering 461 course where 75% is on FEA and the rest is on buckling analysis of structures. The teaching structure that is employed comprises of four weeks of formal lectures (three hours per week) on finite element method and review of strength-of-materials and elasticity and five weeks of tutorial sessions (three hours per week) on the use of Strand7 (2010) FEA software to model different structural problems. The lectures on FEA focus on correct use of finite-element technology rather than fundamental theories, as the course is offered at the undergraduate level with short contact hours (12 hours of lecturing). The topics covered in the lectures include the introduction to finite element method; choice of displacement functions for elements; revision of matrix algebra; 1D element: spring, bars and beams; 2D plain stress/strain element, plate and shell element; introduction of 3D element; loading conditions; interpreting results; convergence test; errors and accuracy in linear analysis. At the end, students were also introduced very briefly about the material and geometric nonlinearities in the FEA. At the same time, the three hour per week tutorial sessions are designed to enable students to improve their finite element modelling skills through set up of various finite element models and analyse them using a commercial software package strand7. In order to promote lifelong learning or self-directed learning, only three weeks of basic software training with a few examples are provided by the lecturer. Then the students are required to model a given problem as part of their assignment project. Therefore, they are forced to learn many program features and modelling strategies on their own. Over the years that the course has been run it has been clearly demonstrated, that this type of learning is efficient and effective. Several students have become “expert” in using the Strand7 software.

Educational Objectives

The educational objectives for teaching of FEA focus on providing basic theoretical background on finite element method and hands-on experience in solving various simple engineering problems by finite element method (FEM) and correctly interpreting and evaluating the quality of the results. The educational objectives for the FEA component of this course are as follows:

1. *FEM Theory and strength-of-material theory*. Understand the fundamental basis of the finite element and strength-of-materials theories.

2. *Element Characteristics*. Know the physical behavior and usage of each element type commonly used in practice.

3. *FEM Modeling Practice*. Be able to select a suitable finite element model for a given engineering problem.

4. *FEM Solution Interpretation and Verification*. Be able to interpret and evaluate finite element solution quality, including the importance of verification.

5. *FEM Assumptions and Limitations.* Be aware of the assumptions and limitations of FEM.

Assignment project design and goal

The undergraduate course on FEA requires students to carry out one assignment project. The assignment is to correctly model a simply supported beam with and without opening as shown in Figure 1 and requires students to obtain the displacements, stresses and load carrying capacity of the beam and compare it with that of theoretical values. The time duration of this project is three-weeks. The assignment project is carefully designed and requires students to apply the theoretical understanding of both FEM and strength-of-material as out lined in the five phases in Table 1. The project consisted of five phases and the educational objectives for each phase addresses are shown in Table 1. Phases 2 through 5 require the use of Strand7 finite element software. The students are then required to write a professional engineering report on their findings.

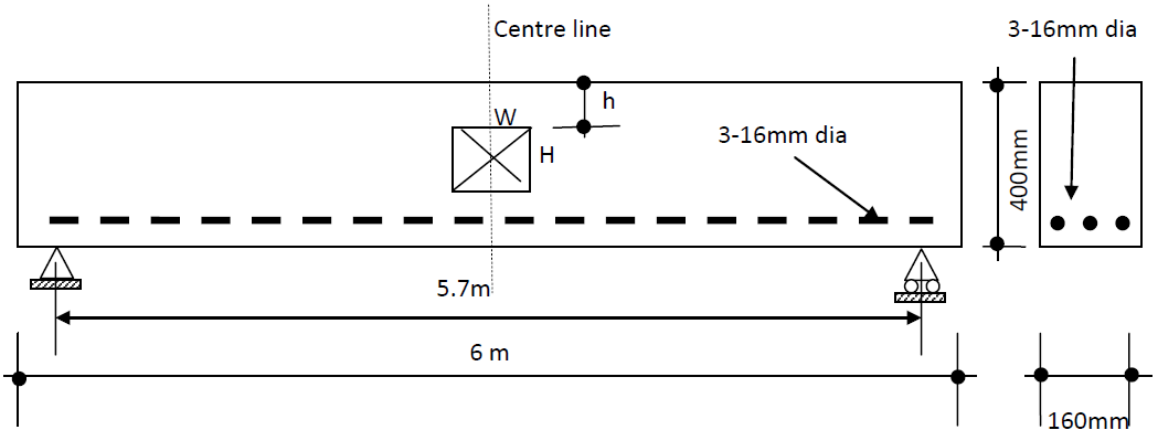

Figure 1 Assignment project on finite element modelling and analysis of simply supported beam with and without opening

The *goal* of this assignment project is to support the teaching of finite element theory and to emphasize assumptions and limitations in the application of finite element method to a simply supported beam which can be easily analyzed with traditional mechanics of materials techniques. The exercises in this assignment project illustrate to the student the importance of having a solid education in mechanics of materials theory as well as an understanding of the finite element fundamentals in order to produce and/or recognize valid engineering analysis using *any* commercial finite element code. The overall design concept of the course is focused on the integration of fundamental mechanics of materials and finite element theories with practical finite element analysis.

Table 1 Assignment/project phases and the educational objectives addressed by each

Phase	Educational objectives addressed
1. Application of finite element and strength-of-material theories	1 and 4
2. Correct choice of model type (2D or 3D) and element type(s)	2
3. Correct boundary conditions, load applications and use of symmetry conditions.	3 and 5
4. Accuracy of FEA results through sensitivity analysis, element's aspect ratio check, etc.	2 and 3
5. Check FEA results with that of theoretical values.	4

Assessment

In order to encourage students to both value the theory content as well as develop the familiarity with Strand7 software and report presentation required in professional practice, the assessment of the FEA component of the course had two parts. The first was an assignment on theory worth 10% and the other was the finite element project report required to be submitted by each group consisted of three students worth 30%. The remaining assessment in the course worth 50% was in the final exam on the structural engineering 461 module. The FEA assignment report is expected to be technically sound and professional in nature. The detailed marking scheme for the assessment of the assignment/report is provided in Table 2.

Table 2 Marking scheme for the assignment/report

Item no.	Assessment criteria	Marks
1	Correct element type(s) (including check for aspect ratio)	10
2	Application of symmetry conditions	5
3	Correct boundary conditions and load applications	10
4	Sensitivity analysis of mesh	10
5	Discussion on assumption (s)	5
6	Identify high stress region	10
7	Check for stress singularity in the corners near opening and eliminate it by providing a curvature or fillet in the corner.	10
8	Check the FEA stress with theoretical values based on strength-of-materials fundamentals.	10
9	Check the deflection of beam from FEA with that of theoretical calculation.	10
10	Discussion and report structure	20

Course evaluation and student feedback

Student's feedback has been very positive regarding the learning experience of the course and the assignment. Students were also asked to provide their feedback on *the way the finite element method was taught provided them with great learning opportunities* and *after completing the tutorials and assignment project their confident of correct finite element modelling*. Most of the students provided their positive feedback on the above issues.

Some of the student's comments on the course are as follows:

"The FEA tutorials were very helpful" and "become more knowledgeable in Strand7".

Conclusions

This paper has presented a case study on the use of commercial finite element code in teaching and effective learning of finite element methods at undergraduate level. Most of the students who prefer to do structural engineering majors in the department of civil engineering at Curtin University enrol to the structural engineering 461 during their final year. The underlying philosophy of the course is to introduce the students to the finite element based modelling and analysis technique that are currently being used in engineering practice. Through a combination of theoretical lectures on finite element methods and laboratory tutorials together with assignment project experiences the students an appreciation for the basic theory and its application. The major reason of introducing fundamental finite element theory is to avoid the danger of using finite elements as a *black box*. The tutorials and assignment exercises reinforce an understanding of mechanics of materials theory, finite element theory, knowledge about the physical behavior and usage of each element type, the ability to select a suitable element for a given problem, and the ability to interpret and evaluate finite element solution quality. The assignment project gives the students an appreciation for how powerful the method can be in performing structural analysis. The author feels that this course provided the students a first step in obtaining the proper *education*, not training, to use the best finite element modeling method to solve real complex systems with a high degree of reliability.

References

Karadelis, J.N. (1998) "*A stimulating approach to teaching, learning and assessing finite element methods: a case study*", European journal of engineering education, Vol. 23, No. 1, pp.91-103.

Miner, S.M and Link, R.E. (2000) " *A project based introduction to the finite element method" Proceedings of American society of engineering education, 2000 Annual Conference.*

Oreta, A.W.C. (2005) "*Developing learning modules on structural engineering using commercial software*" Proceedings of 11th ASEP international convention, Malina.

Rencis, J.J., Jolley, W.O. and Grandin, H.T. (2007) "*Teaching fundamentals of finite element theory and applications using sophomore level strength of materials theory*", International journal of mechanical engineering education, Vol. 35, No. 2, pp.114-137.

Strand7 (2010) Introduction to the Strand7 finite element analysis system.

Ural, A. (2010) "*A hands-on finite element modelling experience in a multidisciplinary project based freshman course*", Computer application in engineering education, pp.1-6. DOI 10.1002/cae.20471

Zhuge, Y. and Mills, J.E. (2009) "*Teaching finite element modelling at the undergraduate level: a PBL approach*", Proceedings of Australian association of engineering education, Adelaide, pp. 1-6.

Copyright statement