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Abstract

'Structures 3', CIVL456 an elective subject offered by the Department of Civil, Mining and Environmental Engineering is basically composed of two main topics for matrix structural analysis: Matrix (Stiffness and Flexibility) analysis methods and the Finite Element method. These methods are used for the analysis of two and three dimensional trusses, rigidly jointed frameworks and plates. The subject also briefly covers the analysis of non-linear structures and the solution of Eigen value problems. The subject is covered in a fourteen week session in which there are three contact hours in each week. Typically in each week there is a two hour lecture and a one hour tutorial or a computer laboratory session.

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The methods covered in this subject are numerically very demanding, since the applied loads on the structure are represented in matrix form. Likewise, the displacements induced due to the applied loads are also represented in matrix form. The relationship between the applied loads and the induced displacements are also represented in matrix forms, the stiffness matrix or the flexibility matrix. There are several commercially available programs for the analysis of structures using these methods. In this subject, using such programs is avoided since students cannot gain much benefit by just pressing keys. At the same time, analysing structures manually using these methods is very labour intensive and an error prone task. Hence some other software is used to enhance students' learning and to allow them a more comprehensive view of the analysis procedure.

Traditionally, one computer program, CAL is used to introduce the methods and solve several analysis problems in this subject. In 1996, a second computer program, the spreadsheet EXCEL was introduced to solve some analysis problems by taking advantage of its excellent matrix manipulation capabilities. CAL is a second generation computer program written specifically for teaching structural matrix analysis subjects whereas EXCEL is a general purpose spreadsheet with several functions and capabilities that can be used in a number of applications including Civil Engineering.

The aim of this paper is to describe the contents of this subject, teaching method used and the assessment method. More importantly, the paper describes the two computer programs used as an aid to introduce the subject and solve the analysis problems, CAL and EXCEL. It also describes a survey that was conducted to gauge students' responses about the two computer programs and their applicability and usefulness for structural analysis.

The subject taught

Description

This subject is taught over fourteen weeks in the lecture theatre and the computer labs. In a typical week there is a two hour lecture and one hour is devoted to either a tutorial class or a computer session. In both cases, students are asked to solve a number of problems either manually or by using the computer.

The subject starts with analysing simple spring systems then proceeds to truss members, and trusses. The subject then covers beam elements and frames. Two dimensional and three dimensional problems are covered in this analysis. An introduction to the finite element method is introduced presenting bar, beam and plate elements. Several problems are introduced in the subject and the students are asked to solve them either manually or by using a computer program.

Assessment

The assessment of this subject was composed of both ongoing assessment and an end of year examination. The final year examination had a weight of 50%. There was a mid-session exam worth 20% and 10% was reserved for the submission of a number of tutorial assignments in which the students are asked to manually solve a number of analysis problems. The remaining 20% was reserved for the completion and submission of two assignments. In both assignments, students were asked to develop general purpose solution templates for both CAL and EXCEL. The first assignment was for the analysis of two dimensional trusses and the second assignment was for the analysis of continuous beams. Students were asked to solve one example for a truss in the first assignment and a continuous beam in the second assignment. Students were expected to compare the results of the analyses using both computer programs and to discuss their ease or complexity when applied to aid the solution of the problems.

The Computer Programs

CAL

CAL is a third generation program specifically written to teach structural analysis. It was developed by Wilson at the University of California, Berkeley in 1978 (Wilson 1978). The program is widely known and used by several teaching institutions. Moreover, there are several similar computer programs that have been developed for structural engineering education. Those programs, in general have several logical concepts that resemble CAL. One of those programs is CAL-90 (Hoit 1995).

A number of key words and commands are used to describe the geometrical and physical properties of the structure in hand and to derive the program. For example: STRART and STOP makes the program to start and stop, ZERO creates a null matrix, PRINT prints a matrix, LOADI creates an identity matrix and allows the user to input its values, FRAME creates the stiffness matrix for a frame element, TRUSS creates the stiffness matrix for a truss element, PLANE creates the stiffness matrix for a plane strain element, ADDK assembles the stiffness matrix for the structure, SOLVE calculates nodal displacements, and MEMFRC calculates member forces. A complete list of the commands together with a number of examples are included in Wilson (1978).

CAL is a small program with the capability of manipulating symmetrical matrices. The main reason for using this computer program is its availability and history.

Spreadsheets

Spreadsheets started from Dan Bricklins' frustration. Dan Bricklin, a Masters of Business Administration student, thought there had to be a better way to solve all the tedious calculations his subjects demanded (Rochester 1993). He asked one of his friends, Bob Frankston (a computer programmer), if he could develop a computer program to help him solve all the

monotonous calculations required for his studies. In 1978 Frankston agreed and in January 1979 the first Spreadsheet was completed.

This Spreadsheet was called VisiCalc. The spreadsheet was originally designed for accounting applications, but due to their mathematical based approach, the engineering profession has found more and more applications for the spreadsheet. It has had such an impact that companies like Microsoft have incorporated many engineering functions into their spreadsheets. EXCEL is so engineering inclined that it is believed to be the strongest competitor in the market for spreadsheet users. Because EXCEL is so popular in the engineering field, it has been chosen for this work.

A spreadsheet is a dynamic interactive application. It is divided into cells each having its own address and meaning. Each cell is independent and the individual component in a spreadsheet and its properties can be referenced to, anywhere in the spreadsheet. This means that the spreadsheet can be constructed so that cells work together, or on a stand alone basis. When cells work together, if the value in any particular cell is changed, then the value in all its dependent cells will also change. If the user wants to repeat all calculations changing only one variable, then this particular value is the only one that needs to change. All the calculations will instantly be revised as fast as the computer will allow. These can be very useful when correcting mistakes, because it means that the user only needs to change one cell, or a group of cells instead of reprogramming the whole spreadsheet. This is the appeal for the spreadsheet and the computer.

Some capabilities of EXCEL

Spreadsheets provide a number of matrix manipulation functions and commands. EXCEL for example provides the following functions:

Addition and subtraction of matrices can be done simply by adding or subtracting values of cells and displaying the result in a third one. For example to add a matrix stored in the cells *a2..c4* to a second matrix stored in *a6..c8* and display the results in a third matrix to be shown in the cells *a10..c12*, the user needs to enter the command =a2+a6 in the cell *a10*. This will display the sum of the element in the first row and first column in both matrices. The next step is to copy the contents of cell a10 to the remaining range of cells (for example, *b10..c10* and *a11..c12*). This will automatically result in the sum of the matrices, since spreadsheets can tackle relative addresses. The same procedure applies for subtracting two matrices.

The transpose of a matrix can be calculated by using the function *transpose(range)* which computes the transpose of the matrix indicated by *range* and displays the result in the highlighted range of cells.

For matrix multiplication, EXCEL provides the function *mmult(range1,range2)*. This function multiplies the matrices indicated by *range1 and range2* and displays the result in the highlighted range of cells.

minverse(range) is the function for calculating the inverse of a matrix stored in range and displaying the inverse in the highlighted range of cells.

The determinant of a matrix is calculated using the function *mdeterm(range)* which calculates the determinant of the matrix in *range* and displays the result in the highlighted cell.

The group operator (pressing the return key while holding both the control and shift keys) is required when entering and editing the functions: *transpose(range), mmult(range1,range2), minverse(range), and mdeterm(range)*.

All these functions are dynamic, in other words once a value in the spreadsheet or a matrix is changed, all the affected cells including matrix manipulation functions are recomputed instantly. In addition, these functions can be used recursivelly. For example, calculating the result of multiplying the inverse of one matrix by another

matrix can be achieved by writing =mmult(minverse(b2:c3),e2:f3) which will calculate the inverse of the matrix stored in the range of cells b2:c3 then multiply this inverse by the matrix stored in the range of cells e2:f3. Finally, it will display the computed matrix in the highlighted range of cells.

Use of spreadsheets in civil engineering

Publications on the use of spreadsheets in Engineering can be found as early as 1985 when Cooke and Balakrishnan (1985) published a book about the use of spreadsheets for applications in building and surveying. They present spreadsheets for surveying and for administration in an engineering office.

Malasri and Syed-Mohammad-Ridzuan (1987) and Wenzel (1987) presented ideas on using spreadsheets in teaching reinforced concrete design.

In a work published, Malasri (1987) describes two Lotus 123 reinforced design tool templates. The first provides the user with moment diagrams, weight and cost diagrams, and tension steel and stirrup spacing diagrams. Input to this template includes span, load, material properties, weight and cost, and section proportions. The graphics capability of Lotus 123 is used extensively in building the template. The second template provides the user with a bar combination table. In this template the data base management capability of Lotus 123 is utilised.

Casas and Oppenheim (1987) presented two templates. The first, a retaining wall design tool. The second is a prestressed bridge design tool template which is organised, in separate windows, the engineering design process involved in prestress design. It allows the engineer to verify different alternatives in the design of the concrete girder, hence leading to a manually optimised section.

Hoit et al. (1987) present an integrated design environment (IDECS) which is a unification of three independently developed programs: direct stiffness frame analysis, graphic display of moment diagrams, and a spreadsheet with templates. The result of this integrated set of programs is a design environment allowing a designer to control the design process and to try many designs in real time. The environment was presented as it applies for the design of singly reinforced concrete beams.

Smith and Warner (1992) show in their paper, the construction of spreadsheet templates for the strength design of short and slender circular-concrete columns. These templates include moment-thrust-curvature relations, strength interaction relations & slenderness effects. They also demonstrate how the templates can be used in the analysis and design of concrete-filled steel tubular columns. They show that once a template is constructed, it can be used in real life applications with minimum effort.

Hadi (1996) presented two templates for structural analysis using EXCEL. The first template is for calculating and drawing the deflected shape of plates loaded laterally and the second is for calculating the deflection influence line for reinforced concrete beams.

The survey

In Structures 3, the students were asked to use both programs, CAL and EXCEL to solve two problems, the first being a two-dimensional truss and the second a continuous beam. For both assignments, the students were asked to produce general purpose templates.

Near the end of the session, a student survey was conducted by the Academic Development Services to gauge students' response in using both computer programs. There were in total six comparative questions. Each question was designed to gauge students' response about the effectiveness of CAL versus EXCEL in the learning process.

The first question was to gauge students' opinion about the easiness of using CAL and EXCEL. As shown in \h Figure 1, a higher number of students agreed that EXCEL was easier to use than CAL.

Figure 1   Ease use of use of CAL and EXCEL


Cal, Excel easy to use
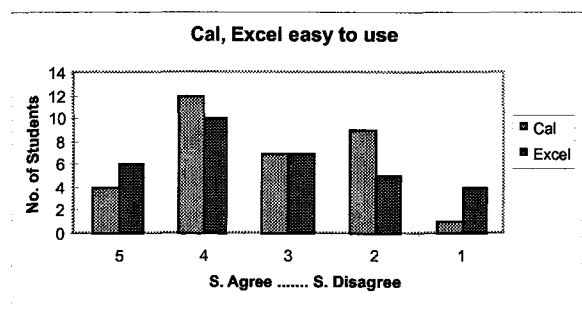
In the second question, the students were asked whether CAL or EXCEL was easier to write code for. As shown in Figure 2, more students thought that CAL was easier. This was expected since, as mentioned above, CAL is written specifically for structural analysis and EXCEL is a general purpose spreadsheet program.

Figure 2   Writing code for CAL and EXCEL

Cal, Excel easy to write code for
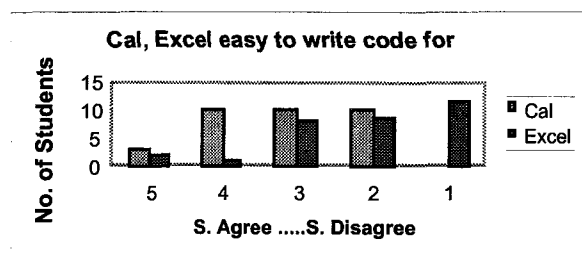
The students were asked what they thought about their understanding in this subject and whether CAL or EXCEL was more useful. Student replies are summarised in Figure 3, which highlights the existence of diversity. The reason for this is the competence of some of the students in using EXCEL. The students who were good in using EXCEL thought that EXCEL was good and helped them in understanding the subject, whereas some other students were struggling in learning EXCEL and hence thought it was an overburden thrown over them.

Figure 3   Assistance of CAL and EXCEL in learning this subject

Cal, Excel assisted my learning in this subject
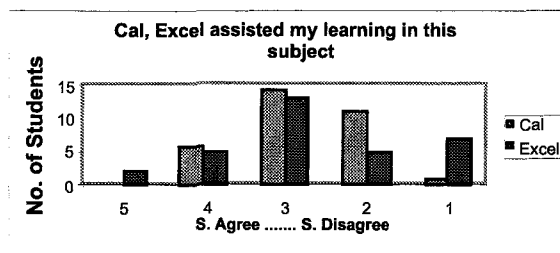
Conclusion

Based on teaching the subject and the students' survey, the following remarks can be concluded:

– CAL is easy to use as a learning tool but it is based on 'Black Box' rather than 'Glass Box' approach, where the user cannot see each and every step of the solution procedure.

– EXCEL is a general purpose spreadsheet with excellent capabilities in matrix manipulation, an important component in structural analysis using the methods covered in this subject.

– Some of the students did prefer using EXCEL to supplement their understanding their knowledge, moreover some other students thought EXCEL was difficult to use and learn. The main reason behind this diversity is this particular group of students were not taught spreadsheets formally. Nevertheless, the majority of students did enjoy using EXCEL.

Finally, based on reflection on the survey and students' response, the assignment component of this subject was changed in the following year and students were asked to use EXCEL for number crunching rather than producing general purpose templates. This proved to be more attractive to students, since such tasks were less demanding. This is evident in the improvement in subject evaluation.

Acknowledgments

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