# CHALLENGES TO PRESENT A POSTGRADUATE FINITE ELEMENT COURSE IN STRUCTURAL MECHANICS AT THE UNIVERSITY OF PRETORIA

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*Summary* This paper shares the authors' experience in developing and teaching a postgraduate finite element course at the University of Pretoria, South Africa. The aspects covered include the tertiary education landscape in South Africa, engineering education in particular and the major employers of engineering graduates. The extent to which these factors affect the content and structure of the finite element course is discussed. The paper concludes with the topics covered in the course, which range from linear elastostatics, linear elastodynamics, geometrically non-linear elasticity and small strain plasticity.

## INTRODUCTION

South Africa (SA) is a developing country that experiences a chronic shortage of engineers [1]. Currently 1 in 3000 people in SA is an engineer, compared to 1 in 543 for Malaysia and 1 in 227 for Brazil [1]. The consequence of this is that the vast majority of graduating engineers are immediately employed fulltime. The majority of these students are employed in the primary sector (mining, petrochemical, electricity generation).

The Department of Mechanical and Aeronautical Engineering at the University of Pretoria (UP) offers the bachelor's degree B.Eng (4 years), honors degree B.Eng (hons) (1 year fulltime), master degree M.Eng (minimum 1 year fulltime) and the doctorate degree Ph.D in Mechanical Engineering. Only the B.Eng degree is compulsory fulltime, where all the other degrees can be obtained part-time (i.e. students are employed fulltime). The Department graduated 12 PhD students in the period 2004-2011, and 68 M.Eng students in the same period. As a comparison, a top tier US institution of similar size graduates this number of students in a single year.

Since the M.Eng and Ph.D degrees have no formal coursework requirement, it is common that all students enrolled for a postgraduate course are B.Eng (hons) students. Usually a significant proportion of these students enroll part-time. To accommodate these part-time students, postgraduate lectures make use of a block-system, where 3 contact sessions of 2 days each are scheduled 1 month apart. Although the total contact time is only 42 hours, a student is expected to spend a total of 320 hours to successfully complete the course. The majority of these hours are spent to complete assignments.

## POSTGRADUATE COURSE IN FINITE ELEMENTS

The number of students enrolled for the course from 2006 to 2011 were 3, 5, 12, 7, 12 and 6. Clearly there is not sufficient interest to justify additional finite element courses. This single course therefore has to cater for the majority of industry needs. Note that those students that graduated from UP were formally taught the finite element method (FEM) during undergraduate studies [2]. However, students returning from industry or from other universities are not required to have prior FEM knowledge, so this does not limit enrollment.

The main challenge in this course is therefore to enable students with no formal training in FEM to use the one month period between contact sessions productively. Since some students travel in excess of 600km to attend the contact sessions, consulting the lecturer in between contact sessions should not be a requirement to be able to complete the assignments. The course material presented during the contact session must therefore be selected judiciously, and the class notes and assignments must be sufficiently detailed.

Since remote access to commercial FEM packages cannot be guaranteed, the course only makes use of Matlab code developed by the authors. Students that do not have access to Matlab make use of Octave. All assignments require the modification of this provided code. By providing a working prototype, very few programming queries arise. The vast majority of students are adept at inspecting the provided code to brush up on programming techniques or commands they have forgotten or are not familiar with.

### Linear elasticity

The content covered include the isoparametric formulation, Gauss quadrature, shear locking, volumetric locking, reduced integration and zero energy modes, patch test, assumed stress formulation [3] and structural dynamics (time domain and frequency domain). A typical assignment requires students to implement a 2D 4 noded assumed stress element by modifying a Matlab implementation of a conventional Q4 element.

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### Geometrically non-linear elasticity

The content covered include the deformation gradient, Green-Lagrange strain, hyperelasticity, Piola Kirchoff stress measure and the consistent tangent. A typical assignment requires students to modify provided Matlab code in order to add follower loads (see Figure 1). Arc length control [4] is also covered, which allows the calculation of the complete load-displacement curve (see Figure 2). All these examples use an 8 noded isoparametric element developed by the students.

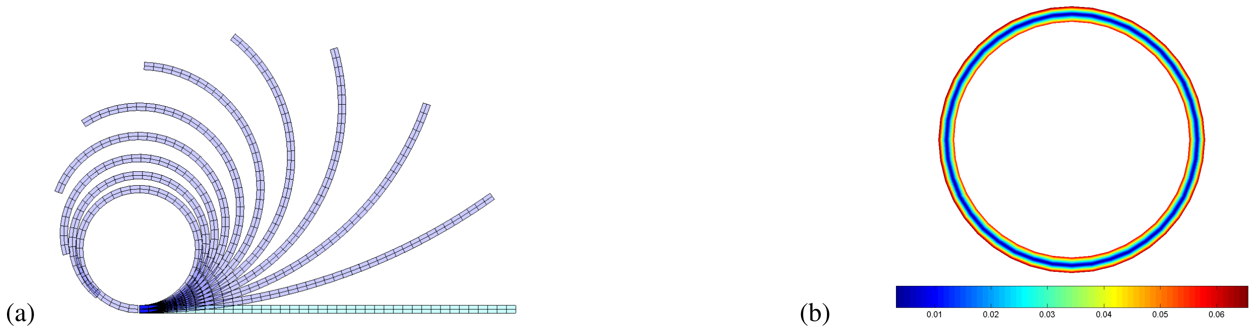


**Figure 1.** (a) Follower loads used to bend a beam into a complete circle with (b) Von Mises stress contour


**Figure 2.** (a) Snap-through behaviour of a Lee frame [2] with (b) load-displacement curves

### Small strain plasticity

The content covered include the decomposition of strain, yield condition, flow rule and post-yielding behaviour. A Matlab implementation using a 4 noded element (bilinear displacement, constant pressure) is provided to the students. A typical assignment calculates residual stresses after a loading-unloading cycle (See Figure 3).


**Figure 3.** (a) Residual $\sigma_{yy}$ stress contour for an unloaded cracked specimen and (b) $\sigma_{yy}$ plot along the bottom edge

### References

[1] Engineering News, web site http://www.engineeringnews.co.za/topic/chronic-shortage

[2] Chandrupatla T.R., Belegundu A.D.: Introduction to finite elements in engineering (3rd ed.), Prentice Hall, 2002.

[3] Cook R.D., Malkus D.S., Plesha M.E., Witt R.J.: Concepts and Applications of Finite Element Analysis, John Wiley & Sons, 2001.

[4] Ritto-Corrêa M., Camotim D.: On the arc-length and other quadratic control methods: Established, less known and new implementation procedures, Computers and Structures 86 (2008) 1353-1368.