A modern approach to learning for structural analysis

Iain A MacLeod (msa@imacleod.com)

Curriculum development

1 Experience in teaching modelling in structural analysis

This sections describes how I introduced modelling to classes in structural analysis at the Department of Civil Engineering, University of Strathclyde.

1.1 Third year class in structural analysis

In the third year class I introduced the principles of modelling and showed how to set up models using a software package. The teaching also covered a range of topics in structural mechanics. The students were required to carry out an assignment consisting of choosing a structure, setting up and solving an analysis model using the software and carrying out a modelling review including a validation of the model and a verification of the results. I provided checklists for validation and verification (see: http://www.imacleod.com/modern-learning/checklists) stressing that when using a checklist one should (a) expect that the checklist might not be complete and (b) that some of the items in the checklist might not be relevant and therefore can be ignored.

For the examination for the third year I used a plane frame structure for which I supplied a diagram of the structure, details of the analysis model and results for the model. The students were required to (a) validate the model and (b) verify the results. I provided model answers to previous examinations of this type so the students were aware of what was expected of them. The validation and verification checklists were issued with the examination paper. A typical examination paper is at: http://www.imacleod.com/modern-learning/exam-paper1

I tuned the examination so as to achieve the basic objectives of: only a small number failing and the average mark and standard deviation of the marks similar to other examination results in the year. I did this by making a suitable degree of difference between the structure used in the paper and those in the examples with solutions that I made available to the students. I used a similar form of frame but changed, for example, from steel to concrete, the supports, the loading etc. I could easily tell which students were struggling to understand the concepts. These were the ones who had difficulty in identifying the differences and tended to answer this year's questions using last year's answers. These students should really have failed but since that would represent about half of the class I could not do that.

What I did was to radically change the style of the examination from being based on solving determinate problems (for which there is a unique solution) to solving a non-determinate problem (which does not have a unique solution) involving a lot of uncertainty. The less able students did not relate well to this change whereas the good students treated it as a challenge. Perhaps my teaching methods could have been improved but I believe that the fundamental problem was that the less able students needed more time to adapt to the different way of thinking.

1.2 Fourth year class in structural analysis

The structure for this class was very similar to the third year but the examination model tended to be a building in 3D and there was a requirement to carry out a stability analysis for the structure.
The examination results were similar to the third year outcomes.

I believe that the learning experience for the students from these classes was very good but by no means optimum. I would now do it differently - see Sections 2 and 4.

2 Integrating analysis and design

One of the faults of the learning process outlined in Section 4 is that analysis and technical design were not integrated. By 'technical design' is inferred the use of codes of practice and other rules for member sizing etc. Figure 1 shows the basic strength relationship - possibly the most common technical design criterion in structural engineering. The applied force action, derived from structural analysis should be less than the predicted resistance, based on strength of materials. theory. Why should one treat use of this expression 'design' but think of the process by which the values of force action are formulated as not being design? For some ideas about this see http://www.imacleod.com/modern-learning/history-eng-ed

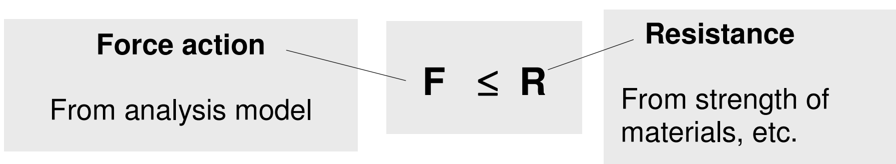


Figure 1 The strength criterion

I use the following definition for *design*: 'The creation of models of future entities'.

The models used in structural engineering include graphical, written, mathematical, etc.

By this definition analysis modelling is clearly a design activity. Whether or not one treats analysis as design is not of great importance in practice. But it is very important in education. We want to help students develop understanding. An important feature in such development is the making of associations among entities. Teaching analysis as a separate entity with little contact with how it can be used limits the potential for making associations and hence limits the potential for understanding. This was the traditional approach but the modern introduction of project work is changing the situation. However an active approach to integrating analysis into the learning for structural design should be pursued.

A good principle would be to have classes in 'structural engineering' which would, at least, cover structural analysis and technical design. The students would be required to apply the modelling process to both the analysis models and the code of practice rules. (Note that in technical design one validates the rules by answering the question 'Is the context within the scope of the rule?' and verifies the outcomes by asking the question 'Have the calculations been carried out correctly?'). Some 'tutorial question' mode of learning might be used but the main learning should be in the context of the design of a structural system - e.g. a roof structure, a building, a bridge. In such contexts topics are integrated with much better potential for understanding.

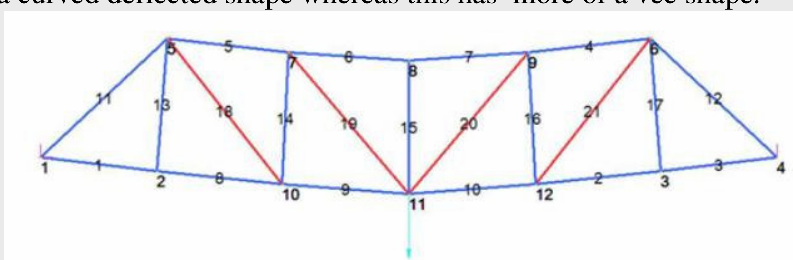
3 Understanding behaviour using the modelling process

3.1 Challenge outcomes

One of the most fruitful ways of helping to develop understanding of behaviour is to encourage students to challenge outcomes e.g. by saying "I do not think that model assumption is correct" or "These results do not look right". If such statements are followed through one can only gain advantage from it. If the challenge is correct then an error has been found but if the perception is wrong and one can explain why it is wrong then one is learning about behaviour.

Case Study Learning by challenging outcomes Truss with point load

The diagram shows the deflected shape of a simply supported truss under a single central point load. I showed this to a third year class and asked if they thought it was right. Most thought it was wrong because their experience of looking at bent forms was that you always get a curved deflected shape whereas this has more of a vee shape.



I told them that their perception of the situation was sensible but wrong. The bending mode deformation of the truss results from axial deformation of the chords and would give a cubic deflection curve under the point loading. However, shear mode deformation due to the axial deformation of the diagonals and the posts of the truss would have a linear deformation (i.e. vee shaped for the simply supported structure) and hence the deflection of this truss must be dominated by the latter mode of deformation.

3.2 Validation of models

An important feature of *Modern Structural Analysis* is the provision of 'validation information'. This is information about the range of applicability of the assumptions made in formulating mathematical relationships for the analysis models. The validation process involves listing all the assumptions made for the model and comparing these with the expected behaviour of the structure using validation information. Doing this provides significant opportunities for developing insights into structural behaviour.

3.3 Verification of results

Via the checklist (Appendix 1) I require students when doing verification to assess both the displacements and the internal actions using:

(a) A qualitative approach where one looks at the results and asks the question - 'Does that look right?'

(b) A quantitative approach where one compares the results of a checking model against those from the main model. The checking model is normally a simplified version of the main model - a ‘back of an envelope’ check where feasible.

Both of these actions have rich potential for developing understanding.

3.4 Sensitivity analysis

Assessing the effects of alterations in to a model is one of the most powerful strategies for interpreting behaviour. This is best done in assignments where students are required to carry out and report on sensitivity analyses. It might also be realistic to require the interpretation of the results of a sensitivity analysis in an examination. I never tried this but examinations can be very valuable for getting students to focus on particular tasks. One would need to give good examples of sensitivity analysis assessments so that the students would understand the sort of response that would be expected of them. This type of requirement might be more relevant to the more able students.

4 A modern curriculum

The changes in the approach to teaching that I have described in the Sections 4 and 5 of this document represent a shift in philosophy of learning which should be treated in a more general way. Process control should be an integral part of an engineering curriculum. Design needs to be treated as a holistic activity where all issues that affect the outcome are taken into consideration. The traditional exclusively topic based approach to learning does not support this principle.

If I were asked to design a learning programme for a civil/structural engineering degree course I would propose that the following principles be adopted:

1. Introduce basic skills of Drawing, Technical writing, Calculating and Using process control strategies etc. at the beginning of the course. Do not have a class in these topics but introduce them through project work and other classes and reinforce them throughout the course. All outcomes from students should conform to the standards for basic skills introduced in the first year of the course as appropriate.
   Graduates should be able to produce hand calculations to a high level of readability but they should normally be expected to do calculations using a maths processor (e.g. Mathcad) and should be proficient in writing worksheets for them. A range of writing skills should be taught but graduates should be able to write technical reports to a high standard.

2. Introduce the design process at the beginning of the course i.e. in just about its simplest form:
   - Inception - define the requirements, gather information
   - Conception - identify options and select the design solution
   - Production

   Provide a range of opportunities to practice using it throughout the course.

3. Introduce the modelling process both for analysis models and design rules (e.g. code of practice rules) at the beginning of the course. Require these processes

also to be used whenever relevant with the objective that, on graduation, it will be second nature for students to use them.

4. Introduce the use of computer software for structural analysis at the beginning of the course. The use of software is a main tool in developing understanding and, the main objection to its early introduction - that students tend to use it inappropriately - is obviated by requiring that they use the modelling process. Start with a simple program for which there is no library for section properties. They are required to calculate the section properties. Students too readily when introduced to use of software in later years get stuck when they find that the library does not provide the shape that they want

5. One can only teach one topic at a time and while some practice in relation to a single topic may be needed, topics should be integrated into multi-topic tasks as soon as is practical. The reason for integrating is that a main feature of understanding is associativity. The integration of topics provides opportunities for developing associations among entities leading to better understanding.

> *Example of associativity*
> If you teach the design of slabs on beams and the design of beams supporting slabs only as separate topics then you are not helping students to understand that the reactive forces on the slab become the loading on the beams.

6. A project is the main vehicle for integration of topics. In each year of the course should have at least one *industrial project* where students work to a realistic brief, where not all the needed information is covered in lectures but where mentor support is available. If necessary limit the scope of activities in the earlier years but in the final year expect all necessary activities to be included.
   Also use *taught projects* where the use of procedures is practiced on potentially real contexts but all the needed information is made available to the students via lectures, websites, etc.

7. Use the philosophy for structural analysis learning described in this document for all modelling activities e.g. in geotechnics, water engineering, etc.

UK degree courses in engineering are moving towards integrating the design process into the curriculum. It is now time to bring in the modelling process.