Structural-Safety

Incorporating SCOSS and CROSS

Topic Paper

SCOSS TOPIC PAPER
Reflective Thinking

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WHO SHOULD READ THIS TOPIC PAPER?

Structural and civil engineers in practice, teachers and students in universities and other further education organisations concerned with structural analysis and design.

BACKGROUND

Reflective thinking is a constant drive to ask questions and to make appropriate responses to them. It is characterised by a healthy scepticism about all inputs to processes, about the processes themselves and about the outcomes from processes.

It is a pervasive activity in all risk reduction strategies such as: using the design process, using predictive models, using codes of practice, adopting an ethical approach.

Some engineers adopt a reflective approach naturally. They may look at a drawing, for example, and quickly identify faults in a design. It need not, however, be a tacit skill. It can be and needs to be fostered.

REFLECTIVE THINKING IN DOING STRUCTURAL ENGINEERING CALCULATIONS

Structural calculations are dominantly concerned with predictive modelling. This is the use of mathematical or heuristic models to estimate the behaviour of systems and components. The two main types of predictive model in structural engineering are:

- Structural analysis (or analysis modelling) where mathematical representations are used to predict displacements, internal force actions, etc. of structures
- Technical assessment i.e. uses of codes of practice (and other rule sets) that involve mathematical models (e.g. for bending) and heuristic models (i.e. empirical rules such as for concrete cover for reinforcement).

In 2002 the Institution of Structural Engineers published *The use of computers for engineering calculations* [1]. Although now out of print it was a landmark publication in that it introduced the concept of a formal modelling process and gave significantly improved definitions of validation and verification that are central issues in the process.

In the pre-computer era, the focus was on processes for the implementation of calculations that were determinate i.e. the processes had unique solutions. Calculations are now dominantly implemented by computer and the scope of structural analysis models is now much more extensive. The basic problem has moved from doing calculations to controlling them; from contexts that were determinate to contexts that are non-determinate (i.e. they do not have unique solutions). The 2002 publication provided a framework for operating the latter type of context but it appears that the philosophy outlined in that document has not been adopted in education and the analysis modelling process tends not to be treated explicitly in practice.

To illustrate this point, consider validation. In structural analysis the validation question: “Is the model capable of satisfying the requirements?” tends not to be used explicitly by engineers. Likewise, the validation question for use of a code of practice: “Is the design context within the scope of the code of practice?”, also tends not to be used in a formal way. But this type of reflective question is critical in reducing risk in structural design. The root causes of major structural failures tend to be more a result of decisions about what calculations should be done (validation) rather than due to errors in carrying out the calculations (verification).

References 2 and 3 give an overview of current reflective thinking in structural engineering.

ARE STRUCTURAL ENGINEERS GOOD AT REFLECTIVE THINKING

The low rate of failures of structural systems shows that, in general, the methods used to control structural safety are effective. But evidence suggests that many engineers are either not good at reflective thinking or that the range of questions that they work with is too narrow. There have been failures in many spheres of engineering whose root cause has been a lack of understanding of fundamental principles. Major failures have been seen in infrastructure systems and in building structures; sometimes with considerable loss of life. Concerns which could have resulted in collapses had they not been recognised are given in publications by Structural-Safety[4]. Studies of these can help to learn lessons from the actions of others and help with the development of reflective thinking.

HOW CAN ENGINEERS BECOME MORE REFLECTIVE

Viewed as a main strategy for reducing risk, reflective thinking needs to be much more explicit and more dominant in professional engineering practice.

Teachers and supervising engineers do encourage students and colleagues to be reflective but there is much scope for extending such activity.

The introduction of computers has fundamentally changed engineering processes. Contexts have become more complex and the need for the special power of the brain to identify patterns, to ask questions, to generate hypotheses has intensified. While software can be programmed to flag up potential errors, we are not yet close to simulating the thinking power of a human brain. As processes become integrated in computing environments (stimulated by BIM) the need for alert engineering control at all stages is essential. Reflective thinking is at the heart of such activity.

Engineers in practice need to improve their own ability to be reflective and to encourage those whom they supervise to develop such skill.

Engineering teachers need to require evidence of reflective thinking in student project outcomes by, for example, requiring the submission of reports on: validation, verification, stability, option assessment, etc.

Especially in innovative situations, engineers need to formulate reflective questions that are specific to a context.

EXAMPLES OF REFLECTIVE THINKING

Of necessity the examples given are for events that took place some years ago. Some more recent cases cannot be published for legal reasons.

The design process
Studies of how engineering design is carried out lead to a conclusion that the following reflective questions, for example, are important in achieving satisfactory outcomes:

- Has all necessary information about the design context been gathered?
- Have all the design requirements been identified? This infers that the requirements have been formally established.
- Has a suitable range of options been identified?
- Is the information about the options sufficient for an assessment?
- Is the process used to assess the options fit for purpose?

Analysis modelling
Reflective questions for analysis modelling include:

- Is the model capable of satisfying the requirements? (the validation question)
- Is the model the most appropriate in the context?
- Has the software been validated and verified?
- Has the model been correctly implemented? (the verification question)

For example, classic structural failures such as the Hartford Connecticut Civic Center collapse (1978) and the failure of the Sleipner Platform (1991), were due to inadequate validation of analysis models.

Technical assessment - i.e. use of codes of practice

Reflective questions in technical assessment include:

- Have all the relevant design issues been identified?
- Do the code provisions adequately address the issues? (validation)
- Have the code provisions been correctly implemented? (verification)

The Ronan Point collapse (1968), for example, resulted from lack of attention to the first two of these questions.

SUMMARY

A fundamental objective of Structural-Safety is to provide information that will help to answer the reflective question: 'Have we identified and addressed all the issues that may cause less than satisfactory performance of the structure being considered?' This should be borne in mind by all designers.

REFERENCES

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3. MacLeod I A and Weir A, Principles for computer analysis of structures, Institution of Structural Engineers, in press
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