Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 40 (1982)

Artikel: On structural computing in education

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DOI: https://doi.org/10.5169/seals-30914

On Structural Computing in Education

Le calcul des structures par ordinateur dans l'enseignement

Festigkeitsberechnungen in der Ausbildung

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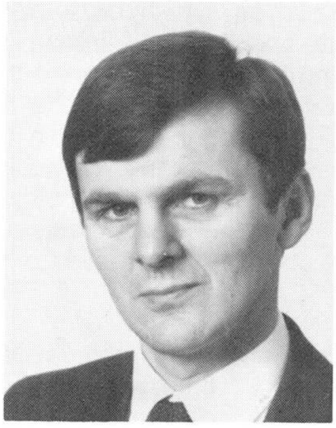

Born in 1940. Degree of civil engineer at Delft University of Technology in 1962. In research until 1970. Moved to Structural data processing at Rijkswaterstaat (State Public Works). Since 1981 head of Bouwresearch, division of Rijkswaterstaat for structural research. Part-time appointed at Delft University since 1979. Joint interest in FEM and CAD.

SUMMARY
Developments in the hardware and software industry are reviewed briefly, and some limitations in education are discussed. Essentials in present-day structural computation are listed and then expanded. A number of aspects are dealt with in more depth. The usefulness of engineering differential equations is stated, and misunderstandings in FEM in education are exposed. This design tool can already be introduced in lower training levels, and major emphasis must be put on the managing and validation of results.

RESUME
L'article donne un bref résumé des développements réalisés par les industries du matériel informatique et dus logiciel. Les aspects principaux de l'analyse des structures par ordinateur sont recensés et certains d'entre eux traités avec plus de détails. L'utilité, pour l'ingénieur, du recours aux équations différentielles est relevée ainsi que divers malentendus relatifs au rôle des éléments finis dans l'enseignement. Cette méthode peut être introduite dès le début du cycle de formation mais un accent tout particulier doit être mis sur les procédures de contrôle et de validation des résultats.

ZUSAMMENFASSUNG
Entwicklungen in der Hardware- und Software-Industrie werden kurz zusammengefasst und Beschränkungen im Unterricht werden erörtert. Wichtige Aspekte der heutigen elektronischen Strukturanalyse werden genannt und erläutert. Einige Gesichtspunkte werden ausführlicher behandelt. Der Nutzen von Differentialgleichungen für den Ingenieur wird dargelegt und Missverständnisse in der Ausbildung über die finite Element-Methode werden aufgedeckt. Dieses Entwurfswerkzeug kann schon bei einem niedrigen Ausbildungsstand eingesetzt werden; die Kontrolle der Ergebnisse soll aber sehr betont werden.

1. PROBLEM STATEMENT

The training of a structural engineer consists of many subjects. Roughly speaking, we distinguish courses which are directed to construction and courses which are connected with design. In this paper we stick to the latter. But even this clear-cut part of the engineer's education is too divers to discuss it in general terms. Therefore we introduce the distinction between two types of structural engineers in the design profession. On the one hand we have design where the (all-round) designer executes all necessary analysis himself, and on the other hand a situation of specialization in which a designer is closely cooperating with a structural analyst who specialized himself in structural computation. The all-round designer will normally be found in smaller design offices and may execute rather common design tasks, whereas the specialized team of a designer and a structural analyst will rather be seen in bigger companies, executing more advanced and less routineous jobs. Taking it roughly, the education in structural computation can be the same for the allround designer and the specialized designer. We will call this allround computing. On the contrary the training of a structural analyst is a chapter by itself. This we will call specialized computing.

The paper tries to trace which parallel developments occur in respect of the use of computers. Noticing several changes we have occasion to question whether or not nowadays ways of computerized computing may be commuted for new ways of computing in the near future. Or we may conclude that trends who are already going, may be strengthened in the future.

2. PARALLEL DEVELOPMENTS

As for the hardware we have seen a development which started with a series of generations of main frames, roughly 25 years ago. At first these computers only have been used in a batch mode, but later on also conversational modes became possible. The introduction of minicomputers has been a big step forward. The nowadays (super)minis are even more powerful than earlier mainframes. And in combination with array processing facilities minis even exceed the facilities of nowadays main-frames. Meanwhile also graphics hardware developed rapidly. Black and white screens are since long time common practise and color screens fastly invade the design profession. Finally the large scale integration (LSI) chips resulted in micro computers which yield a new almost revolutionary situation. Together with new disc facilities (winchester drives) such micro's appear to become design and analysis tools which are easily within reach of small design units, and which introduce advanced programs in user environments which untill now could not think of intensive computerized analysis. And very large integration scale (VLSI) chips are coming right now!

As for the software development a simultaneous evolution has been noticed. In old times all types of separate monolytical non-structured programs came into being. At a later stage chains of programs were introduced as well as the concept of integrated program(ming) systems. User oriented languages and problem oriented languages have been proposed to match the typical hardware shortcomings at the time. Recently all accent is put to what is called engineering working stations. The rigidity which still has been annex to the integrated systems is rapidly releasing by these new design and analysis facilities, offering the combined comfort of computing, storage and retrieval, and graphics presentation techniques.

Parallelly to the already mentioned developments in hardware and software an evolution in applications was seen. Everybody started in early times with programs for trusses and frames, and moved in time to finite element programs. Later on the handling of input and output could get more attention, such that now a total new industry in pre- and postprocessing has appeared to come in being. In fact an integration of hardware and software is becoming possible which connects the fields of computer aided design (CAD) and computer aided manufacturing (CAM), which makes us to use a new slogan, computer aided engineering (CAE). Also CAD and FEM relate to each other progressively more.

Lastly, the author believes that a fourth parallel line will come through more and more. The trend is showing that emphasis is shifting from writing one's own programs to the use of already available programs.

3. BOUNDARY CONDITIONS

Education on the use of computers in structural engineering in the eighties is subject to some serious constraints. First of all the recession in western society puts limits on budgets which have not been known to this extent since long times. Reduced finances result in decreased possibilities to purchase present-days hardware. For the same reason there is high pressure to change the student teacher ratio such that a higher number of students has to be served by one teacher.
Furtheron we must bear in mind that analysis is not the only subject which has to be teached. In fact we want to introduce in a very general way the concept of computer aided engineering. That is to say, the students have to train the use of a working station environment, including new ways of drafting, presenting results and storing or retrieving data. This will put many more calls on the available time, and above that so many other important subject matters ask for their part in the curriculum. This is especially a big problem in universities where no special structural engineering department exists, but in stead of that structural engineering is a specific choice within a civil engineering department. And civil engineering is by nature of much broader spectrum, which almost necessarily reduces depth in structural engineering skill.

4. ESSENTIALS OF COMPUTING EDUCATION

How should a course in allround computing be composed? In universities which distinguish between undergraduates and graduates, this training is a matter for undergraduates. Essentials of this education are:

- To impart to the student basic understanding of structural behaviour.
- Fair knowledge of matrix methods for trusses and framed structures (stiffness method and flexibility method).
- A primer to the finite element method (only stiffness method).
- Emphasis to handle existing programs, and skill to integrate them in the design proces.
- A wide training in the skill to interpret results and to check their validity.

Specialized computing in structural engineering education adds to the above already mentioned essentials a couple of other ones:

- Advanced knowledge of matrix methods in general, and finite element methods in particular.
- The ability to adapt, extend or develop algorithms in structural computation.

These characteristics are typical for graduates. Author believes that still a third category of students is needed, be it only a rather small number. They must combine the above mentioned essentials with the skill of software engineering. It is this group of engineers who extends the library of programs and/or adapts the existing programs.

5. ILLUMINATION OF SOME ESSENTIALS

One can ascertain wide agreement on the necessity first to impart to the student fundamental knowledge about structural behaviour before he should start computerized analysis. This holds both for statics, dynamics and buckling problems. However, what is basic understanding? A lot of misunderstanding still leads an obstinate existence in this respect.
Older colleagues who lecture the design of concrete structures or steel structures may use one or two small typical hand calculation techniques of structural mechanics, sometimes hardly distinguishable from tricks, and are inclined to judge this as basic knowledge of structures. However they can reach a same result when they use a more present-day approach which is better in line with systematics of the stiffness method or the flexibility method. Basic knowledge rather is an aspect regarding the structure and has nothing to do with the method of analysis. Of course, to keep well balanced, we must say alike that lectures on structural mechanics can help a great part to bridge the supposed gap. They must always feel challenged not only to teach the formalisms of the matrix methods, but at the same time to demonstrate how it can be applied by hand for simple calculations in specific practical design circumstances. The one thing needs not exclude the other!

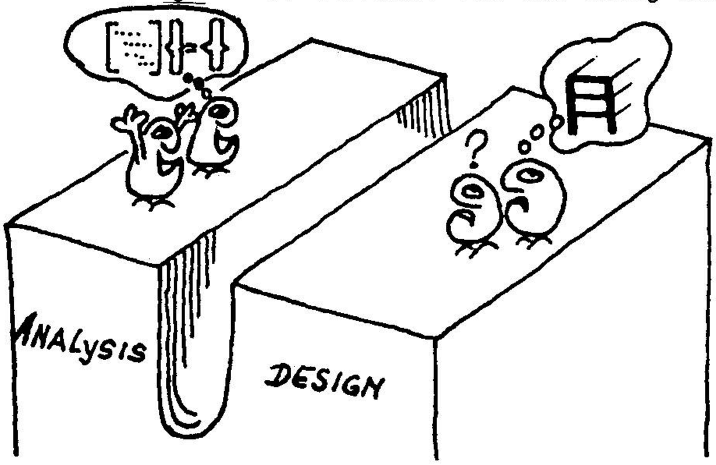

Figure 1.

Lots of possibilities exist for misunderstandings and gaps between classic lecturers in design and present-day teachers of structural analysis.

Basic knowledge is an aspect of the structure, we already said. Therefore the students must get thorough experience in distinguishing and identifying the behaviour of a structure. How is its main way to transfer loads to the supports, and why does it do it this way? Ample training in the use and meaning of moment diagrams and related diagrams is very much needed, and is far more profitable than extensive exercises in the computation itself of such lines. And present-day computer aids progressively more to support this statement.

The more the computer becomes an integrated companion at the engineer's design spot, the more occasion a designer gets to rely on this help.
The fast evolution of the last two years, particularly in the micro market, makes us expect that after a couple of years the computer becomes the personal assistant of the designer. A couple of years implicates that the inflow of students at colleges and universities now, will use this aid as a self-evident mate when they are in the design office later on. Thus, we preferably should get him trained in this way. We are in the advantageous situation that we can instruct a student to execute a considerable number of calculations. The results can be submitted to him immediately in a graphical way, ready for interpretation.
So we have the occasion to confront him with the implications of modifications in his design, and to have him accustom to important types of output. Merely the above mentioned budgetary boundary conditions may be a kill-joy.

Clearly the emphasis should be on interpretation of the output and on validation of the results, casu quo the programs. Still to often one is inclined to believe that results are valid merely because they were achieved by computerized analysis. The enlarged facilities to make many calculations during the education period, offer possibilities to show the student the limits of a program. We can order him to make runs which produce nonsens, and stimulate a critical attitude in this way.

6. ARE DIFFERENTIAL EQUATIONS SUPERFLUOUS?

When we discuss numerical methods in engineering, the question rises whether or not to train a student in differential equations. It is rather clear that the treatment of differential equations in the past (many of which had no clear physical or engineering back ground) is of doubtable importance in a decade in which numerical techniques are widely available. However, we should beware for the extreme to remove from the curriculum all matter of differential equations. In stead we right now get more time to derive and present typical engineering differential equations which apply for specific types of structures. It is a rich experience to know (and thus be able to recognize.) the solution of such engineering differential equations. Typical examples are linear structural systems with a distributed spring component, be it of second order (extension, shear, cables) or of fourth order (bending). Above that, such solutions are welcome references to check the validity (rather: the degree of approximation) of numerical calculations! In practise, this part of education may be reserved to students of graduate levels. At least futural structural analysts will attend such courses.

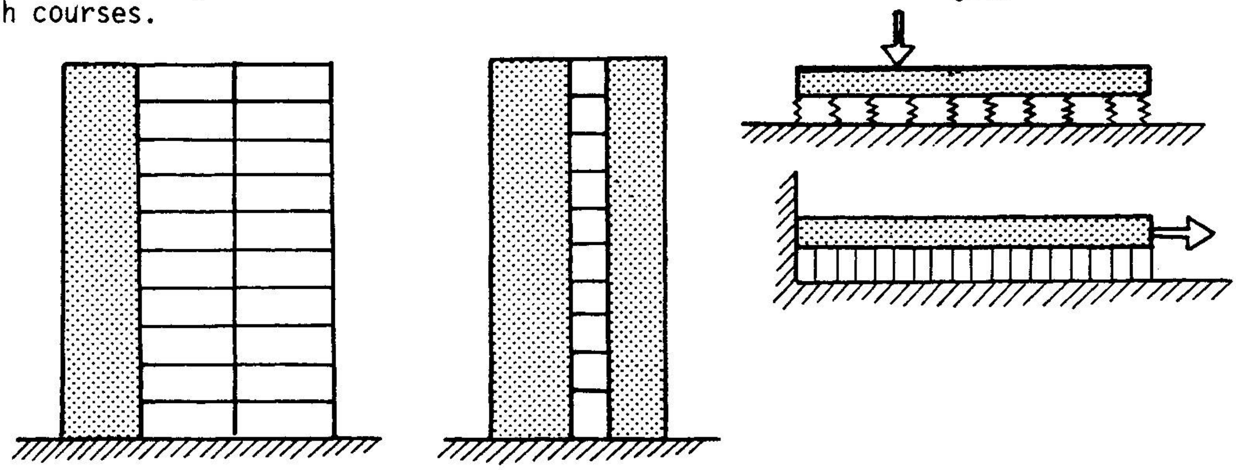

Figure 2. Examples of wall-systems and of structures with spring systems, which are governed by typical engineering differential equations, which also yield useful validation material for numerical tools.

7. FEM IN EDUCATION. WHAT AND WHEN?

In section 4 a primer to the finite element method has been proposed for undergraduate level, and advanced knowledge for graduates. The latter part of the proposal does not meet serious objections. It is widely agreed that a small number of specialized structural engineers must have in depth knowledge on the variational methods which lie behind, and on the applicability for all problems, including dynamics, buckling, and nonlinear analysis, both materially and geometrically. However, unfortunately still a lot of resistance is offered to an introductory course on FEM (a primer) at lower levels of training.

This opposition is allied to the misunderstanding on the basic understanding of structural behaviour, which we already touched in section 5. Many structural teachers seem still to be loaded with a tremendous prejudice against this analysis tool. Sometimes it appeares impossible to convince colleagues that the finite element concept really true can be explained in a simple way, and that it even helps to understand structural behaviour better. Instead they keep nursing initial deeply rooted ideas, which meanwhile rendered out of date completely.

For, present-day reality confronts designers with a complete FEM-industry, which provides analysis tools of ever growing usefulness and elegance. Especially the pre- and postprocessing facilities will become powerful aids. This also holds for education. Here again it applies that students need not be loaded anymore by nonrelevant details, but that they can stick to their very engineering design and analysis task. So, we can afford to ask them to examine a number of structural congifurations, right now yielding the basic understanding, of which others right here fear that it will not be gained!

8. HOW TO MANAGE FEM-RESULTS.

A broad training in the skill to interpret results has been proposed in section 4, and we illuminated this somewhat in the following sections.
A most important aspect regarding this training is the check of equilibrium both globally and for parts of the structure.

An example of a global equilibrium check is shown in fig. 3. A concentrated load F is subjected to a simply supported orthotropic bridge slab, and causes a distribution of longitudinal moments m. The slab can be seen as a beam of length l and width b. The mid-span moment in this beam is $\frac{1}{4}Fl$, and this value must be equal to the integral of the moments m across the width of the slab. Trivial you say? Yes, but your attention must be drawn to it when you start doing such jobs! We must cultivate a student's attitude that he does not concentrate on the numerical tool (which FEM really is), but on the information which it yields about the structural behaviour (which is the main responsibility).

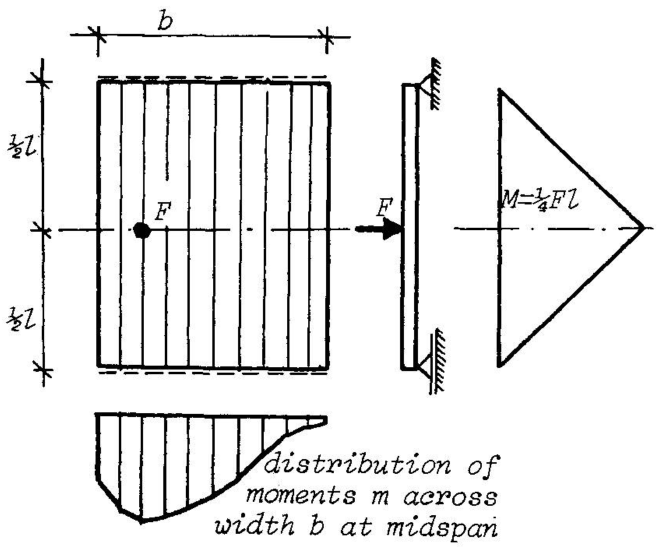

Figure 3.
An example for checking global equilibrium.

A typical example of a local equilibrium check is found in the corner of a slab with free edges, which corner is supported by a single point support, see fig. 4.

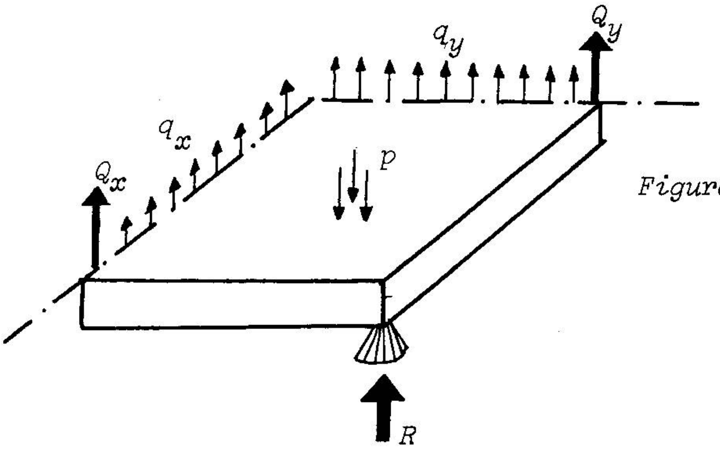

Figure 4. An example for checking local equilibrium.

An educative question is to verify the printed value of the support reaction R, considering a square part of the slab near the support. Everybody will take account of the distributed shear forces q_x and q_y in the slab and of (eventually applied) load p on this part of the slab. But does everybody realize himself that concentrated shear forces Q_x and Q_y occur in the edge zones of free edges? They even will strongly dominate the distributed shear forces q_x and q_y. Basic knowledge of slab behaviour is a prerequisite here to execute a proper equilibrium check. Therefore, a plea for finite element education always presupposes that adequate understanding of structural behaviour is teached simultaneously.

The slab examples shown above make clear that the application of FEM provides much detailed information which improves our design skill. However, honestly speaking, the FEM sometimes introduces new problems which we had not before. Important examples are stress concentrations in singular points, which occur in plate and shell structures. A continuously refined mesh would in the limit result in infinite values of the stresses. It is not possible yet to present a general solution how to handle such situations. In practise one may decide to investigate such important details and connections experimentally, or (if possible) the structure is modified such that infinite stresses do not occur anymore. And in how many cases "local limit analysis" will be called in to face this problem? The question rises whether or not we ask the right questions to the computer. Is it information on stresses that we need? Or is it an energy quantity which maybe better describes the initiation of plasticity, or cracks, or crack propagation? And how to define such new criteria such that no mesh dependency occurs? Plenty of reasons to pay attention to this interpretation problem in the future.

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