Viewpoint

Structural behaviour revisited: who will take up the education challenge?

David Brohn laments the level of understanding of structural behaviour among civil engineering graduates and calls on universities to address the issue in their teaching.

Introduction

In the 1970s, I published several papers on diagnostic testing of the conceptual understanding of structural behaviour of engineering graduates[1–4] based on testing Arup graduates. The Arup Partnership sponsored the development of a two-day training course, 'Understanding Structural Behaviour', to address this deficiency.

I also wrote a textbook[5] which demonstrated how qualitative understanding of structural behaviour could be applied to conventional topics in structural analysis. This approach is unlike most other published texts or books in that it takes the qualitative and intuitive understanding of structural behaviour as the priority.

The paradigm shift in structural engineering

In the early 1990s, there was a paradigm shift from hand-based to computer-based calculations. When the first reliable version of Windows 3.1 was made available, software developers could see that the adoption of that system gave them a reliable, worldwide platform. The commercial development of inexpensive desktop computers also encouraged the development of a wide range of software for the structural engineer, and in a period of about 15 years, every engineer with access to a computer presumably became the 'world's greatest analyst'.

In the case of teaching structural analysis, before computers, academics could reasonably focus their efforts on formal methods of structural analysis because such skills were required in the design office. But if nearly all computational analysis and, in the immediate future, nearly all structural design in steel and reinforced concrete for conventional structures is carried out by computer, what are the skills that the academic should be developing in students? What should the new *educational* paradigm be?

This is an example of a general issue with a paradigm shift, as the originator of this term discusses[6]: when old certainties disappear, how best should we proceed until a compelling new framework appears?

In 2009, the Institution of Structural Engineers addressed this educational issue and recognised

TABLE 1: Selection of Brohn test results

Ref.	Course date	Client	No. of delegates	Test score (%)
1	May 09		7	31
2	Dec 12		23	23
3	Nov 13		17	22
4	Dec 14		20	17
5	Mar 16		9	30
6	Jan 17		20	35
7	Mar 17	IStructE	18	20
8	Mar 19	IStructE	16	24
9	Nov 20		9	19
10	Dec 20		23	25
11	Dec 20	IStructE (Zoom)	20	18
12	Mar 21		23	20
13	May 21	IStructE (Zoom)	13	23

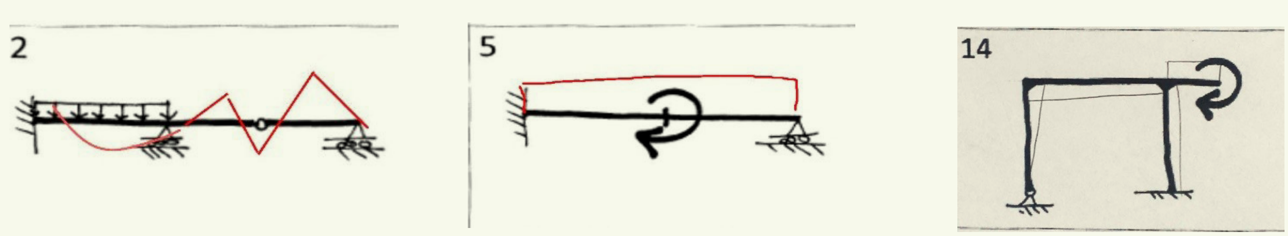


FIGURE 1: Examples of incorrect solutions

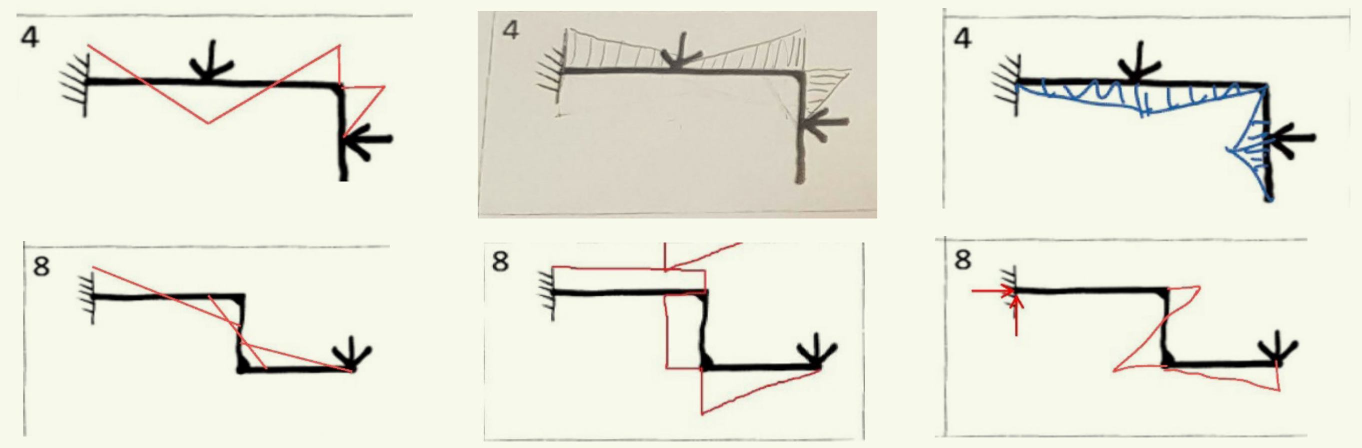


FIGURE 2: Examples of solutions given to questions on statically determinate cantilevers

that the deficiency in an understanding of structural behaviour was of such importance that it was decided to set up a committee, with Dr Graham Owens, Past-President of the Institution, to implement the outcomes[7]. Its key objective was 'to improve understanding of structural behaviour at the undergraduate level'. The output has been a series of *Essential Knowledge Texts* and an annual Academics Conference.

Their support for this approach is confirmed by the Institution's own Certificate in Structural Behaviour[8]. Successful candidates report that this is now sought by employers.

However, this certificate has the obvious weakness that it tests only one part of the Brohn three-part solution. There is no evidence that, say, recognising the correct deflected shape means that candidates could solve the other parts correctly.

'Brohn test' results

At the start of the two-day 'Understanding Structural Behaviour' course, the delegates are given a test, with each item depicting a beam or frame structure with a given loading configuration, and asked to sketch the shape of the moment diagram. In the early years of giving the test, the mean score was about 35%, but today a similar group would usually not even achieve 25%. This worsening performance must be attributed to the way in which this skill is taught in nearly all universities.

Table 1 shows a selection of results from groups for which we hold the full results of the Brohn test. All clients, apart from one, are internally recognised leaders in structural design. It is likely that the lower scores in the Zoom courses reflect the lack of office contact for many newly graduated employees. This shows a continuing decline in an understanding of structural behaviour.

Since the test is scored in binary (no partial credit), it might be speculated that many solutions were close to being correct, but not exactly correct. However, the reality is that many delegates have very limited ability to even relate the deflected shape to the bending moment diagram, which shows a fundamental lack of understanding.

For example, the test results in Table 2 are from December 2020, and the 23 delegates are employed by one of the world's leading structural consultants, based in the UK (not Arup). This group attended the course by Zoom. Their performance is discussed below.

The delegates had attended leading universities in the UK: Imperial College London, Glasgow, Bristol, Sheffield, Bath, Nottingham, Cardiff, City, Cambridge, Surrey, UCL, Edinburgh, Leeds and Manchester.

What conclusions can we derive from the test results?

The mean score of this group was 25%, with a widely varying range of 0% to 72%. The errors are often gross and reflect a poor understanding of structural behaviour (Figure 1).

Included in the test from its initiation are two 'bankers', statically determinate cantilevers. Surprisingly, on average 50% of the delegates produce an incorrect solution (Figure 2).

TABLE 2: Brohn test results, December 2020

Delegate no.	Date of graduation	Score (%)
1	2011	11
2	2015	0
3	2018	17
4	2012	22
5	2017	33
6	2017	50
7	2018	50
8	2019	0
9	2017	72
10	2018	61
11	2019	33
12	2015	28
13	2014	33
14	2003	0
15	2019	11
16	2012	17
17	2017	50
18	2018	22
19	2018	0
20	2018	11
21	2014	11
22	2015	11
23	2014	50

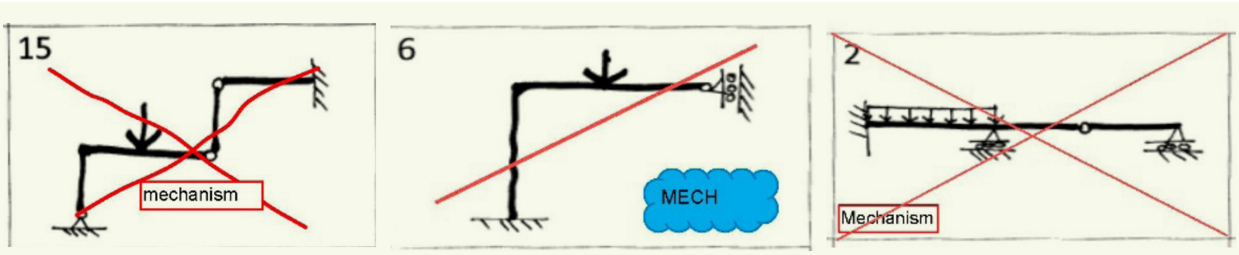
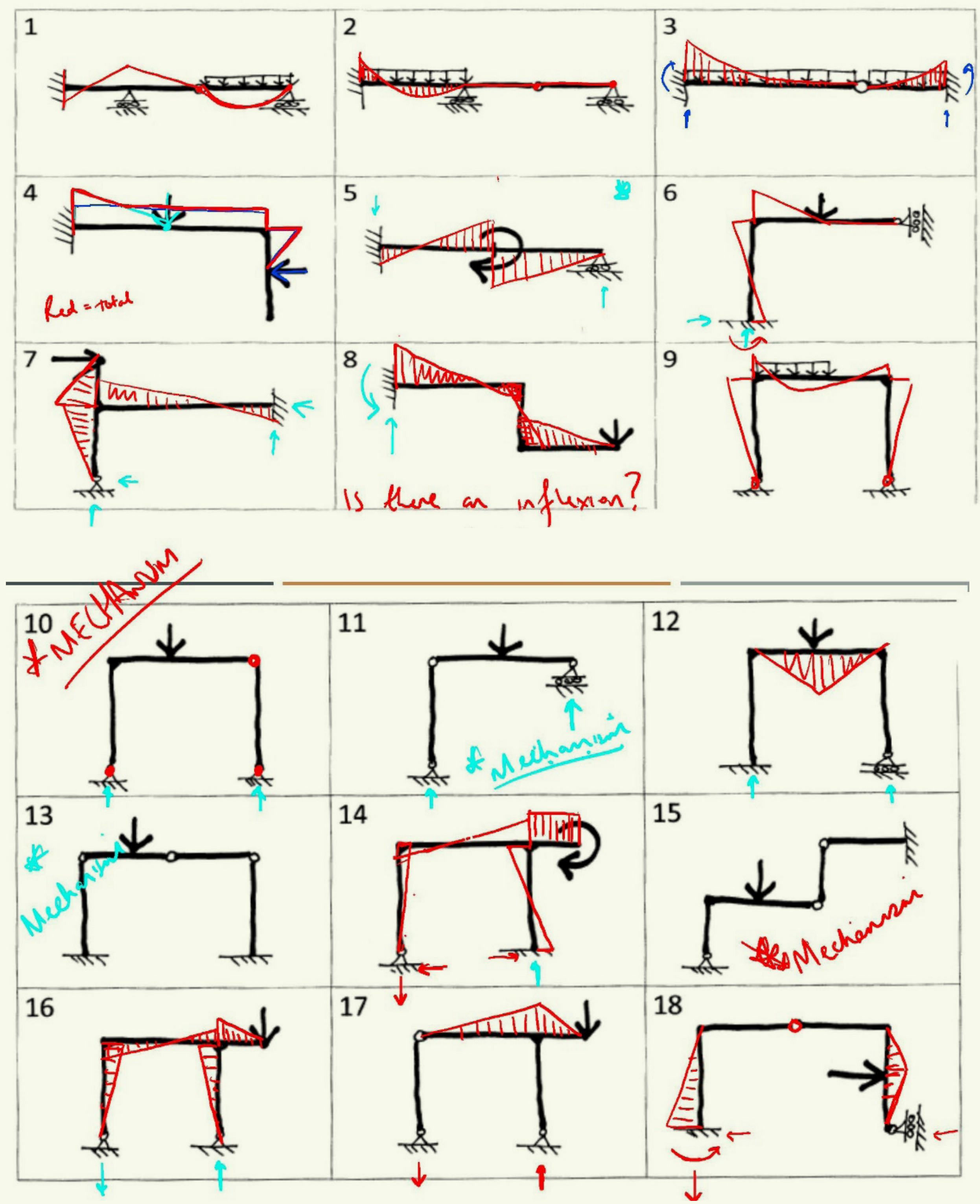


FIGURE 3: Attempts to identify mechanism

FIGURE 4: Even best-performing students are confused by deflected shape and mechanisms



The identification of a mechanism seems to be very confused (Figure 3).

The highest score demonstrates a consistent understanding of structural behaviour, but there is still the confusion over the deflected shape, item 8 and the mechanisms, items 10 and 15 (Figure 4).

Only one delegate demonstrated the Brohn method, which consists of the deflected shape, reactions and bending moment diagram, as the solution sequence (Figure 5).

This poor performance is typical of tests conducted over the last few years. Although the sample of all graduates is small, they have generally attended the best universities. This confirms that the failure to teach a sound understanding of structural behaviour lies with those teaching the subject of structural analysis.

The narrative

An understanding of structural behaviour is crucial at key stages in the development of the final structural solution:

- →| creating the structure in collaboration with the architect and client
- →| modelling the real structure to create the engineering model
- →| checking the computer output.

But if the average graduate is unable to solve these Brohn test structures with confidence, it is inconceivable that they will be able to understand more complex systems which would test the validity of the design decisions. This means that they use the computer as an *alternative* to understanding the behaviour.

Why can well-qualified graduates from leading universities not solve these problems?

The most obvious answer is that they are not taught to solve them. Feedback from the course delegates suggests that the approach was dealt with in the early years of their undergraduate studies and not mentioned again.

The committee[7] formed by the Institution to focus on this skill did not achieve that objective and the subject was relegated to one of many *Essential Knowledge Texts*[9]. A once-in-a-generation opportunity was lost.

But it is a problem for the academic; the syllabus in structures is already overloaded and without clear guidance from, say, the Institution or the Joint Board of Moderators, identifying one method as being crucially important is difficult.

But there is a more significant issue in teaching the Brohn method. Typically, topics in structural analysis result in an algorithm and, provided that the input data is appropriate, the results will be correct. That is a *linear, predictable* process.

Solving the Brohn test items does not have a predictable sequence; the thinking required is circular and there is nothing to memorise. The correct solution will only be determined if the student has a sound understanding of structural behaviour, and that requires practice. The difficulty for the academic is that practice and competence do not fit well into the course programme; the emphasis on memorising solutions is quickly learned by the student as a reliable way of passing the examination.

Feedback from one delegate, when asked if he had studied the topic at university, was that they were taught to *memorise* a range of deflected shapes until he got totally bored!

I appreciate that this is a difficult and sensitive issue, but I have the experience of being an external examiner for a university. It was an unusual department in that it had decided to appoint only experienced engineers to teach the structural subjects, in particular Structural Analysis. But in checking the final year examination in this subject, the scope of the paper was identical to a paper I had set 30 years previously at Bristol Polytechnic: strain energy, virtual work, flexibility, stiffness, collapse mechanisms, etc.

The way forward

To confirm some of the points raised above, I asked the delegates to comment on the scope of the teaching in the subject of structural analysis. Figures 6 and 7 present the responses to the questionnaire.

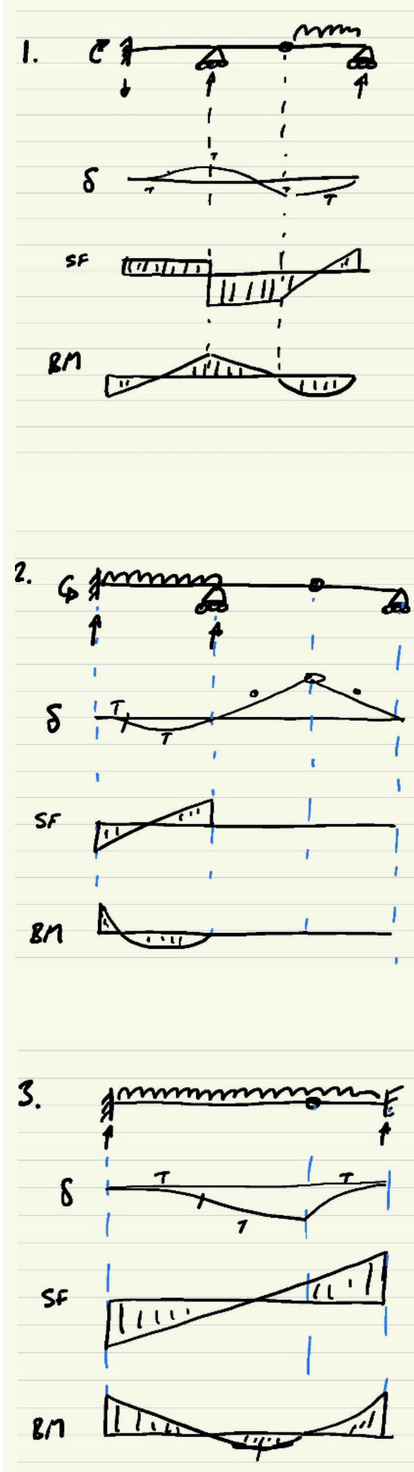
In occasional discussions I have had with academic colleagues, the justification for teaching topics that that have no *practical* relevance in the modern design office is that undergraduates need to 'know the fundamentals'. But if those fundamentals do not provide the skill required to draw the bending moment on a loaded cantilever, then that explanation is not working out very well.

Perhaps this old saw is relevant: 'It is easier to move a graveyard than change a syllabus'.

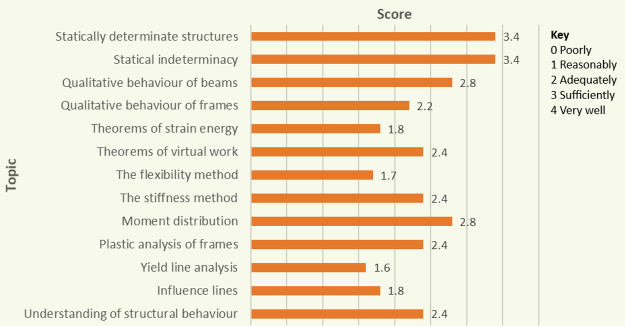
On the training course, in the practice problems, the greatest difficulty the delegates experience is getting stuck in the solution, when the error would be seen by inspecting another part of the solution.

But there is another *possible* explanation. It is now generally agreed that the brain hemispheres have different activities associated with them: the left hemisphere addresses analytical thinking while the right addresses spatial and graphical thinking. There are innumerable sources for this discussion since the work of Sperry and Gazzaniga in the 1960s which led to Sperry winning the Nobel prize.

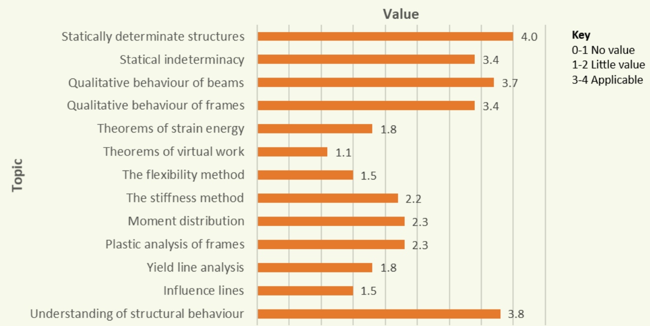
↓**FIGURE 5:** Solution demonstrating Brohn method



↘**FIGURE 6:** Student assessment of teaching of topics on undergraduate courses



↙**FIGURE 7:** Student assessment of direct value of topics in design office

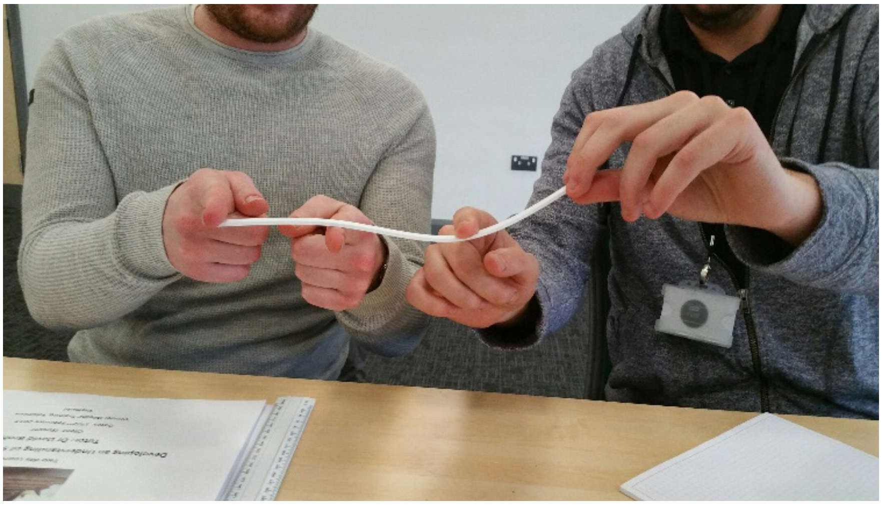


It is most notable on the training courses that the delegates have great difficulty in visualising the deflected shapes, but this is helped by providing them with plastic strips so that they can 'feel' the effect of the load and see the deflected shape (Figure 8).

But this is why the taught course is so well supported by leading consultants in their postgraduate training programmes; that circular thinking matches the design process.

The issue is this: without a sound, practised and reliable understanding of structural behaviour, the young graduate will become the servant of the computer and not its master. Isn't it time our teaching institutions took up this challenge?

↘**FIGURE 8:** Plastic strips help students visualise deflected shapes



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David Brohn of New Paradigm Solutions Ltd is a leading figure in the development of an understanding of structural behaviour. His training courses have been given to the UK's leading consultants and his textbook, *Understanding structural analysis*, is now recommended by many universities.

Find out more about David's training courses at **www.etrainingsystems.biz**.

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