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Learning structural engineering

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The Structural Engineering in the 21st Century academic conference held at IStructE in September 2009 has prompted Tim Ibell of the University of Bath to provide his thoughts on structural engineering education in an attempt to encourage other academics to bring forward their philosophies

Inspiration

Good structural engineering education requires an inspirational learning environment. Students should be inspired to want to learn, rather than be taught, such that they carry with them this motivational benefit throughout their career.

Therefore, it is quite imperative that universities employ inspirational structural engineering academics. In general, I believe that this is indeed the case. After all, how can anyone interested in engineering not be enthusiastic about some of the extraordinary structures around us?

The old chestnut

But almost all academics wear two hats. They are teachers and they are researchers. To be classified as a good researcher, in my opinion, one's research portfolio needs to consider the big picture, and not dwell solely on the minutiae of, say, computational detail. With this definition of 'good' in place, good researchers make the best teachers, in my experience. I am yet to find an exception to this rule. Holistic research which combines fundamental insight with future construction needs leads to an outstanding learning environment for students.

Experiment a little

Within this environment, it is imperative that students are allowed to experiment with structural engineering ideas throughout their degree programme. To do this effectively, I feel it is important to expose students to conceptual design at the earliest stage of their studies. Week 1 of first year is a good time to start. Developing an innate appreciation of structural behaviour in its broadest sense is in danger of not developing fully if a student is given closed-form elemental sizing 'design' exercises in the early years, followed by a broader design problem in final year. Conceptual structural design should come first, and the ensuing analytical and sizing issues should lead on in a natural manner as the student comes to understand the educational gaps which need to be plugged in order to realise her/his initial structural ambition.

In order to achieve this, I feel a profound embedment of progressive design projects is required across a curriculum. It is during these frequent design projects that industrial tutoring is of immense benefit. In the uniquely-joint Department of Architecture and Civil Engineering at the University of Bath, we are extremely fortunate to have developed dedicated design studio infrastructure for all students and a suitable operating budget to buy in industrial tutoring. Although each design project we run is led by an in-house academic, almost all design tutoring is conducted by bought-in tutors. Such tutoring is central to our cause, offering a real-world design perspective to our students and reinforcing a culture of professionalism, including ethics and integrity. Tutors range from eminent world-leading professionals to recent graduates, and from architects to structural engineers to building physicists to geotechnical engineers. This interdisciplinary range of industrial tutoring ensures that holistic design is core to success.

Students come to realise rather quickly that good structural design is not about sizing members or following codified rules. It is about producing a structural concept which leads to the satisfaction of an holistic set of requirements, including architectural, environmental, building-physics, material, geotechnical, sustainability and construction issues. They also quickly realise that structural analysis is not about understanding matrices or finite-element formulations. It is about appreciating structural behaviour holistically, such that understanding materials, modelling form & connectivity, using simplified structural models and checking any computational output are at the forefront of the learning experience.

There are many materials

At Bath, we introduce our first-year students to the extraordinary potential breadth of construction materials available to them. We do this as early as possible, to help drive curiosity associated with structural engineering innovation. The students are each asked to write a 2-page paper on a particular material. The list does not include the generic main four materials. Example materials from such a list include limecrete, super-sulphate-cement concrete, waste-aggregate concrete, re-used steel, stainless steel, cables, nets, recycled aluminium, bamboo, green timber, timber-in-the-round, glulam, LVL, inside-out timber, timber laths for gridshells, tension membranes, GFRP, ETFE, structural glass, Bath stone, rammed earth, unfired clay bricks, reinforced masonry, gabions, strawbale, hemp, wattle & daub, natural fibres, cardboard, etc. Students are expected to describe the structural properties, present case studies, present a SWAT analysis of the material, and analyse its carbon credentials. The papers are collated, and each student grades each paper in a peer-assessment approach to ensure that each student has read every paper. In this way, the primary learning outcome is an immediate fascination with the breadth and opportunity of structural materials available to them. The secondary learning outcome is an appreciation of the importance of sustainability to structural engineers. Of course, more in-depth coverage of the four main materials follows in later years, as does coverage of some of the other materials listed above.

And there are many ways in which structures can fail

With material appreciation in mind, the same first-year students are then asked to design in groups a conceptually-open structure. In 2009/10, this was an Engineers-Without-Borders-style rural-village water tower. In groups, the students designed the tower (by assuming the use of 10 old timber poles left lying around in a local swamp) and provided method statements, handed their designs on to another group for checking, and finally handed their designs on to a further group for construction of a model of the tower, which was then tested to destruction under live loading (an incrementally-filled bucket of water). The core learning outcomes in this project are always innovation in thought when resource is scarce, good communication of a design such that someone *else* can build it (this usually throws the students when they realise that they won't be building their own design), and the concept of watching something fail in an unexpected manner, which was buckling predominantly in the water tower project. The first lecture after these tests was on Euler buckling, which suddenly took on great significance to the students at that stage.

Alongside understanding the construction process and failure modes, students need to appreciate scaling effects. Right at the start of first year, we ask our students to design a small model (around about 100mm in scale) to satisfy various creative requirements. The model is conceptual in nature, and is conducted by joint groups of architecture and civil engineering students. When complete, we ask them to scale up their model 20 fold, such that they need to build something more realistic in size. The students then exhibit

their structures on our campus, which attracts all sorts of interested parties. Many of the structures do not survive very long, given their flexible nature, even though the small model appeared to be stable and stiff.

Precedent

University buildings are great opportunities for learning about architecture, structural engineering and building physics. During the first semester of first year, our students are asked to analyse a building of their choice on our campus, and to report their findings on a single A3 sheet. They are asked to draw a structural cross section, to feel the radiators, to feel the windows, to feel the walls, to consider the construction, to discuss the choice of materials, to discuss the acoustics, to discuss the lighting, and to provide a commentary on possible improvements. We see this exercise as important as a simple means to demonstrate a structured approach to the analysis of existing buildings.

In my opinion, most architects probably use precedent study a bit too much. Most structural engineers don't use it enough. It is a simple and effective tool for students of structural engineering to analyse others' work. In their third year, as part of bridge engineering, our students each choose an existing bridge and write a conference paper on it, to include client requirements, aesthetics, loading, construction, durability, material choice, sizing, maintenance and suggested improvements. Further, at the start of our flagship Sir Basil Spence joint design project in final year (where architecture and civil engineering students work collaboratively on a major building design), we set aside a week at the start for the groups to look at precedents. Learning from others' successes is a trick which I do not believe we exploit as much as we could in structural engineering education. There are some excellent examples of coverage of structural engineering failures in degree programmes at certain universities, and these are immensely important. But, I feel there is a place for analogous provision of structural engineering success stories too, however, and Professor Michael Dickson teaches such a unit at Bath, entitled Architectural Structures. It is our most popular option unit.

Communication

I feel students should feel the need to carry with them a sketchbook, and they should be able to write convincingly and appropriately. They should make structural models of their designs, starting from first year, and they should be encouraged to push and prod them, and to analyse the difficulties they might have experienced in building their model. You cannot do this with a computer screen. And when the design project comes to an end, students should be required to defend their design orally in front of eminent designers.

But what about structural analysis?

So far, this article has concentrated on structural design education, which I believe should drive the requirements for structural analysis education, not the other way round. The first semester of first year is entirely joint between architecture and civil engineering students at Bath. While all students enter civil engineering with a mathematics background, not all architecture students have A-level mathematics. One of my jobs is to teach this joint first-year class the fundamentals of structural engineering. Because I cannot rely on calculus in the early stages to introduce various basic concepts, as I would lose a chunk of the class, I concentrate on structural behaviour at a more fundamental level, using merely GCSE mathematics, as appropriate. This apparent handicap turns out to be a fortuitous advantage, as it allows an appropriate mix of 'feel' and mathematics to develop. For instance, I use a simple model of a tarpaulin stretched between two points (representing zero bending moment at the ends of a simply-supported beam) and then apply uniformly-distributed and concentrated loadings along

its length (with the help of various students) to demonstrate the ensuing analogous shapes of bending moment diagrams. This approach extends very successfully into continuous beams or beams with overhangs, and has an immediate resonance with the students.

Three years ago, Professor Michael Dickson, Professor Peter Walker and I redesigned the analytical thread of our structural engineering education at Bath. In essence, we have pared down the breadth of analytical techniques we teach, we have concentrated on ensuring our students understand structural behaviour (deflected shapes, qualitative bending moment diagrams, lines of thrust, etc.) at the expense of some of the more mathematical manipulation which sometimes is expected of students, we have looked to ensure that our students can verify computer output using not only hand checks but also the computational tool itself in a sensitivity-analysis approach, and we have ensured that our finite-element teaching is aimed at modelling and verification aspects in the main.

And finally

I firmly believe that the job of structural engineering academics is to inspire graduates to enter the profession of structural engineering. It is not to merely cover the expected curriculum or to suggest to students that an analytical degree programme is a broad-based educational base for any career. This is not good enough, in my opinion.

Tim Ibell
8 April 2010