

# Enhancing the Teaching and Learning of Structural Concepts through Experience of Seeing and Touching

Tianjian Ji & Adrian Bell

The University of Manchester, UK

---

*The work that we have called Seeing and Touching Structural Concepts has been developed since 1999 for enhancing the teaching and learning of structural concepts in civil engineering courses at the University of Manchester. This includes providing a series of simple demonstration models for illustrating structural concepts in conventional class teaching which allow students to gain a better understanding of the concepts; providing associated engineering examples to demonstrate the application of the structural concepts which help to bridge the gap between the students knowledge and practice, and converting appropriate research output, which particularly involves structural concepts, into teaching material to improve existing course contents. A website with the same title has been developed to benefit a wider community, including students, lecturers and practising engineers in civil engineering and related engineering disciplines. Feedback from our students and other users has been very encouraging and has helped us to improve the quality of the website. A book with the same title is to be published in May 2008.*

## 1. Introduction

Structural concepts are key elements for students to understand, for lecturers to teach and for engineers to use in civil and structural engineering practice. The teaching and learning of structural concepts at university needs to be enhanced to meet changes and challenges in our current learning environment and in the world of work.

In the past a major part of this understanding has been developed through working with hand calculations and through experience with construction. However, now many hand calculations are replaced by the use of computers and new methods of gaining an understanding of structural concepts are desirable. Indeed the understanding of structural concepts, fundamental to the sound and innovative design of structures (buildings, bridges etc) is even more important because of the wide use of computers and the, often unquestioning, reliance placed on the results of computer analyses which although mathematically correct may be flawed if they are based on incorrect assumptions and modelling. This is one reason for criticisms from the construction industry that graduates tend to place over reliance on the use of computers. Graduates, in general, are good at using computers but many are unable to judge whether the results obtained from computers are correct. This suggests that students may not have become adequately familiar with basic structural concepts during their university studies.

Structural concepts and principles are abstract, and they cannot be seen and felt directly. For instance, force paths transmit loads from their points of action to structural supports, and resonance describes the vibration characteristics of a structure responding to a dynamic load applied at a natural frequency of the structure. If such concepts and principles could be made more observable and

touchable, students would be better able to understand and remember them [1]. Physical models are often used in teaching of physics [2, 3] for an enhanced understanding of concepts and in engineering designs [4, 5] for better appreciating the behaviour of structures.

Engineering examples are often not provided in textbooks to illustrate the applications of structural concepts. If lecturers could use related engineering examples and convert appropriate research work into teaching, the interest of students would be stimulated and their understanding of structural concepts would inevitably improve.

It has been observed in class situations that students show a greater interest in topics which are demonstrated physically than in topics that are explained by words and blackboard/OHP/PowerPoint presentations. They show an even greater interest in practical examples which illustrate the use of concepts in the solution of engineering problems rather than in coursework examples. Students are motivated by "hands on" experience and by linking concepts and models to real engineering examples.

This paper summarises our work on enhancing the teaching and learning of structural concepts.

## 2. The Work

In order to improve students' understanding of structural concepts and to deliver lectures more effectively, we have been developing what we called *seeing and touching structural concepts* to supplement traditional class teaching and learning. To enable this, three parallel themes have been followed:

- providing a series of simple demonstration models for illustrating structural concepts and principles in conventional class teaching which allow students to gain a better understanding of the concepts;
- providing associated engineering examples to demonstrate the application of the structural concepts and principles which help to bridge the gap between the students' knowledge and practice;
- converting appropriate research output, which particularly involves structural concepts, into teaching material to improve existing course contents.

Structural concepts that can be physically demonstrated are identified and simple demonstration models, suitable for class use, are provided to illustrate the concepts. Whenever possible, students have been encouraged to help to design and make these models.

Real interest can be generated and a better understanding can be achieved by seeing how concepts are used in the design of real structures. Therefore engineering examples which can illustrate the application of the concepts in practice have been sought and identified. Poor designs which may be illustrated by collapses have also been studied as such applications can often show the consequences of misunderstanding structural concepts.

Research and teaching are undertaken in parallel in universities but links between research output and undergraduate teaching may not always be developed.

Research output, which particularly concerns or illustrates structural concepts, has been converted to forms suitable for linking with simple demonstration models and practical applications for use in class teaching. For example, concepts for designing stiffer structures [6], human whole-body models in structural vibration [7] and the horizontal movements of frame structures induced by vertical loads [8] are presented. We have developed a number of physical models for illustrating structural concepts and identified a number of engineering cases and every day examples for illustrating the applications of these concepts. These models and examples are normally not included in textbooks but are useful to supplement learning and teaching. Students

can quickly grasp and remember a concept when it is physically demonstrated and its application is illustrated.

### 3. Examples

The following examples are abstracted from [9, 10] illustrating a physical model and a practical example which relate to one structural concept.

#### 3.1 An example of demonstration model – a pair of rubber rings

This pair of models shows that *a tied ring is much stiffer than a similar ring without a tie* and demonstrates that *the smaller the internal forces, the stiffer the structure*.

Fig. 1 shows two rubber rings, one with and one without a wire tied across the diameter. The dimensions and material properties of the rings are described and the calculated vertical displacements of the rings are given for a weight of 22.3N. When this weight is placed on the top of each of the two rings, the reduced deformation of the tied ring is apparent and its increased stiffness can be seen and felt. This may be explained since the force in the wire increases when the load is applied, and produces a bending moment in the ring in the opposite direction to the bending moment caused by the external load. In this way the force in the wire balances part of the bending moments in the ring, reducing the internal forces in the ring, thus making it stiffer. (Appropriate equations, diagrams and an example for hand calculation are provided in the section on theoretical background)

Examples of this criterion in practice are tied arches and tied-pitched roofs. The ties help to balance horizontal forces and reduce horizontal displacements, thus effectively increasing the structural stiffness.



Fig. 1: Comparison of the deformations of two rubber rings

#### 3.2 A practical example – Raleigh Arena

The roof structure of the Raleigh Arena (Fig. 2) consists of carrying (sagging) cables and stabilising (hogging) cables which are supported by a pair of inclined concrete arches. The structure forms, at least in part, a self-balanced system, which effectively reduces the internal forces in the arches. The carrying cables apply large forces to the arches and some of the vertical components of the forces are transmitted to external columns. Significant portions of the bending moments and the horizontal components of the shear and compressive forces in the arches are self-balancing at the points of contact between the two arches. Most of the horizontal components of the remaining shear and compressive forces in the lower parts of the arches are

balanced by underground ties, which have a similar function to the wire tie in the ring used in the demonstration. The reduced internal forces not only allow the use of less material but also lead to a stiffer structure.

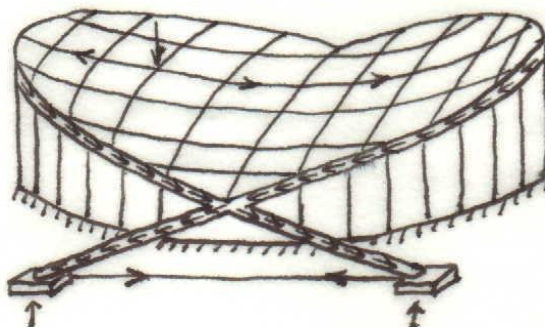


Fig. 2: The force paths of the Rayleigh Arena [11]

The measures for developing other self-balanced systems have been investigated as a research topic, demonstrating that teaching also lead to research and help engineering practice.

#### 4. The links between teaching, practice and research through the study of structural concepts

Teaching and research are normally conducted in parallel at universities but the links between teaching and research may not always be fully developed. There are some links between teaching, practice and research relating to structural concepts and these have been observed and explored. The knowledge base established for teaching and learning of structural concepts has also provided some ideas for research and new concepts have also been abstracted from research work and practical engineering examples.

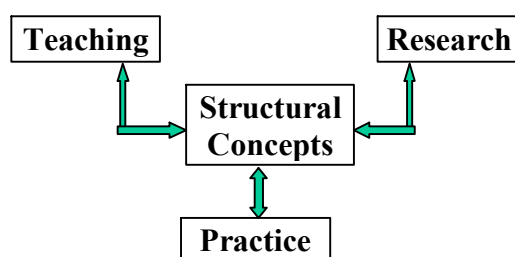


Fig. 3: The interaction between teaching, research and practice through the study of structural concepts

The relationship model shown in Fig. 3 provides alternative ways to view teaching, research and engineering practice where structural concepts are concerned. This paper shows that teaching of structural concepts benefits from related research and engineering practice.

The development of physical models for improving the understanding of structural concepts has also been extended into research for examining the feasibility of new ideas and for verification qualitatively of new findings [6].

## 5. The Outcome

After several years of working on this topic, there have been several outcomes:

### 5.1 A library of demonstration models

Over 50 sets of physical models have been produced. Normally, two related models are provided to show the differences between the behaviour of the two models thus illustrating the concept. Small-scale quick experiments are also included for real-life demonstration.

### 5.2 Practical examples

Linking to the demonstration of structural concepts, over 60 appropriate examples from engineering practice and everyday life have been identified and collected to show how the concepts are applied or used in practice. The examples that come from everyday life should be familiar to most people.

### 5.3 Presentation of structural concepts

A new format for the presentation and teaching of structural concepts is given as follows:

- a) the definitions and concepts are first presented in a brief form to emphasise the main points of the topic and attract students' attention;
- b) explanations or theories follow to show how and where the concepts come from and what assumptions are involved, together with examples using hand calculation.
- c) model demonstrations are provided to enhance the understanding of the concepts, which can be seen and touched by students during and after a lecture. Thus students are motivated and become more attentive in the class;
- d) practical examples, either a successful story or a failure, are also given to show how the concept has been applied in practice and what the effect is.

### 5.4 A website

As only limited number of students and engineers will actually see and touch the models developed and receive our lectures, a website, Seeing and Touching Structural Concepts, ([www.structuralconcepts.org](http://www.structuralconcepts.org)), was developed in April 2006 where the contents developed in (a), (c) and (d) in 5.3 have been made available at the site. Over 230 photos have been provided to show the models, their use in demonstrating concepts and practical examples. Video clips have also been provided for demonstrating some concepts.

Questionnaires were distributed to our students in 2006 and 2007. The feedback was very positive and encouraging, and suggestions for improvements were also received. The suggested improvements included:

- provide more model demonstrations and practical examples
- include what mathematical formulas are used to calculate the concepts.
- introduce the website to the first-year students
- have references for each chapter so one can look these up if there is a need for a further investigation.
- include movies for demonstration which would be more appealing to students

The website was updated in January 2008 in which all sections were re-written and all photos are legally presented, using either our own photos or those with permissions. It now contains 57 sections of model demonstration, 66 sections of practical examples and 12 video clips. A section of references for each chapter is also added.

The website received over 18000 visitors up to the end of March 2008, benefiting a wider community of students, engineers and lecturers in civil engineering and related disciplines. The photos and other materials in the website can be downloaded for lecturers to use in their own teaching.

### 5.5 A book

The above mentioned work has been presented in a book form and is to be published by Taylor & Francis in 2008 [9]. Each of the nineteen chapters is presented in the form described in 5.3. Line drawings are provided in the sections of theoretical background for illustrating theory and examples calculated by hand. In particular, some physical models are analysed using basic theories linking the models to the related theory. The book and the website are complementary to each other. The book allows that one can read at anytime and anywhere, and provides theoretical background while the website provides downloadable colour photos and video clips. Twelve chapters of the book have been used in three course modules taught by the authors in the second semester of the 07/08 academic year.

## 6. The Website Used as a Student Centred Learning Resource and Feedback

It is always hoped that students learn effectively and actively and this, in part, requires appropriate activities and/or stimulators being provided. Students were asked to study, *Seeing and Touching Structural Concepts*, at the website, [www.structuralconcepts.org](http://www.structuralconcepts.org), where structural concepts are demonstrated by physical models and their applications are shown by practical examples. It was hoped that students could not only quickly revise a number of concepts they had studied previously but could also gain an improved understanding of these structural concepts.

*Enhancing the understanding of structural concepts* was introduced to the course module Structural/Stress Analysis 4 in 2006 when the website was available internally and students were asked to study part of the website relating to Statics and undertake a piece of individual coursework. They were asked to design/make a physical model that demonstrate one structural concept or identify an example from engineering practice or everyday life where a structural concept was used creatively. After reading through the coursework, we felt that the individual submissions were interesting and varied and included some creative components. The coursework assignment was revised and improved in 2007 on the basis of the previous submissions. It was hoped that the revised coursework would encourage students to consider and explain structural concepts in a simple manner motivating further study and the development of a greater understanding and awareness of the use of structural concepts.

Another improvement made in 2007 was that all the coursework submissions were collected to form a booklet [12]. This booklet, titled "*Enhancing the understanding of structural concepts*", was distributed to all the students in the class enabling them to learn from each other as well as from lecturers and textbooks. The students enjoyed reading their own work and voted the best three of models or examples from all the submissions.

The coursework return was excellent. All students submitted the coursework and four students even made two different submissions. Several good and interesting new models or examples were proposed. A number of students made their own models and/or provided photographs of experiments. As lecturers, we felt that we had learnt from the students' submissions, which were enjoyable to read. Three models/examples in this booklet have been included in the website.

A drawback of making the submissions widely available was the cost of photocopying which is also black and white. In 2008 the students' submissions were made through using Blackboard and all the submissions are compiled into three categories, model demonstration, practical examples and essays on learning of structural concepts, and displayed on Blackboard. The electronic booklet is available to all 70 students in the class. This saves the cost of photocopying and will allow the use of colour photos. Three students volunteered to design three covers of the booklet and one student provided a video clip of his model demonstration.

Questionnaires were designed by two students who took the course module for feedback about the website and about the coursework separately. The website evaluation questionnaire consists of 14 questions covering the usability, contents and opinions about the website while the coursework evaluation questionnaire consists of 14 questions relating to the effects and opinions about the coursework on leaning and understanding of structural concepts. The questionnaires for the website were used in 2006, 2007 and 2008 and that for the coursework was used in 2007 and 2008. The feedback for the coursework not only provided suggestions for improvements but also showed how students enjoyed and benefited from conducting their own individual coursework and reading through others coursework.

## 7. Conclusions

The work described was initially developed for helping students to gain a better understanding of structural concepts. However, the work has been extended gradually and significantly. In addition to the benefit to our own students, the outcome has also been made available to students, lecturers and engineers in civil structural engineering and related engineering disciplines through using a website and a book. The work itself has benefited from our own research and from engineering practice, and equally, it has contributed to our research and engineering practice.

## Acknowledgement

The development of the work described in this paper and the website were supported by the Educational Trust of the Institution of Structural Engineers and The University of Manchester. The authors are grateful for the current support from the Engineering Subject Centre, The Higher Education Academy at Loughborough University, for the project, Seeing and Touching Structural Concepts - developing a student centre learning environment.

## References

1. Ji, T. and Bell, A. J., (2000) Seeing and Touching Structural Concepts in Class Teaching, The Proceedings of the Conference on Civil Engineering Education in the 21st Century, Southampton, UK, 26-28 April 2000
2. Sprott, J C, (2006), Physics Demonstrations: A Sourcebook for Teachers of Physics, The University of Wisconsin Press, ISBN 0 299 21580 6.
3. Ehrlich, R, (1990), Turning the World Inside Out and 174 Other Simple Physics Demonstrations, Princeton University Press, ISBN 0 691 02395 6.
4. Kawaguchi, M, (2004), Physical models as powerful weapons in structural design, IASS Symposium: Shell and Spatial Structures from Models to Realisation, Montpellier, September 2004.
5. Schlaich, J, (2004), Conceptual Design of Light Structures, IASS Symposium: Shell and Spatial Structures from Models to Realisation, Montpellier, September 2004.

6. Ji, T, (2003), Concepts for designing stiffer structures, *The Structural Engineer*, Vol.81, No.21, p.36-42.
7. Ellis, B. R. and Ji, T., (1997), Human-structure interaction in vertical vibrations, *Structures and Buildings, the Proceedings of Civil Engineers*, Vol. 122, No.1, pp.1-9.
8. Ji, T, Ellis, B R and Bell, A J, (2003), Horizontal movements of frame structures induced by vertical loads. *Structures and Buildings, the Proceedings of the Institution of Civil Engineers*, Vol.156, No.2, pp141-150.
9. Ji, T and Bell A J, (2008), *Seeing and Touching Structural Concepts*, [www.structuralconcepts.org](http://www.structuralconcepts.org).
10. Ji, T and Bell A J, (2008), *Seeing and Touching Structural Concepts*, Taylor & Francis, ISBN 9780415397742
11. Bobrowski, J, (1986), Design philosophy for long spans in buildings and bridges, *Journal of Structural Engineer*, Vol. 64A, No.1, pp. 5-12.
12. The University of Manchester (2007), *Enhancing the understanding of structural concepts – a collection of students' coursework*.