TEACHING STRUCTURAL MECHANICS WITH MODELS

Davide Bigoni[1], Francesco Dal Corso[1], Diego Misseroni,[1]
[1]*DICAM, University of Trento, Trento, Italy*

Summary Several models are presented to help teaching structural mechanics at all levels to engineering and physics students. The simpler models have been developed to explain the concepts of elastic beam, segmental arch, truss structure, elastic frame, and Euler buckling. More sophisticated models have been designed to introduce advanced concepts such as flutter instability under tangential follower load and configurational forces under bending and torsion.

INTRODUCTION

In the last decade we have developed physical teaching models to improve the presentation and understanding of scientific results, especially to engineering and physics students (at undergraduate and graduate level), but also to all levels, ranging from untrained audiences to peers in the scientific community.

Digital technology has indisputable merits and is of crucial importance in teaching. However, it tends to reduce physical intuition in students generally and for students used to an intuitive approach (such as those involved in engineering studies) it can be difficult to understand how principles are applied in the real world. This is particularly true in mechanical engineering, probably the hardest discipline in engineering studies.

Several mechanical models developed in our laboratory have been shown to be of primary importance (i) as proof-of-concepts of newly discovered phenomena; (ii) as teaching tools at different levels, including PhD programs; (iii) as demonstrators at public exhibitions, even for untrained public.

Our models have been conceived, designed, and realized to give tangible, vivid evidence of non-intuitive mechanical phenomena. Some of them have been invented for illustrating results obtained within EU financial schemes, others have been addressed to scientific presentations, and others have been designed to help students in understanding basic and advanced concepts of mechanics.

Our results and findings provide a breakthrough innovation in engineering education, through a simplification in the teaching of mechanics. We will continue developing our methods, thus contributing, through engineering education, to a sustainable and equal opportunities human development.

MODELS FOR BASIC STRUCTURAL ANALYSIS

Cross and Morgan wrote in 1932: '*the ability of a designer of continuous structures is measured chiefly by his ability to visualize the deformation of the structure under load. If he cannot form a rough picture of these deformations when he begins the analysis he will probably analyse the structure in some very awkward and difficult way; if he cannot picture these deformations after he has made the analysis, he doesn't know what he is talking about*'. This statement remains valid today. However, the visualization of the deformation of a structure is more complex than it may appear and for this reason, teaching models are fundamental to stimulate students' interest and to simplify learning. We have developed several structural models for Civil engineering students, for elastic beam, segmental arch, truss structure [1], elastic frame [2], and Euler's buckling, Fig. 1.

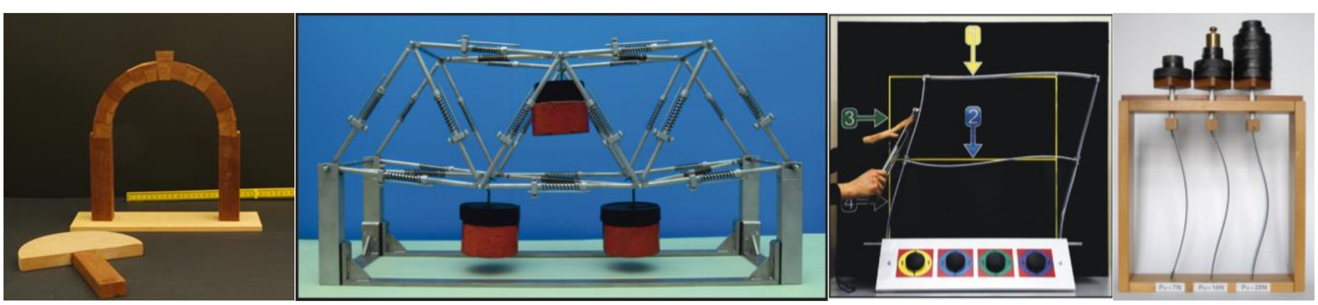

Fig. 1 from left to right, models for: Segmental arch; Truss structure; Elastic frame and Euler's buckling

a) Corresponding author. Email: davide.bigoni@unitn.it

ADVANCED MODELS FOR FLUTTER INSTABILITY & CONFIGURATIONAL FORCES

Proof-of-concept-models have been designed by us to give evidence to previously unknown mechanical phenomena. These include: buckling of an elastic rod under tensile dead load [3], flutter instability induced by dry friction [4], effects of curvature constraint on instability [5], existence of configurational forces [6], effects of configurational forces on instability [7], the elastica arm scale [8], the torsional gun [9], Fig. 2. All these phenomena are so innovative that it is hard to imagine their real world implications without a working physical model.

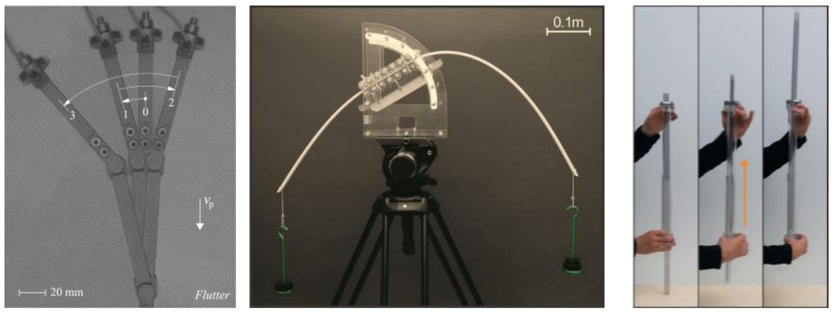

Fig. 2 From left to right, models for: Flutter instability; The elastica arm scale; The torsional gun

CONCLUSIONS

Usually engineers face the problem of characterizing new materials of unknown properties and this is done using standard testing machines. Our models originate from an of 'inverted approach': first we develop a theory to describe a phenomenon and then we build a model which will behave physically according to the theory. In this sense, our laboratory is unique: we use our testing machines with data acquisition to fully define the behaviour of our physical models to see how well it fits the theoretical models. We have thus been able to show complex nonlinear instabilities such as flutter instability in the real world which were previously only demonstrated mathematically. We have discovered and demonstrated buckling instability of a bar in tension and the existence of configurational forces. We have invented a new type of elastically deformable arm balance and a torsional actuator, each one with its associated model. These models have been used to engage both our peers and the public in our discoveries. Teaching models of truss structures and frame structures have been developed to enhance teaching at the undergraduate level.

ACKNOWLEDGEMENT

The authors gratefully acknowledge financial support from the ERC Advanced Grant 'Instabilities and nonlocal multiscale modelling of materials' FP7-PEOPLE-IDEAS-ERC-2013-AdG (2014-2019).

References

[1] Bigoni, D., Dal Corso, F., Misseroni D. and Tommasini, M. A teaching model for truss structures. *Eur. J. Phys.* **33**:1179–1186, 2012.
[2] Misseroni D., Bigoni, D. and Dal Corso, F. A model for teaching elastic frames. *J. Materials Education*, **36**:169-174, 2014.
[3] Zaccaria, D., Bigoni, D., Noselli, G. and Misseroni, D. Structures buckling under tensile dead load. *Proc. Royal Soc. A* **467**:1687-1700, 2011.
[4] Bigoni, D, Noselli, G. Experimental evidence of flutter and divergence instabilities induced by dry friction. *J. Mech. Phys. Solids* 59:2208–2226, 2011.
[5] Bigoni, D., Misseroni, D., Noselli, G. and Zaccaria, D. Effects of the constraint's curvature on structural instability: tensile buckling and multiple bifurcations. *Proc. Royal Soc. A* **468**:2191-2209, 2012..
[6] Bigoni, D., Dal Corso, F., Bosi, F. and Misseroni, D. Eshelby-like forces acting on elastic structures: theoretical and experimental proof. *Mech. Materials* **80**: 368–374, 2015.
[7] Bigoni, D., Bosi, F., Dal Corso, F. and Misseroni, D. Instability of a penetrating blade. *J. Mech. Phys. Solids* **64**:411-425, 2014.
[8] Bosi, F., Misseroni, D., Dal Corso, F. and Bigoni, D. An elastica arm scale. *Proc. Royal Soc. A* **470**:20140232, 2014.
[9] Bigoni, D., Dal Corso, F., Misseroni, D. and Bosi, F. Torsional locomotion. *Proc. Royal Soc. A* **470**:20140599, 2014.