Experimental models to support the teaching of structural mechanics

Rui Miguel Água-Doce Alves, IST DE Civil

Abstract: This thesis has two main goals: contributing to the reorganization of the Structural Mechanics Lab at Instituto Superior Técnico and assemble a set of new experiments/ that may be acquired or even made and added to that same Lab. The thesis lists a series of guides for carrying out various experiments, for each and every equipment available in the Lab, ready to be used by the students and the teachers. These guides always include a description of the equipment, the methodology for the experiments, a brief theoretical background and, in some cases, tables/forms ready to be filled with the results of the experiment. The last chapter is a collection of interesting experiments and their equipment that might be acquired and even, in some simple cases, made in-house. Some of them were already implemented in other universities and, for the cases judged more appropriate, proposals of acquisition are, briefly, made.. Others are simpler models that can easily be replicated/built in the lab itself. The description of each experiment also includes the key concepts and theoretical aspects behind the experiments More than forty guides were produced, ready to be used by the students and teachers at DECivil of the Instituto Superior Técnico as part of their courses in the field of Structural Mechanics and proposals were made of new experiments that may be added to the list of current experiments/equipment.
Keyworkds: Experiments, Equipment, Lab, Structural Mechanics

1 – Introduction

Civil engineering, like many other engineering areas, is versatile, covering several fields. This work arises with the motivation to develop new processes that might facilitate the learning, and the teaching, of one of those fields, the structural mechanics. In the scope of this work, it was made the following division: statics and dynamics of rigid bodies and mechanics of deformable bodies.

During an engineering course, it's not always easy for the student to absorb some of the more complex concepts but what is at first contact something new and hard to comprehend will, in most of the cases, be the foundation of the next courses. Therefore, it's of the foremost importance to develop any means to make it easier for students to learn and comprehend those concepts. Also, it makes the teacher's lives easier and more rewarding.

It's with that idea in mind that this thesis was created, to develop a library of experiments to be used in the teaching of structural mechanics in the civil engineering course at Instituto Superior Técnico.

The Department of Civil Engineering (DECivil) at Instituto Superior Técncico already possesses a didactic lab with a large set of equipment, to be used by the teachers and support their lectures. These equipment and the experiments possible to be done with them were cataloged and a guide was made to each and every one of those experiments. Those guides include a description of the equipment, the methodology for the experiment and a theoretical background of the concepts addressed in that experiment.

After this mentioned cataloging, a research was made, in order to find new experiments that could be acquired and added to the collection. These new experiments can come in different forms, either by adapting the already

existing equipment or by acquiring/producing new ones. The best case is to acquire/produce new equipment that could be easily carried to the classroom, so that the teacher could use mid-lecture.
The biggest difficulties were the state of the equipment, which was not always the best, either because some of the parts were missing or simply because they weren't assembled (some of the equipments share the same support framework and there weren't enough of those for every equipment). Also, when researching, most of the experiments found were not about structural mechanics, most of them were about chemistry, optics or electricity.

2 – Static and dynamic of rigid bodies

In this chapter, the equipment and experiments address concepts of the static and dynamic of rigid bodies. These equipments were all tested, except the ones that weren't assembled, in order to see if everything was working as it was supposed to.
For the first part, static of rigid bodies, there are experiments to address the equilibrium of forces (Figure 1),

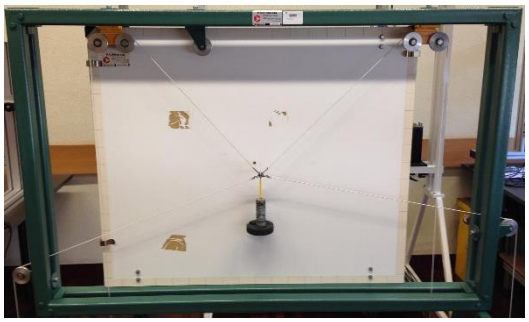

Figure 1 – Equilibrium of forces

Shear and bending moment in beams (Figure 2 and 3) and friction (Figure 4).

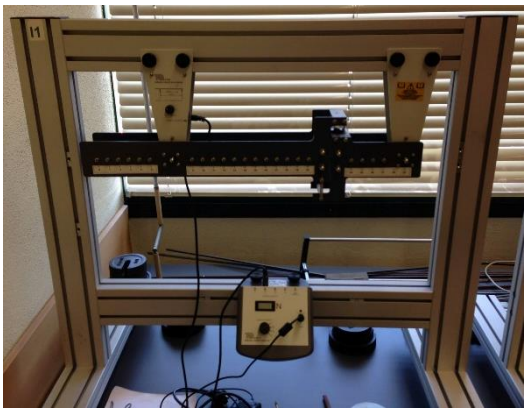

Figure 2 – Shear stress in beams

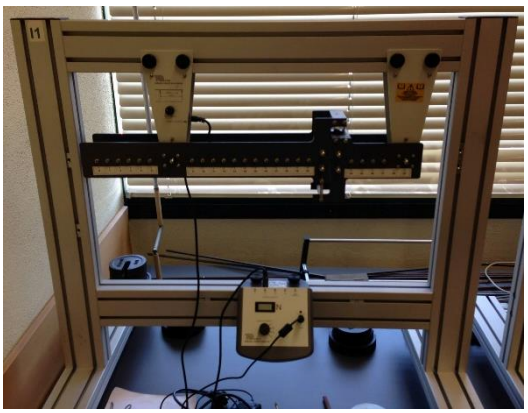

Figure 3 – Bending moment in beams

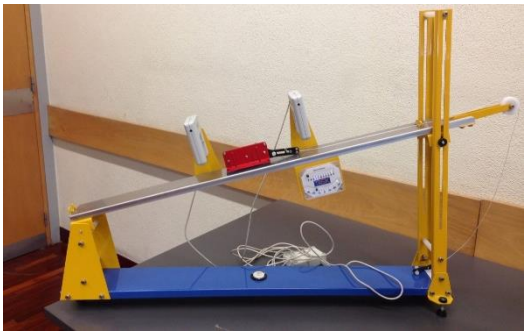

Figure 4 - Friction

Although friction experiments involve movement, it was included in this part of the chapter because all of these concepts are studied in the same course at Instituto Superior Técnico.
The second part covers the dynamics of rigid bodies and the experiments are

about simple mechanisms (Figure 5),

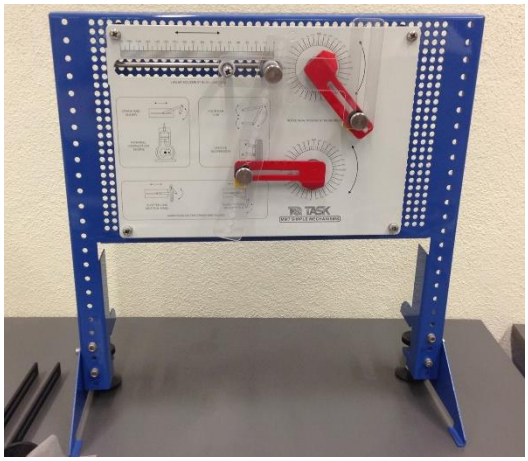

Figure 5 – Simple mechanisms

there's an equipment called Airtrack that addresses the elastic and inelastic collisions (Figure 6), there's also a kit that addresses simple dynamic concepts related to pendulums and springs (Figure 7),

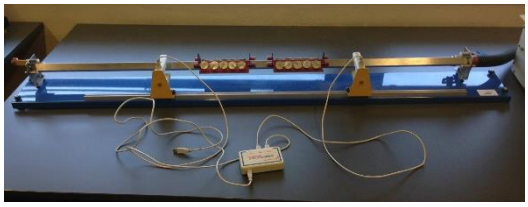

Figure 6 - Airtrack

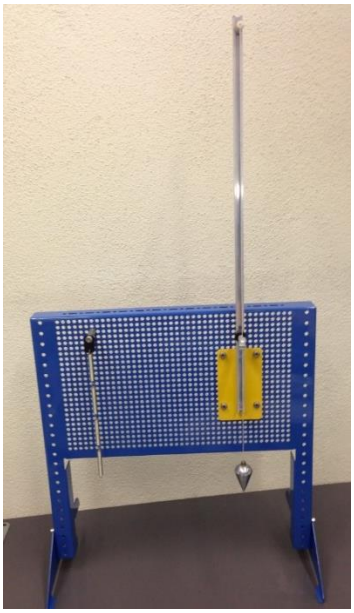

Figure 7 – Pendulum and Spring

and, lastly, an equipment to study forced and free vibration (Figure 8).

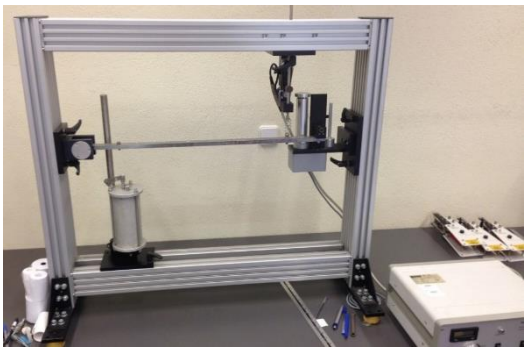

Figure 8 – Forced and free vibration

3 – Mechanics of deformable bodies

In this second chapter, experiments that address more advanced concepts are listed. As in the previous chapter, the equipments were tested, when possible.

The first part of the chapter deals with the field of the strength of materials, where the students have the first contact with the concepts of tension and deformation. There's a photoelasticity equipment (Figure 9) that makes it possible to observe the tensions that are generated when actions are applied on parts made of materials with some special properties,

Figure 9 – Photoelasticity

an equipment to study the tension in beams submitted to a bending moment (Figure 10), a continuous beam to study the static equilibrium of a beam and the relations between the beams' properties and section with its length and deflection (Figure 11),

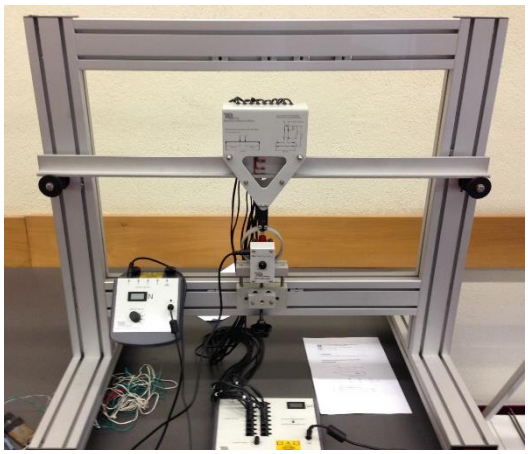

Figure 10 – Bending moment tensions

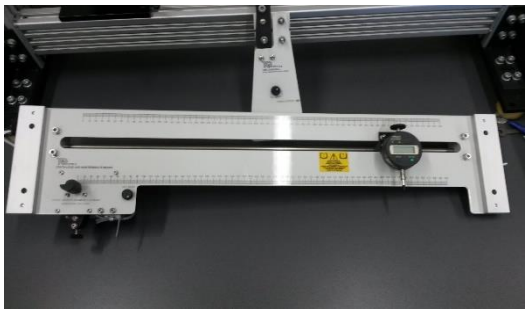

Figure 11 – Continuous beam

an equipment to study the deflection of beams (Figure 12) and another one to study the deflection and reactions in a frame (Figure 13).

Figure 12 – Deflection of beams

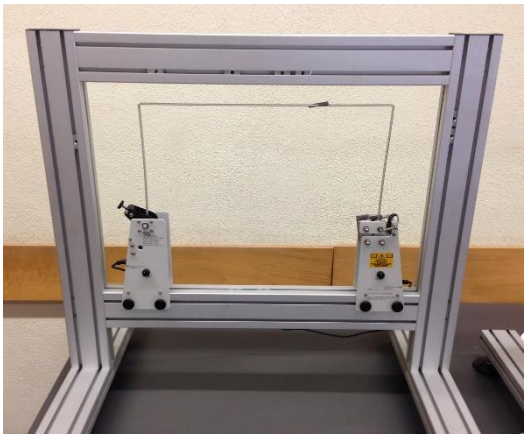

Figure 13 – Deflection and reactions in a frame

In the second part of this chapter, experiments that address the more advanced concepts, regarding structural analysis and design, like the settlement of structures (Figure 14),

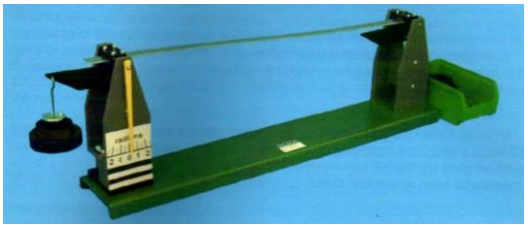

Figure 14 – Settlement of structures

truss structures (Figure 15), the Maxwell-Betti Theorem (Figure 16), the Muller-Breslau Theorem (Figure 17), the moment distribution coefficient (Figure 18) and fixing moments (Figure 19).

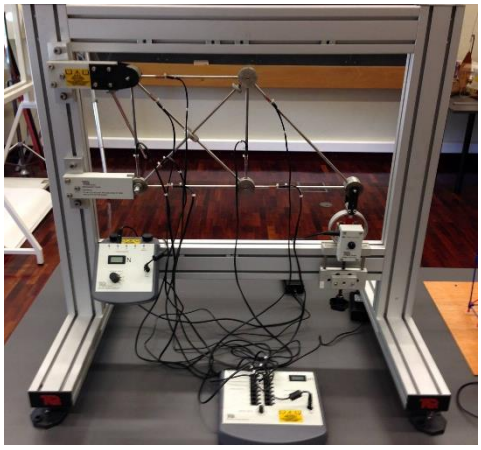

Figure 15 - Truss

Figure 16 – Maxwell-Betti theorem

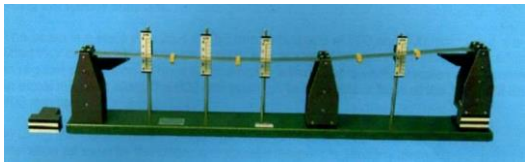

Figure 17 – Muller-Breslau theorem

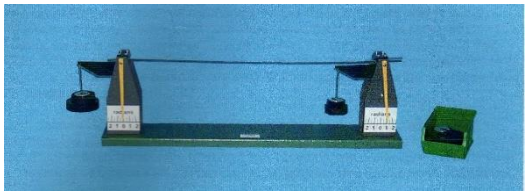

Figure 18 – Moment distribution coefficient

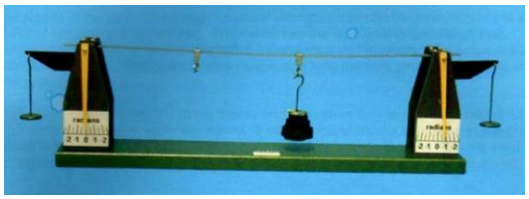

Figure 19 – Fixing moments

4 – New experiments and equipment

Upon finishing the reorganization of the lab, the research for new experiments and equipment started. The best results were found in other universities that already started using this kind of approach to improve the teaching of structural mechanics.

In the University of the Sunshine Coast, Australia, several equipments were developed in order to address concepts like the center of mass (Figure 20),

Figure 20 – Center of Mass

reactions (Figure 21), deflection in beams (Figure 22) and columns (Figure 23).

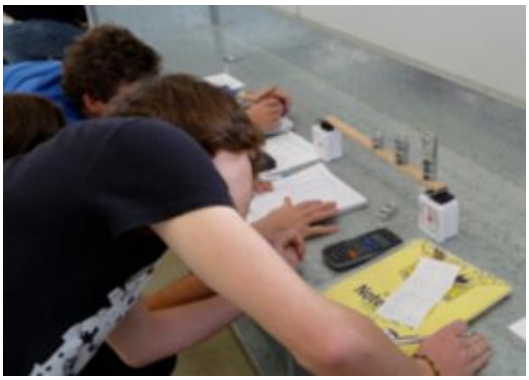

Figure 21 - Reactions

Figure 22 – Deflection in beams

Figure 23 - Columns

In the Nagoya University, Japan, a very versatile equipment called Bururu was developed to study the effect of dynamic actions in structures (Figure 24),

Figure 24 - Bururu

and in Portugal, in FEUP, in a separated room, an equipment to study the deflection of beams (among other things) was built and it's meant to be used during the lecture, by video and audio transmission through a camera that can be remotely controlled (Figure 25).

Figure 25 – FEUP equipment

In the University of Trento, Italy, a 3D truss structure was built with special elements that make it easy to see which elements are experimenting tension or compression (Figure 26).

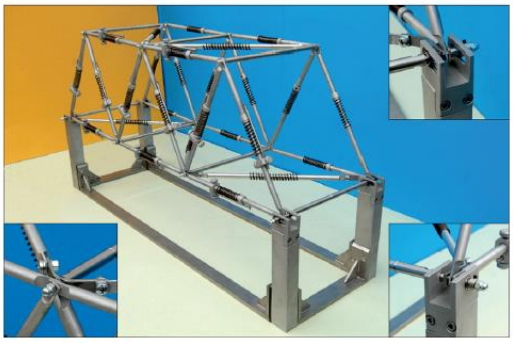

Figure 26 – 3D Truss

The Istambul Kultur University, Turkey, had a different approach, in which the experiment is based on having the students build their own truss structures, with wood sticks and glue, and then those are tested and compared (Figure 27).

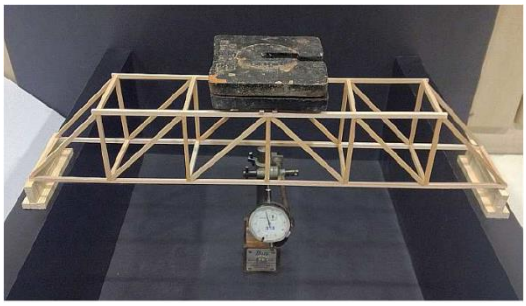

Figure 27 – Wood truss

Lastly, in Universidade Federal de Ouro Preto, Brazil, the objective of a thesis was to develop an equipment that could improve the teaching of the behavior of structures. They created the project Mola, which demonstrates how simple columns or frame structures behave when submitted to forces (Figure 28).

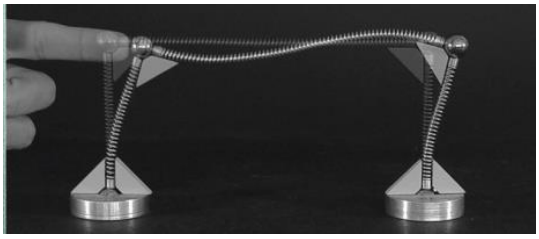

Figure 28 - Mola

Lastly, some other simple experiments were found, most of them can easily be bought/produced and carried to the classroom, like the Newton's cradle (Figure 29).

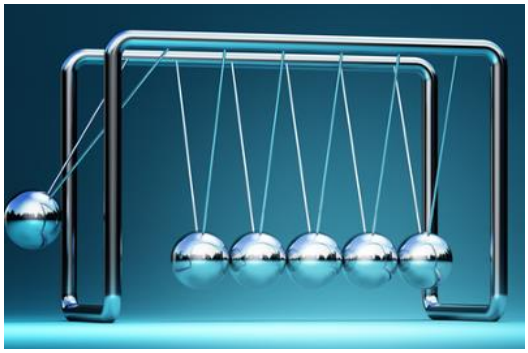

Figure 29 – Newton cradle

5 - Conclusions

Nowadays there's a growing need to enhance teaching processes, to transform the classic lecture into something more appealing to the students. Using technology, this can be easily done creating equipments and experiments, like those mentioned in this thesis, or even new ones.

Having finished the first part, the structural mechanics lab at Instituto Superior Técnico now possesses a collection of over forty experiments ready to be used by the teachers and the students.

Other universities already started doing the same and these ideas, equipments and experiments should be shared, especially among teachers, so that they can be implemented in more places. FEUP started doing this because it was perceived that it's very hard to capture the student's attention when they have access to wi-fi on their cellphones.

Now, the course of civil engineering at Instituto Superior Técnico has not only the previously mentioned collection of experiments ready to use, but also a set of new equipments/experiments that can be acquired in the future, in order to make the collection grow further.~

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