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DEVELOPMENT OF DIDACTIC EQUIPMENT FOR IN-CLASS EXPERIMENTAL ANALYSIS OF BEAM BENDING

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ABSTRACT

This work presents the design and development of an educational equipment intended to provide for experimental stress analysis techniques out of the laboratory, that is, for in-class demonstration problems. The equipment was designed in order to present the theory of beam bending in different loading/supports configurations. It was designed for portability while allowing for ease of use by students both in handling of loads/supports and measurement methods. The design, construction, testing and validation against analytical and numerical methods are presented.

Keywords: educational equipment; experimental stress analysis; beam bending

INTRODUCTION

General practices and educational procedures for teaching of solid mechanics and mechanics of materials are based on problem solving and well established. A common difficulty faced while teaching these courses lies in the translation from abstraction to physical reality. This is overcome, as possible, with demonstration problems closely related to practical engineering problems. Other strategies are helpful and can be used with advantages: project based learning (Crone, 2002) computer assisted problem-solving (Philpot, 2003) use of experimental apparatus to demonstrate theory (Kadlowec, 2002). For that purpose an educational project was established at several courses related with Mechanics of Materials and currently teaching at the University of Minho. This project consists in the development of a portable equipment intended to provide for experimental analysis of beam bending theory out of the laboratory, that is, for in-class demonstration problems.

The equipment was designed allowing for different loading/supports configurations while maintaining simplicity, ease of use and portability. These requisites are adequate for out-of laboratory testing and student motivation for experimental demonstrations. In this manner the equipment can be used for experimental stress analysis in field tests that are recognized as more attractive for student motivation. Results are presented for experimental analysis and comparison with analytical and numerical methods. These results allowed to evaluate the reliability of the equipment and establish guidelines for proper use and measurement protocol.

DESIGN

The main concept of the didactic equipment was to be light, versatile, practical and transportable in order to allow for various case studies of beam bending theory and experimental application for in-class use. The prototype was developed for beams of rectangular section with up to 10 mm of width. These can be made of different materials being at present used with steel. The design of general dimensions, weight loads, beam section and supports had to account for the need to obtain measurable displacements without using large weights. Stiffness was therefore a main requisite in preliminary calculations. In Figure 1 one can see the equipment representation in 3D view.

In order to reduce costs standard materials were used wherever possible. For example, Bosh Rexroth 3842990720/1000 aluminium profiles (#1 and #2 in Figure 1). Aluminium alloy is the main material used for the equipment structure and accessories except the support and loads shafts that require higher local stiffness and hardness (#4 and #5 in Figure 1).

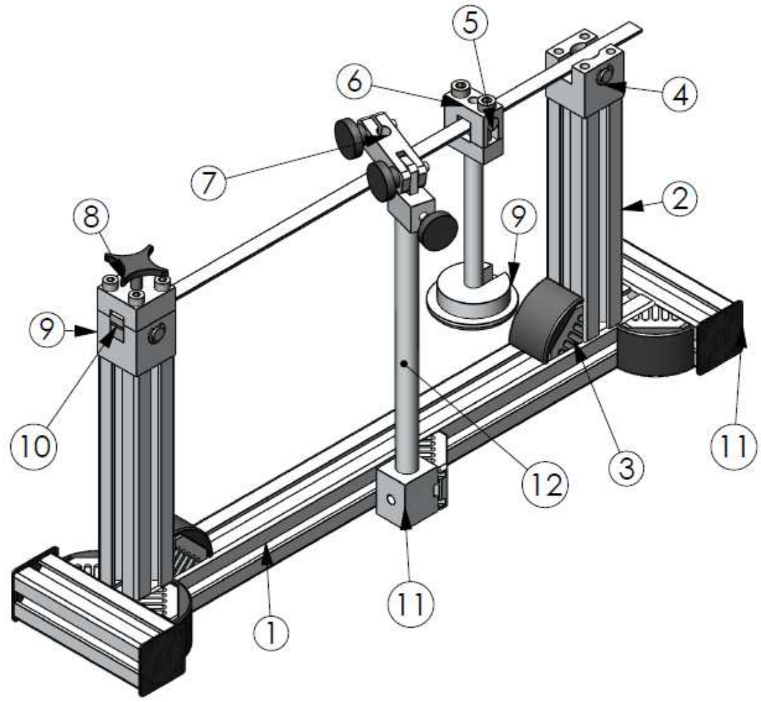

Fig.1 3D representation of equipment

The main decision took regarding overall dimensions started with the length of the beam between supports that is of 270 mm. This served as basis for designing the rest of the equipment within overall dimensions that allowed it to be carried in a reasonable sized transport case.

To determine the section of the test beam the width was fixed at 10 mm, based on the dimensions of the profile and supports (#2 and #9 in Figure 1). The moment of inertia of the beam was calculated for a targeted 2 mm of deflection. Considering E = 200GPa (young's modulus for steel) a thickness of 1.5mm for the beam was considered acceptable in the preliminary calculations.

The system to apply and increment the load (#6 in Figure 1) is comprised of discs of 27.54 grams and a main support with mass of 109 grams. The maximum mass in this configuration is of 509.59 grams.

Seeking to increase the flexibility of the equipment the supports allow two configurations: simply supported and fixed. The general principle for this application is presented in Figure 2 requiring the use of small steel shafts that can be easily swapped for a spacer and compression plates.

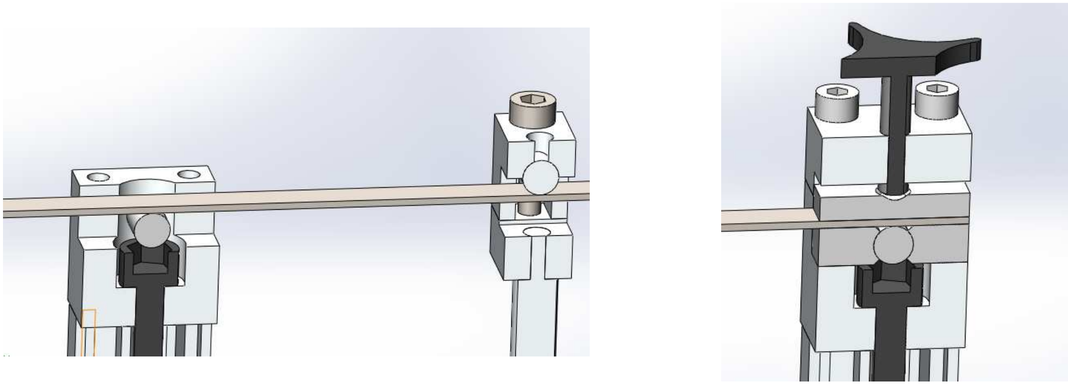

Fig.2 3D representation of supports: simple support (left) and clamping (right)

To measure the local displacement a dial gauge is used, supported by part number 7 in Figure 1. The final section of the test beam, obtained from standard steel bar is 10.11x2.3 mm. The distance between supports can achieve a maximum value of 370 mm. In Figure 3 a photograph of the final equipment built is presented.

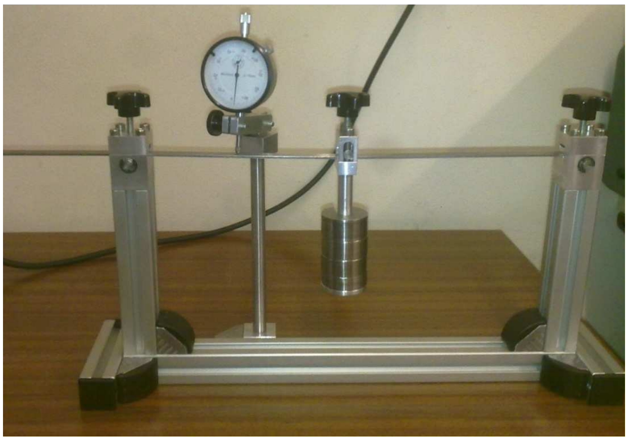

Fig.3 Visualization of equipment at maximum load and span

RESULTS AND VALIDATION

For experimental validation two case studies were used: load application at L/2 and measurement at the same point (mid-span); and load application at 3/4L with measurement at L/2. (Fig. 4). For further validation of experimental values these were compared with analytical solutions and numerical simulations using "SolidWorks Simulation" software. The analytical study was performed using readily available equations from the literature (Beer; Johnston; DeWolf, 2008).

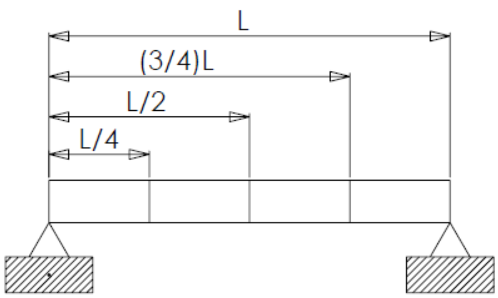

Fig.4 Diagram with the layout of beam and load/measurement application.

In Figure 5 one can observe the results for L/2 load application and measurement at L/2. The maximum difference between analytical and experimental occurs at 3.07 N corresponding to a difference of 25.5% of difference. Comparing numerical and analytical results the maximum difference occurs at 5.546N (4%) while comparing with experimental values occurs at 2 N as with the analytical comparison. For this load case the main difficulty is associated with reading displacement values at the same point of load application while for lower loads the uncertainty of displacement measurements increases.

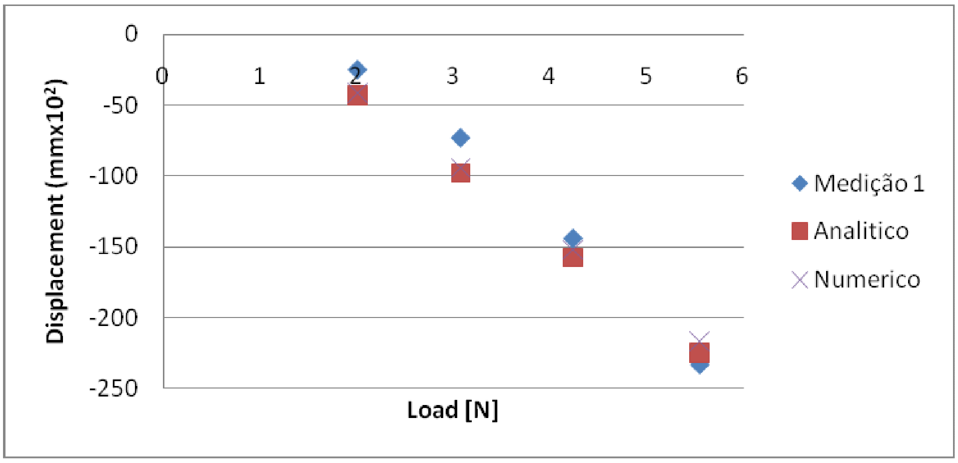

Fig.5 Experimental, analytical and numerical results at load in L/2 and measurement in L/2

Figure 6 presents results for ¾ L load application and measurement at L/2. For this load case the maximum difference between analytical and experimental results is equal at both experimental measurements equating to 16.2% of difference at 5.546 N.

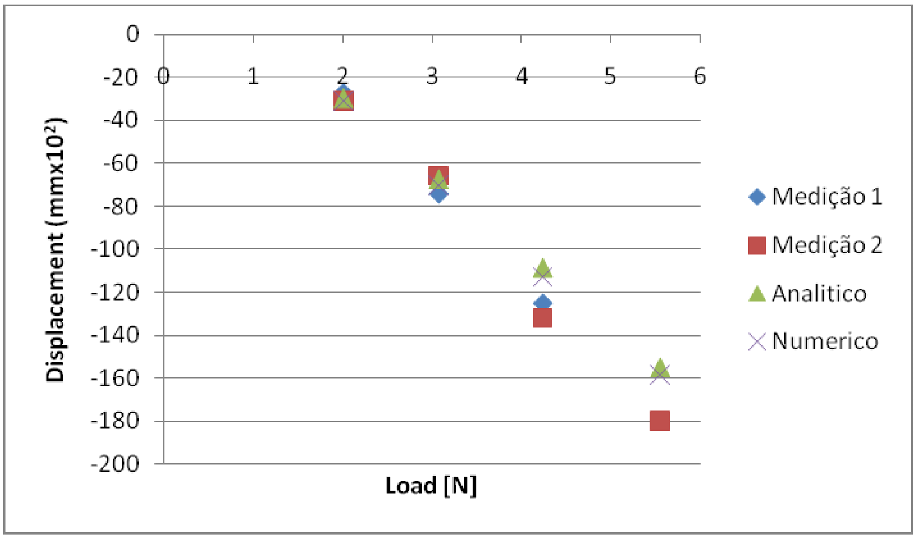

Fig.6 Experimental, analytical and numerical results at load in ¾ L and measurement in L/2

CONCLUSIONS

This article presents the design of an educational equipment intended for in-class demonstration of beam bending theory. The developed equipment is easy to transport, simple and capable of analyzing different loading conditions and supports.

The equipment proved capable to provide reliable results while validation tests were performed in order to identify frequent errors and establish adequate testing protocol. From a comparison between analytical, numerical and experimental results it resulted that larger errors are present for very low loads when the process for displacement measurement is more sensitive. Also difficulties in measurement at load application point were identified. The understanding of such limitations in experimental measurements and comparison with hand calculations are helpful for a better understanding of underlying theory by students.

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