Some remarks on wood experiments carried out in Brazil in the 18th century

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ABSTRACT: It is fundamental to the work of conservators/restorers to understand how our ancestors analyzed building materials. The parameters that directed them to make their choices are also important to be known. Manuscripts that belong to Portuguese archives indicate that the first experiments on wood samples performed in Brazil were carried out in Bahia, in the 18th century. They were not carried out in Rio de Janeiro, in the 19th century, as it was believed. The documents contain information about tropical wood beams of different sizes and weights.

A comparison between the old data contained in the documents and contemporaneous values of different kind of analysis obtained for the same type of woods is presented on this paper. It was also used throughout this investigation the data obtained from a document that contains results from experiments with other Brazilian woods. These experiments were carried out in Portugal in 1760.

1 INTRODUCTION

The knowledge of the constitution and behaviour of ancient building materials is very important to conservators/restorers' work. To have a good idea of the parameters that were taken into consideration by ancient people while choosing the building materials to employ in their constructions, it is necessary to analyse the results of experiments that were made centuries ago.

Accordingly to specialized bibliography, systematic experiments of building materials in Brazil date back to the 19th century. Those experiments were carried out in Rio de Janeiro. However, recent investigation demonstrated that some Portuguese historical archives – Ultramarine (UHA) and Military Historical Archives (MHA) – have manuscripts from the second half of the 18th century that prove that the oldest experiments made in Brazil took place in Bahia instead. The documents refer to experiments on Brazilian wood samples. The manuscripts contain tables that gather information about samples of different weights and sizes, their densities and their mechanical behaviour. The documentary sources that were analysed were the following:

- The studies developed in 1779/1780 by artillery colonel from Gôa, Theodózio da Sylva Reboxo – MHA (1779/1780), UHA (1780);
- The manuscript book written in 1790 by Joaquim Amorim de Castro – UHA (1790);
- A table with information of weights of woods per cubic feet that contains results of experiments that were carried out in Portugal by colonels Antonio de Brito Freire and Christiano Frederico Weinholtz, in 1790, as informed by Vandelli (~1815).

Despite botanical classification had been elaborated by the Swedish Carl von Linné in 1753, the woods were identified in those manuscripts by their ordinary names. This kind of identification is responsible for some difficulties of analysing the results of the experiments presented on the tables. Especially when the objective is to compare data from the 18th century to data from the present. Nevertheless, the results obtained in the experiments that took place in

the 18th century were compared to values achieved by the use of contemporaneous formulas. Old units of measurements were converted to new ones.

2 THE DOCUMENTS FROM THE 18TH CENTURY

2.1 Colonel Reboxo's experimentation

The tests were carried out in Bahia in 1779/1780. The version of the document that belongs to the Military Historical Archive is accompanied by a full description of the aspects of the woods after being submitted to compressive strength. The fact that the whole experiment had been systematically registered demonstrates the perception of the Cartesian method at Reboxo's time. It can also be noticed through the reading of the document that colonel Reboxo analysed woods from Gôa as well.

The table itself contains all the information listed below.

- Name of the woods;
- Number of each sample;
- Span;
- Dimensions of each timber – Reboxo basically used samples that measured 20, 22 and 40 inches per sections of 1x1, 2x2, 1x2 and 2x2 inches (one Portuguese inch measured 2.75cm at that time, and not 2.54cm as it does nowadays);
- Density of each timber – In half of the cases, the values indicated by colonel Reboxo were similar to the ones found in the literature today to woods with the same vulgar denomination;
- Position of each sample while submitted to compressive strength – Some of the beams had a square section. Others, rectangular ones. When the rectangular-sectioned timbers were tested, some were placed with the smallest dimension in horizontal position, and others with the smallest dimension parallel to the vertical axis;
- The conditions of the beam – Beam fixed at one end, freely supported at other; beam with ends fixed; beam supported at both ends;
- Failure load;
- Deflection – This indication was given through the angle that each sample formed with the horizontal line when submitted to compressive strength;
- Days when the experiments were performed;
- "Meyas proporcionais".

After verifying in ancient books – Belidor (1729); Jombert (1764); Belidor (1782-1790); Trincano (1786) – what was the methodology of testing wood samples to compressive strength in the late 18th century, it was discovered the meaning of the expression "Meyas proporcionais". "Meyas proporcionais" consisted in values that expressed comparisons between the individual failure load obtained for each sample of the same kind of wood, although they had not the same dimensions. The way adopted in the 18th century to calculate the "Meyas proporcionais" was the following:

$$P \text{ ---------- } bh^2/L$$

$$P_1 \text{ ---------- } b_1h_1^2/L_1$$

Where P = load, b = width, h = height and L = length of the beam.

$b_1h_1^2/L_1$ is constant and is equivalent to 36 square inches if considered a standard timber of 36"x1"x1".

P_1= load to be defined to the standard timber. That means the load that a timber with the standard proportions would bear. It was calculated as above indicated, considering a standard timber of 36"x1"x1".

It is interesting to emphasize that Galileo, Mariotte and Coulomb had established a correlation between failure load and bh^2, as Timoshenko (1953) indicated. The length of the sample was not considered while doing the proposed evaluation. Thus, the difference among the methodology of their calculation and the one used by Belidor was only the proportion of the components of the formula.

Sixteen "meyas proporcionais" indicated on colonel Reboxo's table were recalculated by considering the proportion above mentioned and other information available on the same table.

For that purpose, only results of Brazilian wooden beams supported at both ends were verified. The reasons for taking this decision were:

- It corresponds to the major part of samples listed on the table;
- Only two, among the 123 beams analysed by Reboxo, had both ends fixed. It is not a representative number of samples to come to a scientific conclusion. Besides that, the results of the strength tests indicated on the table were very different in between. Thus, they could not be considered as parameters for comparison;
- It is impossible to know whether the incases were satisfactorily made or not;
- Only eight beams were fixed at one end, freely supported at other. In this case, it is also impossible to know if the incases had the necessary rigidity or not. If not, the results could not be considered as representative;
- The idea was to analyse the characteristics of Brazilian samples. Thus, results obtained from wood samples from Gôa, another Portuguese colony at that period, were not submitted to evaluation.

Ten results of the recalculated "meyas proporcionais" were almost the same of the ones presented by Reboxo. The other six oscillated between 10 and 20% of the values indicated on the table. The divergences between the calculations probably came from the following reasons:

- The fact that some of the timbers had one of its extremities incased;
- Eventual errors while calculation were made when the experiments were going on and also when the tables were in elaboration, not detected at that moment.
- Eventual mistakes during the filling of the tables;
- Problems when the transcription of the data was made in the 18th century – It was verified, for example, slight differences between the table from UHA and the one that belongs to MHA. There is also an indication that the tables consisted in copies. Maybe other problems had occurred while the transcription of the data was made;

In order to verify the accuracy of the results obtained in the experiment made in the 18th century, other evaluations were also made. For instance, by using the data obtained from colonel Reboxo's table, the modulus of elasticity (E), the bending moment (M) and the resistance moment (W) of each type of wood were calculated. In order to determinate E, M and W, characteristics from each kind of wood were obtained from bibliography – Bacellar (1959); IPT (1986); Lorenzi (1992) – whenever possible (in some cases, it was difficult – or even impossible – to know exactly to what kind of wood the data referred to). One of the conclusions of the recent studies that have been made by Santiago and Miranda (1998) and Santiago (unpubl.) was that these experiments were carefully made in the 18th century, despite there were some discrepancies in the obtained results due to the use of damaged samples. Some of the imperfections detected on the beams were the presence of knots, and that the samples did not have the same humidity degree while being tested. It was verified through the reading of the post-test detailed description of the 123 samples that is adjoined to the document that belongs to the Military Historical Archive from Lisbon.

2.2 The document of Joaquim Amorim de Castro (1790)

The second document that has been studied was the manuscript book written by Joaquim Amorim de Castro in 1790. It contains a full description of the characteristics and proposed uses of the 47 different kinds of tropical woods. Watercolor paintings of each sample were included in the text.

The table included in the manuscript shows a comparison between the mechanical strengths of all 47 woods that had been catalogued by Joaquim de Castro. It contains the following information:

- Dimensions of timbers – All of them measured 0.5"x7.5"x0.33" (at that time, one Portuguese inch measured 2.75cm, as stated beforehand);
- Position of timbers while submitted to experimentation – All the timbers were analysed in the same position. Besides that, there was a clear indication that all the timbers were horizontally placed during experimentation. In the case of Reboxo's analyses, it was indicated that the timbers were supported by small pillars with different heights. It means that the beams had some inclination when submitted to the test;
- Failure load of each sample.

In the past, some professionals defended the analysis of inclined beams. Jean Baptiste Bullet, for instance, considered that an inclined sample would present a resistance value between the values of a sample tested in vertical position and another in horizontal position. Accordingly to Bullet (1741), the results of a compressive test on a sample inclined 45^{o} would be the average of the two latter experiments. On the other side, Belidor (1729) had another thought: as it was not possible to verify the behaviour of samples in vertical position, Bullet's affirmative could never be proved. Thus, Belidor's point of view was that it was not valid to test inclined samples. The samples should, then, be tested only in horizontal position. Nevertheless, Reboxo, fifty years later, tested inclined beams instead of horizontally positioned beams.

Through the analysis of the above-mentioned information, it can be noticed that in the 18th century the methodology of testing samples of wood to compressive strength and buckling was still unknown.

The values indicated in Castro's table were compared to data from the XXth century. It was noticed that most of the densities that could be inferred from the 18th century indications of mass and volume were smaller then the ones considered as characteristics to the supposed types of woods tested. Santiago (unpubl.) states that. The possible reasons for that could be:

- Lack of precision in the analyses;
- Use of damaged samples (samples with high humidity percentile or showing imperfections, for instance);
- Problems of identifying the woods at present time (due to the use of vulgar names at the time).

2.3 Some experiments made in Lisbon (1760)

The table with the results of the tests on wood samples made by colonels Antonio de Brito Freire and Christiano Frederico Weinholtz, in Lisbon, in 1760, presents only weights per cubic feet of samples of different types of woods. After converting the given data to current units (g), a comparison of densities was made. In most cases, the values found were smaller than the ones listed in today's bibliography. Probably because:

- The mentioned woods were identified only by their vernacular names;
- Just one determination for each kind of sample is indicated on the table;

3 CONCLUSIONS

An investigation like this is permeated by many difficulties. In spite of that, if one needs to study the mechanical behaviour of woods that have been employed in historical monuments centuries ago must analyse the data contained in old documents. In order to do that, it is necessary:

- To study the methodology of analysis in the period that the documents were written;
- To compare ancient data to recent information about the different types of woods obtained in books;
- To have a critical view of the problem – It is possible to establish a comparison between old and recent results of tests and to conclude what was the methodology used in the past to analyse the sample. But the results obtained on a theoretical basis for a specific type of wood cannot be accepted as a standard for that kind of wood. If there is, for example, the possibility of comparing results of tests found in documents to the behaviour of a real structure made of wood, it will be fundamental to do a botanical investigation on the wood sample to precise exactly what was the vegetal species used as a building material in that construction. A correct classification of the wood used eliminates problems of mistaken interpretation by comparing different samples identified by the same vulgar denomination.

REFERENCES

MHA 1779/1780. *Mappa da experienciaz das madr.^{s} q' fêz nesta Cid.^{e} da B.^{a} o Coronel d'Artr.^{a} de Gôa Theodozio da S.^{a} Raboxo* [sic]. Salvador: Mss.

UHA 1780. *Mappa da experienciaz das madr.^{s} q' fêz nesta Cid.^{e} da B.^{a} o Coronel d'Artr.^{a} de Gôa Theodozio da S.^{a} Raboxo* [sic]. Salvador: Mss.

UHA 1790. *Memória sobre as madeiras das matas do termo da vila de Cachoeira (Bahia), redigida pelo Juiz de Fóra Joaquim de Amorim Castro, em 1790, para D. Maria I*. Cachoeira: Mss.

Bacellar, Ruy H. 1959. *Formulário técnico*, RJ/SP/Porto Alegre: Globo.

Belidor, Bernard Forest de 1729. *La science des ingenieurs*, Paris: Claude Jombert.

Belidor, Bernard Forest de 1782-1790. *Architecture hydraulique*, t. I. Paris: Jombert Jeune.

Bullet, Jean-Baptiste 1741. *L'architecture pratique*, Paris: Ch. J. B. Delespine & Jean-Th. Herissant.

IPT, 1986. *Manual de conservação de madeiras*, 2 vol. São Paulo: Secretaria de Indústria, Comércio, Ciência e Tecnologia.

Jombert, Charles-Antoine 1764. *Architecture moderne*, Paris: Ch. A. Jombert.

Lorenzi, Harri 1992. *Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil*, Nova Odessa: Plantarum.

Santiago, Cybèle Celestino and MIRANDA, Murilo Alves 1998. «Caracterização de madeiras brasileiras: estudo de caso do século XVIII», In *Preprints VI EBRAMEM*, p. 77-89. Florianópolis: UFSC.

Santiago, Cybèle Celestino Unpublished. *Estudo dos materiais de construção de Vitrúvio até ao século XVIII. Uma visão crítico-interpretativa à luz da ciência contemporânea.* PhD thesis on Conservation of monuments (University of Évora, Portugal).

Timoshenko, Stephan 1953. *History of strength of materials*, New York: Mc Graw-Hill Book Company.

Trincano 1786. *Élémens de fortification*, Toul: Joseph Carey.

Vandelli, Domingos ~1815. «Memorias sobre algumas produções naturais deste Reino, as quais ou são pouco conhecidas, ou não se aproveitam», In Academia Real das Sciencias de Lisboa 1990 (reimpression), *Memorias Economicas para o adiantamento da agricultura, das artes e da industria em Portugal, e suas conquistas (1789-1815)*, t. I, p. 143-155. Lisbon: Banco de Portugal.