CASE STUDY: ASSESSMENT OF THE MECHANICAL PROPERTIES OF AN OLD "PITCH PINE" TIMBER STRUCTURE.

Manuel C. TOUZA VÁZQUEZ*

*Centro de Innovación y Servicios Tecnológicos de la Madera (CIS-Madera), Spain.

Abstract

The accurate assessment of the mechanical properties of old timber structures is still a great source of conflicts among architects, engineers and constructors. Even nowadays and with the exception of a minor amount of historically important buildings, this situation is commonly used as a justification for the integral replacement of all the timber structural components [1].

This paper presents a case study detailing the procedure followed to assess the mechanical properties of old timber beams made up of "pitch pine" employed as structural floors in a 19th century building. After many years abandoned, it was decided to transform the building into a public museum.

A priori, the assessment of the timber mechanical properties appears to be particularly difficult because there are not any grading rules for old "pitch pine" beams and even in the case they have existed, several beams had been hidden inside artistic covers or over suspended decorative ceilings.

Under these conditions it was planned a two-step inspection. In the first step, the biological degradation of the timber would be assessed employing the resistograph and, during the second step, six load tests would be carried out on individual members in order to assess the mechanical behaviour of the timber beams.

All the necessary work was carried out in few days with a reduced budget and the museum was inaugurated in 2007 preserving (with a minimum reinforcement of some elements) all the existing timber floor beams.

1. INTRODUCTION

The original construction dates from 1886 and it was a two-storey building with a new floor added in 1929. The building, located in A Coruña (Spain) has an historic value as it was the residence of an important republican politician at the beginning of the Spanish civil war (1936-39). After many years abandoned it was decided to transform the building into a public museum trying to maintain as many original elements as possible.

The walls of the building are made of stone and masonry and there are two types of timber floors. The original structure, above the first and second floor, is formed by beams with a nominal section of 30x23 cm, net clearances between 6 and 6,2 m and average distances among centers of 1,4 m. On the floor added in 1929, the structure is formed by beams with a nominal section of 25x9 cm, spaced 0,3 m and also by beams of 25x21 cm, spaced 1,3 m.

As a consequence of the new loads required by the change of the use of the building it was needed an inspection about the conservation and strength capacity of the existing floor beams.

A priori, the assessment of the mechanical properties of the beams it was very complicated because they were made of "pitch pine" (*Pinus* spp.) a common species in some Spanish buildings constructed during the second half of the 19^{th} and the beginning of the 20^{th} century. The structural properties of the aged timber are unknown and there is not any stress grading standard to enable the classification of the existing elements. In addition, several beams were hidden inside artistic covers made of another wood so it was impossible to check the presence of existing breakage as well as singularities like knots, slope of grain, etc.

Figure 1. General view of the building and detail of a room where the beams are hidden inside artistic covers.

Under these conditions, it was planned a two-step inspection.

In the first step, the biological degradation of the timber will be assessed by means of a visual inspection and using the resistograph as a non-destructive technique. The resistograph was also used to check the size and geometry of the covered beams.

In a second step, load tests were performed on different individual floor beams. The tests were performed using portable cans and water to apply the load. The measured deflection of the structure under load has been used to estimate the elastic modulus (MoE) of the beams, that along with density serves to derive other strength values. Additionally, the load tests were used to understand the entire structural system behaviour, mainly the capacity of each beam to transmit the load to other beams, an important parameter in old buildings, frequently ignored.

2. METHODOLOGY

The routine of a typical inspection, although may vary depending on each particular situation, it is usually divided into a visual inspection and two later steps, as follows:

The visual inspection includes a revision of the main elements within the structure, looking for evidences of moisture damage (water leakages, rising damps, etc), biological degradation and also structural singularities (knots and fiber deviation in critical zones) or mechanical damages (fractures, previous repairs, etc). Wooden species identification and basic geometrical dimensions measurements are also included within this step. The objective of the visual inspection is to get an overall idea of the state of the building and planify the next steps.

During the first step an instrumental analysis is carried out by means of in situ non-destructive techniques (NDT). It includes, typically, moisture content measures, drill resistance evaluation through resistograph and, in some cases, other NDT as sound/ultrasound velocity measurements. The objective of this second step is to provide accurate information about the biological damages and the effective section of the structural elements, especially those located in the critical zones of the structure.

The second step is focused into the assessment of the mechanical properties of the structure and is particularly important when is planned a change of use of the building. The most common method is the grading approach that requires the evaluation of the timber quality (not always possible) and the existence of a stress grading standard, for which strength values are allocated. Other alternatives are the performance of load tests (that can be carried out in the whole structures or in individual members) and, in some cases, the use of sound/ultrasound velocity measurements. These last alternatives provide an estimation of the Modulus of Elasticity (Moe) of the timber, which along with density may serve to derive other strength values.

The final report should provide accurate information in order to perform a safety assessment of the structure and, if needed, a design of the restoration plans. The data obtained should also be presented in a clear and graphical way in order to facilitate all the necessary subsequent works of technicians and carpenters.

3. ASSESMENT OF THE TIMBER STRUCTURE

3.1 Visual inspection

The anatomical identification of wood samples concludes that the beams were made of "pitch pine" (*Pinus* spp.) a common species used in Spanish buildings during the second half of the 19th and the beginning of the 20th century. The commercial name "pitch pine" comprises several pine species of American origin, mainly in the group of southern yellow pines (*Pinus palustris,P. taeda,P. echinata, P. elliotti*) or Honduras pitch pine (*Pinus caribaea*).

The name makes reference to the high resin content of the heartwood of some pine species that in the United States were an important source of naval stores (turpentine, tar, etc) used to waterproof vessels and sailings. Later, selected species were used as a first source of construction timber and shipped all over the world.

Although, the exact identification of the timber species is not always possible, historic evidences pointed out that "longleaf pine" or "Georgia pitch pine" (*Pinus palustris*) was the most important species of the pitch pines group**.** The timber from virgin forests (longleaf pines mature between 200 and 400 years with diameters at breast height in the range of 60-80 cm) was much appreciated for its rigidity, density, strength properties and natural durability.

Due to wood shortages in Europe, important volumes of slow growth *Pinus palustris* were imported from the United States during the 19th century with peaks of the timber cuttings by the 1880s and 1890s. Since the beginning of the 20th century the resource began to be scarce and by the 1920s most of the virgin forests disappeared. So, most timber structures built after 1900 should be made from second generation trees and do not exhibit the mechanical properties associated to the first generation timber.

As a reference of the reputation obtained by the timber from first generation trees, in Spanish stores which sell recycled beams from old buildings, the price of a cubic meter from a "pitch pine" is twice as much as one from a "riga pine", considered the best quality of European *Pinus sylvestris*.

During the visual inspection no external evidences of active insect damage (presence of wooden dust, termite channels, etc) has been found. Some beams exhibit exit holes from old beetle's attacks but checking the surface of the beams with a knife show that they are limited to a minimum layer of sapwood.

Concerning fungal attacks there are some evidences of old leakages from the bathrooms and recent local water infiltrations from the roof and some windows, being possible to identify some attacks of cellar fungus (*Coniophora puteana*) a typical brown rot fungus. The integrity of structural timber elements close to these areas will be assessed in a posterior stage.

The encounter of the beams with the walls of the building has been designed in a proper way, letting some ventilation and covering the edge of the beams with pitch, a common construction practice in the past oriented to waterproof the timber from possible rising damps from the walls.

No symptoms of mechanical failures (excessive deflections, initial tensile fractures, etc) has been detected during the visual inspection and when it has been possible to observe the beams, they show a high grading quality with singularities as knots being very scarce and of small size.

The overall impression is that the existing timber structure is quite in good condition and worth to be preserved.

3.2 Instrumental analysis

The floor beams were examined with a resistograph (Resistograph 3450-S of Rinn Tech) and its moisture content measured with a moisture meter type GANN Hydromette RTU 600.

The resistograph is a portable drilling device used to detect internal singularities within trees and beams. The method is based on the measure of drilling resistance along a small needle path (1,5 mm in diameter) when is inserted with constant drive into the wood. The power consumption of the drilling device is measured electronically as a value of the drilling resistance. The measurements are stored in a computer and the data obtained may also be printed out immediately in a wax paper for a first interpretation on site.

When it is used by a skilled operator, this technique is capable of measuring the extent and severity of biological degradation accurately, thus providing the ratio of sound to degraded timber remaining (effective section), and its position within the cross-section of each beam.

All the edges of the beams were examined with the resistograph in their encounters with the walls, a critical zone more prone to dampness and in consequence to the decay by fungi. Additional measurements were made in those points where the visual inspection detected other possible sources of dampness.

Concerning the beams hidden inside an artistic cover, the resistograph has been used to obtain their nominal dimensions and, by comparison of the obtained profiles, to conclude that the beams are also made from “pitch pine”.

The instrumental analysis confirms that most of the original structure, above the first and second floor, is in a good state of conservation. In most of the beams, the moisture content ranges between 17 and 20% and the timber is sounded with some old beetles attacks in a minimum surface layer of sapwood. Some wooden parts into the walls also exhibit slight attacks by brown rot fungi, mostly located on the external portion of the section and with a minor incidence from the structural point of view.

The timber floor structure above the first floor is formed by 12 main beams and all are in a good conservation state, so no interventions or repairs are needed due to biological degradation.

Above the second floor, the edges of 3 of the 14 timber beams exhibit more important attacks from brown rot fungi and some intervention is needed. In two of the beams the degradation seems to be linked to old leakages from the bathroom and they will be probably kept in service with a minor intervention. The edge of the third beam is hidden by an artistic cover and presents an important fungal attack due to recent water infiltrations from the roof.

Figure 2 shows the plan of the timber floor structure above the first floor and summarize the results obtained with the resistograph. The blue color means a sound section of the timber and the pink one indicates a slight degradation. For each inspected beam, the numbers inside the circles identify the obtained profile if posterior consultations are needed.

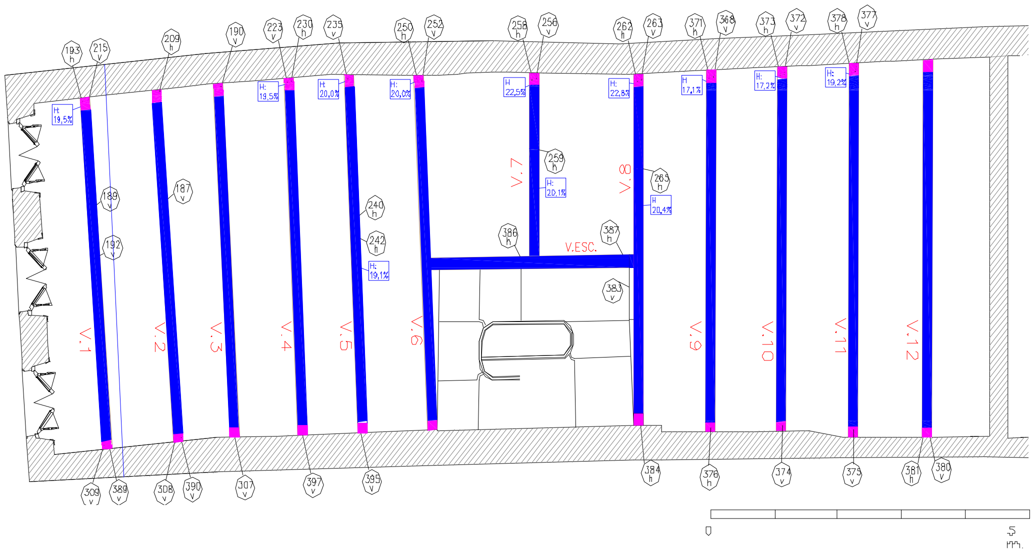

Figure 2. Plan view of the timber floor structure above the first floor. Sound timber is represented by blue color while a pink tone indicates a slight degradation. Each obtained profile can be identified by the numbers inside the circle.

Figure 3 shows a resistograph profile obtained in a beam with a minimum portion of sapwood affected by biological degradation in their edges.

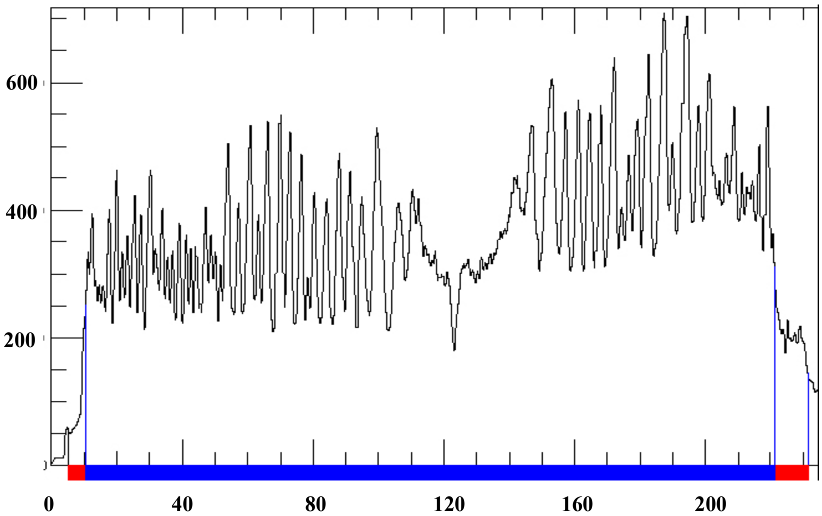

Figure 3. Resistograph profile obtained in the beam referenced as V-2 in the previous plan. The penetration depth (in mm) is reported on the x- axis, whilst the drill resistance is to be found on the y-axes. The effective section considered in the beam is marked in blue color.

Finally, a portion of the timber floor structure above the third floor is affected by recent water infiltrations. There are a total of 29 beams and the edges of 8 of them exhibit high moisture contents (>25%) in their encounters with the walls which let the development of dry rot fungi. After analyzing the resistograph profiles it was concluded that all the beams may be conserved but minor repairs are needed in the encounters of 17 beams with one of the walls of the building.

3.3 Assessment of the mechanical properties

The intended change of the use of the building requires an assessment of the mechanical properties of the beams.

As it was noted previously, the strength of aged wooden beam is highly dependent on the size and position of certain growth characteristics as knots and the slope of its grain. The influence of these growth characteristics may vary depending on each particular species and origin so for each combination the application of the grading approach requires the previous existence of a stress grading standard, for which strength values are allocated.

In the case of the "pitch pine", there are not any grading rules for old beams and even in the case they had existed, several beams are hidden inside artistic covers or over suspended decorative ceilings. Under these conditions the traditional grading approach is not allowable.

For these reasons it was decided to perform a load test on 6 individual members. These tests were done following the procedure detailed in the European standard UNE-EN 380:1998 [2]. Portable cans filled with water were used as load material until reaching the equivalent to a variable action of 5 kN/m^2. This figure is the maximum imposed load (ranges between 3 and 5 kN/m^2) specified by the Eurocode 1 for areas without obstacles for moving people as museums or exhibition rooms [3].

Following the procedure detailed in UNE-EN 380:1998, in a first stage the beams are loaded until the half of the maximum load ($Q = 2{,}5\ kN/m^3$). The load is maintained during a minimum time of 120 seconds and the deformations are measured. Next, load is ramped down to $Q = 0$ and the residual deformations are measured. In a second stage the beams are loaded until the maximum load ($Q = 5\ kN/m^3$). The load is maintained during a minimum time of 1200 seconds and the deformations are measured. Next, the load is ramped down to $Q = 0$ and the residual deformations are also measured.

The deflection of each tested beam was measured with 3 indicators located at its center and edges. The deflection of the beside beams were also measured in order to understand the capacity of the structure to transmit the load and the real MoE of the tested beam. Figure 4 shows the distribution of the indicators during the test of the beam referenced as V-2 on the floor structure above the first floor.

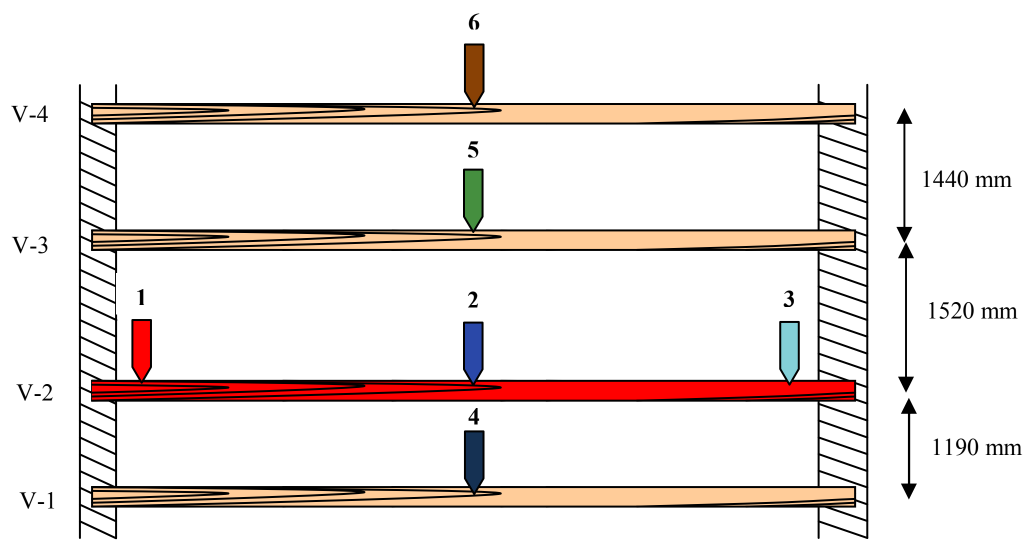

Figure 4. Sketch with the distribution of the indicators during the test of the beam V-2.

The MoE of a beam with uniform load supported at both ends can be calculated as:

$$E = 5\ q\ L^4 / \delta\ 384\ I \qquad (1)$$

Where:

δ = maximum net deflection (mm).
q = net uniform load (N/mm), taking into account the load distributed to other beams.
L = net length of beam (mm).
I = moment of Inertia (mm4) / $I = (b \cdot h^3)/12$, where b is the net width/depth of the beam, and h is the net thickness of the beam.

During the tests it was considered a security limit equivalent to a deformation of L/350.

Figure 5 shows the measured deformations during the test of the beam V-2. The colours of the lines are the same previously used to reference the position of each indicator.

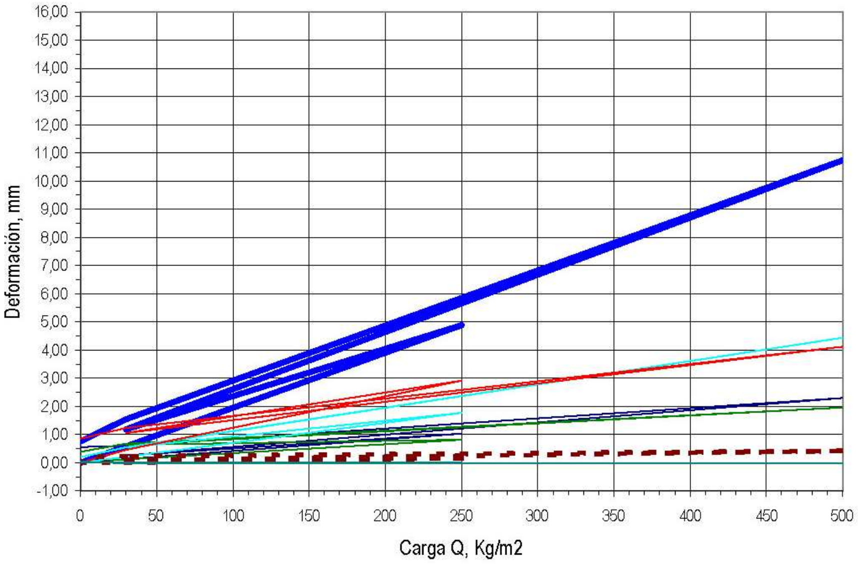

Figure 5. Deformations measured during the test of the beam V-2.

Several results were obtained after the completion of the six load tests:

As for the mechanical properties, it could be obtained a medium MoE ($E_{0,mean}$) of 14,300 N/mm^2 for the tested beams. As reference, the Italian standard UNI 11119:2004 established a MoE of 13,000 N//mm^2 for the best quality of aged Italian pines [4]. Additionally, the resistograph profiles and some pieces of timber were also used to estimate the medium density ($\rho_{0,mean}$) of the beams in 700 kg/m^3.

The obtained values of MoE and density may be considered very high for the genus *Pinus*. Both values, together with the minor singularities existing in the observed beams, were considered to propose a value of 30 N/mm^2 as characteristic bending strength ($f_{m,k}$) for the beams.

Additionally, the load tests gave a better understanding of the entire structural system behaviour, mainly the capacity of each floor beam to transmit the load to other beams. As a medium value it could be estimated that when a uniform load is applied over a single beam, almost half of the load was transmitted to adjacent beams, mainly through the disposition of the joists and /or the wooden slabs which hold the suspended ceilings.

In Spain there is not a specific Building Code for old buildings, although the works have been initiated and it is expected to complete them during the next years. Since 2006, the Technical Building Code (TBC) is the regulatory framework regulating the basic quality requirements that buildings must comply with, including facilities, to satisfy the basic requirements of safety and habitability.

The imposed load specified by the TBC for variable actions in areas without obstacles for moving people as museums or exhibition rooms is 5 kN/m^2 and the deflection due to these actions is L/350 (user comforts) [5]. Both requirements were satisfied during the load tests.

4 CONCLUSIONS

This paper presents a case study where six load tests were performed on individual beams as an alternative method in the assessment of the mechanical properties of old timber beams made up from “pitch pine” used as structural floors in a Spanish 19th century building.

Despite the limited number of tests, the obtained results have pointed out not only the high strength values of “pitch pine” timber but also a better understanding of the entire structural system behaviour, mainly the capacity of each floor beam to transmit the load to other beams.

The tests were also successfully used to check the requirements of deflection limits intended to ensure the user comfort under the imposed load specified by the TBC for variable actions in areas without obstacles for moving people as museums or exhibition rooms.

All the needed work was carried out in few days and the museum was inaugurated preserving, with a minimum reinforcement of some elements, the entire original timber floor beams.

Nowadays, CIS-Madera is carrying out a project to develop a grading system to assign strength classes to aged beams of “pitch pine” that are a very common material in the old buildings existing in Galicia, Spain. Preliminary results confirm the extraordinary properties of the timber and it is expected that will help to preserve many other buildings in the next future.

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