Timber Bodies Strength of Materials: Fundamental Principles, Test Specimens Proposal

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Abstract

To reduce the economic cost of a Timber Structure, the first condition is to have a "rational" Structural Code, that is, a Code supported by research and a specific theory. To establish a rational Structural Timber Code, a specific theoretical support is needed. The objective of this paper is to cooperate in the construction of this theoretical support. To design timber structures, it is necessary to have mathematical models able to reproduce the resistance of timber bodies under different solicitations. In this paper, a "road map" to arrive to a specific Strength of Materials of Timber Bodies is proposed. This theory will be the tool needed to develop the mathematical models whose quantification will be obtained by testing "basic test specimens" obtained from timber of any particular timber building (like in concrete or soil mechanics). Finally, a "basic test specimen" for practical application of the theory is proposed. In this case, the experimental support is referred to "willow" wood.

Keywords: strength of materials; timber structures; test specimen; willow wood.

1 Introduction

To reduce the economic cost of timber structures and make them competitive, it is necessary to reduce "security margins" but without any reduction of structural security. Our proposal is the following:

a) To define timber bodies rupture mechanisms under different kinds of solicitations. This means establishing a specific theory referred to the resistance of timber bodies; it must be the support of a "rational" Structural Timber Code.

b) To be able to determine the mechanical characteristics of the particular timber employed in any timber structure. This requires testing that timber.

c) It is possible to adopt an adequate security margin based on the rupture mechanisms and the mechanical characteristics of the timber employed.

2 Characteristics of Structural Codes

There are some theoretical models for the redaction of a Structural Code of any material. For timber constructions, there are two main models:

a) To use value tables with the minimum strength of the wood bodies under different solicitations in building constructions.

b) To determine experimentally in each circumstance the strength of the employed timber.

As the strength of a particular wood has a very large variability –geographical region where the tree is planted, specific place in that region, part of the tree where the timber is cut–, to assure a minimum security level in timber structures the tables of model (a) must present the minimum results. Consequently, this way of working results in structures unnecessarily expensive in the majority of circumstances.

Adopting the (b) procedure arrives to the maximum proficiency of natural resources. In this paper we adopt this second way and try to establish a "road map" to arrive to the redaction of a rational Timber Structures Code that is a strong condition to arrive to optimum timber structures design.

2.1 The redaction of rational Structural Codes

The redaction of a "Structural Timber Code" needs a specific theoretical support, mainly if one is convinced that a Code referred to any structural material must be a design guide that helps him in his essential task, the creation of a particular structure to solve particular problems in the best way possible. A Code must be a guide to work and not an imposition of how to work.

In this theoretical framework the redaction of a coherent and profitable Structural Timber Code needs the development of a coherent and complete theory about the comportment of timber bodies when they are externally loaded.

The guidance of design works without unnecessary impositions implies to indicate two kinds of structural characteristics emerging from a more general social accord about security and life quality levels: 1) the limits of serviceability conditions, or the indication of admissible maximum values of structure modifications under the action of service loads; this means that if one of these limit values is surpassed, the building will become "out of service" from the point of view of life quality; 2) the security margin referred to any kind of structural collapse, in other words, the relation between "service loads" and "ultimate loads". This is the way to assure the actual security level of a structure and consequently of the building it supports.

"Service loads" are the maximum loads that can be applied to any structure according to given design data. Generally there is a specific "limit load" for any of the Service Limit States (SLS) defined in the Code. If one of those limit loads is surpassed, with simple and adequate actions –it may be only the reduction of this load to acceptable values– the structure can be put again in "service conditions".

"Ultimate loads" are the loads that will create in the structure any of its collapse situations. There is a specific "ultimate load" for each of the Ultimate Limit States (ULS) defined in the Code. To put a structure again in service conditions after a collapse situation, important and expensive reparation works will be needed.

3 A proposed way to the redaction a "Timber Bodies Strength of Materials"

The main purpose of establishing a Timber Bodies Strength of Materials is the construction of mathematical models representative of actual response of timber bodies to different solicitations. In the proposed design way it is necessary to have two different group of mathematical models:

a) Mathematical models referred to Serviceability Limit State conditions.
b) Mathematical models representative of Ultimate Limit State conditions.

3.1 Serviceability Limit State (SLS)

To establish SLS it is necessary to previously define the structural characteristics that can become undesirable for users; this means that surpassing this SLS will be unsatisfactory for the normal use of the building. Then the admissible maximum values of these characteristics must be established. There are three main origins of SLS: structural, aesthetic and degradation ones:

a) Structural SLS: excessive deformations of loaded structural members, cracks due to load action; vibrations originated by repeated loads, etc. It seems possible to calculate these states employing the Strength of Material for linear elastic bodies adapted to timber bodies, as it have been proposed in reference [1].

b) Aesthetic: discoloration; stains. These are not consequences of load actions, but the design of a structure includes its durability and therefore a well-defined plan of periodic inspection visits and maintenance works.

c) Degradation: biological, chemical, physical. Initial protective actions against wood degradation are also part of the design work. The future routine actions to avoid degradation problems must be included in the periodic inspection and maintenance plan.

3.2 Ultimate Limit States (ULS)

To establish ULS it is necessary to know the "ultimate strength mechanisms" of timber bodies under different kinds of possible solicitations. An ultimate strength mechanism is the internal resistant configuration adopted by the material to equilibrate the maximum value of a given solicitation. We think that the ultimate strength mechanisms that must be determined first are: tension, compression, flexion, shear and torsion, in this order of priority.

The way to fulfil this target is the experimental way. The target is to understand as well as possible all the phenomena related to timber bodies mechanical properties in ULS.

The ultimate strength mechanism experimentally determined for a given solicitation and a given timber may not be necessarily the same for all kinds of structural wood, but only for some of them. This possibility must also be investigated, and the groups –or families– of wood with similar mechanical characteristics must be defined.

Finally, for the experimental determination of any ultimate strength mechanism we will test well-defined test specimens made of a specific kind of wood with well-known mechanical characteristics. As a consequence, experimental results are only referred to a well-defined body made of a specific wood. To be useful in structural design, these experimental results must be generalized.

3.3 Generalization of the experimental results

Assuming that the families of trees with similar mechanical characteristics are well-known, any experimental results can be generalized essentially in three aspects: size, mechanical characteristics and timber strength:

a) To obtain experimental results independent from tests specimen dimensions (L_i), usually the length changes (ΔL_i) are substituted by specific deformations ($\varepsilon_i = \Delta L_i / L_i$).

b) To obtain experimental results of the mechanical characteristics independent from the particular test specimen, the internal forces (N_i) are substituted by stresses [$\sigma_i = (N_i / A_i)$]. (A_i) is the area where (N_i) is applied.

c) To obtain experimental results independent from the tested timber strength, these results must be referred to a parameter representative of individual timber strengths. This parameter is the strength experimentally determined by testing normalized bodies made of that timber.

Specific deformations and stresses are well-known parameters employed for any kind of strength of particular materials analysis, and no further explanations are needed.

The definition of test specimens is strongly linked to the studied material and can't be generalized. This means that the next task to accomplish in the construction of a "timber bodies strength of materials" is to define "test specimens" representative of the family of the analyzed wood.

To complete this work we have analyzed possible tests specimens for willow wood.

4 Definition of normalized tests specimens

As it has been said, the way of design work we are proposing implies the definition of test specimens that would be valid all around the technical world. It means that tests specimens must be normalized.

Taking into account that our proposal is to test the employed timber in any structure, tests specimens must have some specific qualities: 1) to be representative of timber mechanical properties and structural work; 2) to be geometrically simple; 3) their testing must be operatively simple; 4) to be economic.

We think that tests specimens must be free or almost free of defects (knots, holes due to biological attacks, marrow, fungus, fissures, Kino bags, resin or other substances).

4.1 Tests specimens considered

We will analyze some possible tests specimens of willow wood. The purpose is to select one or more test specimens which are representative of mechanical properties and structural work. The most representative structural solicitations are: traction, compression and flexion. The test specimens must be geometrically simple bodies tested in the simplest way possible, whenever the results variability is acceptable.

a) Tensile test:

25 mm x 25 mm x 400 mm specimens were tested.

In order to obtain a central calibrated length in a simple way, the heads or regions of load application were reinforced by gluing wood of the same material and section on both sides of the specimen.

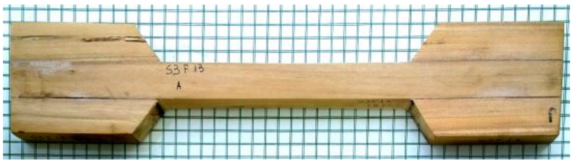

Figure 1. Tensile test specimen

No good adhesion results were obtained with glue available in the market. To solve this problem, joint covers were placed on both sides of the heads to achieve the unitary work of its components. Among the several types of joint cover materials tested, hardboard was the most efficient.

Figure 2. Tensile test specimen with joint cover

Under these conditions, an average tensile stress σ_t=65.6 MPa with very little dispersion was obtained.

However, the alignment of the specimens with the jaws of the testing machine was complex because this test is susceptible to undesired flexo-traction solicitations instead of simple traction.

Due to this problem –the difficulty of obtaining simple tension loads– traction test is not convenient to be used routinely.

b) Compression test:

In this case we have adopted tests specimens of 3 (three) different dimensions: 25 mm x 25 mm x 100 mm , 50 mm x 50 mm x 150 mm and 50 mm x 50 mm x 250 mm. The obtained results are the following:

i) Specimens of 25 mm x 25 mm x 100 mm, slenderness (1:4). An average ultimate compression stress σ_c = 27.4 MPa was obtained.

Figure 3. Test specimen showing flexo-compression

ii) Specimens of 50 mm x 50 mm x 150 mm, slenderness (1:3). The average ultimate compression stress was σ_c = 28.4 MPa.

Figure 4. Compression test specimen of 50 mm x 50 mm x 150 mm

iii) Specimens of 50 mm x 50 mm x 250 mm, slenderness (1:5). The average ultimate compression stress value was σ_c =29.5 MPa.

Analyzing the three (3) sizes studied, it was found that the most appropriate section is 50 mm x 50 mm, because specimens of 25 mm x 25 mm section are conditioned by defects of the wood and its correct alignment is difficult. Those of 50 mm x 50 mm section with slenderness (1:5) and (1:3) give similar results but the second one has a smaller dispersion.
Consequently, we propose to adopt test specimens with section 50 mm x 50 mm and 150 mm length as the most convenient test specimen for compression tests.

c) Flexion test:

In order to perform pure flexion tests a four (4) loads test was adopted (figure 5).

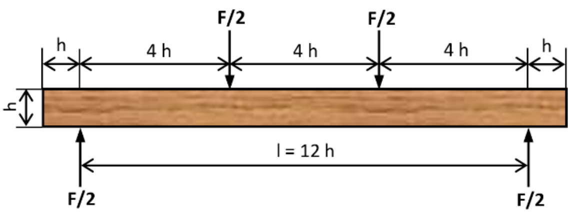

Figure 5

Willow wood test specimens with the same ratios [section side / length] and [section side / load application points] were tested (figure 5 and 6).

Figure 6. Pure flexion tests

Specimens with three (3) different dimensions (figure 7) have been tested:

- 50 mm x 50 mm x 700 mm
- 40 mm x 40 mm x 560 mm
- 25 mm x 25 mm x 350 mm

Figure 7

Dividing the value of the ultimate Flexure Moment by the flexural Module the following "reference stress" values were obtained:

- Specimens of 25 mm side: σ_f = 69.6 MPa
- Specimens of 40 mm side: σ_f = 46.2 MPa
- Specimens of 50 mm side: σ_f = 48.7 MPa

The higher stress values obtained in the 25 mm side specimens may be due to the fact that, in this case, it is easier to select specimens without knots or other defects. In addition, this specimens show less results dispersion.

Considering the smaller amount of wood needed and the lower load values to apply, we conclude that for a flexion test the more convenient specimens to adopt are those of square section 25 mm side and 350 mm length.

In this case –willow wood– the following equivalence ratios were obtained:

a) Based on the compression test ($\sigma_c = 28.4$ MPa)

$$\sigma_t = -2.3 \times \sigma_c \qquad (1)$$

$$\sigma_f = 2.4 \times \sigma_c \qquad (2)$$

b) Based on the flexion test ($\sigma_f = 69.6$ MPa)

$$\sigma_c = -0.4 \times \sigma_f \qquad (3)$$

$$\sigma_t = 0.94 \times \sigma_f \qquad (4)$$

4.2 Proposal

From the obtained tests results, we propose to adopt the following two tests to be performed in any structural timber construction:

1. Simple compression tests with the following standard specimen:

   50 mm x 50 mm x 150 mm

2. Pure flexion tests with the following standard specimen:

   25 mm x 25 mm x 350 mm

This proposal is made because the fracture of compressed specimens is caused by shear and it is ductile rupture while flexion fracture is produced by traction and it is a fragile one (figure 6). We consider that will be appropriate to adopt both standard tests to cover the main mechanical properties of the material.

5 References

[1] Cobas A.C., Tortoriello M.A., Cichero R.A., Lima L.J.: “Timber constructions as a main participant in the solution of housing problem”, 2019 IABSE Congress New York City.