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INNOVATIONS IN THE DESIGN OF TIMBER STRUCTURES

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Abstract. *The paper presents different drafts for the structural design of wooden structures, including the one based on allowable stresses and the one based on limit states.*
As the "orientation method" the paper uses the draft design on allowable stresses. Thus, all the relevant factors influencing the change in wood's elastic and mechanical characteristics-be they determined by regulations or by scientific researches-are taken into consideration in relation to wood properties as they are defined by the Yugoslav Standards.

Key words: *Timber Structures, Innovation in the Design, Relevant Factors*

IN GENERAL

Technical mechanics studies the problems of the behaviour of materials which are influenced by external forces. Besides, the following characteristics are usually ascribed to the material:

- Ideal elasticity regardless of the external forces intensity, temperature and the protraction of external loading action.
- Material has the same composition in all its points - it is ideally homogenous both before and after forces input (there is a continuum of media).
- Complete isotropy (material has the same mechanical characteristics in all directions).

Basically, timber as a material, in a mechanical sense, does not come up to any of these criteria.

Timber is a quasi-elastic material because complete stress and deformation linearity does not exist. The development of dilatations-sliping also depends on the intensity of forces, on loading duration, on temperature and on moisture content.

Timber is a non-homogenous material composed of several elastic and amorphous elements, which are often full of cracks, and with many cavities filled with water or air.

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Timber is an entirely an-isotropic material because it has different mechanical characteristics in different directions.

Timber structures are, in technical standards, calculated following the principles of technical mechanics, but the effect of anisotropy and non-homogeneity, and even non-elasticity, is encompassed with appropriate factors, that is the following are taken into account:

– Moisture content and temperature,
– Duration of load,
– Timber yield,
– Material and geometrical imperfection,
– Anisotropy direction,
– Various of mass density, and the like.

1. Concepts of Structure Calculation

There are three different concepts for the calculation of structural elements and structures in standards here and abroad. They are:

a) Design according to allowable stresses

In timber structures, allowable stress is defined by the relationship between the guaranteed mean timber strength at breaking, which is obtained through laboratory testing of standard samples, and safety coefficients n (n=2, 4). The basic condition is that the actual stress σ and deformations *f* be smaller than allowed at given most unsuitable loading, that is

$$\sigma \le \sigma_d \quad \text{and} \quad f \le f_d \,.$$

This calculation concept is also used in steel and concrete structures. In steel structures, allowable stresses are directly determined on the basis of boundary values (mean boundary values) material stretching limits or yield, i.e. straining strength, limits, and adequate safety coefficient n (n = 3/2, 4/3).

In concrete structures, allowable stresses are determined on the basis of characteristic cube strength and adequate safety coefficient n (n = 2, 5, 4).

b) design according to limit states with global safety coefficient

According to this concept, given loading is multiplied by global safety coefficient, and the actual stress is compared with characteristic strength material, that is

$$\gamma \cdot \sigma \le f_k$$

This concept is used in timber and steel structures. Values of characteristic strength material are defined by standards obtained through laboratory testing.

c) design according to limit states with partial safety coefficients

According to this concept, loadings, i.e. actual stresses, are multiplied by coefficients (loading increase factors), and characteristic strength value by safety coefficient, so that

$$\gamma_i \cdot \sigma_i \leq f_k / \gamma_k$$

This concept is used in concrete, steel and timber structures.

In Yugoslav timber structures standards, the only concept used is the one based on allowable stresses. The forthcoming changes and additions to these standards are expected to introduce other concepts, too. Such a modification would enable the application of Second Order Theory in space beam structures, and this would increase the accuracy of timber structure calculation.

All these concepts are based on mechanical, or mathematical grounds set up in 18th century by Newton. Leibnic, Hocke and Bernoulli.

2. Timber as a Resistance Material

In current civil engineering practice, besides traditionally classical timber structures (consisting of solid timber elements), modern timber structures, whose elements are obtained in industrial procedures, are very important. The development of modern technology brought about new timber-based composite materials, with superior mechanical, physical and chemical characteristics. These are glued laminated elements, various timber-based panel materials obtained through special technology procedures, as well as elements obtained by combining different materials (timber, metal, concrete, etc). Composite structures, such as composites timber-timber, timber-steel, timber-concrete, and reinforced and pre-strained timber structures, belong to a special group.

Products obtained by mechanical processing of tree trunks constitute **solid timber**. Depending on the type of mechanical processing, solid timber can be:

- *Rounded solid* timber or rounded timber material obtained with no special mechanical processing, without the bark. Rounded tree bulk is measured crossways at the middle of its length.
- *Half-rounded solid* timber or half-rounded timber material obtained by partial processing of rounded timber, in these ways:
  - if the round log is trimmed on one side only (flich),
  - if it is trimmed on two sides (planson), and
  - if it is trimmed on three sides (wenches).
- *Hewn solid* timber or hewn timber material is sharp-edged material obtained by sawing the tree trunk into the wanted shape.
- *Sawn solid* timber or sawn timber material is sharp-edged material obtained by sawing the tree trunk. Sawn materials used in practice, are: boards, laths, planks and beams. Boards with maximum width of 20 cm, beams with the smaller side longer than 10 cm, and small beams whose larger side section is more than 10 cm are used as supporting structure elements.

In compliance with existing standards, solid timber for resistancing constructions is divided into three quality classes (class I-large carrying capacity material, class II-medium carrying capacity material, and class III-small carrying capacity material). Coniferous timber material is divided into three, and hard grown material into two quality classes.

Timber-based panel products are products obtained through special technological procedures where timber is used as the basic material. In civil engineering practice, the following are used:

– veneer boards or plywood boards made from veneer with crossed fibers,

– fiber boards made from timber fibers, and

– chipboards made from timber splinters.

Glued laminated elements are obtained in special technological procedures by gluing lamellas from special processed boards. Laminated material is most often class I and II coniferous material, and less often oak or beech. During the processing procedure, material humidity is 15%. Laminated elements most often have a rectangular cross section (whose width is 8-20 cm), and rarely chest-like or a "T" section. Maximum lamella thickness is 32 mm. Glue thickness is not more than 0,2 mm. Lamella maximum width is 200 mm. Lamellas are glued with water-resistant glue under pressure of 50-80 N/cm^2. Depending on technological possibilities, glued laminated element height is 2200 mm or (in Yugoslavia) 1800 mm. In practice, the relationship between laminated element cross-section height and width is from 4 to 10, although it is possible to apply the section with side relationship from 15 to 20. Transporting and assembling conditions determine laminated element length, and it is not more than 40m. Curved girders are determined with a rectangle of 4×40 m. In laminated elements various class timber can be applied, depending on the re-distribution of stress, i.e. movements.

Laminating process also enables the processing of reinforced sections, and also pre-stressed girders.

3. Definition of Mechanical Characteristics

Timber structures calculation, depending on the procedure used, is based on the criterion of the use of allowable stresses, i.e. characteristic stress values. Both stress values are determined through experimental procedures, by testing standard samples and they depend on stress fracture f average value.

Stress fracture f average value represents the average value of limit timber strength (timber strength at breaking). It is determined by statistical methods due to obvious dissolving of testing results.

Stress characteristic value f_m is obtained on the basis of experimental testing of standard samples and it represents the value of 5% fractals on the statistical curve of strength values distribution.

Fracture stress f_o basic value is fracture stress average value which is reduced by the coefficient which takes into account the influence of element size and shape, loading type and duration, and the degree of structure safety.

Stress *od* allowable value represents fracture value average value which is reduced by safety coefficient m.

All these characteristics are dependent on several factors, such as timber sort, origin, growth, living conditions; these can vary even within one tree trunk in its cross section and along the beam axis. Moisture content (fig. 1) and mass density (fig. 2) is of immense importance. Timber quality, which is most often classified according to its strength, is also of great importance.

Timber is an isotropic material because it displays various mechanical characteristics in different anisotropy directions. Also, there are differences in mechanical characteristics depending on stress type (fig. 3), as well as on loading action duration (fig. 4).

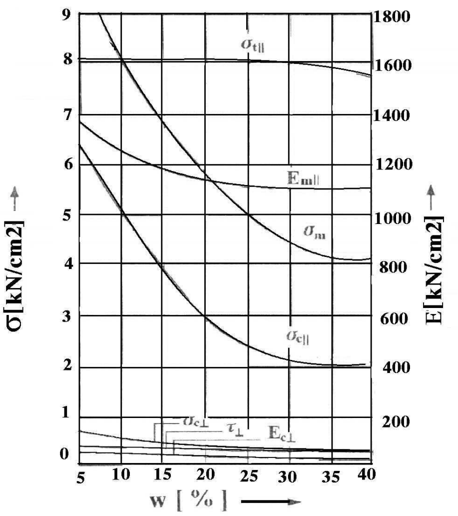

Fig. 1. Moisture content and strength (elasticity) correlation

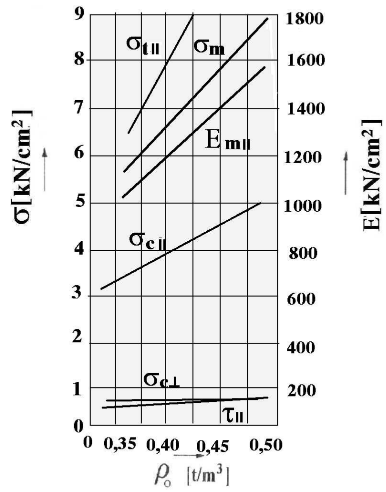

Fig. 2. Correlation of moisture content and elasticity with mass density

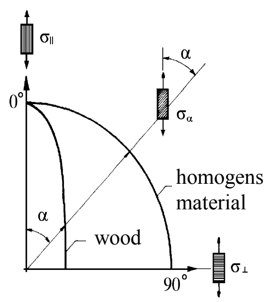

Fig. 3. Changes in timber strengt depending on stress direction

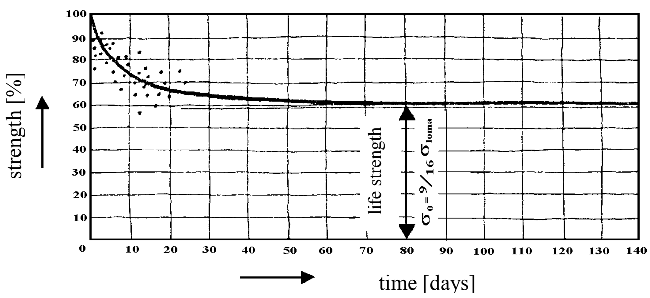

Fig. 4. Durable timber strength

Figure 5 represents statistical curve of the result distribution of small "pure timber" samples testing, with 12-15% humidity, as well as samples matching the structural elements of quality classes I, II, and III and unsorted timber.

Coniferous timber of class II is an example where stress f, f_m, f_o and *od* values are indicated, as well as fractal 5% and the corresponding safety factors.

Characteristic f_m stress value is obtained from the expression:

$$f_m = f - 1.64c$$

where: c - stands for the standard deviation of testing results

1,64 - stands for the constant corresponding to 5% fractal.

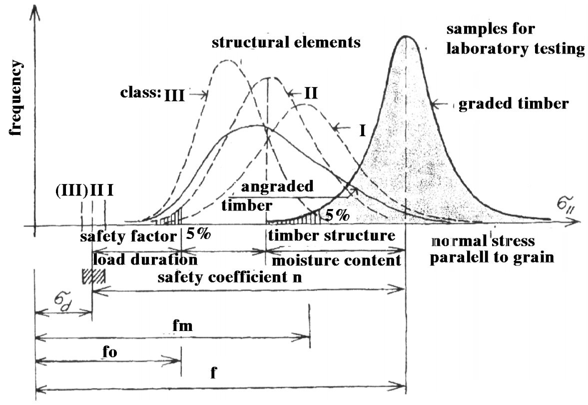

Fig. 5. Timber strength statistical distribution

4. Conclusion

Current Yugoslav standards for timber structure calculation are based on the concept of allowable stresses. This concept is slowly being abandoned in the world and the concept of limit states is being adopted. These two concepts are completely different, but it is still possible to use in both of them certain reduction factors, and even expressions. With the aim of modernizing timber structure calculations according to JUS, it is possible to use some expressions and factors from regulations based on boundary conditions, but with great attention. Sometimes, even with non-linear expressions, results can be completely wrong, and certain relations cannot even be compared. Stress reduction and elasticity module factors, due to humidity changes, timber yield, loading duration, structure maintaining, and the like, do not have any essential differences in these concepts.

The introduction of limit states concept in Yugoslavia is inevitable; however, old references and engineering experience gained over the years on the idea of allowable stresses should not be overlooked. The transition to new concept demands different way of thinking and approach to the issues; at the same time, it is a new challenge for designers.

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INOVACIJE PRORAČUNA DRVENIH KONSTRUKCIJA

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U radu su izloženi različiti koncepti dimenzionisanja drvenih konstrukcija prema konceptu dopuštenih napona i prema graničnim stanjima.

U radu je, kao "reperna metoda" korišćen koncept dopuštenih napona, tako da su svi relevantni faktori koji utiču na promenu elastomehaničkih karakteristika drveta, bilo da su definisani propisima ili naučnim istraživanjima, uzeti u odnosu na karakteristike drveta definisane JUS-om.

Ključne reči: *drvene konstrukcije, inovacije proračuna, relevantni faktori*