South America Timber Structures Code

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Abstract

Some of the countries of South America don't have a code for the design of timber structures and they use the European Standards. As we have a great quantity of hardwoods in South America, the European Codes must be calibrated for hardwoods utilization. In Brazil we did the first Timber Structures Code using the LRFD in 1997 with emphasis on the utilization of hardwoods. This work aims to present the Brazilian Code for Timber Structures Design, NBR7199/1997, relating the new revision for grading recommendations for softwoods and hardwoods grown in South America. Details of drawings, wood preservation (South America have different types of termites), fire recommendations design, connections and constructive timber systems. Based on the Brazilian experience we can propose a South American Code on the subject of timber structures design.

Keywords: South American Code, timber structures, normalization

Introduction

The Brazilian timber design code is based on the Limit States Design concept used with the partial factor method, moving from an Allowable Stress Design of 1982 to a Probabilistic Limit States Design in 1997 using a calibration coefficient to convert tabulated medium strength properties to characteristic 5% values of load effects and resistances.

In this paper the main content of the limit states design code and the new revision are presented and an overview is given of the work that is going on the revision of the Brazilian Code NBR7190/1997 – Design of Timber Structures. References are made in this paper for strength class materials and design factors adopted for limit states design and serviceability. Types and design of timber joints are also presented. The test methods to determine strength and stiffness properties of wood and timber joints are presented in annex of the code.

Besides the principal text there are six annexes referred to: timber structures drawing, test methods to wood properties determination, test methods to mechanical connections strength determination, recommendations for wood durability, table of medium values of strength and stiffness wood species used in civil construction in Brazil and finally the philosophy of the code calibration.

The global objective of the code is to fix the general conditions that must be followed in design, construction and control of current timber structures, namely: bridges, buildings, roofs, decks and formworks.

Loads

The code presents tables for permanent loads factors that give the maximum and minimum values used to produce the more critical combinations for design loads. Also in order to consider the wood behavior under impact situation the code reduces the live load factor of 0.75 in the loads combination.

Material Properties

The properties to consider in design of timber structures are: density, strength, stiffness and moisture content. The specified properties of strength and stiffness correspond to the class of moisture content of 12%, that is 25 degrees Celsius and 65% of relative humidity.

Characterization of Wood Properties

The complete and the minimum strength characterization of wood properties to design of timber structures can be made according annex B of the code. Besides these two types of characterization it is possible to use a simplified characterization of strength using only compression parallel to grain tests. The resistance to normal stress allows a variation coefficient of 18% and the resistance to tangential stress allows a variation coefficient of 28%. Others strength values can be taken by:

$$f_{co,k} / f_{to,k} = 0{,}77$$

$$f_{tM,k} / f_{to,k} = 1{,}0$$

$$f_{c90,k} / f_{co,k} = 0{,}25$$

$$f_{eo,k} / f_{co,k} = 1{,}0$$

$$f_{e90,k} / f_{co,k} = 0{,}25$$

For softwoods: $f_{vo,k} / f_{co,k} = 0{,}15$

For hardwoods: $f_{vo,k} / f_{co,k} = 0{,}12$

Strength Classes

A strength class is simply a group of species/strength grade combinations which have similar properties. The solid timber strength classes are defined in *NBR7190/1997*. Eight classes are defined: three for softwoods, prefixed C, and five for hardwoods, prefixed D. The softwood strength classes are C20 (weakest), C25 and C30. The hardwood strength classes are D20, D30, D40, D50 and D60. The numbers represent the characteristic compression parallel to grain stress for each strength class, a value which is used for designing to NBR7190:1997 which satisfy the requirements for each strength class and gives the appropriate design stresses and elastic module. There are a very large number of possible combinations of sizes, strength grades and species available in Brazil. The availability of any particular species, grade and size may vary around the country. When a strength class is specified suppliers can provide any of the species/grades which meet the requirements of that strength class. Tables 2 and 3 shows the softwoods and hardwoods included in NBR7190/1997 which are likely to be available strength graded to the standards indicated.

Hardwood Graded to NBR7190/2008(draft)

Values of the strength and stiffness properties of forty-two tropical and forestation species were utilized. Adequate statistical analysis was conducted and five classes to hardwoods were defined.

Table 1 Strength class for hardwoods.

Strength Classes	$f_{c0,k}$ **(MPa)**	$f_{v0,k}$ **(MPa)**	$E_{c0,m}$ **(MPa)**	$\rho_{bas,m}$ **(kg/m3)**	$\rho_{ap,m,12\%}$ **(kg/m3)**
C20	20	4	9500	500	650
C30	30	5	14500	650	800
C40	40	6	19500	750	950
C50	50	7	22000	770	970
C60	60	8	24500	800	1000

Softwood graded to NBR7190/2007

Values of the strength and stiffness properties of ten pinus species were utilized. Adequate statistical analysis was conducted and three classes to hardwoods were defined.

Table 2 Strength class for softwoods.

Strength Classes	$f_{c0,k}$ **(MPa)**	$f_{v0,k}$ **(MPa)**	$E_{c0,m}$ **(MPa)**	$\rho_{bas,m}$ **(kg/m3)**	$\rho_{ap,m,12\%}$ **(kg/m3)**
C 20	20	4	3 500	400	500
C 25	25	5	8 500	450	550
C 30	30	6	14.500	500	600

Representative Strength and Stiffness Values

The design values Xd of one wood property is obtained from the characteristic value Xk by the following formulae:

$$X_d = k_{mod} \frac{X_k}{\gamma_w}$$

Where γ_w the partial safety is factor of wood properties and k_{mod} is the modification factor that considers the influences that are not accounted in factor γ_w.

Modification Factors

The global modification factors k_{mod} is composed by the product of three partial modification factors, that is:

$$k_{mod} = k_{mod,1} \cdot k_{mod,2} \cdot k_{mod,3}$$

The partial modification factor number 1, $k_{mod,1}$, consider the load classes and types of materials used, that is:

Table 3 – Values of $\mathbf{k_{mod,1}}$

Load Classes	Sawn wood, Glulam, Plywood	Recomposed wood
Dead load	0,60	0,30
Long duration load	0,70	0,45
Médium duration load	0,80	0,65
Short duration load	0,90	0,90
Instantanous	1,10	1,10

The partial modification factor number 2, $k_{mod,2}$, consider the classes of moisture content and types of materials used, that is:

Table 4 – Values of $\mathbf{k_{mod,2}}$

Classes of moisture content	Sawn wood, Glulam, Plywood	Recomposed wood
(1) e (2)	1,0	1,0
(3) e (4)	0,8	0,9

(1) corresponds a 12% moisture content wood and relativity humidity < 65%

(2) corresponds a 15% moisture content wood and $65\% < U_{amb} \leq 75\%$ relativity humidity

(3) corresponds a 18% moisture content wood and 75% $< U_{amb} \leq$ 85% relativity humidity

(4) corresponds a 25% moisture content wood and relativity humidity > 85%

In a special case of immersed sawn wood, $k_{mod,2} = 0{,}65$.

The partial modification factor number 3, $k_{mod,3}$, takes account the grading of wood, with values of $k_{mod,3}=0{,}8$ no grading wood and $k_{mod,3}=1{,}0$ for visual and mechanical grading wood. This partial coefficient was reviewed in the new version with the following changes:

Table 5a. Proposed values of kmod, 3 for hardwoods.

Class	$k_{mod,3}$ (visual +proof test)	$k_{mod,3}$(visual+transversal vibration)	$k_{mod,3}$ (visual + stress wave)
SE	1,00	0,95	0,90
S1	0,95	0,90	0,85
S2	0,90	0,85	0,80
S3	0,85	0,80	0,75

Table 5b. Proposed values of kmod, 3 for softwoods - D.

Class	$k_{mod,3}$ (visual +proof test)	$k_{mod,3}$(visual+transversal vibration)	$k_{mod,3}$ (visual + stress wave)
SE-D	1,00	0,90	0,85
S1-D	0,95	0,85	0,80
S2-D	0,90	0,80	0,75
S3-D	0,85	0,75	0,70

Table 5c. Proposed values of kmod, 3 for softwoods - ND.

Classe	$k_{mod,3}$ (visual +proof test)	$k_{mod,3}$(visual+transversal vibration)	$k_{mod,3}$ (visual + stress wave)
SE-ND	1,00	0,85	0,80
S1-ND	0,95	0,80	0,75
S2-ND	0,90	0,75	0,70

S3-ND	0,85	0,70	0,65

For no graded wood the proposed values for hardwoods is kmod, 3 = 0,70.

Partial Safety Factors for Ultimate Limit States:

- the partial factor for compression parallel and normal to grain is $\gamma_{wc} = 1{,}4$
- the partial factor for tension parallel to grain is $\gamma_{wt} = 1{,}8$
- the partial factor for shear is $\gamma_{wv} = 1{,}8$

Stiffness

The design analysis that the safety depends of wood stiffness like the instability in compression elements the elasticity modulus parallel to grain must be taken as:

$$E_{co,ef} = k_{mod,1} \cdot k_{mod,2} \cdot k_{mod,3} \cdot E_{co,m}$$

And the transversal modulus as:

$$G_{ef} = E_{c0,ef} \; / \; 20$$

Design Considerations in Stability of Compression Elements

In the compression design process, slenderness structural elements, may be subject of accidental eccentricity loads and geometrical lumber imperfections and this situation is considered in the code by applying an accidental eccentricity value of L/300. This mean that all the compression members with $\lambda > 40$ must be designed for bending and compression forces, where the bending forces appeared by eccentricity of L/300 multiply by the normal load.

The formulas to be applied in the design of compression members are:

$$\frac{\sigma_{Nd}}{f_{co,d}} + \frac{\sigma_{Md}}{f_{co,d}} \leq 1$$

$$M_d = N_d \cdot e_d$$

$$e_d = e_1 \left(\frac{F_E}{F_E - N_d} \right)$$

$$F_E = \frac{\pi^2 \ E_{co,ef} \ I}{L_o^2}$$

$$e_1 = e_i + e_a$$

$$e_i = \frac{M_{1d}}{N_d}$$ - design eccentricity

$$e_a = L_o / 300$$ - accidental eccentricity

Mechanical Connections

For mechanical connections of wood members the code presents three types of elements:

- steel dowels or bolts
- wood dowels
- steel rings and metal plate connectors

The design of dowels is made as a function of a ratio

$$\beta = \frac{t}{d}$$

where t is the thickness of the wood piece and d the diameter of the dowel.

$$\beta_{lim} = 1{,}25 \sqrt{\frac{f_{yd}}{f_{ed}}}$$

Corresponds to the limit of the wood embedment and the steel dowel bending.

If $\beta \leq \beta_{lim}$ that means wood embedment than $R_{vd,1} = 0{,}40 \frac{t^2}{\beta} f_{ed}$

If $\beta > \beta_{lim}$ that means dowel steel bending than

$$R_{vd,1} = 0{,}625 \frac{d^2}{\beta_{lim}} f_{yd} \qquad (\text{com } \beta = \beta_{lim})$$

$$\text{where} \quad f_{yd} = \frac{f_{yk}}{\gamma_s} \quad \text{and} \quad \gamma_s = 1{,}1$$

Serviceability Limit States

The deflection criteria must also be verified because it can affect the normal utilization of construction as well its stet tic, considering only loads of long duration. The elasticity modulus in this case is give by:

$$E_{co,ef} = k_{mod,1} \cdot k_{mod,2} \cdot k_{mod,3} \cdot E_{co,m}$$

The total displacement must be less than l/300 of the span neither l/150 of the cantilever beam length. The displacement of dead loads can be compensated by given a camber during construction.

Constructive Recommendations

- static system must be clearly defined;
- to avoid deterioration of wood, no durable woods, must be treated with preservatives;
- the minimum areas and width of simple principal structural elements must be 50 cm2 and 5 cm and 18 cm2 and 2.5 cm for secondary structural elements, respectively;
- the minimum area and width of multiple principal structural elements must be 35 cm2 and 2.5 cm, and 18 cm2 and 1.8 cm for secondary structural elements, respectively;
- the minimum bolts diameter is 10 mm;
- the minimum number of dowels in a connection must be two;

Code Annexes

- drawing of timber structures;
- strength and stiffness properties of Brazilian timbers,
- test methods for strength and stiffness determination of properties of timbers;
- test methods for strength and stiffness determination of timber joints;
- recommendations of preservative treatment of wood;
- calibration of 2007 Limit States Design versus 1982 Allowable Stress Design

TABLE 6 – Properties of Brazilian timber species used in civil construction – Tropical

Common name	scientific name	$\rho_{ap(12\%)}$ (Kg/m^3)	$f_{c0,m}$ (MPa)	$f_{t0,m}$ (MPa)	$f_{t90,m}$ (MPa)	$f_{v,m}$ (MPa)	$E_{c0,m}$ (MPa)	**SC**
Angelim Araroba	Votaireopsis araroba	688	50,5	69,2	3,1	7,1	12876	**15**
Angelim Ferro	Hymenolobium spp	1170	79,5	117,8	3,7	11,8	20827	**20**
Angelim Pedra	Hymenolobium petraeum	94	59,8	75,5	3,5	8,8	12912	**39**
Angelim Pedra V.	Dinizia excelsa	1170	76,7	104,9	4,8	11,3	16694	**12**
Branquilho	Termilalia spp	803	48,1	87,9	3,2	9,8	13481	**10**
Cafearana	Andira spp	677	59,1	79,7	3,0	5,9	14098	**11**
Canafístula	Cassia ferruginea	871	52,0	84,9	6,2	11,1	14613	**12**
Casca Grossa	Vochysia spp	801	56,0	120,2	4,1	8,2	16224	**31**
Castelo	Gossypiospermum praecox	759	54,8	99,5	7,5	12,8	11105	**12**
Cedro Amargo	Cedrella odorata	504	39,0	58,1	3,0	6,1	9839	**21**
Cedro Doce	Cedrella spp	500	31,5	71,4	3,0	5,6	8058	**10**
Champagne	Dipterys odorata	1090	93,2	133,5	2,9	10,7	23002	**12**
Cupiúba	Goupia glabra	838	54,4	62,1	3,3	10,4	13627	**33**
Catiúba	Qualea paraensis	1221	83,8	86,2	3,3	11,1	19426	**13**
Garapa Roraima	Apuleia leiocarpa	892	78,4	108,0	6,9	11,9	18359	**12**
Guaiçara	Luetzelburgia spp	825	71,4	115,6	4,2	12,5	14624	**11**
Guarucaia	Peltophorum vogelianum	919	62,4	70,9	5,5	15,5	17212	**13**
Ipê	Tabebuia serratifolia	1068	76,0	96,8	3,1	13,1	18011	**22**
Jatobá	Hymenaea spp	1074	93,3	157,5	3,2	15,7	23607	**20**
Louro Preto	Ocotea spp	684	56,5	111,9	3,3	9,0	14185	**24**
Maçaranduba	Manilkara spp	1143	82,9	138,5	5,4	14,9	22733	**12**
Mandioqueira	Qualea spp	856	71,4	89,1	2,7	10,6	18971	**16**
Oiticica Amarela	Clarisia racemosa	756	69,9	82,5	3,9	10,6	14719	**12**
Quarubarana	Erisma uncinatum	544	37,8	58,1	2,6	5,8	9067	**11**
Sucupira	Diplotropis spp	1106	95,2	123,4	3,4	11,8	21724	**12**
Tatajuba	Bagassa guianensis	940	79,5	78,8	3,9	12,2	19583	**10**

TABLE 7 – Properties of Brazilian timber species used in civil construction– Eucalyptus

Common name	Scientific name	$\rho_{ap(12\%)}$ (Kg/m^3)	$f_{c0,m}$ (MPa)	$f_{t0,m}$ (MPa)	$f_{t90,m}$ (MPa)	$f_{v,m}$ (MPa)	$E_{c0,m}$ (MPa)	**SC**
E. Alba	Eucalyptus alba	705	47,3	69,4	4,6	9,5	13409	**24**
E. Camaldulensis	Eucalyptus camaldulensis	899	48,0	78,1	4,6	9,0	13286	**18**
E. Citriodora	E. citriodora	999	62,0	123,6	3,9	10,7	18421	**68**
E. Cloeziana	E. cloeziana	822	51,8	90,8	4,0	10,5	13963	**21**
E. Dunnii	Eucalyptus dunnii	690	48,9	139,2	6,9	9,8	18029	**15**
E. Grandis	Eucalyptus grandis	640	40,3	70,2	2,6	7,0	12813	**103**
E. Maculata	Eucalyptus maculata	931	63,5	115,6	4,1	10,6	18099	**53**
E. Maidene	Eucaliptus maidene	924	48,3	83,7	4,8	10,3	14431	**10**
E. Microcorys	Eucalyptus microcorys	929	54,9	118,6	4,5	10,3	16782	**31**
E. Paniculata	Eucalyptus paniculata	1087	72,7	147,4	4,7	12,4	19881	**29**
E. Propinqua	Eucalyptus propinqua	952	51,6	89,1	4,7	9,7	15561	**63**
E. Punctata	Eucalyptus punctata	948	78,5	125,6	6,0	12,9	19360	**70**
E. Saligna	Eucalyptus saligna	731	46,8	95,5	4,0	8,2	14933	**67**
E. Tereticornis	Eucalyptus tereticornis	899	57,7	115,9	4,6	9,7	17198	**29**
E. Triantha	Eucalyptus triantha	755	53,9	100,9	2,7	9,2	14617	**08**
E. Umbra	Eucalyptus umbra	889	42,7	90,4	3,0	9,4	14577	**08**
E. Urophylla	Eucalyptus urophylla	739	46,0	85,1	4,1	8,3	13166	**86**

TABLE 8 – Properties of Brazilian timber species used in civil construction – Pinus

Common name	Scientific name	$\rho_{ap(12\%)}$ (Kg/m^3)	$f_{c0,m}$ (MPa)	$f_{t0,m}$ (MPa)	$f_{t90,m}$ (MPa)	$f_{v,m}$ (MPa)	$E_{c0,m}$ (MPa)	**SC**
Pinho do Paraná	Araucaria angustifolia	580	40,9	93,1	1,6	8,8	15225	**15**
Pinus caribea	Pinus caribea var. caribea	579	35,4	64,8	3,2	7,8	8431	**28**
Pinus bahamensis	Pinus caribea var.bahamensis	537	32,6	52,7	2,4	6,8	7110	**32**
Pinus hondurensis	Pinus caribea var.hondurensis	535	42,3	50,3	2,6	7,8	9868	**99**
Pinus elliottii	Pinus elliottii var. elliottii	560	40,4	66,0	2,5	7,4	11889	**21**
Pinus oocarpa	Pinus oocarpa shiede	538	43,6	60,9	2,5	8,0	10904	**71**
Pinus taeda	Pinus taeda L.	645	44,4	82,8	2,8	7,7	13304	**15**

These medium value properties were determined in the Laboratory of Wood and Timber Structures of School of Engineering of São Carlos from Sao Paulo University, where:

$\rho_{ap(12\%)}$ = specific gravity a 12% de umidade; $f_{c0,m}$ = compression parallel to grain.
$f_{t0,m}$ = tension parallel to grain; $f_{t90,m}$ = tension normal to grain;
$f_{v,m}$ = shear strength; $E_{c0,m}$ = elasticity modulus determined in compression parallel to grain tests; n = number of samples; SC = Strength Class

Results and Discussion

These strength classes, based in parallel to grain strength compression, represent the values of the strength and stiffness properties of forty-two tropical hardwood timbers grown in Brazil and eucalyptus and pinus reforestation species were utilized. Adequate statistical analyses were conducted to define the five classes to hardwoods and 3 for softwoods. These results are important subsidy to of NBR 7190 revision - Brazilian Standard to Design and Construction of Wooden Structures, as the mainly for material specification for structural timber design.

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References

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