Comparative Dimensioning of Plane Timber Truss by ABNT NBR 7190:1997 Method and ABNT NBR 7190-1:2022 Method

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Wood, a renewable source and a material with excellent mechanical properties, is one of the oldest materials used in civil construction. In Brazil, its use is widespread in roof structures in the form of plane trusses. Given the Brazilian context of the growing presence of wood in structural systems, in addition to the normative updating processes, this study presents a comparison between calculation methods and possible increases in material consumption of wood for roof structure. The design methods compared are according to the recently published standard ABNT NBR 7190-1 (2022) and its previous version ABNT NBR 7190 (1997). The results were obtained *via* iTruss software, which includes linear-elastic structural analysis by the finite element method (FEM). It was concluded that the ABNT NBR 7190-1 (2022) presents a conservative dimensioning in relation to the previous version of 1997, favoring safety. However, there were no significant increases in wood consumption, demonstrating the efficiency of the revised version.

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INTRODUCTION

Currently, the incessant search to reduce the consumption of non-renewable natural resources stimulates the evolution of knowledge about wood as a structural material for civil construction. When combined with technological advances, it makes possible the development of several types of research approaching this incredible sustainable method (Roszyk *et al*. 2020; Esteves *et al*. 2021; Wang *et al*. 2021; Yang *et al*. 2022). It is precisely the scientific development that allows the updating of regulations and codes to improve the design and execution of structural projects.

In Brazil, after more than two decades of validity, a new code that presents guidelines for the design of timber structures was published, the ABNT NBR 7190-1 (2022) standard. Aiming to ensure that the design of timber structures in the country follows the current state of knowledge, the ABNT NBR 7190 (1997) was canceled and replaced by this new version. ABNT NBR 7190 (1997) is discussed in numerous works that seek to contribute to this scientific progress (Lima, Jr *et al.* 2018; Christoforo *et al*. 2019; Almeida *et al*. 2020; Christoforo *et al*. 2020; Molina *et al*. 2020; Lahr *et al*. 2021; Soares *et al.* 2021). It is noteworthy that there are already works in which the ABNT NBR 7190-1 (2022) code is used in the design (Fraga *et al*. 2021).

With regard to ultimate limit state design, the main changes can be noted:

- Changes in the weighting (γ) and reduction (ψ) coefficients for calculating the combinations of forces applied to the structure;
- Changes in modification coefficients (k_{mod}) that multiply the values of strength (f) and elasticity (E);
- Change from 0.5 to 0.7 in the value of the correction coefficient (k_M) used in the simple and compound bending checks;
- Considerable changes in the equation of stability checks for compressed and flexural compression parts.

In this context, a study comparing calculation methods and possible increases in material consumption between the current Brazilian code and its revision draft, as mentioned earlier, becomes relevant. Therefore, in this study, a design of a timber roofing project was proposed following the guidelines of the two versions of the Brazilian standard NBR 7190 (ABNT 1997; ABNT 2022), aiming at calculation analyses and the presence or absence of significant increases in material consumption. The new version, ABNT NBR 7190-1 (2022), is expected to result in a more refined design because many uncertainties were minimized in the current version.

EXPERIMENTAL

Truss Type and Tile Arrangement

For the geometry of the truss, the Pratt typology with a span of 12 *m* and an angle of 15° between chords ($i \cong 27\%$), commonly used in roofing projects, was admitted. The basic guidelines present in the technical catalogs of corrugated fiber-cement tiles were consulted for the arrangement of tiles. Thus, tiles with a thickness of 6 mm, a minimum longitudinal covering of 20 cm, and a complementary ridge piece with a 300 mm flap with a drilling distance of 10 mm were assumed. Given these considerations, the scheme illustrated in Fig. 1 is sufficient to guarantee the balance stipulated by the catalogs when there is no use of gutters: greater than 25 cm and less than 40 cm.

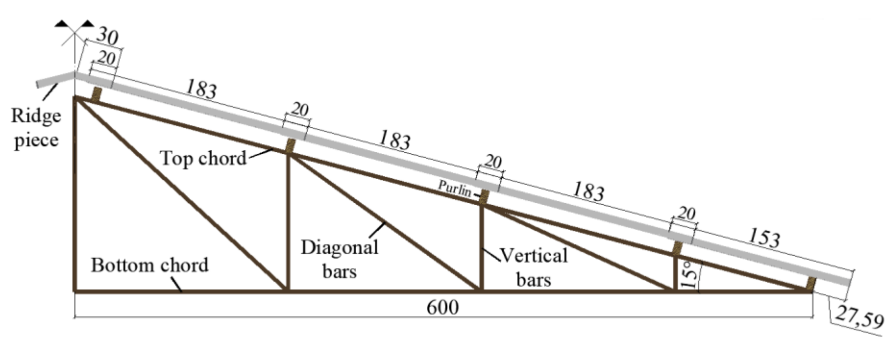

Fig. 1. Typology of the truss adopted and detailing of the tile arrangement (dimensions in cm)

Load and Combination

The permanent actions in roofing designs on timber structures are due to the structure's own weight and the covering materials of the roof. The variable actions in this type of project are those arising from the construction process (workers), overhead cover, and wind action.

Item 6.4 of ABNT NBR 6120 (2019) prescribes that a minimum characteristic overload of 0.25 kN/m^2 of built area in horizontal projection must be provided in the absence of atypical loads. The same item also mentions that in the roof structures, the accidental loads resulting from the construction process have an intensity of 1.0 kN and should be considered only when it is the main variable action, whose efforts are critical in relation to the other combinations. Accidental loads are applied to purlins and upper chord bars. On purlins, the value of 1.0 kN is applied in the middle of its span. This position is unfavorable for simply supported beams. Using the equivalent uniform load method (Moliterno 2010), the value of 0.22 kN/m^2 is obtained in the upper chord bars, which was neglected only in the truss calculation because it is lower than the overload rooftop.

The wind action on the building was quantified according to ABNT NBR 6123 (1988) criteria, resulting in three critical winds for the proposed typology. Table 1 presents a summary of share values and combination coefficients, either by ABNT NBR 7190 (1997) or ABNT NBR 7190-1 (2022).

Table 1. Actions and Comparison of Combination Coefficients

Loads		Combination Coefficients	
Type	**Values (kN/m^2)**	**ABNT NBR 7190 (1997)**	**ABNT NBR 7190-1 (2022)**
Permanents (just roof tiles)	0.1766	γ_g = 1.4 (unfavorable); γ_g = 0.9 (favorable)	γ_g = 1.4 (unfavorable); γ_g = 1.0 (favorable)
Overload	0.25	γ_q = 1.4; ψ_0 = 0.4; ψ_1 = 0.3; ψ_2 = 0.2	γ_q = 1.5; ψ_0 = 0.5; ψ_1 = 0.4; ψ_2 = 0.3
Wind 1	L = R = –1.0215	γ_q = 1.4; ψ_0 = 0.5; ψ_1 = 0.2; ψ_2 = 0.0	γ_q = 1.4; ψ_0 = 0.6; ψ_1 = 0.3; ψ_2 = 0.0
Wind 2	L = R = 0.072		
Wind 3	L = –1.053; R = –0.7425		
Note: Negative values indicate counter-gravity loads; L: left side; R: right side			

Structural Analyses and Dimensioning

The method adopted to obtain the results was the use of the iTruss software (Fraga 2020), which performs linear-elastic structural analysis using the finite element method (FEM). For this purpose, the bi-supported truss model was used as a boundary condition. In addition, continuous chords (perfectly rigid at the ends) and diagonal and vertical bars with perfectly free rotations at their ends were considered. The dimensioning done by the software follows the new revision draft. For this study, the guidelines of the current code were implemented. A single species of wood was admitted in all truss elements, and on the purlin, from the hardwoods group, the class chosen was D40. The stiffness (E), the apparent specific mass (ρ), and the characteristic strength ($f_{c0,k}$; $f_{v0,k}$) were extracted from ABNT NBR 7190-1 (2022), considering parts with a moisture content equal to 12%. This class is equivalent to C40 of ABNT NBR 7190 (1997). The profiles adopted have a rectangular shape and are given in Fig. 2.

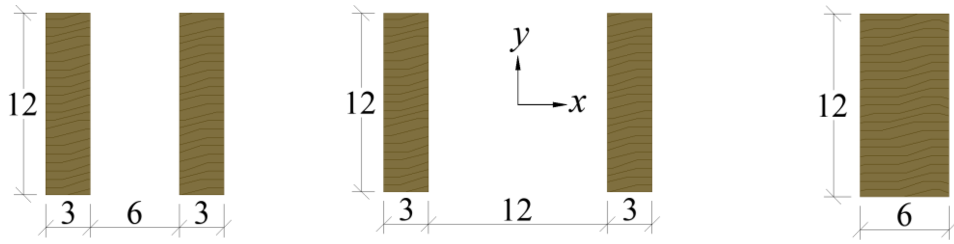

Fig. 2. Profiles typology: (a) chords; (b) diagonal bars; (c) vertical bars and purlins (dimensions in cm)

It is also noteworthy that the estimate of modification coefficients (k_{mod}) is different in the two standards, as ABNT NBR 7190-1 (2022) does not consider the coefficient related to the wood category ($k_{mod,3}$). However, for comparison purposes, the same conditions were assumed in both situations, namely: Long term loading and humidity class (1) with 1st category wood (submitted to the visual inspection process). Under these circumstances, the total modification coefficient (k_{mod}) is equal to 0.70 in both situations.

Measurement Method

The relevant checks for comparison in this article are for flexural-tensile, flexural-compression, simple oblique flexural, and shear strength. In addition to these, checks for stability on both axes were also considered. The other checks indicate identical values for both standards or not expressive in the design. It is worth mentioning that the equations governing the ultimate limit state checks are contained in both standards. In general, these checks consist of the ratio between the requesting stresses and the resisting stresses. That way, if the ratio assumes a value less than or equal to 1.0, the part can be used in the structure. Otherwise, the initial parameters must be changed so that the ratios always result in values less than or equal to 1.0.

RESULTS AND DISCUSSION

In Figs. 3 and 4, the ratios by the current code and the revision draft are compared in each verification. The discussions will be named as situation I, which refers to ABNT NBR 7190 (1997), and situation II to ABNT NBR 7190-1 (2022). It should be noted that the ordinate axis refers to the ratios between requesting stress and resisting stress, whose values must be less than or equal to 1.0 for the part to be approved in the design. Each verification list, depending on the type of request, is contained in the respective standards.

The combination coefficients in Table 1 indicate that it is possible to denote the combinations whose main variable action is in the same direction as the gravity acceleration, the efforts will be slightly greater for situation II. The opposite occurs with the main variable, suction action, whose greatest efforts will occur in the situation I.

Therefore, observing the purlin relationships in Fig. 4, the verification for oblique flexion is 13.5% higher for situation II due to the slightly greater efforts. Furthermore, in this situation, the k_M correction coefficient is equal to 0.7, which is different from the situation I, whose referred value is equal to 0.5. Thus, any piece verified in simple oblique bending by situation II will present conservative sizing, not discarding the slight difference between both that would not lead to expressive wood consumption.

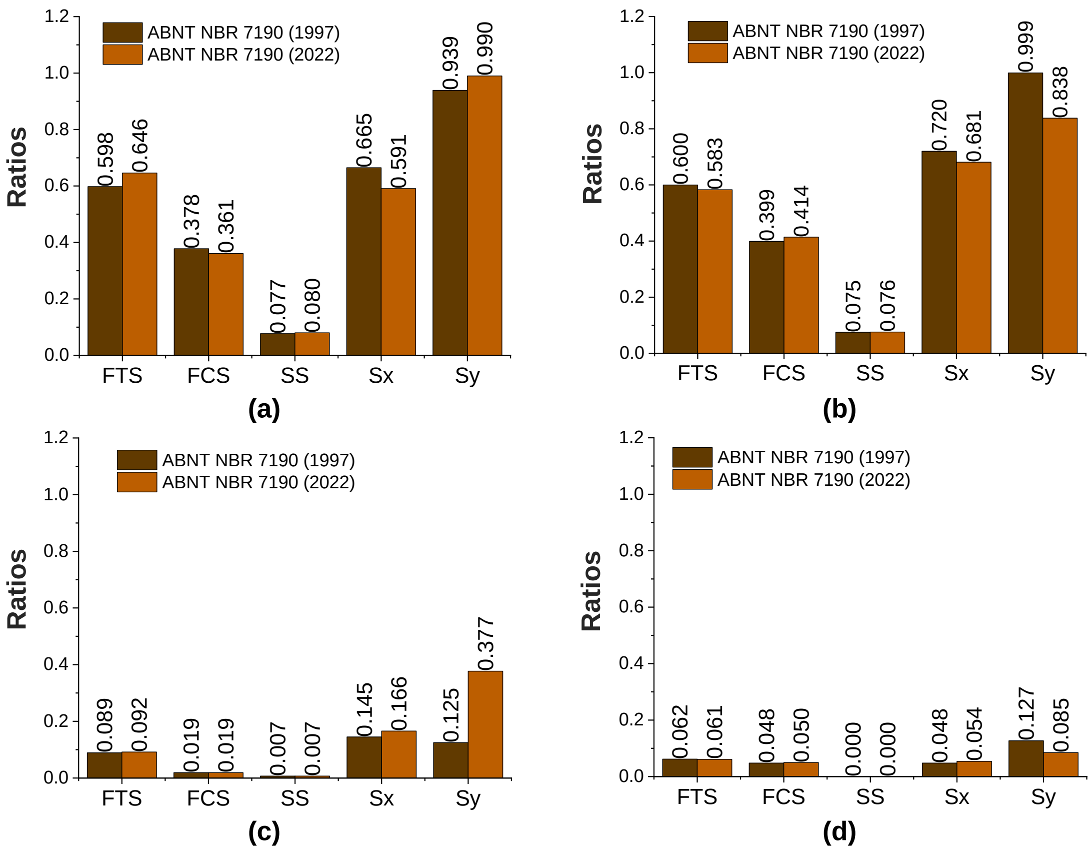

Fig. 3. Ratios in each verification for: (a) bottom chord; (b) top chord; (c) diagonal bars; (d) vertical bars
Note: Verification, FTS: Flexural Tensile Strength; FCS: Flexural Compression Strength; SS: Shear Strength; Sx: Stability around the X-axis, and Sy: Stability around the Y-axis

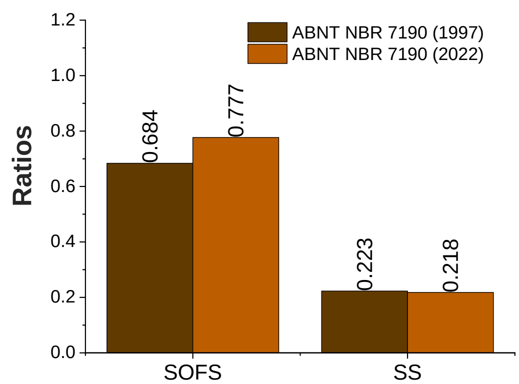

Fig. 4. Ratios in each check for purlins
Note: Verification, SS: Shear Strength and SOF: Simple Oblique Flexural Strength

In the bars of the chords, the inversion of the normal composite bending checks can be noticed precisely due to the combination coefficients. In the lower chord, the bars are tensioned with the combination of main variable overload, leading to slightly higher values for situation II. The inverse is obtained in the compression situation, whose main variable action is the suction wind, producing greater efforts in the situation I. The complete opposite is observed in the upper position, given that both positions present inversions of efforts between each other in the combinations. The k_M correction coefficient does not influence the chords because it is a regular composite bending whose bending forces in relation to the y-axis are non-existent.

It is worth mentioning the verification of stability around the axis of least inertia (y), which in most design cases is the verification that determines the dimensioning of the truss parts. In order for these checks to be met, spacers interposed along the length L of the part were adopted. Despite the close values, 7 spacers were needed for the situation I and 10 spacers for situation II in the lower chord. In the upper position, 5 spacers were placed on the critical bar in the situation I and 7 spacers in situation II. These results reveal that situation II is more conservative in verifying stability in relation to the y-axis. This conclusion is even more visible in the diagonal bars: Due to the incidence of efforts relatively lower than the chords, the same number of spacers was enough to meet both situations. However, there is a divergence of almost 200% in the verifications of discontinuously solidified parts.

It is suggested as a proposal for future work to be carried out on the simulation of other geometries, emphasizing the change in the typology of profiles to consolidate the conclusions pointed out here.

CONCLUSIONS

After processing the proposed roofing project, it was possible to point out the following considerations:

1. In combination with the main variable action in the same direction of gravity, the calculation efforts will be slightly higher for the situation of the ABNT NBR 7190-1 (2022) new code. The opposite occurs with variable main suction actions, whose values obtained by the 1997 code will be slightly higher.
2. In two-axis bending verifications, the new code of ABNT NBR 7190-1 (2022) presents a more conservative design due to the correction coefficient k_M equal to 0.7, which is different from the 1997 code version, whose referred value is equal to 0.5.
3. Stability verifications around the axis of least inertia (y) are responsible for sizing the truss parts. These verifications are also more conservative in the context of ABNT NBR 7190-1 (2022), requiring a greater number of spacers interposed in bars with multiple pieces.
4. Despite the conservative design, the new code of ABNT NBR 7190-1 (2022) does not lead to high wood consumption compared to the 1997 code version, considering the typology of the truss and the profiles proposed in this study.

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