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THE PERCENTILES RATIO 20TH TO 5TH OF BENDING STRENGTH AND STIFFNESS DISTRIBUTION IN THE CASE OF SPANISH SOFTWOODS

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ABSTRACT

A group of databases making a total of approximately 9300 sawn timber pieces from Spanish coniferous species, tested according to European standards and visually graded mainly according Spanish standards were analyzed. The percentiles ratio 20th/5th of bending strength, modulus of elasticity and density distribution were obtained for different combinations of species and visual stress grade. The Eurocode 5 proposes this percentile ratio by a coefficient k_{fi} which is used to determine the design values of mechanical properties in fire situation. The percentile ratios obtained were compared with the specified value in Eurocode 5 for solid timber (k_{fi} = 1,25). In lower grades of Spanish coniferous timber, this value was overly conservative. A value of k_{fi} of 1,4 seems to be more adequate for the case of the bending modulus of elasticity and 1,4 to 1,5 for the bending strength. It is noted that, in the case of the upper grades, this value should be of 1,3; close to the Eurocode proposal. Furthermore, in the case of density, the value should be of 1,1; hence lower than suggested in the code.

Keywords: Characterization, fire situation, reference material properties, structural reliability, timber.

INTRODUCTION

The design values of mechanical properties for the design of a timber structure are obtained from characteristic values, according to EN 1995-1-1:2004 standard (Eurocode 5, Part 1-1). These characteristic values correspond to the 5% percentiles of the distributions for strength verifications at a normal temperature. On the other hand, the 20% percentiles are considered in the design for the situation of fire exposure, according to EN 1995-1-2:2009.

As explained by König (1993, 2004), this different criterion keeps a consistent value of target reliability, as defined in EN 1990:2002 (Eurocode 0). Most of the fire tests performed in the past had considered mean values of properties rather than characteristic ones; only in few cases were characteristic values known. Design values of material properties for thermal analysis are determined by dividing the mean value of the material property by the partial coefficient for the material in fire design. The combination of a partial safety factor of $\gamma M,fi$ = 1,0; and the use of the 20th percentile for the reference material properties, was chosen in order to harmonize the fire section of Eurocode 5 safety levels, with those of the fire sections of the other Eurocodes. The 20% percentiles are obtained multiplying the 5% percentiles by a conversion factor called k_{fi}, whose value is proposed as k_{fi} = 1,25 for solid timber. Hence, k_{fi}, is a simplified proposed value for the ratio 20th/5th percentile of a material property, to be used uniformly across different species and different properties. This conversion factor is used regardless of whether the verification method is simplified (reduced cross-section, or reduced properties method) or advanced.

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As a summary, the design value of a material property under fire, for verification of mechanical strength, is calculated as $P_{d,fi} = k_{fi}\, P_{0,05}\, k_{mod,fi} / \gamma_{M,fi}$, where "P" stands for the property, k_{fi} is the conversion factor, $k_{mod,fi}$ the modification factor and $\gamma_{M,fi}$, the partial safety factor for timber in a fire (Eurocode 5, 2009). In the Spanish building regulations (Spanish building Code, CTE 2006), the Eurocode 5 is basically implemented, being this code normally used in timber based structural design in Spain. According to CTE, both $k_{mod,fi}$ and $\gamma_{M,fi}$, have to be taken as 1,00 (as prescribed in Eurocode 5). Hence, k_{fi} became an extremely relevant parameter in the safety verification process: the higher the value, the better the performance under fire of a given cross section. It is important to have a precise value for this conversion factor since, as in many cases of non-protected timber structures, structural fire behavior tends to govern the structural member dimensioning. The research presented in this paper is important from the point of view of cost saving by reducing beam cross sections. But it is also important from an aesthetical point of view, allowing the use of thinner elements.

The current version of Eurocode 5 has been drafted using, mainly, information from the in-grade testing programs of Central and North European softwoods. However, the distribution of the structural properties of Spanish softwoods is quite different. Particularly relevant is the coefficient of variation (CoV) of the strength distribution, which is notably different. Its value tends to range between 18 and 30% for Central and North European softwoods, while it ranges between 30 and 50% for Spanish softwoods (Ranta-Maunus 2001, Nevado 2013).

It is obvious that, wherever the probabilistic distribution is used to model the variable, the higher the CoV is, the higher the percentiles ratio $20^{th}/5^{th}$. Hence, a conversion factor of 1,25 would be appropriate in just a limited range of distribution and CoV combinations. A simple example can help to visualize this effect. Figure 1 shows that such value could be appropriate only in the case that the bending strength has a rather low CoV, regardless of the distribution used. However, if the CoV is high, the selection of the distribution becomes critical, and the conversion factor of 1,25 is not reasonable, even in the most favorable case of having a Log-normal distribution. It must be noted that in the case of Spanish softwoods (Nevado 2013), CoV values of 40% to 45% (even a bit higher) for the bending strength are not uncommon.

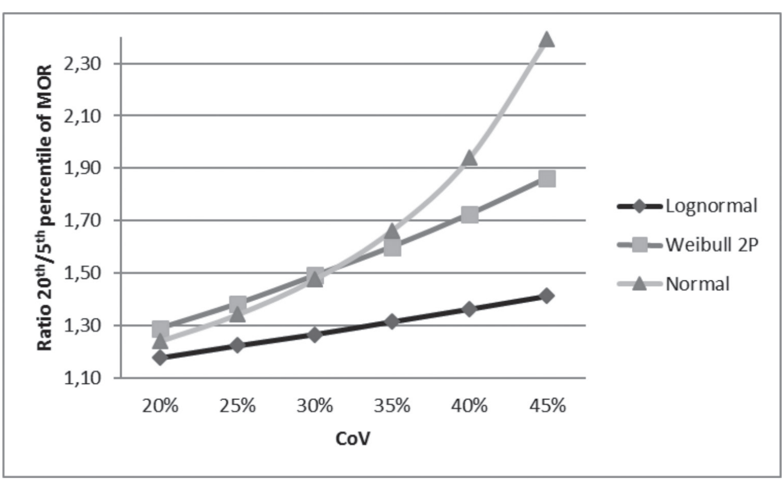

Figure 1. Percentiles Ratio $20^{th}/5^{th}$ of the bending strength, plotted for different values of CoV, adjusting three different theoretical distributions, with an average value of the property of 40 MPa.20% to 45% are CoV values that are common in timber bending strength. Log-normal, Weibull and Normal distributions are commonly proposed ones for probabilistic modeling of resistance parameters (PMC 2006), and 40 MPa is a frequent value for bending strength average in Spanish softwoods (Nevado 2013).

Numerical research was done on a database of 9313 Spanish softwoods specimens tested, as a part of a research task oriented at characterizing the referred population, from a probabilistic point of view, in order to perform structural reliability calculations with such material (Nevado 2013). In the study, density (DEN), bending strength (MOR), and bending modulus of elasticity (MOE) were the three variables analyzed. According to the current version of the Probabilistic Model Code (PMC 2006), these are to be considered reference material properties, to which all other material properties are correlated. Different outcomes came out from the research, some of them related to potential inconsistencies of the standards when using Spanish softwoods in structural design (Nevado 2013). One of the most important was that the value of k_{fi}, as proposed by Eurocode 5, is not consistent at all with the observations made on the Spanish softwoods structural behavior.

MATERIALS AND METHODS

Five coniferous species were studied: Scots pine (*Pinus sylvestrys* L.), Laricio pine (*Pinus nigra* Arn. ssp. *salzmannii*), Maritime pine (*Pinus pinaster* Ait.), Radiata pine (*Pinus radiata* D. Don.), and Aleppo pine (*Pinus halepensis* Mill.). These species have been mechanically characterized in Spain and the three first species have been used in construction for a long time; Radiate pine was introduced in the North of Spain, at the end of XIXth century, in order to get quick growing timber produced for different purposes (mainly structural uses for mining, initially); and finally, Aleppo pine, having being used traditionally in boat building and countryside small buildings, has a certain possibility for future use. As far as they have technical potential to recover part of their former building uses, it has become important to gain knowledge on the true nature of their structural reference properties.

All the material was Spanish grown timber, the species selected representing 80% of the country's softwood forestry area. Geographical distribution of the testing specimens is shown in table 1. Most of the material was tested in the National Agricultural Research Institute of Spain (Instituto Nacional de Investigaciones Agrarias, INIA) in the last decade of the twentieth century; some samples came from more recent testing done in laboratories of different regional research centers. The authors had direct access to the test results of all the 9313 specimens, provided by those persons and institutions cited at the acknowledgments at the end of this paper.

Table 1. Geographical origin of material tested.

Species	Areas of origin	Number of tests	
Scots pine *(Pinus silvestris)*	Castilla-León (50%), Cuenca (42%), Navarra and Alava (8%)	3258	35%
Laricio pine *(Pinus nigra)*	Sistema Ibérico (46%), Sierras de Cazorla and Segura (54%)	3148	34%
Maritime pine *(Pinus pinaster)*	Galicia (62%), Castilla-León (15%) and Cuenca (23%)	1588	17%
Radiata pine *(Pinus radiata)*	Pais Vasco (86%) and Cataluña (14%)	1249	13%
Aleppo pine *(Pinus halepensis)*	Cataluña	70	1%
		9313	100%

All this material had been tested according the European standard EN 408:1995-2010 and following the procedure defined in the EN 384:1995-2010 standard, and so, the results can be considered as a consistent body of data. They were visually graded; in this case, the results were not so homogeneous but, as shown later, this small lack of homogeneity in the grading does not invalidate the general conclusions.

The visual grading was performed according to Spanish standard UNE 56544:1999-2011 for all the species, with two exceptions; one was Maritime pine, graded according New Zealand standard (NZS 3631:1989) which defines three grades (Engineering, Framing 1, and Framing 2). The other exception was sample SC-1, which is a first grade sample of Scots pine, visually graded according internal rules of CESEFOR, one of the cooperating institutions (see acknowledgements).

For each species, four populations have been studied: the material without grading, and three different grades. For Maritime pine the grades has been Engineering, Framing 1, and Framing 2 (referred to as PI-12, PI-34, and PI-5, in the tables, respectively). For all other species and samples, the grades were ME1, ME2, and Rejected material (referred as χ-1, χ-2 and χ-R in the tables, where χ stands for the species). It should be noted that “Rejected grade” means, in the framework of this research, just a third (lower) grade. Furthermore, two populations of Laricio pine round wood (cylindered, and just debarked), sere studied.

Finally, the 9313 specimens have been divided into 31 different samples to be analyzed. Table 2, gives a list with each sample’s size and a short description. “Small cross-section” means timbers with rectangular cross section typically ranging from 40x100 mm to 70x200 mm, with a broad spectrum of combinations. Round timbers diameter ranged from 90 to 200 mm. “Large cross-section” corresponds to pieces with a minimum width of 100 mm. In the case of Radiata pine, A and B are quite different samples in sampling procedure (both from Basque Country), and C is a sample from Catalonia.

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Table 2. Samples description.

Species	Cross-Section	Grade	ID	Number of pieces
Scots+Laricio+Radiata	Large cross-section	all	GE	395
Scots+Laricio	Large cross-section	all	GE-SN	240
Laricio	Large cross-section	all	GN	120
Radiata	Large cross-section	all	GR	155
Scots	Large cross-section	all	GS	120
Aleppo	Small cross-section	all	H	70
Laricio	Cylindrical round	all	NC	440
	Debarked round	all	ND	226
	Small cross-section	all	NI	2362
	Small cross-section	ME-1	NI-1	531
	Small cross-section	ME-2	NI-2	1214
	Small cross-section	Rejected	NI-R	601
All except Radiata	Small cross-section	all	P	6865
Maritime	Small cross-section	all	PI	1588
	Small cross-section	Engineering	PI-12	366
	Small cross-section	Framing 1	PI-34	617
	Small cross-section	Framing 2	PI-5	605
Radiata	Small cross-section Sample A	All	RA	395
	Small cross-section Sample A	ME-1 + ME-2	RA-NR	118
	Small cross-section Sample A	Rejected	RA-R	279
	Small cross-section Sample B	All	RB	549
	Small cross-section Sample B	ME-1	RB-1	102
	Small cross-section Sample B	ME-2	RB-2	234
	Small cross-section Sample B	Rejected	RB-R	213
	Small cross-section Sample C	All	RC	148
	Small cross-section Sample C	All	R	1092
Scots	Small cross-section Sample C	Cesefor 1	SC-1	219
	Small cross-section Except simple C	All	SI	2919
	Small cross-section	ME-1	SI-1	454
	Small cross-section	ME-2	SI-2	1392
	Small cross-section	Rejected	SI-R	1073

Cross-section: "Small cross-section" corresponds to rectangular cross-section pieces from 40x100 mm to 70x200 mm; "Large cross-section" corresponds to rectangular cross-section pieces with a minimum width of 100 mm. "ID": identification key for table 3. Grade: ME-1 and ME-2 according to UNE 56544; Engineering, Framing 1 and 2 according to NZS 3631); Cesefor 1 according to internal rules of Cesefor; All correspond to all pieces without grading.

Most of the material (89%) was tested in boards with widths ranging from 150 to 200 mm, thickness from 40 to 80 mm and length from 2 to 4 m. 6% was tested in large square cross-section with 200 to 250 mm in width, 150 to 200 mm in thickness and length from 4,5 to 5,2 m. The remaining 5% corresponds to round wood with diameters ranging from 80 to 140 mm and lengths from 2,0 to 2,5 m.

For each sample, and for each one of the three main reference material properties (DEN, MOR and MOE), four candidate theoretical distributions have been fitted. The four distributions were Normal (N), Log-normal (LN), and Weibull with two and three parameters (W2 and W3). The reason for choosing these distributions is the general agreement on the fact that the variables to be modelled are pretty well represented by such families. The procedure for the statistical fitting has been as follows.

First stage: data arrangement. For each population and classified sub-population the data where visually arranged and the empirical distribution plotted against four different theoretical proposed distributions: Normal, Lognormal, Weibull with two and three parameters. The parameters are N (μ,σ), LN (ξ , δ) and W (w, k, τ), where μ and σ stands for the expectation and standard deviation of a Normal variate, ξ and δ stands for the median of a Lognormal variate and the standard deviation of its natural logarithm, and w, k and τ stands for the shape, scale and (if it is the case) truncation parameter of a Weibull distribution. The choice of these four options is based on the proposals of previous extensive studies, mainly done on North American, French, and Scandinavian timbers (Foschi *et al.* 1993, Faye 2004, Ranta-Maunus 2001, Soorensen 2000). The graphic arrangement is presented both in form of cumulative distribution function and probability paper, so that the initial conclusions can be visually verified.

Second stage: distribution selection. The four candidate distributions are checked with the Anderson-Darling (A-D) test, the Kolmogorov-Smirnov (K-S) test, and the χ^2 test, being the A-D test the preferred one for selecting the distribution, and the χ^2 test the last resource to make the decision. Whenever it is not possible to reject the corresponding hypothesis through the test cited, the decision is made looking at the best prediction of the relevant (for practical structural design purposes) percentile (5th for density and MOR, and mathematical expectation for MOE).

It has been clearly seen that density and MOE always follows a Log-normal distribution. Regarding MOR, when the material is not classified, it is also clear that Lognormal distribution gives the best fit, but it seems that Weibull three parameters distribution gives a better fit when the populations are graded (both in the higher or lower grades). Normal distribution represents MOR rather well, in particular exceptional cases (round wood, for instance, or ungraded Radiata pine).

Third stage: parameters proposal. The parameters are adjusted to the lower 30% tail in the case of density and MOR, and to all the data for MOE. The reason for making this adjustment is explained in the literature (Foschi *et al.* 1993, Soorensen 2000): it has to do with the fact that the lower tail has a much bigger effect on the calculated reliability, hence, the fit should be better in this part of the distribution. The method used is the Maximum Likelihood Method (MLM), making the referred tail fit with the Least Square Method. More detailed information about the statistical procedures followed can be found in Nevado 2013.

RESULTS AND DISCUSSION

The previous analysis cited, resulted in the determination of the parameters for the distribution. The results of the referred research have been arranged, for the research presented in this paper, in a way that allows the integration of the ratio 20th/5th percentiles simple calculation for the different distribution hypothesis of the studied variables in a single data sheet. For each sample, table 3 shows the ratio 20th/5th percentiles for the empiric (not parametric) distribution (D) and for the theoretical distributions, when adjusted to 100 % of the data, and/or to the lower 30% tail fit.

Table 3. Percentiles ratio 20th/5th, for the different samples, for the distribution adjusted to 100% of the data, for the four theoretical distribution studied (N, LN, W2 and W3), and for the data (D). At the right, distribution adjusted to the lower 30% tail.

	100% data fit															Lower 30% tail fit			
	DEN					MOE					MOR					DEN	MOR		
ID	N	LN	W2	W3	D	N	LN	W2	W3	D	N	LN	W2	W3	D	LN	N	LN	W3
GE	1,12	1,10	1,21	1,09	1,07	1,27	1,38	1,38	1,23	1,23	1,86	1,39	1,72	1,60	1,39	1,07		1,40	
GE-SN	1,12	1,10	1,20	1,10	1,06	1,24	1,36	1,36	1,15	1,15	1,58	1,35	1,57	1,55	1,35	1,09		1,31	
GN	1,10	1,09	1,14	1,07	1,06	1,30	1,36	1,36	1,18	1,18	1,78	1,34	1,65	1,62	1,44	1,07		1,45	
GR	1,07	1,07	1,12	1,07	1,05	1,24	1,33	1,33	1,22	1,22	1,50	1,29	1,54	1,39	1,21	1,06		1,29	
GS	1,09	1,08	1,16	1,08	1,07	1,18	1,28	1,28	1,13	1,13	1,37	1,29	1,43	1,43	1,18	1,05		1,24	
H	1,06	1,06	1,15	1,09	1,09	1,14	1,21	1,21	1,10	1,10	1,41	1,31	1,42	1,42	1,45	1,07		1,44	
NC	1,10	1,09	1,20	1,08	1,06	1,27	1,37	1,37	1,18	1,18	1,54	1,38	1,57	1,56	1,29	1,06	1,29		
ND	1,13	1,10	1,24	1,10	2,00	1,29	1,39	1,39	1,22	1,22	1,45	1,47	1,50	1,50	1,31	1,09	1,29		
NI	1,29	1,11	1,27	1,12	1,08	1,53	1,58	1,58	1,34	1,34	2,34	1,49	1,84	1,74	1,48	1,08		1,52	
NI-1	1,13	1,10	1,24	1,09	1,10	1,36	1,48	1,48	1,26	1,26	1,33	1,23	1,38	1,29	1,30	1,10			1,30
NI-2	1,15	1,11	1,27	1,12	1,08	1,40	1,49	1,49	1,28	1,28	1,92	1,40	1,82	1,62	1,43	1,08			1,46
NI-R	1,12	1,09	1,26	1,05	1,07	1,56	1,59	1,59	1,42	1,42	3,74	1,50	2,05	1,79	1,55	1,07		1,45	
P	1,15	1,12	1,27	1,19	1,09	1,60	1,62	1,62	1,36	1,36	2,51	1,49	1,87	1,80	1,49	1,09		1,51	
PI	1,13	1,10	1,21	1,10	1,09	1,70	1,67	1,67	1,36	1,36	2,36	1,50	1,84	1,78	1,55	1,09		1,54	
PI-12	1,11	1,09	1,17	1,10	1,42	1,47	1,53	1,53	1,38	1,38	1,31	1,24	1,36	1,36	1,40	1,11			1,31
PI-34	1,12	1,10	1,20	1,10	1,11	1,64	1,64	1,64	1,28	1,28	1,65	1,36	1,60	1,52	1,46	1,08			1,50
PI-5	1,11	1,09	1,20	1,07	1,08	1,72	1,70	1,70	1,38	1,38	2,06	1,42	1,79	1,70	1,46	1,07		1,42	
RA	1,09	1,08	1,14	1,08	1,07	1,31	1,41	1,41	1,31	1,31	4,72	1,54	2,10	1,76	1,54	1,08		1,55	
RA-NR	1,08	1,07	1,14	1,07	1,09	1,22	1,31	1,31	1,19	1,19	2,31	1,44	1,86	1,52	1,54	1,09			1,51
RA-R	1,08	1,07	1,14	1,07	1,07	1,22	1,24	1,24	1,32	1,32	2,90	1,46	1,95	1,63	1,57	1,07		1,49	
RB	1,11	1,10	1,17	1,10	1,10	1,38	1,43	1,43	1,35	1,35	2,21	1,43	1,82	1,52	1,49	1,10		1,50	
RB-1	1,10	1,09	1,15	1,10	1,16	1,32	1,41	1,41	1,47	1,47	1,74	1,37	1,64	1,47	1,32	1,13			1,37
RB-2	1,12	1,10	1,18	1,11	1,10	1,34	1,40	1,40	1,32	1,32	1,94	1,39	1,73	1,45	1,42	1,09			1,43
RB-R	1,10	1,09	1,16	1,10	1,09	1,38	1,43	1,43	1,31	1,31	2,30	1,43	1,84	1,47	1,57	1,10		1,53	
RC	1,12	1,10	1,18	1,08	1,07	1,31	1,39	1,39	1,25	1,25	1,52	1,31	1,53	1,39	1,45	1,08			1,38
R	1,11	1,09	1,17	1,09	1,09	1,46	1,51	1,51	1,28	1,28	2,49	1,47	1,88	1,71	1,52	1,09		1,54	
SC-1	1,12	1,10	1,20	1,09	1,10	1,35	1,45	1,45	1,30	1,30	1,29	1,20	1,37	1,25	1,33	1,09		1,25	
SI	1,12	1,10	1,19	1,13	1,07	1,38	0,69	0,69	1,30	1,30	2,14	1,45	1,78	1,65	1,46	1,07		1,46	
SI-1	1,12	1,10	1,19	1,12	1,08	1,24	1,32	1,32	1,20	1,20	1,29	1,22	1,35	1,32	1,31	1,09			1,30
SI-2	1,11	1,10	1,19	1,13	1,08	1,31	1,39	1,39	1,22	1,22	1,71	1,36	1,63	1,47	1,35	1,08			1,41
SI-R	1,11	1,09	1,20	1,11	1,07	1,36	1,43	1,43	1,25	1,25	2,11	1,41	1,81	1,60	1,40	1,06		1,41	

It can be easily seen, at first sight inspection of the non-parametric distribution (D) in table 3, that a value of $k_{fi} = 1,25$ is not at all consistent with the data. In fact, the only population where such a value can be considered as acceptable, is the case of round wood (NC and ND), and only when MOR is considered. We can also find other isolated cases in which the referred value could be acceptable, like Scots pine and Radiata pine in large cross-section, regarding MOR, or the case of Scots pine regarding MOE.

Table 4 shows the mean values of each material property and its coefficient of variation, for each distribution and adjustment.

In the case of MOR, a value of k_{fi} = 1,25 would be acceptable only in the case of a Normal distribution fit to the lowest tail. However, this is only a good fit for specific material (round wood, cylindrical or conical): in most tested material, the best fit is a LN distribution for the third grade or the sample without grading, or where it belongs to the third grade or a W3 distribution when the material is graded to the first and second grades. Hence, again k_{fi} should clearly be higher than 1,40. It seems likely that an upper limit for k_{fi} should be, in MOR, of ~1,5; if the material is not classified or "rejected", and ~1,4 if it is graded. The difference can have certain economic effect, as the benefits of classification to the best grades are reduced, as long as k_{fi} should be significantly smaller for the higher grades than for the lower grades. It can be seen that, if the material is graded to the first grades, k_{fi} = 1,25 would be reasonable (although slightly conservative).

In the case of MOE, it is shown that 1,25 would only be an acceptable value for k_{fi} when a W3 distribution is used: but, as shown in Nevado 2013, the best fit is obtained with a LN distribution, and, in this case k_{fi} should be a bit higher than 1,40.

The characteristic value of the load carrying capacity of timber joints depends on the characteristic value of density (5th percentile at a normal temperature). In case of a fire situation the characteristic value (20th percentile) is obtained multiplying the characteristic value at a normal temperature by the conversion factor. Then, when the density (DEN) is a critical design parameter (as, for instance, when the governing limit state is a dowel type joint failure) taking k_{fi} = 1,25 is unsafe. In Nevado (2013) it was shown that the best fit is obtained with a LN distribution. It is clear from table 4 that k_{fi} value should be a bit lower than 1,10 (regardless of whether the distribution is fitted to the lower tail or not).

Table 4. Average values and associated coefficient of variation (CoV) of the percentiles ratio 20th/5th, from the data of table 3. Underlined, the best fitted distributions. Subscript "30" indicates that the adjustment is done for the lower 30% of the data.

		N	LN	W2	W3	D	LN_{30}	N_{30}	LN_{30}	$W3_{30}$
DEN	m	1,12	1,09	1,19	1,10	1,12	1,08			
	CoV	3%	1%	3%	2%	16%	1%			
MOE	m	1,37	1,41	1,41	1,28	1,28				
	CoV	11%	13%	13%	7%	7%				
MOR	m	2,01	1,38	1,68	1,54	1,42		1,29	1,44	1,40
	CoV	37%	7%	12%	10%	7%		0%	7%	6%

An important issue is the difference between the values suggested by the selected parametric distribution, and the non-parametric distribution (D). In the case of MOR and DEN, there is no significant difference. But in the case of MOE, there is a difference: it is clear that k_{fi} = 1,25 would be reasonable if the non-parametric distribution is used, and too conservative if the parametric Log-normal distribution is used. It is also clear that the adjustment to the 30% lower tail of the strength distribution has no effect on the conclusion on the approximate value of k_{fi}.

It must be noted that the CoV of the ratio is rather small, particularly when the distribution is fitted to the lower tail, meaning that the results are consistent enough throughout the different populations. The only exception would be MOR when modeled as having a Normal distribution: but this is just quite a minor part of all the cases. In order to check if the k_{fi} values proposed in the standards could be better fitted to one or another species, from the inspection of table 3, it is clear that there is no such effect, nor it is the case when we look at density or MOE. Only one important nuance can be found on this point: in the case of MOR, the lower the grade, the more inappropriate the proposed value of 1,25 seems to be. It is clearly shown in table 5. The value k_{fi} = 1,25 would be appropriate (just a bit conservative), for the highest quality timber (first grade). It is interesting that, for MOR, the value would be exactly 1,25 just in sample SC-1. In the second and third grade, k_{fi} = 1,45 ~ 1,46 are more correct values. And, if the material is not graded, k_{fi} should be as high as 1,51. The remarkably low CoV of the indicated central values enforces the idea that this effect should be taken into account.

Table 5. Average values (m) and associated coefficient of variation (CoV) of the percentiles ratio 20th/5th, for MOR of the different grades.

ID	LN	W2	W3	D	$W3_{30}$
NI-1	1,23	1,38	1,29	1,30	1,30
PI-12	1,24	1,36	1,36	1,40	1,31
RB-1	1,37	1,64	1,47	1,32	1,37
SI-1	1,22	1,35	1,32	1,31	1,30
m	1,27	1,43	1,36	1,33	**1,32**
CoV	6%	10%	6%	3%	**3%**

MOR - FIRST GRADE

ID	LN	W2	W3	D	$W3_{30}$
NI-2	1,40	1,82	1,62	1,43	1,46
PI-34	1,36	1,60	1,52	1,46	1,50
RB-2	1,39	1,73	1,45	1,42	1,43
SI-2	1,36	1,63	1,47	1,35	1,41
m	1,38	1,70	1,51	1,42	**1,45**
CoV	1%	6%	5%	3%	**3%**

MOR - SECOND GRADE

ID	LN	W2	W3	D	LN_{30}
NI-R	1,50	2,05	1,79	1,55	1,45
PI-5	1,42	1,79	1,70	1,46	1,42
RA-R	1,46	1,95	1,63	1,57	1,49
RB-R	1,43	1,84	1,47	1,57	1,53
SI-R	1,41	1,81	1,60	1,40	1,41
m	1,44	1,89	1,64	1,51	**1,46**
CoV	3%	6%	7%	5%	**3%**

MOR - THIRD GRADE

ID	LN	W2	W3	D	LN_{30}
GE	1,39	1,72	1,60	1,39	1,40
NI	1,49	1,84	1,74	1,48	1,52
P	1,49	1,87	1,80	1,49	1,51
PI	1,50	1,84	1,78	1,55	1,54
R	1,47	1,88	1,71	1,52	1,54
SI	1,45	1,78	1,65	1,46	1,46
m	1,48	1,84	1,74	1,50	**1,51**
CoV	1%	2%	3%	2%	**2%**

MOR - UNGRADED

If a particular value of k_{fi} should be established as a National Determined Parameter (NDP) is a matter of consideration. The former version (experimental standard) ENV 1995-1-2:1994 includes the conversion factor as a boxed value and could be changed in the National Application Documents (NAD) (König 1993). Nowadays, this is not possible under the current version of the EN 1995-1-2:2004 standard. But, the economic importance of the referred results for the use of Spanish timbers would suggest that a way to take advantage of a higher k_{fi} value should be explored for the future version of Eurocodes. EN 1995-1-2, section. 2,3; table 2,1 gives different values for solid timber and glued-laminated timber, precisely, because of statistical reasons, being $k_{fi,glulam}$ = 1,15 while $k_{fi,timber}$ = 1,25. It is an important nuance: using a value of $k_{fi,glulam}$ = 1,25 with glulam would lead to unsafe solutions. Hence, there should not be logical objection to the use a higher value for $k_{fi,timber}$, in some cases. Also for the same reason, the fact could be considered that a $k_{fi,timber}$ = 1,25 leads to unsafe solutions in the case of Spanish timbers when density is the governing dimensioning property.

CONCLUSIONS

A database of approximately 9300 test results from Spanish softwoods has been statistically processed to check if the value for the conversion factor between the 20th and the 5th percentiles, referred to as k_{fi}, for the reference material properties (density, bending strength, and bending modulus of elasticity) is close enough to the value of 1,25 proposed in the relevant standards. This is a key coefficient when dealing with fire performance of the analyzed structure.

The results show that this value can be acceptable just in the case of round wood of Laricio pine. In the general case of visually graded Spanish coniferous sawn timber, when the studied properties are modeled with parametric distributions, such a value is too conservative for bending strength and modulus of elasticity, and clearly unsafe in the case of density. Values of ~ 1,4 seems to be more realistic for bending modulus of elasticity, while for bending strength the value would be within the range of ~ 1,4 to ~ 1,5.

Furthermore, regarding bending strength, more adequate values can be proposed by grades, being ~ 1,3; ~ 1,4; and ~ 1,5 realistic values for the first grade, the second grade, and the ungraded or rejected material, respectively.

For density, the value ~1,1 would be consistent with the data. It must be noted that the referred effect seems to be absolutely species-independent. The referred conclusions stand for density and bending strength also when non-parametric distribution is considered, but not for the case of modulus of elasticity.

Further research on the topic should include a detailed comparison of the results obtained, with the data on which the value given in the standards is based, before a modification is proposed at a European level, or, at least, before the k_{fi} parameter is proposed to be determined on a national basis.

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