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ORIGINAL ARTICLE

A determination method of compressive design value of dimensional lumber

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Abstract

The objective of this study was to develop a determination method of compressive design value of dimensional lumber for its safety design and rational application as a green building material. A total of 1049 full-size 2 × 4 samples of Chinese larch (*Larix gmelinii*) dimensional lumber, including visual grades Ic, IIc, IIIc, and IVc, were tested by static compressive tests. Compression strength parallel to grain (UCS) of different grades were summarized. By the least square method, the fitted parameters and results for UCS were obtained under different probability distribution models (normal, lognormal and 2-P-Weibull) and test data points (100, 75, 50, 25, and 15%). Based on reliability analysis method, relationships between the reliability index and partial factor were investigated under different probability distribution models, fitting data points, load combinations and load ratios. Finally, this study suggested that the lognormal distribution, 25% data points, load combination of dead load plus residential live load, and load ratio of 1.0 be selected for the determination of compressive design value of Chinese larch dimensional lumber. For Chinese larch dimensional lumber, the compressive design values of grade Ic, IIc, IIIc and IVc were 22.9, 18.3, 14.6 and 13.8 MPa, respectively.

Keywords Compressive design value · Dimensional lumber · Full size · Reliability analysis

Introduction

With the increasing demands on green building, wood or wood composite has became a common construction material owing to its environment friendliness, sustainability. In past 20 years, modern wood structures have been rapidly developed in China, especially for light wood structure [1]. Dimensional lumber as a main material is thus widely used in wood structures, which needs a great deal of import from foreign countries [2]. On the other hand, Chinese government and some research institutions have began to manufacture the dimensional lumber used from China's own tree species [3, 4].

Chinese larch (*Larix gmelinii*), comprised 55% of the wooded areas and 75% of forest stocks in China's frigid temperate zone, is an abundant wood resource and can be used to manufacture fabricate dimensional lumber, glued lumber, and wood-based composites owing to its excellent mechanical properties [5].

To utilize Chinese larch as dimensional lumber and to promote development of Chinese light wood structure, a lot of research works have been conducted [6–15]. The effects of testing methods [6], visual grades [7–10] and dimension size [11, 12] on mechanical properties of Chinese larch dimensional lumber were investigated as well as relationships between different mechanical properties. Jiang et al. [13] and Zhao et al. [14] analyzed the characteristic values of strength by nonparametric and parametric methods. The probability distribution of compression strength for different dimension sizes was also investigated with different probability distribution models [15]. However, due to lack of sufficient research on the mechanical properties of Chinese larch dimensional lumber, there is no specified determination method of strength design value which is an important strength index in practical engineering design and should be determined by a reasonable method [16].

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Hence, for the safety design and rational application of Chinese dimensional lumber as a green building material in building structures, the objective of this study was to develop a determination method of compressive design value for dimensional lumber.

Materials and methods

Materials

Larch, collected from the Cuigang and Pangu forest farms of Heilongjiang province, China, was selected as test raw materials. The logs with a diameter range of 160–340 mm and an average tree age of 35 years were cut into 2 × 4 dimensional lumber samples. And the length of each sample was 4000 mm. The main grade reduction defects of Chinese larch dimensional lumber were wood knot, and waney edges and crack, as shown in Fig. 1. According to visual grading specifications in Chinese national code [17], these dimensional lumbers were divided into four different groups of visual grades, i.e., grades Ic, IIc, IIIc, and IVc, which can be equated to grades SS, No. 1, No. 2, and No. 3 in the NLGA standard [18].

The number of samples (NO), mean value (AVG), and coefficient of variation (COV) of density for each grade are shown in Table 1. Before compressive testing, all samples were conditioned at 20 °C and 65% relative humidity in a standard room, to arrive at the equilibrium moisture content. The measured average moisture content was 11.3% with a standard deviation of 1.11% [19].

Static testing method

Two specimens with a length of 350 mm were cut from each sample. One specimen contained the maximum grade reduction defect and another specimen contained the second maximum grade reduction defect according to Chinese national code GB/T 28,993 [20]. The static compressive tests were conducted with a load rate of 1 mm/min, as shown in Fig. 2. The UCS of each specimen was calculated as follows:

$$\mathrm{UCS} = F_{\max} / (bt) \tag{1}$$

where $F_{\max}$ is the maximum load (N); b is the width of specimen (mm); t is the thickness of specimen (mm). At last, smaller UCS of the above two specimens was considered as the final UCS of each sample.

It is well known that the moisture content of structural wood materials will directly affect its test strength value, and will also affect the subsequent determination of compressive design value [21]. Therefore, to unify the test strength value and compressive design value, each country often specifies a moisture content point as the reference point.

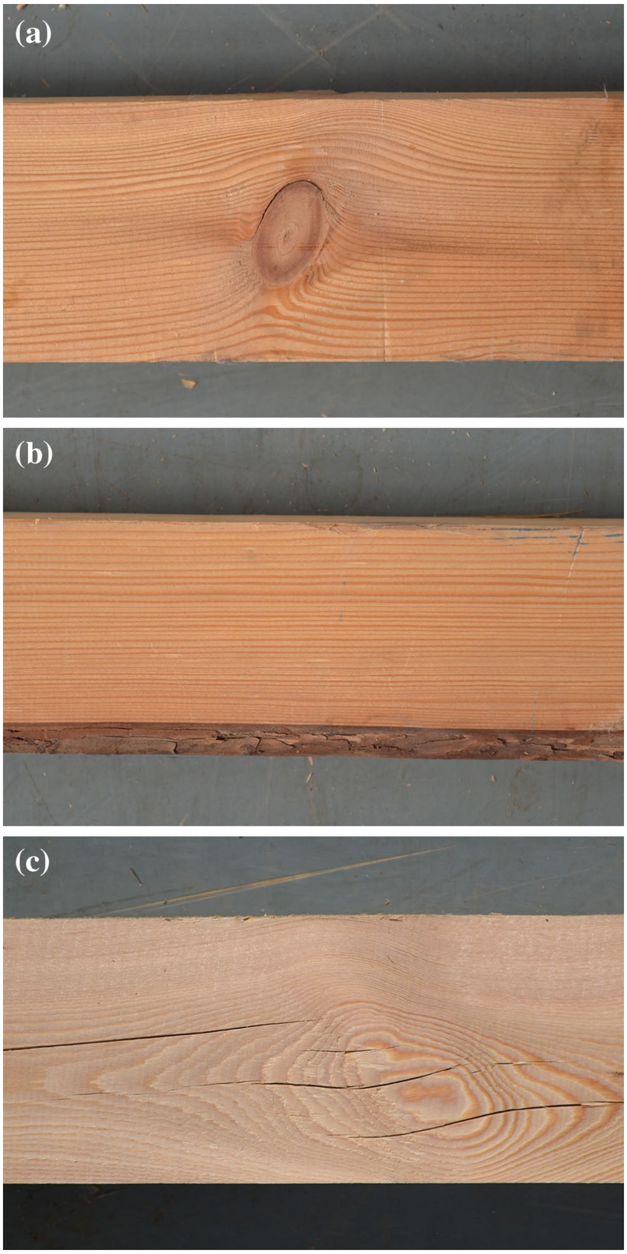

Fig. 1 Main grade reduction defects of Chinese larch dimensional lumber: **a** wood knot; **b** waney edges; **c** crack

Table 1 Number of sample and density of each grade dimensional lumber

Grade	No.	Density	
		AVG (kg/m^3)	COV (%)
Ic	418	647	10.9
IIc	207	649	11.0
IIIc	274	649	11.5
IVc	150	658	11.0

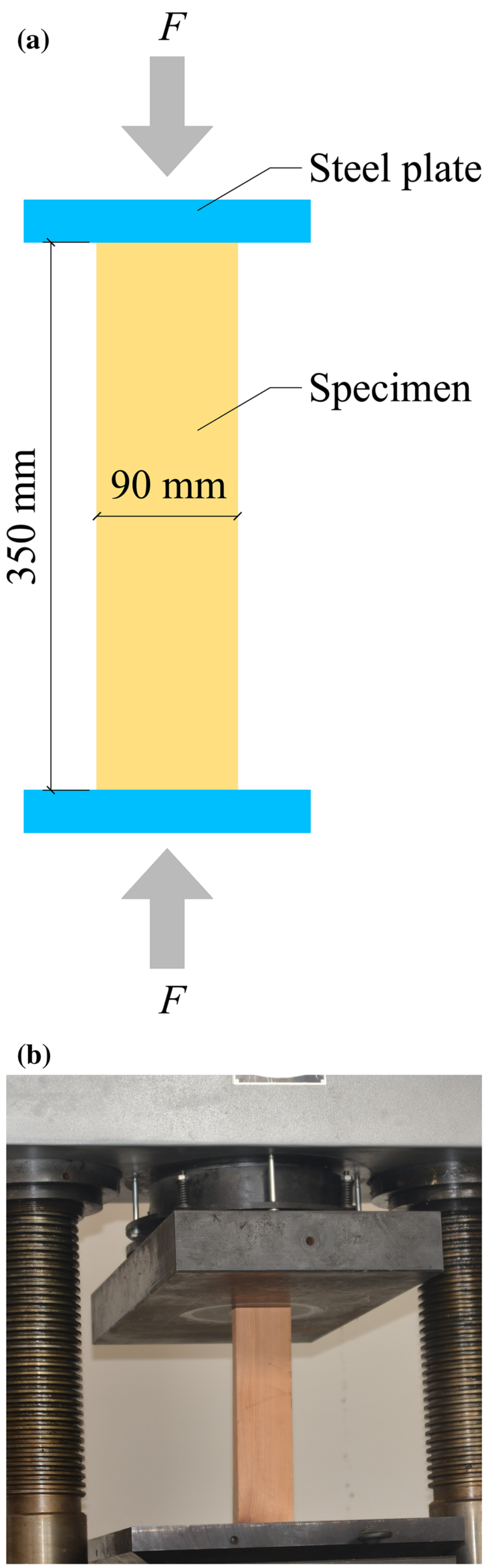

Fig. 2 Static compressive test on specimens: **a** schematic drawing; **b** photo

For example, 15% moisture content was selected as the reference point in United States and Canada [22, 23] while 12% moisture content in China [17]. According to the specified reference point, the dry moisture content for Chinese larch dimensional lumber was set to 12%, and the actual measured moisture content ranged from 9 to 17%. The UCS of each sample, adjusted to 12% MC (UCS_{12}) in accordance with ASTM D1990 [24], can be represented as follows:

$$\mathrm{UCS} = \begin{cases} \mathrm{UCS} & \mathrm{UCS} \leqslant 9.66\mathrm{MPa} \\ \mathrm{UCS} + (\mathrm{UCS} - 9.66) \times (M_1 - 12)/(34 - M_1) & \mathrm{UCS} > 9.66\mathrm{MPa} \end{cases} \tag{2}$$

where M_1 is the actual measured moisture content of sample (%).

Statistical analysis

Probability distribution model

In timber structure, three types of probability distribution model including normal, lognormal and 2-P-Weibull distribution are common used to fit the probability distribution of test UCS_{12}. The cumulative distribution function ($F_0(x)$) with different models could be expressed as follows:

$$\text{Normal: } F_0(x) = \frac{1}{\sqrt{2\pi\sigma}} \int_{-\infty}^{x} e^{-\frac{(t-\mu)^2}{2\sigma^2}}\,\mathrm{d}t \tag{3}$$

$$\text{Lognormal: } F_0(x) = \frac{1}{\sqrt{2\pi\sigma}} \int_{-\infty}^{x} \frac{1}{t} \mathrm{e}^{-\frac{(\ln(t)-\mu)^2}{2\sigma^2}}\,\mathrm{d}\,t \tag{4}$$

$$\text{2-P-Weibull: } F_0(x) = 1 - \mathrm{e}^{-(x/\lambda)^k} \tag{5}$$

where x is a random variable of UCS_{12} obtained by static compressive tests; μ and σ are the statistical parameters of mean value and standard deviation; λ and k are the scale parameter and shape parameter, respectively. These unknown parameters μ, σ, λ and k used in different probability distribution models were determined by the least square method.

Besides, the fitting rear-end probability distribution of UCS_{12} had a great influence on the calculation of compressive design value, as reported by Foschi et al. [25]. If all test data points (100%) were used to fit directly, the rear-end probability of UCS_{12} fitted by different probability distribution models may differ from the test value. Especially when the test data points are less, this difference between them may be more pronounced [25]. To reduce this difference and to accurately predict the rear-end probability of UCS_{12}, only the first part (75, 50, 25, and 15%) from all test data points which were sorted in ascending order was used to fit, as shown in Fig. 3.

One-way analysis of variance (ANOVA)

The differences in UCS_{12} between different grades were analyzed by one-way analysis of variance (ANOVA); multiple comparisons for different grades were calculated by the least significant difference (LSD) method using SPSS 19.0 (IBM SPSS Corporation, Chicago, USA). Significance level was set to 0.05.

Reliability analysis

In classical determination method, uncertainties are not considered. However, the resistance and bearing loads are randomness [16, 26]. In view of reliability analysis concepts, it is important to determine the statistical parameters of random variables and limit states. Random variables give the uncertainty and are defined by described probability distribution model and statistical distribution parameters. Limit state function defines a failure event for determining the corresponding failure probability.

Resistance variables

For determining the resistance, statistical parameters of short-term compression strength uncertainty are needed first to be investigated and would be determined by following analysis. The statistical parameters of geometric dimension uncertainty, calculation model uncertainty and the uncertainty of long-term load effect are summarized in Table 2 according to Chinese national standards [17].

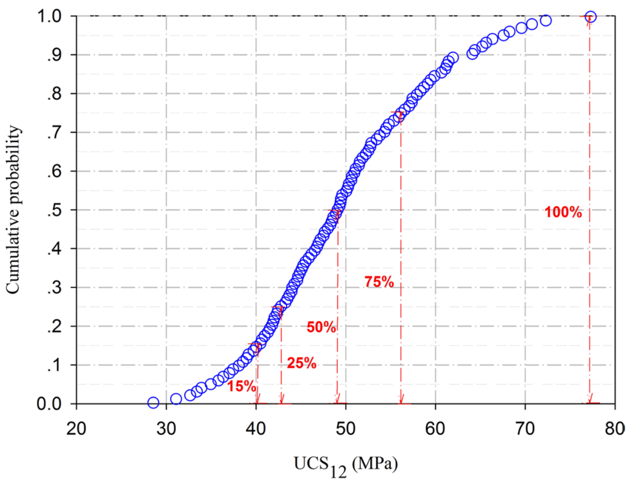

Fig. 3 Fitted by different test data points for three types of probability distribution models

Table 2 Resistance random variables parameters [17]

Random variables	Distribution	AVG	COV (%)
Geometric dimensions (K_A)	Normal	1.00	5
Equation precision of resistance (K_P)	Normal	1.00	5
Long-term loading effect (K_Q)	Normal	0.72	12

Load random variables

As specified by Chinese national standards [17, 27], five types of load including the dead load (*D*), residential occupancy load (*R*), official occupancy load (*O*), snow load (*S*) and wind load (*W*) were considered in reliability analysis. Random variables of load are summarized in Table 3, with the probability distribution model and statistical distribution parameters.

Analysis method

According to reliability design requirements [28, 29], the limit state equation for structural members, i.e., the performance function, could be expressed as follows:

$$G = R - (D + L) \tag{6}$$

where *R, D*, and *L* are random variables representing the resistance, dead load (*D*), and live load (*R, O, W*, or *S*), respectively.

For dimensional lumber as a compression member [16], the performance function could be converted to Eq. 7, as follows:

$$G = f_s K_A K_P K_Q - \frac{f_k k_D (d + \rho l) K_B}{\gamma_R \left(\gamma_D + \rho \psi \gamma_L \right)} \tag{7}$$

where f_s is a random variable and represents the short-term UCS_{12} whose AVG and COV with different probability distribution models would be determined by the least square method; K_A, K_P, K_Q and K_B are also random variables, their statistical parameters in Tables 2 and 3; *d, l* are random

Table 3 Load random variables parameters [17, 27]

Random variables	Distribution	Nominal AVG	Cov (%)
Dead load (*D*)	Normal	1.06	7
Residential occupancy load (*R*)	Extreme-I	0.644	23.3
Official occupancy load (*O*)	Extreme-I	0.524	28.8
Snow load (*S*)	Extreme-I	1.04	22
Wind load (*W*)	Extreme-I	1.00	19
Uncertainty of the load effect (K_B)	Normal	1.00	5

variables and represent the nominal dead load (D/D_K) and live load (L/L_K), their statistical parameters in Table 3; K_D is a constant value for the adjust factor of long-term load and is equal to the mean value of random variable K_Q; f_k is the characteristic value of UCS_{12} and is a constant value; ρ is the ratio of characteristic value of live load to that of dead load (L_K/D_K) and is a constant variable; γ_D and γ_L are the partial factor for dead load and live load, and are constant value; Ψ is the load combination factor and is a constant value.

In reliability analysis, four types of load combination were considered, including constant load plus residential occupancy live load ($D+R$), constant load plus official occupancy live load ($D+O$), constant load plus snow live load ($D+S$), and constant load plus wind live load ($D+W$). And seven kinds of load ratio were considered, including $\rho=0$, 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, where $\rho=0$, said the constant load acting alone. The values of γ_D, γ_L and Ψ were specified in Chinese national standard GB 50,009-2012 [27]. The structural safety level was specified as grade two and the design life was specified as 50 years. Therefore, the target reliability β_0 should be 3.2 for compression test where a ductile failure happened.

The first-order second-moment method was used and performed for all data cells and simulation load cases in reliability analysis, and its calculation program was compiled based on the Matlab 7 software (MathWorks Corporation, Massachusetts Natick, USA). The effects of the fitting data points, probability distribution model, load combination and load ratio on the reliability index (β) were investigated.

Results and discussion

Results of static compressive test

The statistical parameters of the adjusted compression strength (UCS_{12}) of each grade dimensional lumber calculated by Eq. 2 are shown in Table 4, including the number of samples (NO), mean value (AVG), and coefficient of variation (COV). It could be found that the adjusted value (UCS_{12}) is slightly lower than the un-adjusted value (UCS), and there was no significant difference between them.

Table 4 Statistical parameters of compression strength for different grades

Grade	No.	Un-adjusted value (UCS)		Adjusted value (UCS_{12})	
		AVG (MPa)	COV (%)	AVG (MPa)	COV (%)
Ic	418	49.555a	19.5	49.841a	19.3
IIc	207	38.282b	17.0	38.386b	17.1
IIIc	274	41.401b	24.8	40.956b	24.7
IVc	150	39.608b	28.8	39.000b	28.5

Furthermore, the UCS_{12} AVG comparisons between different grades are also shown in Table 4 by one-way anova method. Results indicated that the UCS_{12} AVG of grade Ic was significantly higher than that of grades IIc, IIIc and IVc ($p<0.01$); however, there was no significant difference between the UCS_{12} AVG of grades IIc, IIIc and IVc ($p>0.05$). This was mainly due to the fact that the main grade reduction defect for grade IIc was wood knot, accounts for 90%, while that for grades IIIc and IVc was wood knot, crack or waney edges, each account for about 20–30%. And from the actual compression test, the wood knot could lead to a significant reduction in strength; however the crack and waney edges had less effect on strength. Because of the crack and waney edges, these pieces of dimensional lumber were downgraded to grade IIIc or IVc which may have a higher strength than grade IIc. The similar results also were reported for *Tsuga Canadensis* [14].

In practical engineering design, all structural materials, including dimensional lumber, should follow the principle that the strength design value of high grade should not be lower than that of low grade [17]. In view of the fact that the UCS_{12} AVG of grade IIc was slight lower than that of grade IIIc and IVc (Table 4), it was necessary to modify the UCS_{12} data of grades IIc, IIIc and IVc if the final determined compressive design value was contrary to this principle requirement. And it is well known that in reliability analysis, the determined strength design value depends not only on the mean value, but also on the coefficient of variation, rear-end probability distribution, and so on [16, 26]. Therefore, the UCS_{12} data were not modified at last, because the coefficient of variation of UCS_{12} was significantly increased with the grade from IIc to IVc, 17.1, 24.7 and 28.5% (Table 4), respectively.

Probability distribution

Histograms of UCS_{12} of each grade are shown in Fig. 4. The unknown parameters μ and σ used in normal, lognormal and 2-P-Weibull distribution models (Eqs. 3–5) were determined by the least square method. The fitting results are shown in Table 5. Based on the fitting parameters, the predicted and actual test cumulative probability distribution curves were plotted. To compare the differences between the predicted and actual test cumulative probability, the curves of grade Ic was given as an illustrative example, as shown in Fig. 5.

From Fig. 5, it could be found that the fitting data points and probability distribution model had significant effects on the fitting results. For grade Ic, when 100% test data points were used to fit, the UCS_{12} at the rear-end probability ($P<0.2$) fitted by normal and 2-P-Weibull probability distribution was lower than that the test value, while that fitted by lognormal probability distribution was close to the test value. With the decrease of fitting data points from 100

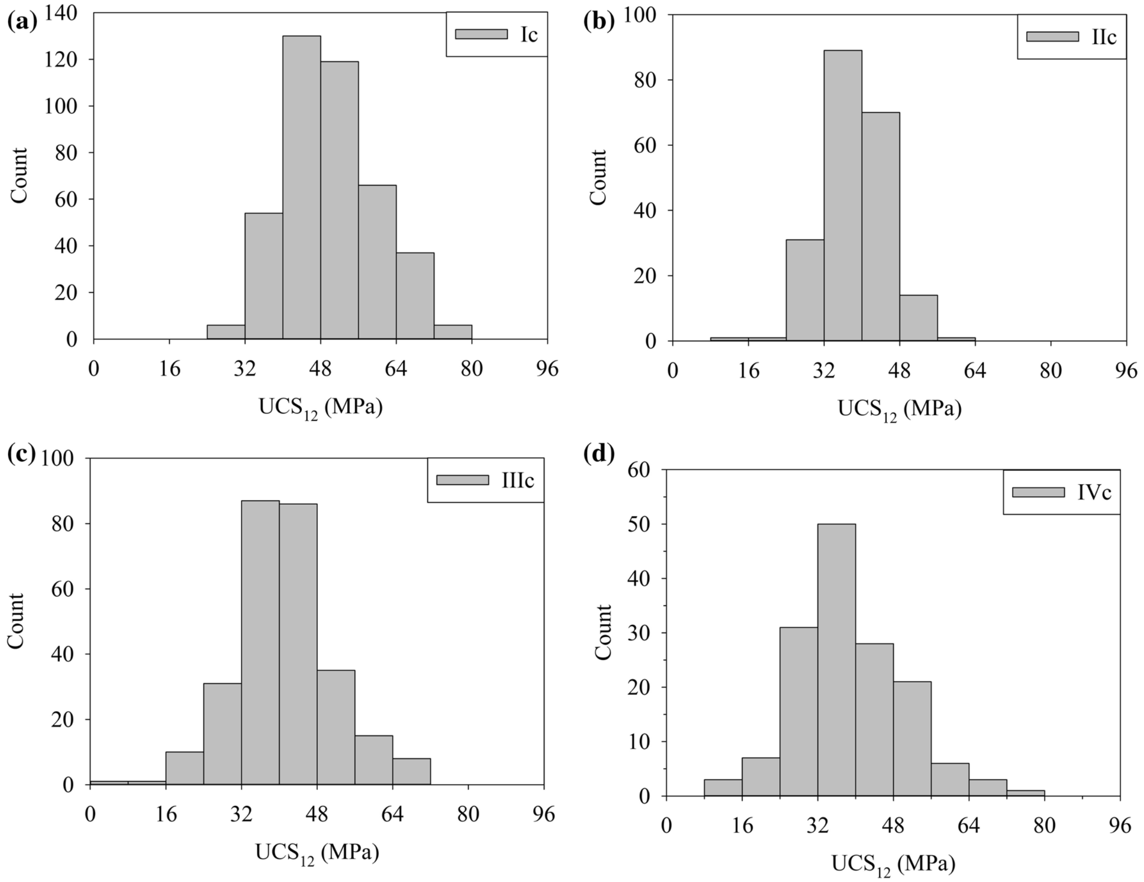

Fig. 4 Histograms of UCS$_{12}$ of different grades: **a** Ic; **b** IIc; **c** IIIc; **d** IVc

Table 5 Characteristic values and fitting results of UCS$_{12}$ of different grades

Grades	f_k/MPa	Model	Fitting AVG/MPa					Fitting COV/%				
			100%	75%	50%	25%	15%	100%	75%	50%	25%	15%
Ic	34.4	Normal	49.2	49.0	48.8	48.1	48.8	19.5	18.4	17.6	16.2	17.0
		Lognormal	49.9	49.8	50.0	50.2	52.2	19.8	19.5	20.0	20.2	22.8
		2-P-Weibull	48.8	48.5	48.0	46.6	46.9	20.0	18.1	16.4	13.5	13.9
IIc	26.3	Normal	38.3	38.3	38.2	38.3	39.9	16.5	16.8	16.4	16.2	18.6
		Lognormal	38.6	38.8	39.0	39.9	43.7	16.7	17.7	18.4	20.0	26.2
		2-P-Weibull	37.9	37.9	37.6	37.1	38.2	16.8	16.5	15.2	13.5	15.2
IIIc	23.1	Normal	40.5	40.5	40.4	41.9	42.2	22.7	22.1	21.7	24.3	24.7
		Lognormal	41.3	41.4	41.9	46.8	50.5	23.2	23.7	25.4	34.6	39.7
		2-P-Weibull	40.2	40.1	39.7	40.9	41.1	22.8	21.6	20.2	22.0	22.4
IVc	22.0	Normal	38.2	37.8	37.2	37.7	42.0	27.7	25.6	22.5	23.2	28.4
		Lognormal	39.1	39.0	38.8	41.7	54.1	28.1	27.6	26.5	32.5	49.5
		2-P-Weibull	38.0	37.6	36.7	36.7	41.9	27.8	25.4	21.1	20.7	27.3

f_k represents the characteristic value of UCS$_{12}$; AVG represents the mean value of UCS$_{12}$; COV represents the coefficient of variation of UCS$_{12}$

to 15%, the UCS$_{12}$ of grade Ic at the rear-end probability fitted by different distribution models began to be the same. Besides, the fitting results indicated that the fitting AVG and COV with 15% data points for grade IVc were 54.1 MPa and 49.5%, and were seriously deviated from the test value (Table 5).

For all conditions with different fitting data points, the fitting results (Fig. 5) also indicated that the UCS$_{12}$ fitted

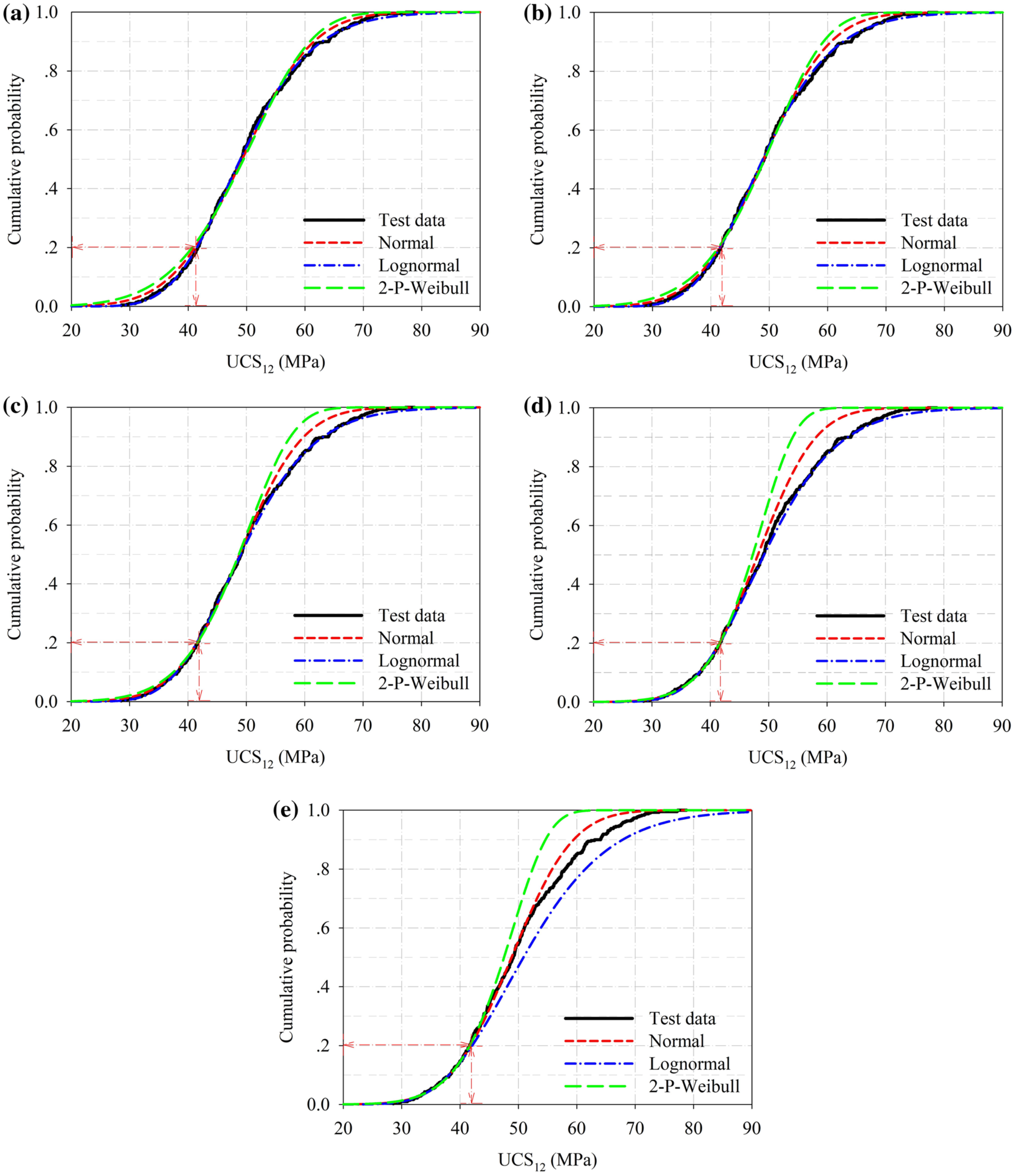

Fig. 5 Fitting results of UCS_{12} of grade Ic with different fitting data points: **a** 100% test data points; **b** 75% test data points; **c** 50% test data points; **d** 25% test data points; **e** 15% test data points

by lognormal probability distribution was higher than that by normal and 2-P-Weibull probability distribution, especially at the rear-end probability ($P < 0.2$) and the front-end probability ($0.8 < P < 1.0$). This could lead to the following calculated partial factor (γ_R) by lognormal probability distribution was higher than that by normal and 2-P-Weibull probability distribution, when at the same target reliability index ($\beta_0 = 3.2$).

The strength characteristic value is an important strength index, which reflects the characteristics of structural material itself [13, 16] and can be used to mark the strength level of material. For structural wood materials, the strength value corresponding to the 5% quantile value at 75% confidence is generally defined as the strength characteristic value [13, 16, 30]. The method used to determine the strength characteristic value mainly includes parametric and nonparametric method. For dimensional lumber produced by China itself, due to lack of sufficient basic data, there may be a large difference between the predicted probability value and the test value, especially in the rear-end probability section (Fig. 5), when using the parameter method (normal, lognormal or 2-P-Weibull) to infer its strength characteristic value. These factors may eventually lead to a large deviation between the predicted strength characteristic value and the true value. Therefore, in this study, the characteristic values of compression strength of Chinese larch dimensional lumber were determined by nonparametric method which was specified according to ASTM 2915-09 [30]. Based on the total number of samples of each grade dimensional lumber (Table 1), the order of tested data point which was used to determine the characteristic values of compression strength should be 18th for grades Ic, 8th for grade IIc, 11th for grade IIIc, and 6th for grade IVc, and the corresponding strength of the order of tested data point was 34.3 MPa for grades Ic, 26.3 MPa for grade IIc, 23.1 MPa for grade IIIc, and 22.0 MPa for grade IVc, respectively (Table 5).

Influencing factors of reliability index

The fitting data points and probability distribution model

The relationships between the reliability index (β) and resistance partial factor (γ_R) under different fitting data points and probability distribution models were similar for each grade dimensional lumber. Therefore, to investigate the effects of fitting data points and probability distribution models on the reliability index, relationship curves of β-γ_R of grade Ic under the load combination of $D+R$ at the load ratio of 1.0 was given as an illustrative example, as shown in Fig. 6.

It can be seen from Fig. 6 that when at the same resistance partial factor, the reliability index obtained by lognormal distribution is the largest, followed by normal distribution and 2-P-Weibull distribution is the smallest. This difference was most obvious when the fitting AVG and COV with 100% test data points (Table 5) were selected for reliability analysis, as shown in Fig. 6a. This was mainly due to that the UCS_{12} at the rear-end probability fitted by normal and 2-P-Weibull distribution is significantly lower than the test value, and that fitted by lognormal distribution is closer to the test value (Fig. 5a). However, with the reduction of fitting data points from 100 to 15%, the reliability indexes calculated by different probability distributions began to converge. In the case of reliability analysis using 25% or 15% test data points (Fig. 6d, e), when the reliability index β was less than the target reliability index ($\beta_0=3.2$), the reliability indexes calculated by three different probability distributions were basically the same. This was mainly attributed to that the UCS_{12} at the rear-end probability fitted by different probability distributions began to be consistent (Fig. 5d, e).

Which kind of fitting data points and probability distribution model should be adopted for determining the compressive design value of dimensional lumber? In Canadian national code [25], the reliability analysis results indicated that the reliability indexes calculated by three different probability distributions using 15% test data points were basically the same, when the reliability index β was less than the target reliability index. Finally, the 2-P-Weibull distribution and 15% test data points were selected for determining the strength design value of dimensional lumber. However, the determination method of strength design value used in each country is different due to different national circumstances [16, 31].

For China, due to the fact that China has only begun to carry out the full-size test for Chinese dimensional lumber in last 15 years, the accumulated data are relatively small. This may lead to a big difference between the predicted probability value and the actual test value, which could directly affect the final determined reliability index and design value. Furthermore, compressive test for dimensional lumber belongs to ductile failure, and the corresponding target reliability index (β_0) for this is thus specified to 3.2 according to Chinese national standard [28, 29]. When using 25% or 15% test data points, the reliability indexes calculated by three probability distributions are basically the same (Fig. 6d, e). However, the fitting AVG and COV with 15% test data points for grade IVc Chinese larch dimensional lumber seriously deviate from the test value, as shown in Table 5. Therefore, considering the economic rationality and the experience accumulated by predecessors, it was finally suggested that the lognormal distribution and 25% test data points be selected for determining the compressive design value of Chinese larch dimensional lumber.

The load combination and load ratio

According to the above analysis, the lognormal distribution and 25% test data points were selected for reliability analysis, and were used to investigate the relationships between the reliability index (β) and resistance partial factor (γ_R) under different load combinations ($D+R$, $D+L$, $D+S$, $D+W$) and load ratios ($\rho=0.0$, 0.25, 0.5, 1.0, 2.0, 3.0, 4.0). Because the laws of β-γ_R curves were similar for each grade, the grade Ic dimensional lumber was given as an illustrative example, as shown in Fig. 7.

It could be seen from Fig. 7 that when at the same resistance partial factor, the reliability index non-linearly increased with the increase of load ratio for the case of $D+R$ and $D+O$ load combinations, however, the reliability index changes little for the $D+S$ and $D+W$ load combinations, which was mainly affected by the statistical value of the live load and constant load [16].

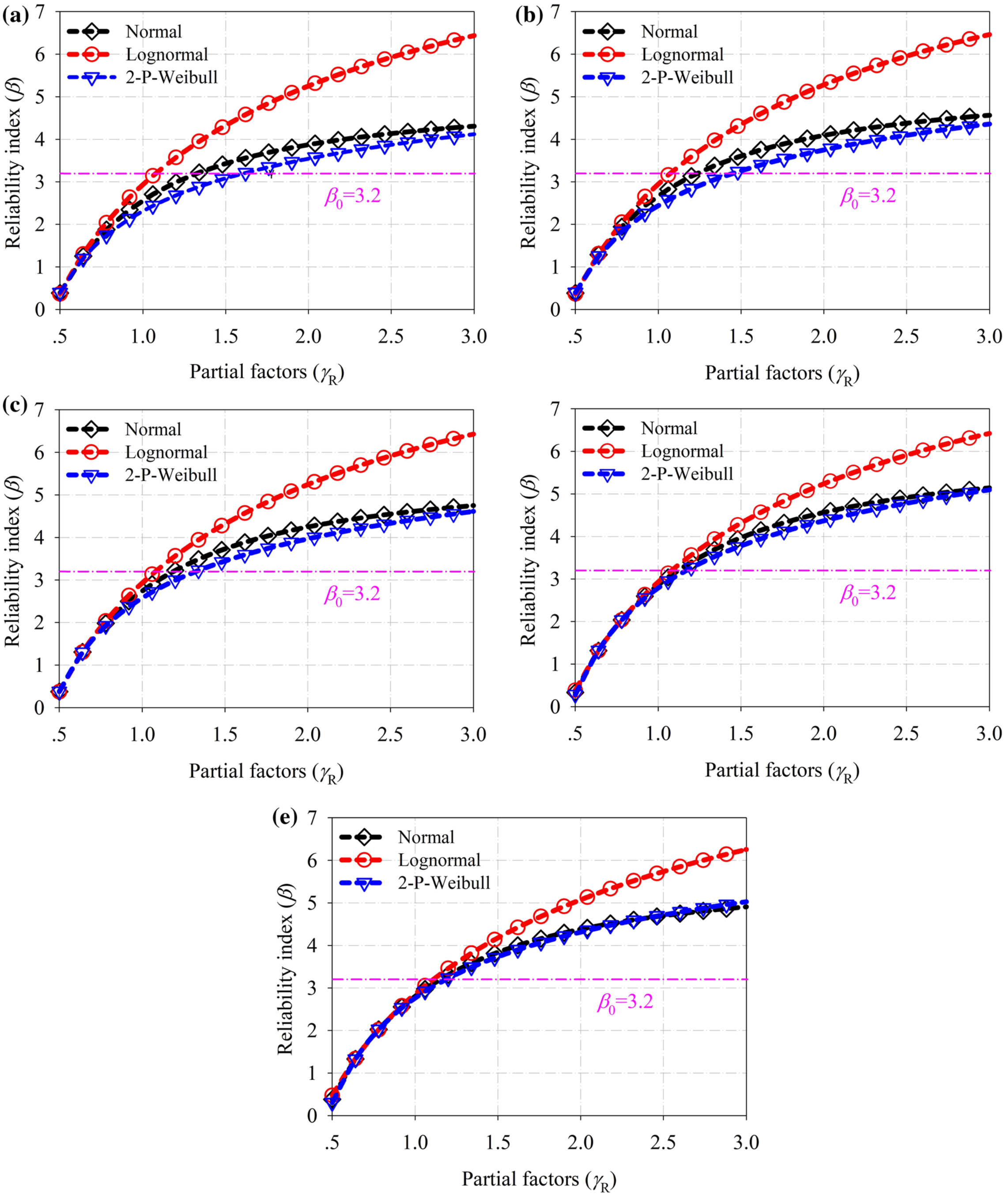

Fig. 6 The β-γ_R relation of grade Ic dimensional lumber under the load combination $D+R$ and the load ratio $\rho=1.0$ with different type distributions and different fitting data points: **a** 100% test data points; **b** 75% test data points; **c** 50% test data points; **d** 25% test data points; **e** 15% test data points

Table 6 shows the corresponding resistance partial factor when the calculated reliability index arrived at the specified target reliability index ($\beta_0=3.2$). For different grades of dimensional lumber, there were similar results for the resistance partial factor under different load combinations. When the load ratio was less than 0.25, i.e., the load combination was controlled by the dead load (D), the resistance partial factor under the $D+W$ load combination was the largest, and that under the $D+O$ load combination was the smallest. While when the load ratio was more than 0.25, i.e., the load combination was controlled by the live load, the resistance partial factor under the $D+S$ load combination was the largest, and that under the $D+O$ load combination was still the smallest.

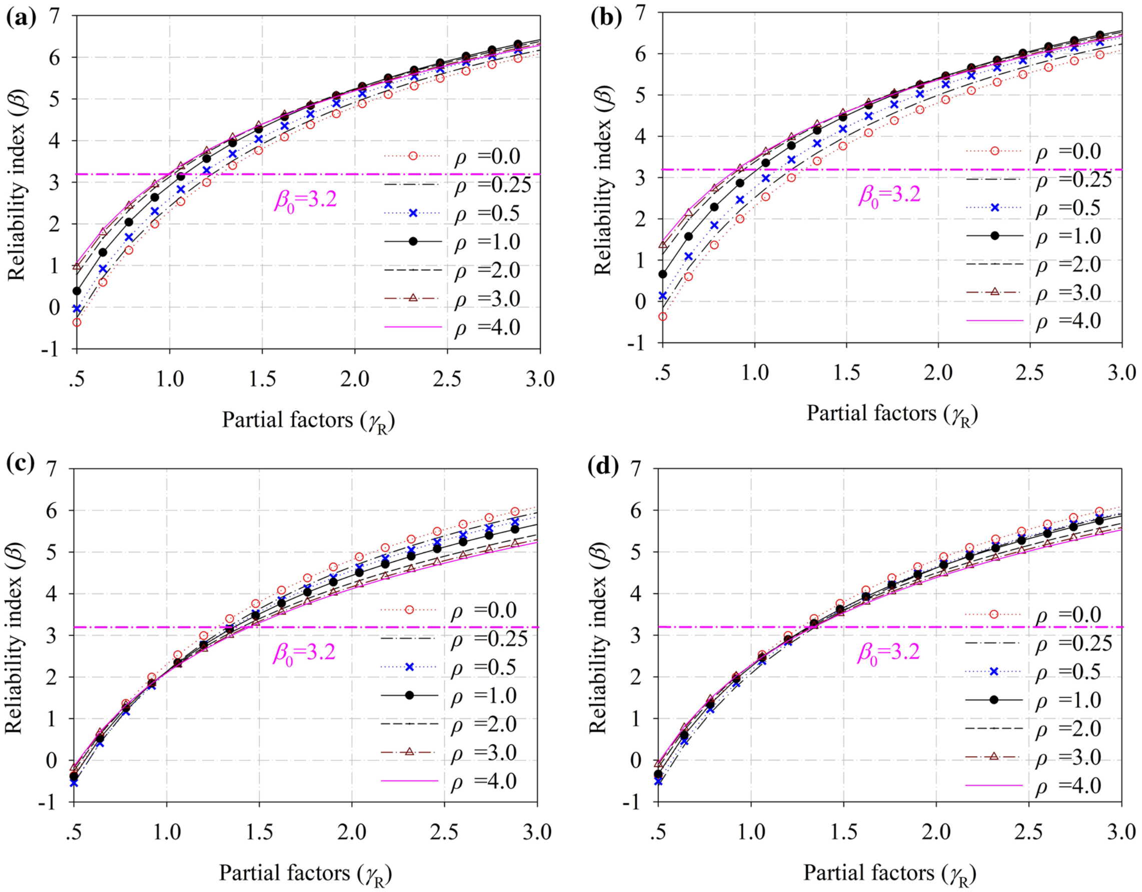

Fig. 7 The β-γ_R relation of grade Ic dimensional lumber under different load combinations and load ratios: **a** $D+R$; **b** $D+O$; **c** $D+S$; **d** $D+W$

Table 6 Partial factors for different grades of dimensional lumber under different load combinations and ratios

Grade	Load combination	Load ratios						
		0.0	0.25	0.5	1.0	2.0	3.0	4.0
Ic	$D+R$	1.270	1.228	1.172	1.080	1.018	1.000	0.990
	$D+O$	1.270	1.200	1.124	1.014	0.940	0.914	0.902
	$D+S$	1.270	1.330	1.352	1.364	1.404	1.430	1.446
	$D+W$	1.270	1.346	1.324	1.308	1.318	1.330	1.340
IIc	$D+R$	1.216	1.176	1.122	1.034	0.976	0.956	0.948
	$D+O$	1.216	1.150	1.076	0.970	0.900	0.876	0.864
	$D+S$	1.216	1.274	1.294	1.306	1.344	1.370	1.386
	$D+W$	1.216	1.290	1.268	1.252	1.262	1.274	1.282
IIIc	$D+R$	1.356	1.314	1.250	1.140	1.054	1.020	1.002
	$D+O$	1.356	1.284	1.198	1.066	0.962	0.924	0.902
	$D+S$	1.356	1.420	1.436	1.424	1.436	1.448	1.458
	$D+W$	1.356	1.440	1.410	1.378	1.366	1.366	1.368
IVc	$D+R$	1.366	1.324	1.258	1.148	1.064	1.032	1.014
	$D+O$	1.366	1.292	1.206	1.076	0.974	0.934	0.916
	$D+S$	1.366	1.430	1.446	1.438	1.452	1.466	1.478
	$D+W$	1.366	1.450	1.420	1.390	1.380	1.380	1.384

Table 7 Compressive design value for different grades of dimensional lumber

Tree species of dimensional lumber	f_d/MPa			
	Ic	IIc	IIIc	IVc
Chinese larch	22.943	18.294	14.577	13.769
Spruce–Pine–Fir (SPF)	17.25	13.8	13.8	8.05

Besides, it could be seen from Table 6 that the resistance partial factor increased gradually from IIc to IVc at the same load combination and load ratio except for grade Ic, which was consistent with the coefficient of variation of different grades of dimensional lumber (COV: IIc < Ic < IIIc < IVc) shown in Table 4. The higher the coefficient of variation was, the greater the resistance partial factor was.

Design value of compression strength

According to the target reliability requirement by limit state design method, the design value of structural wood materials could be calculated as [16, 17]:

$$f_d = f_k K_D / \gamma_R \tag{8}$$

where f_d is the compressive design value; f_k is the characteristic value of UCS_{12} (Table 5); K_D is the adjust factor for long loading effect and is specified to be 0.72 based on Chinese national standard GB 50,005-2003 [17]; γ_R is the resistance partial factor shown in Table 6.

The compressive design value should be a fixed value for each grade dimensional lumber. Therefore, it should be first determined which kind of load combination and load ratio to choose for determining the compressive design value. From the above analysis results in Table 6, it was the most conservative method that the load combination of $D+R$ was selected when the load ratio was no greater than 0.25 while the load combination of $D+S$ was selected when the load ratio was more than 0.25. But this method is too conservative to make full use of material and is lack of economic rationality. Therefore, it was finally suggested that the load combination of $D+R$ and the load ratio of 1.0 be selected to determine the compressive design value for Chinese dimensional lumber, just as mentioned by Zhu et al. [16].

According to the above determination method, the compressive design value of each grade was calculated by Eq. 8. Compared with common imported 2 × 4 Spruce-Pine-Fir (SPF) dimensional lumber for China, the compressive design value of Chinese larch dimensional lumber was higher for each grade, as shown in Table 7. Furthermore, the final determined compressive design values of grade Ic, IIc, IIIc, IVc of 2 × 4 dimensional lumber were 22.9, 18.3, 14.6 and 13.8 MPa, and met the principle requirements that the strength design value of the high grade should not be lower than the low grade [17].

Conclusions

To utilize the Chinese larch as dimensional lumber and to promote the development of Chinese light wood structure, a determination method of compressive design value for dimensional lumber was developed. Based on the analysis results, this study suggested that the lognormal distribution, the 25% data points, the load combination of dead load plus residential live load, and the load ratio of 1.0 be selected for the determination of compressive design value. For Chinese larch dimensional lumber, the compressive design values of grades Ic, IIc, IIIc and IVc of 2 × 4 dimensional lumber were 22.9, 18.3, 14.6 and 13.8 MPa, respectively.

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