Strength grading of structural timber

Fortuna, Barbara; Plos, Mitja; Šuligoj, Tamara; Turk, Goran

UDRUGA HRVATSKIH GRAĐEVINSKIH FAKULTETA

FAKULTET GRAĐEVINARSTVA, ARHITEKTURE I GEODEZIJE

Z 2018 T

DOI: https://doi.org/10.31534/CO/ZT.2018.09

Strength grading of structural timber

Barbara Fortuna[1], Mitja Plos[1], Tamara Šuligoj[1], Goran Turk[1]

(1) University of Ljubljana, Faculty of Civil and Geodetic Engineering, Slovenia, {barbara.fortuna; mitja.plos; tamara.suligoj; goran.turk}@fgg.uni-lj.si

Abstract

All timber used for construction in the EU has to be strength graded and CE marked. To grade a piece of timber we can use visual or machine grading. The procedure to obtain and approve the settings for a new machine or visual standard is described. The approval is restricted to wood species, size of specimen and source of origin. A comparison of visual and machine grading is based on the German DIN 4074-1 visual grading standard and the Slovenian STIG grading machine for Slovenian spruce. The results show that machine grading is a better option, since we can grade to higher strength grades and the number of pieces in a grade is higher. Also, machine grading is faster, easier to implement and more reliable. Machine grading operates in multiple grading combinations, whereas visual grading usually has only one grade combination. To produce the highest grade glulam, machine grading is needed.

Keywords: strength grading, visual grading, machine grading, timber

Ocjena čvrstoće drvene građe

Sažetak

Sva drvena građa koja se koristi za konstrukcije u EU-u mora biti ocijenjena po čvrstoći te markirana CE oznakom. Ocjena čvrstoće može se provoditi vizualno ili strojno. U radu je opisana procedura za novi standard vizualnog i strojnog ispitivanja. Svaka procedura limitirana je na određenu vrstu drva, dimenzije i izvor građe. Dana je usporedba vizualnog ocjenjivanja građe prema njemačkom standardu DIN 4074-1 i strojnog ocjenjivanja građe koristeći uređaj STIG za slovensku smreku. Prema prikazanim rezultatima, strojno ocjenjivanje je bolje jer je brže, ima veći kapacitet, može ocijeniti drvenu građu bolje kvalitete te je pouzdanije. Vizualno ocjenjivanje, pored drugih nedostataka, vezano je uz jednu konfiguraciju ocjenjivanja dok strojno može obavljati ocjenjivanje u višestrukim kombinacijama. Pouzdano ocjenjivanje drvene građe visoke kvalitete iznimno je važno za zahtjevne drvene konstrukcije, posebice lijepljene lamelirane drvene nosače.

Ključne riječi: ocjenjivanje čvrstoće, vizualno ocjenjivanje, strojno ocjenjivanje, drvena građa

1. Introduction

All products, used in construction in the European member states, have to be marked with CE marking. Affixing the mark, a manufacturer with the declaration of conformity takes over the responsibility for the conformity of the product with its declared performance [1] and that the product complies with the harmonized standards and therefore meets the essential requirements of the European Council's Regulation for construction products [2]. Strength grading of structural timber is regulated with a set of harmonised standards EN 14081 [3, 4] for timber with a rectangular cross-section. Timber is sorted based on its mechanical properties, i.e. strength, stiffness and density into strength grades or strength classes. Despite the name, strength grading is not always governed by the strength itself since stiffness and density are also the grade determining properties [5]. The objective of this paper is a presentation of some basic terms and procedures that are directly connected with strength grading of timber.

2. Strength grade

The European standard EN 338 Structural timber – Strength Classes defines strength grades or strength classes as groups of specimens/elements of the same species and sources with similar strength properties. Strength properties are described with three grade-determining properties: strength (*MOR*), modulus of elasticity (*MOE*) and density (ρ). In order to assign specimens to a specific strength grade, the characteristic values of the three grade determining properties (GDP) have to meet the requirements, that is a 5th percentile value for *MOR* and ρ and a mean value for *MOE*.
Strength grades are defined for bending strength tests for softwoods (C-grades) and hardwoods (D-grades) and tension strength classes for softwood (T-grades). Classes are designed so that they fit well to the property profiles of most common species [5].
The methods of strength grading of structural timber with rectangular cross-section are defined by the set of EN 14081 and supporting standards. The standard gives two options, visual and machine grading. For both, the assignments to strength grades can be made on the basis of comprehensive testing and analysis. Before use, the results need to be presented for confirmation in a grading report and approved by Task Group 1 (TG1) of the European standardization committee (CEN/TC 124/WG2/TG1).
When determining a grade, one cannot just take a piece of timber and non-destructively, or destructively for that matter, determine the board's strength grade [6]. To determine, for example, the 5 % value at least 20 pieces in each grade are needed. Moreover, if we take a sample of timber boards and try to determine their grades, another problem appears. Namely, the question about the grade combination that we want to use to allocate the pieces. As an example, we took 1020 boards and optimally graded them to a grade combination with a single grade (C24) and to a grade combination with two grades (C40 and C24). As we can see in Table 1, the number of pieces that were allocated to C24 grade are not the same. Even if we sum the number of the boards in C40 and C24 for the latter combination, we only get 890 boards in grade C24 or higher. Whereas if we take the first

combination with only one (C24) grade, we get 999 boards in grade C24 or higher. These differences are due to the statistical definition of timber grades and need to be understood and considered.

Table 1. Allocation of boards to optimum grades in cases of two different grade combinations, only C24 and C24 - C40.

Optimum grading		Grade combination	
		C24	C40 - C24
Number of boards in a grade	C40	0	550
	C24	999	340
	Reject	21	130
	Total	1020	1020

3. Strength grading

Visual grading is the basic method of strength grading. Structural timber has to be visually inspected and specified visual parameters have to be evaluated according to the valid grading rules, defined by a validated national standard. When visually grading, we measure the physical anomalies in timber like knots, ring width, the slope of grain, pith, wane and so on. Visual standards give the maximum values of these characteristics for a certain grade. The number of grades into which one can grade is also predefined by the standards and has to be followed. Since visual grading can be very subjective, the highest grades from EN 338 are not represented in the standards, so one can only grade to the lower half of the grades [7]. In Slovenia there was no national standard, therefore DIN 4074-5 was used. The valid transformation from visual grades to the corresponding strength grade in the EN 338 are listed separately for softwoods and hardwoods in the EN 1912 standard, per species and source of timber.

Machine grading is a more advanced method of strength grading which should enable safer, more objective and more reliable strength grading. Timber is sorted by a machine measuring one or more physical timber properties. EN 14081 defines output and machine-controlled grading. In Europe, mostly machine-controlled grading is used. Recently, the first Slovenian strength grading machine was approved by TG1 for spruce and fir. For the derivation of the settings for a new machine, a sample with the minimum of 900 boards has to be tested. To obtain a representative sample, each board has to be sawn from a different log and at least four sub-samples of 100 boards have to be created. All the specimens have to be non-destructively tested and the indicating property (IP) has to be measured with the strength grading machine. The IP can be any physical characteristic measured by the machine. In our work we used a sound propagation machine from the Slovenian company ILKON d.o.o. called the STIG strength timber grading machine. The STIG uses the dynamic modulus of elasticity (E_{dyn}) as the IP. The machine determines the 1st eigen frequency from the measured audio signal of a hammer impact on the end of the specimen. After we concluded with the non-destructive measurements, the specimens were destructively tested. Bending

MOR, *MOE* and *ρ* were measured and calculated according to standards EN 408 and EN 384.

3.1. Derivation of the settings

The first step of the settings derivation is the selection of the grade combination into which the pieces will be sorted. It is not possible to uniquely determine the strength grade of a specific piece. The same piece can be graded into different grades, depending on the selected grade combination and on the properties of other pieces from the sample.
It is rather sensible to select such a grade combination that pieces are as evenly distributed as possible and selected grades are not too close to each other (e.g. C30 - C27).

3.1.1. Optimal grading

Before determining the final settings, optimal grading of the pieces must be carried out. Optimal grading is defined in EN 14081-2. Graded pieces are sorted, fulfilling the required values of the grade determining properties (GDP), into the highest possible grades within the selected grade combination. The so determined grade of a piece is its optimum grade.

3.1.2. Grade assignments

After the determination of optimum grades of the pieces, they need to be sorted into the assigned strength grade based on the IP determined by the machine. Pieces should be ranked by their IP and, based on the calculated characteristic values of GDPs, assigned to strength grades. The IP value of the last piece that fulfils the required GDP values is considered as the setting for that strength grade. As a result, each piece can be described with its optimum and assigned grade. In order to ensure sufficient safety of the strength grading, size and cost matrices have to be calculated for each grade combination. The values in the size matrices represent the numbers of correctly graded (assigned) pieces (on the diagonal), wrongly downgraded pieces (above the diagonal) and wrongly upgraded pieces (under the diagonal). The numbers of wrongly upgraded pieces are limited indirectly by the maximum value of 0,20 in the cells in the global cost matrices, which is formed on the basis of size matrix and prescribed penalties for wrongly assigned pieces.
The described procedure was made for the STIG strength timber grader on 1020 pieces of Slovenian spruce and fir (*Picea abies* and *Abies alba*). In order to get a representative sample for the whole of Slovenia, specimens were collected from four different growth areas with four different cross section (40 x 100 mm, 50 x 150 mm, 44 x 210 mm, 140 x 140 mm). The settings were derived for four different grade combinations.
Settings, timber source, species and cross-sectional dimensions for which settings can be used were presented in the report for approval in the ITT (Initial Type Testing) table. In Table 2, a section of the ITT is presented.
We can see that the settings or the limit values for a grade can change depending on the grade combination. If we look at the values for C24 we can see that the setting of the IP changes from 10300 when grading to solely C24 to 11200 when grading to C24 and C35. This is due to the fact that the pieces with the highest GDP are allocated to C35, which leaves us with lower quality pieces. From these low-quality pieces we need to exclude more

of the lowest quality pieces to achieve the required GDP criteria. This is illustrated in Figure 1 where the scatter plot of all the boards is displayed along with the two settings for C24 grade.

Table 2. Section of the ITT table for STIG Strength timber grading machine

Permitted timber size (mm)	Grade or grade combination	Settings (IP=E_{dyn})
$36 \leq t_n \leq 154$ mm $90 \leq b_n \leq 230$ mm	C40	15000
	C24	10700
	C35	13700
	C24	11200
	C30	12800
	C18	8870
	C24	10300

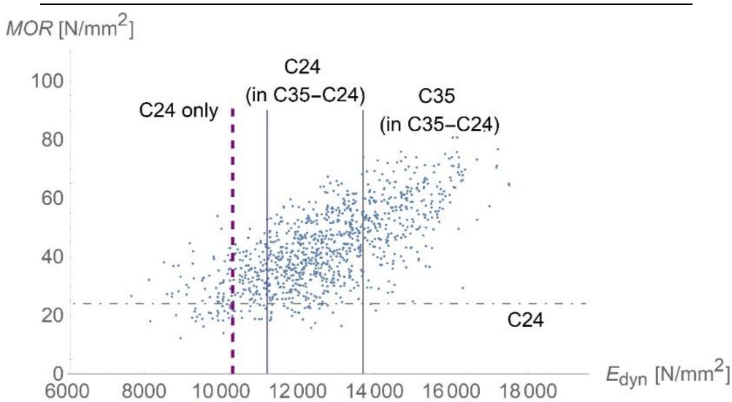

Figure 1. *MOR* and measured E_{dyn} of the 1020 spruce and fir boards with the STIG settings of the boards for the grade combination of solely grade C24 (dashed lines; left) and grade combination C35-C24 (solid lines; right).

The correlation between the IP of the STIG machine and the strength was around 0.7. That might not seem high, but if we make a comparison between the output of the STIG and the DIN 4074-1, which is presented in Table 3, we can see that machine grading is a much better option and that, although conservative, visual grading is also a viable option.

Since the most used grade is currently C24, we present at the efficiency of the two systems grading to this or higher grades. Visual grading is able to grade 68 % of the boards to C24 or higher, whereas machine grading delivers 81 % of the boards. If we look beyond C24, visual grading allocates 10 % to C30 and machine grading allocates 28 % to grade C35. On top of that, using the STIG we can even expect to allocate 10 % of the boards to C40. With C40 grade material, we can produce glulam beams with the highest strength grade (GL32).

Table 3. A comparison between the effectiveness of machine grading (STIG) and visual grading (DIN 4074-1) on spruce boards

Visual grading			Machine grading		
	Optimum grading	DIN 4074-1		Optimum grading	STIG
C30	86 %	10 %	C35	72 %	28 %
C24	3 %	58 %	C24	15 %	53 %
C18	8 %	15 %			
Reject	3 %	17 %	Reject	13 %	19 %

4. Conclusion

The strength grade of a piece of timber can be determined either through visual or machine grading. Both methods are adequate, but machine grading is more reliable, precise and can be used for grading into higher grades. It is worth mentioning that time needed to properly visual grade a single board exceeds several minutes, while machine grading is much faster.

Literature

[1] Regulation (EU) No 305/2011 of the European parliament and the council of the European Union, https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:088:0005:0043:EN:PDF, 12. 7. 2018.

[2] Council Directive 89/106/EEC Construction products (CPD) of 21 December 1988 on the approximation of laws, regulation and administrative provision of the Member States relating to the construction products, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31993L0068, 12. 7. 2018.

[3] EN 14081-1: Timber Structures. Strength graded structural timber with rectangular cross section. General requirements, Brussels, 2016.

[4] C 92/139: Commission communication in the framework of the implementation of Regultation (EU) No 305/2011, Official Journal of the European Union, 2018/C 092/06.

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=uriserv:OJ.C_.2018.092.01.0139.01.ENG, 12. 7. 2018

[5] Ridley-Ellis, D., Stapel, P., Baño, V.: Strength grading of sawn timber in Europe: and explanation for engineers and researchers. European journal of wood and wood products, 74(3), pp: 291-306, 2016, doi: 10.1007/s00107-016-1034-1.

[6] Stapel, P., Van de Kuilen, J.-W.: Effects of grading procedures on the scatter of characteristic values of European grown sawn timber. Materials and Structures, 46(9), pp: 1587-1598, 2013, doi: 10.1617/s11527-012-9999-7.

[7] Stapel, P., Van de Kuilen, J.-W.: Efficiency of visual strength grading of timber with respect to origin, species, cross section, and grading rules: a critical evaluation of the common standards. Holzforschung, 68(2), pp: 203-216, 2014, doi: 10.1515/hf-2013-0042.