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Impact of clause 5.3.2 in EN384:2010 on grading of timber

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1 Introduction

This report outlines the issues related to the application of clause 5.3.2 in EN384:2010 “Structural timber - Determination of characteristic values of mechanical properties and density” which is used in the development of new settings for machine strength grading.

The purpose of this clause is to make an adjustment of measured values of modulus of elasticity in bending (MoE) made over the full span of a four point bending test (referred to as global MoE in EN408, Figure 1) to a ‘shear free’ value comparable with a measurement of stiffness made on a portion of the span under pure bending (referred to as local MoE in EN408, Figure 2).

Global MoE was introduced in the 2003 revision of EN408, and is now the expected method of measurement for the purposes of developing grading settings.

The equation in clause 5.3.2 of EN384:2010 for calculation of shear free MOE (E_{EN384}) from global MoE (E_{global}) is:

$$E_{EN384} = 1.3 \times E_{global} - 2690 \qquad [\text{N/mm}^2] \qquad [1]$$

This empirical equation is based on the results of tests in which both local and global MoE measurements were made. It describes the equation of a one-way linear regression line of a scatter plot of local MoE (E_{local}) against global MoE.

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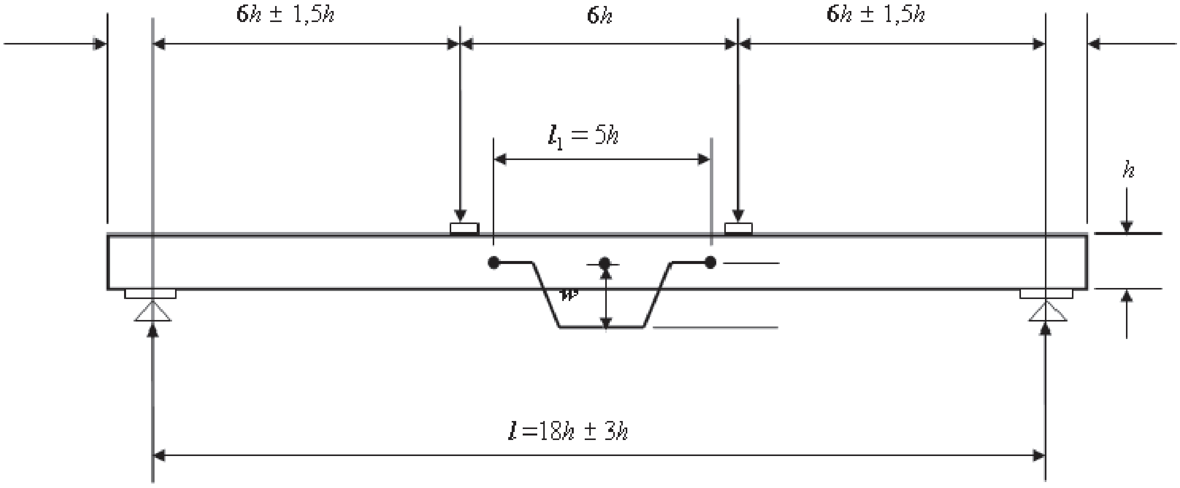

Figure 1: Test arrangement for measurement of local MoE (EN408:2003 Figure 1)

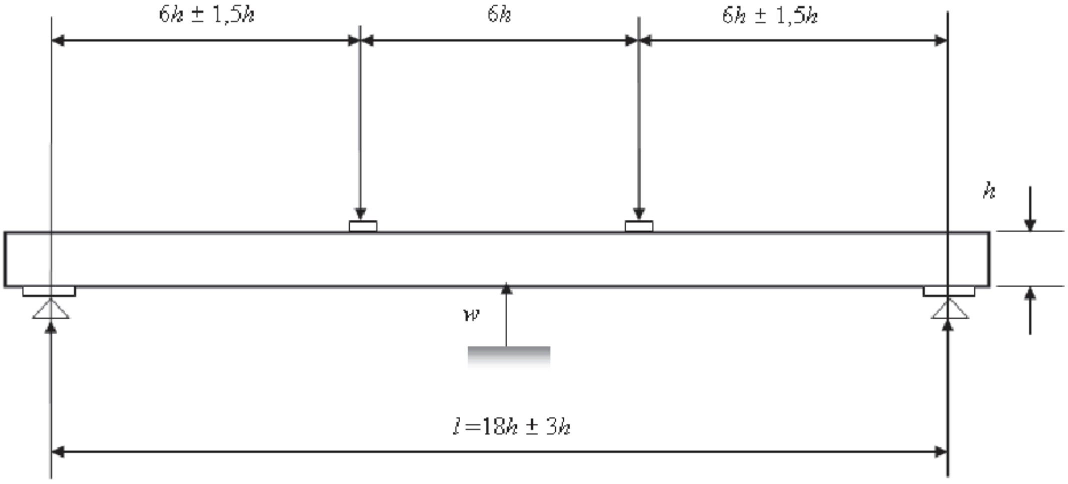

Figure 2: Test arrangement for measurement of global MoE (EN408:2003 Figure 3)

2 Issues with the approach

British spruce has relatively low MoE and will therefore be at the extreme end of the regression model that produced the adjustment equation presented in clause 5.3.2 of EN384:2010. As is to be expected with extrapolated empirical models, this equation becomes mechanically inconsistent for very low values of MoE. More importantly, the equation penalises lower stiffness timber (C14 and C16) which can have a significant impact on grading yields when the MoE is the governing grade determining property (as is the case with British spruce).

2.1 Limit of mechanical inconsistency

Below a global MoE of 2070 N/mm^2 the clause produces a negative shear free MoE, which is clearly an impossible situation. This is not, however, the limit of mechanical consistency for this equation.

Assuming perfect measurements, the deflection at the span centre of a beam with uniform modulus of elasticity, *E,* and shear modulus of *E*/16 tested in four-point loading to EN408:2010 with standard test geometry (shear span 6 times the depth) will arise from the sources summarised in Table 1.

Table 1. Components of central deflection of a uniform beam in four point bending.

Source of deflection		~% of total central deflection
Bending of the central portion	Bending of the central portion (length 6 times depth) under pure bending moment.	12%
	Deflection due to inclination of the shear span due to bending of the central portion.	50%
Bending of the shear span	Bending of the shear spans (length 6 times depth) under linearly varying bending moment.	33%
Shear deformation in the shear span	Shear deformation of the shear span under uniform shear force.	4%
	Total	100%

Even though the deflection measured to obtain local MoE is small in comparison to the total deflection of the beam at the centre of the span, about 60% of that total deflection arises from bending of the central portion. The global MoE measurement is not independent of the local MoE measurement and it is therefore not expected to obtain a global MoE that is much higher than the local MoE.

A low stiffness defect at the centre of the span will decrease local MoE more than it decreases global MoE and this situation defines the lower bound of the E_{local}/E_{global} ratio. Shear deformation, embedment of the loading points, testing machine flexibility and shortening of the specimen height under compression will all act to reduce global MoE but not local MoE and so the limiting case of minimum E_{local}/E_{global} is to assume they do not occur.

The extreme limiting case is a beam that is infinitely stiff except for a single, discrete, low stiffness defect located in the centre of the span. For standard test geometry this limit equates to:

$$\frac{E_{local}}{E_{global}} > 0.326 \qquad [2]$$

The EN384 equation produces a E_{local}/E_{global} ratio below this limit for values of global MoE below 2760 N/mm^2. For C14 timber, one board in 500 would be expected to have a MoE lower than this value (of the extreme limiting case of mechanical consistency). A much larger proportion of boards would have measured stiffness values reduced by unrealistic amounts.

2.2 Impact on grading yields

The following calculations assume that grades of timber have a shear-free mean modulus of elasticity in bending of *E* with CoV of 20% and a shear modulus of *E*/16 (typical values experimentally observed and implied by EN338).

The adjustment made by clause 5.3.2 of EN384:2010 is shown relative to measured values of global MoE in Figure 3. The figure also shows probability density curves for timber of grades C14, C16 and C24 (for which global MoE has been calculated as *E*/1.04).

If the timber were uniform and homogeneous it would be expected that measured global MoE values be increased by 4% to correct for the shear deformation present in global MoE measurements but not in local MoE measurements. However, EN384 imposes significant reductions for lower stiffness timber implying that low stiffness defects are present at the centre of the span for these grade. The size of the reduction is implausible for values of stiffness at the lower end of the C14 and C16 range and is not in line with previous research findings (Table 2).

The consequence of this is that much higher values of global MoE are required for lower grades, relative to the grade stiffness requirement. The potential impact on the yield with a perfect grading machine for C16 timber (for which grade is limited by stiffness alone) is illustrated in Figure 4. For 100% yield a global MoE of 8 kN/mm^2 is required which is 5% higher than the required MoE grade limit (7.6 N/mm^2). This is despite the expectation that measured values of global MoE would be 4% lower than the shear free MoE (*i.e.* a global MoE mean requirement of 7.3 N/mm^2 is expected – for which the optimum yield is only 75%).

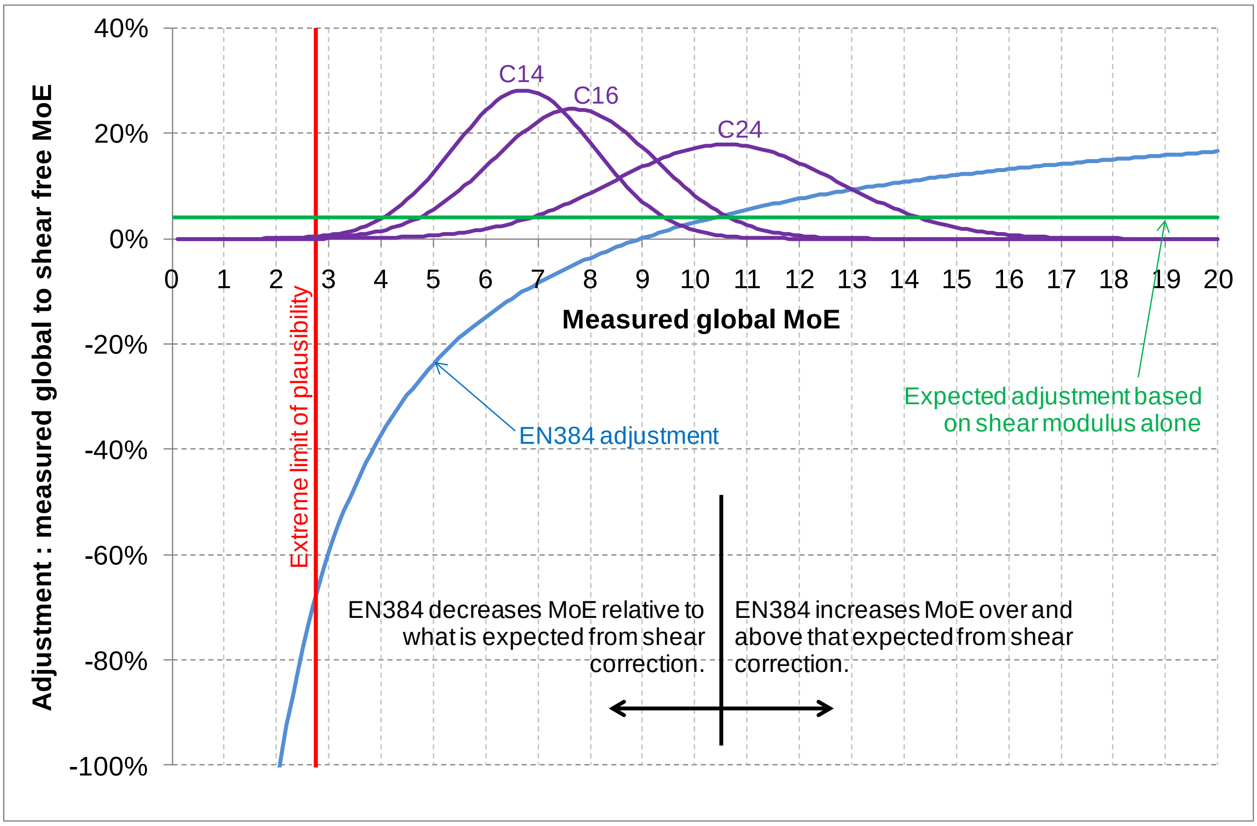

Figure 3: EN384 adjustment relative to measured global MoE

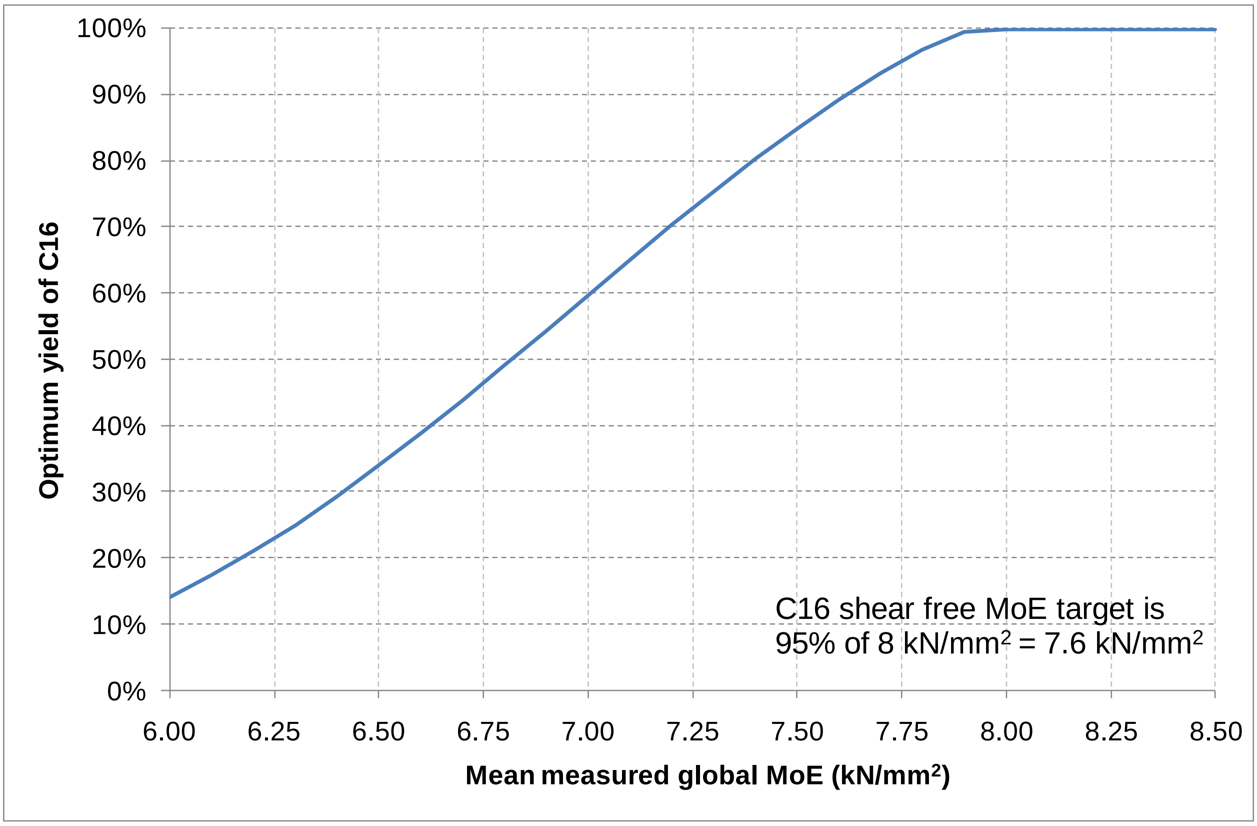

Figure 4: Optimum grading yield for C16

Table 2. Summary of previous research findings.

	$E_{local} = m \times E_{global} + c$		@ E_{global} = 4000 N/mm^2		@ E_{global} = 14000 N/mm^2	
Dataset	Slope, m [-]	Intercept, c [N/mm^2]	E_{local} [N/mm^2]		E_{local} [N/mm^2]	
EN384:2010 equation	**1.30**	**-2690**	**2510**	**-37%**	**15510**	**11%**
Boström & Holmqvist (1999)	1.14	-838	3722	-7%	15122	+8%
Ravenshorst & van de Kuilen (2009)	1.16	-239	4401	+10%	16001	+14%
Solli (2000)	1.18	-856	3864	-3%	15664	+12%
Holland (2000)	0.95	251	4051	+1%	13551	-3%
Holland (2000) Annex 2	1.05	-583	3617	-10%	14117	+1%
Denzler et al. (2008)	1.22	-1584	3296	-18%	15496	+11%

3 References

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