Technical note on the determination of strength reduction factors using ASTM D245

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Introduction

The US standard 'Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber', ASTM D245 (ASTM, 2019) is based on the assumption that knots act as voids and presents a simplified way to account for the reductions in bending capacity due to these voids.

It is worthwhile considering the equations given in the code and comparing them with a similar approach based on first principles. The first principles approach compares (i) reduced sections with knots with (ii) entire sections without knots. The basis for the comparisons is their elastic section moduli, assuming that knots can transmit zero tension forces and so act as voids below the neutral axis. It is assumed that knots can transmit compressive forces, which would be above the neutral axis for a typical timber joist in normal vertical bending.

Three cases are considered by ASTM D245 and each case has several associated formulae, with variants based (i) on joist height (h) and width (b) and (ii) on the strength reduction factor (SR) being less than or more than 45%.

Narrow edge knots

The strength reductions for knots in the narrow horizontal edge/face of joists are defined by D245 as follows (for fairly typical small timber joist sizes of 50mm wide x 100mm height):

Where $SR < 45\%$,

$$SR = 100\left[1 - \frac{k - (1/24)}{b}\right] \tag{1}$$

Where $SR \geq 45\%\ and\ b < 152mm$,

$$SR = 100\left[1 - \frac{k - (1/24)}{b + (3/8)}\right] \tag{2}$$

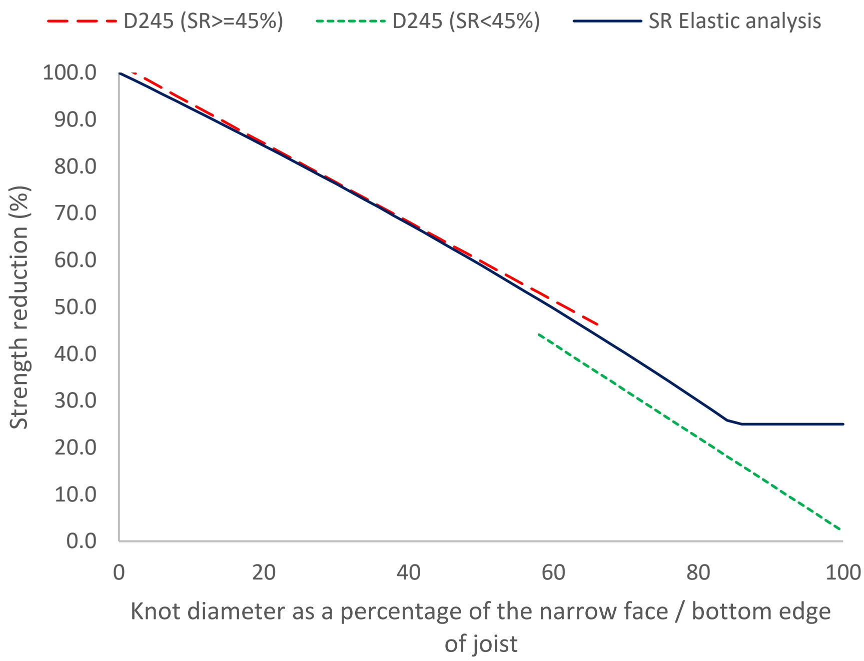

Figure 1. Comparison of strength reduction values due to knots in the narrow face (i.e. bottom edge) of a timber joist using ASTM D245 and the elastic section modulus (Elastic analysis) (for timber b < 152mm and h < 152mm)

The formulae of D245 align reasonably well with a calculation based on the elastic section modulus of a joist, as is shown in Figure 1. Two points should be noted. Firstly, due to the overlap of the two D245 formulae, it is not clear which SR values apply for knot diameters around 60% to 70% of the joist thicknesses (b). Secondly, D245 assumes that narrow face knots extend upwards only to the mid-height of the joist and based on this assumption, the weakest possible scenario occurs with a knot whose diameter equals the width of the joist (i.e. knot diameter is 100% of bottom edge of joist). This would leave the top half of the joist intact and this much reduced section has an elastic section modulus of 25% of the full section modulus. Therefore, strength reduction values of SR should have a lower limit of 25%. These two points are minor issues (and the first point can in part be dealt with by reference to tables in D245). These two points are likely to be dealt with using common sense by practising engineers in the USA.

Wide face knots at mid-height

ASTM D245 presents a total of five different formulae for the condition of a wide face through knot at mid-height. Bearing in mind the difference between output of the code and a theoretical analysis based on the elastic section moduli of joists, these different formulae appear to be very minor changes to an approach that does not accord well with the theoretical analysis.

The strength reductions for knots in the wide vertical face of joists are defined as follows (for fairly typical small timber joist sizes of 50mm wide x 100mm height):

Where $SR < 45\%, h \leq 305mm$

$$SR = 100\left[1 - \frac{k - (1/24)}{h}\right] \quad (3)$$

Where $SR \geq 45\%\ and\ h < 152mm,$

$$SR = 100\left[1 - \frac{k - (1/24)}{b + (3/8)}\right] \quad (4)$$

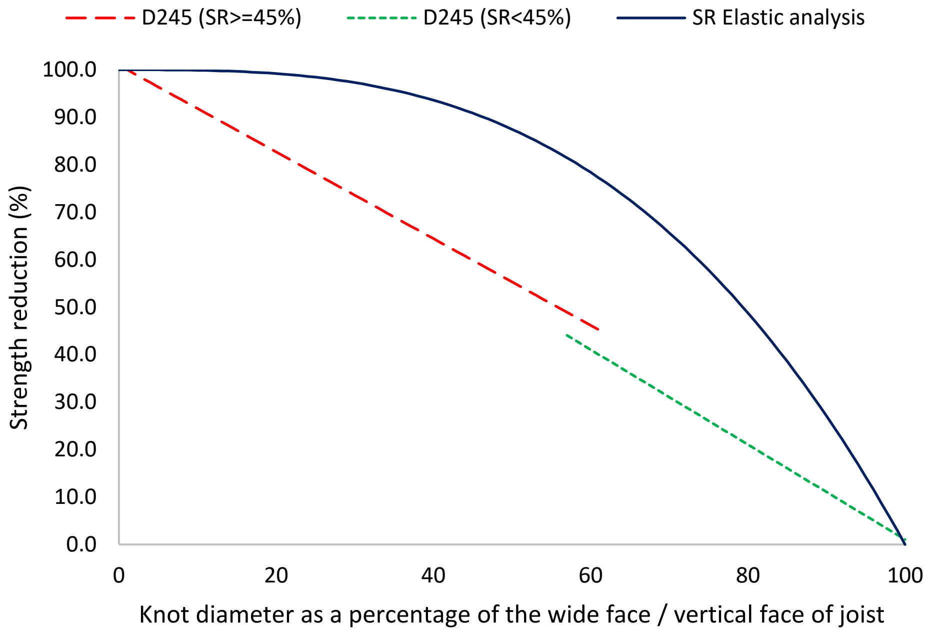

Figure 2. Comparison of strength reduction values due to knots in the wide (i.e. vertical face) of a timber joist using ASTM D245 and the elastic section modulus (Elastic analysis) for timber h < 152mm

Reference should be made to the graph in Figure 2. Firstly, the formulae of D245 give significantly conservative answers compared to the calculation based on the elastic section modulus of a joist. It is unclear why such conservative formulae are used as a relatively simple formula is available to more closely mirror the strength reduction based on the elastic modulus of the section:

$$SR = 100\left(1 - \left(\frac{k}{h}\right)^3\right) \quad (5)$$

It may be that, as these simplified formulae are applied to wide face knots at varying distances from the neutral axis, a choice was made to be conservative, to cover more possible knot positions. Thus, the very approximate methods used in D245 were understood and partially accounted for at the time of its creation.

Secondly, once again, there is an issue with the overlap of the two D245 formulae (with duplicate SR values for knot diameters between 57% and 61%). This second point is relatively minor and can be dealt with by reference to tables presented in D245. It must be remembered that the strength reductions are approximate and small issues like this are relatively unimportant.

Wide face knots at the lower edge

ASTM D245 again presents five different formulae for the condition of a wide face through knot at the lower edge. These different formulae appear to be very minor changes to an approach that accords well with the theoretical analysis.

The strength reductions for knots in the wide vertical face of joists are defined as follows (for fairly typical small timber joist sizes of 50mm wide x 100mm height):

Where $SR < 45\%, h \leq 305mm$

$$SR = 100\left[1 - \frac{k - (1/24)}{h}\right]^2 \qquad (6)$$

Where $SR \geq 45\%\ and\ h < 152mm,$

$$SR = 100\left[1 - \frac{k - (1/24)}{b + (3/8)}\right]^2 \qquad (7)$$

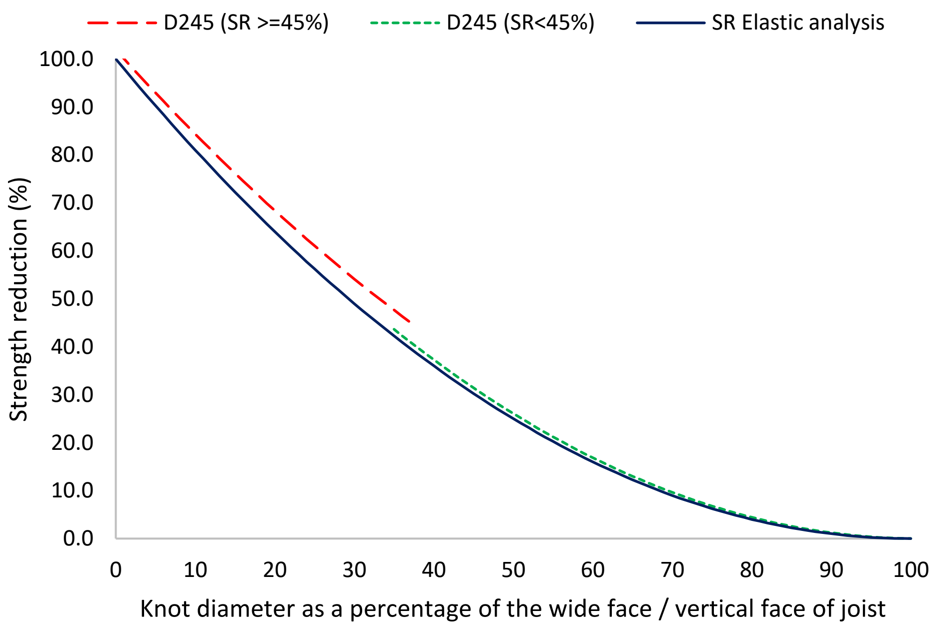

Figure 3. Comparison of strength reduction values due to knots located at the bottom edge of the wide (i.e. vertical face) of a timber joist using ASTM D245 and the elastic section modulus (Elastic analysis) for timber h < 152mm

This third and final D245 graph compares strength reduction values using formulae from D245 with those calculated using the elastic section modulus of the joists. The two methods of analysis correlate more closely than in the other two graphs. However, once again there is a very minor issue with the overlap of the two D245 formulae (this time, with duplicate SR values for knot diameters between 34% and 37%).

Other wide face and narrow face knots

The three D245 graphs represent just three particular 'knot types' from a very wide variety of possible sizes, locations and orientations of knots. The graph below, Figure 4, illustrates strength reductions in bending, based on the elastic section modulus of a joist and considers solely horizontal through knots of varying diameters, but this time the knots in the graph are located at varying heights within a joist in normal vertical bending.

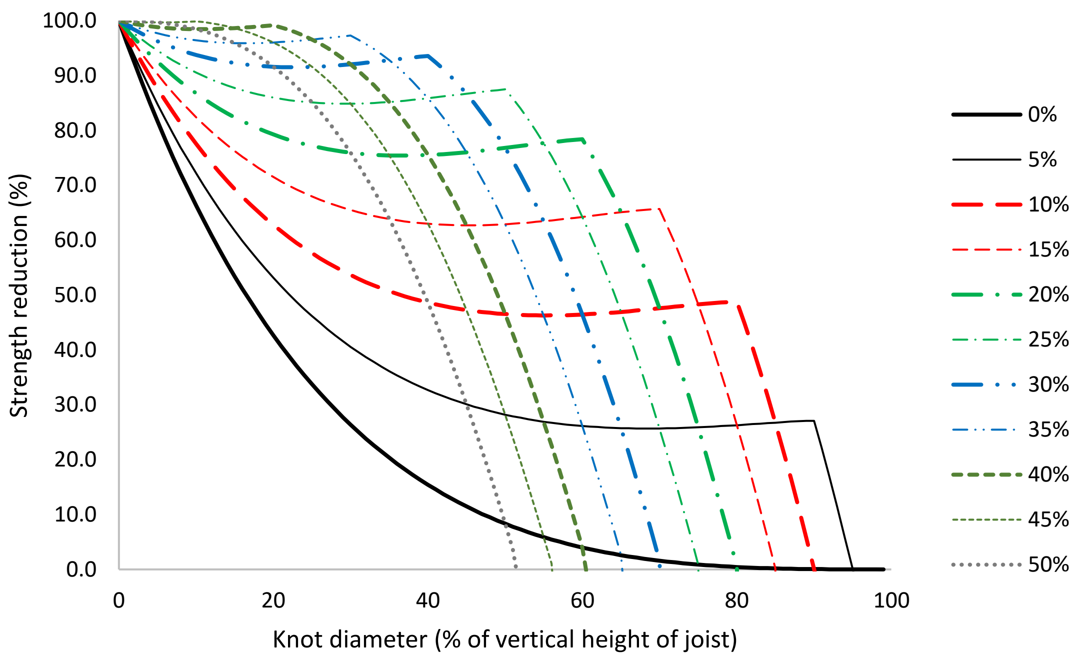

Figure 4. Comparison of strength reductions for knots (with bottom edge of knot located at differing distances from the base of the joist, given by different colours and line types, as % of vertical height of joist)

It should be noted that the lines on the graph in Figure 4 represent just horizontal through knot and that further graphs would need to be drawn for knots aligned diagonally, inner and outer arris knots, splay knots, and knots in joists containing the pith. It is clear that the model adopted in D245, which reduces all knots to one of just three 'knot types', is a significant over-simplification which does not model well the reality of knots in joists (even the simplified 'reality' of knots acting as voids).

There is an optional refinement in D245, described in outline, that allows for some gradual increase of the strength reduction factor as the location of a wide face knot nears the mid-height centre line of a joist. This requires interpolation and appears to be an afterthought that only applies to single spanning simply supported joists in bending (ASTM, 2019). So, although this may not generally be applicable, it is applicable to the method of testing carried out in this study. Therefore, a further set of results have been processed using this interpolative approach. Even with this minor refinement, these further results show no significant improvement in the overall approaches used and the comments above still stand.

Conclusions

From all of the above, it is seen that the D245 model is a simple one that is based on an unproven assumption that knots in tension act as voids. This assumption is not proven by research and is questionable. Additionally, based on this assumption, the simple D245 models do not accord well with the wide range of knots that occur in timber joists, presenting only three simple approaches to a myriad of significantly varying possibilities.

References

ASTM (2019) ‘D245-06. Standard Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber’. West Conshohocken, PA, USA: American Society for Testing and Materials, ASTM International, pp. 1–17. doi: 10.1520/D0245-06R19.2.