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The bearing strength capacity perpendicular to grain of norway spruce – Evaluation of three structural timber design models

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HIGHLIGHTS

- Current models to predict the compressive strength perp to grain are unreliable.
- Only one model based on yield slip-line theory is accurate.
- The V.d. Put model is the candidate for future building design code implementation.

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ABSTRACT

The perpendicular to grain compressive strength of timber is known to be much lower than the strength parallel to grain. Many timber structures, however, rely on this property especially in bearings that occur frequently in building practice. The linear elastic–plastic behaviour of structural timber loaded perpendicular to grain has been a problematic issue for decades which is reflected in the differences between the prediction models in structural design codes over the world. This article concentrates on the evaluation of the strength predictive ability of three of the latest bearing models having an empirical, semi-empirical or physical background. On the bases of a large database of over 1000 test results covering eight practical load cases, it is shown that the accuracy and consistency of the physical model is the best, which makes it a potential candidate for the new generation timber design codes.

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1. Introduction

It was Borg Madsen [1] who called Compression Perpendicular to Grain (CPG) a Cinderella property, when he complained that not enough engineering thinking was being applied to a property as the compressive strength perpendicular to grain. He referred to the ASTM-D-143 standard test method of 1926 [2], and the empirical design approach which is still in use in countries like the US, Canada, Australia/New Zealand and in Asia. He notes correctly that, with respect to perpendicular to grain, load introduction for both the “strength limit state” (ULS) as well as the “serviceability limit state” (SLS) can govern the design of timber structures. For serviceability considerations, deformations are the key issues being influenced by the initial elastic deformation and creep deformation which is driven by the wood species and moisture conditions. Thelanderson and Mårtensson [3] conclude that “design with respect to ULS need only be made when bearing failure may reduce the structural capacity of structural members or otherwise affect the safety of the structural system. In all cases where design in ULS is not necessary, design should be made in the SLS”. This, however, presumes that the design for ULS situations is sufficiently accurate and reliable. Leijten [4] showed that the bearing capacity design models mainly used around the world do not comply, and that this assumption is far from accurate. A common and unified approach to tackle the issue seems far away. This study, however, aims to improve this situation. It also hopes to contribute to the ongoing revision of Eurocode 5 with the aim to improve code design models.

A relatively easy way out for design code regulations is to prescribe calculation methods resulting in conservative predictions. Usually, an important input parameter for the models prescribed in the design codes is the standard CPG strength. The lack of a unified approach to determine the CPG strength has led to situations like in the Scandinavian countries. In these European countries, the standard characteristic bearing strength is 2–3 times higher than the stress at proportional limit determined by tests. This is considered questionable and far from conservative, Thelanderson and Mårtensson [3]. Also Kevarinmäki [5] concludes that the short-term CPG strength value for Spruce in Finland is too high, 6.5 N/mm^2, and is associated with a deformation generally

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exceeding 10% of the timber member depth. He argues that 3.3 N/mm^2 would be more appropriate.

It will be shown that the reliability and accuracy of calculation models used for design in practice is an issue to be considered. The evaluation presented below focuses on the reliability and predictability of a three models. One of the models is currently in use for practice, while the other models have been published but not yet been accepted or had sufficient credibility. Such undertaking requires a large database of experimental test results covering most of the design situations occurring in practice. In addition, all tests must have been carried out using the same test procedure and using the same method to determine and define the CPG strength.

2. Load cases

In order to support and distinguish the best predicting model, a sufficient number of test load configuration cases should be evaluated. The load configurations should, to a large extent, reflect building practice situations. In Fig. 1 an overview is presented of these load configuration cases categorized as B–F. These categories were introduced in Leijten et al. [6] and incorporate fully and partially loaded cases. The arrow indicates the force applied, and a steel plate underneath takes care of uniform equal load introduction. The area with the highest CPG stress fails. In cases where the loaded area is as big as the support area, as in load cases D and E, both areas fail due to CPG simultaneously. Cases G and H are load cases without a direct support, so-called discrete supports, Load case H was later added by Lathuilliere [7]. Obviously one can vertically flip these load cases. It is assumed, however, that the timber at the load introduction fails in CPG. Load case J is added to check for the interaction between nearby loaded areas.

To enable comparison between the experimental test results carried out and reported by different researchers, all the experiments should use as a starting point a common standard test procedure and evaluation method to determine the CPG strength. The specimen used by the standard test method is shown in Fig. 1 as load case A. This standardized specimen of clear wood is loaded over the full upper surface of 45×70 mm with a depth of 90 mm. The specimen depth equals the distance between the loaded surface and the bearing support. The deformation used for the load-deformation curves is the change of this distance. The latter is not fully in agreement with the test standard CEN/EN 408 [8]. However, Le Clevé [9] has shown that taking the deformation as the change in depth of the specimen is the preferred measuring method and provides more consistent results than using the CEN/EN 408 method, Fig. 2. In this study, all evaluations were done by following the principles of CEN/EN408 but having a gauge length equal to the specimen depth.

The CPG strength in CEN/EN408 [8] is defined as the intersection of a line (2) parallel to the linear part of the load–displacement

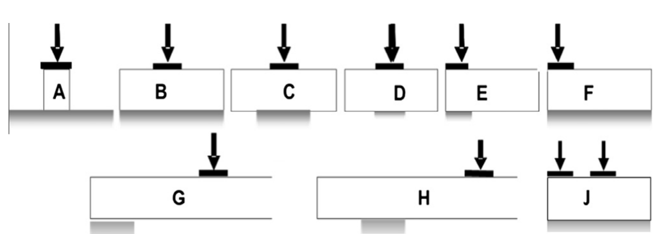

Fig. 1. Overview of load cases or categories (after [6] and [7]). (A) standard specimen EN408; (B) center load, full support; (C and D) opposite load, local support; (E) end load, local support; (F) end load, full support; (G and H) discrete load; (J) two spaced loads, full support.

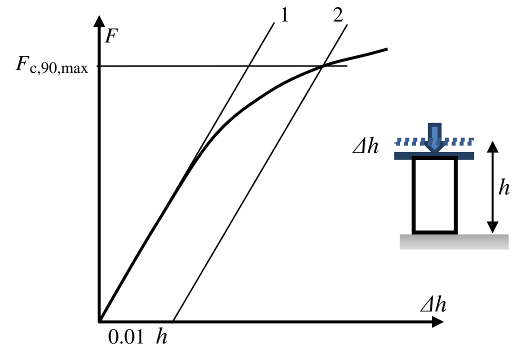

Fig. 2. Definition of CPG strength.

curve, line (1) that is off-set by 1% of the standardized specimen depth, Fig. 2. In cases B to G, where the test specimen dimensions deviate from the standard specimen, the same method is employed to determine the CPG strength. The deformations are plotted in [mm] and not in percentages of the specimen depth, the reason being that in the loading categories G and H it is not the whole specimen depth which is affected by the CPG stresses, Leijten et al. [10]. Furthermore, when the depth of the test specimen differs from the standard 90 mm, the 1% off-set line (2) is off-set 1% of the actual specimen depth. Only for category D and E the 1% off-set refers to half the specimen depth.

3. The experimental data

A literature search results in many reports dealing with CPG. Besides strength and stiffness data, there is also information about factors that influence these properties. These are the wood species, load case, moisture content, specimen shape, annual ring orientation, etc. All of these have drawn attention and have been investigated. The literature listing that follows is not exhaustive. Kollmann and Coté [11] reports pre-WWII test results by Graf [12] and Suenson [13]. These investigations counts only one test per load case which is considered insufficient and therefore these results are discarded from the analyses. However, since load case C is not covered by any researcher besides Graf [12], and considering the load deformation curves of his study are available, including one for the cube test specimen, it is decided to add these results to this study. Gehri [14] and Hübner [15] p.13 make reference to additional studies by researchers like Föppl [16], Staudacher [17,18], Gaber [19], Frey-Wesseling and Stüssi [20] and Rothmund [21]. They do not report, however, if these researchers made use of a reference standard test specimen, a standard test method or have a common definition of the CPG strength. This is why their research results have been omitted from this study. Although Kühne [22] p.42 accurately defined how to derive the CPG strength values, he did not apply any off-set and, without reporting the load deformation curves, his elaborate test results also cannot be taken into account. This is why many sources mentioned in [6] are not used for this more accurate analysis. Many other sources originating from the US like Basta [23], report tests that were carried out in accordance with ASTM-D-143 [2]. In [23] an elaborate literature review is provided about CPG tests using this ASTM standard. The focus is not exclusively on Spruce (Picea Abies) but on many different wood species, dealing with effects of moisture, annual ring orientation, etc. This standard test procedure does not determine the CPG strength as a physical material property but is only based on load case B, Fig. 1. The definition of the CPG values obtained with this method was once based on the proportional limit, but it is now based on a 1 mm deformation limit. As reported

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