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# A general bearing deformation model for timber Compression perpendicular to grain

A.J.M. Leijten

*Dept. of Build Environment, Eindhoven University of Technology, PO Box 513, 5600 MB Eindhoven, The Netherlands*

## HIGHLIGHTS

- Structural design models for bearing deformation of timber beams have not yet been accepted in the major building design codes over the world.
- A new and simple model for the bearing deformation is proposed and compared with three other models.
- The evaluation used a new data base of more than 1100 experimental test results covering softwood and hardwood species and most load cases that occur in building practice.
- The new model is the preferred model because of its reliability in accurate prediction and ease of use for the practical engineer.

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## ABSTRACT

This study focuses on a new and unique model to determine the elastic bearing deformation of structural timber. Available models that aim to predict the deformation are usually limited in their application. The performance of a simple model is compared to three other models, all being evaluated using experimental test data for the wood species Norway Spruce, Poplar, Beech, Cumaru and Akki and covering eight different load cases. The results show a simple model to have the best performance in deformation prediction and so is a potential candidate for introduction in updated structural timber design codes.



## 1. Introduction

In building practice, perpendicular to grain load situations occur in many places. These might be where timber beams (joists) find support, or where studs in timber frames load the bottom and top rail perpendicular to grain. In pre-stressed timber bridge decks, a relatively high pre-stress perpendicular to grain keeps the individual bridge desk laminations together. Currently, structural timber designers are looking for ways to design higher timber frame houses and even multi-storey mid high-rise buildings, where knowledge about strength and deformation of bearing supports becomes increasingly important. Recently, advances have been made in the development of reliable calculation models for the bearing strength capacity, Leijten [1]. What has to be done is to evaluate bearing deformation models that are easy to apply, accurate and can be used for most bearing situations. The elastic-plastic material behaviour, considering all possible load situations, is hard to predict. This study presents a physical deformation model based on spreading of the bearing stresses which, in a unique way, is able to cover all load cases and is also simple in application and sufficiently accurate for practice. The load cases evaluated are given in Fig. 1 where load case A represents the standardized test piece for the determination of the compression strength and stiffness perpendicular to grain (CPG). Using the stress spreading model proposed by Van der Put [2] and the stiffness data from the standardized test, the deformation of the other load cases can now be derived.

Although not leading to direct structural failure, CPG deformations can create substantial damage to building components that do not follow the bearing deformation. Knowledge about shrinkage, the elastic and creep deformation, including mechanic-sorption, are key ingredients for a successful estimation of the total bearing deformation during the life-time of a structure. This article focuses on the evaluation of the bearing deformation which can be characterised by the onset of non-linear behaviour. The elastic deformation forms the starting point for estimation of additional influences like creep.

*E-mail address:* adleijten@gmail.com

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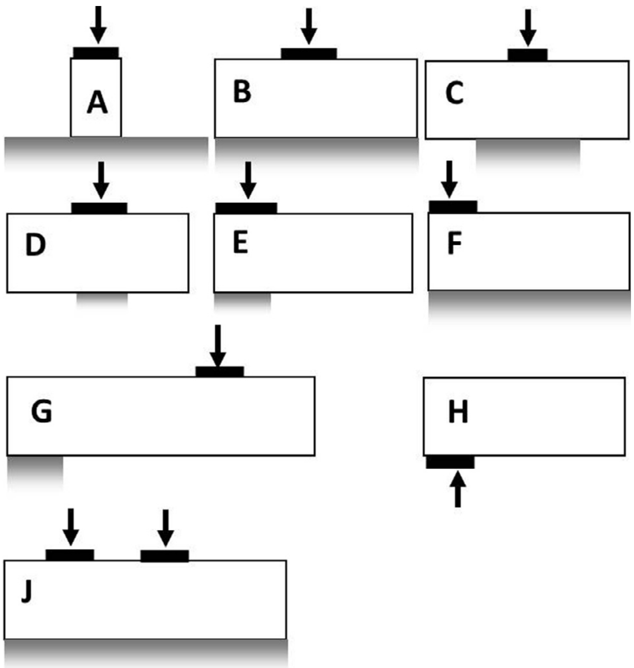


**Fig. 1.** Load cases evaluated in Leijten [1].

Not only are deformation models dealing with bearing deformation scars neither of them have yet been accepted by the leading structural timber design codes in the world. This article aims at ending this situation.

## 2. Bearing deformation models

Deformation models are hard to find in literature. In 1982, Madsen et al. [3] published a bearing deformation model presented in Eq. (1). The model is based on Hook's Law (strain is proportional with the applied stress) as a starting point. The spreading of the bearing stresses was recognised and the total deformation $\delta$ is dependent on the depth of the timber beam, $h$. Further parameters are: the applied load perpendicular to grain $F_{c,90}$, the width of the loaded area $b$, and a reduced loaded length parallel to grain $l_r$ and $l_e$, depending on the depth and the distance to the end face, as well as the modulus of elasticity perpendicular to grain $E_{90}$. The parameters $l_r$ and $l_e$ have, as stated by the author, no physical meaning but are empirical in nature and thus do not relate to the CPG.

$$\delta = \frac{hF_{c,90,d}}{b(l_r + l_e)E_{90}} \tag{1}$$

In the European Design Code of 1987 [4] an empirical model, Eq. (2) is presented but only for the load cases B and F. Hook's Law is again applied but now modified with a factor $k_u$. It is assumed this factor was determined by evaluation of test results.

$$\delta = k_u \frac{hF_{c,90}}{blE_{90}}$$
with
$$k_u = \begin{cases} \frac{l}{l+2h} & \text{for } a \geqslant h \\ \frac{l}{l+2h}\left(1 + 2\left(1 - \frac{a}{h}\right)^2\right) & \text{for } a < h \end{cases} \tag{2}$$

The $a/h$ ratio in the modification factor refers to the ratio of the end grain distance $a$, and the beam depth $h$. It was F. Mårtensson [5] who proposed another empirical deformation model, Eq (3) that again takes Hook's law as a starting point. The total deformation $\delta$ is dependent of the beam depth $h$, the load $F_{c,90}$, effective loaded area $A$, and the modulus of elasticity perpendicular to grain $E_{90}$. The factor $\mu$ considers the influence of the depth to bearing length ratio.

$$\delta = \frac{hF_{c,90,d}}{A(1 + \mu\frac{h}{L})E_{90}} \tag{3}$$

Based on the evaluation of tests and final element calculations, $\mu = 0.3$ is proposed. This applies for situations where the loaded area is not too close to the beam end. The author does not specify, however, any specific values for boundary conditions. Furthermore, A. Mårtensson states that deformations caused by creep and mechanic-sorption are believed to be covered by reducing the $E_{90}$. Gehri [6], mentioned the necessity to use realistic values for the $E_{90}$ and that strength and deformation considerations should not be mixed. Apparently, this model is too limited in its application to be accepted by the timber design codes, as none of the structural timber codes have adopted it. In those days, $E_{90}$ values were taken as a percentage of the same property parallel to grain and, later in this article, this issue will be elaborated on. Van der Put [2] as well as Blass and Görlacher [7] came up with a deformation model similarly based on Hook's law, but with the assumption of a certain spreading of the bearing stresses in grain direction, combined with the assumption of a linear elastic material behaviour, Eq. (4). The assumption is that the timber outside the stress spreading area does not significantly prevent any bearing deformation. In Eq. (4) the assumed stress spreading gradient is 1:1, the load perpendicular to grain $F_{c,90}$, and the depth and width of the beam are $h$ and $b$ respectively. The length parallel to grain of the loaded area is $l$, while the support stress length is the effective length, $l_{ef}$ (Fig. 2).

$$d\delta = \varepsilon dh = \frac{\sigma dh}{E_{90}} = \frac{F_{c,90}}{b(l+2h)E_{90}}dh$$
$$\delta = \frac{F_{c,90}}{2bE_{90}} \ln\left(1 + 2\frac{h}{l}\right) \tag{4}$$

This stress spreading approach can be applied to all load cases. As shown in Fig. 3 for load case C the total deformation can be calculated by splitting up the stressed area into two parts. One caused by the top loaded area with loaded length $l$ and depth $h_1$, and the second caused by the bottom support with loaded length $l_s$ and depth $h_2$, having an common intersection length indicated by the horizontal dotted line, the so-called effective length $l_{ef}$. The total deformation is approximated as the summation of the deformation of both stressed areas. Similarly, this can be applied for close spaced loads and to situations where the loads are close to the end face, load case F and J, Fig. 4. A dotted horizontal line parallel to grain divides the stressed areas at locations where they start to either interfere with other stressed area or touch the end face.

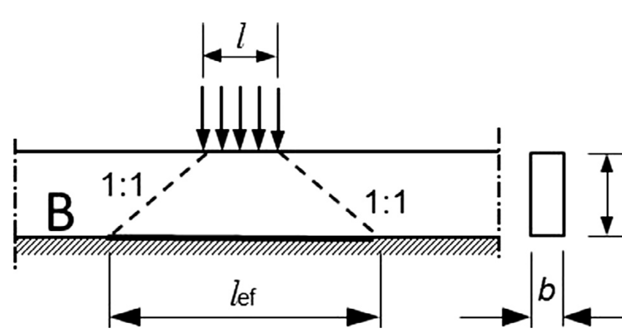


**Fig. 2.** Stress spreading gradient for load case B.