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Splitting of timber beams caused by perpendicular to grain forces of multiple connections

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A B S T R A C T

Beams, which are loaded perpendicular to grain by connections along the span, may fail by splitting. Empirical and semi-empirical models assume that when multiple connections are spaced more than twice the beam depth, the splitting strength of each connection is not influenced. New evidence has emerged from recent laboratory experiments, with up to five connections per beam, which proves that this assumption does not hold and results in a non-conservative estimation of the splitting capacity. Evaluation of the test data shows that a simple adjustment factor can be derived to account for multiple connections that fit well into the current Eurocode 5 fracture model.

1. Introduction

There are cases, as indicated by Fig. 1, where connection forces are perpendicular to the grain direction of the timber beam. If dowel type fasteners, like screws, punched metal plates, nail plates or glued in rods or any other type of force transmitting device, do not transfer the force high enough into the beam brittle splitting failure may occur. In that case, it is the splitting that is governing and not the strength of the connection and splitting will occur at the location where the total connection force is transferred to the beam. This location is known as the largest loaded edge distance which, in the particular case of Fig. 1, is equal to the penetration or insertion depth of the fasteners. It will be of no surprise to find that this distance is an important parameter in the models that aim to predict the splitting capacity.

2. Predictive models for single and two connections

A splitting model based on fracture mechanics is reported by Van der Put [1]. This model is accepted by the Eurocode 5 [2] and is given in Eq. (1) where $F_{90,k}$ is the characteristic splitting capacity, b the width, w is a parameter to account for punched metal plates and is added more for political than technical reasons, h_e is the loaded edge distance, h is the beam depth and k_1 a fracture mechanical parameter. The value $k_1 = 14$ was chosen for Spruce in Eurocode 5 [2] and represents the characteristic value for the fracture parameter. The derivation takes one connection at mid span of a simply supported beam as a starting point. An important fact is that this model is independent of the type of fasteners used for the connection as it considers unstable crack growth outside the connection area. For this reason the type of fasteners as well as the fastener pattern or load introduction as for instance by screws as shown in Fig. 1 are irrelevant.

$$F_{90,k} = k_1 b\, w \sqrt{\frac{h_e}{1-\frac{h_e}{h}}} \quad \text{where } k_1 = \sqrt{\frac{5}{3} G G_c} = 14 \tag{1}$$

The theory by Van der Put [1] takes as starting point that splitting is governed by shear deformations, fracture mode II. An excellent overview and derivation of this theory is also given by Jensen et al. [3] who in addition provides the background of later splitting models, predicting the splitting capacity of beams loaded by a single connection at mid span. Many tests with hardwoods and softwoods and with different type of fasteners, such as axially loaded screws, punched metal plates and dowel type fasteners, in addition to references by Ehlbeck et al. [4] are reported by Schoenmakers [5]. Models that account for more than one connection are rare; only Jensen [6] and Schoenmakers [5] both derived closed formed expressions based on fracture mechanics for two connections. Experiments by Kasim and Quenneville [7] reported that their experiments with two spaced connections indicated that the splitting capacity per connection decreased. This reduction continues when the number of connections increases to three, as in Leijten and Schoenmakers [8]. The spacing of the connections in this investigation was twice the beam depth. This disqualifies models that assume connections to act independently of each other, such as the model by Ehlbeck et al. [4]. To check if the splitting capacity reduction continues, experiments with up to five connections were carried out and are reported here.

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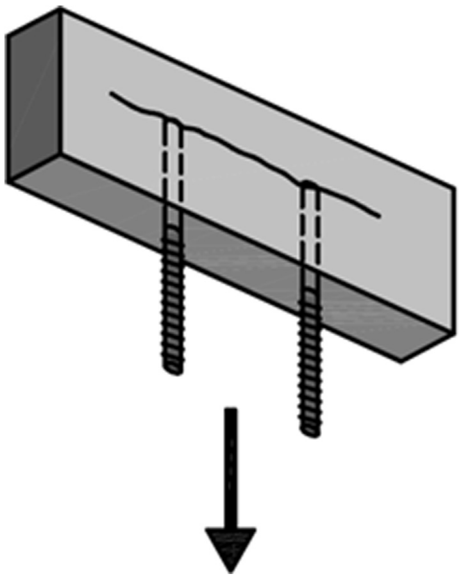

Fig. 1. Part of timber beam loaded perpendicular to grain by screws or glued in rods, [5].

3. Experimental test program

Tests with simply supported beams were carried out following EN408. The wood species used for the experiments was Norway spruce assigned to strength class C24 (characteristic bending strength of 24 N/mm^2), and all having a mean cross-sectional dimension of 45 × 220 mm. The mean density was around 455 kg/m^3 and the average moisture content 12%. In Table 1, the test series are grouped according to the type of fastener, the number of connections and other parameters as indicated in col. (2) to (9). The total span col. (4) is the distance between the two supports of the simply supported beam. In col. (5) the distance given is between the edge of the support to the nearest fastener. The spacing of the connections for beams, loaded by three, four and five connections, was evenly distributed, respecting a minimum distance of twice the beam depth. In col. (8) the ratio of the largest loaded edge distance of the fastener, h_e and the beam depth, h is presented. This ratio is very important, as it is decisive for the splitting capacity in the Eurocode 5 [2] model that will be used later in the evaluation of the results. Test Series 20 and 21 had visible drying cracks in contrast to all beams in other test Series.

Nailed connections had 3, 4 and 5 rows of 5 nails with a diameter of 4 mm, equalling 15, 20 and 25 nails, respectively, in a rectangular pattern with minimum spacing in accordance with Eurocode 5 [2]. For the connections with dowels, four closely spaced (4*d*) 12 mm diameter dowels were used, set in a square pattern, Fig. 2. All connections had steel side plates of 15 mm thickness. The test setup using four connections is shown in Fig. 3. All beams failed in a brittle splitting mode.

All experiments were carried out load controlled. Connections were loaded by separate hydraulic actuators, each having a load cell to check for any differences in load. This, however, proved to be insignificant. Crack initiation and crack growth direction were studied, using small LVDT transducers mounted at close distance on either side of each connection. In addition, a high speed camera was used to observe the crack growth visually. In tests with three connections, 70% had crack initiation that started at the connection nearest to the support, but a dominant crack growth direction was difficult to determine. In 30% of the tests, however, a symmetric crack growth could be determined. For the tests with four and five connections, the location of the crack initiation could not be determined with certainty. Due to the deflection of the beam, the connection forces become vertically slightly off set. Analyses showed the result of this effect to be insignificant.

4. Experimental results

Before the test data can be evaluated, some adjustments must be carried out to obtain a common basis for comparison. As shown in Table 1, col. (9), different loaded edge to beam depth, h_e/h ratios, have been used for a number of test series. For this reason, a reference h_e/h ratio was set arbitrarily as $h_{ref} = 0.42\,h$ and a correction factor k_{cor} was used to bring all test values in line with this reference. This factor was derived, using the fracture model in Eurocode 5 [8], as:

$$k_{cor} = \sqrt{\frac{h_{e,n}\left(1-\frac{h_{ref}}{h}\right)}{h_{ref}\left(1-\frac{h_{e,n}}{h}\right)}} \quad (2)$$

Table 1
Overview of the test series.

(1) Test Series	(2) Number of connections	(3) Number of tests	(4) Total span [mm]	(5) Smallest distance to support [mm]	(6) Fastener diameter (nails*) (dowels) [mm]	(7) Number of fasteners	(8) Largest edge distance to beam depth ratio *he/h*
1	1	5	1600	800	4*	25	0.47
2	1	5	1600	800	4*	20	0.47
3	1	4	1600	800	4*	20	0.47
4	1	5	1400	700	4*	15	0.47
5	1	5	1200	600	4*	15	0.47
6	1	5	1000	500	4*	15	0.47
7	1	3	1400	700	12	4	0.47
8	1	5	1200	600	12	4	0.44
9	1	5	1000	500	12	4	0.44
10	1	10	800	326	12	4	0.33
11	2	5	1600	400	12	4	0.44
12	2	5	1600	200	12	4	0.44
13	2	10	2886	880	12	4	0.33
14	2	5	2886	880	12	4	0.33
15	3	10	2000	440	12	4	0.46
16	3	10	2000	440	12	4	0.33
17	4	11	2540	440	12	4	0.33
18	5	8	3600	540	12	4	0.33
19	5	9	3600	540	12	4	0.33
With drying cracks							
20	3	11	2884	660	12	4	0.42
21	4	9	2492	440	12	4	0.42