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Splitting of Timber Caused by Multiple Connections

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Abstract

The models, developed in the past that aiming at predicting the splitting failure of timber beams loaded perpendicular to grain by timber connections, are empirical, semi-empirical or based linear elastic fracture mechanics. They consider only one connection at mid span and have been calibrated to a single connection mid span test. Laboratory test are presented for multiple connections. Some model attempted to explain and predict the behavior for multiple connections but they were not very successful. The model presented in this paper by Schoenmakers [6], which is based on linear elastic fracture mechanics, explains the test results with more success although it only applies, at present, to two connections.

Keywords

Timber, splitting, connections, LEFM

1 Introduction

In recent years, timber researchers that focus focused on the problem of the failure of beams exposed to forces perpendicular to grain by timber connections, Figure 1. This type of failure is brittle and understanding of this phenomenon is important. Since the introduction of the Eurocode for Structural Timber Design In EN1995-1-1 (Eurocode 5) [1] a linear elastic fracture model has been implemented based on a model by Van der Put and Leijten [2]. This model does not consider how the load is applied or the type, number and spacing of fasteners but only the conditions for unstable crack growth outside the connection

area. Other empirical or semi-empirical models Ehlbeck and Görlacher [3], Franke et al. [4], among others, take into account the influence of the number of rows, columns and the spacing of the fasteners (nails, dowels). An excellent overview of the models available for single connections is given by Jensen et al. [5].

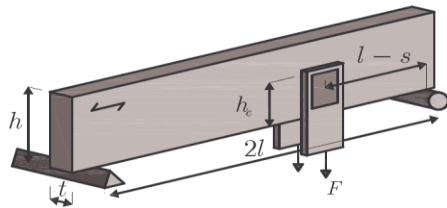


Figure 1. Beam loaded by single connection.

A systematic and comprehensive study into the influence of the fastener pattern of rows and columns at mid span connections with 4 mm and 6mm nails was carried out by Schoenmakers [6].

2 Models for Multiple Connections

The overall majority of test which have been reported so far, focus on a test configuration with a single connection at mid span. In practice more than one connection, not even at mid span, may occur. Test results by Schoenmakers [6] and others show that for

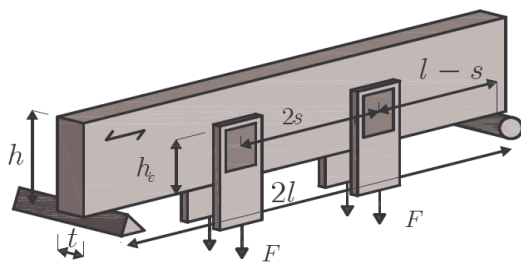


Figure 2. Beam with two connections.

others show that, for of out-of-center placed connections, the splitting strength is not

changed. This is in contrast to the design guideline by EN1995-1-1[1] that restricts the shear force on either side of the connection. This force should not exceed the shear force of a single mid-span connection. There are models, particular the empirical German model by Ehlbeck and Görlacher [3], that assume multiple connections, when enough spaced, (eg: twice the beam depth) can be considered as individual connections and no interaction will affect the load carrying splitting capacity. This is based on the assumption that the governing failure is triggered by tensile stresses perpendicular to grain. Apparently this assumption was not checked by laboratory tested. Kasim and Quenneville [5] reported that the spacing between two connections increased the total splitting load capacity did not exceed 1.4 the single connection splitting strength,

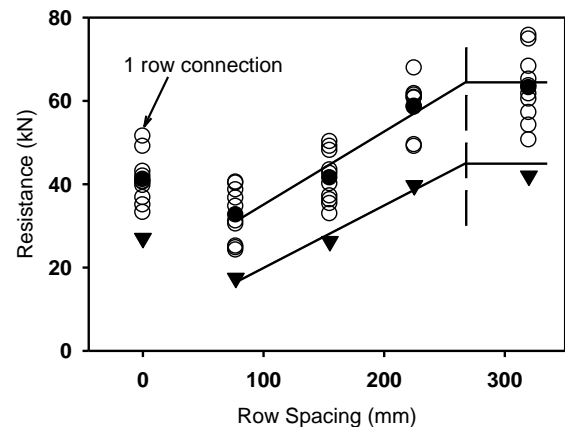


Figure 3. Splitting strength change with increasing connection spacing [5].

Figure 3. This phenomenon was left unexplained by the authors.

Jensen [8] tried to explain this using a beam-on-elastic-foundation model combined with Linear Elastic Fracture Mechanical Model (LEFM) with somewhat more success. The

same approach, with the compliance method, was used but for two connections symmetrically positioned along the beam span. An important assumption of the theoretical approach was to assume symmetrical crack development. This means that the main

This model resulted in two failure options. If the cracks merged between the two connections prior to failure, the failure load was the same as for a situation with a single connection. If the cracks did not merge the failure load would be twice the single mid-span connection strength.

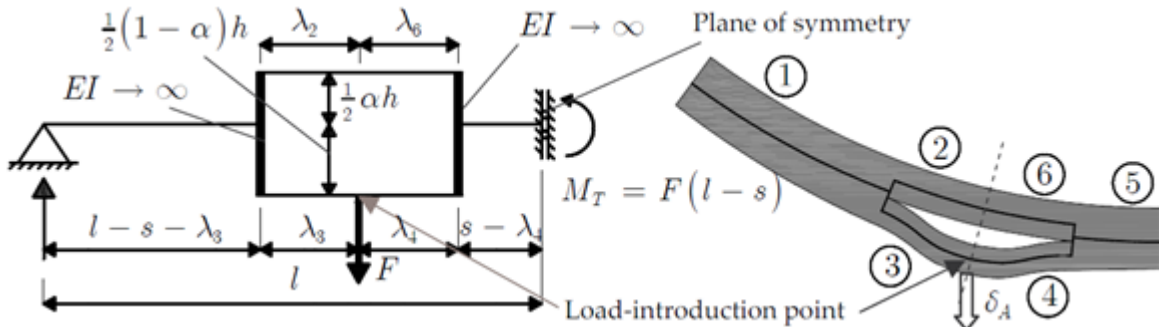
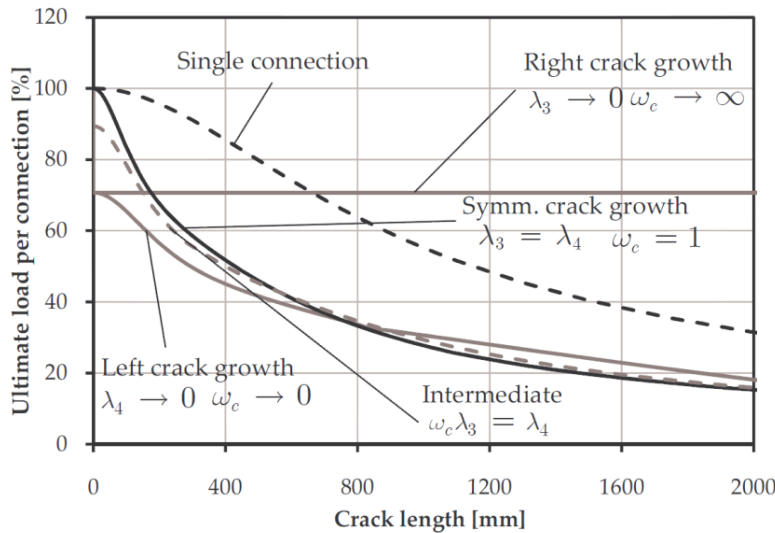


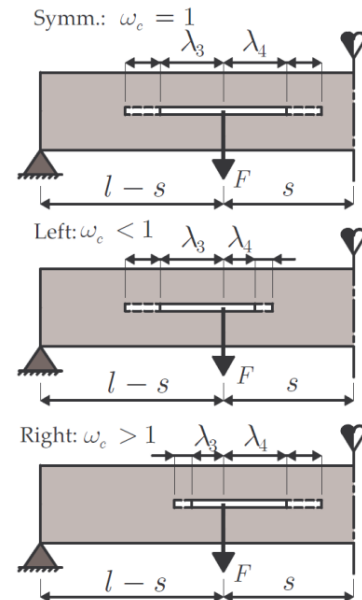
Figure 4. Model by Schoenmakers [6].

Both approaches didn't match the test results of Kasim and Quenneville [5]. Applying the

assumption in Jensen's model was crack propagation on either side of the connections at an equal rate at the same moment.



(a)



(b)

Figure 5. Model results by Schoenmakers [6] - connection extending equally.

same LEFM method, Schoenmakers [6] put forward a different solution. The beam was modelled as shown in Figure 4 and accounts for the situation where crack growth might be not symmetrical on either side of the connection. Essentially, this is different from previous model assumptions. The results of this model are represented by Figure 5(a). To the right a symmetrical part of the beam is shown including the initial crack on either side of the connection, Figure 5(b). The crack lengths were denoted by λ , and the subscripts 3 and 4 indicate the position of the crack on the right or left hand side of the connection. The horizontal axis of Figure 5 denotes the crack length. Usually, when a dominant crack grows, other cracks grow simultaneously but at different rates. Plausible situations were investigated and evaluated. The critical failure load of a single mid span connection is taken as reference (100%), top curve in Figure 5. This curve goes down with increasing crack length and increasing symmetrical crack growth is likely to occur. Now two connections are considered. For different crack growths rates on either side of the connection, the parameter ω_c is introduced. This parameter represents the ratio of the length of two cracks on either side of the connection, for instance $\omega_c = \lambda_4 / \lambda_3$ including the increments, Figure 5(b). For a symmetrical crack growth, $\lambda_4 = \lambda_3$ this parameter become $\omega_c = 1$, Figure 5 (b) top. This line is indicated in the graph, Figure 5(a). A small crack length starts at 100% meaning the splitting strength with two connections is twice the single connection strength; this agrees with Jensen's [8] model.

If the crack growth towards to support is dominant, while the crack growth towards mid span is very small, resulting in $\omega_c \ll 1$, the

critical load per connection would not exceed about 0.71 times the single connection critical splitting load. In total the failure load would be about 1.4 the single connection splitting strength. This explains the results of Kasim and Quenneville [7]. If the crack growth towards mid span is dominant while the crack growth towards the support is very small, resulting in $\omega_c \gg 1$, the critical load per connection will not exceed 0.71 times the single connection splitting load. In total, the failure load would be 1.4 the single connection splitting load. For intermediate situations of crack growth, the failure load can go up to about 0.9 times the single connection splitting load so creating a total load of 1.8. Nature will usually choose the situation with the lowest resistance and the maximum failure will happen at about 1.4 time the single load splitting load.

3 Experimental Verification

Apart from the theoretical model development, Schoenmakers [6] performed many tests, some of which were conducted to verify his two connection model. Later tests by Leijten, used three equally spaced connections along the span, Figure 6. The latter tests were carried out in 2013 and used timber from the same batch of Spruce beams as Schoenmakers [6], strength class C24 (5% characteristic bending strength is 24 N/mm²).

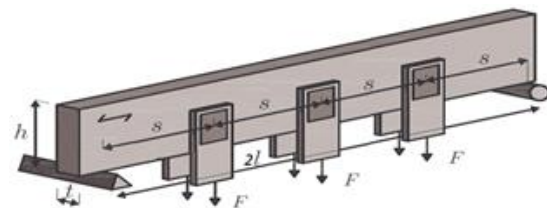


Figure 6. Arrangement with three connections,

The glued laminated beams used had a mean density of 450 kg/m³ and moisture content of 12.7%. The cross-section varied from 45x300 for the glued laminated beams to 40x220mm² for the solid beam. Nailed connections had 5 rows of 5 nails= 25 nails in a square pattern. For the other tests sawn timber beams was used with a mean density of 455 kg/m³ and 12.9% m.c. For the sawn wood beams four close spaced (4*d*) 12mm diameter dowels were used set in a square pattern. All beams failed brittle by splitting. In addition, Schoenmakers [6] also tested cantilevered beams with connections at the end and half way the cantilever length but these are omitted here. Series comprised of three connections were equally spaced at two times the beam depth, 2*h* along the span. All three connections were loaded by separate hydraulic actuators, each having a load cell to check for any differences. These were insignificant. Crack initiation and growth direction were studied with special LVDT's 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 70% of the tests, the crack initiation started at the connections near the support. A dominant crack growth direction was difficult to determine. In 30% of tests a symmetric crack growth could be determined. In 50% of the cases a leading crack direction could not be established. To allow comparison between test series using different cross-sections, distance from the support, number and type of fasteners the mean apparent fracture parameter $(GG_c)^{0.5}$ was calculated per test series with Eq.(1).

This fracture parameter was further adjusted for the following reasons: From evaluation of his total data base, Schoenmakers [5] found a 10% higher mean value with glued laminated beams.

This takes 10% off for test series 1, 2 and 9 & 10.

$$F_{ult} = 2F_{crit} = 2t \sqrt{\frac{GG_c h \alpha}{\frac{3}{5}(1 - \alpha)}} \quad (1)$$

where,

- F_{ult} the splitting capacity
- F_{ult} the splitting force on each side of the connection
- t beam width
- G shear modulus
- G_c material parameter by calibration to tests
- h beam depth
- α ratio of loaded edge distance and depth

When beams with two or three connections are tested the weakest will always fail first and distorts comparison of the mean value between series. Therefore the average values of the

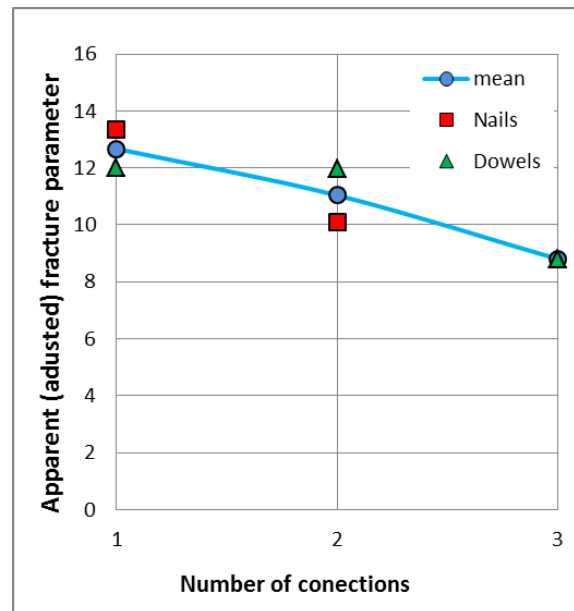


Figure 7. Decrease in fracture parameter.

fracture parameter of these test series were adjusted using established statistical procedures, Douwen et al. [9]. It assumes that the results are normally distributed resulting in a rise of the mean fracture parameter of approximately 10%. Having taken these factors into account the nailed connections showed a distinct difference in strength between tests with one and two connections. The strength ratio of 0.70, which is close to the predicted value by Schoenmakers [5] of 0.71, agrees well with Kasim and Quenneville [7]. For connections with dowels the situation is different because no significant difference is found between the corrected fracture parameter of one and two connections, i.e. 11.97 and 11.21 respectively. Apparently three connections apparently have a very significant effect, with a drop in strength to 0.64 per connection. No model is yet able to explain this behavior. Schoenmakers model might be a good candidate, however, when extended to three connections.

The consequences of these test results are considerable if one understands that in a number of semi-empirical and empirical models, the connections are considered as separate connections when spaced more than twice the beam depth. In Figure 8 the total load of all connections together is presented as ratio of the single connection strength on the vertical axis. The number of connections is shown on the horizontal axis. The two dots for beams with two connections represent the mean splitting strength for connections with nails and for dowels. The predictions by EN1995-1-1 are always safe and show no increase with the number of connections. As such the EN1995-1-1 prediction is conservative. There is one curve in Figure 8 that assumes a proportional increase of the splitting strength. This curve is based on Ehlbeck and Görlacher [3] which forms the backbone of

the German DIN 1052 standard and is clearly an unsafe design approach. Schoenmakers' model predicts 1.4 for two connections as lower boundary which seems to be closer to the reality than the other models. The Schoenmakers' model would be a good candidate to model three connections in future.

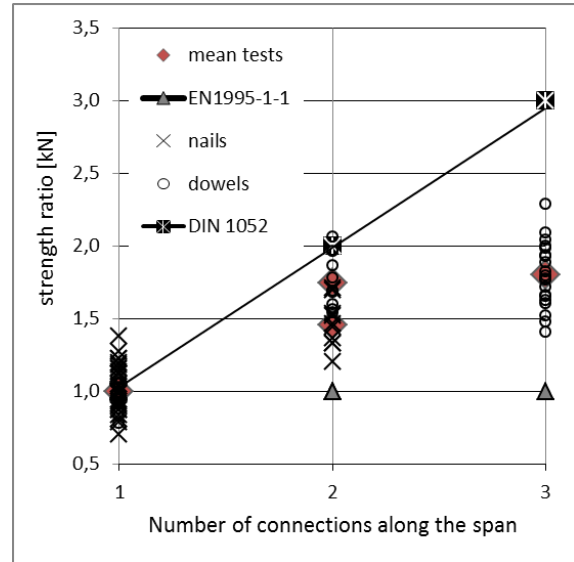


Figure 8. Strength of multiple connections.

4 Conclusions

Multiple connections spaced along the span of a simply supported beam significantly affect the total load bearing splitting capacity compared to one connection. None of the empirical or semi-empirical models are able to predict the correct splitting capacity. Only the fracture model by Schoenmakers [5] for two connections is able to provide a satisfactory prediction of the splitting capacity and is a promising candidate for the explanation of the splitting strength with three connections. Current Eurocode 5 splitting provisions are conservative while the DIN 1052 model grossly overestimates the splitting strength.

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