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Technical simulation of knots in structural wood

IZABELA BURAWSKA, MARCIN ZBIEĆ, JACEK KALICIŃSKI, PIOTR BEER
Department of Technology, Organization and Management in Wood Industry, Faculty of Wood Technology, Warsaw University of Life Sciences - SGGW

Abstract: *Technical simulation of knots in structural wood.* Wood, as inhomogeneous material, creates many difficulties for both designers and engineers. This situation is related to the highly variable properties of wood, even within a single element. Therefore, it is complicated to predict woods technical parameters, what causes necessity of using high quality timber, free from defects, along with application of high safety factors. At the same time, attempts have been made to non-destructively evaluate wood strength parameters, by numerical analysis and others. In such analyzes it is necessary to make some simplifications. The aim of study was to verify the similarity of knots to the openings from mechanical point of view. It was found, that knot and the corresponding opening of the same shape, size and location, equally affect the ultimate force and MOR. There are no statistically significant differences between the mean values of MOE and deflection gain in any range of loads.

Keywords: wood defect, numerical analysis, knot, opening

INTRODUCTION

Knots are the most common defect of structural wood. Their presence lowers grade of timber and strength parameters, depending on their size, location and condition. Knots infected with biological corrosion reject wooden element from the use in building construction. Sound knots with a large diameter or groups of smaller knots, weakening structural elements subjected to tensile forces, are also undesirable. In the slightest extent knots reduce the stiffness of bended timber (expressed by the modulus of elasticity), while in the greatest - bending strength [Dzbeński, 1984]. It is estimated that presence of knots decreases tensile strength by up to 85% [Krzysik, 1975; Dahl, 2009]. Therefore knots are the common cause of total exclusion of wood from structural applications.

Therefore, for the construction of new structures in a cost-effective and rational way, it is essential to use strength graded timber. This is made possible through the use of timber with guaranteed physical and mechanical properties [Dzbeński et al, 2000]. These properties can be predicted on the basis of a visual grading of timber or by initial, non-destructive testing, enabling determination of timber parameters, which are correlated with its strength. There are a number of standards, providing guidelines on principles and methods for determining the grade of structural wood. Among these are PN-EN 14081-1:2007, PN-EN 518:2000, as well as foreign: EN 14081-4:2005, BS4978:2007, STN 49 1531:2001 and other.

Regarding shortage of high quality raw materials and continuously increasing stock prices, attempts to obtain a more sustainable, cost-effective and rational materials management are noticeable recently. As a supplement it is necessary to develop a system predicting the strength properties of wood basing on its structural properties. For this purpose, computer programs for non-destructive analysis of wood under load are useful.

The high heterogeneity of wood leads to the need for certain simplification of analysis. A very complex structure of wood, subjected to additional disturbances in the form of natural defects of varying size and placement, makes the analysis very difficult. There is need to develop a universal method of simulating natural wood defects, knots in particular. Many problems occur in a description of material, especially in strength parameters, as well as method for determination of extent and the way of bonding defects with surrounding wood.

Numerical tests carried out simultaneously with experimental studies complemented to the development of methods for predicting load capacity and strength of wood. The issue of modelling the nonlinearity of grain direction, proprietary to knots, is not so clear. There are no clear answers on how to model a spiral grain and whether it is necessary at all. More and more methods are being developed, such as using change in the material axis directions [Baño et al., 2011], as well as more complex, using the theory of laminar flow of liquid stream over an obstacle that reflects knot [Guindos, Guaita, 2012].

Modelling deals also with knot itself. In case of wood numerical analysis, it is necessary to make some simplifications. However, control of the data introduced into the program is required. Based on numerical studies it was found that in terms of strength, highest degree of conformity to the real timber board was gained when knot was modelled as a bore [Baño, 2009]. Knot modelled as element made of material with a higher density and differently oriented material axis, adherent or partially adherent to the surrounding wood, caused greater error of load capacity estimation. So far numerical analyses were practically limited to centric knots, analyzed as bores. Obviously, depending on sawing method, knots may have a different shape. Therefore, the aim of study is to technically review the assumptions that may be used in numerical analysis, simplifying the knot to the opening, corresponding in shape and position.

MATERIALS AND METHODS

Tests were carried out using pine samples in semi-technical scale, with dimensions 20mmx40mmx800mm.

Samples were divided into two series. A-series was created by samples loaded with natural defect in form of a knot with varying shape, position and size. For each sample has been matched sample of B-series, similar with fiber pattern. These samples have been weakened with simulated defect in the form of opening. The shape of the opening, its size and location were corresponding to the naturally defected sample of A-series.

Figure 1 shows an example set of samples used in the study.

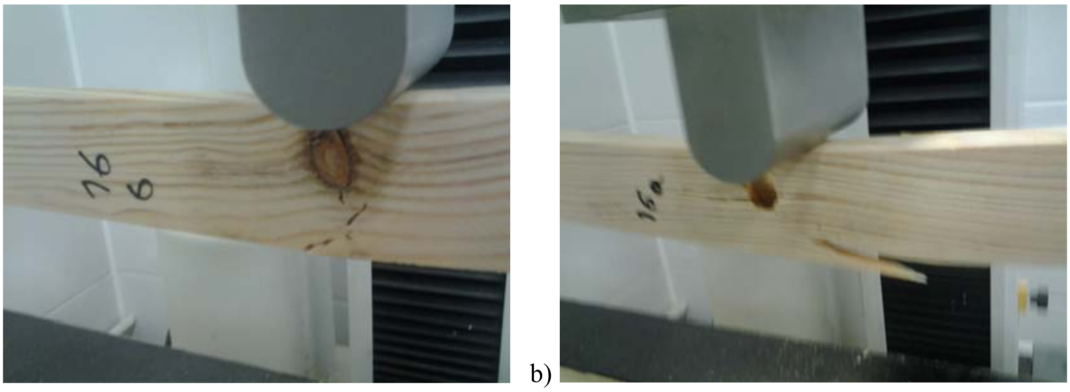
a) b)

Fig. 1. Exemplary set of samples a) A- series (naturally defected with knot), b) B-series (weakened with opening of the same position, shape and size)

Samples weakened in natural and controlled way were tested in aim to determine bending strength. Free support and 3-point bending scheme was applied, according to the EN 408:2012 (figure 2).

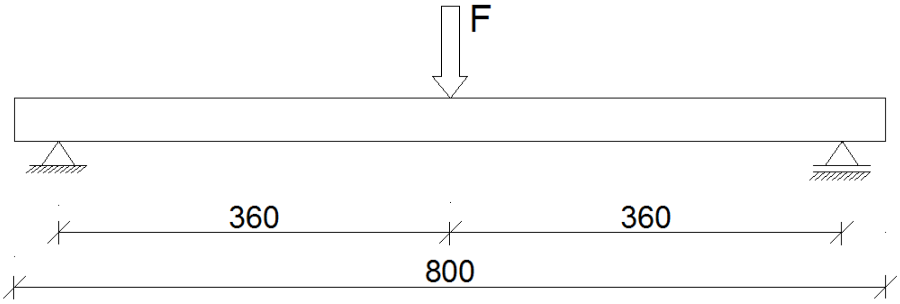

Fig. 2 Testing station diagram

The feed rate of load-carrying beam was equal to 7.2 mm/min. A PC and multi-channel measuring system were used to record the results. During the study load and displacement in the middle of the span were measured. Based on the obtained data, ultimate force, MOR, MOE and deflection for varying values of load were determined. Photographic documentation of the fracture type was also gathered.

RESULTS AND DISCUSSION

Basing on performed tests, load - displacement dependencies for each sample were obtained. Comparing the graphs for A-series samples, loaded with natural defect and for B-series, loaded with simulated defect of the same shape, size and location, it can be seen that they have the similar properties. Figures 3-6 show exemplary sets of samples together with designated load - displacement dependencies.

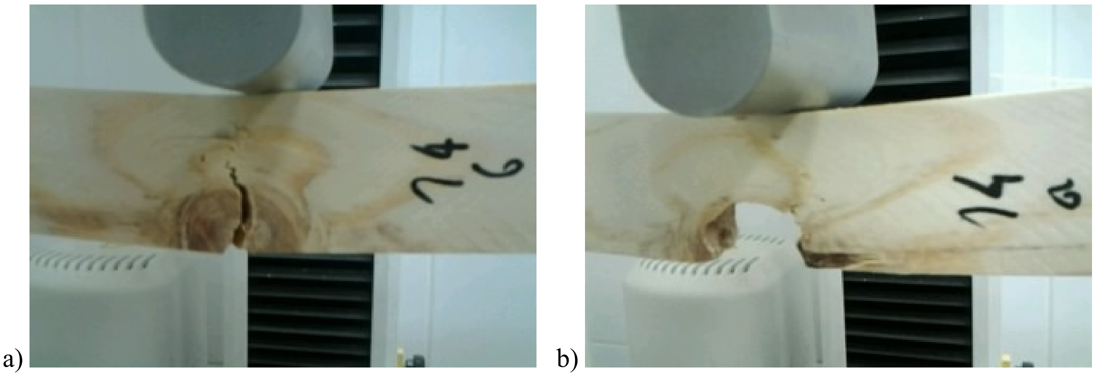

Fig. 3 Exemplary sample no 14, a) loaded with natural defect- knot, b) weakened with opening

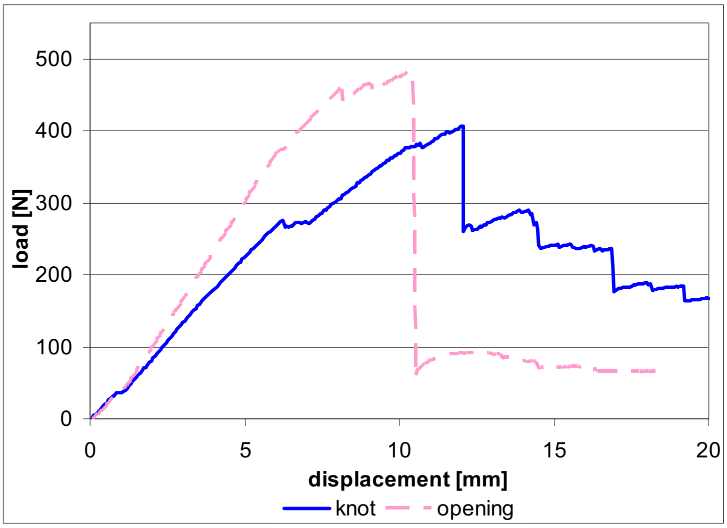

Fig. 4 Load - displacement dependence for set of corresponding samples (14a and 14b)

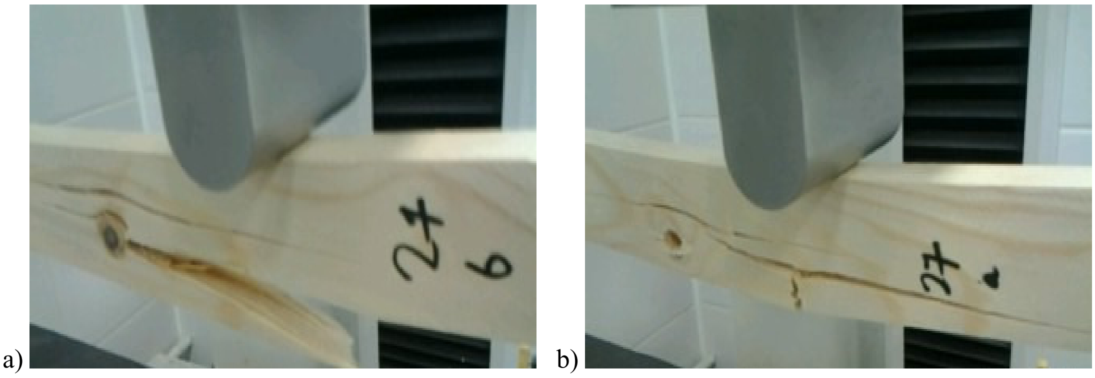

Fig. 5 Exemplary sample no 27, a) loaded with natural defect- knot, b) weakened with bore

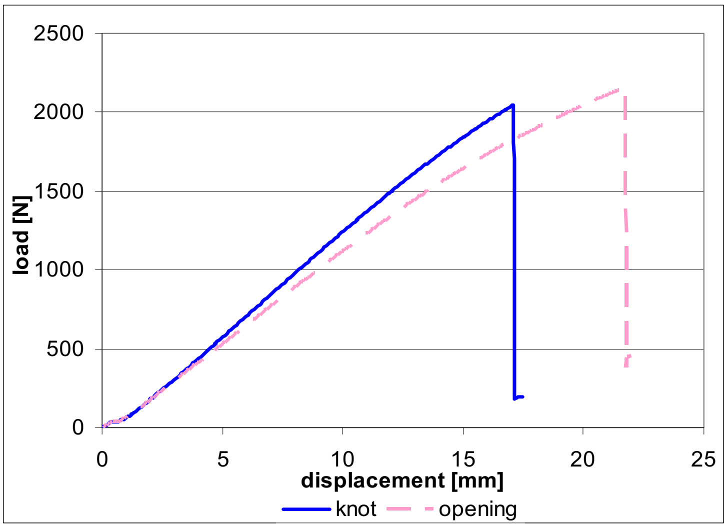

Fig. 6 Load - displacement dependence for set of corresponding samples (27a and 27b)

Basing on the analysis of the graphs, it can be seen, that in case of samples weakened with simulated defects (openings) character of destruction is more rapid in relation to samples weakened with natural defects. Destruction takes place in most cases without accompanying indirect cracks. Figure 7 shows ultimate load values reached for consequent pairs weakened with knot or opening. It can be seen, that for each set of samples ultimate load is similar. Statistical analysis, partially shown in Table 1, shows that mean differences between ultimate force reached by samples of A and B-series are not statistically significant (at the 95% level). Statistical analysis was performed using t-test. It can be noticed, that samples used in the study were selected randomly. Both high quality samples, weakened with small knot located in the neutral zone of bending element (samples no 15, 30) as well as samples of very low quality, with high resin content and large knot located in the tension zone (sample no 14, 21) were tested.

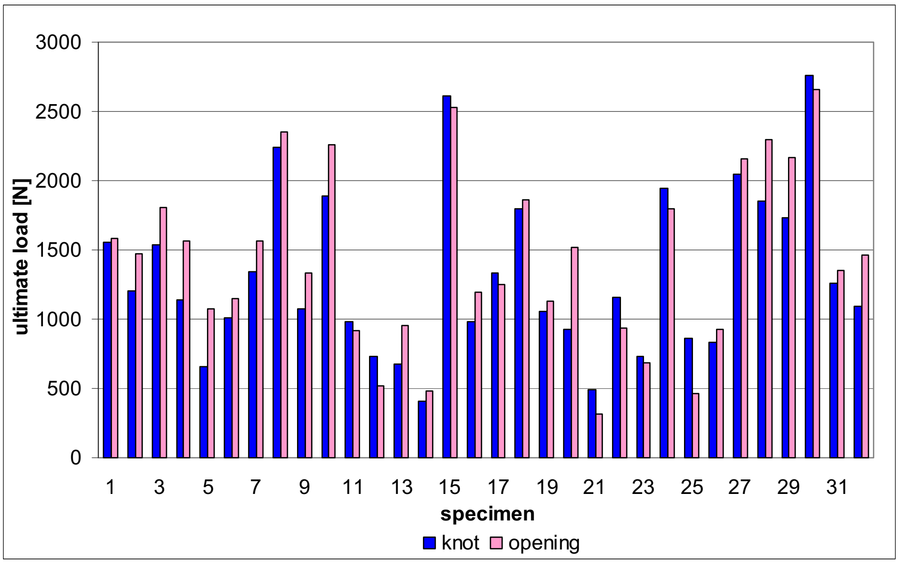

Fig. 7 Ultimate load depending on the type of defect

Tab. 1 Average ultimate load depending on the type of defect (knot/opening)

Parameter	**Knot**	**Opening**
Mean ultimate load [N]	1310.2	1428.7
Standard deviation [N]	591.8	634.6
Coeff. of variation [%]	45.2	44.4

Figure 8 shows MOR values obtained for each pair. The scatter of results between the average values is clearly visible (table 2), but it indicates only a varying quality samples used for testing. There is a noticeable correlation of MOR results for the corresponding samples of both series. Statistical analysis did not show statistically significant differences between the values of MOR gathered for A-series (weakening with knots) and B- series (weakening with openings).

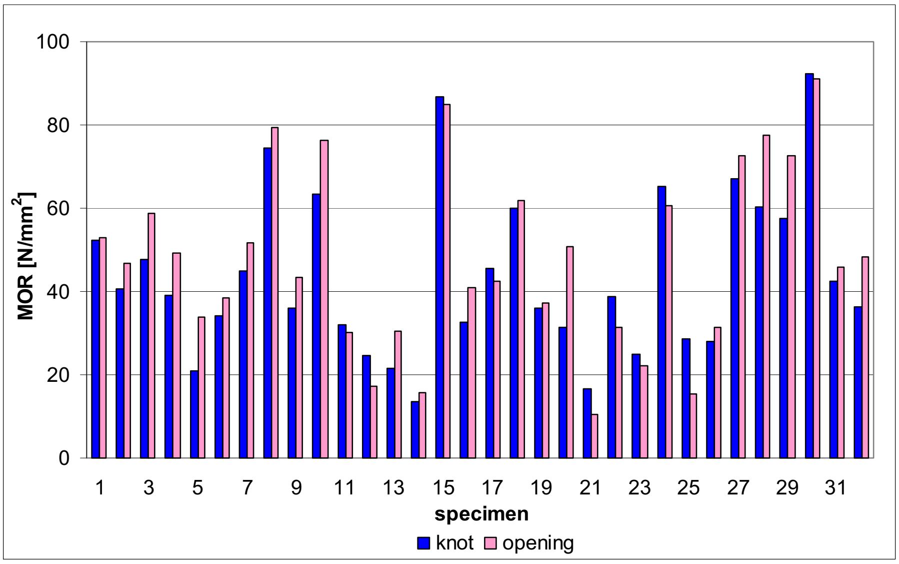

Fig. 8 MOR depending on the type of defect

Tab. 2 Average MOR depending on the type of defect (knot/opening)

Parameter	Knot	Opening
Mean MOR [N/mm^2]	43.6	45.9
Standard deviation [N/mm^2]	21.6	19.7
Coeff. of variation [%]	45.1	46.9

Statistical analysis showed, that the differences between the mean values of MOE (table 3) and deflection gain in any range of forces, including the elastic range of element (table 4) are statistically insignificant. Figure 9 shows MOE values for each sample, while figure 10 presents deflection gain within the range of 10-40% of ultimate force.

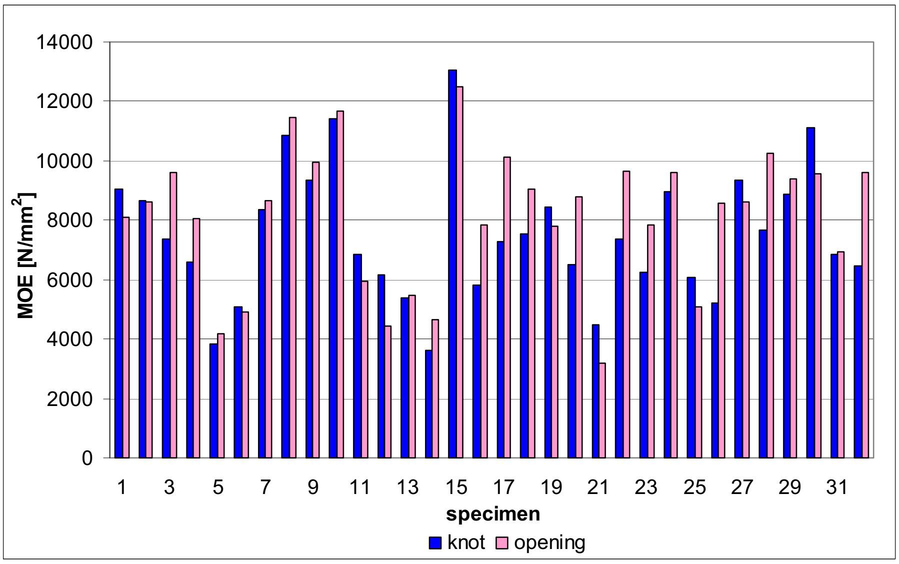

Fig. 9 MOE depending on the type of defect

Tab. 3 Average MOE depending on the type of defect (knot/opening)

Parameter	Knot	Opening
Mean MOE [N/mm^2]	7496.5	7915.8
Standard deviation [N/mm^2]	2216.8	2328.4
Coeff. of variation [%]	29.6	29.4

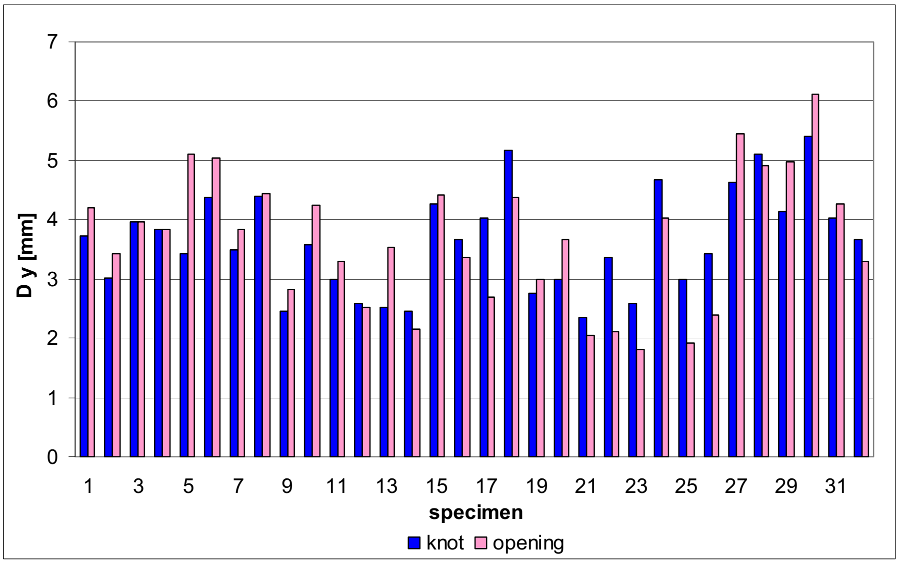

Fig. 10 Deflection gain within the elastic range of element (10-40% of ultimate load) depending on the type of defect

Tab. 4 Average deflection gain in the elastic range of element depending on the type of defect (knot/opening)

Parameter	Knot	Opening
Mean deflection gain [mm]	3.63	3.58
Standard deviation [mm]	0.85	1.12
Coeff. of variation [%]	23.4	31.3

CONCLUSIONS

Basing on the performed studies, one may conclude:

- element loaded with natural defect in form of a knot corresponds to the element weakened with opening in terms of bending strength parameters (MOR, MOE, ultimate force, deflection),
- fractures of elements weakened with opening are more severe, often without warning audible cracks,
- it is reasonable to make simplifications of the knots into the openings of the same shape, location and size in FEM- calculations.

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Streszczenie: *Techniczne odwzorowanie sęków w drewnie konstrukcyjnym.* Drewno, jako materiał niejednorodny, stwarza wiele trudności zarówno konstruktorom jak i projektantom. Związane to jest z dużą zmiennością jego właściwości, nawet w obrębie jednego elementu. W związku z tym utrudnione jest przewidywanie jego parametrów technicznych, co skutkuje koniecznością stosowania drewna bardzo wysokiej jakości, pozbawionego wad, przy jednoczesnym stosowaniu wysokich współczynników bezpieczeństwa. Jednocześnie trwają próby dokonywania nieniszczącej oceny parametrów wytrzymałościowych, m.in. poprzez badania numeryczne. W analizach tych niezbędne jest wprowadzanie pewnych uproszczeń. Celem przeprowadzonych badań była weryfikacja podobieństwa sęków do otworów pod względem mechanicznym. Na podstawie badań stwierdzono, że sęk oraz otwór o tym samym kształcie, położeniu i wielkości jednakowo wpływają na redukcję nośności oraz MOR. Brak jest różnic istotnych statystycznie pomiędzy średnimi wartościami MOE oraz wzrostem ugięcia w dowolnym zakresie sił.

Corresponding author:

Izabela Burawska
Department of Technology, Organization and Management in Wood Industry,
Faculty of Wood Technology,
Warsaw University of Life Sciences – SGGW,
159 Nowoursynowska St., B. 34,
Poland
email: izaburawska@o2.pl