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Local concentration of stresses as a result of the notch in different positions to the bottom surface of bending solid timber beam based on numerical analysis in Solidworks Simulation environment

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Abstract: *Local concentration of stresses as a result of the notch in different positions to the bottom surface of bending solid timber beam based on numerical analysis in Solidworks Simulation environment.* The study investigated the phenomenon of local concentration of stresses in the bent timber beams weakened by the opening. Weakness in the timber simulate knotholes or decayed knots. It was found that the value of local concentration of stresses and stress concentration factor depends , i.a., on the strength of the bending load, cross-sectional dimensions of beams, as well as the size and location of the opening in relation to the bottom surface of bending beam.

Keywords: bending, notch, normal stresses, numerical analysis

INTRODUCTION

Timber strength class directly depends on the quality of wood raw material from which it is harvested. Wood sawn from logs with a small diameter and from high parts is loaded with natural defects such as knots, which are the most important criterion, determining the grade of timber [Krzosek, 2009]. The adverse effect of knots manifests itself in reducing longitudinal tensile, bending and compression. Research shows that the impact of knothole made by decayed or loosed knot is comparable with the effect of a knot itself [Krzysik, 1975]. However, knotholes are even more negative since they act as a notch in structural elements. It was shown that all the discontinuities of geometry, which include openings, grooves, etc. cause the disorder of stress distribution [Stachurski, 2010].

The aim of this paper is to investigate the influence of size of the opening, as the remnant of the knot, and its position relative to the bottom surface of the bending beams on the normal stress distribution.

NUMERICAL ANALISYS

The model of wooden structural element and analysis of its behavior under the load was conducted using the finite element method in Solidworks Simulation. Considered element was modeled as a solid timber pine beam, as orthotropic elastic material with cross-section dimensions of 50x100x2000 mm and the characteristic values of the resistance parameters were specific to timber class C22 (table 1.).

Table 1 Material parameters

5% modulus of elasticity parallel E_x	6700 MPa	Compression parallel	20 MPa
Mean modulus of elasticity perpendicular E_y	330 MPa	Compression perpendicular	2.4 MPa
Mean modulus of elasticity perpendicular E_z	330 MPa	Shear	3.8 MPa
Mean shear modulus G_{xy}	630 MPa	Yield point	20 MPa
Mean shear modulus G_{xz}	630 MPa	Poisson's Ratio ν_{xy}	0.4
Mean shear modulus G_{yz}	630 MPa	Poisson's Ratio ν_{xz}	0.025
Tension parallel	13 MPa	Poisson's Ratio ν_{yz}	0.4
Tension perpendicular	0.4 MPa	Density	340 kg/m^3

A model of real instruments applied during resistance tests was prepared with the recommendations of the PN-EN 408:2004 standard (Fig. 1.). The support and upper points of contact were designed as made of alloy steel, which was available in the software directory. Figure 2 shows the scheme of the supports and upper points of contact.

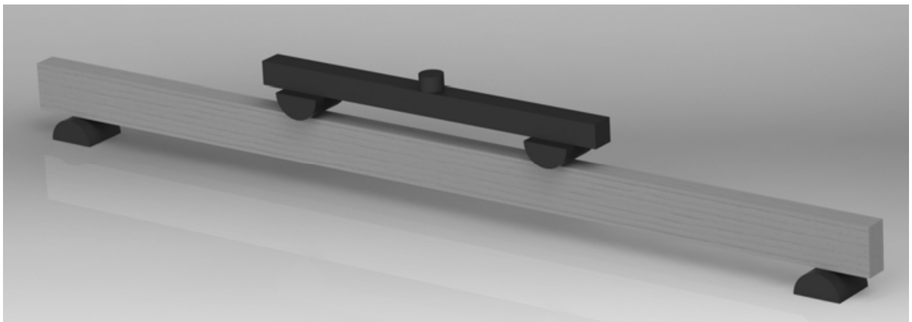

Fig. 1. Experimental workplace view

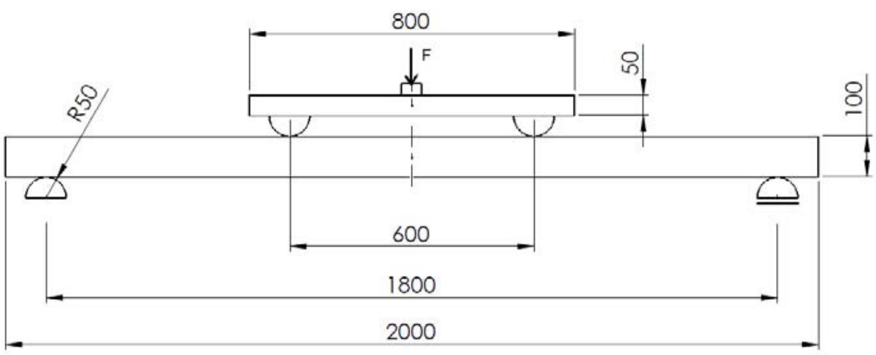

Fig. 2. View of the layout of the support and upper points of contact

Points of weakness of wooden beams made by decayed of loosed knots were modeled as openings with a diameter of 10mm and 20mm, located perpendicularly to the side surface of the element. Openings in posterior tests were moved by 5mm (Fig. 3.). Middle of the φ10 opening was located 6,5mm and middle of φ20 opening was located 11.5mm from the bottom surface of the beam. In both cases to obtain the thickness of the stretched fibers of 1.5mm.

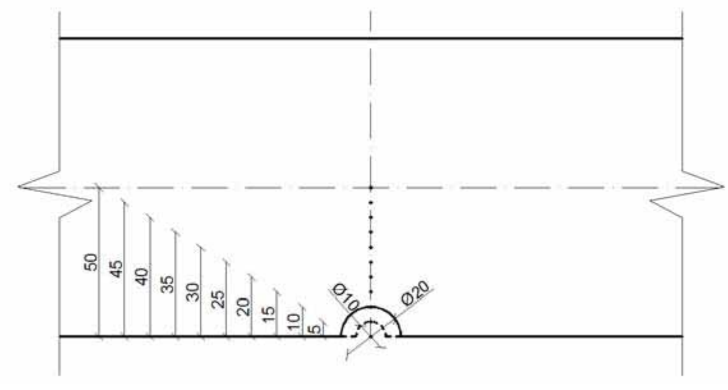

Fig. 3. Location of φ10 and φ20 openings in respect to the bottom surface of the beam

Beam weakened by φ10 and φ20 openings differently positioned was loaded by force P=6kN and P=8kN, to investigate the impact of load on the normal stresses distribution. For comparison and verification of the results beam without any openings was analyzed as well.

Measurement point of maximum normal stress depends on the distance of the middle of the opening to the bottom surface of the beam, further called as base surface. For φ10 and φ20 openings, for which the distance from the middle of the opening to base surface is less than their radius, the maximum normal stress was measured at A point (Fig. 4a.). However, for longer distances, point B was the place for measurement of maximum normal stress (Fig. 4b.).

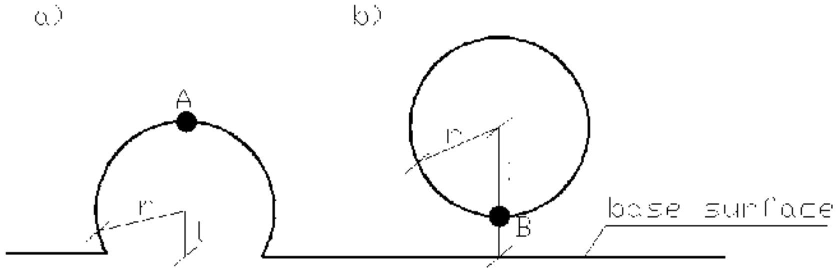

Fig. 4. Location of the measurement points a) when $l \le r$, b) when $l > r$; where l - distance between the middle of the opening and the base surface, r- opening radius

DISCUSSION OF RESULTS

Figure no 5 presents a chart showing the dependence of the results of normal stress around the knothole from its position against the base surface.

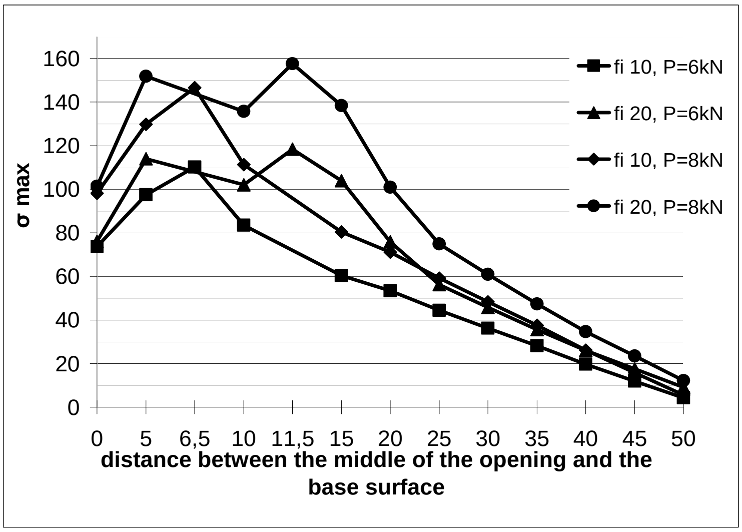

Fig. 5. Maximum normal stresses depending on the position of the center of the hole relative to the base area and loading force

The simulations showed that the normal stress distribution in the cross section depends on the distance between the middle of the opening and the base surface, its diameter and the value of loading force. The highest value of normal stress for the beam loaded by force P=6kN and P=8kN was obtained for the φ20 opening, when distance between the middle of the opening and the base surface was 11.5 mm. Longer distances were less important for the distribution of normal stress values. The same trend occurred for the φ10 opening. Once the maximum normal stress was reached for the distance between the middle of the opening and the base surface 6.5 mm, along with approaching to neutral bending axis of the beam impact of the opening was decreasing. In both cases, the maximum normal stresses appeared at measuring point located 1.5 mm to base surface. This is related to takeover of the whole normal stress by lower fibers of a small total thickness.

At a distance between the middle of the φ20 opening and the base surface 5 mm values of maximum normal stresses got precipitously high. This may indicate a greater impact of measuring point on the maximum normal stress value than the degree of weakening of the cross. The value of maximum normal stresses for the distance between the middle of the φ20 opening and the base surface 5 mm was read into a point distant from it about 15 mm, while for the distance 10 mm, was read into a point 20 mm away from the base surface.

The effect of loading on the normal stress distribution in the beam is clear. The greater the loading force, the larger values normal stresses gets..

Figure no 6 shows the location of the φ10 and φ20 openings that received the highest normal stress values while beams were loaded by force P=6kN. The most disadvantageous is a opening that is away at a small distance from the lower surface of the beam, although there are still stretched fibers.

a/	b/

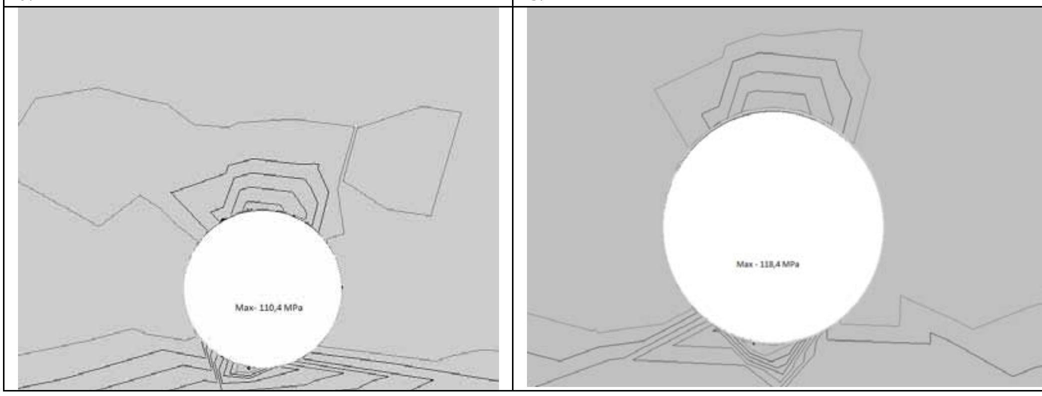

Fig. 6. Maximum normal stresses in openings a) φ10, b) φ20

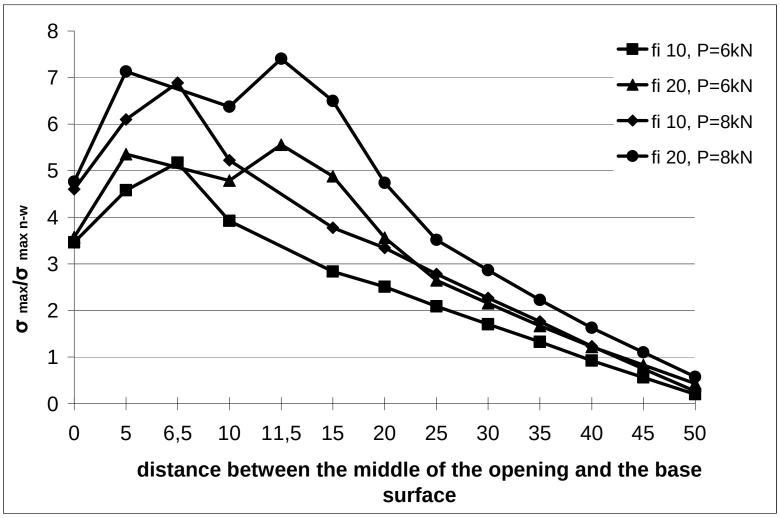

Fig. 7. The ratio of σ_{max}/ $\sigma_{max\ n\text{-}w}$ depending on the location of the middle of the opening relative to the base surface and loading force, explanation of the symbols in the text

Figure no 7 shows the dependence between ratio of the maximum normal stress (σ_{max}) and the maximum normal stress occurring in the nonweakened beam ($\sigma_{max,\ n\text{-}w}$), located in the extreme tension fiber and the distance between the middle of the opening and the base surface and load values.

Ratio of σ_{max} and $\sigma_{max,n\text{-}w}$, while moving toward the neutral axis, decreases. For φ10 and φ20 opening, whose center is located on the base surface, the ratio of normal stresses is similar for the load P=6kN and P=8kN. This indicates a comparable impact φ10 and φ20 opening positioned on the base surface on the distribution of normal stresses. The distance between the middle of the opening and the base surface increases until reaching the elevation of middle equal to the radius increased by 1.5 mm. For a load P=8kN ratio of σ_{max} and $\sigma_{max\ n,w}$ is 7.4. After reaching the maximum value, the value of ratio decreases.

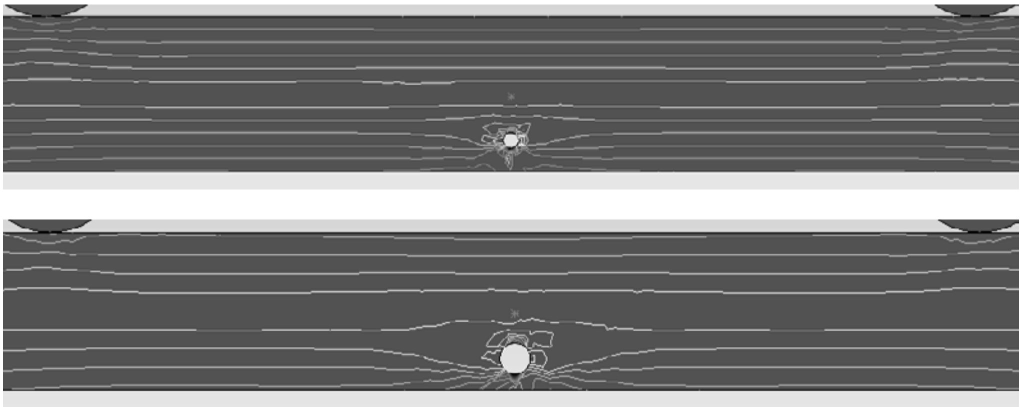

Fig. 8 Distribution of normal stresses to the φ10 opening (top) and φ20 opening (bottom) located in the middle of the span of beams

Figure no 8 shows the normal stress distribution for the two corresponding openings - φ10 and φ20, whose middles are 30 mm from the base surface. A different course of normal stress distribution is noticeable for both beams. In surroundings of small openings there is a rapid increase of stress but in relatively small area covering almost only the opening.
A short distance from the opening quickly compensates stress. Openings with a higher diameter cause less severe stress in their environment, in relation to smaller openings.

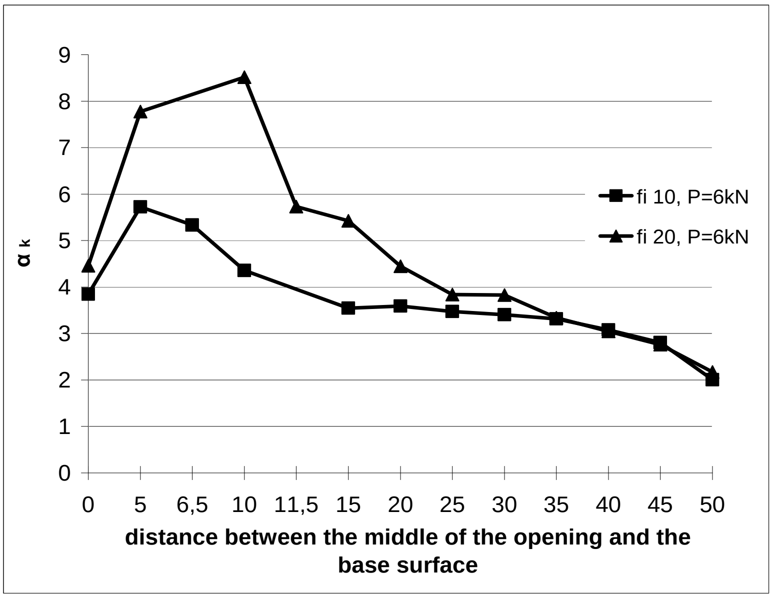

Fig. 9. The shape factor depending on the position of the middle of the opening relative to the base surface

To estimate stress amplification in vicinity of a geometric discontinuity can be used geometric stress concentration factors. Figure no 9 shows the distribution ratio of shape factor α_k depending on the distance between the middle of the opening and the base surface. Shape factor can be described as the ratio of stress increased by existence of the notch (which in this case occurs as an opening), and the stress at the same point, but for non-weakened material. The value of the shape factor depends on the value of the load. Higher forces result in a greater ratio of maximum stress occurring around the opening to the stresses that occur without an opening. Also the dimension of the opening has a huge influence. For φ10 opening which middle was located in 5mm to the base surface ratio was 5.7, while for φ20 this ratio was 7.8. The maximum value of the ratio of shape occurred in both cases, when the distance between the middle of the opening and the base surface was equal to the radius of the opening.

CONCLUSIONS

1) The highest normal stresses around the top of opening occur whenever the opening is beyond the section. The highest normal stresses around the bottom of the opening is always present whenever the opening is completely in a cross-section.
2) The smaller the thickness of the stretched fibers below the opening, the greater the value of normal stresses occur around the opening.
3) The normal maximum stress depends on the size of the opening, as the opening has a larger diameter the stress gets higher. Changing the size of maximum stress is not proportional, and as it approaches the neutral axis it disappears.
4) The ratio of maximum normal stresses around the opening to the maximum stress occurring in the beam without weakness, located in the extreme tension fiber is dependent on the load. For the force P=6kN it ranges from 0.2 to 5.2 for φ10 and from 0.4 to 5.6 for φ20. For the force P=8kN it ranges from 0.3 to 6.9 for φ10 and from 0.6 to 7.4 for φ20.
5) Shape factor reaches the highest value for openings whose middle is located at a distance equal to the radius of the opening. May therefore be concluded that for these cases, levels of stress accumulation is the greatest.

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Streszczenie: *Miejscowa koncentracja naprężeń jako skutek karbu o zmiennym usytuowaniu w stosunku do powierzchni dolnej zginanej belki na podstawie analizy numerycznej w Solidworks Simulation.* W pracy sprawdzano wpływ otworu, jako pozostałości po sęku wypadającym lub zepsutym na rozkład naprężeń normalnych w zginanej belce drewnianej. Wpływ ten zależał głównie od wartości obciążenia, średnicy sęka oraz od położenia jego środka od powierzchni bazowej, którą stanowiła dolna powierzchnia belki. Wykazano, że najbardziej niekorzystny pod względem maksymalnych naprężeń normalnych jest otwór, który całkowicie mieści się w przekroju, i który powoduje pracę niewielkiej grubości włókien rozciąganych.

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