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THE INFLUENCE OF ORTHOTROPY LEVEL FOR PERPENDICULAR TO GRAIN STRESSES IN GLULAM DOUBLE TAPERED BEAMS

W. Gilewski*, J. Pełczyński**

Abstract: *This paper presents parametric analysis of distribution of the delamination normal stress perpendicular to the grain in double tapered, simply supported beams made of glued laminated timber. The parameters are height of the beam in the apex area and the level of diversity of orthotropic material properties from the isotropy to orthotropy according to the standards of design. The calculations are performed by the finite element method (FEM) in terms of the linear theory of elasticity with plane stress assumption. The results of the FEM calculations are referred to the indications of the design standards.*

Keywords: Orthotropy, Glulam, Perpendicular to grain stress.

1. Introduction

One of the most important feature of the design of double tapered simply supported beams (see Fig. 1) with a glued-laminated timber is a need to consider delaminating action of stress perpendicular to the wood fibers and the possible reinforcement against this stress (Franke et al., 2015; Thelanderson and Larsen, 2003; Vratusa et al., 2011). In traditional calculations of beams this stress is neglected. Design standards provide formulae for normal stresses perpendicular to grain (dependent on the value of bending moment and slope of the beam in apex area) and the extent of their occurrence in the apex zone – the width of the zone is equal to twice the height of the beam (see Fig. 1). In real design the values and the distribution of these stresses depend on the geometry of the beam, the load (including the way of load application on the beam height), and material parameters. The purpose of this study is to evaluate the effect of variation of orthotropic properties of the beam on both the level and distribution of delaminating stresses.

2. Modeling

Modeling of the beam is based on a 2D linear theory of elasticity in plane stress condition for seven cases of orthotropic physical properties (Tab. 1). Geometry, load and boundary conditions are shown in Fig. 1.

Tab. 1: Material parameters.

Material	E_1 [MPa]	E_2 [MPa]	ν_{12}	G_{12} [MPa]
Ort-1 (EN)	12600	420	0.35	780
Ort-2	12600	2450	0.35	1428
Ort-3	12600	4480	0.35	2076
Ort-4	12600	6510	0.35	2724
Ort-5	12600	8540	0.35	3371
Ort-6	12600	10570	0.35	4019
Ort-7 (Isotropy)	12600	12600	0.35	4667

* Prof. Wojciech Gilewski, PhD., DSc.: Institute of Building Engineering, Warsaw University of Technology, Al. Armii Ludowej 16; 00-637, Warszawa; PL,w.gilewski@il.pw.edu.pl

** Jan Pełczyński, MSc: Institute of Building Engineering, Warsaw University of Technology, Al. Armii Ludowej 16; 00-637, Warszawa; PL, j.pelczynski@il.pw.edu.pl

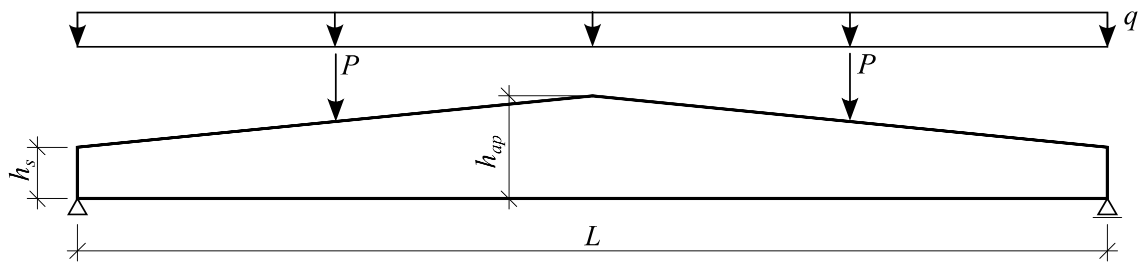

Fig. 1: Geometry, boundary conditions and loads.

The calculations were performed using the Abaqus FEM software (ABAQUS documentation, 2017, Zienkiewicz and Taylor, 2000). Two dimensional 8-node biquadratic solid plane stress elements (CPS8R) with reduced integration were used (Abaqus documentation 2017).

Figs. 2 – 5 present examples of distributions of tensile stresses perpendicular to the fibers for both the largest and lowest beam height considered in the analysis and for four of seven considered material properties loaded with either concentrated forces or distributed load.

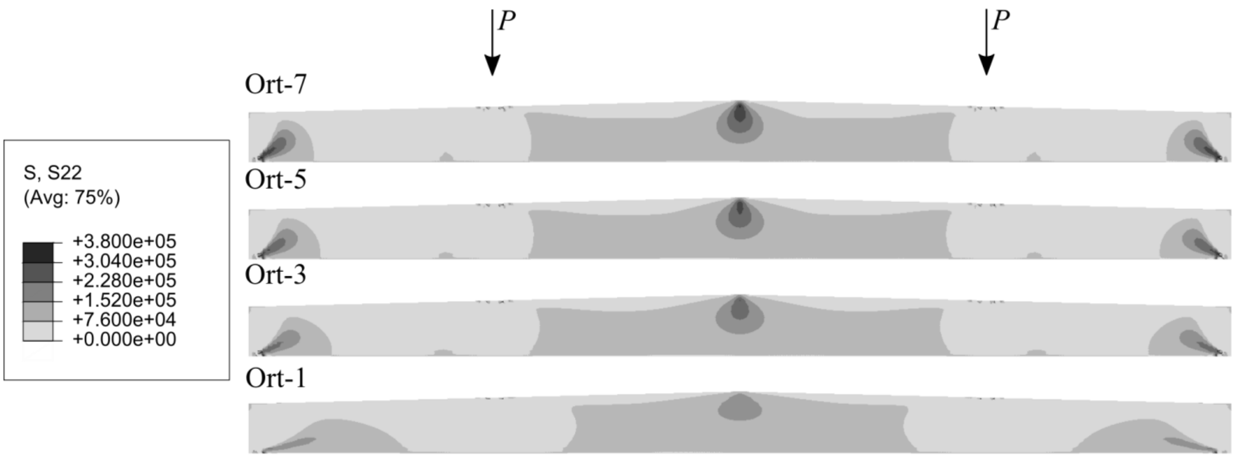

Fig. 2: Positive stress perpendicular to the grain.

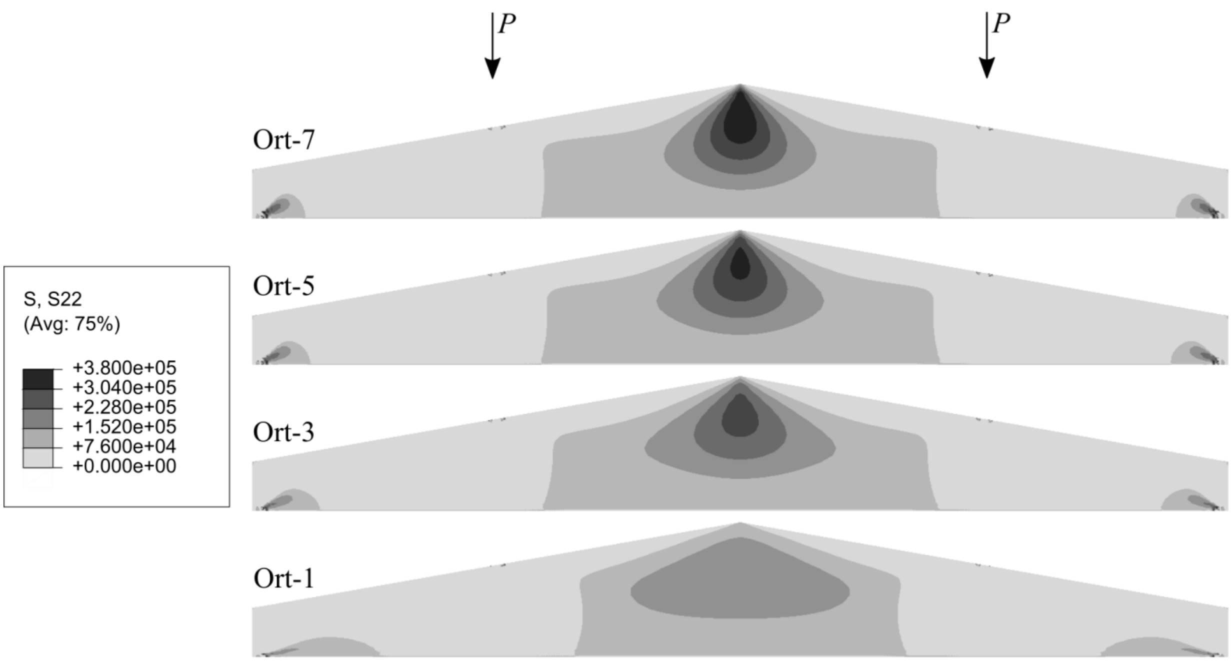

Fig. 3: Positive stress perpendicular to the grain.

The area of strictly positive tensile stress for the beam loaded with two concentrated forces is much wider than twice the height of standard design in the apex area (Figs. 2 and 3). This is particularly noticeable for low apex height. However, the level of the analyzed stresses deserves attention – from this point of view, the area of the zone in the beam of higher apex is wider. The width of the zones of significant stress is similar for different levels of orthotropy. The depth of the zone of significant stress is bigger for materials close to isotropy and is less than half the apex height. Strongly orthotropic properties lead to the lowest stress values. Tensile stresses in the boundary zones are not examined in this study.

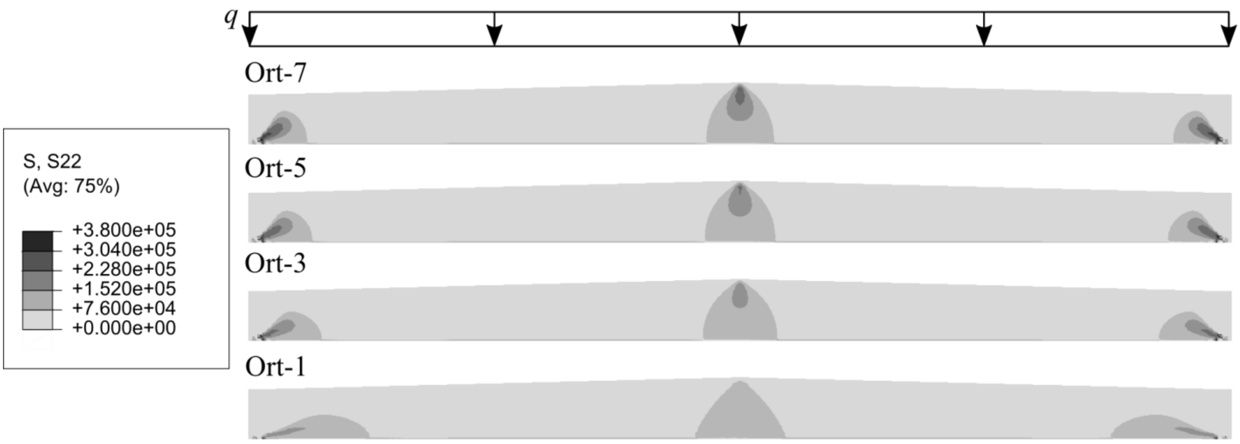

Fig. 4: Maximum stress perpendicular to the grain.

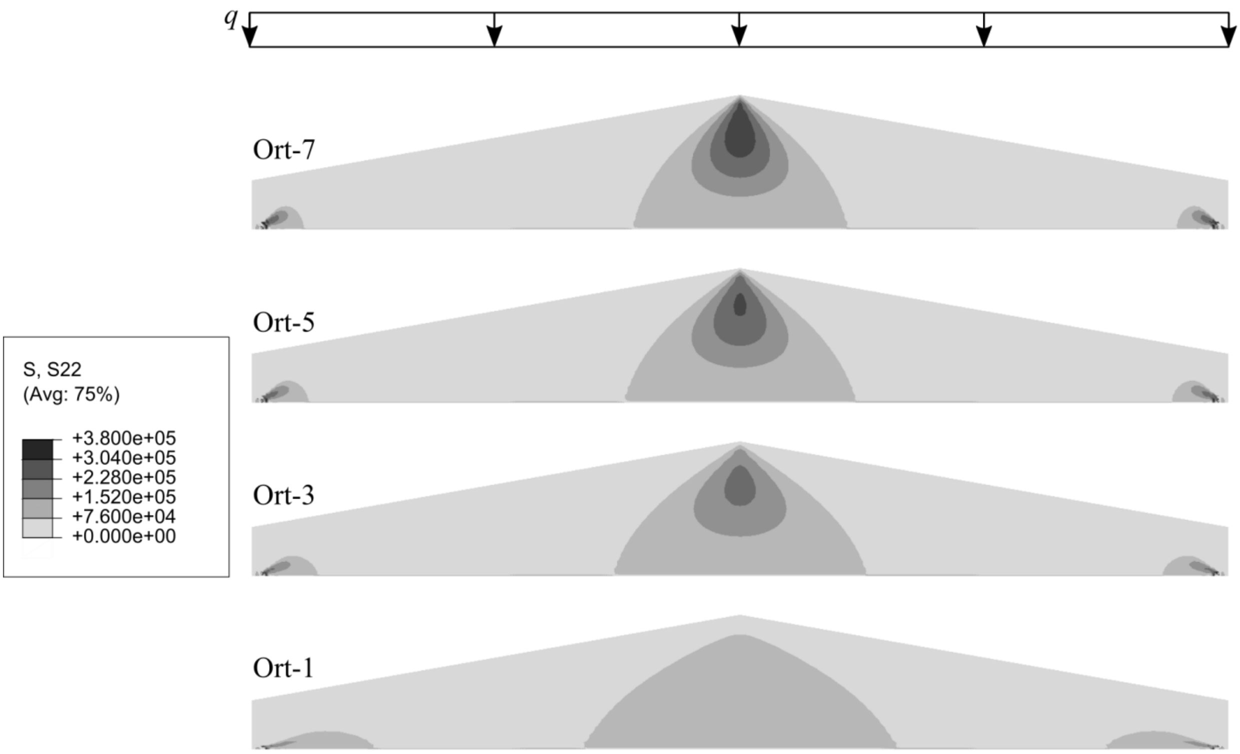

Fig. 5: Maximum stress perpendicular to the grain.

The zone of tensile stresses for uniformly distributed load is smaller than for the concentrated load. For distributed load the width of the zone in both higher and lower beams is close to doubled apex height, what is assumed in design codes. The depth of the relevant stress is smaller the case of uniformly distributed load – the stress is concentrated on the apex. Strong variation of the orthotropic properties leads to the reduction of gradients of stresses perpendicular to grain of the beam.

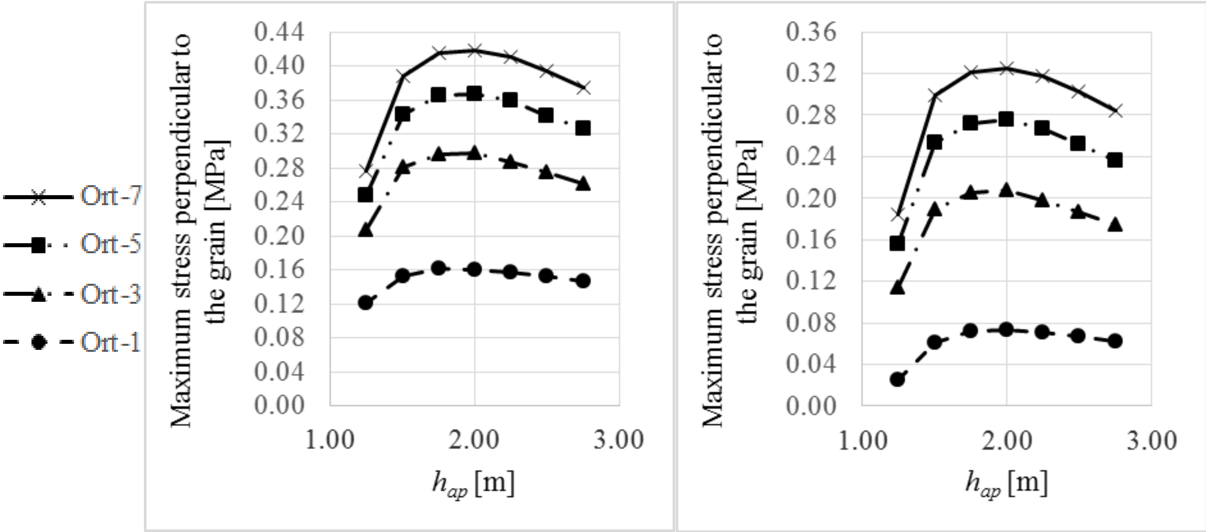

Fig. 6: Maximum stress perpendicular to the grain for a) concentrated forces; b) distributed load.

The maximum values of normal stress perpendicular to the fibers depend on the height of the apex and differentiation of the properties of orthotropy (see Fig. 6). Higher stress values are obtained for materials close to isotropy. Strong orthotropic material properties results in smaller stress variation according to the apex height. It is worth to mention that the greatest value for isotropy occur when the apex height is two times larger than the height in the boundary zone – the extreme moves in the direction of 1.75 for beams with different orthotropic properties, regardless of the type of load (see also Danielsson, 2010).

3. Conclusions

The paper presents parametric analysis of values and zones of normal stresses perpendicular to the grain of double tapered simply supported beams made of glued laminated timber. The width of the areas of stresses in the apex area depends on a small extent on diversity of orthotropic properties of the beam. In the extent relevant to the design the width corresponds to the area of standard design. Strong orthotropic material properties reduce the value of positive normal stress gradients and reduces their distribution. A visible impact of the beam geometry on the stress concentrations leads to the conclusion that in the beams with geometry not considered in design codes computational methods within the theory of elasticity are to be applied. The maximum values of normal stress perpendicular to the fibers are much higher for materials close to isotropy. Strong orthotropic material properties result in smaller stress variation according to the apex height.

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