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Influence of Grain Inclination Angle on Shear Buckling of Laminated Timber Sheathing Products

S.R. Atashipour[a,b,*], U.A. Girhammar[a]

[a] Department of Engineering Sciences and Mathematics, Division of Wood Science and Engineering, Luleå University of Technology, Skellefteå, Sweden
[b] Department of Civil and Environmental Engineering, Division of Structural Engineering, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden

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ABSTRACT

Recent advances in timber production industries have enabled production of new innovative laminated timber products having layers with grain inclination angle. This paper is aimed to study influence of grain inclination angle in the laminated veneer lumber (LVL) and plywood sheathings on their shear buckling loads. Two extreme edge conditions of simply supported and clamped edges are considered. First, an accurate differential quadrature (DQ) computational code is developed using MAPLE programming software to obtain eigen buckling values and their corresponding eigen mode shapes. Next, for convenience of engineering calculations, approximate algebraic formulae are presented to predict critical shear buckling loads and mode shapes of LVL and plywood panels having layers with grain inclination angle, with adequate accuracy. Furthermore, finite element (FE) modelling is conducted for several cases using ANSYS software to show validity and accuracy of the predicted results for the problem. It is shown that the highest shear buckling loads of LVL sheathings is achievable when the inclination angle of about 30° with respect to the shorter edges is considered for production of LVL panels, whereas the same angle with respect to the long edges of the LVL sheathings results in a relatively lower buckling load. Considering similar inclination angle with respect to any edges of a plywood sheathings will also results in its highest prebuckling capacity. It is also demonstrated that, under optimal design and certain loading circumstances, LVL shows a higher shear buckling capacity compared to a similar plywood sheathing.

1. Introduction

Nowadays, bio-composite structures have attracted much attention in design of many engineering applications. This is due to their superior properties and advantages as environmentally-friendly materials over other conventional materials.

Laminated veneer lumber (LVL) and plywood sheets are two types of high quality engineered timber products manufactured from thin plies of wood veneer that are glued together. In recent years, LVL and plywood sheets have been increasingly used in the building construction industry; e.g. as thin sheets in design of stabilising walls [1,2], beams and columns [1,3,4], floor cassette and joists [2–5], roof components [2,3], etc.

Because of their relatively high strength and thin-walled nature, LVL and plywood sheathings may be, in some building structures (e.g. sheathing/web panels surrounded by flanges/stiffeners), susceptible to shear buckling before reaching their material strength. This study is therefore devoted to shear buckling analysis of different laminated timber sheathings.

Unlike normal buckling of layered panels, the shear buckling problem has attracted less attention [6,7]; and most of the research studies available in literature on shear buckling of layered panels have dealt with analyses of common cross-ply (so-called special orthotropic) panels. Recently, Atashipour and Girhammar [8] presented a review of researches about shear buckling of composite plates and studied the shear buckling of a common LVL panel.

Plywood sheets are normally manufactured in such a way that their layers having wood grain aligned 90° to one another. Also, most of the plies in a common LVL have identical grain direction, but a few are aligned cross-wise. However, investigators have recently shown their interest toward the innovative idea of using angle plies in design of laminated timber products (e.g. see [9–11]). Apparently, shear buckling performance of LVL and plywood sheathings would significantly affected when their plies arranged nonparallel to the length of the material.

This paper is devoted to investigating influence of grain inclination angle on shear buckling loads of LVL and plywood sheathings. Two different extreme edge conditions of simply-supported and clamped are

* Corresponding author at: Department of Civil and Environmental Engineering, Division of Structural Engineering, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden.
E-mail address: rasoul.atashipour@chalmers.se (S.R. Atashipour).

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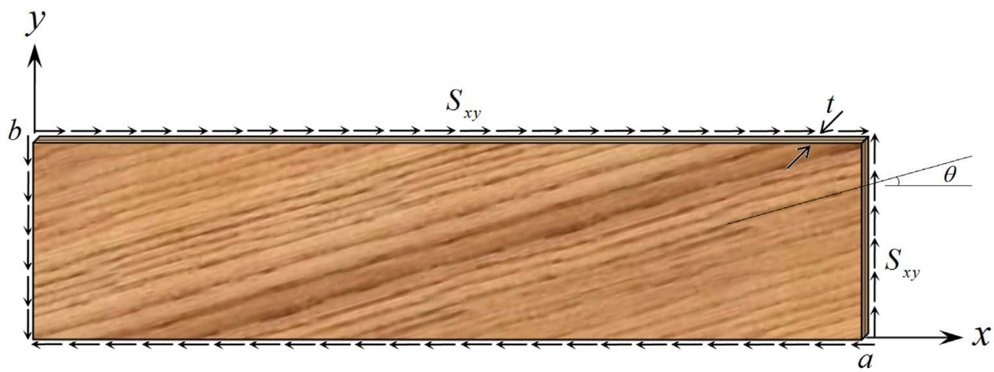

Fig. 1. Coordinate system and geometry of a layered timber sheathing under shear load.

considered. An accurate differential quadrature (DQ) computational code is developed using MAPLE programming software to obtain buckling load values and their mode shapes. Next, for convenience of engineering calculations, approximate, but efficient, algebraic formulae are presented to predict critical shear buckling loads and mode shapes of LVL and plywood panels having layers with grain inclination angle, with adequate accuracy. Also, some finite element (FE) modellings are conducted using ANSYS software to show the validity and accuracy of the predicted results for the problem.

2. Governing equations of the problem

Consider a rectangular N-ply laminated timber sheathing of length a, width b and total thickness t with inclination angle θ between horizontal edges and the grain orientation of the face-plies, subjected to a uniformly distributed shear load per unit length S_{xy} around its edges, as shown in Fig. 1.

The classical laminated plate theory (CLPT) is utilized here to study the shear buckling of LVL and plywood sheathings. It should be noted that layered timber products are usually produced by odd number of plies and symmetric layup sequence with respect to their middle surface to avoid warping. In other words, coupling between in-plane and transverse deformations vanishes. Therefore, the governing equation of transverse deformations for a symmetrically layered generally orthotropic plate should be solved for the problem, which is represented as

$$\overline{D}_{11}\frac{\partial^4 w}{\partial x^4} + 4\overline{D}_{16}\frac{\partial^4 w}{\partial x^3 \partial y} + 2(\overline{D}_{12} + 2\overline{D}_{66})\frac{\partial^4 w}{\partial x^2 \partial y^2} + 4\overline{D}_{26}\frac{\partial^4 w}{\partial x \partial y^3} + \overline{D}_{22}\frac{\partial^4 w}{\partial y^4} = 2S_{xy}\frac{\partial^2 w}{\partial x \partial y} \tag{1}$$

where w is transverse displacement, and $\overline{D}_{ij}$ are some stiffness parameters. The laminated timber sheathing which are considered here are assumed to be fabricated in a way that their edges are not parallel to the grain orientation (axes of material orthotropy) of each ply. An angle θ is considered between the longitudinal (horizontal) edges and the grain orientation of the face-plies (see Fig. 1). Therefore, the stiffness parameters $\overline{D}_{ij}$ are defined as

$$\overline{D}_{ij} = \int_{-t/2}^{t/2} \overline{Q}_{ij} z^2 \mathrm{d}z = \frac{1}{3}\sum_{k=1}^{N} \overline{Q}_{ij}^{(k)}(z_k^3 - z_{k-1}^3), \quad (i,j = 1,2,6) \tag{2}$$

where z_k and z_{k-1} represent the distance between the middle surface of the laminated sheathing to the upper and lower surfaces of the k-th layer, respectively, as shown in Fig. 2.

Also, $\overline{Q}_{ij}$ are the coefficients of the transformed stiffness matrix and are related to the stiffness coefficients of the stress-strain matrix Q_{ij} (corresponding to a special orthotropic plate or the case in which the principal material axes are parallel to the edges of the plate; i.e. $\theta = 0$) as follows

$$\begin{aligned}
\overline{Q}_{11}^{(k)} &= Q_{11}^{(k)}\cos^4\theta + 2(Q_{12}^{(k)} + 2Q_{66}^{(k)})\sin^2\theta\cos^2\theta + Q_{22}^{(k)}\sin^4\theta \\
\overline{Q}_{12}^{(k)} &= (Q_{11}^{(k)} + Q_{22}^{(k)} - 4Q_{66}^{(k)})\sin^2\theta\cos^2\theta + Q_{12}^{(k)}(\sin^4\theta + \cos^4\theta) \\
\overline{Q}_{22}^{(k)} &= Q_{11}^{(k)}\sin^4\theta + 2(Q_{12}^{(k)} + 2Q_{66}^{(k)})\sin^2\theta\cos^2\theta + Q_{22}^{(k)}\cos^4\theta \\
\overline{Q}_{16}^{(k)} &= (Q_{11}^{(k)} - Q_{12}^{(k)} - 2Q_{66}^{(k)})\sin\theta\cos^3\theta \\
&\quad + (Q_{12}^{(k)} - Q_{22}^{(k)} + 2Q_{66}^{(k)})\sin^3\theta\cos\theta \\
\overline{Q}_{26}^{(k)} &= (Q_{11}^{(k)} - Q_{12}^{(k)} - 2Q_{66}^{(k)})\sin^3\theta\cos\theta \\
&\quad + (Q_{12}^{(k)} - Q_{22}^{(k)} + 2Q_{66}^{(k)})\sin\theta\cos^3\theta \\
\overline{Q}_{66}^{(k)} &= (Q_{11}^{(k)} + Q_{22}^{(k)} - 2Q_{12}^{(k)} - 2Q_{66}^{(k)})\sin^2\theta\cos^2\theta + Q_{66}^{(k)}(\sin^4\theta + \cos^4\theta)
\end{aligned} \tag{3}$$

The coefficients Q_{ij}, for the k-th layer of the sheathing, are expressed as

$$Q_{11}^{(k)} = \frac{E_1^{(k)}}{1 - \nu_{12}^{(k)}\nu_{21}^{(k)}}, \quad Q_{12}^{(k)} = \frac{\nu_{21}^{(k)}E_1^{(k)}}{1 - \nu_{12}^{(k)}\nu_{21}^{(k)}}, \quad Q_{22}^{(k)} = \frac{E_2^{(k)}}{1 - \nu_{12}^{(k)}\nu_{21}^{(k)}}, \quad Q_{66}^{(k)} = G_{12}^{(k)} \tag{4}$$

in which E_1 and E_2 are modulus of elasticity in directions parallel and perpendicular to the grain directions, respectively; G_{12} is the in-plane shear modulus and ν_{ij} are the Poisson's ratios related to a common layered sheet.

Two extreme edge conditions are considered here, namely clamped and simply supported. Thus, the following boundary conditions should be considered at the plate edges:

Clamped:

$$\begin{aligned}
&w|_{x=0,a} = 0, \quad w|_{y=0,b} = 0 \\
&\partial w/\partial x|_{x=0,a} = 0, \quad \partial w/\partial y|_{y=0,b} = 0
\end{aligned} \tag{5a}$$

Simply supported:

$$\begin{aligned}
&w|_{x=0,a} = 0, \quad w|_{y=0,b} = 0 \\
&\partial^2 w/\partial x^2|_{x=0,a} = 0, \quad \partial^2 w/\partial y^2|_{y=0,b} = 0
\end{aligned} \tag{5b}$$

It should be pointed out that the second boundary equation of the simply supported edge should represent the zero bending moment condition; in other words:

$$\begin{aligned}
&-\left(\overline{D}_{11}\frac{\partial^2 w}{\partial x^2} + \overline{D}_{12}\frac{\partial^2 w}{\partial y^2} + 2\overline{D}_{16}\frac{\partial^2 w}{\partial x \partial y}\right)\Bigg|_{x=0,a} = 0, \\
&-\left(\overline{D}_{12}\frac{\partial^2 w}{\partial x^2} + \overline{D}_{22}\frac{\partial^2 w}{\partial y^2} + 2\overline{D}_{26}\frac{\partial^2 w}{\partial x \partial y}\right)\Bigg|_{y=0,b} = 0
\end{aligned} \tag{6}$$

However, since $w = 0$ along the edges, all the derivatives of w with respect to the coordinates parallel to the edge are also zero. Thus, the edge conditions (Eq. (6)) are simplified as the second of Eq. (5b).