

INFORMATION SHEET

STRUCTURAL MATERIALS



STRESSES IN PLYWOOD COMPONENTS

The information provided below has been taken from the New Zealand Timber Design Guide 2007, published by the Timber Industry Federation and edited by Professor A H Buchanan. To purchase a copy of the Timber Design Guide, visit www.nztif.co.nz

The theory required for detailed design of plywood components can be very complex when allowing for the layering of the plywood, transformed areas for parts with different E values and consideration of stress concentrations at glued joints or gaps in a plywood surface. Quicker approximate methods like the web beam example can be used for satisfactory designs. In the paragraphs that follow, some parts of the theory are explored to assist with an understanding of some key concepts in plywood. Consult the reference texts and standards for more detailed information.

BASIC EQUATIONS

The same simple basic equations used for homogeneous solid materials can be used for plywood, with modifications to allow for the perpendicular plies. The equations for homogeneous materials are:

$$\text{Axial: } N_c^* < \phi N_{nc} \quad N_c^* < \phi k f_c A \quad (22.1)$$

$$\text{Bending: } M^* \leq \phi M_n \quad M^* \leq \phi k f_b Z \quad Z = I / y \quad (22.2)$$

$$\text{Shear: } V^* \leq \phi V_n \quad V^* \leq \phi k f_s A_s \quad A_s = B I / Q \quad (22.3)$$

$$\text{Deflection: } d^2w/dx^2 = - M / E I \quad (22.4)$$

Where k is the product of all k factors appropriate to the service conditions, and ϕ is the strength reduction factor. For plywood, veneers perpendicular to the direction of stress contribute little and the section properties A, Z, Q and I need to be modified using either a transformed area approach, or a set of equations like the ones above adjusted for layers with different E. The properties for standard constructions of plywood and the modified properties can be used in component design.

For engineering calculations, all familiar formulae can be used provided that the correct adjusted plywood section property is used, and component E values adjusted to a common base.

AXIAL STRESS AND BENDING IN THE PLANE OF THE SHEET

Consider a unit width (1 mm wide) of a 3-ply panel under axial load. For stress parallel to the face grain, two of the three veneers carry most of the load, and the perpendicular veneer carries load in the ratio $E_{\text{perpendicular}} / E_{\text{parallel}}$. This is evident from the values in Table 1 where the effective "unit" area of 9 mm 3-ply is 6.09 mm², (reflecting an E ratio of 0.03 as outlined in appendix of AS/NZS 2269, such that $(2 \times 1 + 1 \times 0.03) \times 9 = 6.09$.) The axial stress section properties are not just used for compression and tension, but also for bending in the plane of the plywood. If the 9 mm plywood in this example was a 300 mm deep web in an I-beam, its effective width would be 6.09 mm, and the I value of the sheet in plane would be

$$I = t_{\text{eff}} d^3/12 \quad (I = 6.09 \times 300^3/12 = 45700 \text{ mm}^4),$$

$$\text{not } I = t d^3/12 \quad (I = 9 \times 300^3/12 = 67500 \text{ mm}^4).$$

Table 1: Effective Section Properties for Ecoply Plywood

				Section properties per mm width							
				Parallel to the face grain				Perpendicular to the face grain			
Nominal plywood thickness	Actual thickness	Identity code*	Mass	Moment of inertia	Section modulus	Shear constant	Cross section area	Moment of inertia	Section modulus	Shear constant	Cross section area
				I	Z	I/Q	A	I	Z	I/Q ⁺	A
mm	mm		kg/m ²	mm ⁴	mm ³	mm ²	mm ²	mm ⁴	mm ³	mm ²	mm ²
7	7.2	7-24-3	4.0	30	8.33	5.19	4.87	2.05	1.71	2.30	2.54
9	9	9-30-3	5.0	59	13.0	6.48	6.09	4.01	2.67	2.87	3.18
12	12	12-24-5	6.6	115	19.2	9.26	7.34	33.4	9.27	5.45	5.02
12	12	12-30-4	5.0	127	21.1	9.3	6.20	21.8	7.3	4.40	6.20
15	15	15-30-5	8.3	225	29.9	11.6	9.18	65.2	14.5	6.81	6.27
17	16.8	17-24-7	9.2	285	33.9	12.2	9.82	122	20.4	9.47	7.49
17	16.8	17-24-6	9.2	273	32.5	12.3	11.0	134	22.3	9.50	6.30
19	19.2	19-30-7	10.6	451	46.9	13.7	12.2	157	23.8	10.7	7.60
21	21	21-30-7	11.6	556	52.9	15.2	12.3	239	31.9	11.8	9.36
25	24.6	25-30-9	13.5	897	72.9	17.8	15.3	381	41	13.9	10.10

* Identity code: panel thickness - outermost veneer thickness x 10 - number of plies

+ I/Q values for rolling shear are for stress at the neutral axis calculated as in NZS 3603

BENDING STRESS FOR PLYWOOD LOADED NORMAL TO THE PLANE OF THE SHEET

Consider a 15 mm five-ply panel in bending. The gross Z value in familiar calculations is $Z = bd^2/6$ or 37.5 mm³ per mm width. The effective section Z parallel to the face grain after reducing the E of the two cross plies becomes 29.9 mm³ from Table 22.2 or 80% of the gross value. Using the gross value underestimates the stress in the plywood and it is important to use the tabled numbers. As an aside, some countries actually do use the gross value for Z, I and A, but then they publish different characteristic values for every single thickness and construction of plywood, so when using data for imported plywood it is essential to understand the basis of the calculations.

For stress perpendicular to the face grain, the veneer on the tension edge is ignored in a manner similar to ignoring the cracked part of a reinforced concrete section. This results in slightly lower Z values perpendicular to the grain compared with assuming a symmetrical section. Refer AS/NZS 2269 for sample calculations.

SHEAR STRESSES

Three types of shear stress occur in wood as shown in diagram 1. Sliding and kinking shear are complementary, with failure always occurring in the weaker sliding mode. Plywood combines the effects of sliding and kinking resistance in alternate veneers in panel shear (sometimes called shear-through-thickness) as shown in diagram 2. Rolling shear stresses can occur in both solid wood and in plywood.

PANEL SHEAR

Panel shear is shear that occurs in conjunction with in plane bending and is determined over the full width of the section. The rigorous theory allowing for panel construction shows that in the ratio I/Q (equation 22.3) both the I and the Q contain the adjustments and they cancel out so at maximum shear, the formula reverts to a simple shear stress, using $\tau = 3V / 2 bD$ where b is the full thickness of the plywood.

ROLLING SHEAR

Rolling shear is weaker than sliding shear and becomes the limiting stress mode for shear calculations for plywood loaded perpendicular to the face, and for glued joints in web beams at the interface between the flange and the web.

The ratio I/Q is given in the section property tables (Table 1). Critical surfaces for rolling shear in components are shown in diagram 3. In components with different E values for flanges and webs, sections should be transformed to a common E value in order to determine the shear stresses at the critical surfaces, or the theory from the earlier versions of this manual can be used.

Because shear tests are done on discrete pieces of plywood, the characteristic values assume that the characteristic shear stress is applied to the whole surface area of the material. However, in components, there are discontinuities, and for example, where a sheet of plywood is glued to a frame, the fibres outside the joint provide some support when the joint is narrow, and at the same time there is a stress concentration because of the discontinuity. NZS 3603 gives a factor of 0.5 for reducing the allowable rolling shear stress at edges of plywood sheets glued to framing to allow for the stress concentration. This is unsafe for wide flange-web surfaces and extremely conservative for narrow ones where the fibres provide support. The Canadian code gives the factors shown in Table 2 for different widths of glued joint, for a range of geometries. These should be conservative for radiata pine because the shear properties of radiata pine are better than those of Douglas fir plywood. See the Plywood Construction Manual for more detail.

Diagram 1: Shear modes in solid wood

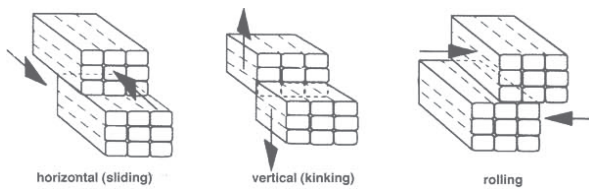


Diagram 2: Shear modes in plywood

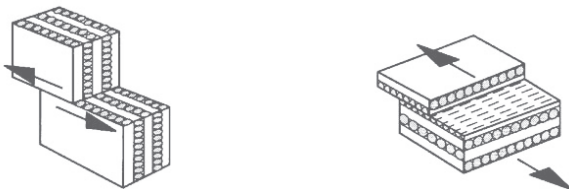


Diagram 3: Critical surfaces for rolling shear in plywood components

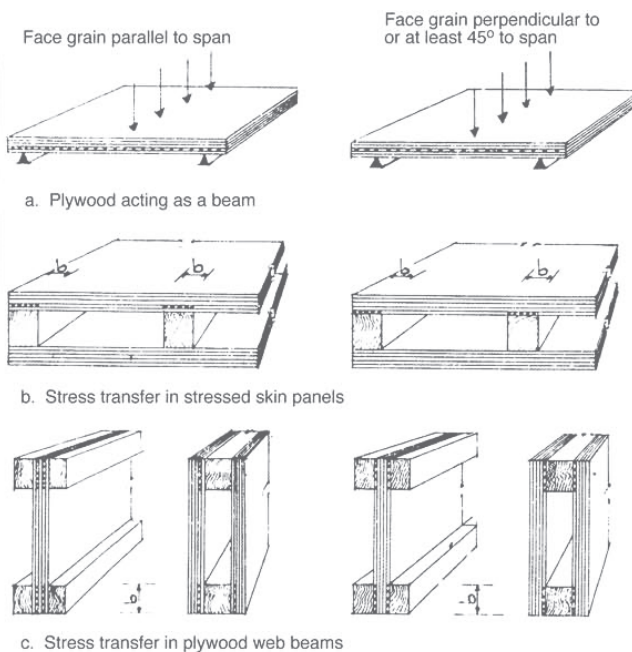


Table 2: Correction factor for flange-web shear stress

Width of glued surface (mm)	At edge of plywood panel (box beam flange)	Within panel, uniform spacing of joists (internal ribs of stressed skin panel)
	Multiply stresses by:	Multiply stresses by:
23	1.3	2.4
45	0.8	1.3
90	0.44	0.8
135	0.44	0.5
180	0.44	0.44