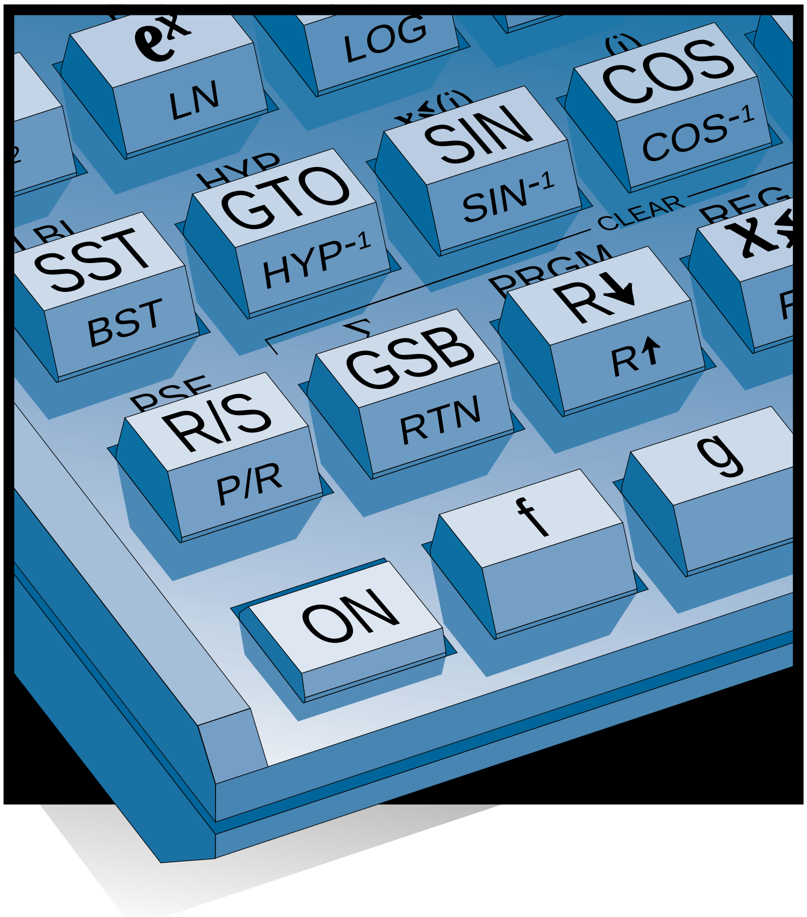
PLYWOOD DESIGN SPECIFICATION

SUPPLEMENT 3

DESIGN AND FABRICATION OF PLYWOOD STRESSED-SKIN PANELS

August 1990



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DO THE RIGHT THING RIGHT™

Wood is good. It is the earth's natural, energy efficient and renewable building material.

Engineered wood is a better use of wood. It uses less wood to make more wood products.

That's why using APA trademarked I-joists, glued laminated timbers, laminated veneer lumber, plywood and oriented strand board is the right thing to do.

A few facts about wood.

- *We're not running out of trees.* One-third of the United States land base – 731 million acres – is covered by forests. About two-thirds of that 731 million acres is suitable for repeated planting and harvesting of timber. But only about half of the land suitable for growing timber is open to logging. Most of that harvestable acreage also is open to other uses, such as camping, hiking, hunting, etc.

- *We're growing more wood every day.* American landowners plant more than two billion trees every year. In addition, millions of trees seed naturally. The forest products industry, which comprises about 15 percent of forestland ownership, is responsible for 41 percent of replanted forest acreage. That works out to more than one billion trees a year, or about three million trees planted every day. This high rate of replanting accounts for the fact that each year, 27 percent more timber is grown than is harvested.

- *Manufacturing wood products is energy efficient.* Wood products made up 47 percent of all industrial raw materials manufactured in the United States, yet consumed only 4 percent of the energy needed to manufacture all industrial raw materials, according to a 1987 study.

Material	Percent of Production	Percent of Energy Use
Wood	47	4
Steel	23	48
Aluminum	2	8

- *Good news for a healthy planet.* For every ton of wood grown, a young forest produces 1.07 tons of oxygen and absorbs 1.47 tons of carbon dioxide.

Wood. It's the right product for the environment.

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THE ENGINEERED
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RATED SHEATHING
32/16 15/32 INCH
SIZED FOR SPACING
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PS 1-95 C-D PRP-108

NOTICE:
The recommendations in this report apply only to panels that bear the APA trademark. Only panels bearing the APA trademark are subject to the Association's quality auditing program.

FOREWORD

This publication presents the recommended method for the design and fabrication of glued plywood stressed-skin panels. Working stresses and other design criteria are given in the PLYWOOD DESIGN SPECIFICATION, abbreviated PDS. References are also made to the American Forest & Paper Association publication entitled NATIONAL DESIGN SPECIFICATION FOR WOOD CONSTRUCTION, and abbreviated NDS.

The recommended design method is based on U.S. Forest Products Laboratory Report No. R1220, supplemented with tests by *APA – The Engineered Wood Association.* The most extensive of these tests are reported in Laboratory Report No. 82.

Presentation of this design method is not intended to preclude further development. Where adequate test data are available, therefore, the design provisions may be appropriately modified. If they are modified, any such change should be noted when referring to this publication.

The plywood use recommendations contained in this publication are based on *APA – The Engineered Wood Association's* continuing program of laboratory testing, product research and comprehensive field experience. However, there are wide variations in quality of workmanship and in the conditions under which plywood is used. Because the Association has no control over those elements, it cannot accept responsibility for plywood performance or designs as actually constructed.

Technical Services Division
APA – The Engineered Wood Association

A Word on Components

Plywood-lumber components are major structural members which depend on the glued joints to integrate the separate pieces into an efficient unit capable of carrying greater loads. Materials in these components may be loaded to an appreciably higher level than in conventional construction.

Since improperly designed or fabricated components could constitute a hazard to life and property, it is strongly recommended that components be designed by qualified architects or engineers, using recognized design and fabrication methods, and that adequate quality control be maintained during manufacture.

To be sure that such quality control has been carefully maintained, we recommend the services of an independent testing agency. A requirement that each unit bear the trademark of an approved agency will assure adequate independent inspection.

CONTENTS – DESIGN AND FABRICATION OF PLYWOOD STRESSED-SKIN PANELS

LIST OF SYMBOLS AND LOCATION

A = Transformed area of a four-foot-wide panel (in.^{2}) – 3.6.2, or a location illustrated in Figure 3.6.1 or area of stringer – Appendix B3

A_{st} = Actual total cross-sectional area of all stringers (in.^{2}) – 3.4.3

A_t = Total cross-sectional area of all stringers and T flanges (in.^{2}) – 3.4.4

$A_{||}$ = Area of parallel plies (in.^{2}) – 4.2

B = Width of section (in.) – 3.6.1, or a location illustrated in 3.6.1

b = Basic spacing, maximum amount of the skin which may be considered to act in conjunction with the stringer for bending stress calculations (in.) – Table 3.2.2, Sections 3.2.2, 3.5

c = Distance from neutral axis to extreme tension or compression fiber (in.) – 3.5.5, 3.5.6, 3.6.2, Appendix A4

C = Factor for calculating allowable deflection – 3.4.4, Appendix A3

d_s = Distance from centroid of stressed-skin panel to centroid of that portion of skin lying outside shear-critical plane of skin (in.) – 3.6.2

d_{st} = Distance from centroid of stressed-skin panel to centroid of that portion of skin lying outside shear-critical plane of top skin (in.) – Appendix B14

d_{sb} = Distance from centroid of stressed-skin panel to centroid of that portion of skin lying outside shear-critical plane of bottom skin (in.) – Appendix B14

E = Modulus of elasticity (lb/in.^{2}) – 3.5.5, 3.6.5, 4.2, Appendix A3

E_{top} = Modulus of elasticity of top skin (lb/in.^{2}) – 3.4.5

EI_g = Gross stiffness (lb-in.^{2}) – 3.4.3, 3.4.4, 3.5.6, 3.6.5, 3.7.3

EI_n = Stiffness of section using all material used in locating neutral axis (lb-in.^{2}) – 3.5.3, 3.5.5

E_{st} = Modulus of elasticity of stringers (lb/in.^{2}) – 3.7.3

F = Allowable stress of top or bottom skin (tension or compression) adjusted in accordance with Section 3.5.4 (lb/in.^{2}) – 3.5.5, Appendix A4

F_c = Allowable axial compressive stress for plywood skins (lb/in.^{2}) – 4.2, 4.3

F_p = Allowable splice-plate stress multiplied by the portion of the width actually spliced (lb/in.^{2}) – 3.5.6

F_s = Allowable rolling shear stress (lb/in.^{2}) – 3.6.4, 3.6.5, Appendix A4

F_{st} = Allowable rolling shear stress in top skin (lb/in.^{2}) – Appendix B16

F_{sb} = Allowable rolling shear stress in bottom skin (lb/in.^{2}) – Appendix B16

F_v = Allowable horizontal shear stress (lb/in.^{2}) – 3.7.3, Appendix A4

f_v = Applied shear stress (lb/in.^{2}) – 3.6.1

G = Modulus of rigidity of stringers (lb/in.^{2}) – 3.4.3, 3.4.4

I = Moment of inertia of one foot width of skin (in.^{4}) – 3.4.5, 3.6.1 or moment of inertia of stringer – Appendix B3

I_g = Gross moment of inertia (in.^{4}) – 3.3.3, 3.4.1.1, 4.2, Appendices A3, A4

I_n = Net moment of inertia (in.^{4}) – 3.3.3, 3.5.1.1, Appendix A4

$I_{\parallel}$ = Effective moment of inertia of plywood parallel to direction of face grain (in.^{4}) – Appendix B3

$I_{\perp}$ = Effective moment of inertia of plywood perpendicular to direction of face grain (in.^{4}) – 3.4.5

L = Span, length or height (ft) – 3.4.3, 3.4.4, 3.5.5, 3.7.3, 4.2, Appendix A3

ℓ = Clear span between stringers (in.) – 3.4.5

M = Bending moment (lb-in.) – 3.5.5

P = Total load on stressed-skin panel (lb) – 3.4.3

P_a = Allowable axial load on stressed-skin panel (lb) – 4.2

Q = Statical moment of area of skin (in.^{3}/ft of width) – 3.6.1, 3.6.2

Q_s = Statical moment for rolling shear (in.^{3}) – 3.6.3, Appendix A4

Q_{st} = Statical moment for rolling shear – top skin (in.^{3}) – Appendix B14

Q_{sb} = Statical moment for rolling shear – bottom skin (in.^{3}) – Appendix B14

Q_v = Statical moment of stressed-skin panel (in.^{3}) – 3.7.1, 3.7.3, Appendix A4

S = Section modulus of stressed-skin panel (in.^{3}) – 4.3

t = Stringer width at stringer-to-plywood glueline (in.) – Figure 3.6.1, 3.6.4, 3.6.5, Appendix A4

V = Shear (lb) – 3.6.1

w = Load (lb/ft^2) – 3.4.5

w_b = Allowable load based on bending (lb/ft^2) – 3.5.5, Appendix A4

w_{bb} = Allowable load based on bending for bottom skin (lb) – Appendix B12

w_{bt} = Allowable load based on bending for top skin (lb) – Appendix B12

w_p = Allowable load based on splice-plate stress (lb/ft^2) – 3.5.6, Appendix A4

w_s = Allowable load based on rolling shear stress (lb/ft^2) – 3.6.5, Appendix A4

w_{sb} = Allowable load based on rolling shear stress in bottom skin (lb/ft^2) – Appendix B16

w_{st} = Allowable load based on rolling shear in top skin (lb/ft^2) – Appendix B16

w_v = Allowable load based on horizontal shear stress (lb/ft^2) – 3.7.3, Appendix A4

w_{Δ} = Allowable load based on deflection (lb/ft^2) – 3.4.4, Appendix A3

y' = Distance from centroid of that portion of plywood panel that lies outside of rolling-shear-critical plane to outermost fiber (in.) – 3.6.2, Appendix B14

Δ = Deflection of top skin between stringers (in.) – 3.4.5, Appendix B8

Δ_s = Deflection due to shear (in.) – 3.4.3

Figure 1. Typical Two-Sided Stressed-Skin Panel

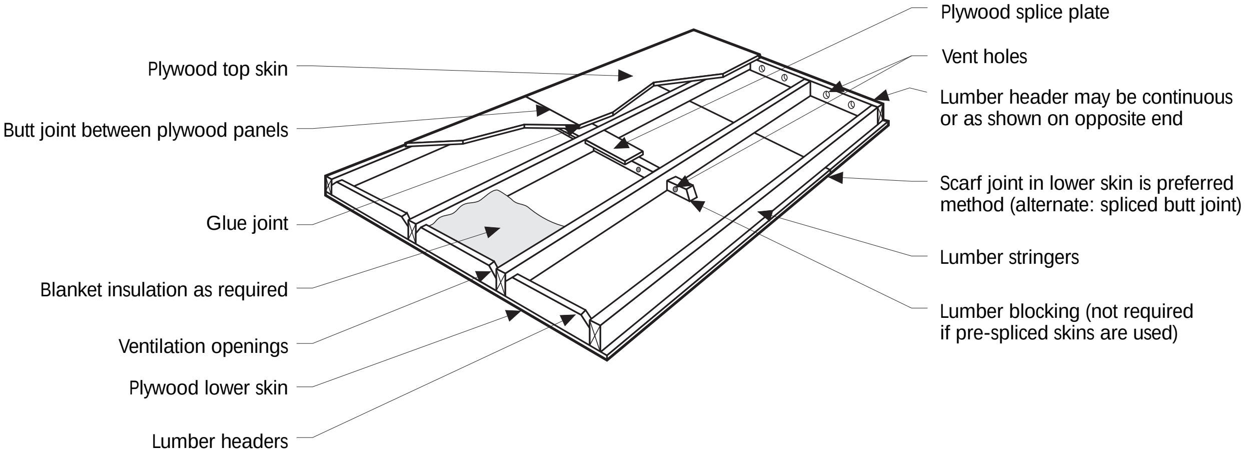


Figure 2. Typical One-Sided Stressed-Skin Panel

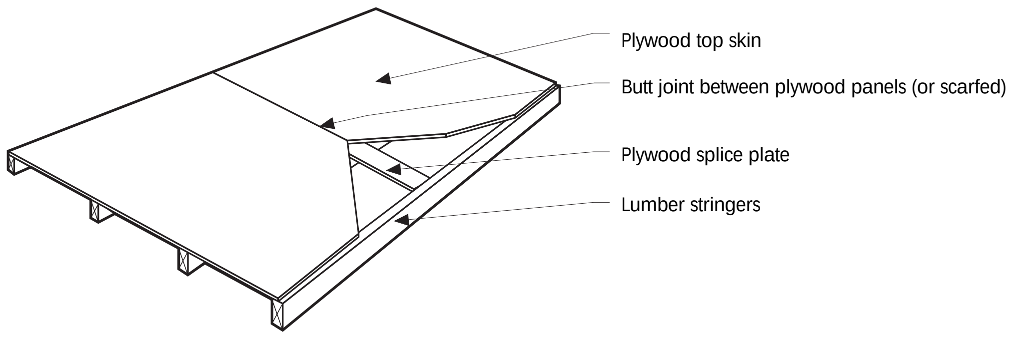
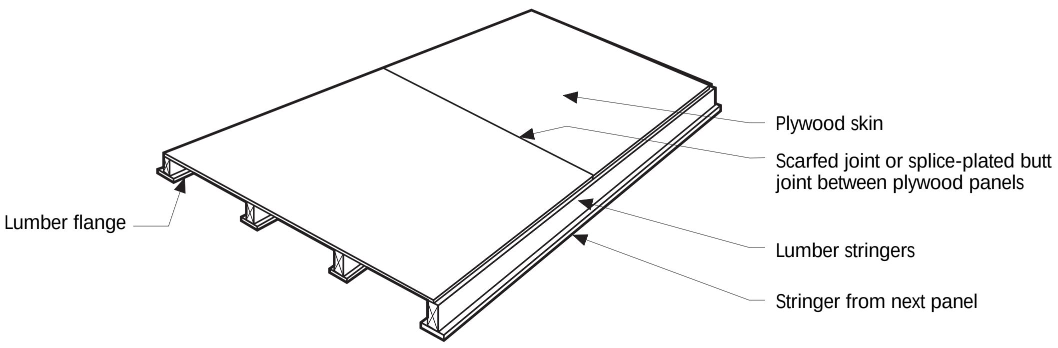


Figure 3. Typical T-Flange Stressed-Skin Panel



1. General

Flat panels with stressed plywood skins and spaced lumber stringers act like a series of built-up I-beams, with the plywood skins taking most of the bending stresses as well as performing a sheathing function, while the lumber stringers take shear stresses.

Since stressed-skin panels are usually relatively shallow, any shear deformation between skins and webs would contribute materially to deflection. For maximum stiffness, therefore, a rigid connection is required between the plywood and the lumber. Thus, all panels considered in this design method are assumed to be assembled with glue.

Although it is possible to use laminated or scarf-jointed members for the stringers of stressed-skin panels, such panels are usually restricted to single-lamination stringers. Their maximum length, therefore, is generally determined by the maximum length of lumber available.

Headers (at the ends of the panel) and blocking (within the panel) serve to align the stringers, back up splice plates, support skin edges, and help to distribute concentrated loads. They may be omitted in some cases, but should always be used when stressed-skin panels are applied with their stringers horizontal on a sloping roof. Without headers and blocking, panels so applied may tend to assume a parallelogram cross section.

Two-sided panels do not require bridging. Stringers in one-sided panels may be bridged as are joists of the same depth in conventional construction.

Owing to the high strength of plywood, calculations will often indicate that a thin bottom skin is structurally sufficient. There is some possibility, however, of a slight bow when 1/4" bottom skins are used with face grain parallel to stringers on 16" centers. Such a bow, although of no importance structurally, may be undesirable from an appearance standpoint. For stringers so spaced, therefore, 5/16" plywood should be a minimum if appearance is a factor.

Panels with both top and bottom skins are most common. One-sided panels are also popular, especially when special ceiling treatment is desired – or when no ceiling is required. A variation of the single-skin panel, with lumber strips on the bottom of the stringers, is called a “T-flange” panel.

A number of decorative plywood surfaces are adaptable for panels where the bottom skin will serve as a ceiling for a habitable room. The design of panels using such decorative plywood must, of course, allow for the special properties of the product.

Curved panels with stressed plywood skins require additional design considerations. See PDS Supplement No. 1 for design of plywood curved panels.

2. Design Considerations

2.1 Transformed Section

In calculating section properties for stressed-skin panels, the designer must take into account the composite nature of the unit. Unless all materials in the panel have similar moduli of elasticity, some method must be employed to make allowance for the differences. Different moduli of elasticity may be reconciled by the use of a “transformed section.” The transformed-section approach is common to structural design of composite sections. It consists of “transforming” the actual section into one of equivalent strength and stiffness, but composed of a single material. For instance, assume a stressed-skin panel with the modulus of elasticity of the stringers half that of the skins. Properties of the section could be stated in terms of those of a transformed section having the modulus of elasticity of the skins, and calculated as if the stringers were only half as wide as they actually are.

Sections are generally transformed to the material of the most highly stressed portion of the panel. Thus, for bending, deflection, and rolling shear, the panel is “normalized” to the material of the skins. For horizontal shear, it is transformed to a material with the properties of the stringers.

2.2 Design Loads

The design live loads must not be less than required by the governing building regulations. Allowance must be made for any temporary erection loads or moving concentrated loads. Roof panels must be designed to resist uplift due to wind load, combined with internal pressure developed by wind through openings in the side walls, minus the dead load of the panels and roofing. Lateral loads which develop diaphragm action may require special consideration, particularly to fastenings between panels, and to framing.

2.3 Allowable Working Stresses

Plywood working stresses are determined as described in PDS Section 5.4. Lumber working stresses are determined as described in PDS Section 5.5. Moisture content in service should not exceed 16%.

2.4 Effective Sections

For all panels, whether containing butt joints or not, deflection and shear stresses are based on the gross section of all material having its grain parallel with the direction of principal stress.

All plywood and all lumber having its grain parallel to the direction of stress may be considered effective in resisting bending stress, except when butt-jointed and except as reduced for *b*-distance in Section 3.5.

The best method for splicing skins, both from the structural and appearance standpoint, is to scarf-joint the plywood to the desired length. PDS Section 5.6 gives strength factors for various slopes of scarf.

Another method, considerably simpler than scarfing, involves the use of plywood splice plates. Allowable stresses for these end joints are also given in PDS Section 5.6. Splice plates are used only between the stringers, and consequently there is a certain percentage of the panel which is not spliced. When calculating the strength of the panel at the splices, only the portion of the skin which is actually spliced should be considered effective.

If desired, lengths of splice plates in skins may be reduced from those listed in the PDS. The strength of the joint will be reduced in proportion. Width and thickness of plates should not be reduced.

2.5 Allowable Deflection

Deflection must not exceed that allowed by the applicable building code. Maximum deflections recommended by most codes are the following proportions of the span ℓ in inches:

Floor Panels	
Live load only	$\ell/360$
Dead plus live load	$\ell/240$

Roof Panels	
Live load only	$\ell/240$
Dead plus live load	$\ell/180$

More severe limitations may be required by special conditions.*

2.6 Camber

Camber may be provided opposite to the direction of anticipated deflection for purposes of appearance or utility. It will have no effect on strength or actual stiffness.

Where roof and floor panels are cambered, a recommended minimum amount is 1.5 times the deflection due to dead load only. This will provide a nearly level panel under conditions of no live load after set has occurred.

Additional camber may be introduced as desired to provide for drainage or appearance. Roof panels must be designed to prevent ponding of water. Ponding may be prevented either by cambering or by providing slope or stiffness such that it will not occur.*

2.7 Continuous and Cantilevered Spans

Stressed-skin panels may be cantilevered and/or continuous over interior supports. Stresses can be figured by normal engineering formulas for multiple-span application or for cantilever action. Negative moments, of course, require that the top skin be adequately spliced for tension, and the bottom skin thick enough to perform with the lower allowable compressive stresses.

2.8 Connections

2.8.1 General

Connections of panels to supporting members must resist uplift as well as downward loads. Connections between stressed-skin panels must transfer concentrated loads between sections without excessive differential deflection. Connections should also be detailed to restrain slight bowing which sometimes results from moisture changes.

To avoid bowing, which can be caused by slight expansion of panels, it is advisable not to drive them tightly together. A suitable allowance is about 1/16" at the side of 4-ft-wide panels, and perhaps 1/4" at the ends of 20-ft-long panels.

2.8.2 Diaphragms

A roof, wall or floor designed as a shear diaphragm may require more fastening than would ordinarily be needed simply to attach the panels. Such additional fastening may be designed in accordance with the APA publication entitled *Design/Construction Guide – Diaphragms*, Form No. L350, and with accepted engineering practice.

The glueline between the stringers and plywood skins must transfer shear due to loads in the plane of the panel, as well as shear due to loads perpendicular to the stressed-skin panels. These shear stresses

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*For further discussion, see section on camber in American Institute of Timber Construction *Timber Construction Manual,* and AITC Technical Note No. 5 *Roof Slope and Drainage for Flat or Nearly Flat Roofs.*

will be additive and the resultant stress should be checked against the allowable rolling shear stress of plywood, appropriately adjusted for duration of load. When analyzing the shear stress, appropriate load combinations should be selected, since the diaphragm load will generally not occur at the same time as full vertical dead load and live load.

The allowable diaphragm load may be limited by the glueline stresses, particularly if one-sided or T-flange stressed-skin panels are used.

3. Flexural Panel Design

3.1 General

Due to the structural efficiency possible with stressed-skin panels, whereby relatively shallow panels prove adequate for strength, the design is likely to be controlled by the allowable deflection. The first aspect of the assumed section to be checked, therefore, will be deflection. Moment will be checked next, and shear last – since it is least likely to control. Shear will, however, sometimes govern when one or both skins are thick and the span is short.

3.2 Trial Section

3.2.1 General

Stressed-skin panels are designed by a “cut and try” method. A trial section must first be assumed and then checked for its ability to do the job intended. The whole 4-ft-wide panel is usually designed as a unit, in order to allow for edge conditions. (The equations in the following sections are based on 4-ft-wide panels. They will require adjustment for any other panel width.)

3.2.2 “b Distance”

In some cases the whole 4-ft width of the skins cannot be considered effective, since there is a tendency for thin plywood to dish toward the neutral axis of the panel when stringers are widely spaced. A Basic Spacing, usually referred to as the “*b* distance”, is used to take this tendency into account. The *b* distance represents the maximum amount of the skin which may be considered to act in conjunction with the stringer for bending stress calculations. A table of *b* distances is given below. Panels in which the clear distance between longitudinal members exceeds 2*b* for both covers should not be considered as having stressed skins.

3.2.3 One-Sided Panels

3.2.3.1 Panels Over 3" Deep – One-sided stressed-skin panels, except the shallow ones covered in Section 3.2.3.2 below, are designed just as are two-sided panels. There is, of course, no bottom skin to be taken into account in calculating moment of inertia, and the resisting moment based on the bottom of the panel uses the allowable bending-stress value for the stringers.

A variation on the one-sided panel is sometimes called a “T-flange” panel, and is illustrated below. The lumber “web” and lumber “bottom flange” may be considered integral for design purposes when they are glued together. When determining load governed by a 1x4 or 2x4 T-flange, use the allowable bending stress of the flange lumber. The allowable tensile stress of the flange lumber should be used for lx6 and 2x6 T-flanges. The designer should use engineering judgment when selecting the allowable stress for other size T-flanges.

Table 3.2.2 Basic Spacing, b, For Various Plywood Thicknesses

Plywood Thickness (in.)	Basic Spacing, *b* (inches)*			
	Face Grain ∥ to Stringers		Face Grain ⊥ to Stringers	
	3, 4, 5-ply 3-layer	5, 6-ply 5-layer	3, 4, 5-ply 3-layer	5, 6-ply 5-layer
Unsanded Panels				
5/16	12	–	13	–
3/8	14	–	17	–
15/32, 1/2	18	22	21	27
19/32, 5/8	23	28	22	31
23/32, 3/4	31	32	29	31
Sanded Panels				
1/4	9	–	10	–
11/32	12	–	13	–
3/8	19	–	15	–
15/32	19	22	18	24
1/2	20	24	19	26
19/32	–	27	–	28
5/8	–	28	–	30
23/32	–	33	–	34
3/4	–	35	–	36
Touch-Sanded Panels				
1/2	19	24	21	27
19/32, 5/8	26	28	24	29
23/32, 3/4	32	34	28	36
1-1/8 (2-4-1)	–	55	–	55

*Use value in boldface for plywood thickness and orientation unless another layup is specified and available.

3.2.3.2 Panels Less Than 3" Deep – In one-sided stressed-skin panels less than 3" deep, the tendency for the skins to dish is more serious than in other panels. This factor should be taken into account in their design. When designing such shallow sections, a value of 0.5*b* should be used in place of the full *b* value given in the table. (See Sections 3.4.1.2 and 3.5.1.2.)

3.3 Neutral Axis and Moment of Inertia

3.3.1 Allowance for Surfacing

To allow for resurfacing of lumber members for gluing, they should be considered 1/16" smaller in dimension perpendicular to each gluing surface than their standard lumber size. Stringers for two-sided panels, which have two gluing surfaces, should then be considered 1/8" smaller than their standard lumber size.

3.3.2 Transformed Section

Since stiffness of plywood skins may be different from that of lumber stringers, it is necessary to calculate on the basis of a "transformed section." A transformed section is a section equivalent in strength and stiffness to the actual one, but "transformed" to the properties of one material. Use of such a device simplifies calculation.

Where a portion of a section is to be transformed to another material, its actual area must be multiplied by the ratio of its actual stiffness to that of the other material, thus arriving at an "effective" area of the new material.

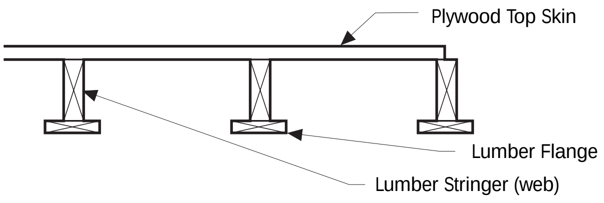
3.3.3 Gross and Net Sections

It will sometimes be necessary to compute one moment of inertia for deflection and shear, and another for bending stress, since the two considerations are based on different aspects of panel behavior. Allowable bending stresses are determined by applying suitable reduction factors to the stresses obtained at ultimate; allowable deflections are arbitrarily set, and applied, of course, to the behavior of the panel in its working range. "Dishing" of the skins at high load has been mentioned in Section 3.2.2. Because of it, a smaller net section may be effective at ultimate loads than in the working range. For thin skins and wide stringer spacings, therefore, this net moment of inertia for bending, I_n, may be less than the gross moment of inertia for deflection and shear, I_g.

3.3.4 Calculation Method

The usual system for figuring neutral axis and moment of inertia involves taking moments about the plane of the bottom of the panel. Use the actual resurfaced cross-sectional area of the lumber members, modified as appropriate by transformed section, also considering applicable *b* distances.

Figure 3.2.3 "T-Flange" Panels



3.4 Deflection

3.4.1 Cross Section

3.4.1.1 Other Than Shallow One-Sided Sections – The full 4-ft width of plywood is used for neutral-axis and moment-of-inertia calculations for deflection of most panels. This includes panels like the one sketched below, which does not have a stringer at each edge. The resultant moment of inertia is called the "gross moment of inertia," or I_g.

3.4.1.2 Shallow One-Sided Sections – As mentioned in Section 3.2.3.2, for one-sided sections less than 3" deep, the gross width may be used in computing the moment of inertia only when the clear distance between stringers is less than *b* (from Table 3.2.2). When the clear distance is greater than *b*, the flange width for stiffness calculations must be taken as the sum of the stringer width plus a distance equal to 0.25*b* on each side of each stringer (except, of course, for exterior stringers where only part of that distance is available).*

3.4.2 Neutral Axis for Deflection

Different moduli of elasticity must be reconciled by use of a transformed section in computing both the neutral axis and the moment of inertia. In the neutral-axis calculation, one way of allowing for differences in moduli is to multiply each $A_{||}$ by its appropriate E. (See Appendix B, Section B5.)

3.4.3 Stiffness

The EI, using the neutral axis computed in 3.4.2, will be a stiffness factor for bending deflection alone. It will not include shear deflection.

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*This jump, from gross width where spacing between stringers is *b*, to slightly over half the gross width where spacing is greater than *b*, is in accordance with test results. See Laboratory Report No. 82, STRESSED-SKIN PANEL TESTS, Figure 13.

Figure 3.4.1.1 Total Panel Width Effective (without reference to b distance)

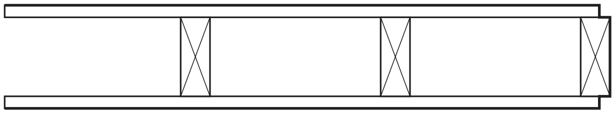
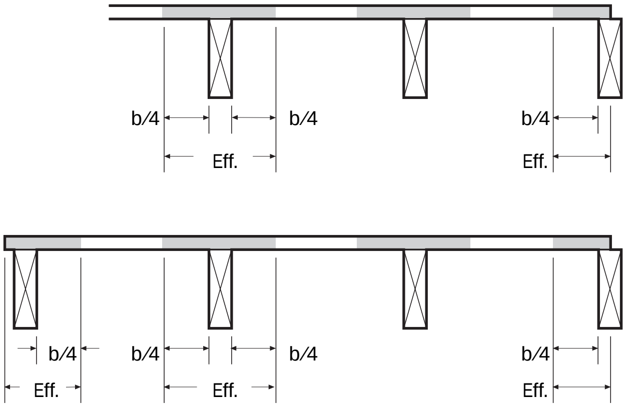


Figure 3.4.1.2 Effective Width is Sum of Widths Shown Shaded



In dealing with overall stiffness of the panel, use gross stiffness (EI_g). It reflects the composite nature of the panel. In later calculations, values for effective moment of inertia will be required. They can be obtained by dividing the EI by the appropriate E for the part of the panel being considered. (See Appendix A for simplified equations when moduli of elasticity of skins and stringers are essentially equal, and may be considered to cancel.)

Shear deflection should be considered separately for stressed-skin panels, whereas for most timber design it is "automatically" taken into account in the modulus of elasticity. The moduli listed for timber materials are not actually moduli for pure bending. Listed values for plywood include a 10% allowance, and lumber values include a 3% allowance for shear deflection. These factors are good approximations for most applications, but are excessive for most stressed-skin panels. (See Appendix A for short form, "Approximate" design method which uses listed values.)

Bending deflection must be calculated using a true value for bending modulus of elasticity. This true value is obtained by restoring the amounts mentioned above as having been removed from the modulus of elasticity to approximate shear deflection. A value for shear deflection, computed separately, is then added to the first figure representing the moment deflection. The simple-span shear deflection for uniform (also quarter-point) loading is given by the following equation:

$$\Delta_s = \frac{1.8\,PL}{A_{st}G}$$

where

Δ_s = shear deflection (in.)

P = total load on panel (lb)

L = span length (ft)

A_{st} = actual total cross-sectional area of all stringers (in.^{2})

G = modulus of rigidity of stringers (psi). G may be taken as 0.06 of the true bending modulus of elasticity of stringers.

This equation gives the shear deflection for uniform loading or quarter-point loading. The shear deflection for a single concentrated load at the center is double this amount; the shear deflection of a cantilever with a uniformly distributed load is four times this amount.

3.4.4 Allowable Load

Combining equations for bending and shear deflections for a uniformly loaded simple-span panel, the allowable load based on deflection is then given by the following:*

$$w_\Delta = \frac{1}{CL\left[\frac{7.5L^2}{EI_g} + \frac{0.6}{A_tG}\right]}$$

where

w_Δ = allowable load based on deflection (psf)

C = factor for allowable deflection, usually 360 for floors, 240 for roofs*

L = span length (ft)

EI_g = stiffness factor from Section 3.4.3 for a 4-ft-wide panel (lb-in.^{2})

A_t = actual total cross-sectional area of all stringers, and T-flanges if applicable (in.^{2})

G = modulus of rigidity of stringers (psi). G may be taken as 0.06 of the true bending modulus of elasticity of stringers.

*Note that if the allowable-deflection factor, C, is based on live load only, this equation will yield allowable live load, to which dead load may be added.

The constants shown in the above equation result from collecting constants for the simple-span beam equations, appropriately adjusted for panel width and conversion of units. For instance,

$$7.5 = \frac{5}{384} \text{ x } 4 \text{ x } \frac{1}{12} \text{ x } 1728$$

3.4.5 Top-Skin Deflection

In addition to computing the deflection of the whole panel acting as a unit, the designer must also check the deflection of the top skin between stringers. Sections are usually selected such that deflection only must be checked for this top skin, but for unusual applications moment and shear should also be investigated. For two-sided panels, this skin will be a fixed-end "beam" for which the equation is:

$$\Delta = \frac{4w \ell^4}{384 E_{top} I\, 12}$$

where

A = deflection (in.)

w = load (psf)

ℓ = clear span between stringers (in.)

E_{top} = modulus of elasticity for top skin (psi)

I = moment of inertia (in direction perpendicular to stringers) of 1-ft width of top skin (in.^{4}).

For one-sided panels with four stringers, the skin will act like a 3-span beam, with the following equation:

$$\Delta = \frac{4w \ell^4}{581\, EI\, 12}$$

where all symbols are as above. (For the refined method which includes shear deflection of the plywood, see PDS Section 3.1.3.)

In most stressed-skin panels, the face grain will be parallel to supports and it will therefore be necessary to use in these equations the correct I value for the perpendicular direction. This value for $I_\perp$ can be taken from the PDS.

3.5 Bending Moment

3.5.1 Cross Section

3.5.1.1 Other Than Shallow One-Sided Sections – As mentioned in Section 3.3.3, for bending considerations only it is sometimes necessary to calculate using the reduced section provided by using the *b* distance to arrive at effective skin widths. If the clear distance between stringers is less than *b*, the effective width of skin is equal to the full panel width. Neutral axis and moment of inertia are then as figured above for deflection. If the clear distance is greater than *b*, the effective width of skins must be reduced. It equals the sum of the widths of the stringers plus a portion of the skin extending a distance equal to 0.5*b* each side of each stringer (except, of course, for outside stringers where only part of that distance is available). The resultant moment of inertia is called the "net moment of inertia," or I_n.

3.5.1.2 Shallow One-Sided Sections – The neutral axis and moment of inertia used for shallow one-sided panels are the same as those used above for deflection; that is, using 0.25*b* instead of 0.5*b* when stringer spacing is greater than *b* (Figure 3.4.1.2).

3.5.2 Neutral Axis for Moment

A new neutral axis for bending should be computed using the proper section determined in the paragraph above. Only those plies whose grain is parallel to the span are used. As for deflection, the different stiffnesses of the materials must be considered.

3.5.3 Moment of Inertia

The EI_n of the section for bending is computed considering the material used in locating the neutral axis.

Figure 3.4.5 Top-Skin Deflection

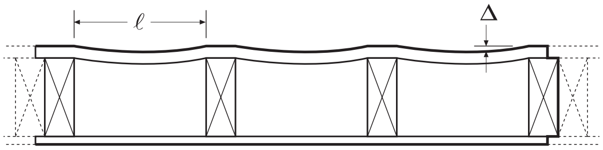
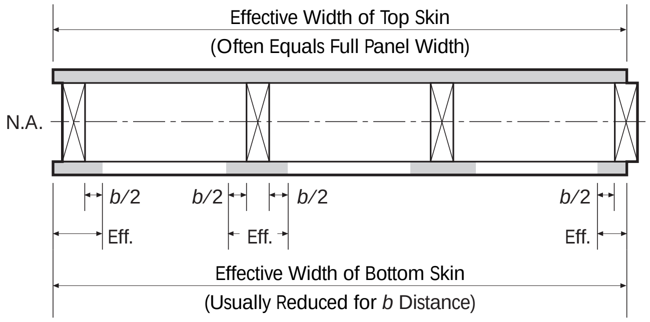


Figure 3.5.1



3.5.4 Allowable Stresses

As the spacing between framing members is increased, the allowable load is reduced in two ways. The first has been accounted for in considering the *b* distance. The second involves reductions in allowable stresses. The allowable stresses, both in tension and compression, for the grade of plywood used, are reduced in accordance with Figure 3.5.4.

This reduction is to provide against buckling of the skins. It applies to working stresses in both tension and compression parallel to grain, but not to rolling-shear stresses.

3.5.5 Allowable Load

Most stressed-skin panels with spaced stringers are not symmetrical about the neutral axis. For such "unbalanced sections," it will be necessary to calculate the allowable load in bending as determined both by the top skin and by the bottom. The lower of these values will then govern, unless there is a splice in an area of high moment. (If there is, an additional check on the splice will be required.)

For uniform loads, the general equation

$$M = \frac{FI}{c}$$

reduces to the following:

$$w_b = \frac{8F\,(EI_n)}{48\,cL^2\,E}$$

where

w_b = allowable load based on bending (psf)

F = allowable stress (either tension or compression adjusted in accordance with Sec. 3.5.4) (psi)

EI_n = stiffness factor computed in Section 3.5.3 for bending (lb-in.^{2})

c = distance from neutral axis to extreme tension or compression fiber (in.)

L = span (ft)

E = appropriate modulus of elasticity for the skin being considered (psi).

3.5.6 Splice-Plate Design

Resisting moment of the splice must be computed using the allowable stresses from PLYWOOD DESIGN SPECIFICATION Section 5.6. In the case of splice plates, this allowable stress is applied over only the width of skin actually covered by splice plates. The gross I is used for calculating this splice-plate resisting moment, since full width of skins is effective at this point, due to the stiffening effect of splice plate and blocking.

The following equation is valid for a splice plate at the point of maximum moment.

$$w_p = \frac{8F_p\,(EI_g)}{48\,cL^2\,E}$$

where

w_p = allowable load based on splice-place stress (psf)

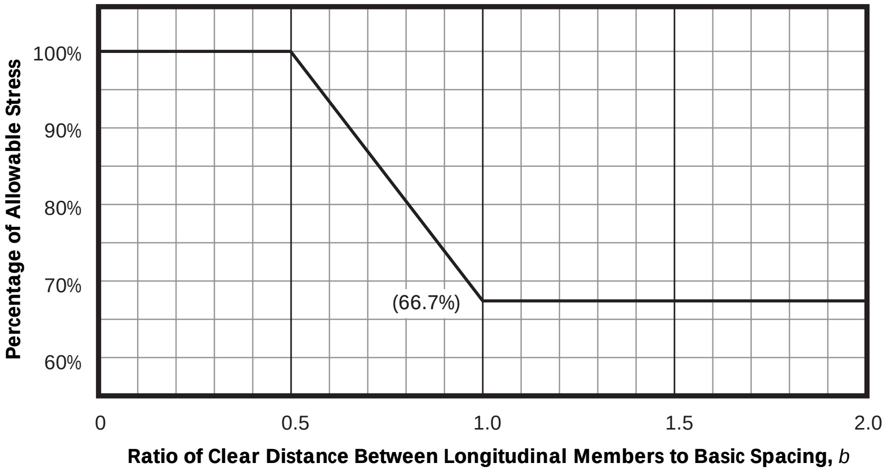
F_p = allowable splice-plate stress multiplied by the proportion of the width actually spliced (psi)

EI_g = Stiffness factor computed in Section 3.4.3 for deflection (lb-in.^{2})

and other symbols are as above.

If the splice is in an area of high moment, and is found to control the design, often the best thing to do is to change the location of the splice to an area of lower stress.

Figure 3.5.4
Stress Reduction Factor for Framing Member Spacing



3.6 Rolling Shear

3.6.1 Location of Critical Stress

When the plywood skin has its face grain parallel to the longitudinal framing members, as is usually the case, the critical shear plane lies within the plywood. It is between the inner face ply and the adjacent perpendicular ply (at A or B).

When the face grain of the skin is perpendicular to the framing members, the critical rolling-shear plane lies between the inner face and the framing member (at A' or B').

The standard equation for shear is

$$f_v = \frac{VQ.}{IB}$$

An “unbalanced” stressed-skin panel has two values for Q – one for the thicker skin, and one for the thinner. Since the Q of the thicker skin is almost always larger than that of the thinner skin, it is generally sufficient to compute rolling shear only for the thicker skin.

3.6.2 Transformed Section

In calculating Q, as in calculating neutral axis and moment of inertia, it is necessary to use a “transformed section.” The approach used here, however, is typically different. The Q calculated is for that area outside the shear-critical plane, not the Q for the entire skin. Since skins are typically applied with face grain parallel to the stringers, the skin’s shear-critical plane is at the first glueline away from the stringer. In a 5-ply skin, for instance, the Q is calculated for the outer four plies.

Table 3.6.2 eliminates the complication which is involved in calculating the Q for this transformed section. With this table, the designer can calculate the Q of the plies outside the critical plane by simply multiplying the two numbers. One of these numbers is given directly in the table. It represents the “transformed” area of the required plies, A, for a 4-ft-wide panel.

The distance (d_s) by which this area must be multiplied is not presented directly, but is easy to obtain. It is the distance from the centroid of the transformed area to the neutral axis of the stressed-skin panel. Note that the neutral axis is as determined for deflection, in Section 3.4.2. To obtain d_s, subtract from the total distance between N.A. and outside of panel, c, the distance between outside of panel and centroid of transformed area outside the critical plane for rolling shear, y'. In equation form,

$$d_s = c - y'$$

3.6.3 Statical Moment

The Q_s, or statical moment for rolling shear, is then given by the following equation:

$$Q_s = A\, d_s$$

3.6.4 Allowable Capacity

It is convenient to compute a value for the sum of the allowable shear stress times the applicable shear width, $\Sigma F_s t$, over all joints. Note that due to stress concentrations, the allowable stress in rolling shear for exterior stringers is only half that for interior stringers.

This reduction applies to exterior stringers whose clear distance to the panel edge is less than half the clear distance between stringers.

3.6.5 Allowable Load

The allowable uniform load on a simple-span stressed-skin panel as determined by rolling shear can be expressed by the following equation:

$$w_s = \frac{2(EI_g)\,\Sigma F_s t}{4Q_s\, LE}$$

where

w_s = allowable load based on rolling shear stress (psf)

EI_g = stiffness factor, computed in Section 3.4.3 (lb-in.^{2})

Figure 3.6.1 Location of Critical Rolling Shear Stress

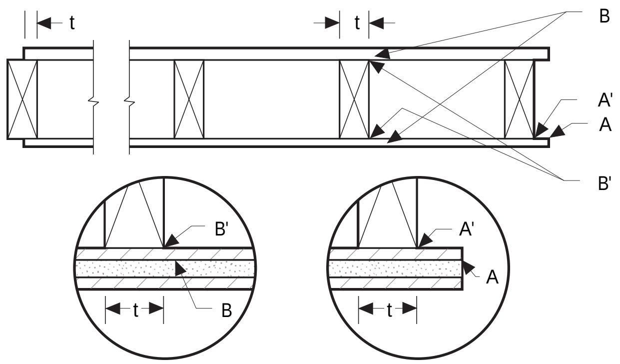


*Table 3.6.2 A and y' for Computing Q_s**

Plywood Thickness (in.)	STRUCTURAL I Grades				All Other Panels			
	Face Grain ‖ to Stringers		Face Grain ⊥ to Stringers		Face Grain ‖ to Stringers		Face Grain ⊥ to Stringers	
	Area (in.^{2})	y' (in.)	Area (in.^{2})	y' (in.)	Area (in.^{2})	y' (in.)	Area (in.^{2})	y' (in.)
Unsanded Panels								
5/16	3.22	0.0335	4.75	0.149	3.00	0.0375	2.64	0.149
3/8	4.46	0.0465	5.75	0.180	3.72	0.0465	3.19	0.180
15/32, 1/2	5.42	0.0565	8.70	0.227	4.60	0.0575	4.03	0.227
19/32, 5/8	9.22	0.176	11.0	0.305	4.64	0.0580	5.14	0.289
23/32, 3/4	11.2	0.176	11.3	0.352	5.57	0.0580	6.25	0.352
Sanded Panels								
1/4	2.54	0.0265	2.51	0.121	2.54	0.0265	1.39	0.121
11/32	2.54	0.0265	3.00	0.168	2.54	0.0265	1.67	0.168
3/8	3.36	0.0350	4.50	0.184	3.36	0.0350	2.50	0.184
15/32	3.89	0.0405	9.01	0.231	3.89	0.0405	5.00	0.231
1/2	3.89	0.0405	10.1	0.246	3.89	0.0405	5.64	0.246
19/32	8.69	0.193	10.0	0.293	6.32	0.156	5.56	0.293
5/8	9.07	0.207	11.0	0.309	6.53	0.151	6.11	0.309
23/32	11.6	0.262	12.5	0.356	7.92	0.220	6.95	0.356
3/4	12.1	0.278	15.1	0.371	8.19	0.233	8.32	0.371
Touch-Sanded PaneIs								
1/2	4.56	0.0475	9.95	0.226	4.56	0.0475	4.64	0.224
19/32, 5/8	7.92	0.174	11.2	0.279	4.38	0.0685	6.24	0.279
23/32, 3/4	10.4	0.177	14.5	0.345	5.06	0.0790	8.06	0.345
1-1/8 (2•4•1)	–	–	–	–	12.5	0.354	16.2	0.542

*Area based on 48"-wide panel. For other widths, use a proportionate area.

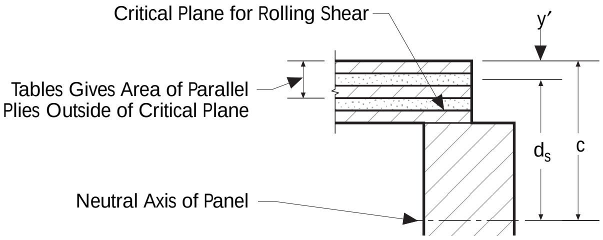
$\Sigma F_s t$ = sum of the glueline widths over each stringer, each multiplied by its applicable allowable rolling-shear stress, computed in Section 3.6.4 (lb-in.)

Q_s = the first moment (about the neutral axis) of the parallel plies outside of the critical rolling-shear plane, full 4-ft panel width (in.^{3})

L = length of the panel (ft)

E = modulus of elasticity of thicker skin (psi).

Figure 3.6.2



3.7 Horizontal Shear

3.7.1 Statical Moment

The Q to be used in the equation for horizontal shear includes the statical moment of all parallel-grain material above (or below) the neutral axis. Thus the value of Q_s obtained above for rolling shear for the top skin cannot be used since it will not include the stringers, and generally will not include the bottom parallel ply of the top skin.

Again a transformed section is required, to allow for differences in modulus of elasticity, in calculating both Q and effective I. Since the whole depth of the plywood is involved, the area is that listed in the PDS. The "d" distance is to the mid-depth of the skin. But the effectiveness of the skin must be "transformed" to be compatible with the stringer. Thus the Q_v of the panel is given in the following equation:

$$Q_v = Q_{stringers} + \frac{E_{skins}}{E_{stringers}} \text{ x } Q_{skin}$$

Note that the neutral axis is as determined for deflection, in Section 3.4.2.

3.7.2 Allowable Shear Stress

Allowable horizontal shear stresses for stress-grade lumber are given in the NATIONAL DESIGN SPECIFICATION FOR WOOD CONSTRUCTION (NDS).

3.7.3 Allowable Load

The equation for allowable uniform load on a stressed-skin panel is as follows:

$$w_v = \frac{2(EI_g)\,\Sigma F_v t}{4Q_v\,L\,E_{st}}$$

where

w_v = allowable load based on horizontal shear stress (psf)

EI_g = Stiffness factor, computed in Section 3.4.3 (lb-in.^{2})

F_v = allowable horizontal shear stress in the lumber stringers (psi)

t = stringer width (in.)

Q_v = first moment about the neutral axis of all parallel-grain material above (or below) the neutral axis of the 4-ft-wide panel (in.^{3})

L = length of the panel (ft)

E_{st} = modulus of elasticity of stringers (psi).

3.8 Final Allowable Load

The final allowable load on the panel is the lowest of the figures obtained in Section 3.4 through 3.7 above.

4. Wall Panel Design

4.1 General

Stressed-skin panels used for walls, or other applications where they are loaded in axial compression, can be designed in accordance with standard procedures. In practice, when these panels are used for walls, their thickness is usually determined by appearance, acoustics, or insulation requirements, and sometimes by the necessity for wind resistance, but seldom by their actual load-bearing capacity as columns.

4.2 Vertical-Load Formula

Few practical end joints for stressed-skin panels will provide any appreciable degree of fixity. Under vertical load, therefore, panels will behave as pin-ended columns. The pin-ended-column equations reduce to:

$$P_a = \frac{3.619\ EI_g}{144\ L^2} \quad \text{or } F_c A_{\|}$$

whichever is less

where

P_a = allowable axial load on the panel (lb)

E = appropriate modulus of elasticity (see below) (psi)

I_g = gross moment of inertia of panel about neutral axis (in.^{4})

L = unsupported vertical height of panel (ft)

F_c = allowable compressive stress (axial) for plywood skins (psi)

$A_{\|}$ = total vertical-grain material of stringers and skins (in.^{2}).

Where the moduli of elasticity of skins and stringers are nearly alike, the modulus of elasticity of the skins may be used. Otherwise, calculate EI_g as in Section 3.4.3 for use in this equation.

4.3 Combined Bending and Axial Load

When designing wall panels subject to wind loads, or any other panels where bending and axial stresses are both present, the usual combined-load equation,

$$\frac{P/A}{F_a} \pm \frac{M/S}{F_b} \leqslant 1,$$ reduces to the following:

$$\frac{P}{P_a} + \frac{M/S}{F_c} \leqslant 1.0$$

where

P = total allowable axial load on the panel with combined loading (lb)

P_a = allowable axial load on the panel (from Section 4.2) if axial load only existed (lb)

M = total allowable bending moment on the stressed-skin panel with combined loading (in.-lb)

S = section modulus of stressed-skin panel (compression side) = I_n/c (in.^{3})

F_c = allowable stress in compression parallel to grain from PDS Table 3 (psi).

Values for P_a and F_c can be adjusted for duration of load. See PDS Section 3.3.

PART 2 – FABRICATION OF PLYWOOD STRESSED-SKIN PANELS

1. General

1.1

This specification covers the fabrication of glued plywood stressed-skin panels, with spaced stringers of lumber or plywood, and with skins of plywood glued to one or both sides.

1.2

Plywood stressed-skin panels should be designed by a qualified architect or engineer in accordance with the latest edition of the APA PLYWOOD DESIGN SPECIFICATION (PDS), using the method set forth in Part 1 of this PDS Supplement. Other design methods may be employed, provided they are supported by adequate test data.

1.3

Plywood stressed-skin panels shall be fabricated and assembled in accordance with engineering drawings and specifications, except that minimum requirements herein shall be observed.

1.4

The plywood use recommendations contained in this publication are based on APA's continuing program of laboratory testing, product research and comprehensive field experience. However, there are wide variations in quality of workmanship and in the conditions under which plywood is used. Because the Association has no control over those elements, it cannot accept responsibility for plywood performance or designs as actually constructed.

2. Materials

2.1 Plywood

2.1.1

Plywood shall conform with the latest edition of U.S. Product Standard PS-1 for Construction and Industrial Plywood. Each original panel shall bear the trademark of *APA – The Engineered Wood Association.* Any precut plywood shall be accompanied by an affidavit from the precutter certifying that each original panel was of the specified type and grade, and carried the trademark of *APA – The Engineered Wood Association.*

2.1.2

At time of gluing, the plywood shall be conditioned to a moisture content between 7% and 16%. Pieces to be assembled into a single stressed-skin panel shall be selected for moisture content to conform with Section 3.3.1.

2.1.3

Surfaces of plywood to be glued shall be clean and free from oil, dust, paper tape, and other material which would be detrimental to satisfactory gluing. Medium density overlaid surfaces shall not be relied on for a structural glue bond.

2.2 Lumber

2.2.1

Grades shall be in accordance with current lumber grading rules, except that knotholes up to the same size as the sound and tight knots specified for the grade by the grading rules may be permitted. When lumber is resawn, it shall be regraded on the basis of the new size.

2.2.2

At time of gluing, the lumber shall be conditioned to a moisture content between 7% and 16%. Pieces to be assembled into a single stressed-skin panel shall be selected for moisture content to conform with Section 3.3.1.

2.2.3

Surfaces of lumber to be glued shall be clean and free from oil, dust, and other foreign matter which would be detrimental to satisfactory gluing. Each piece of lumber shall be machine finished, but not sanded, to a smooth surface with a maximum allowable variation of 1/32" in the surface to be glued. Warp, twist, cup or other characteristics which would prevent intimate contact of mating glued surfaces shall not be permitted.

2.3 Glue

2.3.1

Glue shall be of the type specified by designer for anticipated exposure conditions.

2.3.2

Interior type glue shall conform with ASTM Specification D4689. Exterior type glue shall conform with ASTM Specification D2559.

2.3.3

Mixing, spreading, storage-, pot-, and working-life, and assembly time and temperature shall be in accordance with the manufacturers’ recommendations.

3. Fabrication

3.1 Skins

3.1.1

Slope of scarf and finger joints in plywood skins shall not be steeper than 1 in 8 in the tension skin, and 1 in 5 in the compression skin. Scarf and finger joints shall be glued under pressure over their full contact area, and shall meet the requirements of PS 1, Section 3.9. In addition, the aggregate width of all knots and knotholes falling wholly within the critical section shall be not more than 10" on each face of the jointed panel for a 4-ft-wide panel, and proportionately for other widths. The critical section for a scarf joint shall be defined as a 12"-wide strip, 6" on each side of the joint in the panel face, extending across the width of the panel.

3.1.2

Butt joints in plywood skins shall be backed with plywood splice plates centered over the joint and glued over their full contact area. Splice plates shall be at least equal in thickness to the skin, except that minimum thickness shall be 15/32" if nail-glued. Minimum splice plate lengths, face grain parallel with that of the skin, shall be as follows (unless otherwise called for in the design):

Skin Thickness	Splice Plate Length
1/4"	6"
5/16"	8"
3/8" sanded	10"
3/8" unsanded	12"
15/32" & 1/2"	14"
19/32" - 3/4"	16"

3.1.3

Surfaces of high density overlaid plywood to be glued shall be roughened, as by a light sanding, before gluing.

3.2 Framing

3.2.1

Scarf and finger joints may be used in stringers, provided the joints are as required for the grade and stress used in the design. Knots or knotholes in the end joints shall be limited to those permitted by the lumber grade, but in any case shall not exceed 1/4 the nominal width of the piece.

3.2.2

The edges of the framing members to which the plywood skins are to be glued shall be surfaced prior to assembly to provide a maximum variation in depth of 1/1 6" for all members in a panel. (Allow for actual thickness of any splice plates superimposed on blocking.)

3.3 Assembly

3.3.1

The range of moisture content of the various pieces assembled into a single stressed-skin panel shall not exceed 5%.

3.3.2

Plywood skins shall be glued to framing members over their full contact area, using means that will provide close contact and substantially uniform pressure. Where clamping or other positive mechanical means are used, the pressure on the net framing area shall be sufficient to provide adequate contact and ensure good glue bond (100 to 150 psi on the net glued area is recommended), and shall be uniformly distributed by caul plates, beams, or other effective means. In place of mechanical pressure methods, nail-gluing may be used. Nail sizes and spacings shown in the following schedule are suggested as a guide:

> Nails shall be at least 4d for plywood up to 3/8" thick, 6d for 1/2" to 7/8" plywood, 8d for 1" to 1-1/8" plywood. They shall be spaced not to exceed 3" along the framing members for plywood through 3/8", or 4" for plywood 15/32" and thicker, using one line for lumber 2" wide or less, and two lines for lumber more than 2" and up to 4" wide.

Application of pressure or nailing may start at any point, but shall progress to an end or ends. In any case, it shall be the responsibility of the fabricator to produce a continuous glue bond which meets or exceeds applicable specifications.

3.3.3

Where a tongue-and-groove type panel edge joint is specified (and not otherwise detailed), the longitudinal framing member forming the tongue shall be of at least 2" nominal width, set out 3/4" ± 1/16" from the plywood edge. Edges of the tongue shall be eased so as to provide a flat area at least 3/8" wide. Any corresponding framing member forming the base of the groove shall be set back 1/4" to 1" more than the amount by which the tongue protrudes. One skin may be cut back slightly to provide a tight fit for the opposite skin.

3.3.4

Unless otherwise specified, panel length and width shall be accurate within ± 1/8". Panel edges shall be straight within 1/16" for an 8-ft length and proportionately for other lengths. Panels in the same group shall not vary in thickness by more than 1/16", nor differ from design thickness by more than 1/8". Panels shall be square, as measured on the diagonals, within 1/8" for a 4-ft-wide panel and proportionately for other widths. Panels shall lie flat at all points within 1/4" for 4-ft x 8-ft panels, and proportionately for other sizes. Panel edge cross sections shall be square within 1/16" for constructions with lumber stringers 4" deep, and proportionately for other sizes.

3.3.5

Insulation, vapor-barrier materials and ventilation shall be provided as specified in the design. Such materials shall be securely fastened in the assembly in such a way that they cannot interfere in the process of gluing the plywood skins, or with the ventilation pattern. When ventilation is specified, panels shall be vented through blocking and headers on the cool side of the insulation. Provision shall be made to line up the vent holes within and between panels. Stringers shall not be notched for ventilation, unless so specified.

4. Test Samples

4.1

When glue-bond test samples are taken from a member, if not otherwise obtained from trim, they shall be taken as cores approximately 2" in diameter, drilled perpendicular to the plane of the skins, and no deeper than 3/4" into any framing member.

4.2

No samples shall be taken from the same skin at cross sections closer together than 12" along the span of the panel, except as detailed in Paragraph 4.2.2 below. Samples shall be taken at a distance from the panel ends not greater than the panel depth, except as follows:

4.2.1

One sample may be taken from one of the outside longitudinal framing members, within the outer quarters of the panel length, provided the framing member is notched no deeper than 1/2" below its edge. The other outside longitudinal framing member may be sampled similarly, but at the opposite end of the panel.

4.2.2

No more than two samples per butt joint at any one cross section may be taken from skin splice plates. They shall be located midway between longitudinal framing members, and shall be aligned longitudinally, one on each side of the butt joint.

4.3

Where glue-bond test samples have been taken, holes shall be neatly plugged with glued wood inserts.

5. Identification

Each member shall be identified by the appropriate trademark of an independent inspection and testing agency, legibly applied so as to be clearly visible. Locate trademark approximately 2 feet from either end, except appearance of installed panel shall be considered.

A1. General

If all construction materials in the panel have *similar* moduli of elasticity, an "Approximate" method of design may be used in place of the "Transformed Section" method described on page 7. This method will yield answers in substantial agreement with the more refined method so long as moduli of elasticity of skins and stringers do not differ by more than about 10%.

A2. Neutral Axis

The E values are not used in determining the N.A. as on pages 10, 11 or 12.

A3. Deflection

The shear deflection allowance is not restored to the E of the skins and stringers of the panel as on page 11. Approximate shear deflection can then be included in the bending deflection formula. For uniformly loaded simple-span panels the allowable load would be:

$$w_\Delta = \frac{E\,(I_g)}{7.5\,CL^3}$$

I_g from page 11

(This equation is conservative, as shear deflection in a stressed-skin panel is seldom as large as 10%.)

A4. Strength

The shear deflection allowance is not restored to the E of the skins and stringers of the panel as on page 12. E is therefore eliminated in the equations on pages 13, 14, 15, and 16. For uniformly loaded simple-span panels, the allowable load would be:

$$w_b = \frac{F\,(I_n)}{6\,cL^2} \quad \text{for bending}$$

$$w_p = \frac{F\,(I_g)}{6\,cL^2} \quad \text{splice plate}$$

$$w_s = \frac{(I_g)\,\Sigma F_s t}{2\,Q_s L} \quad \text{rolling shear}$$

$$w_v = \frac{(I_g)\,F_v t}{2\,Q_v L} \quad \text{horizontal shear}$$

(These equations are exact if stiffnesses of skins and stringers are equal.)

B1. General

Since this example is intended for use as a general guide through this publication and the PDS, review of those sections pertinent to your specific design is recommended before proceeding. Section references refer to Part 1.

Preliminary considerations as to the grade of plywood and lumber to be used for a given design should include a check on availability. Where full exterior durability is not required for the plywood, APA plywood Exposure 1 may be specified, generally permitting the use of higher allowable plywood shear stresses.

B2. Problem

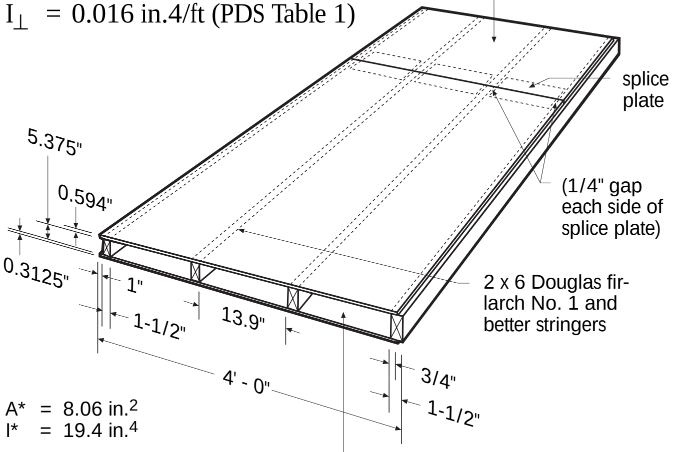
Design a floor panel for a 14-ft span.
Live Load: 40 psf Dead Load: 10 psf
Deflection Limitation: $\ell/360$ under live load only.

B3. Trial Section (See Section 3.2)

Try the section sketched below

Top Skin – 19/32" APA RATED STURD-I-FLOOR 20 oc EXP 1 marked PS-1. (For this thickness and stringer spacing, a 5-ply 5-layer panel should be used for resistance to concentrated floor loads.)

$A_{\|}$ = 2.354 in.2/ft (PDS Table 1)
$I_{\|}$ = 0.123 in.4/ft (PDS Table 1)
$I_{\perp}$ = 0.016 in.4/ft (PDS Table 1)



Bottom Skin – 5/16" APA RATED SHEATHING 20/0 EXP 1 marked PS-1.

$A_{\|}$ = 1.491 in.2/ft (PDS Table 1)
$I_{\|}$ = 0.022 in.4/ft (PDS Table 1)

$$\text{Clear distance between stringers} = \frac{48 - 3 \times 1.5 - 1 - 0.75}{3} = 13.9''$$

$$\text{Total splice plate width} = 3(13.9 - 2(0.25)) = 40.2''$$

*Includes a 1/8" reduction in depth to allow for resurfacing.

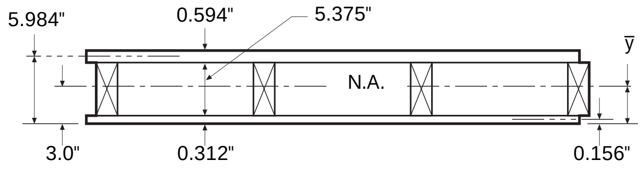
B4. Basic Spacing (See Section 3.2.2)

From Table 3.2.2

for 19/32" 5-ply 5-layer touch-sanded plywood, face grain parallel to stringers,
b = 28"

for 5/16" unsanded plywood, *b* = 12"

B5. Neutral Axis for Deflection (See Section 3.4.2)



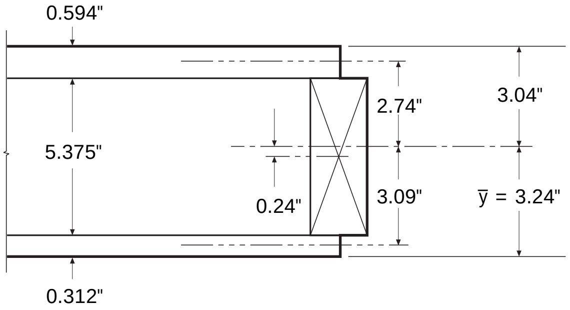
Values of $A_{\|}$ of plywood from PDS Table 1.

Item	E	$A_{\|}$	$A_{\|}E$	y	$A_{\|}Ey$
Top Skin	1,800,000 x 1.1* = 1,980,000	4 x 2.354 = 9.42	18,600,000	5.984	111,300,000
Stringers	1,800,000 x 1.03** = 1,850,000	4 x 8.06 = 32.2	59,600,000	3.000	178,800,000
Bottom Skin	1,800,000 x 1.1* = 1,980,000	4 x 1.491 = 5.96	11,800,000	0.156	1,840,000
Total		47.6	90,000,000		291,940,000

*PDS 5.4.4
**PDS 5.5.5

$$\overline{y} = \frac{\Sigma A_{\|}Ey}{\Sigma A_{\|}E} = \frac{291{,}940{,}000}{90{,}000{,}000} = 3.24''$$

B6. Stiffness (See Section 3.4.3)



Item	E	I*	$A_{\|\|}$	d	d^2	$A_{\|\|}d^2$	$I + A_{\|\|}d^2$	$E(I + A_{\|\|}d^2)$
Top Skin	1,980,000	.492	9.42	2.74	7.51	70.7	71.2	141,000,000
Stringers	1,850,000	77.6	32.2	0.24	0.058	1.87	79.5	147,000,000
Bottom Skin	1,980,000	.088	5.96	3.09	9.55	56.9	57.0	113,000,000
Total							I_g = 207.7	401,000,000

*Values of I of plywood from PDS Table 1 adjusted for four-foot width.

$$EI_g = 401{,}000{,}000 \text{ lb-in.}^2 \text{ per 4-ft width}$$

B7. Allowable Load Based on Deflection (See Section 3.4.4)

$$G = 0.06 \times 1{,}850{,}000 = 111{,}000 \text{ psi}$$

$$w_\Delta = \frac{1}{CL\left[\dfrac{7.5L^2}{EI_g} + \dfrac{0.6}{A_tG}\right]}$$

$$= \frac{1}{360 \times 14\left[\dfrac{7.5 \times 14^2}{401{,}000{,}000} + \dfrac{0.6}{32.2 \times 111{,}000}\right]}$$

$$= \frac{1}{5040\,[0.00000367 + 0.00000017]}$$

$$w_\Delta = 51.7 \text{ psf Live Load} > 40 \text{ psf, OK}$$

For purposes of comparing with other allowable load figures, add 10 psf dead load. Then

$$w_\Delta = 61.7 \text{ psf Total Load} > 50 \text{ psf, OK}$$

B8. Top-Skin Deflection (See Section 3.4.5)

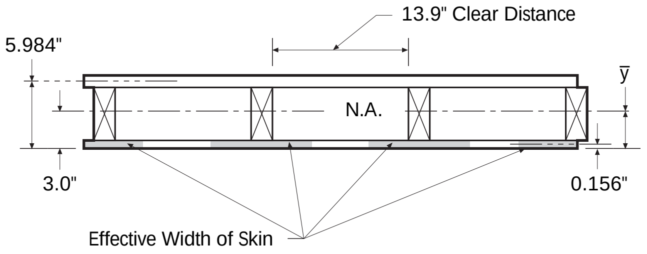
$$\frac{\ell}{360} = \frac{16}{360} = 0.0444"$$

$$\Delta = \frac{w\ell^4}{384 \times EI \times 12}$$

$$= \frac{40 \times 13.9^4}{384 \times 1{,}800{,}000 \times 0.016 \times 12}$$

$$\Delta_{\frac{\ell}{360}} = 0.0113" < 0.0444" \text{ OK}$$

B9. Neutral Axis for Bending Moment (See Section 3.5.2)



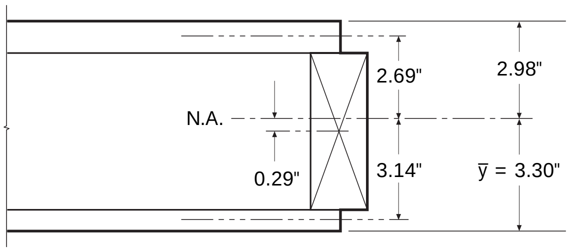
Effective width of top skin = 48"

Effective width of bottom skin = 48" – 3(13.9 – 12) = 42.3"

Item	E	A		$A_{\|\|}$	$A_{\|\|}E$	y	$A_{\|\|}Ey$
Top Skin	1,980,000	4 x 2.354	=	9.42	18,600,000	5.984	111,300,000
Stringers	1,850,000	4 x 8.0625	=	32.2	59,600,000	3.00	178,800,000
Bottom Skin	1,980,000	$\frac{42.3}{12}$ x 1.491	=	5.26	10,400,000	0.156	1,620,000
Total					88,600,000		291,720,000

$$\bar{y} = \frac{\Sigma A_{||}Ey}{\Sigma A_{||}E} = \frac{281{,}720{,}000}{88{,}600{,}000} = 3.30"$$

B10. Stiffness for Bending (See Section 3.5.3)



Item	E	I_o	$A_{\|\|}$	d	d^2	$A_{\|\|}d^2$	$I_o+A_{\|\|}d^2$	$E(I_o+A_{\|\|}d^2)$
Top Skin	1,980,000	.492	9.42	2.69	7.24	68.2	68.7	136,000,000
Stringers	1,850,000	77.6	32.2	0.29	0.084	2.71	80.3	149,000,000
Bottom Skin	1,980,000	0.078	5.26	3.14	9.86	51.9	52.0	103,000,000
Total							I_n = 201.0	388,000,000

$$EI_n = 388{,}000{,}000 \quad \text{lb-in}^2 \text{ per 4-ft width}$$

B11. Allowable Stresses (See Section 3.5.4)

Top skin allowable compressive stress.

Basic F_c from PDS Table 3 = 1540 psi

$$\frac{\text{clear dist.}}{b} = \frac{13.9}{28} = 0.496$$

From Figure 3.5.4, stress reduction factor = 1.00

therefore, $F_c = 1.00 \times 1540 = 1540$ psi

Bottom skin allowable tensile stress.

Basic F_t from PDS Table 3 = 1650 psi

$$\frac{\text{clear dist.}}{b} = \frac{13.9}{12} = 1.16$$

From the graph in Section 3.5.4,
stress reduction factor = 0.667

therefore, $F_t = 0.667 \times 1650 = 1100$ psi

B12. Allowable Load Based on Bending Stress (See Section 3.5.5)

Allowable load if bottom skin controls

$$w_{bb} = \frac{8F_t\,(EI_n)}{48\ cL^2\ E}$$

$$= \frac{8 \times 1100 \times 388{,}000{,}000}{48 \times 3.30 \times 14^2 \times 1{,}980{,}000}$$

w_{bb} = 55.5 psf > 50 psf, OK

Allowable load if top skin controls

$$w_{bt} = \frac{8F_c(EI_n)}{48cL^2\ E}$$

$$= \frac{8 \times 1540 \times 388{,}000{,}000}{48 \times 2.98 \times 14^2 \times 1{,}980{,}000}$$

w_{bt} = 86.1 psf, > 50 psf, OK

B13. Skin Splices (See Section 3.5.6)

Tension Splice

F_t = 1200 psi (from PDS Table 5.6.1.2)

Splice plate to be 13.4" wide

Ration of splice-plate width to total skin width

$$= \frac{3 \times 13.4}{48} = 0.838$$

Allowable stress = 1200 x 0.838 = 1000 psi

$$w_p = 8F\,(EI_g)$$

$$48\ cL^2\ E$$

$$= \frac{8 \times 1000 \times 401{,}000{,}000}{48 \times 3.24 \times 14^2 \times 1{,}980{,}000}$$

w_p = 53.2 psf > 50 psf, OK

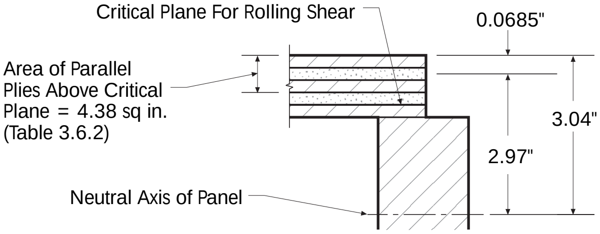
Compression Splice

OK by inspection. See PDS Section 5.6.1.2 and 5.6.2.2.

B14. Statical Moment for Rolling Shear (See Section 3.6.3)

From table in Section 3.6.2,

A for top skin = 4.38 sq in. for a 4-ft panel, and y' = 0.0685"



Then $d_{st} = c - y' = 3.04" - 0.0685" = 2.97"$

$Q_{st} = A\ d_{st}$

$= 4.38 \times 2.97$

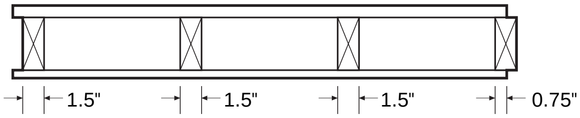
Q_{st} = 13.0 in.^{3} per 4-ft-wide panel.

$d_{sb} = 3.24 - 0.0375 - 3.20$

Q_{sb} = 3.00 x 3.20 = 9.6 in^3/4-ft-wide panel.

B15. Allowable Capacity (See Section 3.6.4)

From PDS Table 3, F_s = 53 psi at interior stringers; $\frac{53}{2}$ psi at exterior stringers



$$\Sigma F_s t = \left(\frac{53}{2} \times 1.5\right) + \left(2 \times 53 \times 1.5\right) + \left(0.75 \times \frac{53}{2}\right)$$

$$= 40 + 159 + 20$$

$\Sigma F_s t$ = 219 lb/in.

B16. Allowable Load Based on Rolling Shear (See Section 3.6.5)

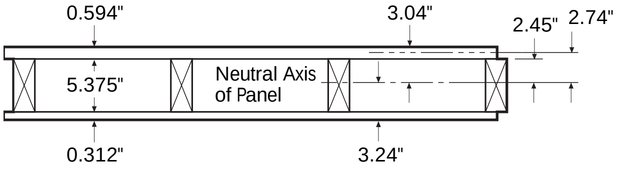
$$w_{st} = \frac{2(EI_g)\ \Sigma F_{st}t}{4Q_{st}\ LE}$$

$$= \frac{2 \text{ x } 401{,}000{,}000 \text{ x } 219}{4 \text{ x } 13.0 \text{ x } 14 \text{ x } 1{,}980{,}000}$$

$$w_{st} = 121.9 \text{ psf} > 50 \text{ psf, OK}$$

$$w_{sb} = \frac{2 \text{ x } 401{,}000{,}000 \text{ x } 219}{4 \text{ x } 9.6 \text{ x } 14 \text{ x } 1{,}980{,}000} = 165 \text{ psf}$$

B17. Statical Moment for Horizontal Shear (See Section 3.7.1)



$$Q_v = Q_{stringers} + \frac{E_{skin}}{E_{stringers}} \text{ x } Q_{skin}$$

$$= 4\left(1.5 \text{ x } 2.45 \text{ x } \frac{2.45}{2}\right)$$

$$+ \frac{1{,}980{,}000}{1{,}850{,}000}\,(4 \text{ x } 2.354 \text{ x } 2.74)$$

$$= 18.0 + 27.6$$

$$Q_v = 45.6 \text{ in.}^3$$

B18. Allowable Load Based on Horizontal Shear (See Section 3.7.3)

From NDS,

F_v = 95 psi for Douglas fir-larch stringers

$$w_v = \frac{2(EI_g)\ F_v t}{4Q_v\ L\ E_{st}}$$

$$= \frac{2 \text{ x } 401{,}000{,}000 \text{ x } 95 \text{ x } (4 \text{ x } 1.5)}{4 \text{ x } 45.6 \text{ x } 14 \text{ x } 1{,}850{,}000}$$

$$w_v = 96.8 \text{ psf} > 50 \text{ psf, OK}$$

B19. Final Allowable Load (See Section 3.8)

Load Summary

w_Δ = 61.7 psf
w_{bb} = 55.5
w_{bt} = 86.1
w_{pb} = 53.2
w_{st} = 121.9
w_v = 96.8

Allowable load is 53.2 psf and is controlled by the bottom-skin splice plate. Since this is greater than the 50 psf required, the panel is OK as designed. Note that, in this case, the allowable load on the panel could be increased slightly by moving the splice plate away from the mid-span of the panel.

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