SUPPLEMENT 5–16

PLYWOOD DESIGN SPECIFICATION

Design and Fabrication of All-Plywood Beams

DECEMBER 2016

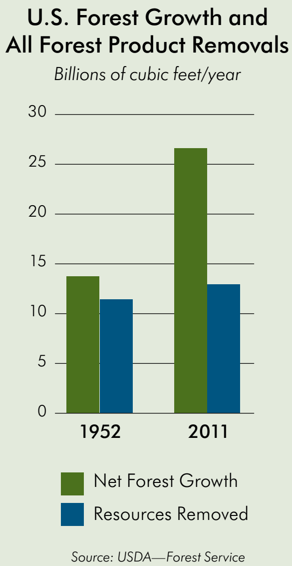
APA

Wood: The Natural Choice

Engineered wood products are among the most beautiful and environmentally friendly building materials. In manufacture, they are produced efficiently from a renewable resource. In construction, the fact that engineered wood products are available in a wide variety of sizes and dimensions means there is less jobsite waste and lower disposal costs. In completed buildings, engineered wood products are carbon storehouses that deliver decades of strong, dependable structural performance. Plus, wood's natural properties, combined with highly efficient wood-frame construction systems, make it a top choice in energy conservation.

A few facts about wood:

We're growing more wood every day. For the past 100 years, the amount of forestland in the United States has remained stable at a level of about 751 million acres.[1] Forests and wooded lands cover over 40 percent of North America's land mass.[2] Net growth of forests has exceeded net removal since 1952[3]; in 2011, net forest growth was measured at double the amount of resources removed.[4] American landowners plant more than two-and-a-half billion new trees every year.[5] In addition, millions of trees seed naturally.



Manufacturing wood is energy efficient. Over 50 percent of the energy consumed in manufacturing wood products comes from bioenergy such as tree bark, sawdust, and other harvesting by-products.[6] Very little of the energy used to manufacture engineered wood comes from fossil fuels. Plus, modern methods allow manufacturers to get more out of each log, ensuring that very little of the forest resource is wasted.

Life Cycle Assessment measures the long-term green value of wood. Studies by CORRIM (Consortium for Research on Renewable Industrial Materials) give scientific validation to the strength of wood as a green building product. In examining building products' life cycles—from extraction of the raw material to demolition of the building at the end of its long lifespan—CORRIM found that wood had a more positive impact on the environment than steel or concrete in terms of embodied energy, global warming potential, air emissions, water emissions and solid waste production. For the complete details of the report, visit www.CORRIM.org.

Wood adds environmental value throughout the life of a structure. When the goal is energy-efficient construction, wood's low thermal conductivity makes it a superior material. As an insulator, wood is six times more efficient than an equivalent thickness of brick, 105 times more efficient than concrete, and 400 times more efficient than steel.[7]

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 is the natural choice for the environment, for design, and for strong, resilient construction.

1. United States Department of Agriculture, U.S. Forest Service, FS-979, June 2011; 2. FAO, UN-ECE (1996) North American Timber Trends Study. ECE/TIM/SP/9. Geneva; Smith et al. (1994), Forest Statistics of the United States, 1992. Gen. Tech. Rep. NC-168; 3. United States Department of Agriculture, U.S. Forest Service; FS-801 Revised September 2009; 4. U.S. Department of Agriculture, U.S. Forest Service, August 2014; 5. Forest Landowners Association, 2011; 6. U.S. Environmental Protection Agency, March 2007; 7. Produced for the Commonwealth of Australia by the Institute for Sustainable Futures, University of Technology, Sydney, 2010.

PLYWOOD DESIGN SPECIFICATION, SUPPLEMENT 5–16

DESIGN AND FABRICATION OF ALL-PLYWOOD BEAMS

December 2016

FOREWORD

This publication formerly was issued as *APA – The Engineered Wood Association Research Report 124-A*, Form D410. It presents recommended methods for the design and fabrication of staple-glued all-plywood beams. Allowable stresses and other design criteria for plywood are given in Part 1, and in APA's PLYWOOD DESIGN SPECIFICATION. References are also made to the ANSI/AWC NATIONAL DESIGN SPECIFICATION FOR WOOD CONSTRUCTION (NDS). Part 2 of this publication covers beam fabrication.

Beam design and fabrication recommendations are based on tests conducted by APA, as described in *APA Research Report 124-A, All-Plywood Beams for Mobile Homes.* The tests showed that such beams comply with the structural load test criteria in the Federal Manufactured Home Construction and Safety Standards. These standards and subsequent amendments are published in the FEDERAL REGISTER by the U.S. Department of Housing and Urban Development, and include procedures and criteria for conducting and evaluating structural load tests on assemblies, such as all-plywood beams. Information in this PLYWOOD DESIGN SPECIFICATION Supplement applies to untreated plywood made in accordance with the latest edition of Voluntary Product Standards *PS 1-09, Structural Plywood,* or *PS 2-10, Performance Standard for Wood-Based Structural-Use Panels.*

All-plywood beams designed and fabricated with these recommendations have been widely used in manufactured homes. Check with model building code regulatory agencies for acceptance of these methods for construction of components to be used in other code-complying structural applications.

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

The technical data in this Supplement are presented as the basis for design and fabrication of all-plywood beams. For such design to result in satisfactory service, adequate materials and fabrication are also required. All plywood should bear the trademark of a certification body, such as APA.

The information contained herein is based on APA's continuing program of laboratory testing, product research and comprehensive field experience. Neither APA, nor its members make any warranty, expressed or implied, or assume any legal liability or responsibility for the use, application of, and/or reference to opinions, findings, conclusions or recommendations included in this publication. Consult your local jurisdiction or design professional to assure compliance with code, construction and performance requirements. Because APA has no control over quality of workmanship or the conditions under which engineered wood products are used, it cannot accept responsibility for product performance or designs as actually constructed.

A WORD ON COMPONENTS

Plywood components are primary structural members which depend on the glued joints to integrate the separate pieces into an efficient unit capable of carrying high stresses. Materials in these components may be stressed to an appreciably higher level than in non-engineered 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 agency accredited by a nationally recognized accreditation body. A requirement that each unit bear the trademark of an approved agency will assure adequate independent inspection.

PLYWOOD PERFORMANCE CATEGORIES

A recent emphasis on the compliance with the Weights and Measures of the National Institute of Standards and Technology (NIST) has led to the designation of *Performance Category* in lieu of *nominal panel thickness* for wood structural panels. As an example, a panel formerly identified as *3/8-inch thickness,* is now designated as *3/8 Performance Category.* This change has no impact on the design values, use recommendations, and qualification or manufacturing requirements of the plywood panels.

The International Building Code (IBC) and International Residential Code (IRC) recognize this change in the 2015 IBC Section 2303.1.5 and 2015 IRC Section R503.2.1 with the following statement:

> *The Performance Category value shall be used as the "nominal panel thickness" or "panel thickness" whenever referenced in this code.*

The same principle applies to this publication.

TABLE OF CONTENTS: PLYWOOD DESIGN SPECIFICATION, SUPPLEMENT 5–16: DESIGN AND FABRICATION OF ALL-PLYWOOD BEAMS

LIST OF SYMBOLS AND LOCATIONS

A = The gross area of the splice plate ($h_s \times L_s$) (in.^{2}); Sections 3.4 and A3.5

A_s = Total effective shear area in the web and flanges, regardless of joints (in.^{2}); Sections 6.2, A6.2.2, and A6.2.3

A_{sw} = Total effective shear area in the web, regardless of joints (in.^{2}); Sections 6.2.2 and A6.2.2

A_{sf} = Total effective shear area in the flanges, regardless of joints (in.^{2}); Sections 6.2.2 and A6.2.2

E = Modulus of elasticity on pure bending (used when calculating bending deflection separately from shear deflection) (psi); Sections 1.5.1, 6.2.1, A1.5, and A6.1

F_b = Allowable stress for bending for all plywood beams ONLY (psi); Sections 1.5, 2, A1.5, and A2.2

F_s = Allowable rolling shear stress for plywood. Note this stress must be reduced 50% for stress concentration at edges of the panel (psi); Sections 3.4, 4, A1.5, A3.5, and A4

F_v = Allowable stress for shear for all plywood beams ONLY (psi); Sections 1.5, 3, A1.5, and A3.4

G = Shear modulus of the plywood web and flanges (See PLYWOOD DESIGN SPECIFICATION) (psi); Sections 6.2, 6.2.1, A1.5, and A6.2.3

I_n = Net moment of inertia about the neutral axis of all continuous parallel-grain material at the *minimum* section containing a web or flange joint (in.^{4}); Sections 2, 2.1, A2.1, and A2.2

I_f = Moment of inertia about the neutral axis of all continuous parallel-grain material of the flanges used for calculating I_n (in.^{4}); Sections 2.1, A2.1, and A3.1

$I_{(flanges)}$ = Moment of inertia about the neutral axis of all parallel-grain material of the flanges regardless of joints used for calculating I_t (in.^{4}); Section 3.1

I_t = Total moment of inertia about the neutral axis of all parallel-grain material in the web and flanges regardless of joints. Disregard web stiffeners and splice plates (in.^{4}); Sections 3, 3.1, 4, 6.1, A3.1, A3.4, A4, and A6.1

I_w = Moment of inertia about the neutral axis of all continuous parallel-grain material of the web used for calculating I_n (in.^{4}); Sections 2.1 and A3.1

$I_{(web)}$ = Moment of inertia about the neutral axis of all parallel-grain material of the web regardless of joints used for calculating I_t (in.^{4}); Section 3.1

I_{ws} = Moment of inertia about the neutral axis of all continuous parallel-grain material of the web splice plate used for calculating I_n (in.^{4}); Sections 2.1 and A2.1

K = A factor determined by the ratio of the beam dimensions and the ratio of the shear modulus of the web (Q_w) and flanges (Q_f); Sections 6.1, 6.2, 6.2.1, A6.2.1, A6.2.3, and Figure 1

L = Clear span of the beam, measured between supports (ft); Sections 2, 6.1, 6.2, A2.2, A6.1, and A6.2.3

L' = Span reduction permitted for calculating load based on shear stress, equal to the beam clear span minus two times the depth of the beam ($L' = L - (2h_w)/12$) (ft); Sections 3, 3.4, 4, A3.4, A3.5, and A4

L_s = Length of the splice plate (minimum permitted length = 12 × nominal thickness of the web) (in.); Section 3.4

Q = Statical moment about the neutral axis of the area of all parallel-grain material in the web and flanges regardless of joints, lying above (or below) the neutral axis. Disregard stiffeners or splice plates (in.^{3}); Sections 3, 3.3, A3.3, and A3.4

Q_w = Statical moment about the neutral axis of the area of all parallel-grain material in the web regardless of joints, lying above (or below) the neutral axis. Disregard stiffeners or splice plates (in.^{3}); Sections 3, 3.3, and A3.3

Q_f = Statical moment about the neutral axis of the area of all parallel-grain material in the flanges regardless of joints, lying above (or below) the neutral axis. Disregard stiffeners or splice plates (in.^{3}); Sections 3, 3.3, A3.3, and A4

b = Effective shear thickness of webs and flanges regardless of joints (in.); use t_s from Table 1, Section 6.2.1, Appendix A, A6.2.1, and Figure 1

c = Distance from neutral axis to extreme fiber in bending. For symmetrical beam cross-sections, this distance is half of the beam depth (in.); Sections 2 and A2.2

d = Depth or "height" of flanges (in.); Section 2.1, Appendix A, A2.1, A4, A6.2.1, A6.2.2, and Figure 1

h_w = Depth or "height" of web (equal to depth or "height" of beam) (in.); Section 2.1, Appendix A, A2.1, A3.1, A6.2.1, A6.2.2, and Figure 1

h_s = Depth or "height" of web splice plate (in.); Section 2.1, Appendix A, and A2.1

ℓ = beam span measured between centers of supports (in.); Section 6

r = Ratio of total shear thickness of webs (Σt_{sw}) to the shear thickness of the webs (b), for use in Figure 1; Sections 6.2.1, A6.2.1, and Figure 1

t_b = Thickness for bending stress and bending deflection of all parallel plies per lamination (in.); Table 1, Sections 1.4, 2, A1.4, A2.1, and A3.1

t_{bf} = Thickness for bending stress and bending deflection of all parallel plies per lamination of the flanges (in.); use t_b from Table 1, Section 2.1

t_{bs} = Thickness for bending stress and bending deflection of all parallel plies per lamination of the web splice plate (in.); use t_b from Table 1, Section 2.1

t_{bw} = Thickness for bending stress and bending deflection of all parallel plies per lamination of the web (in.); use t_b from Table 1, Section 2.1

t_s = Effective shear thickness of continuous webs (and/or web splice plates and stiffeners, if applicable) at the neutral axis of the section (in.); use t_s from Table 1, Sections 1.4, 3, 3.1, A1.4, A3.2, A3.4, A6.2.1, A6.2.2, and Figure 1

t_{sf} = Effective shear thickness of flanges regardless of joints (in.); use t_s from Table 1, Sections 6.2.2 and A4

t_{sw} = Effective shear thickness of webs regardless of joints (in.); use t_s from Table 1, Sections 6.2.1 and 6.2.2

w = Final total allowable load, based on the smallest of those controlled by bending (w_b), horizontal shear (w_v) or rolling shear (w_{sw} and w_{sf}) (lbf/ft); Sections 5, 6.1, 6.2, A6.1, and A6.2.3

w_b = Total uniform load, based on allowable bending stress (lbf/ft); Sections 2, A2.2, and A5

w_{sf} = Total uniform load, based on allowable flange-web rolling shear stress (lbf/ft); Sections A4 and A5

w_{sw} = Total uniform load, based on allowable rolling shear stress (lbf/ft); Sections 2, A3.5, and A5

w_v = Total uniform load, based on allowable horizontal shear stress (lbf/ft); Sections 3, A3.4, and A5

Δ = Total deflection based on bending and shear (in.); Sections 6 and A6.3

Δ_b = Maximum deflection of a single span beam under uniform load based on bending only (in.); Sections 6.1, A6.1, and A6.3

Δ_s = Maximum deflection of a single span beam under uniform load based on shear only (in.); Sections 6.2, A6.2, A6.2.3, and A6.3

PART 1—DESIGN OF ALL-PLYWOOD BEAMS

1. General

This method is applicable to beams fabricated in accordance with Part 2, Fabrication of All-Plywood Beams.

1.1 Plywood Grade

Applicable grades include RATED SHEATHING EXP 1, RATED SHEATHING EXT, STRUCTURAL I RATED SHEATHING EXP 1, and STRUCTURAL I RATED SHEATHING EXT. Panels must be plywood and marked PS 1 or PS 2.

1.2 Plywood Layup

Typical plywood layups are shown in Table 1. Design should be based on the value in **boldface** for each combination of thickness and Span Rating, unless another layup is specified and available.

TABLE 1

EFFECTIVE THICKNESS FOR TYPICAL UNSANDED PS 1 OR PS 2 PLYWOOD CONSTRUCTIONS[a,b]

Plywood Performance Category and (Span Rating)	No. of Plies / No. of Layers	Nominal Face Veneer Thickness (in.)	Thickness for Bending Stress and Bending Deflection, t_b (in.): All plies Group 1 (including STRUCTURAL I)	Thickness for Bending Stress and Bending Deflection, t_b (in.): All Other	Thickness for Shear Stress and Shear Deflection, t_s (in.): All plies Group 1 (including STRUCTURAL I)	Thickness for Shear Stress and Shear Deflection, t_s (in.): All Other
3/8 (24/0)	3/3	1/8	.216	.170	.371	.280
		1/10	**.185**	**.136**	**.371**	**.278**
15/32 (32/16)	3/3	1/6	.302[c]	.220	**.395**[c]	**.295**[c]
	4/3	1/8	**.227**	**.167**	.535	.400
	5/5	1/10	.272	.182	.676	.500
19/32 (40/20)	4/3	1/6	**.270**[c]	**.207**	**.567**[c]	**.421**
		1/6, 1/8				
	5/5	1/8	.347	.236	.707	.518
		1/10	.289	.246	.715	.561
23/32 (48/24)	4/3	1/6	**.320**[c]	.256	**.598**[c]	**.441**
		3/16				
	5/5	1/6	.407	.281	.739	.532
		1/8	.352	**.254**	.739	.539
		1/8, 1/7				
		1/7				
		1/8, 1/6				
		1/10	.373	.293	.746	.573
	6/5	1/8	.352	.299	.879	.694
	7/7	1/10	.373	.290	1.020	.784

a. Use value in **boldface** for combination of plywood thickness and Span Rating unless another layup is specified and available. Check availability of panel layup and species group before specifying.

b. Values do not apply to plywood panels marked "Butt-Jointed Center."

c. Not available in STRUCTURAL I grade.

1.3 Species Group

Section properties are presented below both for plywood having all plies of Group 1 species, and for plywood made with other species combinations. For some designs, it may be advantageous to specify STRUCTURAL I grades or panels with all plies of Group 1 species. Check availability before specifying.

1.4 Effective Thickness

Table 1 gives values of effective thickness of parallel plies (t_b) for calculating bending stress and bending deflection. Also listed is the effective thickness (t_s) for calculating shear stress and shear deflection.

1.5 Allowable Stresses

Design shall be based on allowable stresses and shear modulus, as listed in the PLYWOOD DESIGN SPECIFICATION for Group 1 face plies, except as provided for in Table 2.

TABLE 2

ALLOWABLE STRESSES FOR ALL-PLYWOOD BEAMS[a]

Plywood Grade	Construction	F_b (psi)	E (psi)[b]	F_v (psi)
APA RATED SHEATHING EXPOSURE 1, APA RATED SHEATHING EXTERIOR, STRUCTURAL I APA RATED SHEATHING EXPOSURE 1, STRUCTURAL I APA RATED SHEATHING EXTERIOR	< 5 PLYS	2,800	1,705,000	—
	≥ 5 PLYS	3,300	1,815,000	—
D-D APA RATED SHEATHING EXPOSURE 1	< 5 PLYS	1,050	1,705,000	—
	≥ 5 PLYS	1,275	1,815,000	—
APA RATED SHEATHING EXPOSURE 1, APA RATED SHEATHING EXTERIOR, STRUCTURAL I APA RATED SHEATHING EXPOSURE 1, STRUCTURAL I APA RATED SHEATHING EXTERIOR	Single web, no glued flanges	—	—	190
	≥ 2 webs or glued flanges top and bottom	—	—	225
	Webs regraded[c]	—	—	250
D-D APA RATED SHEATHING EXPOSURE 1	Single web, no glued flanges	—	—	145
	≥ 2 webs or glued flanges top and bottom	—	—	175
	Webs regraded[c]	—	—	195

a. Allowable stresses may be increased for Duration of Load in accordance with the PLYWOOD DESIGN SPECIFICATION.

b. Modulus of Elasticity (E) values have been increased by 10% to permit shear and bending deflections to be calculated separately.

c. For beams with or without flanges, when plywood is regraded to limit core gaps and placement, in accordance with Plywood Design Specifications. Because of the limited effectiveness of splice plates and stiffeners as edge reinforcement, the 1/3 increase in PLYWOOD DESIGN SPECIFICATION **shall not** be taken.

For plywood, which is not specified as Structural I or all Group 1, the designer should use Group 1 stresses in combination with the section properties listed under the heading "All Other." These values have been adjusted to compensate for allowable variations in panel makeup, to simplify design procedures.

1.5.1 Modulus of Elasticity in Pure Bending (E)

When calculating the bending deflection of beams separately from shear deflection, it is customary to use the modulus of elasticity of the materials in pure bending. For plywood, the "bending E" is 10% higher than the effective E values listed in the PLYWOOD DESIGN SPECIFICATION.

2. Determine Total Load Based on Allowable Web and Flange Bending Stress

For single-span beams under uniform load, the total uniform load, w_b, based on allowable bending stress in the web and flanges, can be calculated from the following formula:

$$w_b = \frac{8\,F_b I_n}{12c\,L^2}$$

where:

w_b = Total uniform load, based on allowable bending stress (lbf/ft).

F_b = Allowable plywood bending stress (psi) from Section 1.5.

I_n = Net moment of inertia about the neutral axis of all continuous parallel-grain material at the minimum section containing a web or flange joint (in.^{4}). See Section 2.1.

c = Distance from neutral axis to extreme fiber in bending (in.). For symmetrical beam cross-sections, this distance is half the beam depth.

L = Clear span of the beam, measured between supports (ft).

2.1 Net Moment of Inertia (I_n)

For all-plywood beams it will usually be necessary to check more than one cross section, depending on location of web and flange joints. Webs, flanges, splice plates with joints are not counted at the cross section checked. Sometimes visual comparison of the sections will quickly show which will be critical. The net moment of inertia about the neutral axis of all continuous parallel plies can be calculated by adding applicable values from the following formulas:

$$I_{w\,(web)} = \frac{\Sigma t_{bw} h_w^3}{12}$$

(See Note)

$$I_{ws\,(web\ splice\ plates)} = \frac{\Sigma t_{bs} h_s^3}{12}$$

$$I_{f\,(flanges)} = \frac{\Sigma t_{bf}\,[h_w^3 - (h_w - 2d)^3]}{12}$$

where:

t_b = Thickness of all parallel plies per lamination (in.). Use t_b from Table 1.

d, h_w, h_s = Depth, or "height" of flanges, web and web splice plate (in.).

NOTE: Consider splice plate only if directly glued to the web containing the butt joint.

3. Determine Total Load Based on Allowable Web Shear Stress

For single-span beams under uniform load, the total uniform load, w_v, based on allowable horizontal shear stress at the neutral axis of the web, can be calculated from the following formula:

$$w_v = \frac{2F_v I_t \Sigma t_s}{QL}$$

where:

w_v = Total uniform load, based on allowable horizontal shear stress (lbf/ft).

F_v = Allowable plywood shear stress (psi) from Section 1.5.

I_t = Total moment of inertia about the neutral axis of all parallel-grain material in the web and flanges, regardless of joints (in.^{4}). Disregard stiffeners or web splice plates. See Section 3.1.

t_s = Effective shear thickness of continuous webs (and/or web splice plates and stiffeners, if applicable) at the neutral axis of the section (in.). Use t_s from Table 1.

Q = Statical moment about the neutral axis of the area of all parallel-grain material in the web and flanges regardless of joints, lying above (or below) the neutral axis (in.^{3}). Disregard stiffeners or web splice plates. See Section 3.3.

L = Clear span of beam, measured between supports (ft). A value of $L' = L - 2h_w/12$, where h_w equals the height of the web, may be used if desired.

3.1 Total Moment of Inertia (I_t)

For symmetrical beams, the total moment of inertia about the neutral axis of all parallel plies in the plywood web and flanges can be calculated by adding applicable values from the following formulas. Joints in webs and flanges, and web stiffeners or splice plates, are not considered in calculating I_t.

$$I_{web} = \frac{\Sigma t_{bw} h_w^3}{12}$$

$$I_{flange} = \frac{\Sigma t_{bf}\,[b_w^3 - (h_w - 2d)^3]}{12}$$

3.2 Effective Total Web Shear Thickness (t_s)

As is true for bending, a number of cross sections must be considered, depending on location of joints in webs and flanges.

The proximity of these sections to end or interior supports must be considered, because shear forces are higher near the supports. Web joints in single-web beams should be located 24 inches or more from supports. See Part 2, Fabrication of All-Plywood Beams. Also, in calculating shear, all loads may be ignored that fall within a distance from the support equal to the beam depth. Therefore, the maximum shear stress for beams with single-layer webs will occur either at an unreinforced web section, located adjacent to the web stiffener over the support, or at h_w from the support. For beams with multiple-layer webs, the maximum horizontal shear stress will occur at the web joint located nearest to the support.

3.3 Statical Moment of Area of Parallel Plies (Q)

The statical moment of the area of parallel plies in the web and flanges, above or below the neutral axis, can be calculated from the general formula Q = A y, where A = area of parallel plies above or below the neutral axis, and y = distance from the neutral axis to the centroid of the area of the parallel plies above or below the neutral axis. For a symmetrical beam, Q can be calculated by adding applicable values from the following formulas:

$$Q_{w\,(web)} = \Sigma t_{bw} \frac{h_w}{2} \frac{h_w}{4} = \frac{\Sigma t_{bw}\, h_w^2}{8}$$

$$Q_{f\,(flange)} = \Sigma t_{bf}\, d \frac{(h_w - d)}{2}$$

where:

d = Depth of flange (in.)

3.4 Web Splices (F_s)

Butt joints in single-layer webs shall be spliced with plywood web splice plates in accordance with Part 2, Section 3.5 of this Specification. When web splice plates are specified for beams with multiple-layer web laminations, the splice plate shall be glued directly to the web lamination containing the butt joint. In accordance with the PLYWOOD DESIGN SPECIFICATION, the web splice plate grade and thickness shall be equal to the web lamination, and its length shall be at least 12 times its nominal thickness, t. The splice plate shall be centered over the joint. The beam web-joint design for vertical shear capacity shall be based on the allowable rolling shear stress, reduced 50% for stress concentration at the web joint in accordance with the PLYWOOD DESIGN SPECIFICATION. Shear capacity shall be reduced proportionately for shorter splice plate lengths.

$$w_{sw} = \frac{2\, F_s\, A}{L}$$

where:

w_{sw} = Total uniform load at web splice, based on allowable rolling shear stress (lbf/ft).

F_s = Allowable plywood rolling shear stress (psi). See PLYWOOD DESIGN SPECIFICATION. **NOTE:** This stress must be reduced 50% for stress concentrations at edge of panel. See PLYWOOD DESIGN SPECIFICATION.

A = The gross area of the splice plate ($h_s \times L_s$) (in.^{2}) where h_s is the depth or "height" of the web splice plate (in.).

L = Clear span of beam, measured between supports (ft). A value of $L' = L - 2h_w$, where h_w equals the height of the web, may be used if desired.

L_s = Length of the splice plate (minimum permitted length = 12 × nominal thickness of the web) (in.).

4. Determine Total Load Based on Allowable Flange-Web Shear Stress (F_s)

For uniformly loaded, single-span beams with plywood flanges, the maximum flange-web shear stress will occur at the supports, where shear forces are highest. The total uniform load (w_s) based on allowable shear stress between the web and flange can be calculated from the following formula:

$$w_{sf} = \frac{2F_s I_t d}{Q_f L}$$

where:

w_{sf} = Total uniform load at flange/web interface, based on allowable rolling shear stress (lbf/ft).

F_s = Allowable plywood rolling shear stress (psi). This stress must be reduced 50% for stress concentration at the edge of the panel. See PLYWOOD DESIGN SPECIFICATION.

I_t = Total moment of inertia about the neutral axis of all parallel-grain material in the web and flanges, regardless of joints (in.^{4}). Disregard web stiffeners or splice plates. See Section 3.1.

d = Depth of flange (in.).

Q_f = Statical moment about the neutral axis of the area of all parallel-grain material in the top or bottom flange, regardless of joints (in.^{3}). See Section 3.3.

L = Clear span of beam, measured between supports (ft). A value of $L' = L - 2h_w$, where h_w equals the height of the web, may be used if desired.

5. Determine Final Total Allowable Load (w)

The final allowable load will be the smallest of those controlled by bending, horizontal shear, or rolling shear.

6. Calculate Deflection at Allowable Load (Δ)

The total deflection may be determined by separately calculating and adding the bending deflection and shear deflection of the beam. Paragraph 3280.305 (d) of the Federal Manufactured Home Construction and Safety Standards requires that deflection be less than $\ell/180$ at design live load. All-plywood beams are usually stiffer.

6.1 Bending Deflection (Δ_b)

For single-span beams under uniform load, the maximum bending deflection may be calculated by the following formula:

$$\Delta_b = \frac{5\, w\, L^4 \times 1{,}728}{384\, E\, I_t}$$

where:

w = Final total allowable load (lbf/ft). See Section 5.

L = Clear span measured between supports (ft).

E = Modulus of elasticity of plywood in pure bending (psi). See Section 1.5.1.

I_t = Total moment of inertia about the neutral axis of all parallel-grain material in the web and flanges, regardless of joints (in.^{4}). Disregard web stiffeners and splice plates. See Section 3.1.

6.2 Shear Deflection (Δ_s)

The shear deflection for a single-span beam under uniform load is given in the following formula:

$$\Delta_s = \frac{K\,w\,L^2}{8\,A_s\,G}$$

where:

K = A factor determined by the ratio of the beam dimensions and the ratio of the shear modulus (G) of the web and flange. See Section 6.2.1.

A_s = Total effective shear area in the web and flanges, regardless of joints ($in.^2$).

G = Shear modulus of the plywood web and flanges (psi). See PLYWOOD DESIGN SPECIFICATION.

NOTE: For derivation of shear-deflection equations, and for other loading conditions or beam configurations, see *Forest Service Research Note FPL-0210.* Information in this publication should allow the engineer to handle non-uniform loads, multiple spans, non-symmetrical beams, and beams whose webs and flanges have different shear or elastic moduli.

6.2.1 Shear Deflection Constant (K)

For symmetrical beams with webs and flanges having equal shear modulus, G, and equal modulus of elasticity, E, values for K are determined from Figure 1.

$$\text{For use in Figure 1,} \quad r = \frac{\Sigma t_{sw}}{b}$$

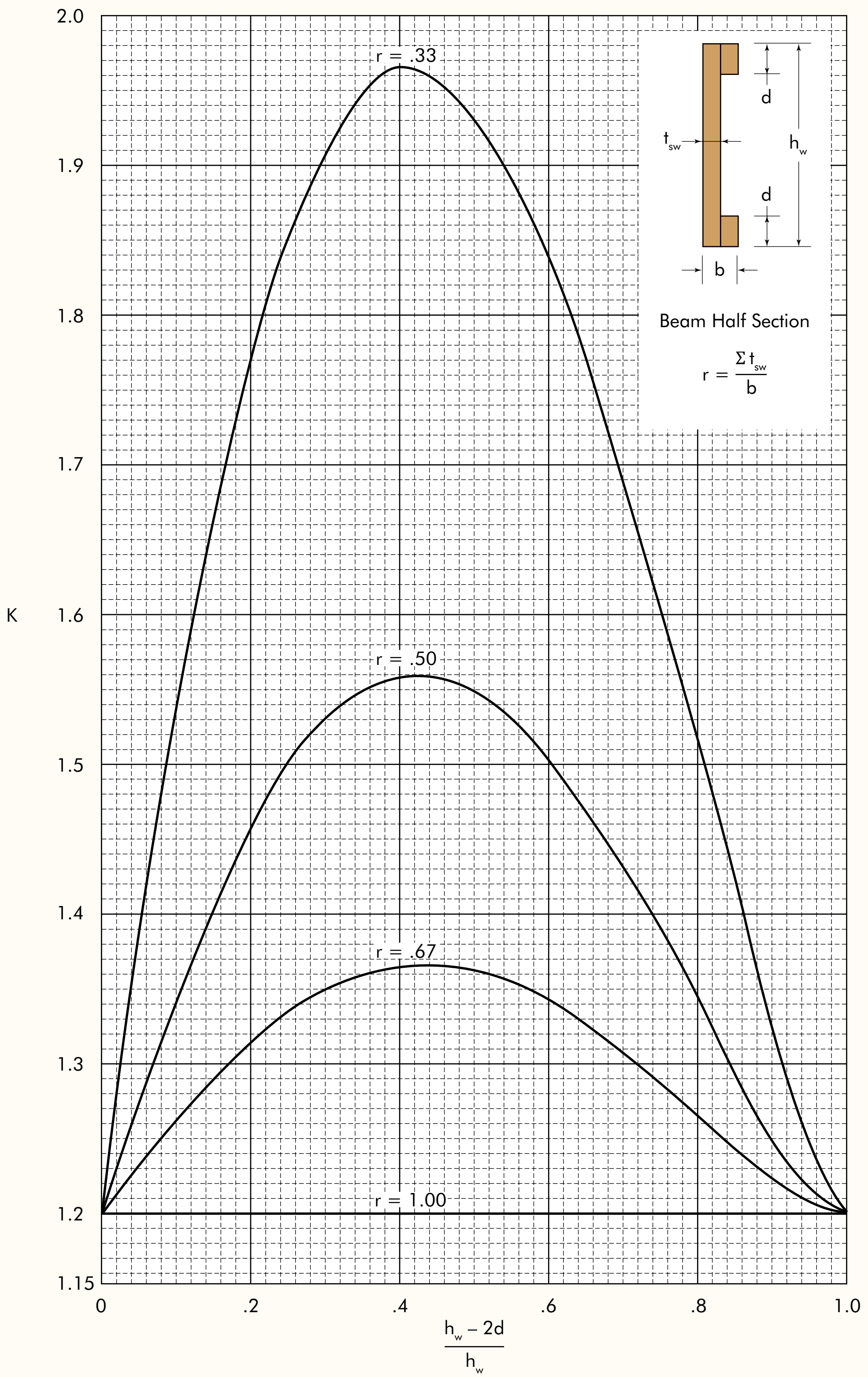
where:

t_{sw} = Total effective shear thickness of webs, regardless of joints (in.). See Table 1. Disregard web splice plates or stiffeners.

b = Total effective shear thickness of webs and flanges, regardless of joints (in.). See Table 1.

FIGURE 1

SHEAR DEFLECTION CONSTANT (K) FOR SYMMETRICAL BEAMS WITH EQUAL SHEAR MODULI FOR WEB AND FLANGE



6.2.2 *Effective Shear Area (A_s)*

The effective shear area in the webs and flanges (A_{sw} and A_{sf}) can be calculated by adding applicable values from the following formulas:

$A_{sw\ (web)} = \Sigma\ (t_{sw} h_w)$

$A_{sf\ (flanges)} = \Sigma\ (t_{sf}\ d)$

where:

t_{sf} = Effective shear thickness of flanges regardless of joints (in.). See Table 1.

t_{sw} = Effective shear thickness of webs regardless of joints (in.). See Table 1.

d = Depth or "height" of flanges (in.).

h_w = Depth or "height" of web (in.).

7. Beam Support and Connection Details

As final steps in the overall design, determine the structural adequacy of beam supports and connections for beam half-sections at end or interior bearing walls, and connection details for attaching trussed rafters to beam half-sections, in accordance with recognized engineering practice. Designs should be based on allowable stresses listed in the NDS or on stresses supported by adequate test data which are approved by the authority having jurisdiction responsible for design approval or inspection.

7.1

The compression edges of the beam shall be positively restrained from lateral buckling. This can usually be accomplished by structural panel roof sheathing, trussed rafters spaced not further than 24 inches o.c., and/or by ceiling material.

7.2

Details for connecting ridge beam half-sections at the site shall be in accordance with manufacturer's installation instructions approved by the authority having jurisdiction responsible for design approval or inspection. Fasteners shall not be used in tension areas where bending stresses exceed one-half of the allowable bending stress. See Section 1.5. For further information on lag screws or bolts for connecting ridge beam half-sections, see *APA Technical Note: Fastener Loads for Plywood Ridge Beam Connections,* Form M320, or the NDS.

PART 2—FABRICATION OF ALL-PLYWOOD BEAMS

1. Scope

1.1

This specification covers the fabrication of all-plywood beams. The design and fabrication of these beams is based on the results of tests which demonstrate compliance with the structural performance requirements of the Federal Manufactured Housing Construction and Safety Standards as published by the U.S. Department of Housing and Urban Development (HUD).

1.2

The beams should be designed in accordance with the method suggested in Part 1, Design of All-Plywood Beams. The latest edition of APA's PLYWOOD DESIGN SPECIFICATION should be used where indicated. Other design methods may be employed, provided they are supported by adequate test data.

1.3

The product use recommendations in this publication are based on APA's continuing programs of laboratory testing, product research, and comprehensive field experience. However, because the Association has no control over quality of workmanship or the conditions under which engineered wood products are used, it cannot accept responsibility for product performance or designs as actually constructed.

2. Materials

2.1 Plywood

Plywood shall conform to the latest edition of *Voluntary Product Standard PS 1-09, Structural Plywood,* or *PS 2-10, Performance Standard for Wood-Based Structural-Use Panels.* Each original panel shall bear the trademark of a certification body, such as APA. 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 a certification body, such as APA.

2.1.1

If required by the authority having jurisdiction responsible for design approval or inspection, plywood cut for webs or flanges shall be accompanied by written confirmation from the cutter certifying that the original plywood panel was of the specified type and grade, and was stamped with the trademark of a certification body, such as APA.

2.1.2

The recommended plywood grades are RATED SHEATHING EXP 1, RATED SHEATHING EXT, STRUCTURAL I RATED SHEATHING EXP 1, and STRUCTURAL I RATED SHEATHING EXT. Panels must be marked PS 1 or PS 2.

NOTE: In some instances, plywood of grades other than STRUCTURAL I may have all plies of Group 1 or other species group. If specified by design, the plywood shall be accompanied by written confirmation from the plywood manufacturer certifying that all plies are of the required species group.

2.1.3

For some designs, a specific plywood layup may be required to satisfy span or load conditions. In these instances, the plywood shall be accompanied by written confirmation from the plywood manufacturer certifying that it was manufactured with the specified layup, subject to PS 1 or PS 2 manufacturing tolerances.

2.1.4

Plywood pieces cut 4-1/2 inches or less in width for flanges shall be visually inspected after cutting for size of knots. Pieces containing knots in face or back plies larger than two-thirds of the flange width shall not be used in fabricating flanges for ridge beams.

NOTE: Knot size is determined by (1) a difference in color of limbwood and surrounding trunkwood; (2) an abrupt change in growth ring width between the knot and bordering trunkwood; and (3) the diameter of circular or oval shape described by points where checks on the face of a knot that extend radially from its center to its side experience an abrupt change in direction.

2.1.5

Surfaces of plywood to be glued shall be dry, clean, and free from oil, dust, paper tape or other materials which would be detrimental to satisfactory gluing. At the time of gluing, the plywood moisture content shall be 15% or less.

2.2 Adhesive

Adhesive shall be of the type specified by designer for anticipated exposure conditions. For products intended for code compliance, such as International Building Code or International Residential Code, adhesives used for fabrication of all-plywood beams shall conform to ASTM Specification D2559. For other applications, adhesives shall conform to requirements specified by regulatory agencies responsible for approval of design or inspection of the product.

2.3 Staples

Staples shall be 16 gage or thicker with a minimum 7/16-inch-width crown, made from galvanized steel wire. Staple length shall be approximately 1/8 inch less than the total thickness of the materials joined.

3. Fabrication

3.1 General

Plywood beams shall be fabricated with adhesive and staples.

3.1.1

Plywood face grain for webs, flanges, web splice plates and stiffeners shall be oriented parallel to the span (i.e., horizontally).

3.1.2

Dimensions and tolerances shall be as specified in the design.

3.2 Web and Flange End Joints

3.2.1

End joints in plywood webs and flanges shall be located as specified in the design. Joints in any web or flange lamination shall be spaced at least 24 inches from the nearest joint in any other lamination.

3.2.2

Butt joints at ends of plywood web or flange pieces shall be trimmed square and tightly butted (maximum gap 1/32 inch).

3.2.3

In single-web beams, joints in webs shall be located at least 24 inches from any end or interior support.

3.3 Adhesive Application

3.3.1

Mixing of the adhesive (if applicable), spreading, storage-, pot-, and working-life, and assembly time and temperature shall be in accordance with the adhesive manufacturer's recommendations.

3.3.2

Adhesive shall be spread uniformly over the full contact area of mating web and/or flange surfaces. Application by roller, notched trowel or spray equipment is recommended to ensure complete adhesive coverage. The adhesive may be spread on one or both mating surfaces.

3.3.3

Unless otherwise specified by the adhesive manufacturer, an adhesive spread rate of approximately 1.7 gallons per 100 square feet of glued area is suggested.

3.3.4

When web or flange laminations are glued under pressure, such pressure shall be applied by clamping or other mechanical means. Pressure shall be sufficient to provide close contact and ensure good glue bonds (100 to 150 psi is suggested, unless otherwise specified by the adhesive manufacturer). Movement of the members shall be prevented until the adhesive develops sufficient handling strength, as recommended by the adhesive manufacturer.

3.3.5

In any case, **it shall be the responsibility of the fabricator to produce an adhesive bond which meets or exceeds applicable specifications.**

3.4 Staple Installation

3.4.1

Staples shall be installed with their crowns *parallel* to the plywood face-grain direction. Staple spacing shall be as shown in Figure 2. Staple crowns shall not penetrate the surface of the plywood greater than the thickness of the surface ply.

3.4.2

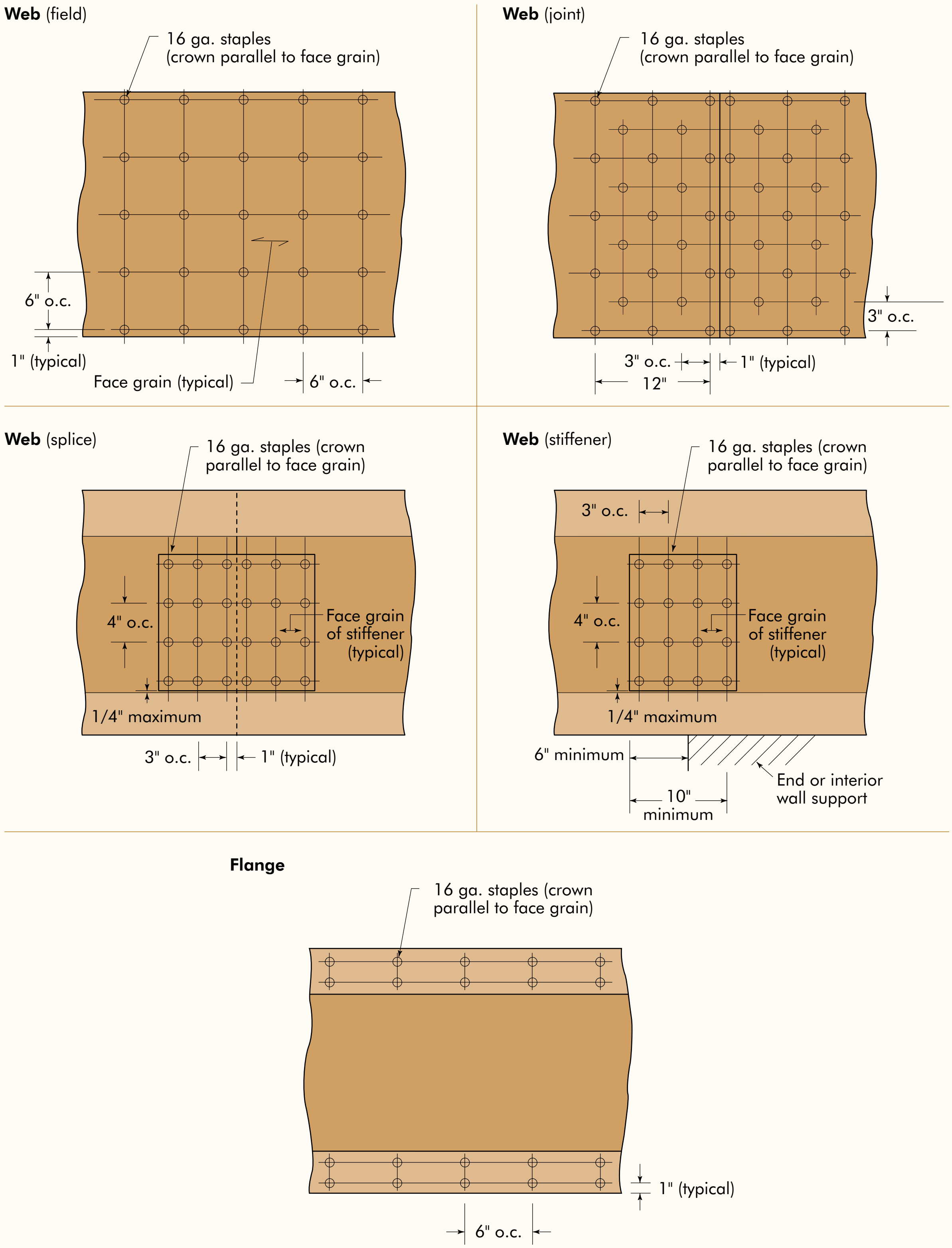
Hand pressure may be needed during stapling to flatten plywood webs and flanges, to ensure uniform contact between mating glued surfaces.

3.4.3

Installation of staples may start at any point, but shall progress to the end or ends of each piece.

FIGURE 2

STAPLE SPACING FOR PLYWOOD WEBS, FLANGES, SPLICE PLATES AND STIFFENERS[a]



a. Staple location tolerances shall be ± 1 inch for field spacings and ± 1/2 inch for edge distances, unless otherwise specified in the design.

3.5 Web Splices

Splices at butt joints in webs shall be as specified in the design. Butt joints shall be spliced with a plywood plate centered over the joint. The splice plate shall be glued over its full contact area and stapled to the web in accordance with Figure 2. The plate shall extend to at least 1/4 inch of each flange (if applicable), shall be equal in thickness and grade to the web, of a length as specified in the design or in the PLYWOOD DESIGN SPECIFICATION, and shall have its face-grain direction parallel with that of the web. In multiple-layer webs, the splice plate shall be directly glued to the web containing the butt joint.

3.6 Web Stiffeners

3.6.1

Stiffeners for single-layer webs shall be located as shown in the design, but in any case, they shall be placed at end supports and at interior concentrated-load points.

3.6.2

The stiffeners shall consist of a plywood plate glued over its full contact area and stapled to the web in accordance with Figure 2. The plate shall extend to at least 1/4 inch of each flange (if applicable), shall be at least equal in thickness and grade to the web, of a length as specified in the design but in no case less than 10 inches, and shall have its face-grain direction parallel with that of the web. The end or ends of the stiffener shall extend at least 6 inches beyond the edge of the support at the end and any interior supports. Best performance will be obtained if the stiffener actually contacts the inner edges of the plywood flanges on the loaded side of the beam.

3.6.3

Cutouts for openings in plywood webs may be provided at locations shown in the design. Single-layer webs shall be reinforced at cutouts with a plywood web stiffener per design.

4. Test Samples

4.1 General

Quality control and testing of beams shall be in accordance with the requirements of the authority having jurisdiction responsible for design approval and inspection.

5. Identification

5.1 General

If required, beams shall be identified as specified by the authority having jurisdiction responsible for design approval or inspection.

5.2 Unsymmetrical Beams

If the beam is designed such that it must be installed with a specific orientation, the top edge shall be clearly marked so that the proper orientation can be verified during in-plant inspection of the construction.

LITERATURE CITED

(Listed in order of appearance. Latest version applies unless otherwise specified.)

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7. International Code Council. *International Residential Code* (IRC). Country Club Hills, Illinois.
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10. USDA Forest Products Laboratory. *Simplified Method for Calculating Shear Deflection in Beams.* Forest Products Laboratory Research Note FPL-0210. Madison, Wisconsin.
11. APA – The Engineered Wood Association. *Technical Note: Fastener Loads for Plywood Ridge Beam Connections,* Form M320. Tacoma, Washington.
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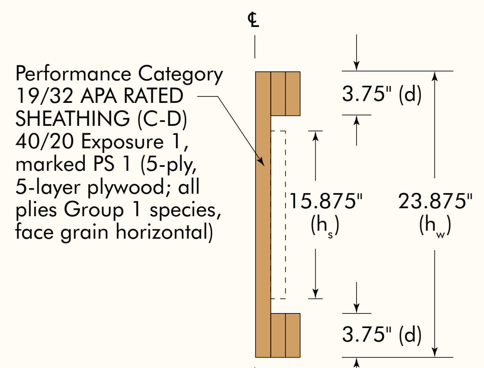
APPENDIX A—DESIGN EXAMPLE FOR ALL-PLYWOOD BEAMS

Problem: Given the 24-ft-span, 23-7/8-inch deep all-plywood ridge beam shown. Determine the allowable total load and deflection. Beam to be fabricated in accordance with Part 2, Fabrication of All-Plywood Beams.

Design is based on single-span condition, where deflection and bending stress are greatest. Shear stresses for multiple-span conditions may be as much as 25% greater than stresses for single-span conditions.



Beam Half-Section

A1. Plywood Design Information

A1.1 Plywood Grade

Design is based on RATED SHEATHING Exposure 1 (panels marked PS 1 or PS 2).

A1.2 Plywood Layup

Design is based on 5-ply, 5-layer Performance Category 19/32 plywood. To avoid further restriction on availability, thickness of plies is not specified.

A1.3 Species Group

Design is based on plywood having all plies of Species Group 1.

A1.4 Effective Thickness

From Table 1, minimum t_b = 0.289"; t_s = 0.707" for Performance Category 19/32, 5-ply, 5-layer plywood.

A1.5 Allowable Stresses

Bending Stress (F_b)

From Table 2, the basic bending stress for 5-ply, 5-layer plywood is 3,300 psi. This may be increased by 15% for snow-load duration.

$$F_b = 3{,}300 \times 1.15 = 3{,}800 \text{ psi}$$

Shear in Plane Perpendicular to Plies (F_v)

From Table 3 of PLYWOOD DESIGN SPECIFICATION, the allowable stress for shear in plane perpendicular to plies for beams with flanges top and bottom is 225 psi. This may be increased by 15% for snow-load duration.

$$F_v = 225 \times 1.15 = 260 \text{ psi}$$

Rolling-Shear Stress (F_s)

From Table 3 of PLYWOOD DESIGN SPECIFICATION, the basic rolling-shear stress is 53 psi for RATED SHEATHING Exposure 1.

Since this plywood has been specified as having all plies of Group 1 species, however, it is eligible for a basic stress of 75 psi. This stress must be reduced 50% in accordance with PLYWOOD DESIGN SPECIFICATION for stress concentration at the edge of the panel, but may be increased by 15% for snow-load duration.

$$F_s = 75 \times 0.5 \times 1.15 = 43.1 \text{ psi}$$

Modulus of Elasticity in Pure Bending (E)

From Table 2, the Modulus of Elasticity for plywood having face plies of Group 1 species is 1,815,000 psi. This value has been increased 10% to obtain E in pure bending when shear deflection is considered separately. (Part 1, Section 1.5.1.)

$$E = 1{,}815{,}000 \text{ psi}$$

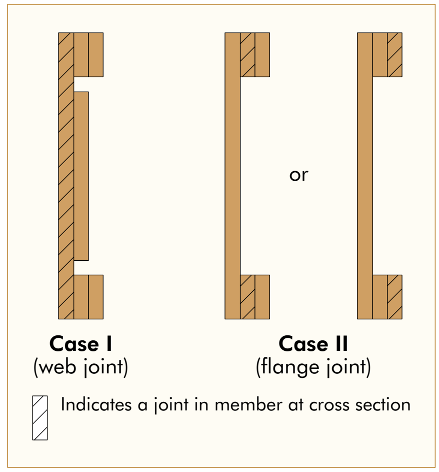
Shear Modulus (G)

From Table 3 of PLYWOOD DESIGN SPECIFICATION, G = 90,000 psi for plywood having face plies of Group 1 species.

A2. Determine Total Load Based on Allowable Web and Flange Bending Stress

A2.1 Net Moment of Inertia (I_n) (Part 1, Section 2.1)

For this design example, the following beam cross-sections are possible at web or flange joint locations:



A visual comparison of the three possible cross-sections reveals that the *minimum* section for bending stress calculations occurs at a web joint (Case 1).

$$I_{ws\,(\text{web splice plate})} = \frac{\Sigma\, t_b h_s^3}{12} = \frac{0.289 \times 15.875^3}{12} = 96 \text{ in.}^4$$

$$I_{f\,(\text{flanges})} = \frac{\Sigma\, t_b\, [h_w^3 - (h_w - 2d)^3]}{12} = \frac{2 \times 0.289\,(23.875^3 - 16.375^3)}{12} = 444 \text{ in.}^4$$

$$I_n = I_{ws} + I_f = 96 + 444 = 540 \text{ in.}^4$$

A2.2 Calculate Total Load Based on Allowable Web and Flange Bending Stress (w_b) (Part 1, Section 2)

$$w_b = \frac{8\, F_b I_n}{12c\, L^2} = \frac{8 \times 3800 \times 540}{12 \times \dfrac{23.875}{2} \times 24^2} = 199 \text{ lbf/ft}$$

A3. Determine Total Load Based on Allowable Web Shear Stress

A3.1 Total Moment of Inertia (I_t) (Part 1, Section 3.1)

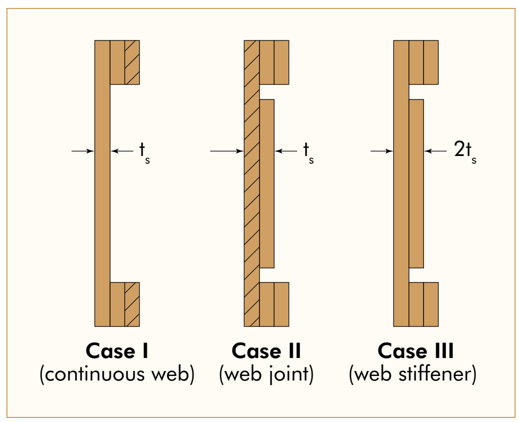
$$I_{w\,(\text{web})} = \frac{\Sigma\, t_b\, h_w^3}{12} = \frac{0.289 \times 23.875^3}{12} = 328 \text{ in.}^4$$

$$I_{f\,(\text{flanges})} = 444 \text{ in.}^4 \text{ (from A2.1)}$$

$$I_t = I_w + I_f = 328 + 444 = 772 \text{ in.}^4$$

A3.2 Effective Total Web Shear Thickness (t_s) (Part 1, Section 3)

For this design example, the effective web thickness (t_s) for shear calculations is shown on the following cross-sections which may occur along the beam:



A visual comparison of the three possible cross sections reveals that the minimum thickness for horizontal shear calculations occurs at either a continuous (unreinforced) web (Case I), or at a web joint (Case II). If the beam is detailed so that web joints are kept out of high-shear areas, then the controlling location will be in the unreinforced web (Case I), at the edge of the bearing stiffeners, near the end support. Total t_s, therefore, equals 0.707 inch (Case I). The design method permits ignoring all loads within a distance from either support equal to h_w. Since clear span is given as 24 ft, the effective length for calculating w_v is 24 ft, less 2 ft at each end, or 20 ft.

A3.3 Statical Moment of Area of Parallel Plies (Q) (Part 1, Section 3.3)

$$Q_{w\,(web)} = \frac{\Sigma t_b\, h_w^2}{8} = \frac{0.289 \times 23.875^2}{8} = 20.6 \text{ in.}^3$$

$$Q_{f\,(flanges)} = \frac{\Sigma t_b\, d\,(h_w - d)}{2} = \frac{2 \times 0.289 \times 3.75 \times (23.875 - 3.75)}{2} = 21.8 \text{ in.}^3$$

$$Q = Q_w + Q_f = 20.6 + 21.8 = 42.4 \text{ in.}^3$$

A3.4 Calculate Total Load Based on Allowable Web Shear Stress (w_v) (Part 1, Section 3)

$$w_v = \frac{2\, F_v I_t\, \Sigma t_s}{QL'} = \frac{2 \times 260 \times 772 \times 0.707}{42.4 \times 20} = 335 \text{ lbf/ft}$$

NOTE: If a higher total load were required, the length of the web stiffener could be extended until the horizontal shear stress in the unreinforced web was within allowable limits.

A3.5 Calculate Total Load Based on Allowable Web Splice Plate Shear Stress (w_{sw}) (Part 1, Section 3.4)

$$w_{sw} = \frac{2\, F_s A}{L'} = \frac{2 \times 43.1 \times 0.594 \times 12 \times 15.875}{20} = 488 \text{ lbf/ft}$$

NOTE: This calculation assumes that web butt joints are located 24 inches from end supports (minimum distance in accordance with Part 1, Section 3.2) and splice plate length is 12 times nominal thickness of web.

A4. Calculate Total Load Based on Allowable Flange-Web Shear Stress (w_{sf}) (Rolling Shear) (Part 1, Section 4)

$$w_{sf} = \frac{2\, F_s I_t\, d}{Q_f L'} = \frac{2 \times 43.1 \times 772 \times 3.75}{21.8 \times 20} = 572 \text{ lbf/ft}$$

where:

I_t = 772 in.^{4} from A3.1

Q_f = 21.8 in.^{3} from A3.3

A5. Determine Final Total Allowable Load (w)

Stress Criterion	Total Load (lbf/ft)
Bending (web and flange)	w_b = 199 (see A2)
Horizontal shear (web)	w_v = 335 (see A3)
Rolling shear (web splice)	w_{sw} = 488 (see A3)
Rolling shear (flange-web)	w_{sf} = 572 (see A4)

Therefore, the uniform-load capacity for the beam used in this design example is limited by the bending stress. The total allowable load for design is 199 lbf/ft.

A6. Calculate Deflection at Total Allowable Load

A6.1 Bending Deflection (Δ_b)

$$\Delta_b = \frac{5\ w\ L^4 \times 1{,}728}{384\ E\ I_t} = \frac{5 \times 199 \times 24^4 \times 1{,}728}{384 \times 1{,}815{,}000 \times 772} = 1.06 \text{ in.}$$

A6.2 Shear Deflection (Δ_s)

A6.2.1 Shear Deflection Constant, K

$$r = \frac{\Sigma\ t_s}{b} = \frac{0.707}{3 \times 0.707} = 0.33$$

$$\frac{h_w - 2d}{h_w} = \frac{23.875 - 2 \times 3.75}{23.875} = 0.69$$

From Figure 1,

$$\text{For } r = 0.33 \text{ and } \frac{h_w - 2d}{h_w} = 0.69$$

$$K = 1.70$$

A6.2.2 Effective Shear Area (A_s)

$$A_s = A_{sw} + A_{sf} = \Sigma t_s h_w + \Sigma t_s d = (0.707 \times 23.875) + (2 \times 2 \times 0.707 \times 3.75)$$

$$A_s = 27.5 \text{ in.}^2$$

A6.2.3 Calculate (Δ_s)

$$\Delta_s = \frac{K\ w\ L^2}{8\ A_s\ G} = \frac{1.70 \times 199 \times 24^2 \times 12}{8 \times 27.5 \times 90{,}000} = 0.12 \text{ in.}$$

A6.3 Calculate Total Deflection (Δ)

$$\Delta = \Delta_b + \Delta_s = 1.06 + 0.12 = 1.18 \text{ in.} = \frac{L}{244} \text{ @ } w = 199 \text{ lbf/ft}$$

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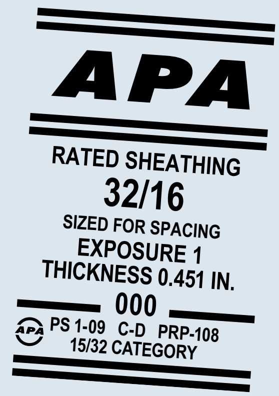

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Plywood Design Specification, Supplement 5–16: Design and Fabrication of All-Plywood Beams

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