SUPPLEMENT 2–12

PLYWOOD DESIGN SPECIFICATION

Design and Fabrication of Glued Plywood-Lumber Beams

DECEMBER 2013

APA

WOOD
The Natural Choice

Engineered wood products are a good choice for the environment. They are manufactured for years of trouble-free, dependable use. They help reduce waste by decreasing disposal costs and product damage. Wood is a renewable resource that is easily manufactured into a variety of viable products.

A few facts about wood.

- ***We're growing more wood every day.*** Forests fully cover one-third of the United States' and one-half of Canada's land mass. 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. Canada's replanting record shows a fourfold increase in the number of trees planted between 1975 and 1990.

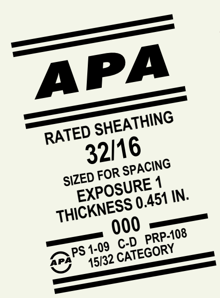
- ***Life Cycle Assessment shows wood is the greenest building product.*** A 2004 Consortium for Research on Renewable Industrial Materials (CORRIM) study gave scientific validation to the strength of wood as a green building product. In examining building products' life cycles – from extraction of the raw material to demolition of the building at the end of its long lifespan – CORRIM found that wood was better for 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.

- ***Manufacturing wood 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 natural choice for the environment, for design and for strong, lasting construction.



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

PLYWOOD DESIGN SPECIFICATION, SUPPLEMENT 2–12

DESIGN AND FABRICATION OF GLUED PLYWOOD-LUMBER BEAMS

December 2013

FOREWORD

This publication presents the recommended method for the design and fabrication of glued plywood and lumber beams. Allowable stresses and other design criteria for plywood are given in the PLYWOOD DESIGN SPECIFICATION. References are also made to the ANSI/AWC NATIONAL DESIGN SPECIFICATION FOR WOOD CONSTRUCTION (NDS).

This design method applies only to beams with joints glued with structural adhesive. Design of mechanically fastened beams is covered in other publications. For further information, contact *APA – The Engineered Wood Association*.

This recommended method is based on data developed by the U.S. Forest Products Laboratory, supplemented with tests by APA. 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*.

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

The technical data in this Supplement are presented as the basis for Design and Fabrication of Glued Plywood-Lumber 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-lumber (dimension lumber or structural composite lumber, SCL) components are primary structural members which depend on the glued joints to integrate the separate pieces into an efficient unit capable of carrying the design loads. 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 wood structural panels.

A change to the International Building Code (IBC) and International Residential Code (IRC) has been approved that recognizes this change in the 2012 IBC Section 2303.1.4 and 2012 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 2–12: DESIGN AND FABRICATION OF GLUED PLYWOOD-LUMBER BEAMS

LIST OF SYMBOLS AND LOCATION

A = Cross-sectional area of the beam (in.^{2}); Part 1, Section 7.2.2

$A_{||}$ = Area of web parallel plies (in.^{2}); Part 1, Section 4.2.3.1

A_{flange} = Cross-sectional area of the beam flanges (in.^{2}); Part 1, Section 7.2.2

A_{web} = Cross-sectional area of the beam webs (in.^{2}); Part 1, Section 7.2.2

C = Load coefficient (in.-lbf, or ft-lbf); Part 1, Figure 2

C_D = Load duration factor adjustment for plywood or flange; PLYWOOD DESIGN SPECIFICATION and NDS

C_F = Size factor adjustment for the flanges; NDS or recognized product evaluation report

E = Tabulated modulus of elasticity of the flanges (psi); NDS or recognized product evaluation report

E' = Allowable modulus of elasticity of the flanges, including adjustments to tabulated values (psi); Part 1, Section 7.2.1, and NDS or recognized product evaluation report

$F_{c\perp}$ = Tabulated stress in compression perpendicular to grain for the flanges (psi); NDS or recognized product evaluation report

$F_{c\perp}'$ = Allowable stress in compression perpendicular to grain for the flanges, including adjustments, if any, to tabulated values (psi); NDS or recognized product evaluation report

F_s = Tabulated plywood rolling shear stress (psi); PLYWOOD DESIGN SPECIFICATION

F_s' = Allowable plywood rolling shear stress, including adjustments to tabulated values (psi); Part 1, Section 6.1 and PLYWOOD DESIGN SPECIFICATION

F_t = Tabulated tensile stress of the flanges parallel to the grain (psi); NDS or recognized product evaluation report

F_t' = Allowable stress of the flanges parallel to the grain, including adjustments to tabulated values (psi); PLYWOOD DESIGN SPECIFICATION, and NDS or recognized product evaluation report

F_v = Tabulated plywood through-the-panel-thickness shear stress (psi); PLYWOOD DESIGN SPECIFICATION

F_v' = Allowable plywood through-the-panel-thickness shear stress (psi), including adjustments to tabulated values; PLYWOOD DESIGN SPECIFICATION

G = Shear modulus (modulus of rigidity) of the webs (psi); PLYWOOD DESIGN SPECIFICATION

I_n = Net moment of inertia for computing M of continuous parallel grain material in section (in.^{4}); Part 1, Section 4.2

I_o = Net moment of inertia of a beam component about itself (in.^{4}); PLYWOOD DESIGN SPECIFICATION and Appendix A, Section A9

I_t = Total moment of inertia about the neutral axis of all parallel-grain material, regardless of any butt joints (in.^{4}); Part 1, Section 5.2

I_x = Moment of inertia about the x axis (in.^{4}); Appendix A, Sections A4 and A9

I_y = Moment of inertia about the y axis (in.^{4}); Appendix A, Section A9

K = A constant determined by beam cross-section; Figure 2

M = Acting moment or allowable bending moment (in.-lbf or ft-lbf); Part 1, Section 4.2.1 and Appendix A, Section A3

M_{flange} = Tabulated allowable flange bending moment (ft-lbf); Appendix B

M_{web} = Tabulated allowable web bending moment (ft-lbf); Appendix B

M_{total} = Tabulated total allowable bending moment (ft-lbf); Appendix B

P_r = Reaction (lbf); Part 1, Section 8.1.1.1

Q = Statical moment about the neutral axis of all parallel-grain material, regardless of any butt joints, lying above (or below) the neutral axis (in.^{3}); Part 1, Section 5.2

Q_{fl} = Statical moment about the neutral axis of all parallel-grain material in the upper (or lower) flanges, regardless of any butt joints (in.^{3}); Part 1, Section 6.1

V = Acting shear load (lbf); Appendix A, Section A3

V_h = Allowable total horizontal shear through the panel thickness on the section (lbf); Part 1, Section 5.2

V_s = Allowable total rolling shear on the section (lbf); Part 1, Sections 6.1 and 6.2

b = Flange width (in.); Part 1, Section 8.1.1.1 and Figure 2

b_1 = Width of flanges plus Σt_s (in.); Part 1, Figure 2

d = Flange depth (in.); Part 1, Section 6.1 and Figure 2

d_1 = $h - 2d$ (in.); Part 1, Figure 2

h = Depth of beam with allowance for surfacing (in.); Part 1, Section 4.1.2 and Figure 2

ℓ = Length of beam (in. or ft); Appendix A, Section A3

ℓ_1 = Horizontal distance from section in question to the intersection of the flange centerlines in tapered beam (in.); Section 5.1

p = Factor for use in finding constant K; Figure 2

s = Factor for use in finding constant K; Figure 2

$t_{||}$ = Total thickness of parallel plies (in.); Part 1, Section 4.2.3.1

t_s = Thickness for shear through the thickness of one outer web (in.); Part 1, Section 6.2 and PLYWOOD DESIGN SPECIFICATION

w = Uniform load (lbf per lineal foot, or lbf per lineal inch); Appendix A, Section A3

x_1 = Thickness of stiffener as measured along the beam span (in.) based on compression perpendicular-to-grain; Part 1, Section 8.1.1.1

x_2 = Thickness of stiffener as measured along the beam span (in.) based on rolling shear of web; Part 1, Section 8.1.1.2

Δ_a = Approximate deflection: Δ_b multiplied by the shear deflection factor (in.); Part 1, Section 7.1

Δ_b = Deflection due to bending (in.); Part 1, Section 7

Δ_s = Deflection due to shear (in.); Part 1, Section 2

Δ_r = Total deflection due to bending and shear: Refined method (in.); Part 1, Section 7.2

ΣI_x = I_t = Total moment of inertia about x axis (in.^{4}); Appendix A, Section A9

ΣI_y = Total moment of inertia about y axis (in.^{4}); Appendix A, Section A9

Σt_s = Total thickness for shear through-the-thickness of all webs at the section (in.); PLYWOOD DESIGN SPECIFICATION

PART 1—DESIGN OF GLUED PLYWOOD-LUMBER BEAMS

1. General

1.1 Beam Behavior

In plywood beams, the lumber or SCL flanges carry most of the bending, and one or more plywood webs carry the shear. Joints between them transfer stresses from one to the other.

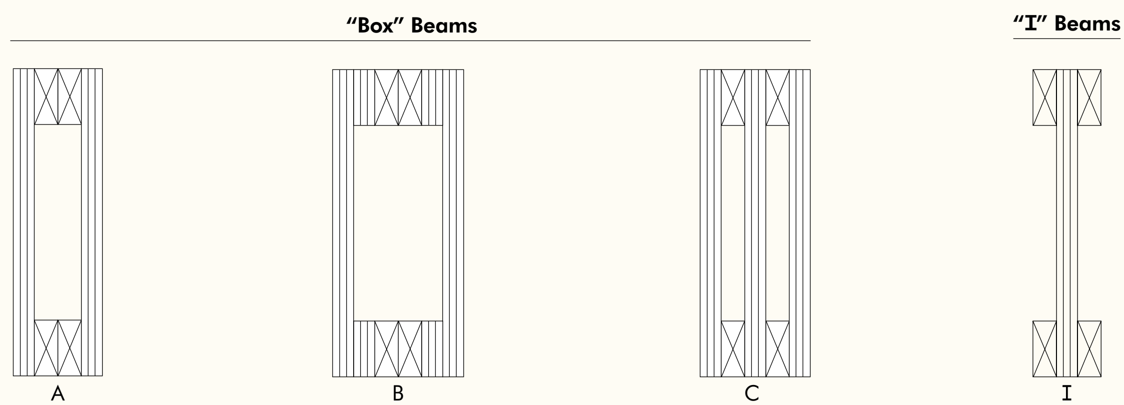
Vertical stiffeners set between flanges distribute concentrated loads and resist web buckling. Deflection resulting from shear is usually significant, and must be added to the bending deflection. Lateral restraint is often required to maintain stability. End joints in flange laminations and webs may require splicing.

1.2 Shape

Loads, spans, and allowable stresses, as well as desired appearance, determine the beam proportions. The depth and cross section may be varied along the length of the beam to fit design requirements, provided the resisting moments and shears at all sections are adequate. Typical cross sections are shown in Figure 1.

FIGURE 1

TYPICAL BEAM SECTIONS, WHICH ARE PERMITTED TO VARY ALONG THE LENGTH AS SPECIFIED IN SECTION 1.2



2. Design Considerations

2.1 Design Loads

The design live loads should not be less than required by the authority having jurisdiction. Dead load is the actual weight of the member and the elements it supports. Allowance should be made for any temporary construction loads, or moving concentrated loads such as cranes.

2.2 Allowable Stresses

Allowable stresses are determined as described in PLYWOOD DESIGN SPECIFICATION or a recognized product evaluation report with due regard for duration of loading. Note also that glued plywood-lumber beams may qualify for an increase in allowable plywood shear-through-the-thickness stress as described in PLYWOOD DESIGN SPECIFICATION or the recognized product evaluation report.

For symmetrical sections, the design should be based on the allowable stress in tension or compression, whichever is less. **When butt joints occur in the tension flange, the design should be based on eighty percent of the allowable tensile stress.**

Values for compression and tension parallel to grain depend on species, grade, number of laminations, slope of scarf joints, and moisture condition. Values are applied as outlined in PLYWOOD DESIGN SPECIFICATION or a recognized product evaluation report.

Allowable stresses for stress-grade lumber or SCL flanges shall not exceed those given in the latest edition of the NDS or a recognized product evaluation report. Allowable stress level at any point in the flanges must be determined on the basis of the number of laminations continuous at that point. **Any lamination with a butt joint within 10 times the lamination thickness of the point under investigation is considered discontinuous.**

2.3 Allowable Deflection

Deflection shall not exceed that allowed by the applicable building code. Maximum deflections recommended are the following proportions of the span, in inches.

Floor Beams	
Live load only	$\ell/360$
Dead plus live load	$\ell/240$
Roof Beams	
Live load only	$\ell/240$
Dead plus live load	$\ell/180$

More severe limitations may be required for special conditions, such as the support of vibrating machinery, long spans, beams over glass windows, or beams supporting deflection sensitive finishes.

2.4 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 beams are cambered, a recommended amount is 1.5 times the deflection due to dead load only. This will provide a nearly level beam under conditions of no live load after set has occurred.

Additional camber may be introduced as desired to provide for drainage or appearance. Roof members must be designed to prevent ponding of water. This may be done either by cambering, or by providing slope or stiffness such that ponding will not occur. For further discussion, see *APA Technical Note on Glulam Beam Camber,* Form S550.

3. Trial Section

3.1 General

The first step in the actual design of a plywood box beam is the selection of a trial section. Suitable beam depths vary somewhat, ranging generally from 1/8 to 1/12 of the span (although ratios up to 1/22 have been successfully used). The depth should ordinarily be equal to an available width of plywood, or such that waste is minimized. Also, as a general rule, the flange depth should be equal to at least 4 times the adjoining plywood web thickness in order to have sufficient contact area between the flange and web for gluing.

3.2 Selection from Table

Appendix B lists preliminary allowable bending and shear capacities for typical glued box beams with two webs.

Determine first the design requirements in terms of maximum moment and shear. A cross section which meets the design requirements may then be selected directly from the table. However, tabular solutions may also be subject to a number of adjustments based on duration of load, allowable flange tensile stress (grade of lumber or SCL), and web thickness and grade. Note that further adjustment is necessary when butt joints are allowed in lumber or SCL flanges. For example, it may be necessary to add a lamination to those shown in the table. The final design must then take into account provisions of PLYWOOD DESIGN SPECIFICATION, which gives allowable-stress reductions applicable to cross sections containing flange butt joints. Also see subsequent sections of this Supplement.

4. Lumber or SCL Flanges

4.1 General

4.1.1 Symmetrical Sections

Symmetrical cross sections are generally used in plywood beams for several practical reasons. These practical considerations usually outweigh the savings in material which theoretically can be achieved with unsymmetrical sections.

The design stresses for flanges are those for allowable stress in direct tension and direct compression. With symmetrical sections, the lower of these allowable stresses will limit the flange design. The following equations assume a symmetrical section.

4.1.2 Allowance for Surfacing

To allow for resurfacing of lumber or SCL flange laminations for gluing, each lamination should be considered 1/8 inch smaller in dimension perpendicular to gluing surfaces (1/16 inch per surface) than its standard size. Check with the SCL manufacturer for recommendation of permissible resurfacing.

To allow for resurfacing for the sake of appearance or uniformity of depth, beams should be designed for an actual depth (h) slightly less than their nominal depth as follows. Actual depth of beams under 24 inches deep should be considered 3/8 inch less than nominal; for beams 24 inches and deeper, actual depth should be considered 1/2 inch less than nominal. This resurfacing also results in reduced flange dimensions.

4.2 Bending Moment

4.2.1 Symmetrical Sections

In a symmetrical section allowable bending moment may be calculated by the formula,

$$M = \frac{F_t' I_n}{0.5h}$$

where

M = Allowable bending moment (in.-lbf)

F_t' = Controlling allowable stress parallel to the grain of the flange lumber (psi) (see NDS or a recognized product evaluation report, and PLYWOOD DESIGN SPECIFICATION)

I_n = Net moment of inertia of continuous parallel-grain material in the section (in.^{4})

h = Depth of beam (after surfacing, see Section 4.1.2) (in.)

4.2.2 Unsymmetrical Sections

When the cross section is not symmetrical about its center, the resisting moment may be calculated as above, except that the distance from the neutral axis to the extreme fiber of each flange is used in place of the value 0.5h, and the moment of inertia is calculated relative to the location of the neutral axis. The location of the neutral axis is computed on the basis of the total cross section, without reduction for butt joints.

4.2.3 Net Moment of Inertia

4.2.3.1 Plywood Webs—When calculating moment of inertia of the plywood webs, consider only parallel-grain material. The total thickness of parallel plies ($t_{||}$) is 1/12 of the appropriate area ($A_{||}$) for tension and compression, as shown in PLYWOOD DESIGN SPECIFICATION.

Butt joints in plywood webs are usually spliced to transmit shear only, with a splice plate only as deep as the clear distance between flanges. If such butt joints in webs are staggered 24 inches or more, only one web need be disregarded in computing moment of inertia for bending stress. When unequal web thicknesses are used, use the most critical condition for computing I_n, unless the location of butt joints is specified in the design. For joints closer than 24 inches, the contribution of the webs should be neglected in computing I_n.

When webs are spliced full-depth so as to carry direct "flange" stresses, they may all be included in computing the moment of inertia with allowable stresses as in PLYWOOD DESIGN SPECIFICATION.

4.2.3.2 Lumber Flanges—Butt joints in the lumber flanges are required by the Fabrication Specification (Part 2 of this supplement) to be spaced at least 30 times the lamination thickness in adjoining lumber laminations, and at least 10 times the lamination thickness in non-adjoining lumber laminations, if not otherwise stipulated in the design (ignore any plywood between laminations).

Therefore, in accordance with PLYWOOD DESIGN SPECIFICATION, if butt-joint location is not otherwise stipulated by the designer, the net moment of inertia of flanges in which butt joints occur, may be calculated by ignoring one lamination and 10 percent of the two adjoining laminations.

Effects of other butt-joint arrangements are as given in PLYWOOD DESIGN SPECIFICATION.

4.2.3.3 SCL Flanges—Full-length SCL flanges are required unless specifically permitted by the SCL manufacturer.

5. Plywood Webs

5.1 General

Plywood webs are primarily stressed in shear-through-the-thickness, although they may also carry bending moment, provided that individual panels are properly spliced to transmit both types of stresses. Also, sufficient contact area with the flanges must be provided to transmit the stresses between web and flange.

The number and thickness of the webs may be varied along the beam length in proportion to the shear requirements (Section 1.2) considering both shear through the panel thickness at the neutral axis, and rolling shear between flange and web. In areas of relatively low shear, where webs are omitted, plywood or lumber shims may be glued to the flanges to maintain beam width as required for appearance or for gluing pressure.

When the depth of a beam is tapered, the net vertical component of the direct forces in the flanges should be considered in determining the net shear to be resisted by the webs and the flange-web joints. This vertical component may add to or subtract from the external shear. It is equal to M/ℓ_1, where M is the bending moment acting on the section, and ℓ_1 is the horizontal distance from the section to the intersection of the flange centerlines.

5.2 Horizontal Shear

The allowable horizontal shear on a section can be calculated by the following formula.

$$V_h = \frac{F_v' I_t \Sigma t_s}{Q}$$

where

V_h = Allowable total horizontal shear through the panel thickness on the section (lbf)

F_v' = Allowable plywood shear stress through the panel thickness (psi), as given in PLYWOOD DESIGN SPECIFICATION, with adjustment as applicable

I_t = Total moment of inertia about the neutral axis of all parallel-grain material, regardless of any butt joints ($in.^4$)

Σt_s = Total shear thickness of all webs at the section, as given in PLYWOOD DESIGN SPECIFICATION (in.)

Q = Statical moment about the neutral axis of all parallel-grain material, regardless of any butt joints, lying above (or below) the neutral axis ($in.^3$)

5.3 Splices

Effectiveness of spliced joints in resisting flexure and shear is given in PLYWOOD DESIGN SPECIFICATION. A 2-inch-wide nominal stiffener alone may be used as a shear-splice plate when the web is 24 inches deep or less, and is no thicker than 3/8 Performance Category or carries no more shear than would be allowed on a 3/8 Performance Category panel.

5.4 Holes in Webs

Holes in plywood webs should be avoided if possible. If they are required, they should be located in areas of low shear, with proper consideration for the shear capacity of the remaining section. It is good practice to avoid sharp corners, and to use a plywood "doubler" in the area of the hole.

6. Flange-Web Joints

Joints between flanges and webs at any section must be designed to transfer the shear acting along that section. Stresses are transferred wholly by adhesive, not by any combination of adhesive with mechanical fasteners.

6.1 Beams with One or Two Webs

The allowable flange-web shear on a glued, symmetrical two-web section in which only one face of each web contacts the flange, or on an I section, may be calculated by the following formula.

$$V_s = \frac{2F_s' \, dI_t}{Q_{fl}}$$

where

V_s = Allowable total shear on the section (lbf)

F_s' = Allowable plywood rolling shear stress (psi). F_s is adjusted per PLYWOOD DESIGN SPECIFICATION, with the 50% reduction for shear concentration.

d = Flange depth (in.)

I_t = Total moment of inertia about the neutral axis of all parallel-grain material, regardless of any butt joints (in.^{4})

Q_{fl} = Statical moment about the neutral axis of all parallel-grain material in the upper (or lower) flanges, regardless of any butt joints (in.^{3})

6.2 Beams with More than Two Webs

For purposes of designing the flange-to-web glued joint, maximum flange-web shear on beams with more than two webs may be computed using the assumption that the horizontal shear stress is equal in all webs. For calculations, flanges are then broken down into areas "tributary" to each web, and flange-web shear figured separately for each contact surface. Tributary areas are generally assigned such that the first moment (Q) of the area tributary to each web is proportional to the thickness of the web.

For a beam in which the center web is less than twice the thickness of an outer web, the maximum stress occurs on the outside web, and allowable shear is given by the following formula.

$$V_s = \frac{F_s' \, dI_t}{Q_{fl}} \times \frac{\Sigma t_s}{t_s}$$

where

Σt_s = Sum of all web shear thicknesses at the section, as given in PLYWOOD DESIGN SPECIFICATION (in.)

t_s = Shear thickness of the outer web (in.)

Other notations are as in Section 6.1.

7. Deflection

The deflection of plywood beams may be taken as the sum of the calculated deflections due to bending and to shear. It should not exceed the values given in Section 2.3.

The bending deflection (Δ_b) may be calculated by conventional engineering formulas, with due regard to loading conditions and fixity of supports. Deflection due to several simultaneously applied loads may be calculated separately and added.

Total deflection may then be obtained by one of the following methods. If the Approximate Method indicates that total deflection governs the design, or nearly does, a check should be made by the Refined Method.

7.1 Approximate Method

The approximate deflection (Δ_a) of simply supported, uniformly loaded plywood beams may be found by multiplying the bending deflection (Δ_b) by a factor depending on the span-depth ratio, to allow for shear deflection. The bending deflection is found by conventional formulas, using the elastic modulus of the flange lumber tabulated in the NDS or of the SCL flange provided in a recognized product evaluation report, and the moment of inertia of all parallel-grain material in the section, regardless of any butt joints.

The following shear-deflection factors may then be applied to the bending deflection, with interpolation permitted.

Span/Depth	Factor
10	1.5
15	1.2
20	1.0

7.2 Refined Method

The total deflection (Δ_r) may be calculated by separately computing the bending deflection (Δ_b) and shear deflection (Δ_s), and adding the two.

7.2.1 *Bending Deflection*

In calculating the bending deflection, the tabulated elastic modulus (E) of the flange lumber may be increased by 3% over the values tabulated in the NDS (E′ = 1.03E, PLYWOOD DESIGN SPECIFICATION). The moment of inertia used for computing the bending deflection is I_t, the moment of inertia of the parallel grain material in the section, regardless of butt joints.

7.2.2 *Shear Deflection*

The shear deflection for simple beams shown in Figure 2 may be calculated using the formula,

$$\Delta_s = \frac{KC}{AG}$$

where

Δ_s = Shear deflection (in.)

K = A constant determined by the beam cross section, and shown in Figure 2

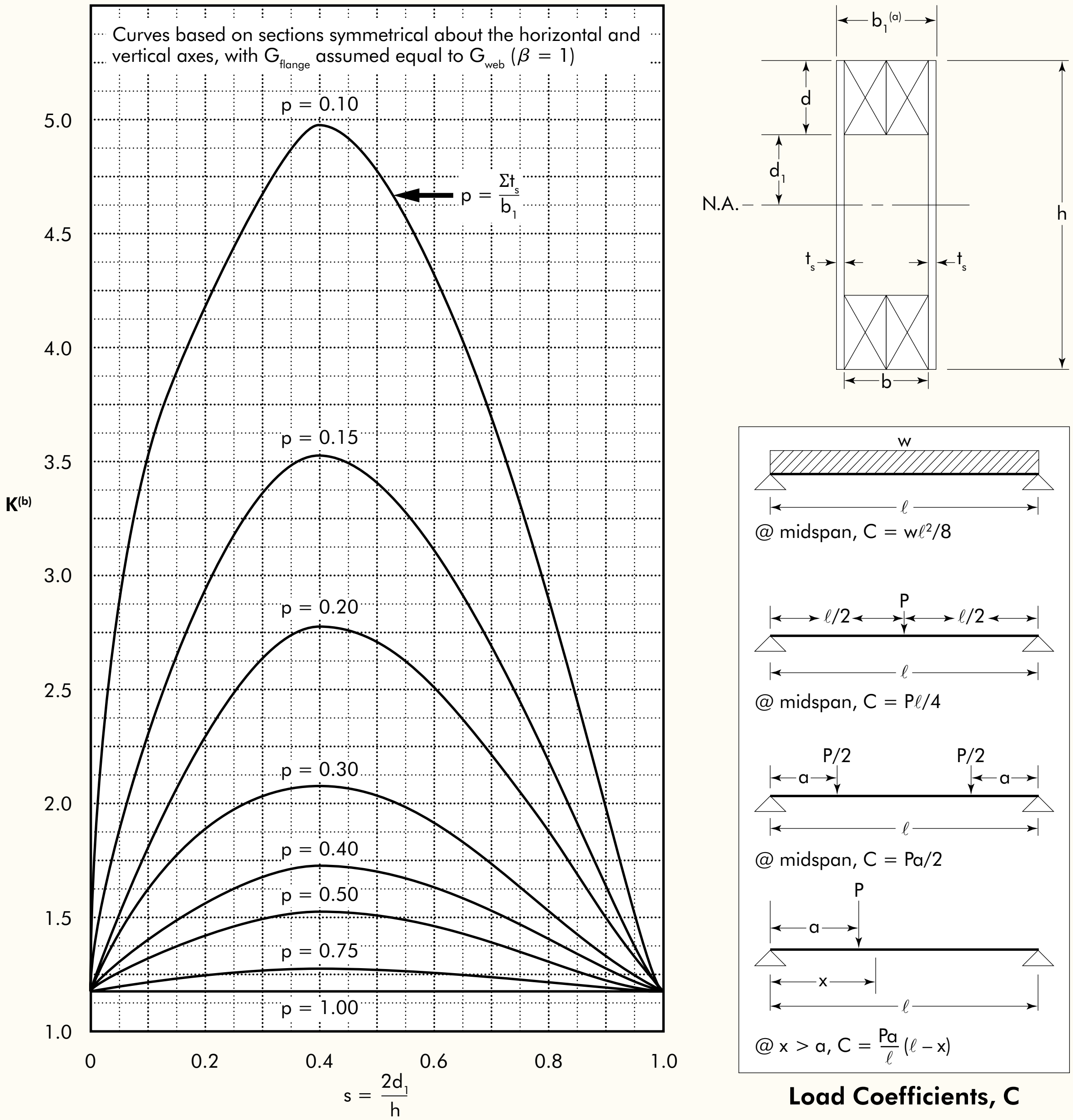
C = A coefficient depending on the manner of loading, also shown in Figure 2

A = $A_{flange} + A_{web}$ = Cross-sectional area of the beam (in.^{2}) (When calculating area of plywood webs (A_{web}), use “Effective Thickness for Shear,” t_s from PLYWOOD DESIGN SPECIFICATION)

G = Shearing modulus of the webs (psi) (see PLYWOOD DESIGN SPECIFICATION)

FIGURE 2

SECTION CONSTANT (K) AND LOAD EFFICIENTS FOR SHEAR DEFLECTION EQUATION



Load Coefficients, C

Note (a): $b_1 = b + \Sigma t_s$

Note (b): $$K = \frac{\frac{9}{2}\left[\frac{1}{p}(1-s) + s\right]\left\{\frac{1}{p^2}\left[\frac{s^5}{2} - s^3 + \frac{s}{2}\right] + \frac{1}{p}\left[-s^5\left(\frac{3}{30\beta} + \frac{2}{3}\right) + s^3\left(\frac{1}{3\beta} + \frac{2}{3}\right) - \frac{s}{2\beta} + \frac{8}{30\beta}\right] + \frac{8s^5}{30}\right\}}{\left[\frac{1}{p}(1-s^3) + s^3\right]^2}$$ where $\beta = \frac{G_{flange}}{G_{web}}$

Section Constant, K

If deflection is critical for loading conditions other than those shown in Figure 2, refer to U.S.D.A. Forest Service Research Note FPL-210: Simplified Method Calculating Shear Deflections of Beams.

8. Stiffeners

8.1 Bearing Stiffeners

Lumber bearing stiffeners are required over reactions and where other heavy concentrated loads occur, to distribute such loads into the beam. They should fit well against the flanges, and the webs should be securely attached to them.

8.1.1 Bearing Stiffeners at Ends of Beams

Bearing stiffeners at ends of beams should be the same width as the lumber or SCL flange at that section. Their dimension parallel to the beam span (thickness) should not be less than that given by the following two considerations.

8.1.1.1 Compressive Strength—The thickness of stiffener must be at least equal to x_1 in the following equation.

$$x_1 = \frac{P_r}{F_{c\perp}' b}$$

where

x_1 = Minimum thickness of stiffener parallel to beam span (in.), limited by compression perpendicular-to-grain of flange

P_r = Reaction (lbf)

$F_{c\perp}'$ = Allowable stress in compression perpendicular to grain for the flange (psi)

b = Flange width (in.)

8.1.1.2 Rolling Shear—For beams with two webs, the thickness of stiffeners must be at least equal to x_2 in the following equation. For beams with more than two webs, the rolling shear stress is less likely to govern.

$$x_2 = \frac{P_r}{2hF_s'}$$

where

x_2 = Minimum thickness of stiffener parallel to beam span (in.), based on rolling shear of web

h = Depth of beam (in.)

F_s' = Allowable plywood rolling shear stress (psi) as given in PLYWOOD DESIGN SPECIFICATION

8.1.2 Bearing Stiffeners Not at Ends of Beam

For bearing stiffeners not at ends of beam, factors given in the NDS may be applied to $F_{c\perp}$.

8.2 Intermediate Stiffeners

Intermediate stiffeners are required to stabilize the flanges, to space them well during fabrication, to reinforce the webs in shear and prevent their buckling, and to serve as backing for gluing of web splice plates where pre-spliced or scarfed webs are not used. Such stiffeners are usually of 2-in.-nominal dimension lumber or SCL, and are equal in width to the lumber or SCL flange between webs, allowing for splice plates, if any.

Intermediate stiffeners spaced 48 inches or less on centers will develop all, or nearly all, the shear strength of a beam of normal proportions, as demonstrated by APA tests.

9. Lateral Stability

Deep, narrow beams, particularly those used on long spans, may require lateral restraint to prevent buckling. The ratio of the total moment of inertia of all parallel-grain material about the horizontal neutral axis to that about the vertical axis will determine the minimum lateral support required, as given in the following table.

$\frac{\Sigma I_x}{\Sigma I_y}$	**Provision for Lateral Bracing**
Up to 5	None required.
5 to 10	Ends held in position at bottom flanges at supports.
10 to 20	Beams held in line at ends (both top and bottom flanges restrained from horizontal movement in planes perpendicular to beam axis).
20 to 30	One edge (either top or bottom) held in line.
30 to 40	Beam restrained by bridging or other bracing at intervals of not more than 8 ft.
More than 40	Compression flanges fully restrained and forced to deflect in a vertical plane, as with a well-fastened joist and sheathing, or stressed-skin panel system.

PART 2—FABRICATION OF GLUED PLYWOOD-LUMBER BEAMS

1. General

1.1

This specification covers the fabrication of glued plywood-lumber beams, in which flanges are stress-graded lumber or structural composite lumber (SCL), and webs are plywood.

1.2

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

1.3

Plywood-lumber beams 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 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 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.

2.1.2

At the time of gluing, the plywood shall be conditioned to a moisture content between 7% and 16%. Pieces to be assembled into a single beam shall be selected for moisture content to conform to Part 2, 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 (MDO) surfaces shall not be relied on for a structural adhesive 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. Lumber for stiffeners shall be 2 inches minimum nominal thickness and of a grade equal to that of the flanges, except for extra stiffeners used only to supply pressure behind splice plates.

2.2.2

At the time of gluing, the lumber shall be conditioned to a moisture content between 7% and 16%. Pieces to be assembled into a single beam shall be selected for moisture content to conform to Part 2, 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 inch 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 Structural Composite Lumber (SCL)

2.3.1

The structural capacities for SCL shall be established and monitored in accordance with ASTM D5456, *Specification for Evaluation of Structural Composite Lumber Products.*

2.3.2

At the time of gluing, the SCL shall be conditioned to a moisture content between 7% and 16%. Pieces to be assembled into a single beam shall be selected for moisture content to conform to Part 2, Section 3.3.1.

2.3.3

Surfaces of SCL to be glued shall be clean and free from oil, dust, moisture retardant coatings and other foreign matter which would be detrimental to satisfactory gluing. **Check with the SCL manufacturer for recommendations of permissible surfacing.**

2.4 Adhesive

2.4.1

Adhesive shall be of the type specified by designer for anticipated exposure conditions. **Check with regulatory agencies responsible for design approval or inspection for adhesive type requirements.**

2.4.2

Interior-type adhesive shall conform to ASTM Specification D3024 or D4689. Exterior-type adhesive shall conform to ASTM Specification D2559.

2.4.3

Mixing, spreading, storage-, pot-, and working-life, and assembly time, temperature, and pressure shall be in accordance with the manufacturer's recommendations.

3. Fabrication

3.1 Webs

3.1.1

Scarf and finger joints shall be glued under pressure and over their full contact area, and shall meet the requirements of PS 1. In addition, no core gap shall intersect the sloped surface of the joint.

3.1.2

Unless otherwise noted in the design, butt joints in plywood webs shall be backed with plywood shear-splice plates centered over the joint and glued over their full contact area. The plate shall extend to within 1/4 inch of each flange on the inside of the beam, and shall be at least equal in thickness to the web being spliced. Face grain of the splice plate shall be parallel to that of the web. Length of the plate shall be at least 12 times the web thickness. Strength may be taken proportionately for shorter splice-plate lengths.

3.1.3

Surfaces of high density overlaid (HDO) 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 flange lumber, 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. Scarf slopes shall not be steeper than 1 in 8 in the tension flange, or 1 in 5 in the compression flange. The above scarf slopes are based on dry conditions of use. For wet conditions of use, see PLYWOOD DESIGN SPECIFICATION.

3.2.2

Full-length SCL flanges are required unless specifically permitted by the SCL manufacturer.

3.2.3

The edges of the framing members to which the plywood webs are to be glued shall be surfaced prior to assembly to provide a maximum variation in depth of 1/16 inch for all members in a beam. (Allow for actual thickness of any splice plates superimposed on stiffeners.)

3.3 Assembly

3.3.1

The range of moisture content of the various pieces assembled into a single beam shall not exceed 5%.

3.3.2

All side-grain wood joints at flanges and stiffeners shall be glued over their full contact area. Scarf and finger joints in stress-grade lumber flanges shall be well scattered throughout. Unless otherwise specified, they shall not be spaced closer than 16 times the lamination thickness in adjoining laminations, measured from center to center. (Ignore plywood between laminations.) In flanges of 3 or less laminations, only 1 joint shall be allowed at any one cross section; in flanges of 4 or more laminations, 2 joints may be allowed at the same cross section.

Unless otherwise specified, butt joints in lumber flanges shall be spaced at least 30 times the lamination thickness in adjoining laminations, and at least 10 times the lamination thickness in non-adjoining laminations. (Ignore plywood between laminations.) No butt joints shall be allowed in portions of beams intended for mechanical splices or other stressed connections, unless specifically covered in the design.

3.3.3

Stiffeners shall be placed as shown in the design, but in any case they shall be spaced not to exceed 4 ft on center, and at reactions and other concentrated load points. Stiffeners shall be held in tight contact with the flanges by positive lateral pressure during assembly.

3.3.4

Unless otherwise specified by the designer, web butt joints shall be staggered at least 24 inches. When glued during assembly, web splice plates shall be backed with one or more lumber stiffeners well machined in width so as to obtain adequate pressure. Where the design calls for the stiffeners to act as the web splices, web butt joints shall be located over the center of the stiffener, within 1/16 inch, and webs shall be glued to the stiffener.

3.3.5

Where two adjacent webs are used, their contacting surfaces shall be glued together over the full flange and stiffener area. Plywood webs 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, as required where webs are enclosed both sides with laminations or where flanges are being glued simultaneously with the beam assembly, the pressure on the net framing area shall be sufficient to provide adequate contact and ensure good adhesive 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. Where webs enclose a flange or another web, nail-gluing may be used in place of mechanical pressure methods. Nail sizes and spacings shown in the following schedule are suggested as a guide:

Nails shall be at least 4d (1-1/2 inches x 0.099 inch) for plywood up to 3/8 Performance Category, 6d (2 inches x 0.113 inch) for 15/32 to 7/8 Performance Category plywood, and 8d (2-1/2 inches x 0.131 inch) for 1 to 1-1/8 Performance Category plywood. They shall be spaced not to exceed 3 inches along the flanges for plywood through 3/8 Performance Category, or 4 inches for plywood 15/32 Performance Category and greater, in lines set in 3/4 inch from the lumber edge, and spaced not over 4 inches apart. Two lines shall be used for 4 inches nominal flange, three lines for lumber 6 inches, 8 inches, and 10 inches nominal flanges, and four lines for 12 inches nominal.

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 adhesive bond which meets or exceeds applicable specifications**.

3.3.6

Unless otherwise specified, width of beams shall equal, within ±1/16 inch, the sum of the lumber or SCL and plywood dimensions, allowing for resurfacing. The net flange dimension in the plane of the laminations shall be no more than 1/4 inch less than the standard surfaced flange width. To allow for resurfacing for finish appearance and uniformity, actual beam depth may be up to 3/8 inch less than nominal for beams up to 24 inches deep, 1/2 inch less for beams 24 inches and deeper, with tolerances of –1/8 inch and +1/4 inch. Length of beam shall be as specified ±1/4 inch.

4. Test Samples

4.1

When adhesive-bond test samples are taken from a member, if not otherwise obtained from trim, they shall be taken as cores approximately 2 inches in diameter, drilled perpendicular to the plane of the webs, either partially or entirely through the member. Samples at flanges shall be taken from the ends of the beams only. Centers of cores shall normally be located in the top corner of the beam at points within 2 inches from one edge and up to 6 inches from the other.

4.2

If necessary for retesting, additional samples may be taken from the ends of the beams within 2 inches from the top or the bottom edge, but not closer together than 6 inches, nor farther in from the end than a distance equal to twice the beam depth, but in no case within 9 inches from the end of the beam at the bottom flange.

4.3

Samples through splice plates shall be taken within the middle half of the span, at the centerline of the beam depth.

4.4

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

5. Identification

Each member shall be identified by a 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 beam shall be considered. If the strength of one flange is different from that of the other, the top flange shall be clearly marked on the outside surface of the finished beam.

LITERATURE CITED

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

1. APA – The Engineered Wood Association. *Plywood Design Specification.* Tacoma, Washington.
2. American Wood Council. *ANSI/AWC National Design Specification for Wood Construction* (NDS). Leesburg, Virginia.
3. USDA Forest Products Laboratory. *Various Studies, Plywood and Lumber Composite Beams.* Madison, Wisconsin.
4. International Code Council. *International Building Code* (IBC). Country Club Hills, Illinois.
5. International Code Council. *International Residential Code* (IRC). Country Club Hills, Illinois.
6. APA – The Engineered Wood Association. *Glulam Beam Camber.* APA Technical Note S550. Tacoma, Washington.
7. USDA Forest Products Laboratory. *Simplified Method for Calculating Shear Deflection in Beams.* Research Note FPL-210. Madison, Wisconsin.
8. US Department of Commerce. *Voluntary Product Standard PS1-09, Structural Plywood.* Available from APA, Tacoma, Washington.
9. US Department of Commerce. *Voluntary Product Standard PS2-10, Performance Standard for Wood-Based Structural-Use Panels.* Available from APA, Tacoma, Washington.
10. ASTM International. *Specification for Evaluation of Structural Composite Lumber Products.* ASTM D5456. West Conshohocken, Pennsylvania.
11. ASTM International. *Performance Specification Protein-Base Adhesives for Structural Laminated Wood Products for Use Under Interior (Dry Use) Exposure Conditions* (Withdrawn 1990). ASTM D3024. West Conshohocken, Pennsylvania.
12. ASTM International. *Standard Specification for Adhesive, Casine-Type.* ASTM D4689. West Conshohocken, Pennsylvania.
13. ASTM International. *Standard Specification for Adhesives for Bonded Structural Wood Products for Use Under Exterior Exposure Conditions.* ASTM D2559. West Conshohocken, Pennsylvania.

APPENDIX A—DESIGN EXAMPLE

A1. General

Since this example is intended for use as a general guide through this publication and the PLYWOOD DESIGN SPECIFICATION, review of those sections pertinent to your specific design is recommended before proceeding.

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, Exposure 1 plywood may be specified. Structural I plywood, if available, may also be specified, which will generally permit the use of higher allowable plywood shear stresses.

A2. Problem

Design a 28-ft simple-span roof beam to support a total uniform load of 290 plf. Maximum design depth for the beam is 24 inches. Allowable deflection under total load = $\ell/240$.

A3. Trial Section (See Section 3)

Acting moment, $M = \dfrac{w\ell^2}{8}$

$$M = \frac{290 \times 28^2}{8} = 28{,}420 \text{ ft-lbf} = 341{,}040 \text{ in.-lbf}$$

Try two Douglas fir-larch No. 1 & Btr 2x4s with 2 unspliced webs of 23/32 Performance Category Rated Sheathing

From Appendix B, 24" depth, allowable moment = 19,662 + 2,197 = 21,859 ft-lbf

$$M_{max} = \left(M_{flange} \times \frac{F_t(\text{No. 1 \& Btr})}{F_t(\text{Select Structural})} \times C_D\right) + (M_{web} \times (\text{Footnote (d), Appendix B}) \times C_D)$$

$$= \left(19{,}662 \times \frac{800}{1{,}000} \times 1.15\right) + (2{,}197 \times 1.42 \times 1.15) = 21{,}677 < 28{,}420 \text{ ft-lbf; NG}$$

Try two Douglas fir-larch Select Structural 2x6s[a] with 2 unspliced webs of 15/32 Performance Category APA STRUCTURAL I RATED SHEATHING

$$M_{max} = (M_{flange} \times C_D) + (M_{web} \times (\text{Footnote (d), Appendix B}) \times C_D)$$

$$= (22{,}779 \times 1.15) + (1{,}904 \times 1.19 \times 1.15) = 28{,}801 \text{ ft-lbf} > 28{,}420 \text{ ft-lbf; OK}$$

NOTE (a): *Increasing lumber width often provides minimal increased capacity due to the effect of C_F.*

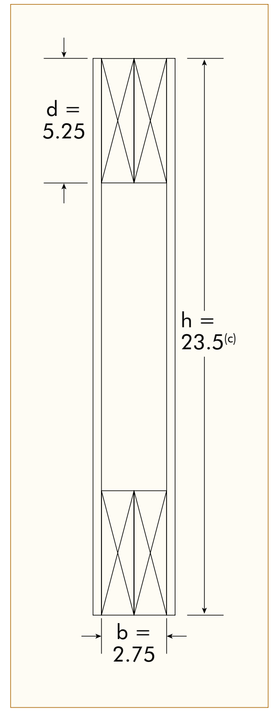
$$\text{Shear load, } V = \frac{w\ell}{2}$$

$$V = \frac{290 \times 28}{2} = 4{,}060 \text{ lbf}$$

From Appendix B, where 15/32 Performance Category APA STRUCTURAL I RATED SHEATHING Exposure 1 is used for webs, maximum allowable shear using 2x6s

$$V_{max} = (2{,}457 \times 1.80^{(b)}) \times 1.15 = 5{,}086 > 4{,}060 \text{ lbf; OK}$$

NOTE (b): *Appendix B, Footnote (e) Adjustment for using Structural I.*



Assume trial section as sketched.

Webs: Two webs; 15/32 Performance Category APA STRUCTURAL I RATED SHEATHING 32/16 EXP 1 plywood, face grain parallel to flanges

Flanges: Two 2x6s; Select Structural Douglas fir-larch (m. c. ≤ 19%)

A4. Section Properties

Before calculating the Moment of Inertia (I) and the Statical Moment (Q) for a given “trial” section, the probable location of “butt” joints (if any) in both the web and flange members must be determined and adjustments applied in accordance with PLYWOOD DESIGN SPECIFICATION. For this example, consider scarf joints of 1:12 slope for both the tension and compression flanges and butt joints in the plywood webs staggered 24 inches. The scarf-jointed lumber seems justified due to the reductions in cross section and allowable tension stress required for butt joints, as shown in PLYWOOD DESIGN SPECIFICATION.

Net Moment of Inertia, I_n (See Part 1, Section 4.2.3):

$$I\text{ (flanges)} = \frac{b}{12}\left[h^3 - (h - 2d)^3\right] = \frac{2.75}{12}\left[23.5^3 - 13^3\right] = 2{,}417\text{ in.}^4$$

$$I_x\text{ (each web)} = \frac{t_{\parallel}^{(d)} \times h^3}{12} = \frac{0.227 \times 23.5^3}{12} = 245\text{ in.}^4$$

NOTE (c): *Flange lumber dimensions allow for surfacing in accordance with Part 1, Section 4.1.2.*

NOTE (d): *From PLYWOOD DESIGN SPECIFICATION, Table 2, Column 4,* $t_{\parallel} = \frac{2.719}{12} = 0.227$ in. *If the plywood face grain is used perpendicular to the flanges, use* $\frac{Area}{12}$ *from Table 2, Column 8 of PLYWOOD DESIGN SPECIFICATION.*

$$I_n = I_x\text{ (flanges)} + I_x\text{ (contributing web[s])} = 2{,}471 + 245 = 2{,}716\text{ in.}^4$$

$$I_t = I_x\text{ (flanges)} + I_x\text{ (all parallel web plys)} = 2{,}471 + 2 \times 245 = 2{,}961\text{ in.}^4$$

Statical Moment, Q (See Part 1, Section 5):

$$Q\text{ (flanges)} = bd\left(\frac{h}{2} - \frac{h}{4}\right) = 2.75 \times 5.25\left(\frac{23.5}{2} - \frac{5.25}{2}\right) = 131.7\text{ in.}^3$$

$$Q\text{ (webs)} = t_{\parallel} \times \frac{h}{2} \times \frac{h}{4} \times \text{number of webs} = 0.227 \times \frac{23.5^2}{8} \times 2 = 31.3\text{ in.}^3$$

$$Q = Q\text{ (flanges)} + Q\text{ (webs)} = 131.7 + 31.3 = 163.0\text{ in.}^3$$

A5. Bending Moment (See Part 1, Section 4.2)

Tabulated stresses for the flange lumber are taken from the NDS Supplement. Plywood stresses are given in the PLYWOOD DESIGN SPECIFICATION.

Assuming dry-use, snow loading, the tabulated stress (F_t) is adjusted as follows:

$$F_t' = F_t \times C_F \times C_D$$

$$F_t' = 1{,}000 \times 1.3 \times 1.15 = 1{,}495\text{ psi}$$

$$\text{Allowable bending moment, } M = \frac{F_t' I_n}{0.5h}$$

$$M = \frac{1{,}495 \times 2{,}716}{0.5 \times 23.5} = 345{,}568\text{ in.-lbf}$$

345,568 in.-lbf > 341,040 in.-lbf; OK

If bending controls the design, and the beam depth is limited, full-depth web splices may be considered. It is often more convenient, however, to increase the number of flange laminations and/or specify a higher grade flange lumber.

A6. Shear (See Part 1, Sections 5 and 6)

A6.1 Shear Through-the-Thickness

From PLYWOOD DESIGN SPECIFICATION, use Group 1 plywood allowable stress for 15/32 Performance Category APA STRUCTURAL I RATED SHEATHING 32/16 Exposure 1. From PLYWOOD DESIGN SPECIFICATION, allowable shear stress, increased 19% and 15% for continuous glued edge framing parallel to face grain and load duration, respectively, in accordance with PLYWOOD DESIGN SPECIFICATION, is:

$$F_v' = 190 \times 1.19 \times 1.15 = 260.0 \text{ psi}$$

Horizontal shear (allowable) (shear through-the-thickness)

$$V_h = \frac{F_v' I_t \Sigma t_s}{Q} = \frac{260.0 \times 2{,}961 \times (2 \times 0.535)}{163.0} = 5{,}054 \text{ lbf} > 4{,}060 \text{ lbf; OK}$$

Where the beam design is controlled by horizontal shear, possible revisions include a specification of thicker plywood, use of STRUCTURAL I plywood (such as in this example), or the addition of web member(s) to the end quarter-sections of the beam.

A6.2 Rolling Shear

As indicated in PLYWOOD DESIGN SPECIFICATION, the basic rolling-shear stress is reduced 50% for plywood beam flange-web shear design.

$$F_s' = 75 \times 0.50 \times 1.15 = 43.1 \text{ psi}$$

Allowable flange-web shear (rolling shear)

$$V_s = \frac{2F_s' dI_t}{Q_{fl}} = \frac{2 \times 43.1 \times 5.25 \times 2{,}961}{131.7} = 10{,}175 \text{ lbf} > 4{,}060 \text{ lbf; OK}$$

Where flange-web (rolling) shear controls the design, STRUCTURAL I plywood webs should be considered. In addition, greater flange-web area may be required.

A7. Deflection (See Part 1, Section 7)

Both the "Approximate" and the "Refined" methods for determining deflection are illustrated below. As a general rule, if the deflection calculates near the allowable limit using the approximate method, recalculate by the refined method before altering the trial conditions.

Approximate Method (total deflection)—

$$\frac{\text{Span}}{\text{depth}} = \frac{28}{2} = 14\text{; use a shear deflection factor of } 1.26^{(e)}$$

NOTE (e): *See Part 1, Section 7.2.*

For simple span, uniform load—

$$\Delta_a = \frac{5w\ell^4}{384EI_t} \times \text{shear deflection factor} = \frac{5 \times 290 \times 28^4 \times 12^3}{384 \times 1{,}900{,}000 \times 2{,}921} \times 1.26 = 0.908 \text{ in.}$$

$$0.908 \text{ in.} = \ell/370 < l/240\text{; OK}$$

Refined Method (total deflection) —

$$E' = 1{,}900{,}000 \times 1.03^{(f)} = 1{,}957{,}000 \text{ psi}$$

NOTE (f): *See Part 1, Section 7.2.1.*

$$p = \frac{\Sigma t_s}{b_1} = \frac{2 \times 0.535}{2.75 + 2 \times 0.535} = 0.280;$$

$$s = \frac{2d_1}{h} = \frac{13}{23.5} = 0.553$$

$$C = M = w\ell^2/8 = 341{,}040 \text{ in.-lbf}$$

From PLYWOOD DESIGN SPECIFICATION, G = 90,000 psi

$$K = 2.10 \text{ (from Figure 2 and } p = 0.280 \text{ above)}$$

$$A = A_{flange} + A_{web} = 2(2.75)(5.25) + 2(0.535)(23.5) = 54.02 \text{ in.}^2$$

$$\Delta_r = \Delta_b + \Delta_s = \frac{5w\ell^4}{384E'I_t} + \frac{KC}{AG} = \frac{5 \times 290 \times 28^4 \times 12^3}{384 \times 1{,}957{,}000 \times 2{,}961} + \frac{2.10 \times 341{,}000}{54.02 \times 90{,}000} = 0.692 + 0.147 = 0.839 \text{ in.}$$

$$0.839 \text{ in.} = \ell/400 < \ell/240; \text{ OK}$$

If deflection controls the design, beam stiffness may be increased by increasing the beam depth and/or, with less pronounced results, the width. Note that STRUCTURAL I plywood provides the maximum effective area for a given panel thickness, making it the stiffest grade for the webs. Also consider using lumber with a higher E.

A8. Bearing Stiffeners (See Part 1, Section 8)

$$P = \text{end reaction} = \frac{w\ell}{2} = 4{,}060 \text{ lbf}$$

$$F_{c\perp}' = F_{c\perp} = 625 \text{ psi}$$

Stiffener thickness required for compression at bearing ends:

$$x_1 = \frac{P}{F_{c\perp}'b} = \frac{4{,}060}{625 \times 2.75} = 2.36 \text{ in.; use double 2x4s at ends.}$$

Stiffener thickness required for rolling shear at bearing ends:

$$x_2 = \frac{P}{2hF'_s} = \frac{4{,}060}{2 \times 23.5 \times 43.1} = 2.00 \text{ in.; double 2x4s; OK}$$

A9. Lateral Stability (See Part 1, Section 9)

$$\Sigma I_y = I_y \text{ (flanges)} + I_y \text{ (webs)}$$

$$I_y \text{ (flanges)} = 2 \times \frac{db^3}{12} = \frac{2 \times 5.25 \times 2.75^3}{12} = 18.2 \text{ in.}^4$$

$$I_y \text{ (webs)} = 2[I_o + A_{\parallel}(y^2)] = 2\left[\left(0.074 \times \frac{23.5}{12}\right) + \left(\frac{2.719}{12} \times 23.5\right)\left(\frac{2.75 + 0.469}{2}\right)^2\right] = 27.88 \text{ in.}^4$$

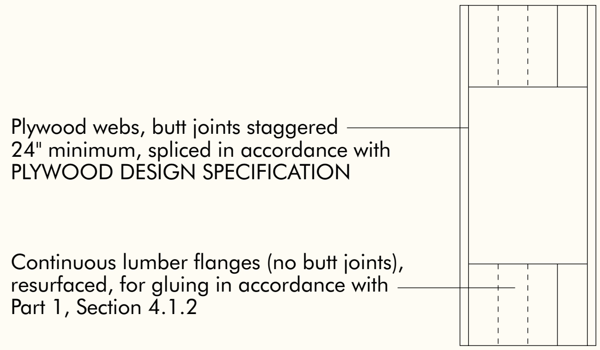
$$\Sigma I_y = 18.2 + 27.88 = 46.1 \text{ in.}^4$$

$$\Sigma I_x/\Sigma I_y = \frac{2{,}961}{46.1} = 64.2$$

For this design example, the compression flange should be fully restrained since the $\Sigma I_x/\Sigma I_y$ ratio exceeds 40 (Part 1, Section 9). This can usually be achieved by sheathing, and/or by ceiling material.

As final steps in the overall design, review the structural adequacy of beam supports and develop beam connection details.

APPENDIX B—PRELIMINARY ALLOWABLE MOMENTS AND SHEARS



Depth (in.)	Flange	Allowable Moment,[a,b] M (ft-lbf) M_{flange}	M_{web}[c,d]	M_{total}	Allowable Shear[a] V_h (lbf) $V_{horizontal}$[e,f]
12	1-2x4	3563	538	4101	1145
	2-2x4	7126	538	7664	1159
	3-2x4	10690	538	11227	1165
16	1-2x4	5657	971	6629	1612
	2-2x4	11314	971	12286	1648
	3-2x4	16971	971	17943	1663
	1-2x6	5863	842	6704	1486
	2-2x6	11725	842	12567	1497
	3-2x6	17588	842	18430	1502
20	1-2x4	7826	1533	9358	2073
	2-2x4	15652	1533	17184	2135
	3-2x4	23477	1533	25010	2162
	1-2x6	8639	1328	9968	1950
	2-2x6	17279	1328	18607	1978
	3-2x6	25918	1328	27247	1990
	1-2x8	8632	1226	9858	1845
	2-2x8	17264	1226	18490	1856
	3-2x8	25896	1226	27122	1861
24	1-2x4	9831	2197	12028	2515
	2-2x4	19662	2197	21859	2606
	3-2x4	29493	2197	31690	2647
	1-2x6	11389	1904	13294	2407
	2-2x6	22779	1904	24683	2457
	3-2x6	34168	1904	36073	2477
	1-2x8	11820	1758	13578	2295
	2-2x8	23639	1758	25397	2321
	3-2x8	35459	1758	37217	2331
	1-2x10	11452	1611	13064	2183
	2-2x10	22905	1611	24516	2192
	3-2x10	34357	1611	35969	2196
30	2-2x4	26229	3463	29691	3317
	3-2x4	39343	3463	42806	3381
	4-2x4	52457	3463	55920	3418
	2-2x6	31666	3001	34667	3189
	3-2x6	47498	3001	50500	3226
	4-2x6	63331	3001	66332	3246
	2-2x8	34101	2770	36871	3051
	3-2x8	51151	2770	53921	3074
	4-2x8	68201	2770	70972	3086
	2-2x10	34397	2539	36936	2898
	3-2x10	51595	2539	54134	2910
	4-2x10	68793	2539	71332	2917
	2-2x12	32692	2309	35001	2768
	3-2x12	49039	2309	51347	2773
	4-2x12	65385	2309	67693	2776

Depth (in.)	Flange	Allowable Moment,[a,b] M (ft-lbf) M_{flange}	M_{web}[c,d]	M_{total}	Allowable Shear[a] V_h (lbf) $V_{horizontal}$[e,f]
36	2-2x4	32842	5015	37856	4014
	3-2x4	49262	5015	54277	4104
	4-2x4	65683	5015	70698	4156
	2-2x6	40721	4346	45067	3915
	3-2x6	61081	4346	65427	3971
	4-2x6	81441	4346	85787	4003
	2-2x8	44930	4012	48942	3785
	3-2x8	67395	4012	71407	3823
	4-2x8	89860	4012	93872	3844
	2-2x10	46605	3677	50283	3626
	3-2x10	69908	3677	73585	3650
	4-2x10	93210	3677	96888	3663
	2-2x12	45487	3343	48831	3475
	3-2x12	68231	3343	71574	3489
	4-2x12	90975	3343	94318	3497
42	2-2x6	49871	5939	55810	4632
	3-2x6	74806	5939	80746	4711
	4-2x6	99742	5939	105681	4755
	2-2x8	55968	5482	61450	4515
	3-2x8	83952	5482	89434	4571
	4-2x8	111936	5482	117418	4602
	2-2x10	59220	5026	64245	4360
	3-2x10	88830	5026	93855	4398
	4-2x10	118440	5026	123465	4419
	2-2x12	58956	4569	63525	4202
	3-2x12	88434	4569	93003	4227
	4-2x12	117912	4569	122481	4241
48	2-2x6	59080	7781	66861	5340
	3-2x6	88621	7781	96402	5443
	4-2x6	118161	7781	125942	5502
	2-2x8	67135	7182	74318	5240
	3-2x8	100703	7182	107885	5316
	4-2x8	134270	7182	141453	5358
	2-2x10	72087	6584	78670	5093
	3-2x10	108130	6584	114714	5147
	4-2x10	144173	6584	150757	5177
	2-2x12	72843	5985	78829	4935
	3-2x12	109265	5985	115250	4973
	4-2x12	145687	5985	151672	4994

Notes:

Bases and Adjustments:

(a) Basis: Normal duration of load (C_D): 1.0 (for ten years, as for occupancy live load)

Adjustments: 0.9 for permanent load (over 50 years)

1.15 for 2 months, as for snow

1.25 for 7 days, as for construction load

1.6 for 10 minutes, as for wind or earthquake

2.0 for impact

(b) Basis: F_t of flange = 1,000 psi, corrected by C_F (Douglas fir-larch Select Structural, NDS)

2x4 = 1,000 x 1.5 = 1,500 psi

2x6 = 1,000 x 1.3 = 1,300 psi

2x8 = 1,000 x 1.2 = 1,200 psi

2x10 = 1,000 x 1.1 = 1,100 psi

2x12 = 1,000 x 1.0 = 1,000 psi

Adjustment: $\frac{F_t}{1{,}000}$ for other tabulated tension stresses.

(C_F in numerator and denominator cancel when flanges are same width.) Also see PLYWOOD DESIGN SPECIFICATION for adjustments due to butt joints.

(c) Basis: One web effective in bending because web joints are assumed to be unspliced.

Adjustment: 2.0 for web splices per PLYWOOD DESIGN SPECIFICATION.

(d) Basis: $A_{||}$ of webs for 15/32 Performance Category APA RATED SHEATHING EXP 1. See PLYWOOD DESIGN SPECIFICATION.

Adjustments: 0.81 for 3/8

0.97 for 3/8 STRUCTURAL I

1.19 for 15/32 STRUCTURAL I

1.02 for 19/32

1.51 for 19/32 STRUCTURAL I

1.42 for 23/32

1.84 for 23/32 STRUCTURAL I

(e) Basis: t_s of webs for 15/32 Performance Category APA RATED SHEATHING EXP 1 (CDX). See PLYWOOD DESIGN SPECIFICATION.

NOTE: Adjustments below may in some cases cause rolling shear to control final design.

Adjustments: 0.93 for 3/8

1.24 for 3/8 STRUCTURAL I

1.80 for 15/32 STRUCTURAL I

1.07 for 19/32

2.37 for 19/32 STRUCTURAL I

1.49 for 23/32

2.48 for 23/32 STRUCTURAL I

(f) Basis: Plywood edges parallel to face grain glued to continuous framing per PLYWOOD DESIGN SPECIFICATION

Adjustments: 1.12, i.e., 1.33/1.19, for all plywood edges glued to framing in accordance with PLYWOOD DESIGN SPECIFICATION

0.84, i.e. 1.00/1.19, for non-glued conditions

See PLYWOOD DESIGN SPECIFICATION for limitations on application of increase.

ADDITIONAL INFORMATION

About APA – The Engineered Wood Association

APA – The Engineered Wood Association is a nonprofit trade association of and for structural wood panel, glulam timber, wood I-joist, structural composite lumber, and other engineered wood product manufacturers. Based in Tacoma, Washington, APA represents approximately 150 mills throughout North America, ranging from small, independently owned and operated companies to large integrated corporations.

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APA's services go far beyond quality testing and inspection. Research and promotion programs play important roles in developing and improving construction systems using wood structural panels, glulam, I-joists, and structural composite lumber, and in helping users and specifiers to better understand and apply engineered wood products. For more information, please see the back cover.

Plywood Design Specification, Supplement 2–12: Design and Fabrication of Glued Plywood-Lumber Beams

We have field representatives in many major U.S. cities and in Canada
who can help answer questions involving APA trademarked products.
For additional assistance in specifying engineered wood products, contact us:

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Form No. S812S/Revised December 2014

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