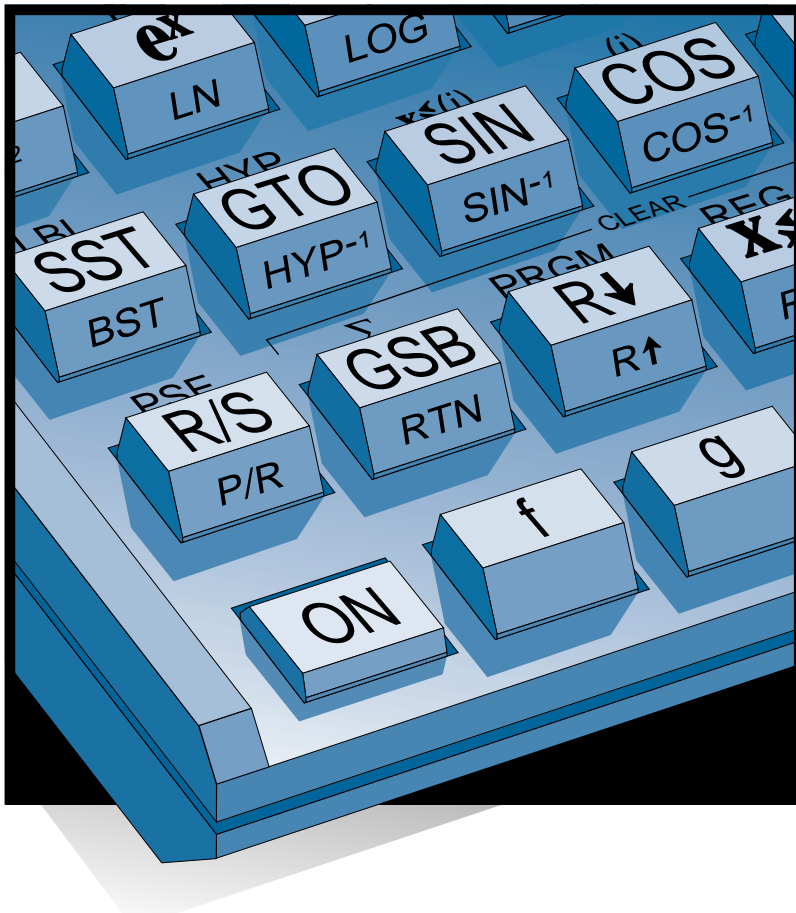


S U P P L E M E N T   2

# DESIGN AND FABRICATION OF GLUED PLYWOOD-LUMBER BEAMS

*July 1992*



**A P A**

*The Engineered Wood Association*

# APA

## The Engineered Wood Association

### DO THE RIGHT THING RIGHT™

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

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

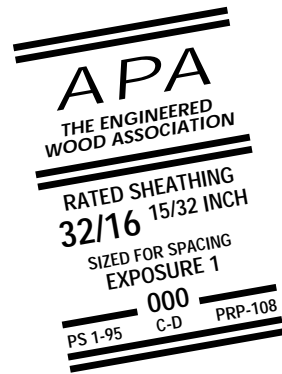
That's why using APA trademarked plywood, oriented strand board and APA EWS glued laminated timbers is the right thing to do.

#### A few facts about wood.

- **We're not running out of trees.** One-third of the United States land base – 731 million acres – is covered by forests. About two-thirds of that 731 million acres is suitable for repeated planting and harvesting of timber. But only about half of the land suitable for growing timber is open to logging. Most of that harvestable acreage also is open to other uses, such as camping, hiking, hunting, etc.
- **We're growing more wood every day.** American landowners plant more than two billion trees every year. In addition, millions of trees seed naturally. The forest products industry, which comprises about 15 percent of forestland ownership, is responsible for 41 percent of replanted forest acreage. That works out to more than one billion trees a year, or about three million trees planted every day. This high rate of replanting accounts for the fact that each year, 27 percent more timber is grown than is harvested.
- **Manufacturing wood products is energy efficient.** Wood products made up 47 percent of all industrial raw materials manufactured in the United States, yet consumed only 4 percent of the energy needed to manufacture all industrial raw materials, according to a 1987 study.
- **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.

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

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



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

This publication presents the recommended method for the design and fabrication of glued plywood and lumber beams. Working stresses and other design criteria are given in the PLYWOOD DESIGN SPECIFICATION, abbreviated PDS. References are also made to the American Forest and Paper Association publication entitled NATIONAL DESIGN SPECIFICATION FOR WOOD CONSTRUCTION, and abbreviated 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*, Technical Services Division.

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

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 change should be noted when referring to this publication.

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

**Technical Services Division**  
**APA – *The Engineered Wood Association***

### A Word on Components

Plywood-lumber components are major structural members which depend on the glued joints to integrate the separate pieces into an efficient unit capable of carrying 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 testing agency. A requirement that each unit bear the trademark of an approved agency will assure adequate independent inspection.

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## LIST OF SYMBOLS AND LOCATION

A	= Cross-sectional area of the beam (in. <sup>2</sup> ) – Part 1, Section 7.2.2	$F_t$	= Tabulated tensile stress of the flange lumber parallel to the grain (psi) – NDS
$A_{  }$	= Area of web parallel plies (in. <sup>2</sup> )– Part 1, Section 4.2.3.1	$F_t'$	= Allowable working stress of the flange lumber parallel to the grain including adjustments to tabulated values (psi) – PDS Section 5.7.3.1 and NDS
$A_{flange}$	= Cross-sectional area of the beam flanges (in. <sup>2</sup> ) – Part 1, Section 7.2.2	$F_v$	= Tabulated plywood through-the-panel-thickness shear stress (psi) – PDS Table 3
$A_{web}$	= Cross-sectional area of the beam webs (in. <sup>2</sup> ) – Part 1, Section 7.2.2	$F_v'$	= Allowable plywood through-the-panel-thickness shear stress (psi) including adjustments to tabulated values – PDS Sections 3.3 and 3.8.1
C	= Load coefficient (in.-lb, or ft-lb) – Part 1, Figure 7.2.2	G	= Shear modulus (modulus of rigidity) of the webs (psi) – PDS Table 3
$C_D$	= Load duration factor adjustment for plywood or flange lumber – PDS Section 3.3.1 and NDS	$I_n$	= Net moment of inertia for computing M of <b>continuous</b> parallel grain material in section (in. <sup>4</sup> ) – Part 1, Section 4.2
$C_F$	= Size factor adjustment for flange lumber – NDS	$I_o$	= Net moment of inertia of a beam component about itself (in. <sup>4</sup> ) – PDS Tables 1 and 2 (I) and Appendix A, Section A9
E	= Tabulated modulus of elasticity of flange lumber (psi) – NDS	$I_t$	= Total moment of inertia about the neutral axis of all parallel-grain material, regardless of any butt joints (in. <sup>4</sup> ) – Part 1, Section 5.2
$E'$	= Allowable modulus of elasticity of flange lumber including adjustments to tabulated values (psi) – Part 1, Section 7.2.1 and NDS	$I_x$	= Moment of inertia about the x axis (in. <sup>4</sup> ) – Appendix A, Sections A4 and A9
$F_{c\perp}$	= Tabulated stress in compression perpendicular to grain for the flange member (psi) – NDS	$I_y$	= Moment of inertia about the y axis (in. <sup>4</sup> ) – Appendix A, Section A9
$F_{c\perp}'$	= Allowable stress in compression perpendicular to grain for the flange member including adjustments, if any, to tabulated values (psi) – NDS	K	= A constant determined by beam cross section – Figure 7.2.2
$F_s$	= Tabulated plywood rolling shear stress (psi) – PDS Table 3	M	= Acting moment or allowable bending moment (in.-lb or ft-lb) – Part 1, Section 4.2.1 and Appendix A, Section A3
$F_s'$	= Allowable plywood rolling shear stress including adjustments to tabulated values (psi) – Part 1, Section 6.1 and PDS Sections 3.3 and 3.8.2		

$M_{\text{flange}}$	= Tabulated allowable flange bending moment (ft-lb) – Appendix B	$\ell$	= Length of beam (in. or ft) – Appendix A, Section A3
$M_{\text{web}}$	= Tabulated allowable web bending moment (ft-lb) – Appendix B	$p$	= Factor for use in finding constant K – Figure 7.2.2
$M_{\text{total}}$	= Tabulated total allowable bending moment (ft-lb) – Appendix B	$s$	= Factor for use in finding constant K – Figure 7.2.2
$P$	= Concentrated load or reaction (lb) – Part 1, Section 8.1.1.1	$t_{\parallel}$	= Total thickness of parallel plies (in.) – Part 1, Section 4.2.3.1
$Q$	= Statical moment about the neutral axis of all parallel-grain material, regardless of any butt joints, lying above (or below) the neutral axis (in. <sup>3</sup> ) – Part 1, Section 5.2	$t_s$	= Thickness for shear through the thickness of one outer web (in.) – Part 1, Section 6.2 and PDS Tables 1 and 2
$Q_{\text{fl}}$	= Statical moment about the neutral axis of all parallel-grain material in the upper (or lower) flanges, regardless of any butt joints (in. <sup>3</sup> ) – Part 1, Section 6.1	$w$	= Uniform load (lb per lineal foot, or lb per lineal inch) – Appendix A, Section A3
$V$	= Acting shear load (lb) – Appendix A, Section A3	$x$	= Thickness of stiffener as measured along the beam span (in.) – Part 1, Section 8.1.1.1
$V_h$	= Allowable total horizontal shear through the panel thickness on the section (lb) – Part 1, Section 5.2	$\Delta_A$	= Approximate deflection: $\Delta_b$ multiplied by the shear deflection factor (in.) – Part 1, Section 7.1
$V_s$	= Allowable total rolling shear on the section (lb) – Part 1, Sections 6.1 and 6.2	$\Delta_b$	= Deflection due to bending (in.) – Part 1, Section 7
$b$	= Flange width (in.) – Part 1, Section 8.1.1.1 and Figure 7.2.2	$\Delta_s$	= Deflection due to shear (in.) – Part 1, Section 7.2.2
$b_1$	= Width of flanges plus $\Sigma t_s$ (in.) – Part 1, Figure 7.2.2	$\Delta_R$	= Total deflection due to bending and shear: Refined method (in.) – Part 1, Section 7.2
$d$	= Flange depth (in.) – Part 1, Section 6.1 and Figure 7.2.2	$\Sigma I_x$	= $I_t$ = Total moment of inertia about x axis (in. <sup>4</sup> ) – Appendix A, Section A9
$d_1$	= $h - 2d$ (in.) – Part 1, Figure 7.2.2	$\Sigma I_y$	= Total moment of inertia about y axis (in. <sup>4</sup> ) – Appendix A, Section A9
$h$	= Depth of beam with allowance for surfacing (in.) – Part 1, Section 4.1.2 and Figure 7.2.2	$\Sigma t_s$	= Total thickness for shear through the thickness of all webs at the section (in.) – PDS Section 2.5 and PDS Tables 1 and 2

PART 1 – DESIGN OF GLUED  
PLYWOOD-LUMBER BEAMS

1. General

1.1 Beam Behavior

In plywood beams, the lumber 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 1.2.

2. Design Considerations

2.1 Design Loads

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

2.2 Allowable Working Stresses

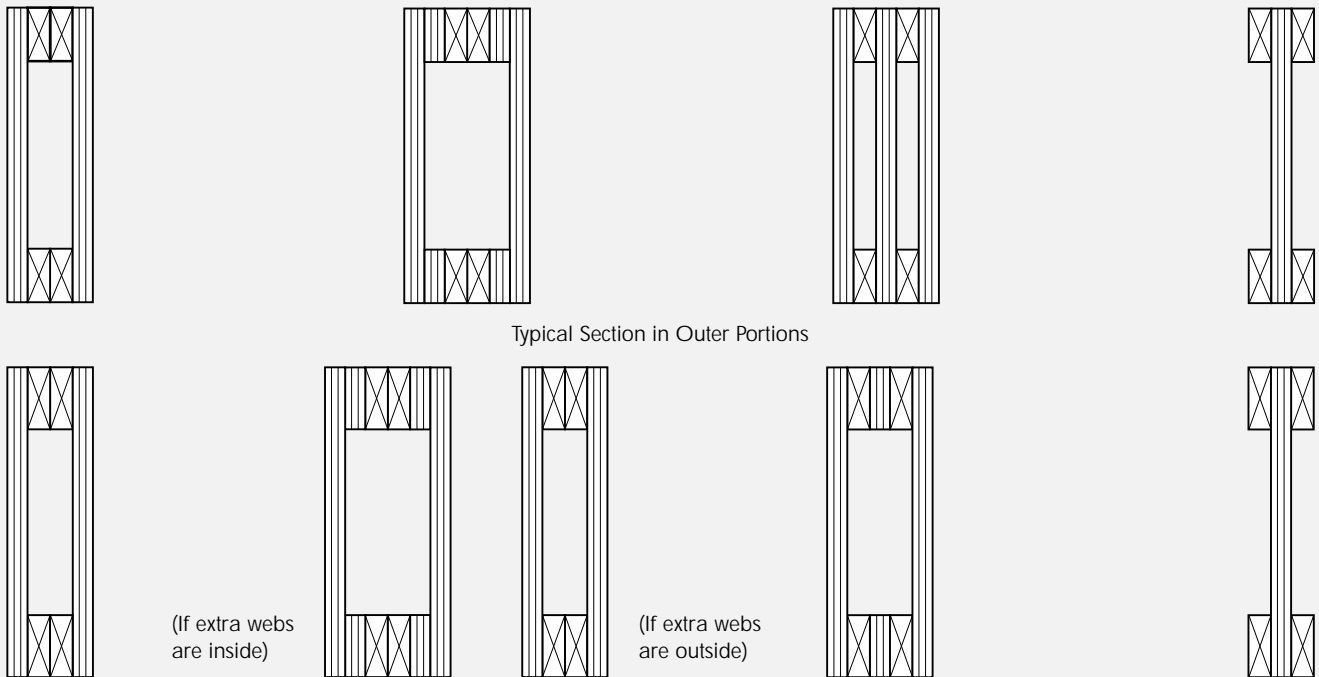
Working stresses are determined as described in PLYWOOD DESIGN SPECIFICATION Sections 5.4 and 5.5, with due regard for duration of loading. Note also that glued plywood-lumber beams may qualify for an increase in allowable plywood shear-through-the-thickness stress as described in PDS Section 3.8.1.

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

Values for compression and tension parallel with lumber grain depend on species, grade, number of laminations, slope of scarf joints, and moisture condition. Values are applied as outlined in PLYWOOD DESIGN SPECIFICATION Sections 5.5 and 5.7.

FIGURE 1.2

TYPICAL BEAM SECTIONS



Allowable stresses for stress-grade lumber flanges shall not exceed those given in the latest edition of the NFPA National Design Specification (NDS). 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 ten times the lamination thickness of the point under investigation is considered discontinuous.

**2.3 Allowable Deflection**

Deflection should not exceed that allowed by the applicable building code. Maximum deflections recommended are the following proportions of the span  $\ell$  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 or beams over glass windows.

**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 EWS Technical Note *Glulam Beam Camber*, EWS 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 four 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 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 maximums may also be subject to a number of adjustments based on duration of load, allowable flange tension stress (grade of lumber), and web thickness and grade. Note that further adjustment will be necessary when butt joints are allowed in lumber 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 PDS Section 5.7.3, which gives allowable-stress reductions applicable to cross sections containing flange butt joints. Also see subsequent sections of this Supplement.

## 4. Lumber 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 flange laminations for gluing, each lamination should be considered 1/8" smaller in dimension perpendicular to gluing surfaces (1/16" per surface) than its standard lumber size.

Beams should be designed for an actual depth (h) slightly less than their nominal depth, to allow for resurfacing for the sake of appearance or uniformity of depth.

Actual depth of beams under 24" deep should be considered 3/8" less than nominal; for beams 24" and deeper, actual depth should be considered 1/2" 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.-lb)

F<sub>t</sub>' = Allowable controlling working stress parallel to the grain of the flange lumber (psi) (see PDS Section 5.7.3.1)

I<sub>n</sub> = Net moment of inertia of continuous parallel-grain material in the section (in.<sup>4</sup>)

h = Depth of beam (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 with due regard for 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<sub>||</sub>) is 1/12 of the appropriate area (A<sub>||</sub>) for tension and compression, as shown in PLYWOOD DESIGN SPECIFICATION, Section 2.6.

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" 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<sub>n</sub>, unless the location of butt joints is specified in the design. For joints closer than 24" the contribution of the webs should be neglected in computing I<sub>n</sub>.

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 Table 5.6.1.2.

**4.2.3.2 Flange Lumber** – Butt joints in the lumber flanges are required by the Fabrication Specification (pg. 14) to be spaced at least 30 times the lamination thickness in adjoining laminations, and at least ten times the lamination thickness in non-adjointing laminations, if not otherwise stipulated in the design. (Ignore any plywood between laminations.)

Therefore, in accordance with PDS Section 5.7, 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 ten percent of the two adjoining laminations.

Effects of other butt-joint arrangements are as given in PDS Section 5.7.

## 5. Plywood Webs

### 5.1 General

Plywood webs are primarily stressed in shear through their 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. Where webs are dropped off, 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 (lb)

$F_v'$  = Allowable plywood shear stress through the panel thickness (psi), as given in PDS Section 3.8.1, with increase if applicable

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

$\Sigma t_s$  = Total shear thickness of all webs at the section (in.) (see PDS Section 2.5)

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

### 5.3 Splices

Effectiveness of spliced joints in resisting flexure and shear is given in PDS Section 5.6. A 2"-wide nominal stiffener alone may be used as a shear-splice plate when the web is 24" deep or less, and is no thicker than 3/8" or carries no more shear than would be allowed on a 3/8" 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 glue, not by any combination of glue 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.

$$V_s = \frac{2F_s' d I_t}{Q_{fl}}$$

where

$V_s$  = Allowable total shear on the section (lb)

$F_s'$  = Allowable plywood rolling shear stress (psi).  $F_s'$  is adjusted per PDS Sections 3.3 and 3.8.2, 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.<sup>4</sup>)

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

## 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.

$$V_s = \frac{F_s' dI_t}{Q_{fl}} \frac{\sum t_s}{t_s}$$

where

$\sum t_s$  = Sum of all web shear thicknesses at the section (in.)  
(see PDS Section 2.5)

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

Other notation 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 ( $\Delta_b$ ) 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 ( $\Delta_A$ ) of simply supported, uniformly loaded plywood beams may be found by multiplying the bending deflection ( $\Delta_b$ ) 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, 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 ( $\Delta_R$ ) may be calculated by separately computing the bending deflection ( $\Delta_b$ ) and shear deflection ( $\Delta_s$ ), 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 ( $E' = 1.03E$ , PDS Section 5.5.5). 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 7.2.2 may be calculated using the formula,

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

where

$\Delta_s$  = Shear deflection (in.)

K = A constant determined by the beam cross section, and shown in Figure 7.2.2, page 11

C = A coefficient depending on the manner of loading, also shown in Figure 7.2.2, page 11

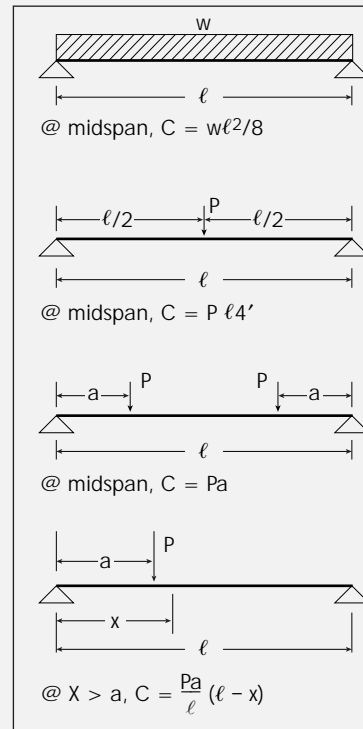
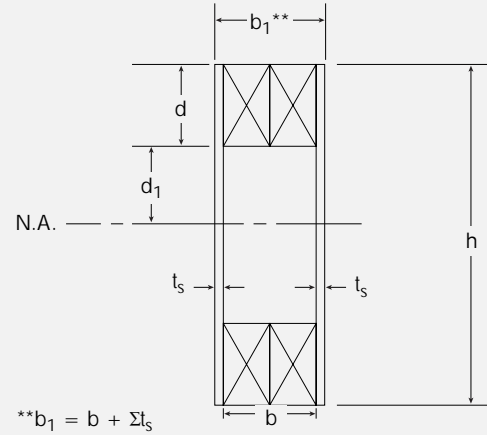
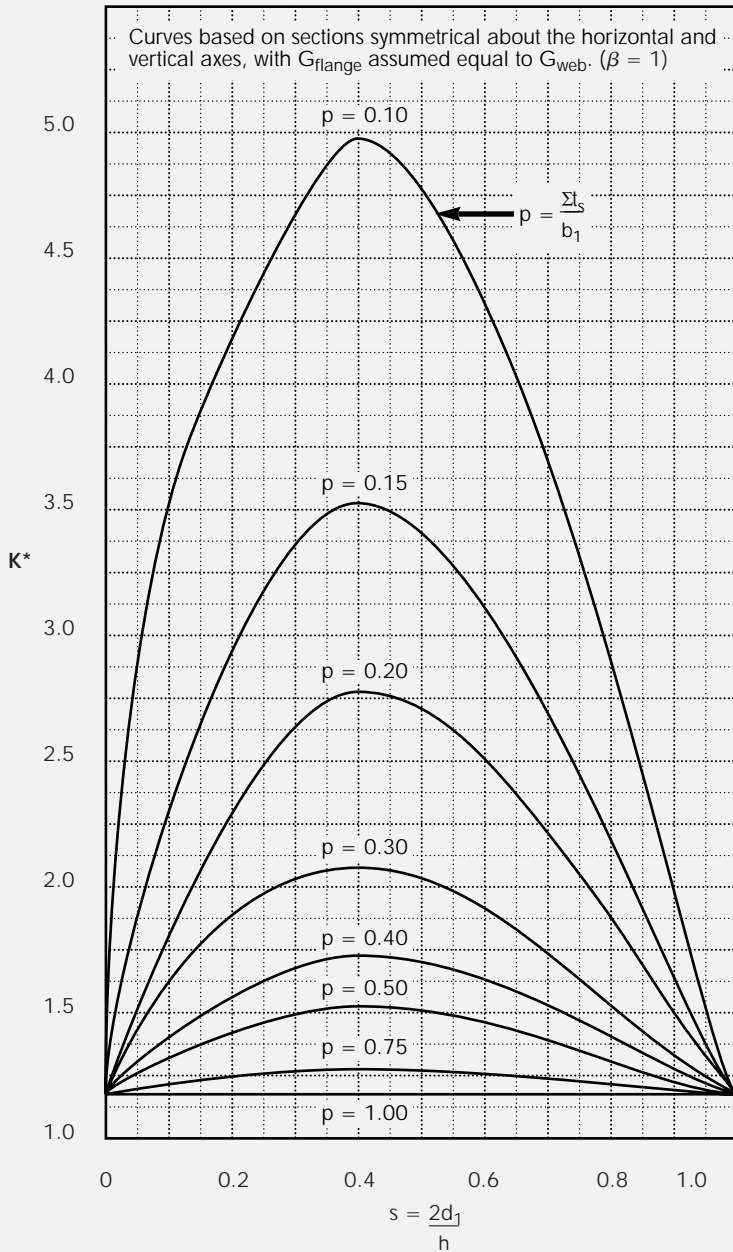
A =  $A_{flange} + A_{web}$  = Cross-sectional area of the beam (in.<sup>2</sup>)  
(When calculating area of plywood webs ( $A_{web}$ ), use “Effective Thickness for Shear,”  $t_s$  from PLYWOOD DESIGN SPECIFICATION, Table 1 or 2, Column 3.)

G = Shearing modulus of the webs (psi) (see PDS Table 3)

If deflection is critical for loading conditions other than those shown in Figure 7.2.2, refer to U.S.D.A. Forest Service Research Note FPL-0210: Simplified Method Calculating Shear Deflections of Beams, or contact APA.

FIGURE 7.2.2

SECTION CONSTANT AND LOAD COEFFICIENTS FOR SHEAR DEFLECTION EQUATION



Load Coefficients, C

$$*K = \frac{\frac{9}{2} \left[ \frac{1}{P} (1-s) + s \right] \left\{ \frac{1}{P^2} \left[ \frac{s^5}{2} - s^3 + \frac{s}{2} \right] + \frac{1}{P} \left[ -s^5 \left( \frac{3}{30\beta} + \frac{2}{3} \right) + s^3 \left( \frac{1}{3\beta} + \frac{2}{3} \right) - \frac{s}{2\beta} + \frac{8}{30\beta} \right] + \frac{8s^5}{30} \right\}}{\left[ \frac{1}{P} (1-s^3) + s^3 \right]^2}$$

where  $\beta = \frac{G_{flange}}{G_{web}}$

Section Constant, K

0

$$p = \frac{\sum t_s}{b_1}$$

## 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 accurately 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 flange at that section. Their dimension parallel to the beam span 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  $x$  in the following equation.

$$x = \frac{P}{F_{c\perp}'b}$$

where

$x$  = Thickness (in.) of stiffener (parallel to beam span)

$P$  = Concentrated load or reaction (lb)

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

$b$  = Flange width (in.)

**8.1.1.2 Rolling Shear** – For beams with one or two webs, the thickness of stiffeners must be at least equal to  $x$  in the following equation. For beams with more than two webs, the rolling shear stress will be less likely to govern.

$$x = \frac{P}{2hF_s'}$$

where

$h$  = Depth of beam (in.)

$F_s'$  = Allowable plywood rolling shear stress (psi) as given in PDS Section 3.8.2

#### 8.1.2 Bearing Stiffeners Not at Ends of Beam

For bearing stiffeners not at ends of beam, factors given in 1997 NDS Section 2.3.10 may be applied to  $F_{c\perp}$ .

### 8.2 Intermediate Stiffeners

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

Intermediate stiffeners spaced 48" or less on centers will develop all, or nearly all, the shear strength of a beam of normal proportions, as evidenced by APA – *The Engineered Wood Association* tests.

## 9. Lateral Stability

Deep, narrow beams, particularly those used on long spans, may require definite 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 glulam, 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 – The Engineered Wood Association PLYWOOD DESIGN SPECIFICATION (PDS)*, using the method set forth in Part 1 of this PDS Supplement. Other design methods may be employed, provided they are supported by adequate test data.

#### 1.3

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

### 2. Materials

#### 2.1 Plywood

##### 2.1.1

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

##### 2.1.2

At 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 with Section 3.3.1.

##### 2.1.3

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

#### 2.2 Lumber

##### 2.2.1

Grades shall be in accordance with current lumber grading rules, except that knotholes up to the same size as the sound and tight knots specified for the grade by the grading rules may be permitted. When lumber is resawn, it shall be regraded on the basis of the new size. Lumber for stiffeners shall be 2" 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 with Section 3.3.1.

### **2.2.3**

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

## **2.3 Glue**

### **2.3.1**

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

### **2.3.2**

Interior-type glue shall conform with ASTM Specification D3024 or D4689. Exterior-type glue shall conform with ASTM Specification D2559.

### **2.3.3**

Mixing, spreading, storage-, pot-, and working-life, and assembly time, temperature, and pressure shall be in accordance with the manufacturers' 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, Section 5.9. 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" 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 twelve times the web thickness.

#### **3.1.3**

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

### **3.2 Framing**

#### **3.2.1**

Scarf and finger joints may be used in 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.

#### **3.2.2**

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" 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 three or less laminations, only one joint shall be allowed at any one cross section; in flanges of four or more laminations, two 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 nonadjoining 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". When glued during assembly, web splice plates shall be backed with one or more lumber stiffeners accurately 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", 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 lumber 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 glue bond (100 to 150 psi on the net glued area is recommended), and shall be uniformly distributed by caul plates, beams, or other effective means. Where webs enclose a lumber 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 for plywood up to 3/8" thick, 6d for 1/2" to 7/8" plywood, 8d for 1" to 1-1/8" plywood. They shall be spaced not to exceed 3" along the flanges for plywood through 3/8", or 4" for plywood 1/2" and thicker, in lines set in 3/4" from the lumber edge, and spaced not over 4" apart. Two lines shall be used for 4" nominal flange lumber, three lines for lumber 6", 8", and 10" nominal, and four lines for 12" 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 glue bond which meets or exceeds applicable specifications.**

#### 3.3.6

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

## **4. Test Samples**

### **4.1**

When glue-bond test samples are taken from a member, if not otherwise obtained from trim, they shall be taken as cores approximately 2" in diameter, drilled perpendicular to the plane of the 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" from one edge and up to 6" from the other.

### **4.2**

If necessary for retesting, additional samples may be taken from the ends of the beams within 2" from the top or the bottom edge, but not closer together than 6", nor farther in from the end than a distance equal to twice the beam depth, but in no case within 9" 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 glue-bond test samples have been taken, holes shall be neatly plugged with glued wood inserts.

## **5. Identification**

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

## APPENDIX A – DESIGN EXAMPLE

### A1. General

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

Preliminary considerations as to the grade of plywood and lumber to be used for a given design should include a check on availability. Where full exterior durability is not required for the plywood, APA plywood may be specified Exposure 1 (Interior with exterior glue), generally permitting 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)

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

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

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

$$\begin{aligned} \text{From Appendix B, 24" depth, max. allowable moment} \\ = 19,662 + 2,197 = 21,859 \text{ ft-lb} \end{aligned}$$

$$\begin{aligned} M_{\max} &= (M_{\text{flange}} \times \frac{F_t(\text{No.1 \& Btr})}{F_t(\text{Select Structural})} \times C_D) + (M_{\text{web}} \\ &\quad \times (\text{footnote \#4}) \times C_D) \\ &= (19,662 \times \frac{800}{1,000} \times 1.15) + (2,197 \times 1.42 \times 1.15) \\ &= 21,677 < 28,420 \text{ ft-lb} \quad \text{NG} \end{aligned}$$

Try two Douglas fir-larch Select Structural 2x6s with 15/32".  
APA STRUCTURAL I RATED SHEATHING

$$\begin{aligned} M_{\max} &= (M_{\text{flange}} \times C_D) + (M_{\text{web}} \times (\text{footnote number 4}) \times C_D) \\ &= (22,779 \times 1.15) + (1,904 \times 1.19 \times 1.15) = 28,801 \text{ ft-lb} \\ &> 28,420 \text{ ft-lb} \quad \text{OK} \end{aligned}$$

NOTE: Increasing lumber width often provides little increased capacity due to the effect of  $C_F$

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

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

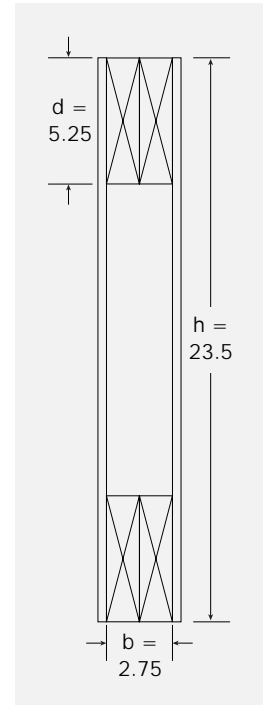
From Appendix B, where 15/32" or 1/2" APA RATED SHEATHING Exposure 1 is used for webs, max. allowable shear using two 2x6's

$$V_{\max} = (2,457 \times 1.80^*) \times 1.15 = 5,086 > 4,060 \text{ lb} \quad \text{OK}$$

Assume trial section as sketched.

Webs: Two webs; 15/32" or 1/2"  
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.  $\leq$  19%)



\*Appendix B, Footnote 5 Adjustment for using Structural I

Note that flange lumber dimensions allow for surfacing per Part 1, Section 4.1.2.

#### 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 per PDS Section 5.7.3. 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, Section 5.7.3.

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

$$I \text{ (flanges)} = \frac{b}{12} [h^3 - (h - 2d)^3]$$

$$= \frac{2.75}{12} [23.5^3 - 13^3] = 2,471 \text{ in.}^4$$

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

$$I_n = I_x \text{ (flanges)} + I_x \text{ (contributing web[s])}$$

$$= 2,471 + 245 = 2,716 \text{ in.}^4$$

$$I_t = I_x \text{ (flanges)} + I_x \text{ (all parallel web plys)}$$

$$= 2,471 + 2 \times 245 = 2,961 \text{ in.}^4$$

\*From PDS Table 2, Column 4,  $t_{\parallel} = \frac{2.719}{12} = 0.227$ ". If the plywood face grain is used perpendicular to the flanges, use  $\frac{\text{area}}{12}$ , from Column 8.

Statical Moment, Q (See Section 5):

$$Q \text{ (flanges)} = bd \left( \frac{h}{2} - \frac{d}{2} \right)$$

$$= 2.75 \times 5.25 \left( \frac{23.5}{2} - \frac{5.25}{2} \right)$$

$$= 131.7 \text{ in.}^3$$

$$Q \text{ (webs)} = t_{\parallel} \times \frac{h}{2} \times \frac{h}{4} \times \text{number of webs}$$

$$= 0.227 \times \frac{23.5^2}{8} \times 2 = 31.3 \text{ in.}^3$$

$$Q = Q \text{ (flanges)} + Q \text{ (webs)}$$

$$= 131.7 + 31.3 = 163.0 \text{ in.}^3$$

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

Tabulated stresses for the flange lumber are taken from Table 4A of the 1997 NDS. Plywood stresses are given in the PDS.

Assuming dry-use “short-term” maximum design loading (2 months), the tabulated stress ( $F_t$ ) is adjusted as follows:

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

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

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

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

$$345,568 \text{ in.-lb} > 341,040 \text{ in.-lb} \quad \text{OK}$$

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)

From PDS Guide to Use of Allowable Stress and Section Property Tables, use Group 1 plywood working stress for 15/32" or 1/2" APA STRUCTURAL I RATED SHEATHING 32/16 Exposure 1. From PDS Table 3, working shear stress, increased 19% for continuous glued edge framing parallel to face grain per PDS Section 3.8.1 and load duration per PDS Section 3.3.1.1, is:

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

As indicated in paragraph 3.8.2 of the PDS, the basic rolling-shear stress is reduced 50% for plywood beam flange-web shear design.

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

Horizontal shear (allowable)

$$V_h = \frac{F_v' I_t \sum t_s}{Q} = \frac{260.0 \times 2,961 \times (2 \times 0.535)}{163.0}$$

$$= 5,054 \text{ lb} > 4,060 \text{ lb} \quad \text{OK}$$

Flange-web shear (allowable)

$$V_s = \frac{2F_s' dI_t}{Q_{fl}} = \frac{2 \times 43.1 \times 5.25 \times 2,961}{131.7}$$

$$= 10,175 \text{ lb} > 4,060 \text{ lb} \quad \text{OK}$$

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.

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) –

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

\*Part 1, Section 7.1

For simple span, uniform load –

$$\begin{aligned} \Delta_A &= \frac{5w\ell^4}{384EI_t} \times \text{shear deflection factor} \\ &= \frac{5 \times 290 \times 28^4 \times 12^3}{384 \times 1,900,000 \times 2,921} \times 1.26 = 0.898 \text{ in.} \end{aligned}$$

$$0.898" = \ell/374 < \ell/240 \quad \text{OK}$$

Refined Method (total deflection) –

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

\*Part 1, Section 7.2.1

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

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

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

From PDS Table 3,  $G = 90,000 \text{ psi}$

$$K = 2.10 \text{ (from Figure 7.2.2)}$$

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

$$\Delta_R = \Delta_b + \Delta_s$$

$$= \frac{5w\ell^4}{384EI_t} + \frac{KC}{AG}$$

$$= \frac{5 \times 290 \times 2^4 \times 12^3}{384 \times 1,957,000 \times 2,961} + \frac{2.10 \times 341,040}{54.02 \times 90,000}$$

$$= 0.692 + 0.147 = 0.839 \text{ in.}$$

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

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)

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

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

Stiffener thickness required for compression at bearing ends:

$$x = \frac{P}{F_{c\perp}'b} = \frac{4,060}{625 \times 2.75} = 2.36 \text{ in.};$$

use double 2x4s at ends.

Stiffener thickness required for rolling shear at bearing ends:

$$x = \frac{P}{2hF_s'} = \frac{4,060}{2 \times 23.5 \times 43.1} = 2.00 \text{ in.};$$

double 2x4s OK

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

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

$$I_y \text{ (flanges)} = 2 \times \frac{db^3}{12}$$

$$= \frac{2 \times 5.25 \times 2.75^3}{12} = 18.2 \text{ in.}^4$$

$$I_y \text{ (webs)} = 2 [I_o + A_{\parallel} (y^2)]$$

$$= 2 [(0.074 \times \frac{23.5}{12}) +$$

$$(\frac{2.719}{12} \times 23.5) (\frac{2.75 + 0.469}{2})^2]$$

$$= 27.88 \text{ in.}^4$$

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

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

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.

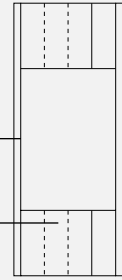
As final steps in the overall design, review the structural adequacy of beam supports and develop beam connection details.

APPENDIX B – PRELIMINARY  
 MAXIMUM MOMENTS AND SHEARS \*

Depth, Flange	Max. Moment, <sup>(1)(2)</sup> M (ft-lb)			Max. Shear, <sup>(1)</sup> V <sub>h</sub> (lb) V <sub>horizontal</sub> <sup>(5)(6)</sup>	
	M <sub>flange</sub>	M <sub>web</sub> <sup>(3)(4)</sup>	M <sub>total</sub>		
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
20"	1-2x6	5863	842	6704	1486
	2-2x6	11725	842	12567	1497
	3-2x6	17588	842	18430	1502
24"	1-2x4	7826	1533	9358	2073
	2-2x4	15652	1533	17184	2135
	3-2x4	23477	1533	25010	2162
28"	1-2x6	8639	1328	9968	1950
	2-2x6	17279	1328	18607	1978
	3-2x6	25918	1328	27247	1990
32"	1-2x8	8632	1226	9858	1845
	2-2x8	17264	1226	18490	1856
	3-2x8	25896	1226	27122	1861
36"	1-2x4	9831	2197	12028	2515
	2-2x4	19662	2197	21859	2606
	3-2x4	29493	2197	31690	2647
40"	1-2x6	11389	1904	13294	2407
	2-2x6	22779	1904	24683	2457
	3-2x6	34168	1904	36073	2477
44"	1-2x8	11820	1758	13578	2295
	2-2x8	23639	1758	25397	2321
	3-2x8	35459	1758	37217	2331
48"	1-2x10	11452	1611	13064	2183
	2-2x10	22905	1611	24516	2192
	3-2x10	34357	1611	35969	2196
52"	2-2x4	26229	3463	29691	3317
	3-2x4	39343	3463	42806	3381
	4-2x4	52457	3463	55920	3418
56"	2-2x6	31666	3001	34667	3189
	3-2x6	47498	3001	50500	3226
	4-2x6	63331	3001	66332	3246
60"	2-2x8	34101	2770	36871	3051
	3-2x8	51151	2770	53921	3074
	4-2x8	68201	2770	70972	3086
64"	2-2x10	34397	2539	36936	2898
	3-2x10	51595	2539	54134	2910
	4-2x10	68793	2539	71332	2917
68"	2-2x12	32692	2309	35001	2768
	3-2x12	49039	2309	51347	2773
	4-2x12	65385	2309	67693	2776

Plywood webs, butt joints staggered 24" minimum, spliced per PDS Section 5.6.3.2

Continuous lumber flanges (no butt joints), resurfaced, for gluing per Part 1, Section 4.1.2



Depth, Flange	Max. Moment, <sup>(1)(2)</sup> M (ft-lb)			Max. Shear, <sup>(1)</sup> V <sub>h</sub> (lb) V <sub>horizontal</sub> <sup>(5)(6)</sup>	
	M <sub>flange</sub>	M <sub>web</sub> <sup>(3)(4)</sup>	M <sub>total</sub>		
36"	2-2x4	32842	5015	37856	4014
	3-2x4	49262	5015	54277	4104
	4-2x4	65683	5015	70698	4156
40"	2-2x6	40721	4346	45067	3915
	3-2x6	61081	4346	65427	3971
	4-2x6	81441	4346	85787	4003
44"	2-2x8	44930	4012	48942	3785
	3-2x8	67395	4012	71407	3823
	4-2x8	89860	4012	93872	3844
48"	2-2x10	46605	3677	50283	3626
	3-2x10	69908	3677	73585	3650
	4-2x10	93210	3677	96888	3663
52"	2-2x12	45487	3343	48831	3475
	3-2x12	68231	3343	71574	3489
	4-2x12	90975	3343	94318	3497
56"	2-2x6	49871	5939	55810	4632
	3-2x6	74806	5939	80746	4711
	4-2x6	99742	5939	105681	4755
60"	2-2x8	55968	5482	61450	4515
	3-2x8	83952	5482	89434	4571
	4-2x8	111936	5482	117418	4602
64"	2-2x10	59220	5026	64245	4360
	3-2x10	88830	5026	93855	4398
	4-2x10	118440	5026	123465	4419
68"	2-2x12	58956	4569	63525	4202
	3-2x12	88434	4569	93003	4227
	4-2x12	117912	4569	122481	4241
72"	2-2x6	59080	7781	66861	5340
	3-2x6	88621	7781	96402	5443
	4-2x6	118161	7781	125942	5502
76"	2-2x8	67135	7182	74318	5240
	3-2x8	100703	7182	107885	5316
	4-2x8	134270	7182	141453	5358
80"	2-2x10	72087	6584	78670	5093
	3-2x10	108130	6584	114714	5147
	4-2x10	144173	6584	150757	5177
84"	2-2x12	72843	5985	78829	4935
	3-2x12	109265	5985	115250	4973
	4-2x12	145687	5985	151672	4994

\*See page 21 for notes.

## Bases and Adjustments:

(1) Basis: Normal duration of load ( $C_D$ ): 1.00

Adjustments: 0.90 for permanent load (over 50 years)

1.15 for 2 months, as for snow

1.25 for 7 days

1.6 for 10 minutes, as for wind or earthquake

2.00 for impact

(2) Basis:  $F_t$  of flange = 1,000 psi, corrected by  $C_F$  (Douglas fir-larch Select Structural, 1997 NDS)

$2 \times 4 = 1,000 \times 1.5 = 1,500$  psi

$2 \times 6 = 1,000 \times 1.3 = 1,300$  psi

$2 \times 8 = 1,000 \times 1.2 = 1,200$  psi

$2 \times 10 = 1,000 \times 1.1 = 1,100$  psi

$2 \times 12 = 1,000 \times 1.0 = 1,000$  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 PDS Section 5.7.3 for adjustments due to butt joints.

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

Adjustment: 2.0 for web splices per PDS 5.6.1.

(4) Basis:  $A_{||}$  of webs for 15/32" or 1/2" APA RATED SHEATHING EXP 1 (CDX). See PDS Tables 1 and 2.

Adjustments: 0.81 for 3/8"

0.97 for 3/8" STRUCTURAL I

1.19 for 15/32" or 1/2" STRUCTURAL I

1.02 for 19/32" or 5/8"

1.51 for 19/32" or 5/8" STRUCTURAL I

1.42 for 23/32" or 3/4"

1.84 for 23/32" or 3/4" STRUCTURAL I

(5) Basis:  $t_s$  of webs for 15/32" or 1/2" APA RATED SHEATHING EXP 1 (CDX). See PDS Tables 1 and 2.

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" or 1/2" STRUCTURAL I

1.07 for 19/32" or 5/8"

2.37 for 19/32" or 5/8" STRUCTURAL I

1.49 for 23/32" or 3/4"

2.48 for 23/32" or 3/4" STRUCTURAL I

(6) Basis: Plywood edges parallel to face grain glued to continuous framing per PDS 3.8.1

Adjustments: 1.12 for all plywood edges glued to framing per PDS 3.8.1 (1.33/1.19)

0.84 for non-glued conditions (1.00/1.19)

## Notes:

NOTES:



## APA RESEARCH AND TESTING

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Form No. S812R  
Revised November 1998/0100

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