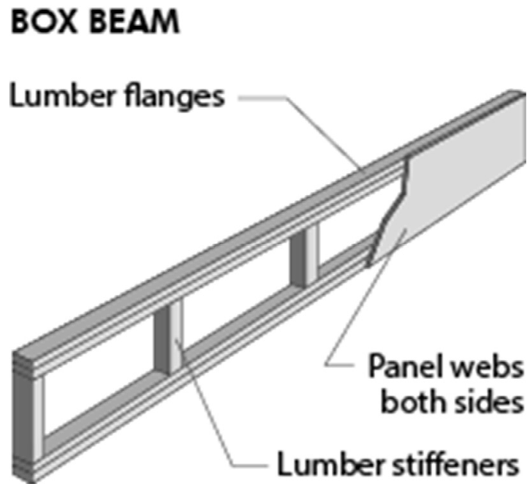
Architecture 544

Wood Structures

Box Beams



- General Shear Stress Equation
- Shear on Common Sections
- Examples

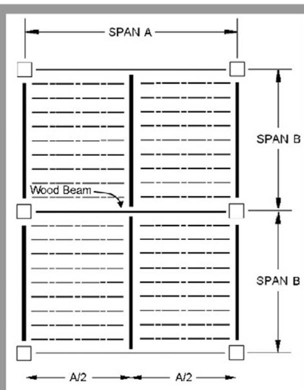
Homework problem – Beam Design

5. Sawn Lumber - Beams

Design the central timber beam shown in the floor system using the given species and grade. Use the given floor D+L load plus the beam selfweight based on the given wood density (moisture is already included). Assume dry conditions (M.C. < 19%) and normal temperatures. Find the timber section with the least area to pass the adjusted allowable stress. Finally, calculate the total D+L deflection including creep. Assume 30% of the Live Load is sustained (long-term).

DATASET: 1 -2-

Wood Species	COAST SITKA SPRUCE
Wood Grade	No.2
Span A	19 FT
Span B	16 FT
Dead Load	19 PSF
Live Load	55 PSF
Wood density, D	30 PCF
actual section width, b	13.5 IN



#	Question	Your Response
1	Tabulated Allow. Bending Stress, Fb	PSI
2	Tabulated Allow. Shear Stress, Fv	PSI
3	Tabulated E modulus, E	PSI
4	Tabulated Emin modulus, Emin	PSI
5	Total point load (D+L)	LBS
6	Max total point load moment	FT-LBS
7	Final actual section depth, d	IN
8	Max selfweight moment (using final d)	FT-LBS
9	Final Section Modulus, Sx	IN^3
10	Size factor, CF	
11	Effective length, le	IN
12	Slenderness Ratio, RB	
13	Euler stress, FbE	PSI
14	Factored bending, F*	PSI
15	Beam stability factor, CL	
16	Factored Allow. Bending Stress, F'b	PSI
17	Factored Allow. Shear Stress, F'v	PSI
18	Total maximum moment, Mmax	FT-LBS
19	Total maximum shear force, Vmax	LBS
20	Actual bending stress, fb	PSI
21	Actual shear stess, fv	PSI
22	Deflection from floor DL, P_DL	IN
23	Deflection from total floor LL, P_LL	IN
24	Deflection from beam selfweight, w_self	IN
25	Long-Term deflection x Kcr	IN
26	Short-Term deflection	IN
27	Total deflection (short + long term w/ creep)	IN

Box Beams

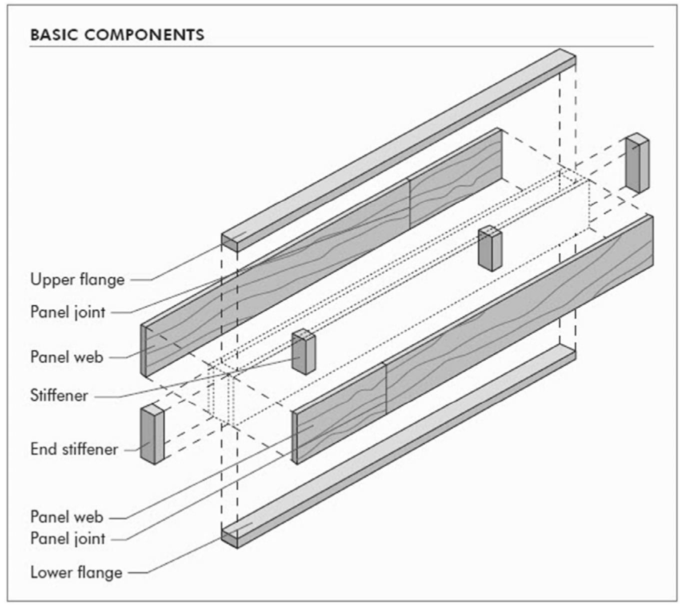
Box beams are built-up beams using dimensioned lumber (2x4 or 2x6) and panels (generally plywood)

The box is framed with the lumber and the sides are skinned with the panels.

The horizontal top and bottom flanges are continuous members as are the vertical ends and internal web stiffeners.

The flanges carry the tension and compression couple (the flexural moment) and the panels carry the shear force.

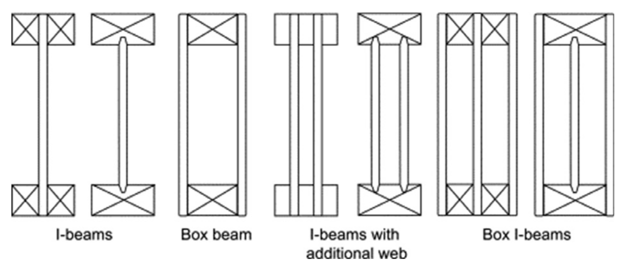
The internal vertical members brace and stiffen the panels.

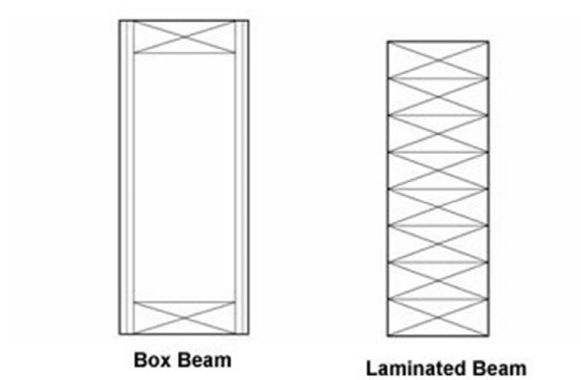


Box Beams

Advantages

- low cost – economic alternative to steel or glulam
- good stiffness and strength
- light weight
- minimal shrinkage, warping or twisting
- ease of fabrication
- material availability
- speed of installation
- can be insulated if desired



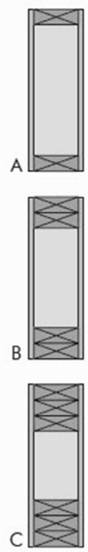


Box Beams

Z416T 2009

APA design with tables
- choose span
- run down column to find passing capacity
- find cross section A, B or C
- find Panel Specifications: thickness in x/32" and rating (rafter o.c. / joist o.c.)

CROSS SECTIONS



ALLOWABLE LOADS[(a)] FOR 12-INCH DEEP ROOF BEAMS OR HEADER (lb/ft)

Panel Specification	Cross Section	Approx. Wt. per ft (lb) 2 x 4	2 x 6	Span (ft) 10	12	14	16	18	20	22	24
15/32" 32/16	A	6	8	238*	198*	170*	147	116	94	78	64
15/32" 32/16	B	9	12	339*	283*	242*	212	176	143	118	91
23/32" 48/24	B	11	14	408*	340	291	223	176	143	118	95
23/32" 48/24	C	13	17	374*	312*	267*	234	198	160	133	105

ALLOWABLE LOADS[(a)] FOR 16-INCH DEEP ROOF BEAMS OR HEADER (lb/ft)

Panel Specification	Cross Section	Approx. Wt. per ft (lb) 2 x 4	2 x 6	Span (ft) 10	12	14	16	18	20	22	24
15/32" 32/16	A	8	10	336*	280*	240*	210	166	134	111	93
15/32" 32/16	B	10	13	475*	396*	340*	297	264	219	181	152
23/32" 48/24	B	13	16	569*	474*	406	342	270	219	181	152
23/32" 48/24	C	15	19	531*	443*	380*	332*	295	266	219	184

ALLOWABLE LOADS[(a)] FOR 20-INCH DEEP ROOF BEAMS OR HEADER (lb/ft)

Panel Specification	Cross Section	Approx. Wt. per ft (lb) 2 x 4	2 x 6	Span (ft) 10	12	14	16	18	20	22	24
15/32" 32/16	A	9	11	440*	367*	315*	273	216	175	144	121
15/32" 32/16	B	12	15	610*	509*	436*	381*	339	297	246	207
23/32" 48/24	B	15	18	728*	607*	520	455	367	297	246	207
23/32" 48/24	C	17	22	693*	577*	495*	433*	385*	346	312	262

ALLOWABLE LOADS[(a)] FOR 24-INCH DEEP ROOF BEAMS OR HEADER (lb/ft)

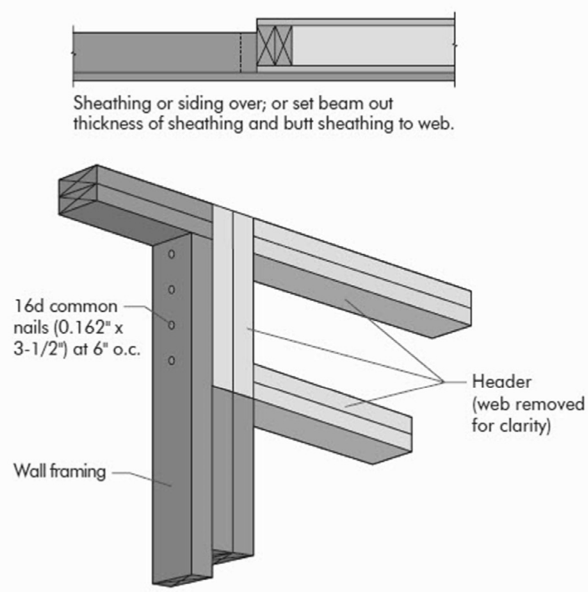
Panel Specification	Cross Section	Approx. Wt. per ft (lb) 2 x 4	2 x 6	Span (ft) 10	12	14	16	18	20	22	24
15/32" 32/16	A	11	13	550*	458*	393*	336	266	215	178	149
15/32" 32/16	B	13	16	744*	620*	531*	465*	413	372	312	262
23/32" 48/24	B	16	20	885*	738*	632*	553	465	377	312	262
23/32" 48/24	C	18	24	854*	711*	610*	533*	474*	427	388	342

(a) Includes 15% snow loading increase.
*Lumber may be No. 2 Douglas-fir or No. 2 southern pine without reduction of tabulated capacity.

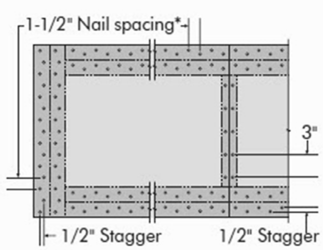
Box Beams APA design with tables (Z416T 2009)

Table assumptions:
- DF - No1 or SP - No1
- panels: APA – expos. 1 4- or 5-ply or OSB
- deflection less than L/240 (total load)
- nail size – 8d common
- nail spacing:
  - flanges 1 ½" o.c.
  - may be doubled in middle half of span
  - end stiffeners 1 ½" o.c.
  - mid stiffeners 3" o.c.

HEADER ATTACHMENT DETAILS



NAILING LAYOUT

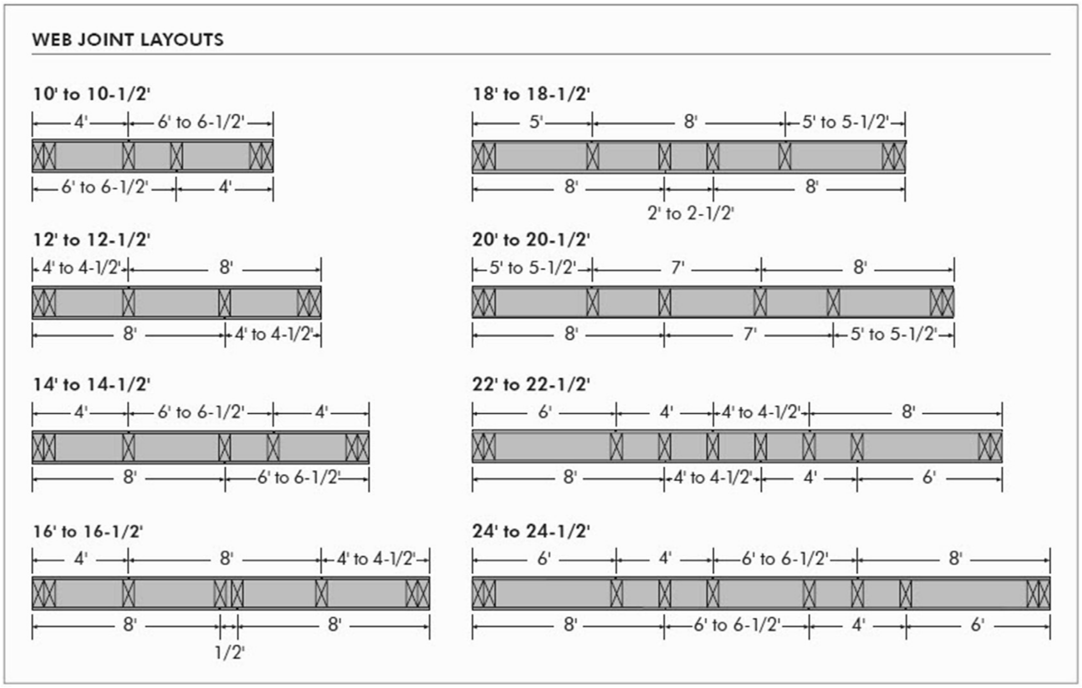


*When end stiffeners extend through the beam, nail spacing is the same as for flanges, except space nails **1 inch on center** when double end stiffeners are used in beams with three members per flange (cross-section C). When end stiffeners are inserted between flanges, nails may be spaced 3 inches on center.

Box Beams

APA design with tables

web panel joint and stiffer layout
flange members are continuous



Box Beams

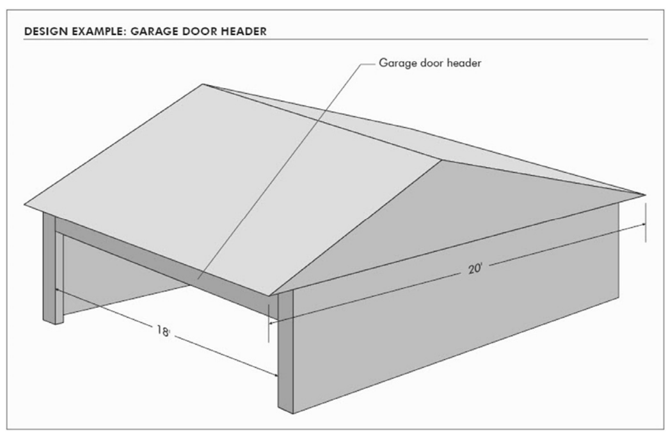
Example:

APA Z416T design with tables

garage door header using 2x4s
span = 18 ft
factored projected roof load = 35 psf
(DL 10 psf + SL 25 psf)

Load on beam:

35 psf x 20 ft / 2 = 350 plf



Box Beams

APA design with tables
Example:

Load on beam:

35 psf x 20 ft / 2 = 350 plf

Choose beam:
follow the 18 ft span column
no 12” or 16” deep sections work
20” with 367 > 350+15 plf works
or
24” with 413 > 350+13 plf works
both options use section “B”

20” deep:
23/32” 48/24 panel and DF No1
or
24” deep:
15/32” 32/16 panel and DF No1

In this case the 24” section uses a thinner and lower rated panel and so would be less costly. If the additional depth were a concern the 20” beam could be used.

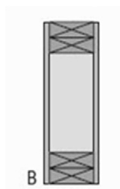
ALLOWABLE LOADS(a) FOR 20-INCH DEEP ROOF BEAMS OR HEADER (lb/ft)

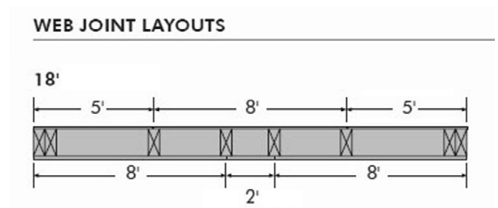
Panel Specification	Cross Section	Approx. Wt. per ft (lb) 2 x 4	2 x 6	Span (ft) 10	12	14	16	18	20	22	24
15/32" 32/16	A	9	11	440*	367*	315*	273	216	175	144	121
15/32" 32/16	B	12	15	610*	509*	436*	381*	339	297	246	207
23/32" 48/24	B	15	18	728*	607*	520	455	367	297	246	207
23/32" 48/24	C	17	22	693*	577*	495*	433*	385*	346	312	262

ALLOWABLE LOADS(a) FOR 24-INCH DEEP ROOF BEAMS OR HEADER (lb/ft)

Panel Specification	Cross Section	Approx. Wt. per ft (lb) 2 x 4	2 x 6	Span (ft) 10	12	14	16	18	20	22	24
15/32" 32/16	A	11	13	550*	458*	393*	336	266	215	178	149
15/32" 32/16	B	13	16	744*	620*	531*	465*	413	372	312	262
23/32" 48/24	B	16	20	885*	738*	632*	553	465	377	312	262
23/32" 48/24	C	18	24	854*	711*	610*	533*	474*	427	388	342

(a) Includes 15% snow loading increase.
*Lumber may be No. 2 Douglas-fir or No. 2 southern pine without reduction of tabulated capacity.





Box Beams

NDS analysis
Based on the previous example find the maximum load capacity.

Load on beam:

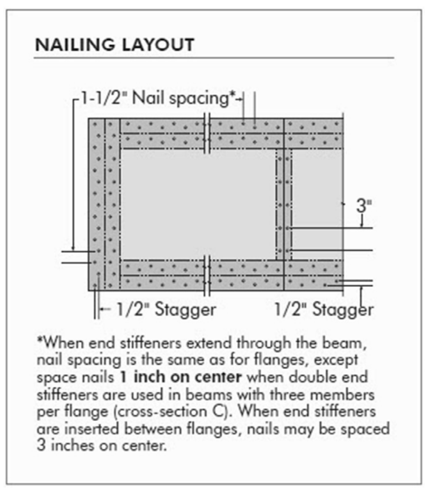
D+S = 35 psf x 20 ft / 2 = 350 plf
C_D = 1.15

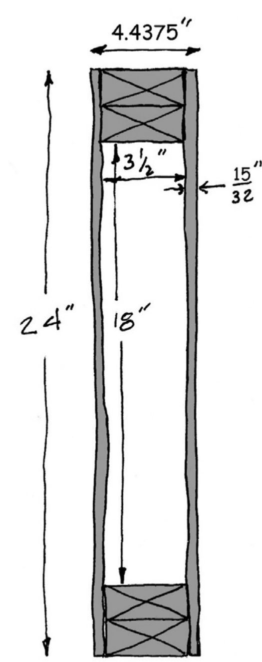
Box Beam Section:

- Douglas Fir No1
- G = 0.5

Nails:

- 8d common
- spacing, s 1 ½” o.c. flange and ends, 3” o.c. web stiffeners
- rows of nails, R = 2 per web per flange (8 total top and bottom)
- allowable load per nail, F_n = 74 lb/nail
- number of webs, N_{web} = 2





Box Beams

Nails:

- 8d common
- allowable load per nail, F_n = 74 lb/nail

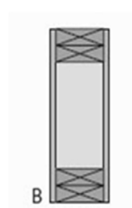
NAILS

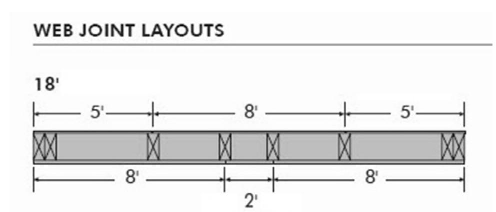
Table 12Q COMMON, BOX, SINKER, or ROOF SHEATHING RING SHANK (RSRS) STEEL WIRE NAILS: Reference Lateral Design Values, Z, for Single Shear (two member) Connections[1,2,3]

for sawn lumber or SCL with wood structural panel side members with an effective G=0.50 (tabulated lateral design values are calculated based on an assumed length of nail penetration, p, into the main member equal to 10D)

Side Member Thickness t_s in.	Nail Diameter D in.	Common Wire Nail (Pennyweight)	Box Nail (Pennyweight)	Sinker Nail (Pennyweight)	RSRS (Dash No.)	G=0.67 Red Oak lbs.	G=0.55 Mixed Maple Southern Pine lbs.	G=0.5 Douglas Fir-Larch lbs.	G=0.49 Douglas Fir-Larch (N) lbs.	G=0.46 Douglas Fir(S) Hem-Fir(N) lbs.	G=0.43 Hem-Fir lbs.	G=0.42 Spruce-Pine-Fir lbs.	G=0.37 Redwood lbs.	G=0.36 Eastern Softwoods Spruce-Pine-Fir(S) Western Cedars Western Woods lbs.	G=0.35 Northern Species lbs.
3/8	0.099		6d	7d		47	45	43	43	42	40	40	38	37	37
	0.113	6d	8d	8d	01	60	56	54	54	52	51	50	47	47	46
	0.120			10d	02	67	62	60	60	58	56	56	52	52	51
	0.128		10d			75	70	68	67	65	63	63	59	58	57
	0.131	8d			03	78	73	71	70	68	66	65	61	61	60
	0.135		16d	12d		83	78	75	74	72	70	69	65	64	63
	0.148	10d	20d	16d		94	88	85	84	82	79	78	73	72	71
7/16	0.099		6d	7d		50	47	45	45	44	43	42	40	40	39
	0.113	6d	8d	8d	01	62	58	56	56	55	53	52	49	49	48
	0.120			10d	02	69	65	63	62	60	59	58	55	54	53
	0.128		10d			77	72	70	69	68	66	65	61	60	59
	0.131	8d			03	80	75	73	72	70	68	67	63	63	62
	0.135		16d	12d		85	80	77	76	74	72	71	67	66	65
	0.148	10d	20d	16d		96	90	87	86	84	81	80	76	75	73
	0.162	16d	40d			114	106	102	101	99	96	95	89	88	86
15/32	0.099		6d	7d		51	48	47	46	45	44	44	41	41	40
	0.113	6d	8d	8d	01	64	60	58	57	56	54	54	51	50	49
	0.120			10d	02	70	66	64	63	62	60	59	56	55	54
	0.128		10d			78	74	71	71	69	67	66	62	62	61
	0.131	8d			03	82	77	74	73	72	70	69	65	64	63
	0.135		16d	12d		86	81	78	77	76	73	72	68	67	66
	0.148	10d	20d	16d		97	91	88	87	85	83	82	77	76	75
	0.162	16d	40d			115	108	104	103	100	97	96	90	89	88

Box Beams



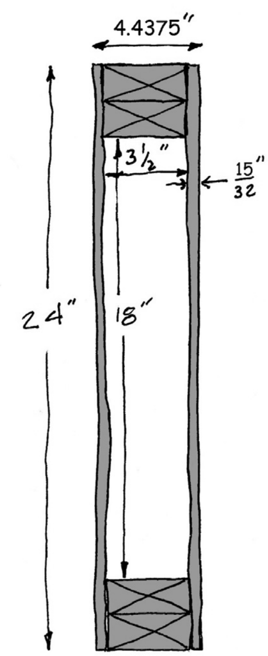


NDS analysis
Based on the previous example
find the maximum load capacity.

Box Beam Section:

Webs:

- depth of section, h = 24 in
- thickness 15/32 = 0.46875 in
- grade and rating: APA Rated Sheathing 32/16 4-ply Exp. 1
- number of webs, N_{web} = 2
- axial Stiffness, EA = 4,150,000 lbs/ft width (Panel Design D510)
- bending thickness, t_{par} = EA/(E 12) =4150/(1700 12) = 0.2034 in based on transformed area normalizing E for flange and web.
- shear capacity $F_v t_v$ = 81 lb/in each web



Flanges:

- 2x4 Douglas Fir – Larch No. 1
- continuous, no but joints. 2 pcs per flange
- depth of flange, d = 3"
- width of flange, b = 3.5" C_F
- allowable tension stress, F_t = 675 (1.5) = 1012.5 psi
- Stiffness, E = 1700000 psi

Box Beams

Douglas Fir – Larch No.1 E = 1700000 psi (NDS Supplement 2018)

15/32" 32/16 panel EA = 4,150,000 lbs/ft width (APA D510)

Species and commercial grade	Size classification	Design values in pounds per square inch (psi)						
		Bending	Tension parallel to grain	Shear parallel to grain	Compression perpendicular to grain	Compression parallel to grain	Modulus of Elasticity	
		F_b	F_t	F_v	$F_{c\perp}$	F_c	E	E_{min}
DOUGLAS FIR-LARCH								
Select Structural	2" & wider	1,500	1,000	180	625	1,700	1,900,000	690,000
No. 1 & Btr		1,200	800	180	625	1,550	1,800,000	660,000
No. 1		1,000	675	180	625	1,500	1,700,000	620,000
No. 2		900	575	180	625	1,350	1,600,000	580,000
No. 3		525	325	180	625	775	1,400,000	510,000

TABLE 8 (Continued)

RATED PANELS DESIGN CAPACITIES

Span Rating	Stress Parallel to Strength Axis				Stress Perpendicular to Strength Axis			
	Plywood				Plywood			
	3-ply	4-ply	5-ply	OSB	3-ply	4-ply	5-ply	OSB
PANEL AXIAL STIFFNESS, EA (lbf/ft of panel width)								
24/0	3,350,000	3,350,000	3,350,000	3,350,000	2,900,000	2,900,000	2,900,000	2,500,000[a]
24/16	3,800,000	3,800,000	3,800,000	3,800,000	2,900,000	2,900,000	2,900,000	2,700,000[a]
32/16	4,150,000	4,150,000	4,150,000	4,150,000	3,600,000	3,600,000	3,600,000	2,700,000
40/20	5,000,000	5,000,000	5,000,000	5,000,000	4,500,000	4,500,000	4,500,000	2,900,000[b]
48/24	NA	5,850,000	5,850,000	5,850,000	NA	5,000,000	5,000,000	3,300,000[b]
16 oc	4,500,000	4,500,000	4,500,000	4,500,000	4,200,000	4,200,000	4,200,000	2,700,000
20 oc	5,000,000	5,000,000	5,000,000	5,000,000	4,500,000	4,500,000	4,500,000	2,900,000[b]
24 oc	NA	5,850,000	5,850,000	5,850,000	NA	5,000,000	5,000,000	3,300,000[b]
32 oc	NA	NA	7,500,000	7,500,000	NA	NA	7,300,000	4,200,000
48 oc	NA	NA	8,200,000	8,200,000	NA	NA	7,300,000	4,600,000

Box Beams

15/32" 32/16 rated panel, 4-ply $F_v t_v$ lbs/in width (APA D510)

$F_v t_v$ = 81 lbs/in

TABLE 8 (Continued)

RATED PANELS DESIGN CAPACITIES

Span Rating	Stress Parallel to Strength Axis				Stress Perpendicular to Strength Axis			
	Plywood				Plywood			
	3-ply	4-ply	5-ply	OSB	3-ply	4-ply	5-ply	OSB
PANEL SHEAR THROUGH THE THICKNESS, $F_v t_v$ (lbf/in. of shear-resisting panel length)								
24/0	53	69	80	155	53	69	80	155
24/16	57	74	86	165	57	74	86	165
32/16	62	81	93	180	62	81	93	180
40/20	68	88	100	195	68	88	100	195
48/24	NA	98	115	220	NA	98	115	220
16 oc	58	75	87	170	58	75	87	170
20 oc	67	87	100	195	67	87	100	195
24 oc	NA	96	110	215	NA	96	110	215
32 oc	NA	NA	120	230	NA	NA	120	230
48 oc	NA	NA	160	305	NA	NA	160	305

Box Beams

equations from APA-H815:

Section Properties:

Moment of Inertia, I
$I_f = 3.5\ (24^3 - (24 - 6)^3\ /12$
$I_f = 2331\ in^4$

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

$I_w = 2(0.2034\ \ 24^3)\ /\ 12$
$I_w = 468.6\ in^4$

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

$I_{total} = 2331 + 468.6 = 2800\ in^4$

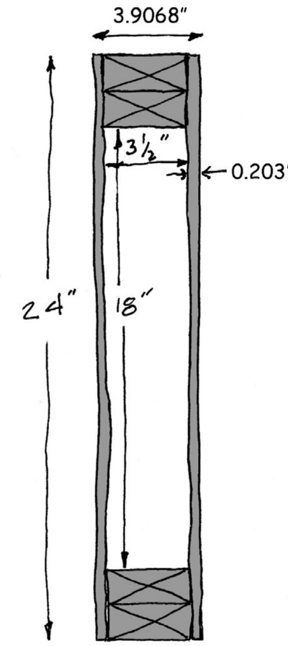
Statical Moment of Area, Q
$Q_f = 3.5\ \ 3\ (24 - 3)\ /\ 2$
$Q_f = 110.25\ in^3$

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

$Q_w = 2\ (0.2034\ 24^2)\ /\ 8$
$Q_w = 29.29\ in^3$

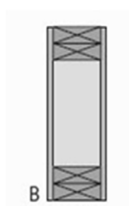
$$Q_{w\,(web)} = \Sigma t_{bw} \frac{h_w}{2} \frac{h_w}{4} = \frac{\Sigma t_{bw}\, h_w^{\,2}}{8}$$

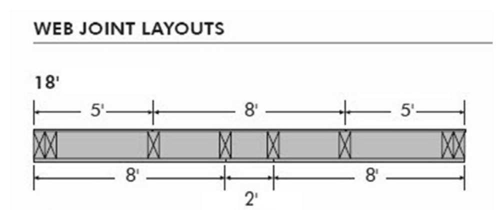
$Q_{total} = 110.25 + 29.29 = 139.5\ in^3$



Transformed Section

Box Beams





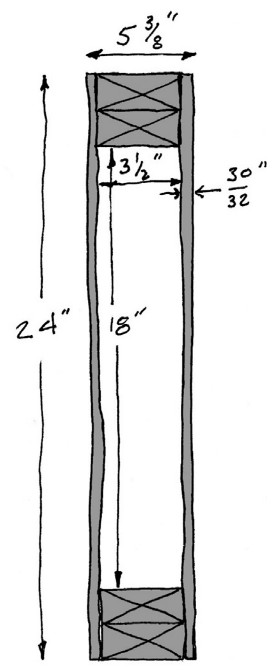
Section Capacities:

Max. Moment
$F = Mc/I$
$M = F_t\ I_f\ /\ (h/2)\ (12)$
$M = 1012.5\ lb/in^2\ (2331\ in^4)\ /\ ((24\ in\ /\ 2)\ (12\ in/ft))$
$M = 16390$ ft-lb

Max Web Shear
$F_v = V_h Q/Ib$
$V_h = (F_v t_v)\ I_t\ (N_{webs})\ /\ Q_t$
$V_h = (81\ lb/in)\ 2800\ in^4\ (2)\ /\ 139.5\ in^3$
$V_h = 3252$ lbs

Max Nail Shear
$V_n = Fn\ I_t\ (N_{webs})\ (Rows)\ /\ (spacing\ Q_f)$
$V_n = 74\ lb/nail\ \ 2800\ in^4\ \ 2\ \ 2\ /\ (1.5\ in/nail\ 110.25\ in^3)$
$V_n = 5011$ lbs

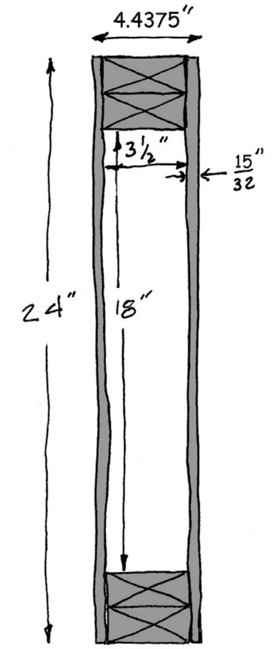
Stiffness
$EI = E\ I_t = 1700000\ 2800 = 4{,}760{,}000{,}000.$



Box Beams

Allowable Uniform Load (D+S)

Bending
$M = w_b L^2/8$
$w_b = M\ (C_D)\ 8\ /\ L^2$
$w_b = 16390\text{ ft-lb}\ (1.15)\ 8\ /\ (18\text{ ft})^2 = 465\text{ plf}$



Web Shear
$V_h = w_v\ L\ /\ 2$
$w_v = V_h\ (C_D)\ 2\ /\ L$
$w_v = 3252\text{ lbs}\ (1.15)\ 2\ /\ 18\text{ ft} = 415\text{ plf}$

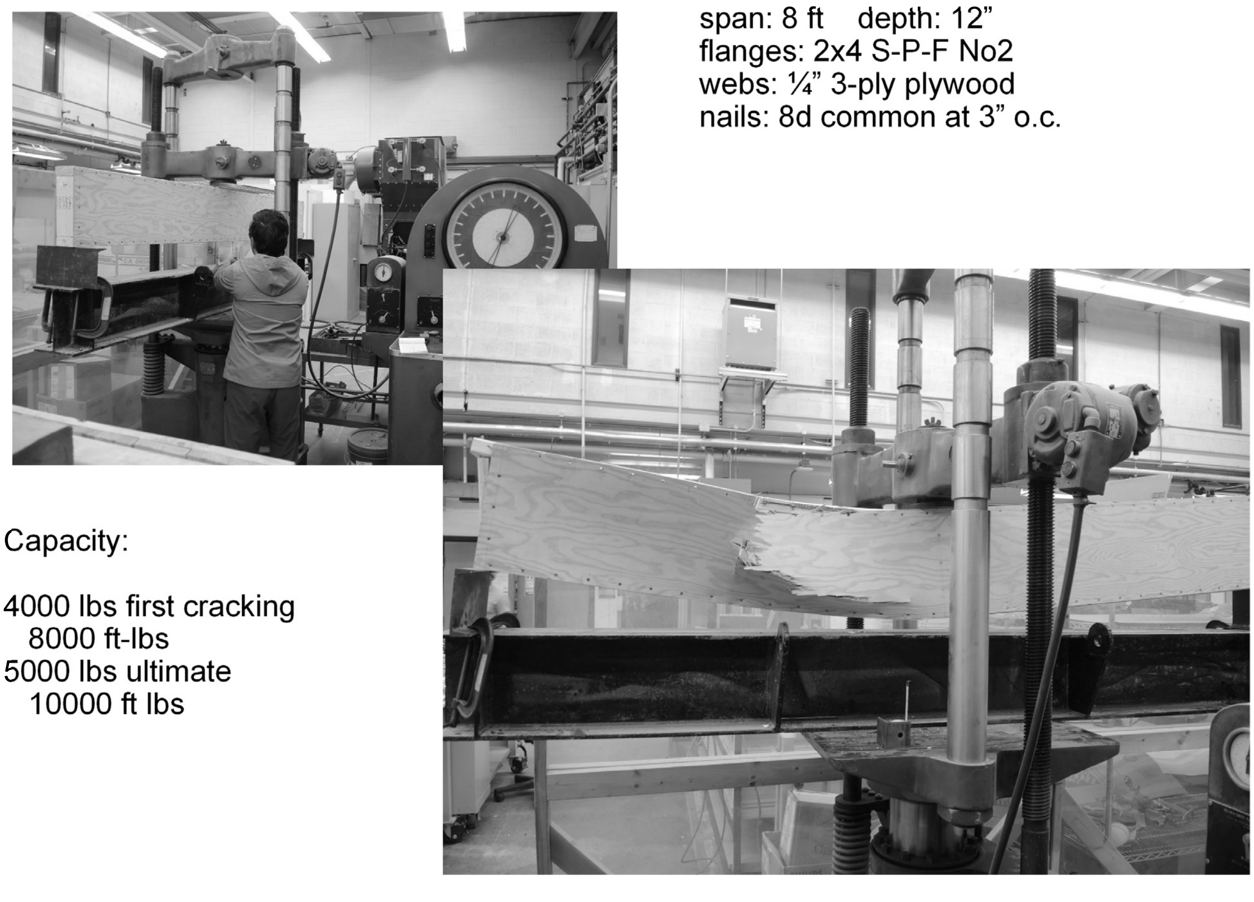
Nail Shear
$V_n = w_n\ L\ /\ 2$
$w_n = V_n\ (C_D)\ 2\ /\ L$
$w_n = 5011\text{ lbs}\ (1.15)\ 2\ /\ 18\text{ ft} = 640\text{ plf}$

Deflection
$\Delta = 5\ K\ w\ L^4\ /\ (384\ EI)$
$\Delta = 5\ (1.5)\ (415)\ (18)^4\ (1728)\ /\ (384\ 4{,}760{,}000{,}000) = 0.31$ "
$L/360 = 18(12)/360 = 0.6$"

K factor for deflection in composite panel section (from APA testing)
for L < 14 ft K = 2.0, else K = 1.5

Box Beams

span: 8 ft depth: 12"
flanges: 2x4 S-P-F No2
webs: ¼" 3-ply plywood
nails: 8d common at 3" o.c.



Capacity:

4000 lbs first cracking
8000 ft-lbs
5000 lbs ultimate
10000 ft lbs

Box Beams

Initial failure: web shear
further failure: nail pull out and head pull through
ultimate failure: tension flange