FOREST RESTORATION BY DESIGN:

Utilizing Low-Value Species Harvested from Forest Restoration Projects in Local CLT Manufacture and Design

APPENDIX

Payton Narancic
M.S. Mass Timber Design Focus
University of Oregon
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APPENDIX

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By
Payton Narancic

Graduate Committee Members: Mark Fretz,
Mariapaola Riggio, and Judith Sheine (Chair)

Outline:

- CLTs are used extensively in construction.
- Properties are determined based on species, grade and layup of longitudinal and transverse layers
- Well established species and grades are typically utilized (SPF, Douglas Fir-Larch, Southern Pine)
- We want to develop confidence in Ponderosa Pine CLT products so that engineers can specifying them for structures
- For design, engineers need reference design values for CLT lamina (F_b, F_t, F_v, F_c, E, E_{min})
- Reference design values are then used to find section properties of the CLT (M_n, V_n, EI, etc) using the shear analogy method.

- To accomplish goals:
    - Determine reference design values for Ponderosa Pine (F_b, F_t, F_v, F_c, E, E_{min}),
        - Clear, straight grain properties from the Wood Handbook (2010)
        - Allowable imperfections and corresponding properties from ASTM D245
    - Develop section and strength (simplified method) analysis tools using the shear analogy method following the CLT Handbook (2013),
    - Determine loading and specifications for a panel subject to a pre-defined environment (i.e., interior, residential floor system, 10 foot span) following IBC 2018/ASTM 7-16,
    - Design a representative panel to meet specifications and relevant code requirements following the CLT Handbook (2013), NDS for Wood Construction (2016), and
    - Perform mechanical property qualification testing (flatwise bending and flatwise shear) on samples extracted from representative panels ASTM D198

TABLE A1

ASD REFERENCE DESIGN VALUES[a,b,c] FOR LAMINATIONS (FOR USE IN THE U.S.)

	Laminations Used in Major Strength Direction						Laminations Used in Minor Strength Direction					
CLT Layup	F_b (psi)	E^d (10^6 psi)	F_t (psi)	F_c (psi)	F_v (psi)	F_s (psi)	F_b (psi)	E^d (10^6 psi)	F_t (psi)	F_c (psi)	F_v (psi)	F_s (psi)
E1	1,950	1.7	1,375	1,800	135	45	500	1.2	250	650	135	45
E2	1,650	1.5	1,020	1,700	180	60	525	1.4	325	775	180	60
E3	1,200	1.2	600	1,400	110	35	350	0.9	150	475	110	35
E4	1,950	1.7	1,375	1,800	175	55	450	1.3	250	725	175	55
V1	900	1.6	575	1,350	180	60	525	1.4	325	775	180	60
V2	875	1.4	450	1,150	135	45	500	1.2	250	650	135	45
V3	750	1.4	450	1,250	175	55	450	1.3	250	725	175	55

For SI: 1 psi = 0.006895 MPa

a. See Section 4 for symbols.

b. Tabulated values are ASD reference design values and not permitted to be increased for the lumber size and flat use adjustment factors in accordance with the NDS. The design values shall be used in conjunction with the section properties provided by the CLT manufacturer based on the actual layup used in manufacturing the CLT panel (see Table A2).

c. Custom CLT layups that are not listed in this table shall be permitted in accordance with 7.2.1.

d. The tabulated E values are published E for lumber. For calculating the CLT design properties shown in Table A2, the transverse E of the lamination is assumed to be E/30, the longitudinal G of the lamination is assumed to be E/16, and the transverse G of the lamination is assumed to be longitudinal G/10.

TABLE A2

ASD REFERENCE DESIGN VALUES[a,b,c] FOR CLT (FOR USE IN THE U.S.)

		Lamination Thickness (in.) in CLT Layup							Major Strength Direction				Minor Strength Direction			
CLT Layup	CLT t_p (in.)	=	⊥	=	⊥	=	⊥	=	$(F_bS)_{eff,f,0}$ (lbf-ft/ft of width)	$(EI)_{eff,f,0}$ (10^6 lbf-in.^{2}/ft of width)	$(GA)_{eff,f,0}$ (10^6 lbf/ft of width)	$V_{s,0}$ (lbf/ft of width)	$(F_bS)_{eff,f,90}$ (lbf-ft/ft of width)	$(EI)_{eff,f,90}$ (10^6 lbf-in.^{2}/ft of width)	$(GA)_{eff,f,90}$ (10^6 lbf/ft of width)	$V_{s,90}$ (lbf/ft of width)
E1	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.46	1,430	160	3.1	0.61	495
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			10,400	440	0.92	1,970	1,370	81	1.2	1,430
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	18,375	1,089	1.4	2,490	3,125	309	1.8	1,960
E2	4 1/8	1 3/8	1 3/8	1 3/8					3,825	102	0.53	1,910	165	3.6	0.56	660
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			8,825	389	1.1	2,625	1,430	95	1.1	1,910
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	15,600	963	1.6	3,325	3,275	360	1.7	2,625
E3	4 1/8	1 3/8	1 3/8	1 3/8					2,800	81	0.35	1,110	110	2.3	0.44	385
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			6,400	311	0.69	1,530	955	61	0.87	1,110
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	11,325	769	1.0	1,940	2,180	232	1.3	1,520
E4	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.50	1,750	140	3.4	0.62	605
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			10,400	440	1.0	2,410	1,230	88	1.2	1,750
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	18,400	1,089	1.5	3,050	2,800	335	1.9	2,400
V1	4 1/8	1 3/8	1 3/8	1 3/8					2,090	108	0.53	1,910	165	3.6	0.59	660
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,800	415	1.1	2,625	1,430	95	1.2	1,910
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	8,500	1,027	1.6	3,325	3,275	360	1.8	2,625
V2	4 1/8	1 3/8	1 3/8	1 3/8					2,030	95	0.46	1,430	160	3.1	0.52	495
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,675	363	0.91	1,970	1,370	81	1.0	1,430
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	8,275	898	1.4	2,490	3,125	309	1.6	1,960
V3	4 1/8	1 3/8	1 3/8	1 3/8					1,740	95	0.49	1,750	140	3.4	0.52	605
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,000	363	0.98	2,420	1,230	88	1.0	1,750
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	7,100	899	1.5	3,050	2,800	335	1.6	2,400

For SI: 1 in. = 25.4 mm; 1 ft = 304.8 mm; 1 lbf = 4.448 N

a. See Section 4 for symbols.

b. This table represents one of many possibilities that the CLT could be manufactured by varying lamination grades, thicknesses, orientations, and layer arrangements in the layup.

c. Custom CLT layups that are not listed in this table shall be permitted in accordance with 7.2.1.

Clear, straight grain properties from the Wood Handbook (2010)

Table 5–3b. Strength properties of some commercially import

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (lbf in^{-2})	Static bending: Modulus of elasticity[c] ($\times 10^6$ lbf in^{-2})
Pine—con.				
Pond	Green	0.51	7,400	1.28
	12%	0.56	11,600	1.75
Ponderosa	Green	0.38	5,100	1.00
	12%	0.40	9,400	1.29
Red	Green	0.41	5,800	1.28
	12%	0.46	11,000	1.63
Sand	Green	0.46	7,500	1.02
	12%	0.48	11,600	1.41

[a]Results of tests on clear specimens in the green and air-dried conditions. Definitio
using 0.71-kg (50-lb) hammer; compression parallel to grain is also called maximu
proportional limit; shear is maximum shearing strength; tension is maximum tensil
to grain.
[b]Specific gravity is based on weight when ovendry and volume when green or at 1
[c]Modulus of elasticity measured from a simply supported, center-loaded beam, on
increased by 10%.
[d]Values for side hardness of the true hickories are from Bendtsen and Ethington (1
[e]Coast Douglas-fir is defined as Douglas-fir growing in Oregon and Washington St
and all counties in Oregon and Washington east of, but adjacent to, the Cascade su
Montana, and Wyoming; and Interior South, Utah, Colorado, Arizona, and New M

ant woods grown in the United States (inch–pound)[a]—con.

Work to maximum load (in-lbf in^{-3})	Impact bending (in.)	Compression parallel to grain (lbf in^{-2})	Compression perpendicular to grain (lbf in^{-2})	Shear parallel to grain (lbf in^{-2})	Tension perpendicular to grain (lbf in^{-2})	Side hardness (lbf)
7.5	—	3,660	440	940	—	—
8.6	—	7,540	910	1,380	—	—
5.2	21	2,450	280	700	310	320
7.1	19	5,320	580	1,130	420	460
6.1	26	2,730	260	690	300	340
9.9	26	6,070	600	1,210	460	560
9.6	—	3,440	450	1,140	—	—
9.6	—	6,920	836	—	—	—

n of properties: impact bending is height of drop that causes complete failure,
m crushing strength; compression perpendicular to grain is fiber stress at
e strength; and side hardness is hardness measured when load is perpendicular

% moisture content.
a span depth ratio of 14/1. To correct for shear deflection, the modulus can be

975).
ate west of the Cascade Mountains summit. Interior West includes California
mmit; Interior North, the remainder of Oregon and Washington plus Idaho,
exico.

Based on ASTM D 143 tests

Clear, straight grain properties from the Wood Handbook (2010)

Table 5–7. Average parallel-to-grain tensile strength of some wood species[a]

Species	Tensile strength (kPa (lb in^{-2}))	
Hardwoods		
Beech, American	86,200	(12,500)
Elm, cedar	120,700	(17,500)
Maple, sugar	108,200	(15,700)
Oak		
Overcup	77,900	(11,300)
Pin	112,400	(16,300)
Poplar, balsam	51,000	(7,400)
Sweetgum	93,800	(13,600)
Willow, black	73,100	(10,600)
Yellow-poplar	109,600	(15,900)
Softwoods		
Baldcypress	58,600	(8,500)
Cedar		
Port-Orford	78,600	(11,400)
Western redcedar	45,500	(6,600)
Douglas-fir, interior north	107,600	(15,600)
Fir		
California red	77,900	(11,300)
Pacific silver	95,100	(13,800)
Hemlock, western	89,600	(13,000)
Larch, western	111,700	(16,200)
Pine		
Eastern white	73,100	(10,600)
Loblolly	80,000	(11,600)
Ponderosa	57,900	(8,400)
Virginia	94,500	(13,700)
Redwood		
Virgin	64,800	(9,400)
Young growth	62,700	(9,100)
Spruce		
Engelmann	84,800	(12,300)
Sitka	59,300	(8,600)

[a]Results of tests on clear, straight-grained specimens tested green. For hardwood species, strength of specimens tested at 12% moisture content averages about 32% higher; for softwoods, about 13% higher.

Clear, straight grain properties from the Wood Handbook (2010)

Table 5–1. Elastic ratios for various species at approximately 12% moisture content[a]

Species	E_T/E_L	E_R/E_L	G_{LR}/E_L	G_{LT}/E_L	G_{RT}/E_L
Hardwoods					
Ash, white	0.080	0.125	0.109	0.077	—
Balsa	0.015	0.046	0.054	0.037	0.005
Basswood	0.027	0.066	0.056	0.046	—
Birch, yellow	0.050	0.078	0.074	0.068	0.017
Cherry, black	0.086	0.197	0.147	0.097	—
Cottonwood, eastern	0.047	0.083	0.076	0.052	—
Mahogany, African	0.050	0.111	0.088	0.059	0.021
Mahogany, Honduras	0.064	0.107	0.066	0.086	0.028
Maple, sugar	0.065	0.132	0.111	0.063	—
Maple, red	0.067	0.140	0.133	0.074	—
Oak, red	0.082	0.154	0.089	0.081	—
Oak, white	0.072	0.163	0.086	—	—
Sweetgum	0.050	0.115	0.089	0.061	0.021
Walnut, black	0.056	0.106	0.085	0.062	0.021
Yellow-poplar	0.043	0.092	0.075	0.069	0.011
Softwoods					
Baldcypress	0.039	0.084	0.063	0.054	0.007
Cedar, northern white	0.081	0.183	0.210	0.187	0.015
Cedar, western red	0.055	0.081	0.087	0.086	0.005
Douglas-fir	0.050	0.068	0.064	0.078	0.007
Fir, subalpine	0.039	0.102	0.070	0.058	0.006
Hemlock, western	0.031	0.058	0.038	0.032	0.003
Larch, western	0.065	0.079	0.063	0.069	0.007
Pine					
Loblolly	0.078	0.113	0.082	0.081	0.013
Lodgepole	0.068	0.102	0.049	0.046	0.005
Longleaf	0.055	0.102	0.071	0.060	0.012
Pond	0.041	0.071	0.050	0.045	0.009
Ponderosa	0.083	0.122	0.138	0.115	0.017
Red	0.044	0.088	0.096	0.081	0.011
Slash	0.045	0.074	0.055	0.053	0.010
Sugar	0.087	0.131	0.124	0.113	0.019
Western white	0.038	0.078	0.052	0.048	0.005
Redwood	0.089	0.087	0.066	0.077	0.011
Spruce, Sitka	0.043	0.078	0.064	0.061	0.003
Spruce, Engelmann	0.059	0.128	0.124	0.120	0.010

[a] E_L may be approximated by increasing modulus of elasticity values in Table 5–3 by 10%.

Table 5–2. Poisson's ratios for various species at approximately 12% moisture content

Species	μ_{LR}	μ_{LT}	μ_{RT}	μ_{TR}	μ_{RL}	μ_{TL}
Hardwoods						
Ash, white	0.371	0.440	0.684	0.360	0.059	0.051
Aspen, quaking	0.489	0.374	—	0.496	0.054	0.022
Balsa	0.229	0.488	0.665	0.231	0.018	0.009
Basswood	0.364	0.406	0.912	0.346	0.034	0.022
Birch, yellow	0.426	0.451	0.697	0.426	0.043	0.024
Cherry, black	0.392	0.428	0.695	0.282	0.086	0.048
Cottonwood, eastern	0.344	0.420	0.875	0.292	0.043	0.018
Mahogany, African	0.297	0.641	0.604	0.264	0.033	0.032
Mahogany, Honduras	0.314	0.533	0.600	0.326	0.033	0.034
Maple, sugar	0.424	0.476	0.774	0.349	0.065	0.037
Maple, red	0.434	0.509	0.762	0.354	0.063	0.044
Oak, red	0.350	0.448	0.560	0.292	0.064	0.033
Oak, white	0.369	0.428	0.618	0.300	0.074	0.036
Sweetgum	0.325	0.403	0.682	0.309	0.044	0.023
Walnut, black	0.495	0.632	0.718	0.367	0.052	0.036
Yellow-poplar	0.318	0.392	0.703	0.329	0.030	0.019
Softwoods						
Baldcypress	0.338	0.326	0.411	0.356	—	—
Cedar, northern white	0.337	0.340	0.458	0.345	—	—
Cedar, western red	0.378	0.296	0.484	0.403	—	—
Douglas-fir	0.292	0.449	0.390	0.374	0.036	0.029
Fir, subalpine	0.341	0.332	0.437	0.336	—	—
Hemlock, western	0.485	0.423	0.442	0.382	—	—
Larch, western	0.355	0.276	0.389	0.352	—	—
Pine						
Loblolly	0.328	0.292	0.382	0.362	—	—
Lodgepole	0.316	0.347	0.469	0.381	—	—
Longleaf	0.332	0.365	0.384	0.342	—	—
Pond	0.280	0.364	0.389	0.320	—	—
Ponderosa	0.337	0.400	0.426	0.359	—	—
Red	0.347	0.315	0.408	0.308	—	—
Slash	0.392	0.444	0.447	0.387	—	—
Sugar	0.356	0.349	0.428	0.358	—	—
Western white	0.329	0.344	0.410	0.334	—	—
Redwood	0.360	0.346	0.373	0.400	—	—
Spruce, Sitka	0.372	0.467	0.435	0.245	0.040	0.025
Spruce, Engelmann	0.422	0.462	0.530	0.255	0.083	0.058

Clear, straight grain properties from the Wood Handbook (2010)

**Table 5–6. Average coefficients of variatio
mechanical properties of clear wood**

Property
Static bending
Modulus of rupture
Modulus of elasticity
Work to maximum load
Impact bending
Compression parallel to grain
Compression perpendicular to grain
Shear parallel to grain, maximum shearing strengt
Tension parallel to grain
Side hardness
Toughness
Specific gravity

[a]Values based on results of tests of green wood from app
50 species. Values for wood adjusted to 12% moisture c
assumed to be approximately of the same magnitude.

n for some

	Coefficient of variation[a] (%)
	16
	22
	34
	25
	18
	28
h	14
	25
	20
	34
	10

proximately
ontent may be

Allowable imperfections and corresponding properties from ASTM D245

		Limiting characteristic
Bending		
	Narrow face knot	0.6 inch
	Knot on centerline of wide face	1.75 inches
	Knot at edge of wide face	1 inch
	Slope of grain	1 in 10
Compression parallel to grain		
	Knot on any face	1.75 inches
	Slope of grain	1 in 8
Shear		
	Size of shake or check	
	Length of end split	

"4.2.5 Strength ratios in tension parallel to grain are 55% of the

	Clear Wood Strength Value (psi)	ASD Factors
Bending	5100	2.1
Compression parallel to grain	2450	1.9
Horizontal shear	700	2.1
Tension parallel to grain	8400	2.1
Modulus of elasticity	1000000	--
Modulus of elasticity (minimum)	1000000	0.94
Compression perpendicular to grain	280	1.67

Strength ratio	Table
60	
60	2
61	3
61	4
61	1
60	
61	3
66	1
50	

TABLE 1 Strength Ratios Corresponding to Various Slopes of Grain

Slope of Grain	Maximum Strength Ratio, %	
	Bending or Tension Parallel to Grain	Compression Parallel to Grain
1 in 6	40	56
1 in 8	53	66
1 in 10	61	74
1 in 12	69	82
1 in 14	74	87
1 in 15	76	100
1 in 16	80	...
1 in 18	85	...
1 in 20	100	...

e corresponding bending strength ratios."

COV (%)	sDEV (psi)	5% Exclusion Value (psi)	Seasoning	Strength Ration (%)	Design values (psi)
16	816	1789	1.25	60	1342
18	441	908	1.50	60	817
14	98	257	1.08	50	139
25	2100	2355	1.25	30	883
--	--	--	1.14	100	1140000
22	220000	678830	1.14	100	773866
28	78	90	1.50	100	136
	Rolling shear assumed 18% of horizontal shear				25

DEFLECTION

$$EI_{eff} = \sum_{i=1}^{n} E_i \cdot b_i \cdot \frac{h_i^3}{12} + \ldots$$

$$GA_{eff} = \frac{\ldots}{\left[\left(\frac{h_1}{2 \cdot G_1 \cdot b}\right) + \left(\ldots\right.\right.}$$

Deflection for a sim

$$\Delta_{max} = \frac{5}{384} \cdot \frac{wL^4}{EI_{eff}} + \frac{1}{8}\ldots$$

where:

EI_{eff} = Effective bending st

GA_{eff} = Effective shear stiffn

$$\sum_{i=1}^{n} E_i \cdot A_i \cdot z_i^2$$

$$\frac{a^2}{\left(\sum_{i=2}^{n-1} \frac{h_i}{G_i \cdot b_i}\right) + \left(\frac{h_n}{2 \cdot G_n \cdot b}\right)\Big]}$$

ply supported beam subjected to a uniform load

$$\cdot \frac{wL^2 k}{GA_{eff}}$$

tiffness of composite section

ness of composite section

BENDING

$$S_{eff} = \frac{2EI_{eff}}{E_1 h}$$

where:

EI_{eff} = Effective bending stiffness
E_1 = Modulus of elasticity of outermost layer
h = Entire thickness of panel

$$M_b \leq F_b' S_{eff}$$

where:

M_b = Applied bending moment due to loads
$F_b' S_{eff}$ = Design bending strength of the panel provided
standard PRG 320 and then multiplied by the a

CLT Handbook

by the manufacturer, calculated, or listed in the product
pplicable adjustment factors.

SHEAR

$$(Ib/Q)_{eff} = \frac{EI_{eff}}{\sum_{i=1}^{n/2} E_i h_i z_i}$$

where:

EI_{eff} = Effective bending stiffness
E_i = Modulus of elasticity of an individual layer
h_i = Thickness of an individual layer, except the midd
z_i = Distance from the centroid of the layer to the ne
where it is to the centroid of the top half of that

$$V_{planar} \leq F_v'(Ib/Q)_{eff}$$

where:

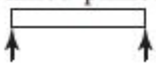
V_{planar} = induced shear due to loads
$F_v'\ (Ib/Q)_{eff}$ = shear strength of the panel provided by t
multiplied by the applicable adjustment

dle layer, which is half its thickness
eutral axis, except for the middle layer,
layer.

the manufacture or calculated per the simplified method
factors.

Rao (2011) Mechanical Vibrations

End Conditions of Beam
Pinned-pinned



$$\omega = \beta^2 \sqrt{\frac{EI}{\rho A}} = (\beta l)^2$$

https://vtechworks.lib.vt.edu/bitstream/handle/10919/28879/Chapter_1.pdf

The 0.5%g acceleration limit within a
represents the frequency range that may be excite
where a harmonic is defined as an integer multipl
human footfalls average about 2 steps per secon
If each downward step is seen as an input force, t
of the 2.4 Hz input force are 4.8 Hz and 7.2
frequency at or near one of these harmonics may
force component of the harmonic may coinci
(Bachmann 1995).

Value of $\beta_n l$
$\beta_1 l = \pi$
$\beta_2 l = 2\pi$
$\beta_3 l = 3\pi$
$\beta_4 l = 4\pi$

$$\sqrt{\frac{EI}{\rho A l^4}}$$

$$EI_{app} = \frac{EI_{eff}}{1 + \dfrac{K_s EI_{eff}}{GA_{eff} L^2}}$$

Loading	End Fixity	K_s
Uniformly distributed	Pinned	11.5
	Fixed	57.6
Concentrated at midspan	Pinned	14.4
	Fixed	57.6
Concentrated at quarter points	Pinned	10.5
Constant moment	Pinned	11.8
Uniformly distributed	Cantilevered	4.8
Concentrated at free-end	Cantilevered	3.6

range of 4 to 8 Hz is highlighted because it ed with the second or third harmonic of walking, le of the step frequency. Under normal walking, d, but can get up to about 2.4 steps per second. then for instance, the second and third harmonic Hz, respectively. Floors that have a natural exhibit an excessive response because the input ide with the resonant frequency of the floor

10 foot clear span
(3) 1 inch layers
Assume 25 lb/ft^3 panel density
40 lb/ft^3 live load

```
%% INPUT
% Laminate design
ti = [1 % Thickness of layers (in)
    1
    1];

n = size(ti,1); % Number of layers

% Elastic moduli of layers (psi)
Ei = [1.14e6
    1.14e6*.083 % From Wood Handbook Table 5.1 (CLT Handbook uses different numbe
    1.14e6];

% Shear moduli of layers (psi)
Gi = [1.14e6*.115 % From Wood Handbook Table 5.1
    1.14e6*.017
    1.14e6*.115];

Li = 40; % Live load (psf)
De = 25*sum(ti)/12; % Dead load (psf)

p_str = De + Li; % Strength design pressure load (psf)
p_ser = Li; % Service design pressure load (psf)
L = 10*12; % Length (in)
b = 12; % Width of panel (in)

F_b = 1342; % Bending strength (psi)
F_b = F_b*.85; % .85 factor recomended by PRG 320 'for conservatism'

F_v = 25; % Rolling shear strength (psi)

F_cp = 136; % Bearing strength (psi)

bw = 3.5; % Bearing width (in)
```

rs based on PRG 320)

```
Moment:     578.125 ft*lbs < 1652.94 ft*lbs ---> OK
Shear:      231.25 lbs < 626.092 lbs ---> OK
Bearing:    231.25 lbs < 5712 lbs ---> OK
Deflection (LL):    0.207905 in < L/360 = 0.333333 in ---> OK
Deflection (DL + LL):   0.24039 in < L/240 = 0.5 in ---> OK
Fundamental bending frequency:  15.9693 Hz
```