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STRUCTURAL CALCULATIONS

FOR

Hemp-Lime IRC Proposal

January 26, 2022

WIND LOAD OOP CHECK
Main Wind Load Resisting System:
ASCE 7-16, Chapter 26 & 27

Input Parameters

Basic Wind Speed, V	110	mph	CA wind speed, Figure 26.5-1
Exposure Catergory	B		Section 26.7.3
Gust Effect Factor, G	0.85		Section 26.11.1
Enclosure Classification	Enclosed		Section 26.12 & 26.2
Topographic Factor, K_{zt}	1.0		Section 26.8.2
Directionality Factor, K_d	0.85		Table 26.6-1
Ground Elevation Factor, K_e	1.00		Table 26.9-1
Length Para to Wind, L	25	ft	
Width Perp to Wind, W	25	ft	
Mean Roof Height, h	15	ft	
Roof Angle, θ	30	degrees	
Velocity Pressure Exposure Co, K_z	0.57		Table 26.10-1

Velocity Pressure

$q = 0.00256 * K_z * K_{zt} * K_d * K_e * V^2 =$ 15.01 PSF   Equation 26.10-1

Internal Pressure Coefficients, GC_{pi}   Table 26.13-1

$GC_{pi} =$ 0.18

External Pressure Coefficients, C_p   Figure 27.3-1

Walls		Roof	
$C_{pww} =$	0.8	$C_{pwr} =$	0.2
$C_{plw} =$	0.2	$C_{plr} =$	0.6
$C_{psw} =$	0.7		

Wind Loads

Walls		Roof	
$p_{ww} =$	10.21 PSF	$p_{wr} =$	2.55 PSF
$p_{lw} =$	2.55 PSF	$p_{lr} =$	7.65 PSF
$p_{sw} =$	8.93 PSF		

Total			
$W_{walls} =$	**15.46 PSF**	$W_{roof} =$	**12.91 PSF**
$W_{walls} =$	**9.27 PSF (ASD)**	$W_{roof} =$	**7.74 PSF (ASD)**

Use   **16 PSF**   **(LRFD) Minimum Design Wind Load per ASCE 27.1.5**

SEISMIC LOAD OOP CHECK

Hempcrete Density

ρ =	32	pcf		ρ =	16	pcf	Lightweight
					22	pcf	Medium
					32	pcf	Heavy

3.5" =	9	PSF
5.5" =	15	PSF
12" =	32	PSF

Exterior Wall Weight

Veneer	23.0	PSF
2x6s @16"	1.4	PSF
1" Clay	9.2	PSF
1" Clay	9.2	PSF
12" Hemp Lime	22.0	PSF
Misc	0.3	PSF
DL=	**65.0**	**PSF**

OOP Seismic Force in SDC C

$F_p = 0.4S_{DS}I_eW$ (ASCE 7-16 12.11.1) S_{DS} = 0.5 (Max for SDC C)

= 0.2 W I_e = 1

= 13.007 PSF   <   15.46 PSF   (From wind)

= 4.3442 W   SDC A

= 8.5844 W   SDC B

Wind load governs OOP design

Check 2x4 studs @ 16" OC with 10ft max height,

Check 1x2 horizontal rails to hold hemp-lime infill in place. Rails span between studs and are spaced 2ft OC vertically

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Wood Column

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DESCRIPTION: OOP 2X4 STUD

Code References

Calculations per NDS 2018, IBC 2018, CBC 2019, ASCE 7-16
Load Combinations Used : ASCE 7-16

General Information

Analysis Method :	Allowable Stress Design	Wood Section Name	**2x4**
End Fixities	Top & Bottom Pinned	Wood Grading/Manuf.	Graded Lumber
Overall Column Height	10 ft	Wood Member Type	Sawn

(Used for non-slender calculations)

				Exact Width	**1.50** in	Allow Stress Modification Factors	
Wood Species	Douglas Fir-Larch			Exact Depth	**3.50** in	Cf or Cv for Bending	1.50
Wood Grade	No.2			Area	5.250 in^2	Cf or Cv for Compression	1.150
F_b +	900.0 psi	Fv	180.0 psi	Ix	5.359 in^4	Cf or Cv for Tension	1.50
F_b -	900.0 psi	Ft	575.0 psi	Iy	0.9844 in^4	Cm : Wet Use Factor	1.0
Fc - Prll	1,350.0 psi	Density	31.210 pcf			Ct : Temperature Factor	1.0
Fc - Perp	625.0 psi					Cfu : Flat Use Factor	1.0

E : Modulus of Elasticity . . .	x-x Bending	y-y Bending	Axial		Kf : Built-up columns	1.0 *NDS 15.3.2*
Basic	1,600.0	1,600.0	1,600.0 ksi		Use Cr : Repetitive ?	No
Minimum	580.0	580.0				

Brace condition for deflection (buckling) along columns :
X-X (width) axis : Fully braced against buckling ABOUT Y-Y Axis
Y-Y (depth) axis : Unbraced Length for buckling ABOUT X-X Axis = 10 ft, K = 1.0

Applied Loads

Service loads entered. Load Factors will be applied for calculations.

Column self weight included : 11.379 lbs * Dead Load Factor
BENDING LOADS . . .
    Wind: Lat. Uniform Load creating Mx-x, W = 0.0320 k/ft

DESIGN SUMMARY

Bending & Shear Check Results

PASS Max. Axial+Bending Stress Ratio = **0.4377** : 1
    Load Combination +D+0.60W+H
    Governing NDS Forumla 1Comp + Mxx, NDS Eq. 3.9-3
    Location of max.above base 5.034 ft
    At maximum location values are . . .
        Applied Axial 0.01138 k
        Applied Mx 0.240 k-ft
        Applied My 0.0 k-ft
        Fc : Allowable 390.971 psi

PASS Maximum Shear Stress Ratio = **0.09524** : 1
    Load Combination +D+0.60W+H
    Location of max.above base 10.0 ft
    Applied Design Shear 27.429 psi
    Allowable Shear 288.0 psi

Maximum SERVICE Lateral Load Reactions . .
Top along Y-Y	0.160 k	Bottom along Y-Y	0.160 k
Top along X-X	0.0 k	Bottom along X-X	0.0 k

Maximum SERVICE Load Lateral Deflections . . .
Along Y-Y 0.8488 in at 5.034 ft above base
    for load combination : W Only
Along X-X 0.0 in at 0.0 ft above base
    for load combination : n/a

Other Factors used to calculate allowable stresses . . .
	Bending	Compression	Tension

Maximum Reactions

Note: Only non-zero reactions are listed.

Load Combination	X-X Axis Reaction @ Base	@ Top k	Y-Y Axis Reaction @ Base	@ Top	Axial Reaction @ Base	My - End Moments @ Base	@ Top k-ft	Mx - End Moments @ Base	@ Top
+D+H					0.011				
+D+L+H					0.011				
+D+Lr+H					0.011				
+D+S+H					0.011				
+D+0.750Lr+0.750L+H					0.011				
+D+0.750L+0.750S+H					0.011				
+D+0.60W+H			0.096	0.096	0.011				
+D+0.750Lr+0.750L+0.450W+H			0.072	0.072	0.011				
+D+0.750L+0.750S+0.450W+H			0.072	0.072	0.011				
+0.60D+0.60W+0.60H			0.096	0.096	0.007				
+D+0.70E+0.60H					0.011				

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Wood Column

DESCRIPTION: OOP 2X4 STUD

Maximum Reactions

Note: Only non-zero reactions are listed.

Load Combination	X-X Axis Reaction @ Base	@ Top	k	Y-Y Axis Reaction @ Base	@ Top	Axial Reaction @ Base	My - End Moments @ Base	@ Top	k-ft	Mx - End Moments @ Base	@ Top
+D+0.750L+0.750S+0.5250E+H						0.011					
+0.60D+0.70E+H						0.007					
D Only						0.011					
Lr Only											
L Only											
S Only											
W Only				0.160	0.160						
E Only											
H Only											

Wood Beam

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DESCRIPTION: Horizontal Rail

CODE REFERENCES

Calculations per NDS 2018, IBC 2018, CBC 2019, ASCE 7-16
Load Combination Set : ASCE 7-16

Material Properties

Analysis Method :	Allowable Stress Design		Fb +	900.0 psi	*E : Modulus of Elasticity*	
Load Combination :	ASCE 7-16		Fb -	900.0 psi	Ebend- xx	1,600.0 ksi
			Fc - Prll	1,350.0 psi	Eminbend - xx	580.0 ksi
Wood Species	: Douglas Fir-Larch		Fc - Perp	625.0 psi		
Wood Grade	: No.2		Fv	180.0 psi		
			Ft	575.0 psi	Density	31.210 pcf
Beam Bracing	: Beam is Fully Braced against lateral-torsional buckling					

W(0.032)

0.750 X 1.50

Span = 1.330 ft
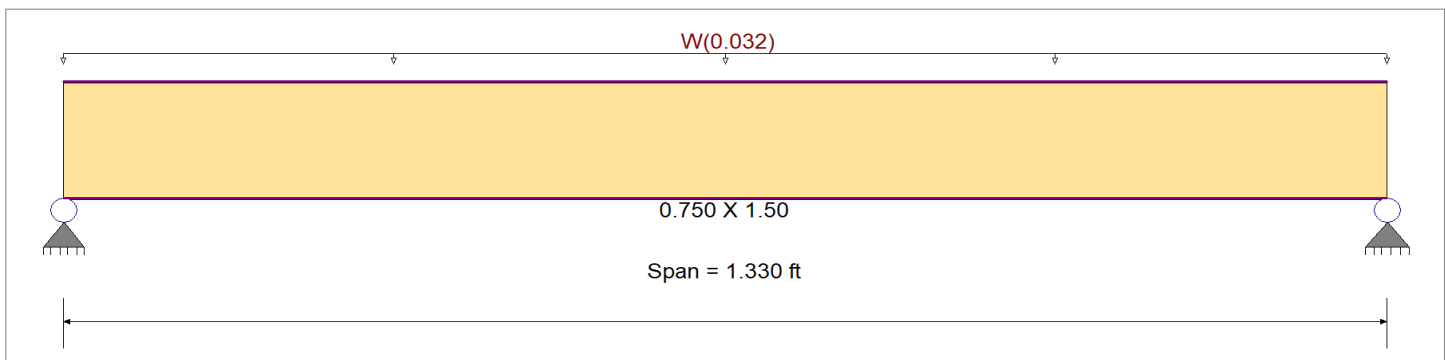
Applied Loads

Service loads entered. Load Factors will be applied for calculations.

Uniform Load : W = 0.0160 ksf, Tributary Width = 2.0 ft, (OOP)

DESIGN SUMMARY

Design OK

Maximum Bending Stress Ratio	=	0.126 : 1	Maximum Shear Stress Ratio	=	0.048 : 1	
Section used for this span		0.750 X 1.50	Section used for this span		0.750 X 1.50	
fb: Actual	=	181.14 psi	fv: Actual	=	13.92 psi	
Fb: Allowable	=	1,440.00 psi	Fv: Allowable	=	288.00 psi	
Load Combination		+D+0.60W+H	Load Combination		+D+0.60W+H	
Location of maximum on span	=	0.665 ft	Location of maximum on span	=	1.209 ft	
Span # where maximum occurs	=	Span # 1	Span # where maximum occurs	=	Span # 1	

Maximum Deflection

Max Downward Transient Deflection	0.007 in	Ratio =	2377	>=360
Max Upward Transient Deflection	0.000 in	Ratio =	0	<360
Max Downward Total Deflection	0.004 in	Ratio =	3962	>=180
Max Upward Total Deflection	0.000 in	Ratio =	0	<180

Vertical Reactions

Support notation : Far left is #1

Values in KIPS

Load Combination	Support 1	Support 2
Overall MAXimum	0.021	0.021
Overall MINimum	0.021	0.021
+D+0.60W+H	0.013	0.013
+D+0.750Lr+0.750L+0.450W+H	0.010	0.010
+D+0.750L+0.750S+0.450W+H	0.010	0.010
+0.60D+0.60W+0.60H	0.013	0.013
W Only	0.021	0.021
H Only		

IN-PLANE LATERAL ANALYSIS
Summary

The wall bracing system intended to be used with the hemp-lime infill is the LIB method described in the IRC. The slight difference between the typical LIB method compared to when used with the hemp-lime is the omission of the gypsum board sheathing, which would trap moisture in the hemp-lime wall.

Although the 1x4 let-in-bracing method in the IRC calls for ½" gypsum board to be installed on one side of the wall, hemp-lime infill improves the structural performance of wood-framed walls enough to match or exceed the performance of the gypsum sheathing. Furthermore, the IRC uses a dead load of 15 PSF for exterior light-framed wood walls when determining seismic bracing requirements while also allowing an additional 50 PSF for veneer without requiring additional braced wall lengths for SDC A, B, and C. Therefore, buildings with hemp-lime infill in SDC A, B, and C can follow Section R602.10 for LIB without needing gypsum board. The minimum braced wall lengths also do not need to be increased for total wall weights up to 65 PSF.

Supporting documents

1. IRC allows for a total wall weight of 65 PSF (framing, insulation, and finishes/veneer) to use the same bracing requirements listed in R610.2, including LIB, without additional requirements or braced wall length multipliers.

TABLE R602.10.3(4)
SEISMIC ADJUSTMENT FACTORS TO THE REQUIRED LENGTH OF WALL BRACING

ITEM NUMBER	ADJUSTMENT BASED ON	STORY	CONDITION	ADJUSTMENT FACTOR[a, b] [Multiply length from Table R602.10.3(3) by this factor]	APPLICABLE METHODS
1	Story height (Section 301.3)	Any story	≤ 10 feet	1.0	All methods
			> 10 feet and ≤ 12 feet	1.2	
2	Braced wall line spacing, townhouses in SDC C	Any story	≤ 35 feet	1.0	
			> 35 feet and ≤ 50 feet	1.43	
3	Braced wall line spacing, in SDC D_0, D_1, D_2[c]	Any story	> 25 feet and ≤ 30 feet	1.2	
			> 30 feet and ≤ 35 feet	1.4	
4	Wall dead load	Any story	> 8 psf and < 15 psf	1.0	
			< 8 psf	0.85	
5	Roof/ceiling dead load for wall supporting	1-, 2- or 3-story building	≤15 psf	1.0	
		2- or 3-story building	> 15 psf and ≤ 25 psf	1.1	
		1-story building or top story	> 15 psf and ≤ 25 psf	1.2	
6	Walls with stone or masonry veneer, townhouses in SDC C[d, e]			1.0	All methods
				1.5	
				1.5	

a. Section R301.2.2.2 states that exterior light-frame wood walls can weigh up to 15 PSF, and Exception 2 states that walls with stone or masonry veneer are allowed in accordance with the provisions of Sections R702.1 and R703.

> **R301.2.2.2 Weights of materials.** Average dead loads shall not exceed 15 pounds per square foot (720 Pa) for the combined roof and ceiling assemblies (on a horizontal projection) or 10 pounds per square foot (480 Pa) for floor assemblies, except as further limited by Section R301.2.2. Dead loads for walls above *grade* shall not exceed:
>
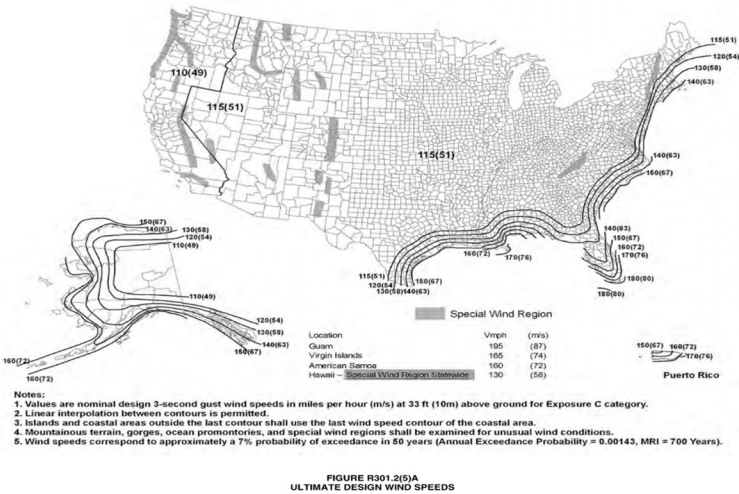> 1. Fifteen pounds per square foot (720 Pa) for exterior light-frame wood walls.

b. Table R703.8(1) allows for a maximum veneer weight of 50 PSF for wood-framed, single-story residences in SDC A, B, and C.

TABLE R703.8(1)
STONE OR MASONRY VENEER LIMITATIONS AND REQUIREMENTS,
WOOD OR STEEL FRAMING, SEISMIC DESIGN CATEGORIES A, B AND C

SEISMIC DESIGN CATEGORY	NUMBER OF WOOD- OR STEEL-FRAMED STORIES	MAXIMUM HEIGHT OF VENEER ABOVE NONCOMBUSTIBLE FOUNDATIONª (feet)	MAXIMUM NOMINAL THICKNESS OF VENEER (inches)	MAXIMUM WEIGHT OF VENEER (psf)ᵇ	WOOD- OR STEEL-FRAMED STORY
A or B	Steel: 1 or 2 Wood: 1, 2 or 3	30	5	50	all
C	1	30	5	50	1 only
	2	30	5	50	top
					bottom
	Wood only: 3	30	5	50	top
					middle
					bottom

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 pound per square foot = 0.479 kPa.
a. An additional 8 feet is permitted for gable end walls. See also story height limitations of Section R301.3.
b. Maximum weight is installed weight and includes weight of mortar, grout, lath and other materials used for installation. Where veneer is placed on both faces of a wall, the combined weight shall not exceed that specified in this table.

2. Out of plane seismic load is less than out of plane wind load
   a. With a basic wind speed of 110, which is the lowest value referenced in the IRC, the OOP wind load is 18 PSF whereas the OOP seismic load is 12 PSF when using a 65 PSF wall dead load located in SDC C.

Location	Vmph	(m/s)
Guam	195	(87)
Virgin Islands	165	(74)
American Samoa	160	(72)
Hawaii – Special Wind Region Statewide	130	(58)

Notes:
1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10m) above ground for Exposure C category.
2. Linear interpolation between contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 7% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00143, MRI = 700 Years).

FIGURE R301.2(5)A
ULTIMATE DESIGN WIND SPEEDS

3. As part of the Agrobat project, referenced in *Bio-aggregate-based Building Materials* by Sofiane Amziane and Laurent Arnaud, the contribution of hempcrete infill was evaluated and compared to let-in-bracing using Standard NF EN 594 [AFN 08]

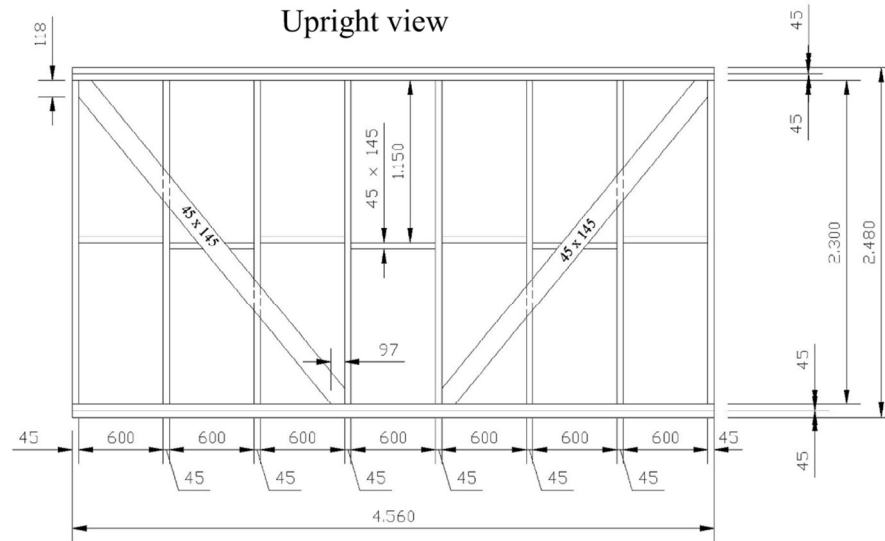   a. The base wall frame was constructed with 2x6 studs @ 24" OC w/ 2x6 LIB,

Figure 8.2. *Structure of the wooden frame*

    b. The skeleton frame to be filled with hempcrete was constructed similarly, but without the LIB
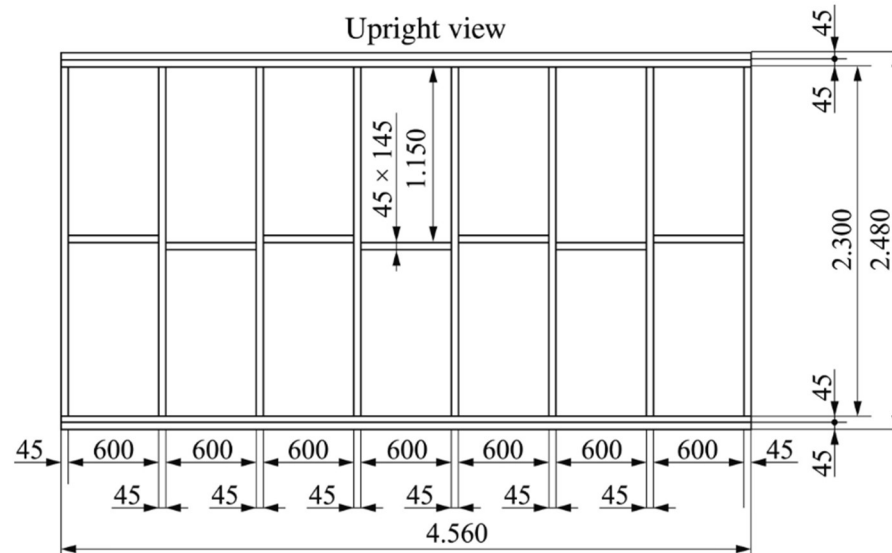

Figure 8.11. *Makeup of the wooden skeleton*

    c. It was found that the hempcrete infill was not only able to substitute the bracing struts, but also greatly improve the mechanical behavior in terms of bracing. The peak charge is 2.2 times higher, and the bracing rigidity increased almost tenfold.

4. Bath University study of hemp-lime demonstrated the additional strength and stiffness hemp-lime infill for compression, in-plane, and out-of-plane loads.
    a. When hemp-lime is being relied upon to provide in-plane racking resistance in a standard 2.4m long by 2.4m high wall panel with 38mm by 89mm C16 studs, the design racking resistance is equivalent to a Category 2 wall construction as detailed in BS 5268 (1996).
        ■ Category 2 uses 30 mm (1.18 in) plasterboard, which is over double the ½" gypboard thickness referenced in the IRC.

Table 2 — Basic racking resistances for a range of materials and combinations of materials

Primary board material	Fixing	Racking resistance	Additional contribution of secondary board on timber frame wall	
			Category 2 or 3 materials	Category 1 material
		kN/m	kN/m	kN/m
Category 1 materials: — 9.5 mm plywood; — 9.0 mm medium board; — 12.0 mm chipboard (type C3M, C4M or C5); — 6.0 mm tempered hardboard; — 9.0 mm OSB (type F2)	3.00 mm diameter wire nails at least 50 mm long, maximum spacing 150 mm on perimeter, 300 mm internal	1.68	0.28	0.84
Category 2 materials: — 12.5 mm bitumen impregnated insulation board;	3.00 mm diameter wire nails at least 50 mm long, maximum spacing 75 mm on perimeter, 150 mm internal	0.90	0.45	1.06
— separating wall of minimum 30 mm plasterboard (in two or more layers)	Each layer should be individually fixed with 2.65 mm diameter plasterboard nails at 150 mm spacing, nails for the outmost layer should be at least 60 mm long	0.90	0.45	1.06
Category 3 materials: — 12.5 mm plasterboard	2.65 mm diameter plasterboard nails at least 40 mm long, maximum spacing 150 mm	0.90	0.45	1.06

NOTE 1   Timber members in wall panels should be not less than 38 mm × 72 mm rectangular section with linings fixed to the narrower face, with ends cut square and assembled in accordance with the relevant clauses of section **6**.

NOTE 2   Timber members of rectangular section less than 38 mm × 72 mm, but not less than 38 mm × 63 mm, should be taken into account for internal walls (excluding separating walls), but in such cases all values for basic racking resistance given in this table should be reduced by 15 %.

NOTE 3   Studs should be spaced at centres not exceeding 610 mm.

NOTE 4   Board edges should be backed by, and nailed to timber framing at all edges except in the case of the underlayers in separating wall construction where it is normal to fix boards horizontally, in which case the intermediate horizontal joint may be unsupported.

NOTE 5   Studs should be of species and stress grade satisfying strength class C16 or better (as defined in BS 5268-2).

NOTE 6   The additional contribution from a secondary layer of category 1, 2 or 3 materials should only be included once in the determination of basic racking resistance, no matter how many additional layers may be fixed to the wall panel.

NOTE 7   The values given in Table 2 together with the modification factors in **4.8** and **4.9** assume that the wall under consideration is adequately fixed to ensure resistance to sliding and overturning.

NOTE 8   Where a secondary board is fixed on the same side of a wall as the primary sheathing then the nail lengths given in the table should be increased to take account of the additional thickness.

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DESCRIPTION: SAMPLE HEADER CALC (2-2X12 SPANNING 9FT)

CODE REFERENCES

Calculations per NDS 2018, IBC 2018, CBC 2019, ASCE 7-16
Load Combination Set : ASCE 7-16

Material Properties

Analysis Method : Allowable Stress Design	$F_b +$	900.0 psi	*E : Modulus of Elasticity*	
Load Combination : ASCE 7-16	$F_b -$	900.0 psi	Ebend- xx	1,600.0 ksi
	Fc - Prll	1,350.0 psi	Eminbend - xx	580.0 ksi
Wood Species : Douglas Fir-Larch	Fc - Perp	625.0 psi		
Wood Grade : No.2	Fv	180.0 psi		
	Ft	575.0 psi	Density	31.210 pcf
Beam Bracing : Completely Unbraced				

D(0.13)
D(0.15) Lr(0.12)

2-2x12

Span = 9.0 ft
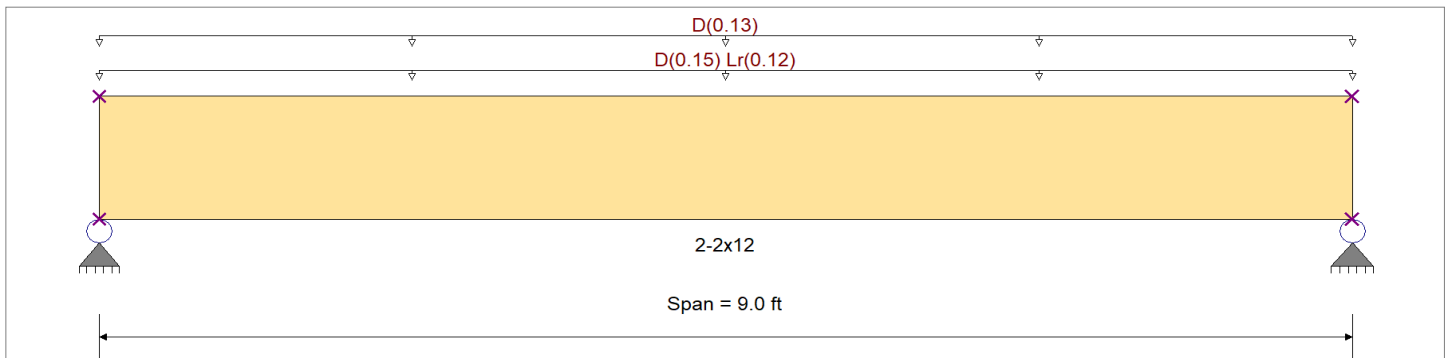
Applied Loads

Service loads entered. Load Factors will be applied for calculations.

Uniform Load : D = 0.0250, Lr = 0.020 ksf, Tributary Width = 6.0 ft, (ROOF)
Uniform Load : D = 0.0650 ksf, Tributary Width = 2.0 ft, (WALL)

DESIGN SUMMARY

				Design OK
Maximum Bending Stress Ratio	=	**0.706** : 1	Maximum Shear Stress Ratio =	**0.283** : 1
Section used for this span		**2-2x12**	Section used for this span	**2-2x12**
fb: Actual	=	768.00 psi	fv: Actual =	63.65 psi
Fb: Allowable	=	1,087.27 psi	Fv: Allowable =	225.00 psi
Load Combination		+D+Lr+H	Load Combination	+D+Lr+H
Location of maximum on span	=	4.500 ft	Location of maximum on span =	8.080 ft
Span # where maximum occurs	=	Span # 1	Span # where maximum occurs =	Span # 1

Maximum Deflection

Max Downward Transient Deflection	0.031 in	Ratio =	3452 >=360
Max Upward Transient Deflection	0.000 in	Ratio =	0 <360
Max Downward Total Deflection	0.104 in	Ratio =	1035 >=180
Max Upward Total Deflection	0.000 in	Ratio =	0 <180

Vertical Reactions

Support notation : Far left is #1   Values in KIPS

Load Combination	Support 1	Support 2
Overall MAXimum	1.800	1.800
Overall MINimum	0.540	0.540
+D+H	1.260	1.260
+D+L+H	1.260	1.260
+D+Lr+H	1.800	1.800
+D+S+H	1.260	1.260
+D+0.750Lr+0.750L+H	1.665	1.665
+D+0.750L+0.750S+H	1.260	1.260
+D+0.60W+H	1.260	1.260
+D+0.750Lr+0.750L+0.450W+H	1.665	1.665
+D+0.750L+0.750S+0.450W+H	1.260	1.260
+0.60D+0.60W+0.60H	0.756	0.756
+D+0.70E+0.60H	1.260	1.260
+D+0.750L+0.750S+0.5250E+H	1.260	1.260

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DESCRIPTION: SAMPLE HEADER CALC (2-2X12 SPANNING 9FT)

Vertical Reactions

Support notation : Far left is #1   Values in KIPS

Load Combination	Support 1	Support 2
+0.60D+0.70E+H	0.756	0.756
D Only	1.260	1.260
Lr Only	0.540	0.540
H Only		