nail it!

introducing the design guide for nail-laminated timber

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fast + epp

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Chapter 23 – Wood

§2304  General Construction Requirements

§2304.9  Lumber Decking

§2304.9.3 Mechanically Laminated Decking
§2304.9.3.1 General
   (definition)

§2304.9.3.2 Nailing
   (between lams and to supports)

§2304.9.3.3 Controlled Random Pattern
2x "joists" at 1-1/2 inches

Choose:
- depth, profile
- species, grade

Continuous vs. butt-jointed laminations
NDS: $C_L$, $C_F$, $C_r$

Other: $K_{\text{layup}}$, $K_{\text{section}}$
\[ \Delta = \frac{0.0069wL^4}{EI} \]

bending strength: 0.67
stiffness: 0.69

Joint rules per:
- IBC 2304.9.2.5
- IBC 2304.9.3.3
- NLT Guide Table 4.1

Layup factors based on:
- IBC Table 2306.1.4
\[ \Delta = \frac{wL^4}{185EI} \]
\[ \Delta = \frac{5wL^4}{384EI} \]

**Bending strength:**
\[ 0.202 \frac{(L/d)^{1/4}}{s^{1/9}} \]

**Stiffness:**
\[ 0.0436 \frac{(L/d)^{9/10}}{s^{1/5}} \]

Joint rules per

- IBC § 2304.9.2.5
- IBC § 2304.9.3.3
- NLT Guide Table 4.1

Layup factors based on European research
- 2x8 NLT
- prefabricated with random staggered joints
- clear span = 18 feet
- 2-span continuous panels
- nail spacing: two rows at 10 inches

$L/d = \frac{18 \times 12}{7.25} = 29.8$

$s = 5”$
strength:
\[ K_{\text{layup},b} = \frac{0.202 \ (29.8)^{1/4}}{\sqrt[5]{1/9}} = 0.39 \]

stiffness:
\[ K_{\text{layup},E} = \frac{0.0436 \ (29.8)^{9/10}}{\sqrt[5]{1/5}} = 0.67 \]

reducing nail spacing to two rows at 5 inches revises K factors to 0.43 and 0.77, respectively
K-section

Gravity design

Shear strength:

\[ X_1 \]

Bending strength and stiffness:

\[ X_1 + X_2 \left( \frac{d_2}{d_1} \right)^3 \]

Shear strength:

\[ X_1 \]

\[ X_1 = X_2 = 0.5 \]
d₁ = 5.5”
d₂ = 3.5”
X₁ = 1/3
X₂ = 2/3

bending strength and stiffness:
\[ K_{\text{section},b} = \frac{1}{3} + \frac{2}{3} \left( \frac{3.5}{5.5} \right)^3 = 0.51 \]

shear strength:
\[ K_{\text{section},v} = 0.33 \]
NDS:
Sections 3.2 – 3.5 (Bending Members)

Section 4.3 (Adjustment Factors)

Supplement Tables 4A, 4B, 4C, 4F (Reference Design Values)
• 2x8 NLT
• prefabricated with random staggered joints
• span = 18 feet
• 2-span continuous panels
• nail spacing: two rows at 10 inches
• lumber: SPF No. 2 or better

\[ K_{\text{layup},b} = 0.39 \text{ (see previous example)} \]
Loads

D: 25 psf NLT + plywood
   20 psf floor finish
   5 psf MEP allowance
   50 psf total

L: 50 psf occupancy (office)
   15 psf partition allowance
   65 psf total
\[ F_b = 875 \text{ psi} \]
\[ C_F = 1.2 \]
\[ C_r = 1.15 \]

\[
\{ \text{per NDS Supplement Table 4A} \}
\]

all other NDS factors = 1.0

\[ K_{\text{layup, b}} = 0.39 \]

per previous example
**ASD strength checks** (per foot width):

\[ F'_{b,NLT} = K_{\text{layup},b} C_F C_r F_b = 0.39 \times 1.2 \times 1.15 \times 875 \approx 470 \text{ psi} \]

\[
M = \frac{\left( \frac{115 \text{ plf}}{12 \frac{\text{in}}{\text{ft}}} \right) \left( 18 \text{ ft} \times 12 \frac{\text{in}}{\text{ft}} \right)^2}{8} \approx 56,000 \text{ lb in}
\]

\[
f_b = \frac{M}{S} = \frac{6M}{bd^2} = \frac{6(56,000 \text{ lb in})}{12 \text{ in}(7.25 \text{ in})^2} \approx 530 \text{ psi} > 470 \text{ psi} \quad \text{NG}
\]
Options?

• use higher grade lumber (Select Structural or MSR)
  • increases $F_b$
• fabricate 3-span panels
  • increases $K_{layup}$ to 0.67
• use 18’ pieces (all laminations simple span)
  • increases $K_{layup}$ to 1.0
• use finger-jointed lumber
  • increases $K_{layup}$ to 1.0
• LRFD?
LRFD strength checks (per foot width):

1.2D + 1.6L governs (q_u = 164 psf)

\[ K_F = 2.54 \]
\[ \phi_b = 0.85 \]  
\[ \lambda = 0.8 \]  

per Appendix N
\[ F'_{b,NLT} = K_{\text{layup},b} C_F C_r K_F \Phi_b \lambda F_b \]
\[ = 0.39(1.2)(1.15)(2.54)(0.85)(0.8)(875) \approx 810 \text{ psi} \]

\[
M = \left( \frac{164 \text{ plf}}{12 \text{ in/ft}} \right) \left( 18 \text{ ft} \times 12 \text{ in/ft} \right)^2 \frac{8}{8} \approx 80,000 \text{ lb in}
\]

\[
f_b = \frac{M}{S} = \frac{6M}{bd^2} = \frac{6(80,000 \text{ lb in})}{12 \text{ in}(7.25 \text{ in})^2} \approx 760 \text{ psi} < 810 \text{ psi} \quad \text{OK}
\]
Vibrations of Steel-Framed Structural Systems Due to Human Activity
Second Edition
NDS: Chapter 16
(Fire Design of Wood Members)

ASD Only

\[ d_{\text{fire}} \]

\[ a_{\text{char}} \]
• 2x8 NLT per previous examples
• supported on 6-3/4” wide glulam beams
• Type IIIA Construction
• 1-hour rating required

effective char depth, \( a_{\text{char}} = 1.8 \text{ in} \)
per NDS Table 16.2.1A
Adjustment Factors for Fire Design per NDS Table 16.2.2:

- bending = 2.85
- bearing = ?? 2.03 is likely conservative
Bending:

\[ F'_{b,NLT} = K_{\text{layup},b} \cdot K_{\text{fire}} \cdot C_F \cdot C_r \cdot F_b = \]
\[ 0.39(2.85)(1.2)(1.15)(875) \approx 1,300 \text{ psi} \]

\[ M \approx 56,000 \text{ lb in} \quad \text{per previous calculations} \]

\[ d_{\text{fire}} = 7.25 \text{ in} - 1.8 \text{ in} = 5.45 \text{ in} \]

\[ f_b = \frac{M}{S} = \frac{6M}{bd^2} = \frac{6(56,000 \text{ lb in})}{12 \text{ in}(5.45 \text{ in})^2} \approx 940 \text{ psi} < 1,300 \text{ psi} \]

OK
Bearing at Interior Support:

\[ w_{\text{bearing,fire}} = 6.75 \text{ in} - 2(1.8 \text{ in}) = 3.15 \text{ in} \]

\[ F'_{c\perp,\text{NLT}} = K_{\text{fire}} C_b F_{c\perp} = 2.03(1.0)(425 \text{ psi}) \approx 860 \text{ psi} \]

\[ V = 115 \text{ plf (18 ft)} \approx 2,100 \text{ lbs (per foot width)} \]

\[ f_{c\perp} = \frac{V}{A} = \frac{V}{b(w_{\text{bearing,fire}})} = \frac{2,100 \text{ lbs}}{12 \text{ in}(3.15 \text{ in})} \approx 56 \text{ psi} \ll 860 \text{ psi} \]

OK
overview

1. gravity design
2. lateral design
3. connections
4. odds & ends
SDPWS: Chapter 4
(Lateral Force-Resisting Systems)

Tables 4.2A and 4.2B
(Blocked Diaphragms)
design example

rigid vs. flexible diaphragms

A

B

C


brace design forces (in kips)

rigid diaphragms

flexible diaphragms

design example

A

B

C

32

14

61

34

65

43

110

52

29

36

68

74

90

95

100

110

97

41

120

61

160

77
diaphragms

sheathed on site

panel joints ⊥ to NLT span

NLT joint

plywood joint

panel joints ∥ to NLT span

NLT joint

plywood joint
pre-sheathed panels

infill panel installed on site

typical

high load

diaphragms
potential load paths:
- perimeter beams
- steel straps
- NLT laminations

chords & collectors
NDS:
Sections 3.6-3.8
(Compression and Tension Members)
Tables 4A, 4B, 4C, 4F
(Reference Design Values)
Section 4.3
(Adjustment Factors)
overview

1. gravity
design
2. lateral
design
3. connections
4. odds &
ends
2015 IBC nailing requirements:
§2304.9.3.2
min nail length = 2.5 * \(b_{\text{lam}}\)

2018 IBC nailing requirements:
Table 2304.9.3.2
2 ¾", 3", 3 ½", 4" nails
2x lams only
nailing patterns

connections

NAILING PATTERN

<table>
<thead>
<tr>
<th>NLT TYPE</th>
<th>NLT DEPTH (NOMINAL)</th>
<th>3 in. long, 0.148 in. diameter nails (staggered)</th>
<th>3 in. long, 0.128 in. diameter nails (staggered)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Laminations</td>
<td>Less than 6 in.</td>
<td>One row @ 7 in. o.c.</td>
<td>One row @ 5 in. o.c.</td>
</tr>
<tr>
<td></td>
<td>More than 6 in.</td>
<td>Two rows @ 14 in. o.c.</td>
<td>Two rows @ 10 in. o.c.</td>
</tr>
<tr>
<td>Butt-Jointed Laminations*</td>
<td>Less than 6 in.</td>
<td>One row @ 7 in. o.c.</td>
<td>One row @ 5 in. o.c.</td>
</tr>
<tr>
<td></td>
<td>More than 6 in.</td>
<td>Two rows @ 10 in. o.c.</td>
<td>Two rows @ 10 in. o.c.</td>
</tr>
</tbody>
</table>

nail spacing
( one row )

nail spacing
(two rows)

(nails in lamination beyond)
IBC toenailing requirements: §2304.9.3.2 feasible only for site-built NLT

alternative means and methods:
match lateral and withdrawal strength
match lateral stiffness?
other rational approaches
self-tapping screws
self-tapping screws
2015 NDS Reference Design Values

- 20D toenails (4” long, 0.192” Ø) @ 7”
  (max 4x nominal laminations, nails every other lam)
- Withdrawal: Table 12.2C
- Shear: Table 12N

For \( G = 0.42 \):

\[
W \cong 72 \text{ lb/ft} \quad Z \cong 200 \text{ lbs/ft}
\]

Could also argue for lower values based
on 33 ksi nail yield strength and/or nail spacing of 8” (4x actual laminations)
connections to supports
connections to supports
overview

1. gravity design
2. lateral design
3. connections
4. odds & ends
\[ b_{\text{effective}} = \text{width of load} + h_{\text{assembly}} \]
openings
openings
openings
common “holes”:
mockup requirements
shop drawings (joint layouts)
weather protection plan
fabrication and erection tolerances
sealers and finishes
This concludes the American Institute of Architects
Continuing Education Systems Course

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