nailed it!

introducing the design guide for nail-laminated timber

california workshops

ian boyle, p.e., s.e.,
fast + epp

aug 22-24, 2018

Disclaimer: This presentation was developed by a third party and is not funded by WoodWorks or the Softwood Lumber Board
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: $K_{\text{layup}}, K_{\text{section}}$
\[ \Delta = 0.0069wL^4/(EI) \]

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

Klayup (table 4.1)
Gravity design

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

Layup factors based on European research

**Table 4.1**

\[ \Delta = \frac{wL^4}{(185EI)} \]
\[ \Delta = \frac{5wL^4}{(384EI)} \]

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

Stiffness:
0.0436 \((L/d)^{9/10} / s^{1/5}\)
• 2x8 NLT
• prefabricated with random staggered joints
• clear span = 18 feet
• 2-span continuous panels
• nail spacing: two rows at 10 inches

$L/d = 18 (12) / 7.25 = 29.8$
$s = 5''$
strength:

\[ K_{\text{layup},b} = 0.202 \left(29.8\right)^{1/4} \left/ \frac{5}{1/9} \right. = 0.39 \]

stiffness:

\[ K_{\text{layup},E} = 0.0436 \left(29.8\right)^{9/10} \left/ \frac{5}{1/5} \right. = 0.67 \]

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

\[ K_{\text{layup,b}} = 0.39 \] (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
\[ F_b = 875 \text{ psi} \]
\[ C_F = 1.2 \]
\[ C_r = 1.15 \]

\{ 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):

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

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

\[
f_b = \frac{M}{S} = \frac{6M}{bd^2} = \frac{6(56,000 \text{ lb in})}{12 \text{ in}(7.25 \text{ in})^2} \approx 530 \text{ psi} > 470 \text{ psi} \quad \text{NG}
\]
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 \( (q_u = 164 \text{ psf}) \)

\[ K_F = 2.54 \]

\[ \phi_b = 0.85 \quad \text{per Appendix N} \]

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

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

\[
f_b = \frac{M}{S} = \frac{6M}{bd^2} = \frac{6(80,000 \text{ lb in})}{12 \text{ in}(7.25 \text{ in})^2} \approx 760 \text{ psi} < 810 \text{ psi} \quad \text{OK}
\]
Floor vibrations

Vibrations of Steel-Framed Structural Systems Due to Human Activity

Second Edition

Graphs showing peak acceleration vs. frequency, and a diagram illustrating resonance, medium damping, high damping, and acceptable acceleration limits.
NDS: Chapter 16
(Fire Design of Wood Members)

ASD Only
• 2x8 NLT per previous examples
• supported on 6-3/4” wide glulam beams
• Type IIIA Construction
• 1-hour rating required

effective char depth, $a_{\text{char}} = 1.8$ 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:

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

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

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

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

OK
Bearing at Interior Support:

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

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

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

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

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
design example

brace design forces (in kips)

rigid diaphragms
flexible diaphragms

A

B

C
sheathed on site

panel joints ⊥ to NLT span

panel joints || to NLT span
pre-sheathed panels

infill panel installed on site

typical

high load
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)
2015 IBC nailing requirements:
\[ \text{§2304.9.3.2} \]
\[ \text{min nail length} = 2.5 \times (b_{\text{lam}}) \]

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

**Nailing Patterns Chart**

<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>

**Note:** 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 $G = 0.42$:

$W \approx 72 \text{ lb/ft}$

$Z \approx 200 \text{ lbs/ft}$

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
effective width = width of load + \( h_{\text{assembly}} \)
openings

width of opening beyond

$V_{\text{lam}} \cos \theta$

$\theta$
openings
openings
common “holes”:
mockup requirements
shop drawings (joint layouts)
weather protection plan
fabrication and erection tolerances
sealers and finishes
Thank you

This concludes the American Institute of Architects Continuing Education Systems Course

Contact Us:
11th Floor, 41 East 11th St.
New York, NY  10003
info@fastepp.com
www.fastepp.com
Tel: 212.905.8999