Lattice Loads

- Forms and shores must be braced to resist all foreseeable lateral loads, such as:
  - Wind,
  - Cable tensions,
  - Inclined supports,
  - Dumping of Concrete, and
  - Other impact such as starting and stopping of equipment
Lateral Loads

ACI Recommends that forms be braced for the following minimum lateral loads, acting in any direction.

- **Slab Forms**
  - The largest value of the following loads:
    - 100 lb per lineal foot of slab edge, or
    - 2\% of total dead load on the form, distributed as a uniform distributed load per lineal foot of slab formed edge.

Slab Forms

- Minimum lateral load requirements for design of slab form bracing are shown in Table 5-6 for various slab thicknesses.
- For slab forms, 100 lb per lineal foot of slab edge, or 2\% of total dead load on the form (distributed as a uniform load per lineal foot of slab edge), whichever is greater.
- Consider only the area of slab formed in a single placement.
Bracing of Slab Forms Supported by individual Shores

Table 5-6
MINIMUM LATERAL FORCE FOR DESIGN OF SLAB FORM BRACING

Note: Special conditions may require
Heavier bracing

<table>
<thead>
<tr>
<th>Solid Slab Thickness in.</th>
<th>Dead Load* Psf</th>
<th>Width of Slab in Direction of Force, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>65</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>115</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>140</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>165</td>
<td>100</td>
</tr>
<tr>
<td>14</td>
<td>190</td>
<td>100</td>
</tr>
<tr>
<td>16</td>
<td>215</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>265</td>
<td>100</td>
</tr>
</tbody>
</table>

* Weight of concrete = 150 psf
Allowance of 15 psf for weight of form

Example

- Find the minimum lateral load for design of bracing for a 50’ x 100’ slab that is 6” thick and 10 feet above grade (h = 10’). Re-calculate the minimum lateral bracing design load if a 25 psf wind force is also applied.
Temporary Structures

Example

For a slab 50 feet wide in the direction of force, find 2 percent of the total dead load distributed uniformly along the 100-ft edge. Allowing 15 psf for form weight, estimate the dead load:

- Dead load, concrete and rebar,
  
  \[ \frac{6 \text{ in.}}{12 \text{ in./ft.}} \times 150 \text{ pcf} = 75 \text{ psf} \]
- Weight of forms, estimated 15 psf
- Total dead load: 75 + 15 = 90 psf

\[ 0.02 [50 \times 90] = 90 \text{ lb per ft} \]

- This is less than the minimum, so use \( H = 100 \) lb per ft for design of bracing members.

Example
Example

- H along 50-ft edge, from Table 5-6, is 180 lb per lineal ft; use for design of the bracing members.

- Suppose the same formwork is enclosed, and local building code calls for 25 psf wind force.

- Wind force applied at slab level would be:

\[(h/2) \times 25 = (10/2) \times 25 = 125 \text{ lb per lineal ft}\]

- This is greater than tabulated value of H along the 100-ft edge, and would be used for design of bracing parallel to the 100-ft slab dimension, but the H value of 180 lb per lineal ft would govern along the 50-ft slab edge.

<table>
<thead>
<tr>
<th>Width of slab in direction of force, ft</th>
<th>20</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
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<td>100</td>
<td>100</td>
<td>100</td>
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</tr>
<tr>
<td>50</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>40</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>30</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

* Slab thickness given for concrete weighing 150 lb per cu ft; allowances of 15 psf for weight of form. For concrete of different weight or for joint slab and beam and slab combinations, estimate dead load per sq ft, and work from dead load column, interpolating as needed on straight line basis.

**NOTE:** Do not interpolate in ranges that begin with 100 lb minimum load.
Example

Slab formwork

Parts of typical slab formwork
Temporary Structures

Slab Form Design

Slab formwork

Parts of typical slab formwork

Design Steps:

Step 1: Estimate design loads
Step 2: Sheathing thickness and spacing of its supports (joist spacing)
Step 3: Joist size and spacing of supports (stringer spacing)
Step 4: Stringer size and span (shore spacing)
Step 5: Shore design to support stringers
Step 6: Check bearing stresses
Step 7: Design lateral bracing
Slab Form Design Example

Design forms to support a flat slab floor 8-inch thick of normal weight concrete, using construction grade Douglas Fir-Larch forming members and steel shoring. Ceiling height is 8 feet and bays are 15x15 feet. Since forms will have continuing reuse, do not adjust base design values for short term load.

---

**STEP 1: ESTIMATE DESIGN LOADS:**

- **Dead load, concrete and rebar,**
  \[ \frac{8 \text{ in.}}{12 \text{ in./ft.}} \times 150 \text{ pcf} = 100 \text{ psf} \]
- **Minimum construction live load on forms**
  50 psf (refer to lecture #1)
- **Weight of forms, estimated**
  8 psf

**Total form design load**

100 + 50 + 8 = **158 psf**
Slab Form Design Example

- **STEP 2: SHEATHING DESIGN:**
  - Assuming 3/4-in. form grade plywood sheathing, from Tables 4-2 and 4-3:
    - $F_b = 1545 \text{ psi}$
    - $F_S = 57 \text{ psi}$
    - $E = 1,500,000 \text{ psi}$
    - $S = 0.412 \text{ in.}^3$
    - $I = 0.197 \text{ in.}^4$
    - $Ib/Q = 6.762 \text{ in.}^2$

---

TABLE 4-2: REPRESENTATIVE BASE DESIGN STRESSES, PSI, NORMAL LOAD DURATION, VISUALLY GRADED DIMENSION LUMBER AT 19 PERCENT MOISTURE, AND PLYWOOD USED WET

Derived from recommendations of the American Forest & Paper Association (Reference 4-3) and from recommendations of the American Plywood Association (Reference 4-8)

| SPECIES AND GRADE | Extreme fiber | Compression | Compression | Horizontal | Modulus of | GRADE | stress, $F_b$ | 1 to grain, $F_{1G}$ | 1 to grain, $F_{2G}$ | shear, $F_s$ (1 to grain) | elasticity, $E$ |
|-------------------|---------------|-------------|-------------|-------------|-------------|
| PLYWOOD SHEATHING USED WET: Plyform S-5, Class 1 (Grades stress level 52) | 1545** | 57** | 1,500,000** | 0.412 | 0.197 | 6.762** | 1,500,000** |

---

TABLE 4-3: EFFECTIVE SECTION PROPERTIES FOR PLYWOOD (12-IN. WIDTHS)*

FACE PLIES OF DIFFERENT SPECIES FROM INNER PLIES

| Standard Plywood, ft. thick, in. | Effective thickness for shear, all grades using exterior glues | 12-in. width, used with face grain parallel to span | 12-in. width, used with face grain perpendicular to span | Area for tension and compression, $i$, in.$^4$ | Moment of inertia, $I$, in.$^4$ | Effective section modulus, $S$, in.$^3$ | Rolling shear constant, $b$, in.$^2$ | Approximate weight, lb | 4x8 sheet | per sq ft |
|-------------------------------|------------------------------------------------------|-------------------------------------------------|--------------------------------|------------------------|-------------------|---------------------|---------------------------|----------------|----------------|
| 1/4                           | 0.288                                                | 0.098                                           | 0.059                          | 0.125                   | 0.046             | 0.001               | 0.009                     | 2.019           | 26             | 0.8          |
| 3/8                           | 0.365                                                | 0.117                                           | 0.077                          | 0.250                   | 0.128             | 0.027               | 0.164                     | 3.119           | 58             | 1.8          |
| 1/2                           | 0.538                                                | 0.157                                           | 0.107                          | 0.500                   | 0.412             | 0.063               | 0.295                     | 6.762           | 63             | 2.2          |
| 3/4                           | 0.715                                                | 0.207                                           | 0.147                          | 0.750                   | 0.696             | 0.104               | 0.394                     | 10.078          | 83             | 2.6          |
| 1                             | 0.892                                                | 0.267                                           | 0.197                          | 1.000                   | 0.982             | 0.145               | 0.591                     | 13.332          | 96             | 3.0          |
Slab Form Design Example

- **CHECK BENDING**
  - For design purposes, consider a 1-foot-wide strip of plywood. Then:

    \[ w = \text{design load of } 158 \text{ psf} \times 1 \text{ ft.} = 158 \text{ lb/lf} \]

    \[ l = 10.95 \sqrt{\frac{fS}{w}} \]

  - Substituting in the equation:

    \[ l = 10.95 \sqrt{\frac{1545 \times 0.412}{158}} = 22.0 \text{ in.} \]

- **CHECK DEFLECTION**
  - For \( \Delta = l/360 \):

    \[ l = 1.69 \sqrt{\frac{EI}{w}} = 1.69 \sqrt{\frac{1500000 \times 0.197}{158}} = 1.69 \sqrt{1870} = 20.8 \text{ in.} \]

    - For \( \Delta = 1/16" \):

    \[ l = 3.23 \sqrt{\frac{EI}{w}} = 3.23 \sqrt{\frac{1500000 \times 0.197}{158}} = 3.23 \sqrt{1870} = 21.2 \text{ in.} \]
Temporary Structures

Slab Form Design Example

- **CHECK ROLLING SHEAR**
  - For design purposes, consider a 1-foot-wide strip of plywood. Then:
    \[ F_s = \frac{VQ}{Ib} \]
  - Since \( V_{\text{max}} = 0.6wL \), so:
    \[ F_s = \frac{VQ}{Ib} = 0.6wL \times \frac{Q}{Ib} \]
  - Substituting in above equation:
    \[ L = \frac{F_s \times Ib}{0.6wQ} = \frac{57}{6.762} \times 6.762 = 4.0 \text{ ft. or 48 inches} \]

- From the above calculations, \( l = 20.8 \text{ in.} \) governs.
- Meaning that joist supports **CANNOT** be more than 20.8 inches apart.
- HOWEVER, in order to select the span, we must consider the size of the plywood sheets and equal spacing of supports.
- In this case, 5 equal spaces of 19.2 inches on an 8-ft. wide plywood sheet will be appropriate.
Slab Form Design Example

- **STEP 3:** JOIST SIZE AND SPACING OF STRINGERS TO SUPPORT THE JOISTS:
  - Check 2x4 construction grade Douglas-Fir-Larch as joist (forms are used repeatedly, so there is no short-term load adjustment).
  - From Table 4-2: $F_b = 1000 \text{ psi}$, $F_V = 180 \text{ psi}$, and $E = 1,500,000 \text{ psi}$.

### Table 4-2: Representative Base Design Stresses, PSI, Normal Load Duration, Visually Graded Dimension lumber at 19 Percent Moisture, and Plywood Used Wet

<table>
<thead>
<tr>
<th>Species and Grade</th>
<th>Extreme Fiber Bending Stress, $F_b$</th>
<th>Compression Parallel to Grain, $F_p$</th>
<th>Compression Perpendicular to Grain, $F_t$</th>
<th>Horizontal Shear, $F_s$</th>
<th>Modulus of Elasticity, $E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Fir-Larch</td>
<td>1000 psi</td>
<td>225 psi</td>
<td>1200 psi</td>
<td>150 psi</td>
<td>1,500,000 psi</td>
</tr>
</tbody>
</table>

- **Slab Form Design Example**

$$ w = \frac{\text{Joist spacing, in.}}{12 \text{ in./ft.}} \times \text{design load, psf} $$

$$ w = \frac{19.2 \text{ in.}}{12 \text{ in./ft.}} \times 158 \text{ psf} = 253 \text{ lb/lf} $$

- From Table 4-1B, for S4S 2x4s: $bd = 5.25 \text{ in.}^2$, $I = 5.36 \text{ in.}^4$, and $S = 3.06 \text{ in.}^3$
Slab Form Design Example

- **CHECK BENDING**

\[ l = 10.95 \sqrt{\frac{F_b'S}{w}} = 10.95 \sqrt{\frac{1000 \times 3.06}{253}} = 38.1 \text{ in.} \]

- **CHECK DEFLECTION**
  - For \( \Delta = l/360 \):

\[ l = 1.693 \sqrt{\frac{EI}{w}} = 1.693 \sqrt{\frac{1500000 \times 5.36}{253}} = 1.693 \sqrt{31778} = 1.693 \times 31.67 = 53.5 \text{ in.} \]

- **CHECK SHEAR**
  - Using the horizontal shear stress formula for a uniformly loaded continuous beam:

\[ f_v = \frac{0.9w}{bd} \left( L - \frac{2d}{12} \right) \]

\[ f_v = 180 = \frac{0.9 \times 253}{5.25} \times \left( L - \frac{2 \times 3.5}{12} \right) \]

\[ 180 = 43.37L - 25.3 \Rightarrow L = 4.73 \text{ ft.} \]

- Or \( L = 4.73' \times 12 \text{ in./ft.} = 56.8 \text{ inches} \)
Slab Form Design Example

- Comparing the three spans calculated above, \( l = 38.1 \) inches governs.
- Considering 15x15 ft. bays and desire for uniform spacing, **36-inch** spacing is a reasonable number.
- This means that the spacing of stringers will be at 5 equal spaces per bay.

\[
(5 \times 36'' = 180 \text{ inches} = 15 \text{ feet})
\]

**STEP 4: STRINGER SIZE AND SPAN:**

\[
w = \frac{\text{Stinger spacing, in.}}{12 \text{ in./ft.}} \times \text{load on form, psf} = \frac{36 \text{ in.}}{12 \text{ in./ft.}} \times 158 \text{ psf} = 474 \text{ lb/ft.}
\]

- Use 4x4 Construction grade Douglas-Fir-Larch stringers. From Table 4-1B for S4S 4x4s: \( bd = 12.25 \text{ in.}^2 \), \( I = 12.50 \text{ in.}^4 \), \( S = 7.15 \text{ in.}^3 \); and \( d = 3.5 \text{ in.} \)
- **CHECK BENDING**

\[
l = 10.95 \sqrt{\frac{F'V}{w}} = 10.95 \sqrt{\frac{1000 \times 7.15}{474}} = 42.5 \text{ in.}
\]
Slab Form Design Example

- **CHECK DEFLECTION**
  - For $\Delta = l/360$
  
  \[
  l = \frac{1.69}{\sqrt{w}} = \frac{1.69}{\sqrt{\frac{150000 \times 12.50}{474}}} = 1.69 \sqrt{\frac{39557}{474}} = 1.69 \times 34.07 = 57.6 \text{ in.}
  \]

- **CHECK SHEAR**
  - Use the horizontal shear stress formula for a uniformly loaded continuous beam:

  \[
  F_v'' = \frac{0.9w}{bdL} \left( L - \frac{2d}{12} \right) \Rightarrow L = \frac{F_v''bd}{0.9w} + \frac{2d}{12}
  \]

  \[
  L = \frac{180 \times 12.25}{0.9 \times 474} + \frac{2 \times 3.5}{12} = 5.17 + 0.58 = 5.75 \text{ ft} = 69 \text{ in.}
  \]

- From the above calculations, $l = 42.5$ inches governs.
- Meaning that stringers supports (shores) **CANNOT** be more than 42.5 inches apart (span of stringers).
- HOWEVER, in order to select an appropriate span, we must consider the dimensions of the bay.
- The 15-ft. bay could be divided into 5 equal spaces of **36 inches** (180”/5 = 36”) which is less than the maximum allowable span of 42.5 inches.
Slab Form Design Example

- Alternatively, we can check the possibility of using a deeper stringer, i.e. 3x6, in order to increase the shore spacing.

- Since bending is dominant here, we will check bending for a 3x6 member.

- For S4S 3x6s from Table 4-2: $F_b = 1000$ psf, and from Table 4-1B, $S = 12.60$ in.$^3$

\[
l = 10.95 \sqrt{\frac{F'_b S}{w}} = 10.95 \sqrt{\frac{1000 \times 12.60}{474}} = 10.95 \times 5.16 = 56.4 \text{ in.}
\]

- Now we can use 45-inch (3’-9”) support spacing for the 3x6 stringers, which will divide the bay into 4 equal spaces (180”/4 = 45”).

---

Slab Form Design Example

- **STEP 5: SHORE DESIGN:**

  - Stringers are placed 36-inches apart, supported by shores spaced 45 inches apart. The area of support for each shore is:

\[
\text{Area} = (36/12) \times (45/12) = 11.25 \text{ ft.}^2
\]

  - Then the total load per shore is:

\[
11.25 \text{ ft.}^2 \times 158 \text{ psf} = 1778 \text{ lb.}
\]
Slab Form Design Example

- Schematic design:

2x4 S4S Joists
19.2" o.c.

3/4" Plywood

3x6 S4S
Stringers
3'-0" o.c.

3'-9"

4x4 shores @
45" (3'-9") o.c.

Table 7-11 (Continued) Allowable Axial Load (Pounds) on Simple Wood Shores of the Indicated Strength and Effective Length

<table>
<thead>
<tr>
<th>Nominal lumber size, in</th>
<th>2x4 rough</th>
<th>2x4 S4S</th>
<th>3x4 rough</th>
<th>3x4 S4S</th>
<th>4x4 rough</th>
<th>4x4 S4S</th>
<th>4x2 rough</th>
<th>4x2 S4S</th>
<th>4x3 rough</th>
<th>4x3 S4S</th>
<th>4x6 rough</th>
<th>4x6 S4S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective length, ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1500</td>
<td>1200</td>
<td>900</td>
<td>600</td>
<td>5100</td>
<td>12900</td>
<td>11300</td>
<td>9100</td>
<td>5900</td>
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<td>6</td>
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<td>10200</td>
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<td>3700</td>
<td>3100</td>
<td>5900</td>
<td>5100</td>
<td>12700</td>
<td>11300</td>
</tr>
<tr>
<td>7</td>
<td>3400</td>
<td>2800</td>
<td>3200</td>
<td>2500</td>
<td>5700</td>
<td>4700</td>
<td>4100</td>
<td>10200</td>
<td>9000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Construction Grade: \( F_p = 1350 \text{ psi} \) \( E = 1,300,000 \text{ psi} \) \( L/d = 50 \text{ or less} \)

Refer to Table 7-11 for wood shoring material. Both 3x4 and 4x4 are more than adequate to carry 1778 lbs for an effective length of 8 feet.
Temporary Structures

Slab Form Design Example

- **Step 6:** Check Bearing Stresses:

- Bearing should be checked where stringers bear on shores and where joists bear on stringers.
  - **Stringers bearing on shore:**
    - Assume the head piece of the adjustable steel shore is $11\frac{1}{2} \times 3\frac{5}{8}$". The 3x6 stringer is actually 2½ in. thick.

![Diagram of bearing area](image)

- If the headpiece is placed parallel to the stringer, bearing area is $2\frac{1}{2} \times 11\frac{1}{2}$ or 28.75 in.$^2$. Bearing stress will be:

  \[
  \frac{\text{total shore load}}{\text{bearing area}} = \frac{1778}{28.75} \approx 62 \text{ psi}
  \]

- This is well below the base $F_{c \perp}$, which is obtained from Table 4-2 (the value of compression $\perp$ to grain, $F_{c \perp}$ for construction grade 2 to 4 in. thick Douglas Fir-Larch is 625 psi).
Temporary Structures

Slab Form Design Example

- Joist bearing on Stringers:
  - The two members are 1½ and 2½ in. wide.
  - Contact bearing area = 2½x1½ = 3.75 in.²
  - Average load transmitted by joist to stringer is:
    \[ \text{Joist spacing} \times \text{joist span} \times \text{form load} \]
    \[
    \frac{19.2}{12} \times \frac{36}{12} \times 158 = 758 \text{ lb.}
    \]
    \[
    \frac{758 \text{ lb}}{3.75 \text{ in.}^2} = 202 \text{ psi}
    \]
    Bearing at this point is also low relative to the 625 psi base value for $F_{c.l}$. 

Questions?

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