Arab Academy for Science, Technology & Maritime Transport
Colleague of Engineering & Technology
Construction & Building Engineering

CB 523
Methods and Equipment for Construction 1

Lecture 4:
Traditional Concrete Formworks
Slab Formwork

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Agenda

- **Slab Formwork Design**
  - **Design procedures**
  - **Complete Example**

Slab Form Design

Design Procedures

- The procedure for applying the equations of Tables 13-5 and 13-5A to the design of a slab form is first to consider a strip of sheathing of the specified thickness and 1 ft (or 1 m) wide (see Figure 13-1 a).
- Determine in turn the maximum allowable span based on the allowable values of bending stress, shear stress, and deflection.
- The lower of these values Will, of course, determine the maximum spacing of the supports (joists).
- For simplicity and economy of design, this maximum span value is usually rounded down to the next lower integer or modular value when selecting joist spacing.
- Based on the selected joist spacing, the joist itself is analyzed to determine its maximum allowable span. The load conditions for the joist are illustrated in Figure 13-l b.
- The joist span selected will be the spacing of the stringers.

Slab Form Design

Design Procedures

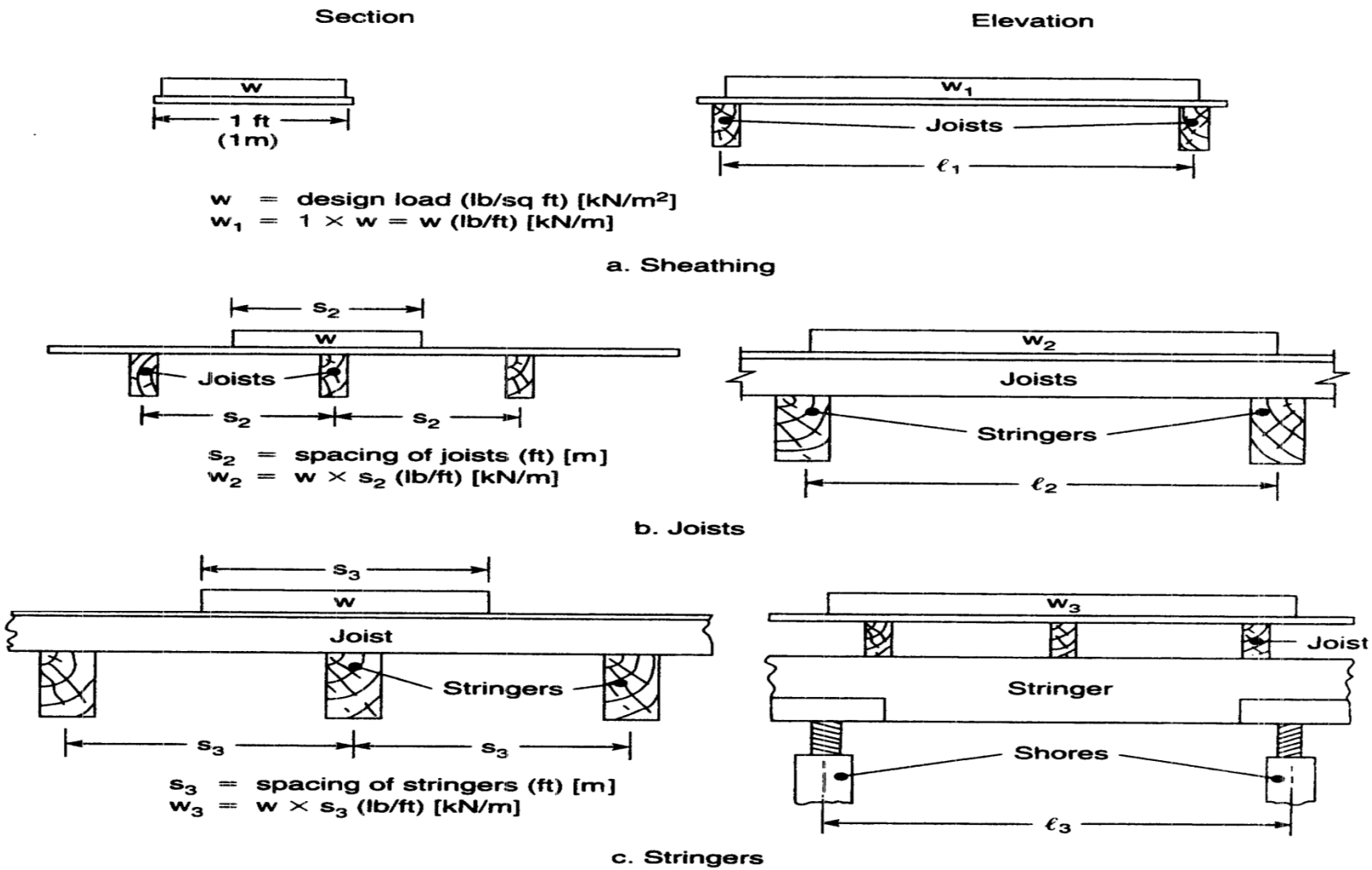


Figure 13–1 Design analysis of form members.

Table 13–5 Concrete form design equations

Design Condition	Support Conditions: *1 Span*	*2 Spans*	*3 or More Spans*
Bending			
Wood	$\ell = 4.0d\left(\frac{F_b b}{w}\right)^{1/2}$	$\ell = 4.0d\left(\frac{F_b b}{w}\right)^{1/2}$	$\ell = 4.46d\left(\frac{F_b b}{w}\right)^{1/2}$
	$\ell = 9.8\left(\frac{F_b S}{w}\right)^{1/2}$	$\ell = 9.8\left(\frac{F_b S}{w}\right)^{1/2}$	$\ell = 10.95\left(\frac{F_b S}{w}\right)^{1/2}$
Plywood	$\ell = 9.8\left(\frac{F_b KS}{w}\right)^{1/2}$	$\ell = 9.8\left(\frac{F_b KS}{w}\right)^{1/2}$	$\ell = 10.95\left(\frac{F_b KS}{w}\right)^{1/2}$
Shear			
Wood	$\ell = 16\,\frac{F_v A}{w} + 2d$	$\ell = 12.8\,\frac{F_v A}{w} + 2d$	$\ell = 13.3\,\frac{F_v A}{w} + 2d$
Plywood	$\ell = 24\,\frac{F_s Ib/Q}{w} + 2d$	$\ell = 19.2\,\frac{F_s Ib/Q}{w} + 2d$	$\ell = 20\,\frac{F_s Ib/Q}{w} + 2d$
Deflection	$\ell = 5.51\left(\frac{EI\Delta}{w}\right)^{1/4}$	$\ell = 6.86\left(\frac{EI\Delta}{w}\right)^{1/4}$	$\ell = 6.46\left(\frac{EI\Delta}{w}\right)^{1/4}$
If $\Delta = 1/180$	$\ell = 1.72\left(\frac{EI}{w}\right)^{1/3}$	$\ell = 2.31\left(\frac{EI}{w}\right)^{1/3}$	$\ell = 2.13\left(\frac{EI}{w}\right)^{1/3}$
If $\Delta = 1/240$	$\ell = 1.57\left(\frac{EI}{w}\right)^{1/3}$	$\ell = 2.10\left(\frac{EI}{w}\right)^{1/3}$	$\ell = 1.94\left(\frac{EI}{w}\right)^{1/3}$
If $\Delta = 1/360$	$\ell = 1.37\left(\frac{EI}{w}\right)^{1/3}$	$\ell = 1.83\left(\frac{EI}{w}\right)^{1/3}$	$\ell = 1.69\left(\frac{EI}{w}\right)^{1/3}$
Compression	f_c or $f_{c\perp} = \frac{P}{A}$		
Tension	$f_t = \frac{P}{A}$		

Notation:

ℓ = length of span, center to center of supports (in.)
F_b = allowable unit stress in bending (psi)
$F_b KS$ = plywood section capacity in bending (lb × in./ft)
F_c = allowable unit stress in compression parallel to grain (psi)
$F_{c\perp}$ = allowable unit stress in compression perpendicular to grain (psi)
$F_s Ib/Q$ = plywood section capacity in rolling shear (lb/ft)
F_v = allowable unit stress in horizontal shear (psi)
f_c = actual unit stress in compression parallel to grain (psi)
$f_{c\perp}$ = actual unit stress in compression perpendicular to grain (psi)
f_t = actual unit stress in tension (psi)
A = area of section (in.^{2})*
E = modulus of elasticity (psi)
I = moment of inertia (in.^{4})*
EI = plywood stiffness capacity (kPamm^4/m)
P = applied force (compression or tension) (lb)
S = section modulus (in.^{3})*
Δ = deflection (in.)
b = width of member (in.)
d = depth of member (in.)
w = uniform load per foot of span (lb/ft)

*For a rectangular member: $A = bd$, $S = bd^2/6$, $I = bd^3/12$

Table 13–5A Metric (SI) concrete form design equations

Design Conditions	Support Conditions: *1 Span*	*2 Spans*	*3 or More Spans*
Bending			
Wood	$\ell = \frac{36.5}{1000} d \left(\frac{F_b b}{w}\right)^{1/2}$	$\ell = \frac{36.5}{1000} d \left(\frac{F_b b}{w}\right)^{1/2}$	$\ell = \frac{40.7}{1000} d \left(\frac{F_b b}{w}\right)^{1/2}$
	$\ell = \frac{89.9}{1000} \left(\frac{F_b S}{w}\right)^{1/2}$	$\ell = \frac{89.9}{1000} \left(\frac{F_b S}{w}\right)^{1/2}$	$\ell = \frac{100}{1000} \left(\frac{F_b S}{w}\right)^{1/2}$
Plywood	$\ell = 2.83 \left(\frac{F_b KS}{w}\right)^{1/2}$	$\ell = 2.83 \left(\frac{F_b KS}{w}\right)^{1/2}$	$\ell = 3.16 \left(\frac{F_b KS}{w}\right)^{1/2}$
Shear			
Wood	$\ell = \frac{1.34}{1000} \frac{F_v A}{w} + 2d$	$\ell = \frac{1.07}{1000} \frac{F_v A}{w} + 2d$	$\ell = \frac{1.11}{1000} \frac{F_v A}{w} + 2d$
Plywood	$\ell = 2.00 \frac{F_s Ib/Q}{w} + 2d$	$\ell = 1.60 \frac{F_s Ib/Q}{w} + 2d$	$\ell = 1.67 \frac{F_s Ib/Q}{w} + 2d$
Deflection	$\ell = \frac{526}{1000} \left(\frac{EI\Delta}{w}\right)^{1/4}$	$\ell = \frac{655}{1000} \left(\frac{EI\Delta}{w}\right)^{1/4}$	$\ell = \frac{617}{1000} \left(\frac{EI\Delta}{w}\right)^{1/4}$
If $\Delta = \frac{1}{180}$	$\ell = \frac{75.1}{1000} \left(\frac{EI}{w}\right)^{1/3}$	$\ell = \frac{101}{1000} \left(\frac{EI}{w}\right)^{1/3}$	$\ell = \frac{93.0}{1000} \left(\frac{EI}{w}\right)^{1/3}$
If $\Delta = \frac{1}{240}$	$\ell = \frac{68.5}{1000} \left(\frac{EI}{w}\right)^{1/3}$	$\ell = \frac{91.7}{1000} \left(\frac{EI}{w}\right)^{1/3}$	$\ell = \frac{84.7}{1000} \left(\frac{EI}{w}\right)^{1/3}$
If $\Delta = \frac{1}{360}$	$\ell = \frac{59.8}{1000} \left(\frac{EI}{w}\right)^{1/3}$	$\ell = \frac{79.9}{1000} \left(\frac{EI}{w}\right)^{1/3}$	$\ell = \frac{73.8}{1000} \left(\frac{EI}{w}\right)^{1/3}$
Compression	f_c or $f_{c\perp} = \frac{P}{A}$		
Tension	$f_t = \frac{P}{A}$		

Notation:

ℓ = length of span, center to center of supports (mm)
F_b = allowable unit stress in bending (kPa)
F_bKS = plywood section capacity in bending (Nmm/m)
F_c = allowable unit stress in compression parallel to grain (kPa)
$F_{c\perp}$ = allowable unit stress in compression perpendicular to grain (kPa)
F_sIb/Q = plywood section capacity in rolling shear (N/m)
f_v = allowable unit stress in horizontal shear (kPa)
f_c = actual unit stress in compression parallel to grain (kPa)
$f_{c\perp}$ = actual unit stress in compression perpendicular to grain (kPa)
f_t = actual unit stress in tension (kPa)
A = area of section (mm^2)*
E = modulus of elasticity (kPa)
I = moment of inertia (mm^4)*
EI = plywood stiffness capacity ($kPamm^4/m$)
P = applied force (compression or tension) (N)
S = section modulus (mm^3)*
Δ = deflection (mm)
b = width of member (mm)
d = depth of member (mm)
w = uniform load per meter of span (kPa/m)

*For a rectangular member: $A = bd$, $S = bd^2/6$, $I = bd^3/12$

Slab Form Design

Design Procedures

- Again, an integer or modular value is selected for stringer spacing. Based on the selected stringer spacing, the process is repeated to determine the maximum stringer span (distance between vertical supports or shores).
- Notice in the design of stringers that the joist loads are actually applied to the stringer as a series of concentrated loads at the points where the joists rest on the stringer. However, it is simpler and sufficiently accurate to treat the load on the stringer as a uniform load.
- The width of the uniform design load applied to the stringer is equal to the stringer spacing as shown in Figure 13-1 c.
- The calculated stringer span must next be checked against the capacity of the shores used to support the stringers.

Slab Form Design

Design Procedures

- The load on each shore is equal to the shore spacing multiplied by the load per unit length of stringer. Thus the maximum shore spacing (or stringer span) is limited to the lower of these two maximum values.
- Although the effect of intermediate form members was ignored in determining allowable stringer span, it is necessary to cheek for crushing at the point where each joist rests on the stringer.
- This is done by dividing the load at this point by the bearing area and comparing the resulting stress to the allowable unit stress in compression perpendicular to the grain.
- A similar procedure is applied at the point where each stringer rests on a vertical support.

Slab Form Design

Design Procedures

To preclude buckling, the maximum allowable load on a rectangular wood column is a function of its unsupported length and least dimension (or *l/d* ratio). The *l/d* ratio must not exceed 50 for a simple solid wood column. For *l/d* ratios less than 50, the following equation applies:

$$F'_c = \frac{0.3E}{(l/d)^2} \leq F_c \qquad \textbf{(13–10)}$$

where F_c = allowable unit stress in compression parallel to the grain (lb/sq in.) [kPa]
F'_c = allowable unit stress in compression parallel to the grain, adjusted for *l/d* ratio (lb/sq in.) [kPa]
E = modulus of elasticity (lb/sq in.) [kPa]
l/d = ratio of member length to least dimension

In using this equation, note that the maximum value used for F'_c may not exceed the value of F_c.

These design procedures are illustrated in the following example. Sheathing design employing plywood is illustrated in Example 13–2.

Slab Form Design

Example

EXAMPLE 13–1

Design the formwork (Figure 13–2) for an elevated concrete floor slab 6 in. (152 mm) thick. Sheathing will be nominal 1-in. (25-mm) lumber while 2 × 8 in. (50 × 200 mm) lumber will be used for joists. Stringers will be 4 × 8 in. (100 × 200 mm) lumber. Assume that all members are continuous over three or more spans. Commercial 4000-lb (17.8-kN) shores will be used. It is estimated that the weight of the formwork will be 5 lb/sq ft (0.24 kPa). The adjusted allowable stresses for the lumber being used are as follows:

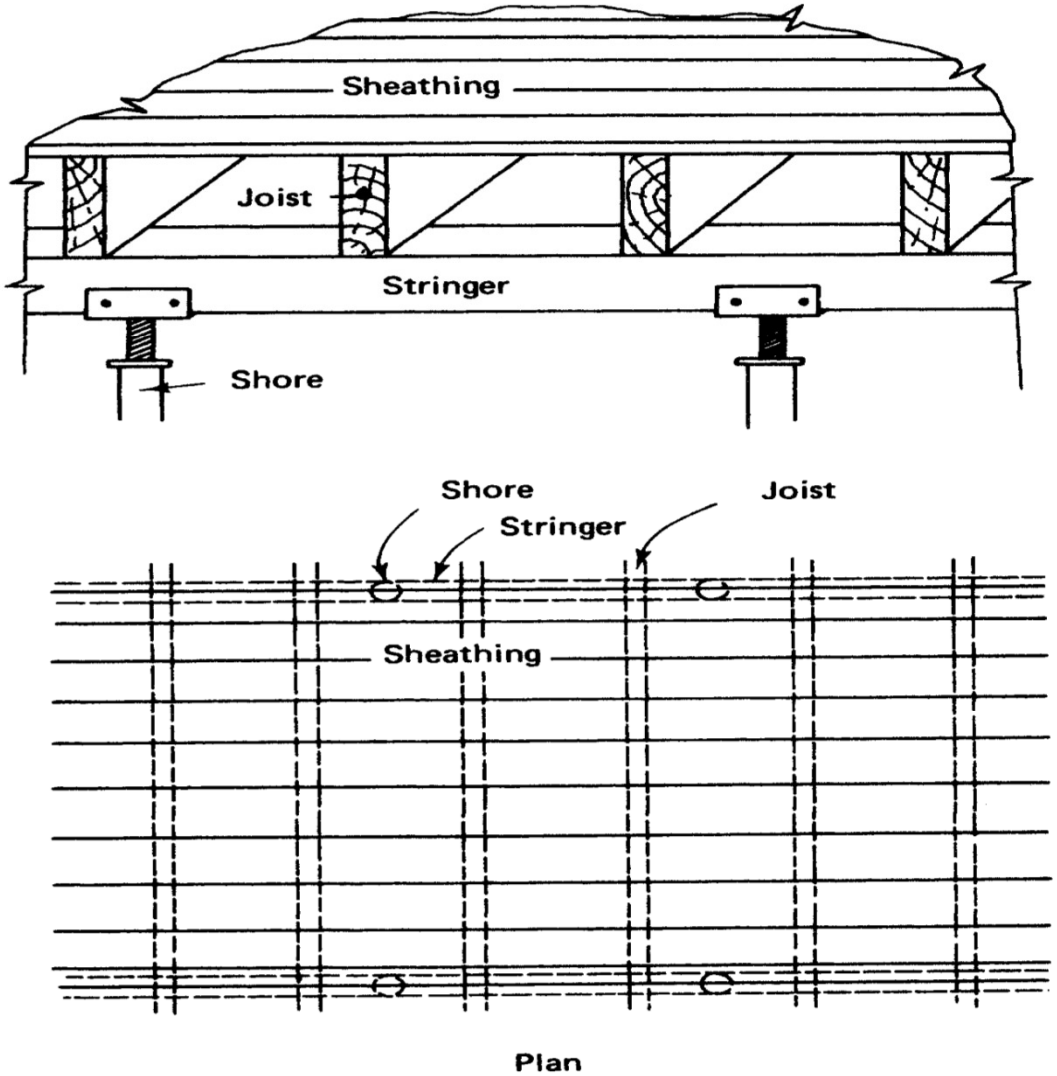
	Sheathing psi [kPa]	Other Members psi [kPa]
F_b	1075 [7412]	1250 [8619]
F_v	174 [1200]	180 [1241]
$F_{c\perp}$		405 [2792]
F_c		850 [5861]
E	1.36×10^6 [9.4×10^6]	1.40×10^6 [9.7×10^6]

Maximum deflection of form members will be limited to $\frac{\ell}{360}$. Use the minimum value of live load permitted by ACI. Determine joist spacing, stringer spacing, and shore spacing.

Slab Form Design

Example

Figure 13–2 Slab form, Example 13–1.



Slab Form Design

Example

SOLUTION

Design Load

Assume concrete density is 150 lb/cu ft (2403 kg/m^3)

$$\begin{aligned} \text{Concrete} = 1 \text{ sq ft} \times 6/12 \text{ ft} \times 150 \text{ lb/cu ft} &= 75 \text{ lb/sq ft} \\ \text{Formwork} &= 5 \text{ lb/sq ft} \\ \text{Live load} &= 50 \text{ lb/sq ft} \\ \text{Design load} &= 130 \text{ lb/sq ft} \end{aligned}$$

$$\left[\begin{aligned} &\text{Pressure per m}^2\text{:} \\ \text{Concrete} = 1 \times 1 \times 0.152 \times 2403 \times 0.0098 &= 3.58 \text{ kPa} \\ \text{Formwork} &= 0.24 \text{ kPa} \\ \text{Live load} &= \underline{2.40 \text{ kPa}} \\ \text{Design load} &= 6.22 \text{ kPa} \end{aligned}\right]$$

Deck Design

Consider a uniformly loaded strip of decking (sheathing) 12 in. (or 1 m) wide placed perpendicular to the joists (Figure 13–1a) and analyze it as a beam. Assume that the strip is continuous over three or more spans and use the appropriate equations of Tables 13–5 and 13–5A.

$$w = (1 \text{ sq ft/lin ft}) \times (130 \text{ lb/sq ft}) = 130 \text{ lb/ft}$$

$$[w = (1 \text{ m}^2\text{/m}) \times (6.22 \text{ kN/m}^2) = 6.22 \text{ kN/m}]$$

Slab Form Design

Example

(a) Bending:

$$l = 4.46\, d\left(\frac{F_b\, b}{w}\right)^{1/2}$$

$$= (4.46)(0.75)\left(\frac{(1075)(12)}{130}\right)^{1/2} = 33.3 \text{ in.}$$

$$\left[\begin{aligned} l &= \frac{40.7}{1000} d\left(\frac{F_b b}{w}\right)^{1/2} \\ &= \frac{(40.7)(19)}{1000}\left(\frac{(7412)(1000)}{6.22}\right)^{1/2} = 844 \text{ mm} \end{aligned}\right]$$

Slab Form Design

Example

(b) Shear:

$$l = 13.3\frac{F_v A}{w} + 2d$$

$$= \frac{(13.3)(174)(12)(0.75)}{130} + (2)(0.75) = 161.7 \text{ in.}$$

$$\left[\begin{aligned} l &= \frac{1.11}{1000}\frac{F_v A}{w} + 2d \\ &= \frac{(1.11)(1200)(1000)(19)}{(1000)(6.22)} + (2)(19) = 4107 \text{ mm} \end{aligned}\right]$$

Slab Form Design

Example

(c) Deflection:

$$l = 1.69\left(\frac{EI}{w}\right)^{1/3} = 1.69\left(\frac{Ebd^3}{w12}\right)^{1/3}$$

$$= 1.69\left(\frac{(1.36 \times 10^6)(12)(0.75)^3}{(130)(12)}\right)^{1/3} = 27.7 \text{ in.}$$

$$\left[\begin{aligned} l &= \frac{73.8}{1000}\left(\frac{EI}{w}\right)^{1/3} = \frac{73.8}{1000}\left(\frac{Ebd^3}{w12}\right)^{1/3} \\ &= \frac{73.8}{1000}\left(\frac{(9.4 \times 10^6)(1000)(19)^3}{(12)(6.22)}\right)^{1/3} = 703 \text{ mm} \end{aligned}\right]$$

Deflection governs in this case and the maximum allowable span is 27.7 in. (703 mm). We will select a 24-in. (610-mm) joist spacing as a modular value for the design.

Slab Form Design

Example

Joist Design

Consider the joist as a uniformly loaded beam supporting a strip of design load 24 in. (610 mm) wide (same as joist spacing; see Figure 13–1b). Joists are 2 × 8 in. (50 × 200 mm) lumber. Assume that the joists are continuous over three spans.

$$w = (2\text{ ft}) \times (1) \times (130\text{ lb/sq ft}) = 260\text{ lb/ft}$$

$$[w = (0.610\text{ m}) \times (1) \times (6.22\text{ kPa}) = 3.79\text{ kN/m}]$$

(a) Bending:

$$l = 10.95\left(\frac{F_b S}{w}\right)^{1/2}$$

$$= 10.95\left(\frac{(1250)(13.14)}{260}\right)^{1/2} = 87.0\text{ in.}$$

$$\left[\begin{aligned} l &= \frac{100}{1000}\left(\frac{F_b\, S}{w}\right)^{1/2} \\ &= \frac{100}{1000}\left(\frac{(8619)(2.153 \times 10^5)}{3.79}\right)^{1/2} = 2213\text{ mm} \end{aligned}\right]$$

Slab Form Design

Example

(b) Shear:

$$l = 13.3\,\frac{F_v A}{w} + 2d$$

$$= \frac{(13.3)(180)(10.88)}{260} + (2)(7.25) = 114.7 \text{ in.}$$

$$\left[\begin{aligned} l &= \frac{1.11}{1000}\,\frac{F_v A}{w} + 2d \\ &= \frac{(1.11)}{(1000)}\,\frac{(1241)(7016)}{(3.79)} + (2)(184) = 2918 \text{ mm} \end{aligned}\right]$$

(c) Deflection:

$$l = 1.69\left(\frac{EI}{w}\right)^{1/3}$$

$$= 1.69\left(\frac{(1.4 \times 10^6)(47.63)}{(260)}\right)^{1/3} = 107.4 \text{ in.}$$

$$\left[\begin{aligned} l &= \frac{73.8}{1000}\left(\frac{EI}{w}\right)^{1/3} \\ &= \frac{73.8}{1000}\left(\frac{(9.7 \times 10^6)(19.83 \times 10^6)}{3.79}\right)^{1/3} = 2732 \text{ mm} \end{aligned}\right]$$

Thus bending governs and the maximum joist span is 87 in. (2213 mm). We will select a stringer spacing (joist span) of 84 in. (2134 mm).

Slab Form Design

Example

Stringer Design

To analyze stringer design, consider a strip of design load 7 ft (2.13 m) wide (equal to stringer spacing) as resting directly on the stringer (Figure 13–1c). Assume the stringer to be continuous over three spans. Stringers are 4 × 8 (100 × 200 mm) lumber. Now analyze the stringer as a beam and determine the maximum allowable span.

$$w = (7)\,(130) = 910 \text{ lb/ft}$$

$$[w = (2.13)\,(1)\,(6.22) = 13.25 \text{ kN/m}]$$

(a) Bending:

$$l = 10.95\left(\frac{F_b\,S}{w}\right)^{1/2}$$

$$= 10.95\left(\frac{(1250)(30.66)}{910}\right)^{1/2} = 71.1 \text{ in.}$$

$$\left[\begin{aligned} l &= \frac{100}{1000}\left(\frac{F_b S}{w}\right)^{1/2} \\ &= \frac{100}{1000}\left(\frac{(8619)(5.024 \times 10^5)}{13.25}\right)^{1/2} = 1808 \text{ mm} \end{aligned}\right]$$

Slab Form Design

Example

(b) Shear:

$$l = \frac{13.3F_vA}{w} + 2d$$

$$= \frac{(13.3)(180)(25.38)}{910} + (2)(7.25) = 81.3 \text{ in.}$$

$$\left[\begin{aligned} l &= \frac{1.11}{1000}\frac{F_vA}{w} + 2d \\ &= \frac{1.11}{1000}\frac{(1241)(16.37 \times 10^3)}{13.25} + (2)(184) = 2070 \text{ mm} \end{aligned}\right]$$

(c) Deflection:

$$l = 1.69\left(\frac{EI}{w}\right)^{1/3}$$

$$= 1.69\left(\frac{(1.4 \times 10^6)(111.1)^3}{910}\right)^{1/3} = 93.8 \text{ in.}$$

$$\left[\begin{aligned} l &= \frac{73.8}{1000}\left(\frac{EI}{w}\right)^{1/3} \\ &= \frac{73.8}{1000}\left(\frac{(9.7 \times 10^6)(46.26 \times 10^6)}{13.25}\right)^{1/3} = 2388 \text{ mm} \end{aligned}\right]$$

Bending governs and the maximum span is 71.1 in. (1808 mm).

Slab Form Design

Example

Now we must check shore strength before selecting the stringer span (shore spacing). The maximum stringer span based on shore strength is equal to the shore strength divided by the load per unit length of stringer.

$$l = \frac{4000}{910} \times 12 = 52.7 \text{ in.}$$

$$\left[l = \frac{17.8}{13.25} = 1.343 \text{ m} \right]$$

Thus the maximum stringer span is limited by shore strength to 52.7 in. (1.343 m). We select a shore spacing of 4 ft (1.22 m) as a modular value.

Before completing our design, we should check for crushing at the point where each joist rests on a stringer. The load at this point is the load per unit length of joist multiplied by the joist span.

$$P = (260)\,(84/12) = 1820 \text{ lb}$$

$$[P = (3.79)\,(2.134) = 8.09 \text{ kN}]$$

$$\text{Bearing area (A)} = (1.5)\,(3.5) = 5.25 \text{ sq in.}$$

$$[\text{A} = (38)\,(89) = 3382 \text{ mm}^2]$$

$$f_{c\perp} = \frac{P}{A} = \frac{1820}{5.25} = 347 \text{ psi} < 405 \text{ psi } (F_{c\perp}) \qquad OK$$

$$f_{c\perp} = \frac{809 \times 10^6}{3382} = 2392 \text{ kPa} < 2792 \text{ kPa } (f_{c\perp})$$

Slab Form Design

Example

Final Design

Decking: nominal 1-in. (25-mm) lumber

Joists: 2 × 8's (50 × 200-mm) at 24-in. (610-mm) spacing

Stringers: 4 × 8's (100 × 200-mm) at 84-in. (2.13-m) spacing

Shore: 4000-lb (17.8-kN) commercial shores at 48-in. (1.22-m) intervals

Thank You

Questions ?