Design of Waffle Slab (without beams) by Direct Design Method

Assume \( S = (32 + x/2)' \), Building spans = (S, S, S) by (S, S, S)
Building Height = 4@10' = 40'
Loads: LL = 40 psf, FF = 20 psf, RW = 20 psf [i.e., (40 + x/2), (20 + x/4), (20 + x/4) psf]
Material Properties: \( f'_c = 3 \) ksi, \( f_s = 20 \) ksi [i.e., \( f'_c = (3 + x/20) \) ksi, \( f_s = (20 + x/4) \) ksi]
Design of Slabs and Ribs

**Slabs**

Assuming 10 square pans per slab; i.e., (3.2'×3.2') c/c and (2.7'×2.7') clear spans (with 6" ribs)

Slab thickness = 2.5" ⇒ Self weight = 2.5×150/12 = 31.25 psf

∴ Total load on slab, \( w = 31.25 + 20 + 20 + 40 = 111.25 \) psf = 0.111 ksf

∴ Maximum Moment for an edge-supported (2.7'×2.7') slab with Support condition Case 2

\[ M_{\text{max}} = 0.045 \times wL^2 = 0.045 \times 111.25 \times (2.7)^2 \approx 0.0365 \text{ ksf} \]

Modulus of rupture = 5\( f'_c = 5\sqrt{3/1000} = 0.274 \) ksi; i.e., Allowable tensile stress = 0.274/2 = 0.137 ksi

\[ S_{\text{sec}} = \frac{bh^2}{6} \Rightarrow 0.0365 = \frac{h^2}{6} \times 0.137 \Rightarrow h_{\text{req}} = \sqrt{(0.0365 \times 6/0.137)} = 1.26" \]

∴ Slab thickness, \( h = 2.5" \) is OK; i.e., \( d = 2" \Rightarrow A_{\text{as(Temp)}} = 0.0025 \times 12 \times 2.5 = 0.075 \text{ in}^2/\text{ft} \)

∴ Use appropriate wire mesh to provide the required \( A_{\text{as(Temp)}} \); i.e., 1/8"-wire diameter (2"×2") mesh

**Ribs**

Maximum clear span = 31'; Slab without edge beam and \( f_y = 40 \) ksi

⇒ Slab thickness = \( L_n(0.8 + f_y/200)/33 = 31\times(0.8 + 40/200)\times12/33 = 11.27" \)

∴ Assume 18" thickness; i.e., 13.5" below slab, with \( b_w = 6" \)

∴ Average thickness without column head = 18 –{(2.7 × 2.7) × 15.5)/(3.2 × 3.2)} = 6.97"

If column head covers (5 × 5 = 25) square pans, average thickness of slab

= 6.97 + {25 × (2.7 × 2.7) × 15.5)/(32 × 32)} = 9.72"

Assuming the entire slab thickness to be = 9.72"

Self weight = 9.72 × 150/12 = 121.5 psf

∴ Total load on slab = 121.5 + 20 + 20 + 40 = 201.5 psf = 0.202 ksf

For design, \( n = 9, k = 0.378, j = 0.874, R = 0.223 \) ksi

\[ d = 18 − 1.5 = 16.5"; A_s = M/f_yj = M\times12/(20\times0.874\times16.5) = M/24.04 \]

∴ Moment capacity \( M_{c(\text{max})} = Rbd^2 = 0.223\times1\times16.5^2 = 60.70 \text{ ksf}, \) or 30.35 ksf/rib

Also, \( A_{s(\text{Temp})} = 0.0025 \times 12 \times 18 = 0.54 \text{ in}^2/\text{ft}; \) or 0.27 in\(^2\)/rib

Punching shear force in slab \( \geq 0.202 \times \{32^2−(16 + 2/12)^2\} = 153.71 \text{ k} \)

and in column head \( \geq 0.202 \times \{32^2−(12/12 + 16.5/12)^2\} = 205.25 \text{ k} \)

∴ Stresses are = 153.71/(4(16 × 12 + 2)×2) = 0.099 ksi and = 205.25/(4(12 + 16.5)×16.5) = 0.109 ksi

Allowable punching shear stress, \( \tau_{\text{punch}} = 2\sqrt{f'_c} = 2\sqrt{3/1000} = 0.110 \) ksi ⇒ OK for punching shear
Panels in the Long and Short Direction

Panel 1 (and all other panels)
Width of Panel = 16.5'
No edge beam along panel length; \( \alpha = 0 \), for all slabs
Also no transverse beam \( \Rightarrow \beta = 0 \), for all slabs
Column strip = Short span (c/c)/4 = 32/4 = 8', Middle strip = 16−8 = 8' (i.e., 2.5 pans per strip)

*Slab (S1)*
Slab size (= 32' x 32' c/c) = 31' x 31'
\[ \therefore M_0 = wL_2L_3^2/8 = 0.202 \times 16.5 \times 31^2/8 = 399.48 \text{ k'} \]
Support (c) \( \Rightarrow M_{\text{Ext}}^- = 0.26 \) \( M_0 = 103.87 \) k', \( M^+ = 0.52 \) \( M_0 = 207.73 \) k', \( M_{\text{Int}}^- = 0.70 \) \( M_0 = 279.64 \) k'
\[ L_2/L_1 = 32/32 = 1.0, \alpha_1L_2/L_1 = 0 \]
\[ \therefore \text{Total column strip moments are} \]
\[ M_{\text{ Ext}}^- = 1.00 \) \( M_0 = 103.87 \) k'; i.e., 103.87 k'/8' = 12.98 k'/'\]
\[ M_{\text{ Int}}^- = 0.75 \) \( M_0 = 209.73 \) k'; i.e., 209.73 k'/8' = 26.22 k'/'
\[ \therefore \text{Total middle strip moments are} \]
\[ M_{\text{ Ext}}^- = 103.87 - 103.87 = 0 \text{ k'}; \text{i.e., 0 k'}/8' = 0 \text{ k}'/' \]
\[ M_{\text{ Int}}^- = 279.64 - 209.73 = 69.91 \text{ k'}; \text{i.e., 69.91 k'}/8' = 8.74 \text{ k}'/' \]

*Slab (S2)*
Slab size (= 32' x 32' c/c) = 31' x 31'
\[ \therefore M_0 = wL_2L_3^2/8 = 0.202 \times 16.5 \times 31^2/8 = 399.48 \text{ k'} \]
Interior Support \( \Rightarrow M_{\text{ Int}}^- = 0.65 \) \( M_0 = 259.67 \) k', \( M^+ = 0.35 \) \( M_0 = 139.82 \) k', \( M_{\text{ Int}}^- = 0.65 \) \( M_0 = 259.67 \) k'
\[ L_2/L_1 = 32/32 = 1.0, \alpha_1L_2/L_1 = 0 \]
\[ \therefore \text{Total column strip moments are} \]
\[ M_{\text{ Int}}^- = 0.75 \) \( M_0 = 194.75 \) k'; i.e., 194.75 k'/8' = 24.34 k'/'\]
\[ \therefore \text{Total middle strip moments are} \]
\[ M_{\text{ Int}}^- = 259.67 - 194.75 = 64.92 \text{ k'}; \text{i.e., 64.92 k'}/8' = 8.11 \text{ k}'/' \]
Denoting slab reinforcement by in²/ (−ve) and rib reinforcement by in²/rib (+ve highlighted)

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### Slab Reinforcement

- #4 @ 4.5" c/c within slab
- 1 #4 extra top between alternate #4 bars
- #4 @ 7.5" c/c

### Sections
- **Section A-A'**
  - 2 #9 through
  - 3.2'
  - #4 @ 4.5" c/c
- **Section B-B'**
  - 2 #9
  - 3.2'
  - #4 @ 4.5" c/c + extra top

### Ribs
- Ribs within Column Strip
- Ribs within Middle Strip