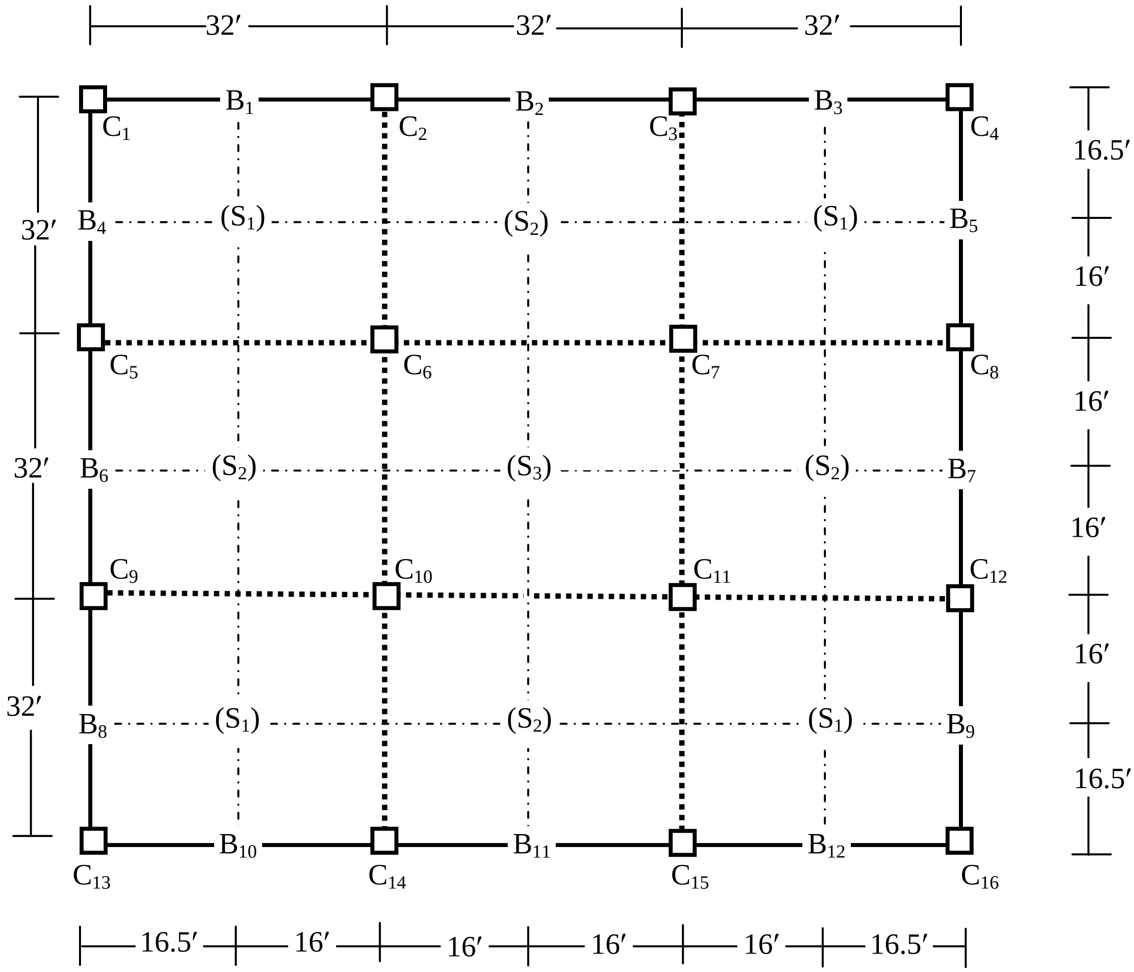
Design of Waffle Slab (without beams) by Direct Design Method



Building Plan

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″ $\Rightarrow$ Self weight = 2.5×150/12 = 31.25 psf

$\therefore$ Total load on slab, w = 31.25 + 20 + 20 + 40 = 111.25 psf = 0.111 ksf

$\therefore$ Maximum Moment for an edge-supported (2.7′×2.7′) slab with Support condition Case 2

$M^{(-)}_{max} = 0.045\, wL^2 = 0.045 \times 0.111 \times (2.7)^2 = 0.0365$ k′/′

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

$S_{sect} = bh^2/6 \Rightarrow 0.0365 = h^2/6 \times 0.137 \Rightarrow h_{req} = \sqrt{(0.0365 \times 6/0.137)} = 1.26''$

$\therefore$ Slab thickness, h = 2.5″ is OK; i.e. d = 2″ $\Rightarrow A_{s(Temp)} = 0.0025\, bh = 0.0025 \times 12 \times 2.5 = 0.075$ in^2/ft

$\therefore$ Use appropriate wire mesh to provide the required $A_{s(Temp)}$; i.e., 1/8″-wire diameter (2″×2″) mesh

Ribs

Maximum clear span = 31′; Slab without edge beam and f_y = 40 ksi

$\Rightarrow$ Slab thickness = $L_n(0.8 + f_y/200)/33 = 31\times (0.8 + 40/200) \times 12/33 = 11.27''$

$\therefore$ Assume 18″ thickness; i.e., 13.5″ below slab, with b_w = 6″

$\therefore$ 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

$\therefore$ Total load on slab = 121.5 + 20 + 20 + 40 $\cong$ 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″; $A_s = M/f_s jd = M\times12/(20\times0.874\times16.5) = M/24.04$

$\therefore$ Moment capacity $M_{c(max)} = Rbd^2 = 0.223\times1\times16.5^2 = 60.70$ k′/′, or 30.35 k′/rib

Also, $A_{s(Temp)} = 0.0025\, bt = 0.0025\times12\times18 = 0.54$ in^2/′; or 0.27 in^2/rib

Punching shear force in slab $\cong 0.202 \times \{32^2-(16 + 2/12)^2\} = 153.71$ k

and in column head $\cong 0.202 \times \{32^2-(12/12 + 16.5/12)^2\} = 205.25$ k

$\therefore$ 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, $\tau_{punch} = 2\sqrt{f_c'} = 2\sqrt{(3/1000)} = 0.110$ ksi $\Rightarrow$ OK for punching shear

Panels in the Long and Short Direction

<u>Panel 1 (and all other panels)</u>

Width of Panel = 16.5′

No edge beam along panel length; $\therefore \alpha_1 = 0$, for all slabs

Also no transverse beam $\Rightarrow \beta_t = 0$, 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)

<u>Slab (S_1)</u>

Slab size (= 32′×32′ c/c) = 31′×31′

$\therefore M_0 = wL_2L_n^2/8 = 0.202\times16.5\times31^2/8 = 399.48$ k′

Support (c) $\Rightarrow M_{Ext}^- = 0.26\ M_0 = 103.87$ k′, $M^+ = 0.52\ M_0 = 207.73$ k′, $M_{Int}^- = 0.70\ M_0 = 279.64$ k′

$L_2/L_1 = 32/32 = 1.0$, $\alpha_1 L_2/L_1 = 0$

$\therefore$ Total column strip moments are

$M_{CExt}^- = 1.00\ M_{Ext}^- = 103.87$ k′; i.e., 103.87 k′/8′ = 12.98 k′/′; $A_{sCExt}^- = 12.98/24.04 = 0.54$ in²/′

$M_C^+ = 0.60\ M^+ = 124.64$ k′; i.e., 124.64 k′/2.5 rib = 49.86 k′/′; $A_{CExt}^+ = 49.86/24.04 = 2.07$ in²/rib

$M_{CInt}^- = 0.75\ M_{Int}^- = 209.73$ k′; 209.73 k′/8′ = 26.22 k′/′; $A_{sCInt}^- = 26.22/24.04 = 1.09$ in²/′

$\therefore$ Total middle strip moments are

$M_{MExt}^- = 103.87 - 103.87 = 0$ k′; i.e., 0 k′/8′ = 0 k′/′; $A_{sMExt}^- = 0/24.04 = 0.0$ in²/′

$M_M^+ = 207.73 - 124.64 = 83.09$ k′; i.e., 83.09 k′/2.5 rib = 33.24 k′/rib; $A_M^+ = 33.24/24.04 = 1.38$ in²/rib

$M_{MInt}^- = 279.64 - 209.73 = 69.91$ k′; i.e., 69.91 k′/8′ = 8.74 k′/′; $A_{MInt}^+ = 8.74/24.04 = 0.36$ in²/′

<u>Slab (S_2)</u>

Slab size (= 32′×32′ c/c) = 31′×31′

$\therefore M_0 = wL_2L_n^2/8 = 0.202\times16.5\times31^2/8 = 399.48$ k′

Interior Support $\Rightarrow M_{Int}^- = 0.65\ M_0 = 259.67$ k′, $M^+ = 0.35\ M_0 = 139.82$ k′, $M_{Int}^- = 0.65\ M_0 = 259.67$ k′

$L_2/L_1 = 32/32 = 1.0$, $\alpha_1 L_2/L_1 = 0$

$\therefore$ Total column strip moments are

$M_{CInt}^- = 0.75\ M_{Ext}^- = 194.75$ k′; i.e., 194.75 k′/8′ = 24.34 k′/′; $A_{sCInt}^- = 24.34/24.04 = 1.01$ in²/′

$M_C^+ = 0.60\ M^+ = 83.89$ k′; i.e., 83.89 k′/2.5 rib = 33.56 k′/rib; $A_{sM}^+ = 33.56/24.04 = 1.40$ in²/rib

$M_{CInt}^- = 0.75\ M_{Int}^- = 194.75$ k′; i.e., 194.75 k′/8′ = 24.34 k′/′; $A_{sCInt}^- = 24.34/24.04 = 1.01$ in²/′

$\therefore$ Total middle strip moments are

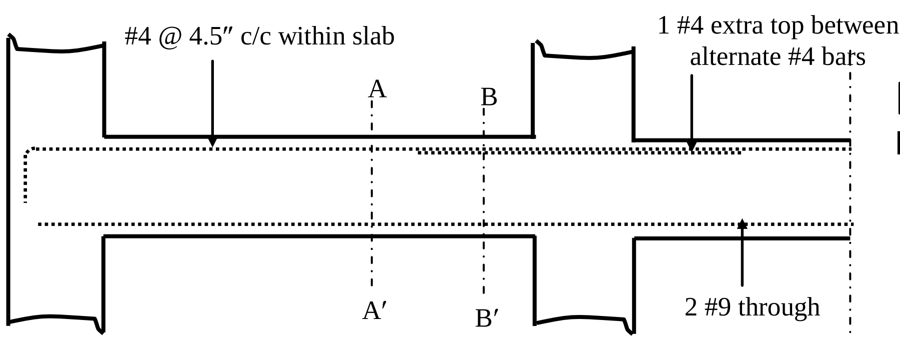
$M_{MInt}^- = 259.67 - 194.75 = 64.92$ k′; i.e., 64.92 k′/8′ = 8.11 k′/′; $A_{sMInt}^- = 8.11/24.04 = 0.34$ in²/′

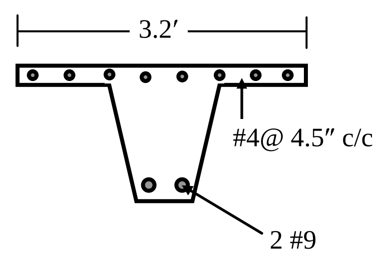
$M_M^+ = 139.82 - 83.89 = 55.93$ k′; i.e., 55.93 k′/2.5 rib = 22.37 k′/rib; $A_{sM}^+ = 22.37/24.04 = 0.93$ in²/rib

$M_{MInt}^- = 259.67 - 194.75 = 64.92$ k′; i.e., 64.92 k′/8′ = 8.11 k′/′; $A_{sMInt}^- = 8.11/24.04 = 0.34$ in²/′

Denoting slab reinforcement by in^2/′ (–ve) and rib reinforcement by in^2/rib (+ve highlighted)

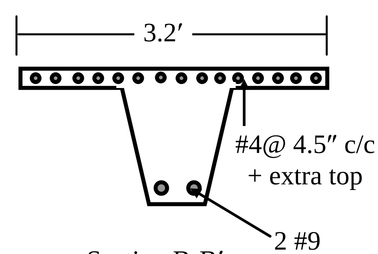
–0.54	2.07	–1.09	–1.01	1.40	–1.01	–1.09	2.07	–0.54
0.00	1.38	–0.36	–0.34	0.93	–0.34	–0.36	1.38	0.00
–0.54	2.07	–1.09	–1.01	1.40	–1.01	–1.09	2.07	–0.54
–0.54	2.07	–1.09	–1.01	1.40	–1.01	–1.09	2.07	–0.54
0.00	1.38	–0.36	–0.34	0.93	–0.34	–0.36	1.38	0.00
–0.54	2.07	–1.09	–1.01	1.40	–1.01	–1.09	2.07	–0.54
–0.54	2.07	–1.09	–1.01	1.40	–1.01	–1.09	2.07	–0.54
0.00	1.38	–0.36	–0.34	0.93	–0.34	–0.36	1.38	0.00
–0.54	2.07	–1.09	–1.01	1.40	–1.01	–1.09	2.07	–0.54



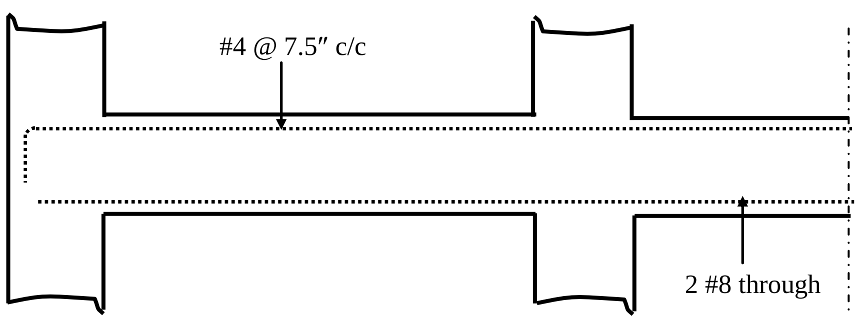


Section A-A′

Ribs within Column Strip



Section B-B′



Ribs within Middle Strip