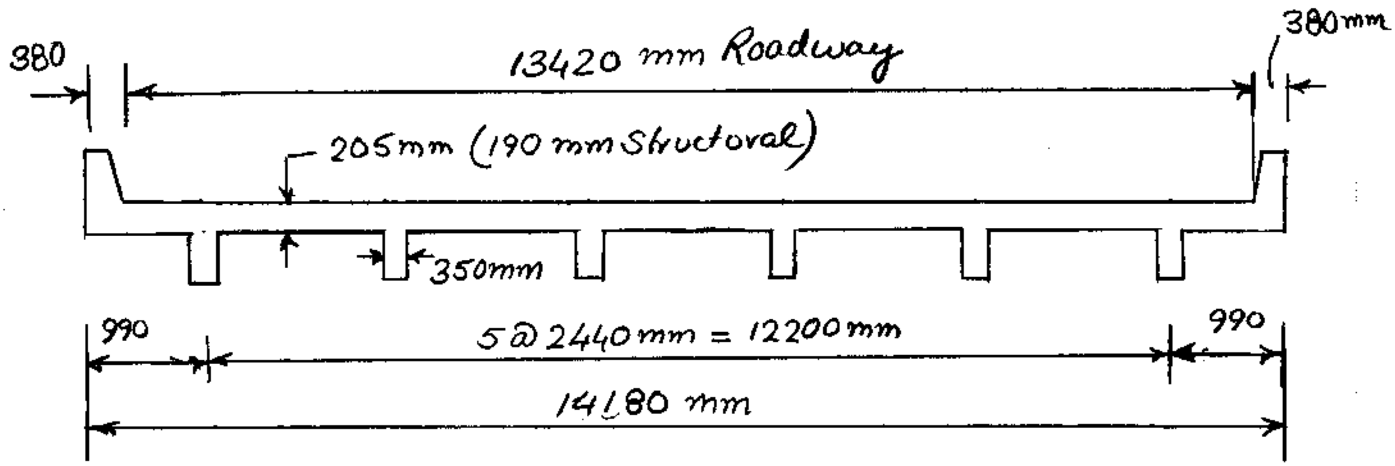
CONCRETE DECK DESIGN

Example 7.10.1 Barker & Puckett

Use the approximate method of Analysis to design the deck of the reinforced concrete T-Beam Bridge shown below for HL-93 Live Load. The T-Beams supporting the deck are at 2440 mm c/c and have a stem width of 350 mm. The deck overhang is approximately 0.4 times the spacing between T-Beams.

Allow for sacrificial wear of 15 mm of concrete surface and for a future wearing surface of 75 mm thick bitominous overlay. Use $f_c' = 30\,MPa$, $f_Y = 400\,MPa$ and Compare the deck design with the design obtained by the Emperical Method of [A 9.7.2]



Example 7.10.1 Barker & Puckett

Deck Thickness

Minimum thickness of concrete deck Slab [A 9.7.1.1] $= 175$ mm

Minimum Deck Thickness to control deflections for continuous spans [A 2.5.2.6.3-1] $= \dfrac{S + 3000}{30} \geq 165$ mm

$= \dfrac{2440 + 3000}{30} = 181.3$ mm

Governs

Use Slab Thickness h_s $= 190$ mm for structural Thickness

Allowance for sacrifical thickness $= 15$ mm

$\Rightarrow$ Thickness for Dead Weight of Deck Slab $= h = 190 + 15 = 205$ mm

Thickness of Deck Slab in Overhang portion $= h_o = \quad = 230$ mm

Weights of Components

Ref Table A 3.5.1-1

Weights of components for 1 mm width

Concrete Barrier $= P_b$ $= 2400 \times 10^{-9}$ Kg/mm^3 $\times 9.81 \times 197{,}325$ mm^2

$= \quad = 4.65$ N/mm^2

Future Wearing Surface $= w_{DW}$ $= 2250 \times 10^{-9} \times 9.81 \times 75 = 1.66 \times 10^{-3}$

Slab 205 mm thick $= w_s$ $= 2400 \times 10^{-9} \times 9.81 \times 205 = 4.83 \times 10^{-3}$

Cantilever Overhang 230 mm thick $= w_o$ $= 2400 \times 10^{-9} \times 9.81 \times 230 = 5.42 \times 10^{-3}$ N/mm^2

Example 7.10.1 Barker & Puckett

Bending Moments & Forces

For Analysis of Decks, Approximate Analysis of strips is acceptable [A.9.6.1]

+ive Design moment = Max +ive moment in any panel

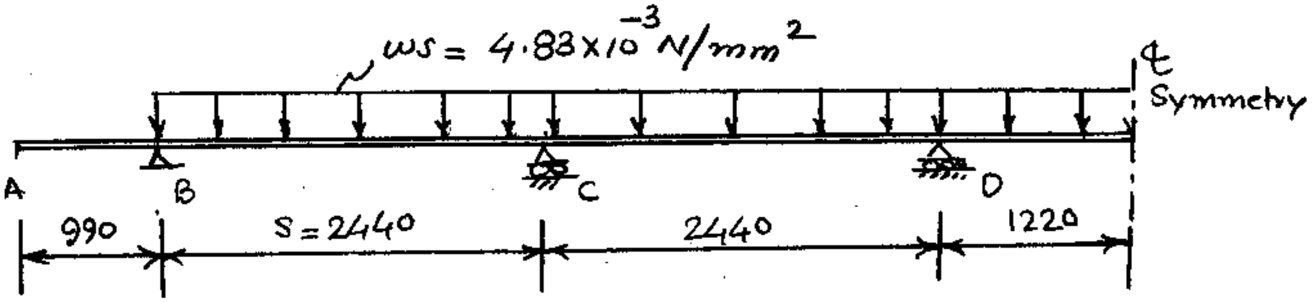
−ive Design moment = Max −ive moment over any girder

[Ref: A 4.6.2.1-1]

Deck Slab

$h = 205\ mm$, $w_s = 4.83 \times 10^{-3}\ N/mm^2$ $S = 2440\ mm\ c/c$

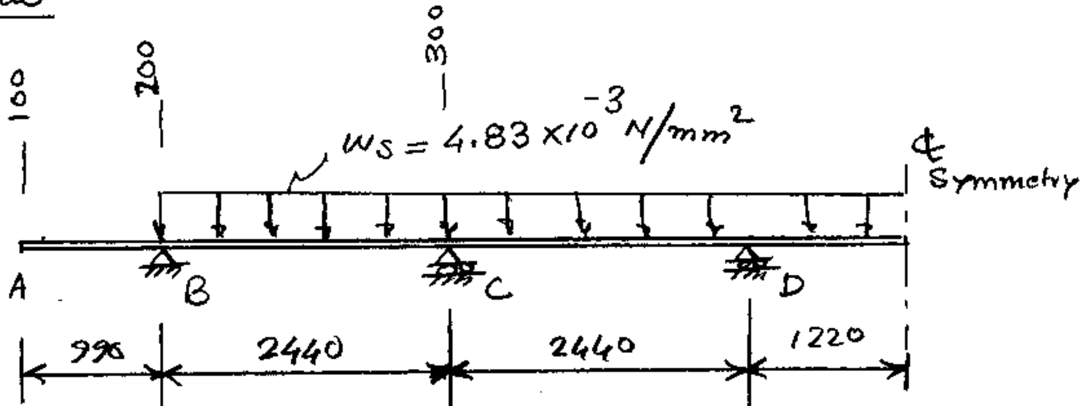
$$FEM = \pm\frac{w_s S^2}{12} = \frac{4.83\times10^{-3}\times(2440)^2}{12} = \pm 2396\ N\text{-}mm$$



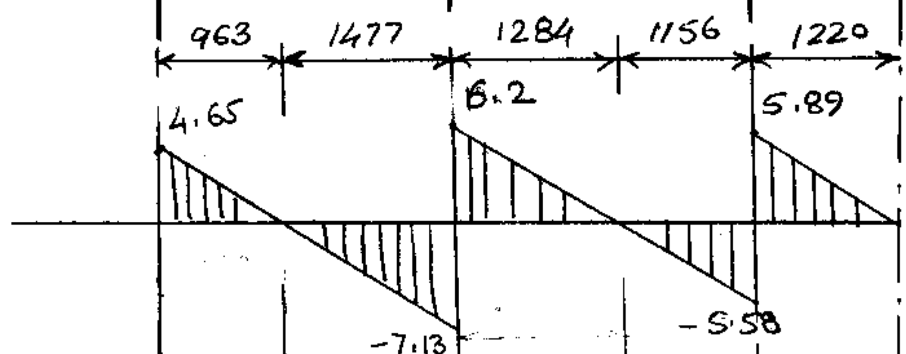
	Stm 100	200	300		
Rel. K	3		4		2
Dist. Factor	1.0	0.429	0.571	0.667	0.333
C.O Factor	0.5	0.5	0.5	0.5	0.5
FEM	2396	−2396	2396	−2396	2396
	−2396	−1198			
		+513	+684	+342	
			−114	−228	−114
		+48.9	+65.1	+32.6	
			−10.85	−21.7	−10.9
		+4.65	+6.2		
End Moment	0	−3027	+3027	−2271	+2271

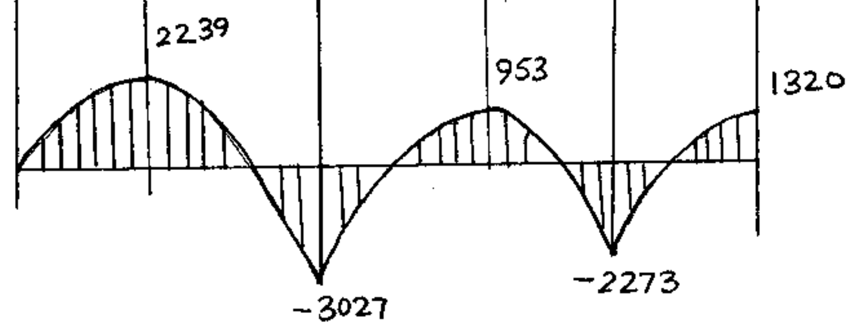
Example 7.10.1 Barker & Puckett

Deck Slab



End Moment	0	−3027	+3027	−2271	+2271
Span Reactions Dead Load	+5.89	+5.89	+5.89	+5.89	+5.89
Span Reaction Moments	−1.24	+1.24	+0.31	−0.31	—
Total Reaction N/mm	4.65	7.13	6.2	5.58	5.89





Max +ive moment $= M_{204} = 2239 \simeq 2240$ N-mm/mm

Max −ive moment $= M_{300} = -3027$ N-mm/m.

Example 7.10.1 Barker & Puckett

Deck Slab

Deck-Slab Analysis using Influence Coefficients

Using Coefficients in Table A-1 of Appendix A

$$R_{200} = R_B = w_s \times (\text{Net Area w/o Cantilever}) \times S$$

$$= 4.83 \times 10^{-3} \times 0.3928 \times 2440 = \underline{4.63} \text{ N/mm}$$

$$M_{204} = \quad = w_s \times (\text{Net Area w/o Cantilever}) \times S^2$$

$$= 4.83 \times 10^{-3} (0.0772) \times (2440)^2 = \underline{2220} \text{ N-mm/mm}$$

$$M_{300} = \quad = w_s \times (\text{Net Area w/o Cantilever})\, S^2$$

$$= 4.83 \times 10^{-3} (-0.1071) \times (2440)^2 = \underline{-3080} \text{ N-mm/mm}$$

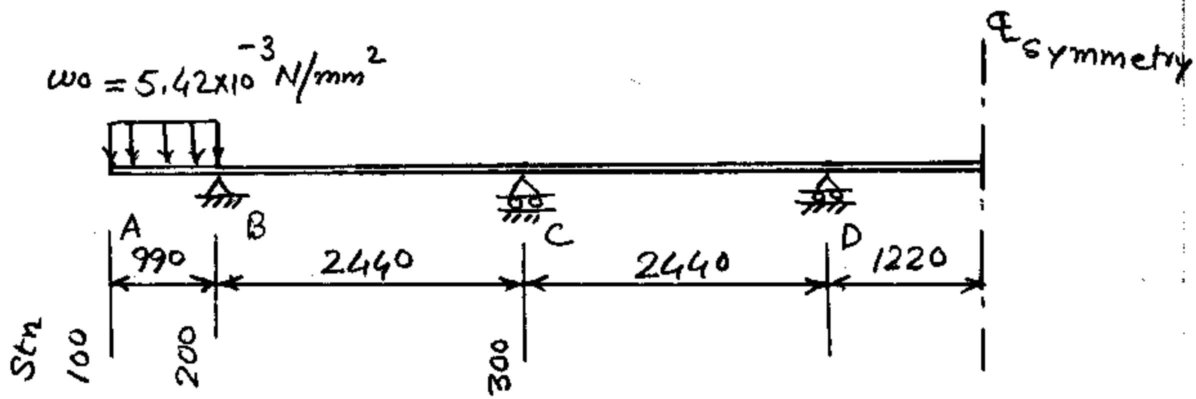
* Examination of the Exact Analysis from Moment Distribution and the Influence Line Coefficients A.1 show that they are in excellent agreement with each other.

2. Overhang Portion Load

Parameters
$h_o = 230$ mm
$w_o = 5.42 \times 10^{-3}$ N/mm^2
$L = 990$ mm.

Example 7.10.1 Barker & Puckett

Overhang Portion Loading



Using Influence Line coefficients Table A-1 in Appendix A

$M_{200} = w_0 \times (\text{Net Area Cantilever}) \times L^2$

$= 5.42 \times 10^{-3} (-0.50) \times (990)^2 \qquad = -2656$ N-mm/m

$M_{204} = 5.42 \times 10^{-3} (-0.2460) \times (990)^2 \qquad = -1307$ N-mm/m

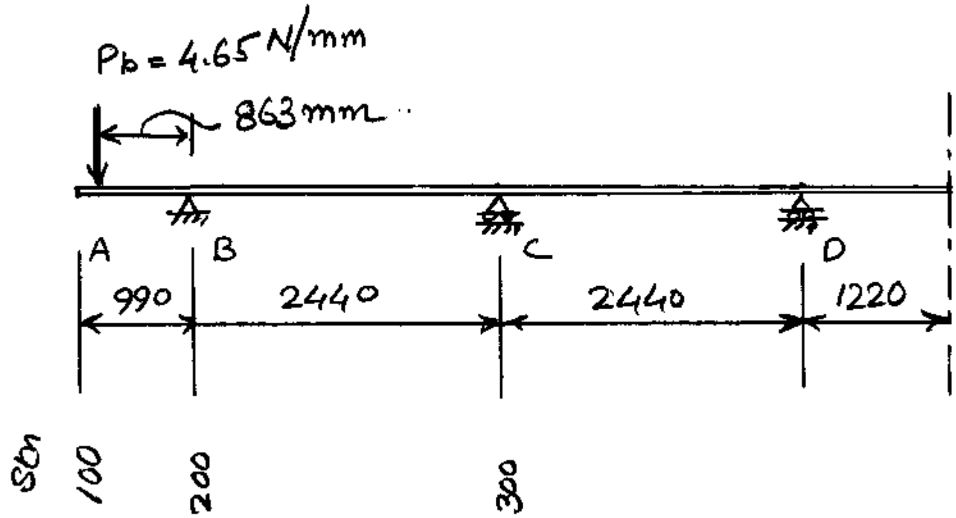
$M_{300} = 5.42 \times 10^{-3} (0.1350) \times 990 \qquad = 717$ N-mm/m

Example 10.7.1 Barker & Puckett

Barrier Load

P_b = Barrier Load = 4.65 N/mm

L = 990 − 127 = 863 mm



$$R_{200} = P_b \times \text{Influence Line Ordinate} \times$$
$$= 4.65 \times \left(1.0 + 1.27 \times \frac{L}{S}\right)$$
$$= 4.65 \times \left(1.0 + 1.27 \times \frac{863}{2440}\right) = 6.74 \text{ N/mm}$$

$$M_{200} = P_b \times \text{Influence Line Ordinate} \times L$$
$$= 4.65 \times (-1.0) \times 863 = -4013 \text{ N-mm/mm}$$

$$M_{204} = 4.65 \times (-0.492) \times 863 = -1974 \text{ N-mm/mm}$$

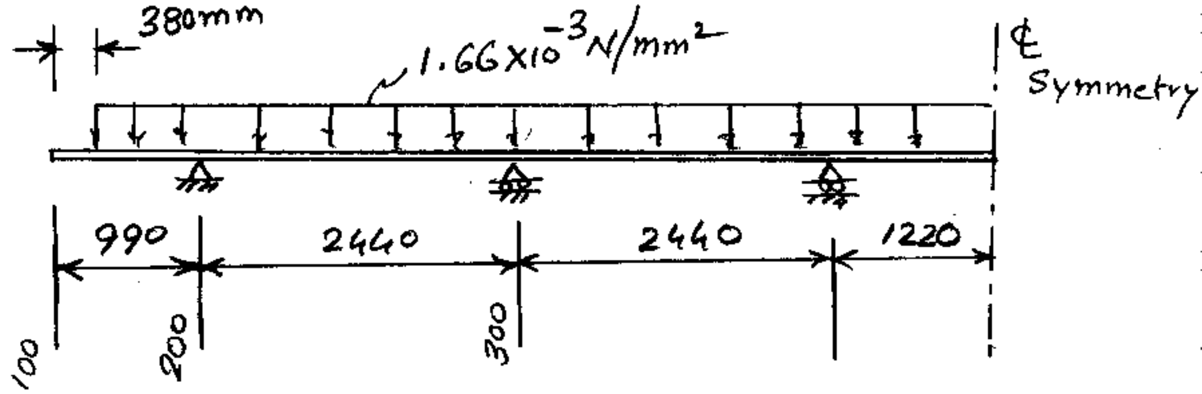
$$M_{300} = 4.65 \times (0.270) \times 863 = 1083 \text{ N-mm/mm}$$

Example 10.7.1 Barker & Puckett

Future wearing Surface Loading

Future Wearing Surface = FWS = w_{DW} $= 1.66 \times 10^{-3}\ N/mm^2$

The loading is placed curb to curb as shown below:



L = Length of Cantilever Portion $= 990 - 380 = 610\,mm$

$$R_{200} = w_{DW}\left[\text{Net area cantilever} \times L + \text{Net area w/o Cantilever} \times S\right]$$

$$= 1.66 \times 10^{-3}\left[\left(1.0 + 0.635\,\frac{L}{S}\right)L \quad + \quad 0.3928)\,S\right]$$

$$= 1.66 \times 10^{-3}\left[\left(1.0 + 0.635 \times \frac{610}{2440}\right)610 \;+\; (0.3928)\,2440\right]$$

$$= 2.76\ N/mm$$

$$M_{200} = w_{DW}\left[(\text{Net area Cantilever})\,L^2\right.$$

$$= 1.66 \times 10^{-3} \times (-0.50)(610)^2 \qquad = -309\ N\text{-}mm$$

$$M_{204} = w_{DW}\left[(\text{Net area Cantilever}) \times L^2 + (\text{Net area w/o Cantilever})\,S^2\right]$$

$$= 1.66 \times 10^{-3}\left[(-0.246)(610)^2 + (0.0772)(2440)^2\right] = 611\ N\text{-}mm/m$$

$$M_{300} = 1.66 \times 10^{-3}\left[(0.135)(610)^2 + (-0.1071)(2440)^2\right] = -975N\text{-}mm/$$

Example 10.7.1 Barker & Puckett

Vehicle Live Load

strip to be designed for 145 KN axle load [A 3.6.1.3.3]
Design truck to be placed such that center of the wheel is not closer than 300 mm from curb for the design of overhang and 600 mm from the edge of 3600 mm wide design lane for design of all other components [A3.6.1.3.1]

The width of equivalent interior transverse strip (mm) over which the wheel load may be considered to be distributed is given as Table [A 4.6.2.1.3-1]:

- Overhang 1140 + 0.833 X
- Positive moment : 660 + 0.55S
- Negative Moment : 1220 + 0.25 S

where,

X = distance from wheel load to centerline of Support.
S = c/c spacing of beams.

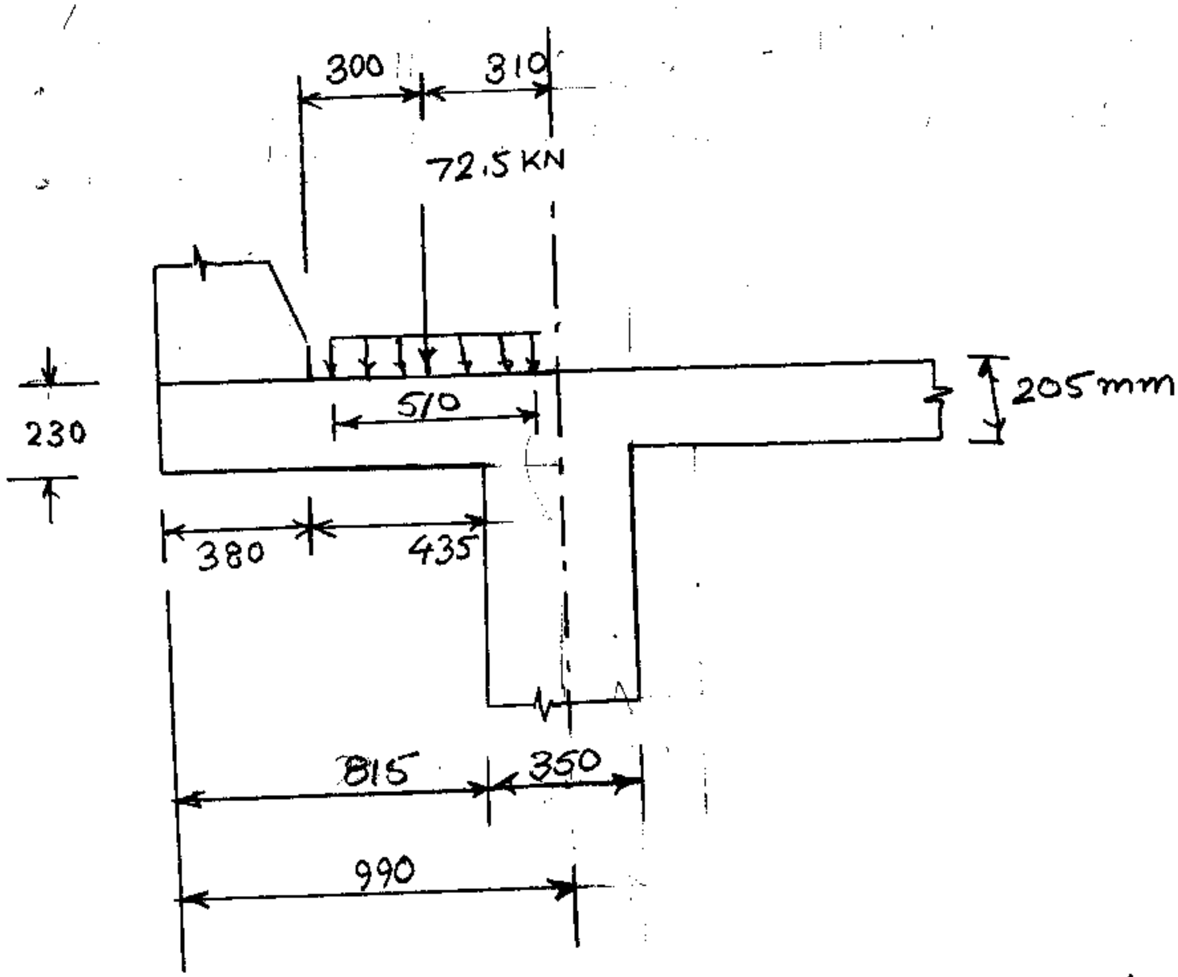
Tire Contact area is a rectangle with width = 510 mm and length $= l = 2.28\,\gamma\left(1+\frac{IM}{100}\right)P$

IM = Dynamic load allowance = 33%
P = Wheel Load = 72.5 KN
γ = Load Factor = 1.75

$$l = 2.28 \times 1.75\left(1+\frac{33}{100}\right)72.5 = 385\ \text{mm}.$$

Example 10.7.1 Barker & Puckett

Vehicle Line Load



X = distance from wheel load to ℄ of girder

= 310 mm

Equivalent strip widths

- Overhang : 1140 + 0.833X = 1140+0.833×310 = 1400 m
- Positive Moment : 660 + 0.55S = 660+0.55×2440 = 2000 m
- Negative Moment : 1220 + 0.25S = 1220+0.25×2440 = 1830 m

Example 10.7.1 Barker & Puckett

Overhang Negative Live Load Moment

Critical placement of wheel for negative BM in overhang portion is shown in the previous Figure

$$\text{Number of Design Lanes} = INT\left(\frac{13420}{3600}\right) = INT(3.7) = 3$$

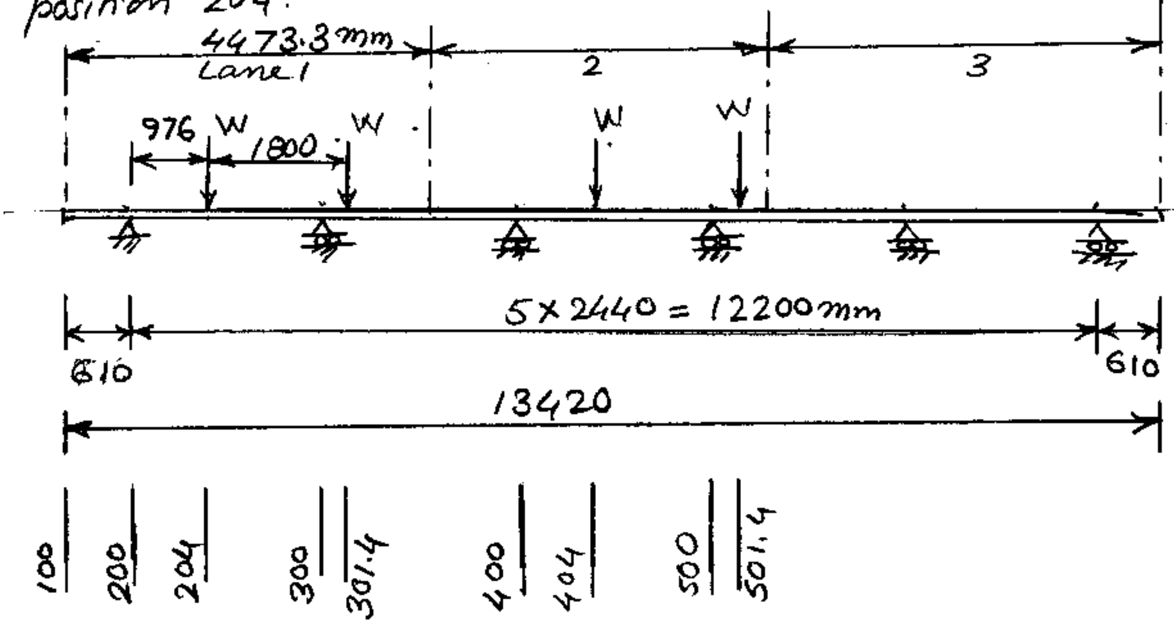
$$M_{200} = -\frac{(72.5 \times 10^3) \times 310}{1400 \text{ mm}} = -16{,}054 \text{ N-mm/mm}$$

$$= -16.054 \text{ KN-mm/mm}$$

$$M_{200} = \underbrace{1.2}_{\text{multiple presence factor one lane loaded.}} \times -16.054 = -19.26 \text{ KN-mm/mm}$$

Maximum Positive Live Load Moment

For repeating equal spans max positive moment occurs @ 0.4S position in first span i.e at position 204.



Example 10.7.1 Barker & Puckett

Max positive moment

one lane loaded, using influence coefficients in Table A.1

$$R_{200} = 1.2\,(0.5100 - 0.0486)\,\frac{72.5\times10^3}{2000\cdot mm} = 20.1\ N/mm$$

$$M_{204} = \underbrace{1.2}_{\text{multiple presence factor}}\,(0.2040 - 0.0195)\times 2440 \times \frac{72.5\times10^3}{2000} = 19{,}580\ N\text{-}mm/mm$$

Max Positive Moment 2-Lanes loaded

$$R_{200} = 1.0\,(0.5100 - 0.0486 + 0.0214 - 0.0039)\times\frac{72.5\times10^3}{2000}$$

$$= 17.4\ N/mm$$

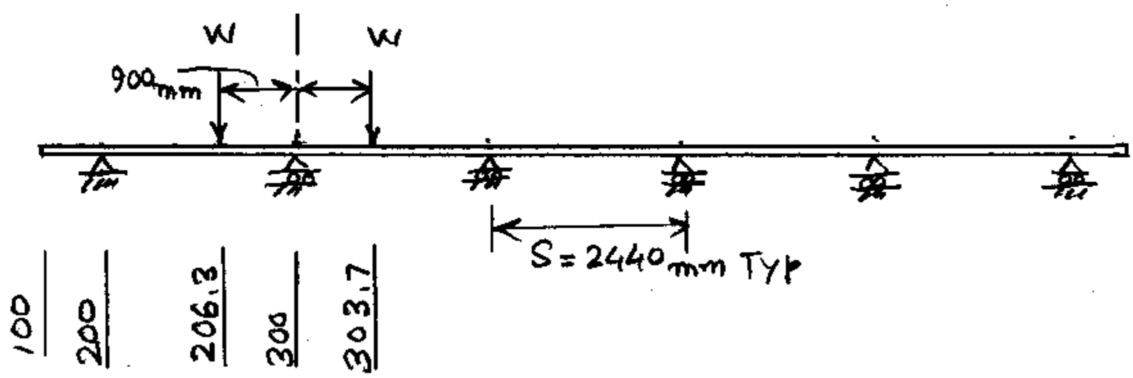
$$M_{204} = 1.0\,(0.2040 - 0.0195 + 0.0086 - 0.0016)\times 2440 \times \frac{72.5\times10^3}{2000}$$

$$= 16900\ Nmm/mm$$

⇒ One exterior Lane loaded governs

Maximum Interior Negative Live Load Moment

The critical placement for -ive moment is for the loads to be on each side of the first interior support as shown below:

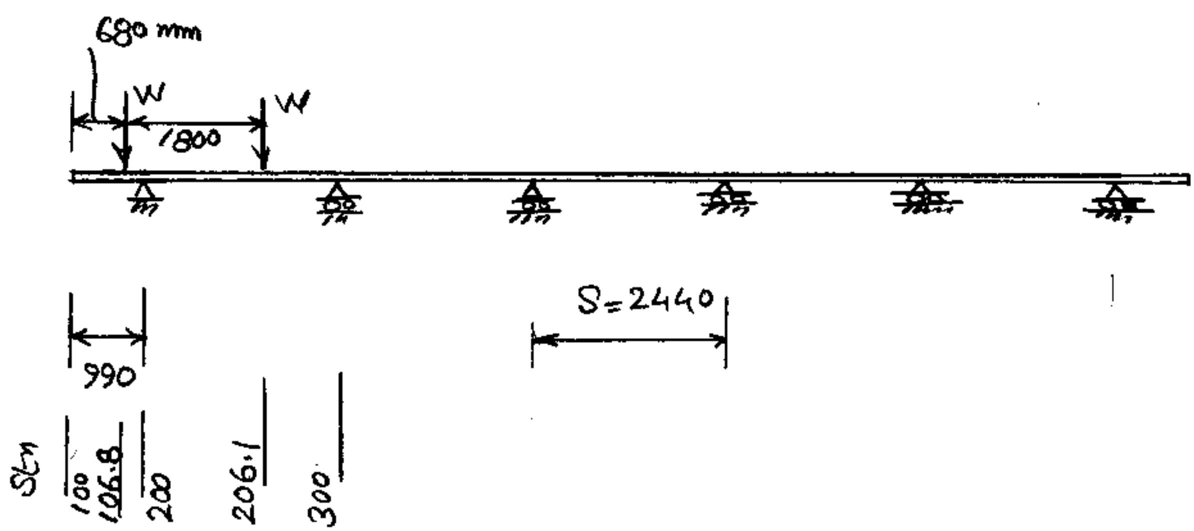


Max Interior -ive live load

$$M_{300} = 1.2\left(-0.1007 - 0.0781\right) \times 2440 \times \frac{72.5 \times 10^3}{1830}$$

$$= -20{,}740 \text{ Nmm/mm}.$$

Max Live Load Reaction on Exterior Girder



$$R_{200} = 1.2\left(1.1614 + 0.2869\right)\frac{72.5 \times 10^3}{1400} = 90.0 \text{ N/mm}$$

Example 10.7.1 Barker & Puckett

Strength Limit State

The combined effect of loads considered so far can be stated as:

$$\eta \sum \gamma_i Q_i = \eta \left[\gamma_p DC + \gamma_p DW + 1.75 (LL + IM) \right]$$

where

$$\eta = \text{Load Modifier} = \eta_D \eta_R \eta_I \geqslant 0.9$$

[A 1.3.2.1-2]

$\eta_D = 0.95$

$\eta_R = 0.95$

$\eta_I = 1.05$

$$\Rightarrow \eta = \eta_D \eta_R \eta_I = (0.95)(0.95)(1.05) = 0.95$$

$IM = 33\%$

$\gamma_p = 1.25, 1.5$

Combining all the force effects, from all loadings

$$R_{200} = 0.95\left[1.25(4.63 + 6.75 + 6.74) + 1.5(2.76) + 1.75(1.33)(90.0)\right] = 224.5 \text{ N/mm}$$

$$M_{200} = 0.95\left[1.25(-2656 - 4013) + 1.5(-309) + 1.75(1.33)(-19260)\right] = -50950 \text{ N-mm/mm} = 50.95 \text{ KN-mm/mm}$$

$$M_{204} = 0.95\left[1.25(2220) + 0.9^{*}(-1307 - 1974) + 1.5(611) + 1.75(1.33)(19580)\right] = 44000 \text{ N-mm} = 44.0 \text{ KN-mm}$$

* - Minimum Load Factor Applied.

Example 10.7-1 Barker & Puckett

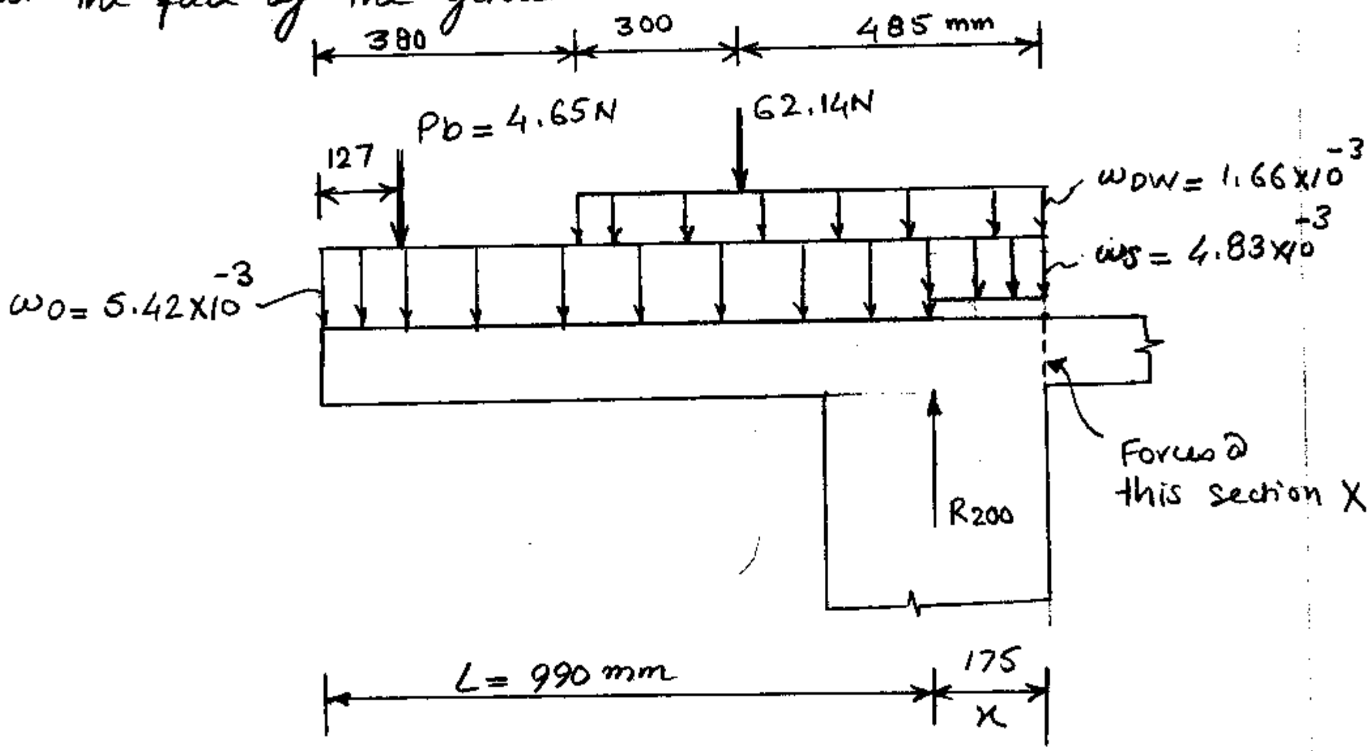
Strength Limit State

$$M_{300} = 0.95\left[1.25(-3080) + 0.9^{*}(717+1083) + 1.5(-975) + 1.75(1.33)(-20740)\right] = -49370$$

$$= -49.37 \text{ KN-mm}$$

Note: M_{200} and M_{300} are almost equal $\simeq -50$. KN-mm/mm

The computed moments may be reduced to their value at the face of the girder.



$$\text{Equivalent wheel Load/mm} = \frac{72.5\times10^{3}\times1.2}{1400 \text{ mm}} = 62.14 \text{ N/mm}.$$

Example 10.7.1 Barker & Puckett

Forces @ Girder Face

Deck Slab

$$M_x = -\frac{1}{2} w_s x^2 + R_{200} \cdot x$$

$$= -\frac{1}{2}\, 4.83\times10^{-3} (175)^2 + 4.63 \times 175 \qquad = 736 \text{ N-mm/mm}$$

Overhang

$$M_x = -w_O L \left(\frac{L}{2} + x\right) + R_{200} \cdot X$$

$$= -5.42\times10^{-3} \times 990 \left(\frac{990}{2} + 175\right) + 6.75 \times 175 = -2414 \text{ N-mm}$$

Barrier

$$M_x = -P_b (L + x - 127) + R_{200} \cdot X$$

$$= 4.65 (990 + 175 - 127) + 6.74 \times 175 \qquad = -3647$$

Future Wearing Course

$$M_x = -\frac{1}{2} w_{DW} (L + x - 380)^2 + R_{200} \cdot x$$

$$= -\frac{1}{2} \times 1.66\times10^{-3} (990 + 175 - 380)^2 + 2.76 \times 175 = -28$$

Live Load

$$M_x = -P_b (485) + R_{200} \cdot x$$

$$= -62.14 \times 485 + 90 \times 175 \qquad = -14388$$

Strength Limit State Moment @ X

$$M_{200.72} = 0.95 \left[0.9 \times 736 + 1.25 (-2414 - 3647) + 1.5 \times (-28) + 1.75 \times 1.33 \times (-14388) \right] = -38420 \text{ N-mm}$$

$= -38.42$ KN-mm

* Note* & Modified Moment -30.42 KN-mm/mm is 23% less than unmodified moment -50.98 KN-mm

Example 10.7.1 Barker & Puckett

Reinforcement Design.

$$f_c' = 30 \text{ MPa}$$
$$f_y = 400 \text{ MPa}$$

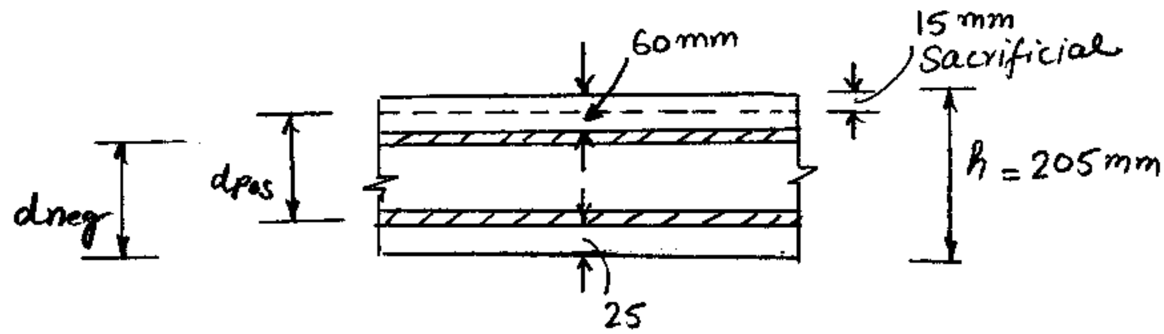
Concrete Cover Requirements [A 5.12.3-1]

Deck surface subject to wear = 60 mm.

Bottom of CIP Slabs = 25 mm

Use No. 15 bars $d_b = 16\text{ mm}$, $A_b = 200\text{ mm}^2$

Effective Depths of Slab



$$d_{pos} = 205 - 15 - 25 - 16/2 = 157 \text{ mm}$$

$$d_{neg} = 205 - 60 - 16/2 = 137 \text{ mm}$$

$$\phi M_n = \phi A_s f_y \left(d - a/2\right)$$

where,
$$a = \frac{A_s f_y}{0.85 f_c' b}$$

Assuming
$$\left(d - a/2\right) \simeq jd = 0.92\, d$$

$$\Rightarrow \boxed{A_s \simeq \frac{M_u/\phi}{f_y\, jd}}$$

Example 10.7.1 Barker & Puckett

Reinforcement Design

$$A_s \simeq \frac{(M_u/\phi)}{f_y(jd)}$$

For $j = 0.92$, $f_y = 400$, $\phi = 0.9$

$$A_s = \frac{M_u}{0.9 \times 400 \times 0.92 d}$$

$$A_s \simeq \frac{M_u}{330 d}$$

Minimum reinforcement for components containing no prestressing steel

$$\rho = \frac{A_s}{bd} \geqslant 0.03 \frac{f_c'}{f_y}$$

In the present case

$$\min A_s = 0.03 \frac{f_c'}{f_y} \cdot b d$$

$$\min A_s = 0.03 \times \frac{30}{400} \times (1) \, d = 0.00225 d \ \frac{mm^2}{mm}$$

max spacing of primary reinforcement for slabs is

$1.5 h$ or 450 mm [A5.10.3.2]

$1.5 \times 190 = \underline{285 \text{ mm}}$ governs

Example 10.7.1 Barker & Puckett

Reinforcement Design

Positive Moment Reinforcement

A_b #15 bar $= 200\ mm^2$

$M_u^+ = 44000\ N\text{-}mm/mm$, $d_{pos} = 157\ mm$

$$A_s \simeq \frac{M_u}{330\, d} = \frac{44000}{330 \times 157} = 0.85\ mm^2/mm$$

$$\min A_s = 0.00225\, d = 0.00225 \times 157 = 0.35\ mm^2/mm$$

OK

$$\text{spacing} = S = \frac{A_b}{A_{req}}$$

$$S = \frac{200\ mm^2}{0.85} = 235\ mm\ c/c$$

use 225 mm c/c

$$A_s \text{ provided} = \frac{A_b}{S} = \frac{200}{225} = 0.889\ mm^2/mm$$

$$a = \frac{A_s f_y}{0.85 f_c' b} = \frac{0.889 \times 400}{0.85 \times 30 \times 1} = 14\ mm$$

Check Moment Capacity

$$\phi M_n = M_u = \phi A_s f_y \left(d - a/2\right)$$

$$= 0.9 \times 0.889 \times 400 \left(157 - 14/2\right)$$

$$= 48{,}000\ N\text{-}mm/mm > M_u^+ (44000\ N\text{-}mm/mm)$$

OK

For Transverse bottom bars use #15 @ 225 mm c/c

Example 10.7.1 Barker & Puckett

Negative Moment Reinforcement

$$M_u^- = 38.42 \text{ KN-mm/mm} = 38{,}420 \text{ N-mm/mm}$$

$$d_{neg} = 137 \text{ mm.}$$

$$\text{trial } A_s = \frac{M_u}{330\,d} = \frac{38420}{330 \times 137} = 0.85 \text{ mm}^2/\text{mm.}$$

$$\min A_s = 0.00225\,d = 0.00225 \times 137 = 0.31 \text{ mm}^2/\text{mm}$$

OK

$$\text{Spacing} = S = \frac{A_b}{A_{req}} = \frac{200}{0.85} = 235 \text{ mm c/c}$$

use 225 mm c/c

$$A_s \text{ provided} = \frac{A_b}{S} = \frac{200}{225} = 0.889 \text{ mm}^2/\text{mm}$$

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{0.889 \times 400}{0.85 \times 30 \times 1} = 14 \text{ mm}$$

Check moment Capacity

$$\phi M_n = M_u = \phi A_s f_y \left(d - a/2\right)$$

$$= 0.9 \times 0.889 \times 400 \left(137 - 14/2\right)$$

$$= 41{,}600 \text{ N-mm/mm}$$

$$= 41.6 \text{ KN-mm/mm} > M_u^- \left(38.42 \text{ KN-mm/mm}\right)$$

OK

Example 10.7.1 Barker & Puckett

Distribution Reinforcement

Distribution Reinforcement is %age of primary reinforcement.

$$\text{\%age of Dist Steel} = \frac{3840}{\sqrt{S_e}} \leq 67\%$$

S_e = Effective Span Length
= clear span between girders
= $2440 - 350$ = 2090 mm

$$\text{\%age Dist Steel} = \frac{3840}{\sqrt{2090}} = 84\%$$

use 67%

$$\text{Distribution Steel} = 0.67 \times 0.889 = 0.596\ mm^2/mm$$

Using # 10 bar, $A_b = 100\ mm^2$

$$S = \frac{A_b}{A_{req}} = \frac{100}{0.596} = 167\ mm\ c/c$$

use 150 mm c/c

Use # 10 bars @ 150 mm c/c as distribution Steel.

Temp/Shrinkage Steel

Min Temp/shrinkage steel shall be:

$$\text{min Temp } A_s \text{ per face} \geq 0.75\frac{A_g}{2 f_y} \qquad [A\ 5.10.8-2]$$

$$\geq \frac{0.75\ (205)(1)}{2\ (400)} = 0.192\ mm^2/mm$$

Using # 10 bars

$$S = \frac{A_b}{A_{req}} = \frac{100}{0.192} = 520\ mm\ c/c$$

Use # 10 @ 450 mm c/c OK

Example 10.7.1 Barker & Puckett

Control of Cracking

Cracking is controlled by limiting the tensile stress in reinforcement under service load (f_s) to be less than allowable tensile stress (f_{sa})

$$f_s \leq f_{sa} = \frac{Z}{(d_c A)^{1/3}} \leq 0.6 f_y$$

Z = 23000 N/mm for severe exposure

d_c = depth of concrete from extreme tension fiber to center of closest bar $\leq$ 50 mm.

A = Effective concrete tensile area per bar having the same centroid as the reinforcement

Service Load tensile stress calculated on the basis of transformed elastic section.

$$E_c = 0.043\, \gamma_c^{1.5} \sqrt{f_c'} \qquad [A\ 5.4.2.4]$$

$$\gamma_c = 2400\ \text{Kg/m}^3$$

$$E_c = 0.043 \times (2400)^{1.5} \sqrt{30} = 27{,}700\ \text{MPa}$$

$$\text{Modular Ratio } n = \frac{E_s}{E_c} = \frac{200{,}000}{27{,}700} = 7.22$$

Use 7.0

Example 10.7.1 Barker & Puckett

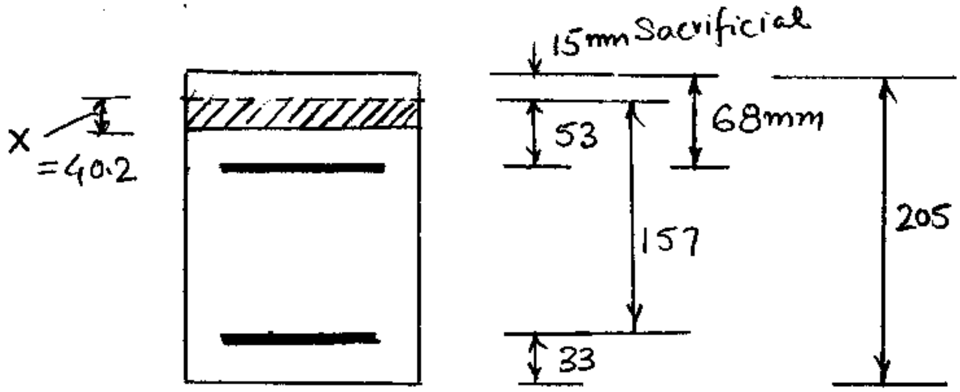
Control of Cracking

Check cracking in +ive Bending

$$M^{+}_{\text{Service}} = M_{DC} + D_{DW} + 1.33\,M_{LL}$$

$$= (2220 - 1307 - 1974) + 611 + 1.33\,(19580)$$

$$= 25600 \text{ N-mm/mm} = 25.6 \text{ KN-mm/mm}$$



Assuming top steel is on tension side

$$0.5\, b\, x^2 = n A_s' (d' - x) + n A_s (d - x)$$

$$0.5\, b x^2 = 7\,(0.889)(53 - x) + 7\,(0.889)(157 - x)$$

$$\Rightarrow \quad x^2 + 24.9x - 2614 = 0$$

$$\Rightarrow \quad x = 40.2 < 53$$ Top steel on tension side

$$I_{cr}\Big|_{x} = \frac{b x^3}{3} + n A_s' (d' - x)^2 + n A_s (d - x)^2$$

$$= \frac{(1)(40.2)^3}{3} + 7 \times 0.889\,(53 - 40.2)^2 + 7.0 \times 0.889\,(157 - 40.2)^2$$

$$= 107{,}600 \text{ mm}^4$$

Example 10.7.1 Barker & Puckett

Crack Control

Tensile stress in bottom steel $= f_s = n \frac{M}{I_{cr}} y$

$$= 7 \times \frac{25{,}600 (157 - 40.2)}{107600}$$

$$= 195 \text{ MPa}$$

The +ive moment tensile steel is located at 33 mm from extreme tension fiber

$\Rightarrow d_c = 33 \text{ mm} \leq 50 \text{ mm}$

$A = 2 d_c . s$

$= 2 \times 33 \times 225 \text{ mm c/c} \quad = 14850 \text{ mm}^2$

$$f_{sA} = \frac{Z}{(d_c \; A)^{1/3}} = \frac{23000}{(33 \times 14850)^{1/3}} = 293 \text{ MPa} > 0.6 f_y = 240$$

use $f_{sA} = 240$ MPa

$f_s \leq f_{sA}$

$195 < 240$ MPa <u>OK</u>

Example 10.7.1 Barker & Puckett

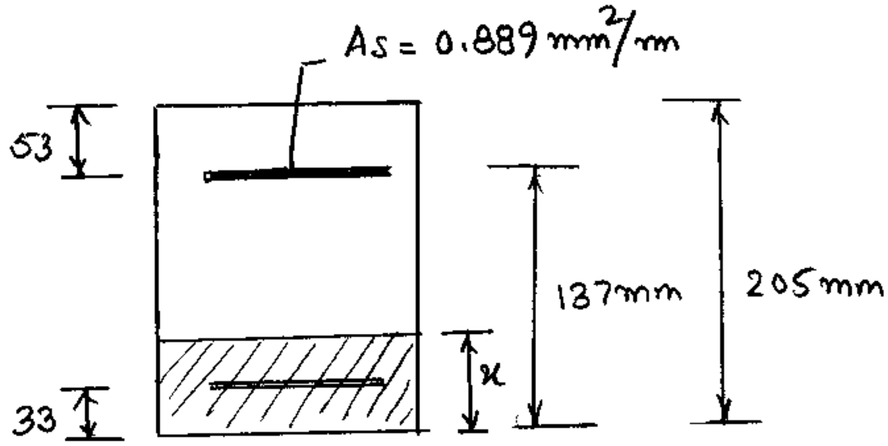
Crack Control

Check Negative Steel

$$M_{200.72} = M_{DC} + M_{DW} + 1.33\,M_{LL}$$

$$= (736 - 2414 - 3647) + (-28) + 1.33(-14388)$$

$$= -24{,}490 \text{ N-mm/mm} = -24.49 \text{ kN-m/mm}$$



$$0.5\,b x^2 + (n-1) A_s' (x - d') = n A_s (d - x)$$

$$0.5\,(1) x^2 + (7-1)(0.889)(x - 33) = 7\,(0.889)(137 - x)$$

$$x^2 + 23.1x - 2057 = 0$$

$$\Rightarrow \quad x = 35.3 \text{ mm.}$$

$$I_{cr} = \frac{1}{3}(1)(35.3)^3 + 6\,(0.889)(35.3 - 33)^2 + 7(0.889)(137 - 35.3)^2$$

$$= 79{,}050 \text{ mm}^4$$

Tensile Stress topsteel $= f_s = n \dfrac{M}{I_{cr}} y = 7 \times \dfrac{24490}{79050} \times (137 - 35.3)$

$$= 221 \text{ MPa}$$

Example 7.10.1 Barker & Puckett

Crack Control

Check of negative Steel

Top tensile steel is located @ 53 mm from extreme tension fiber, therefore

$dc = 53 \text{ mm} \leqslant 50$

$A = 2dc \cdot S = 2 \times 50 \times 225 = 22500 \text{ mm}^2$

$$f_{sa} = \frac{Z}{[dc\ A]^{1/3}} = \frac{23000}{(50 \times 22500)^{1/3}} = 222 \text{ MPa} < 0.6 f_y$$

$f_s \leqslant f_{sa}$

$221 < 222$ MPa <u>OK</u>

Example 10.7.1 Barker & Puckett

Empirical Design of Deck Slab

Research has shown that the primary structural action of concrete decks is NOT Flexure, but internal arching. The arching creates an internal compressive dome requiring minimum amount of isotropic reinforcement [C 9.7.2.1]

Empirical Design Requirements as per [A 9.7.2.4]

1. Design Conditions

   Design depth excludes the loss due to wear

   $h = 190$ mm

- Supporting components are made of steel or concrete — YES
- Deck is fully CIP and water cured — YES
- $6.0 < \dfrac{S_e}{h} = \dfrac{2090}{190} = 11.0 < 18.0$ — OK
- Core Depth $= 205 - 60 - 25 = 120$ mm > 100 — OK
- Effective Span $= S_e = 2090$ mm < 4100 mm — OK
- Min Slab depth $= 175$ mm < 190 mm — OK
- Overhang $= 990$ mm $> 5h = 5 \times 190 = 950$ — OK
- $f_c' = 30$ MPa > 28 MPa — OK
- Deck to be made composite with girder — YES

Example 7.10.1 Barker & Puckett

Empirical Design

Reinforcement Requirements [A 9.7.2.5]

- Four Layers isotropic reinforcement $f_y \geq 400$ MPa
- Outer Layers placed in direction of effective length
- Bottom layers : min $A_s = 0.570\ mm^2/mm$
  using #15 bars $S = \frac{A_b}{A_{req}} = \frac{200}{0.57} = 350$ mm c/c

  Use #15 bars @ 350 mm c/c
- Top layers : min $A_s = 0.380\ mm^2/mm$
  Use #10 bars $S = \frac{100}{0.38} = 260$ mm c/c

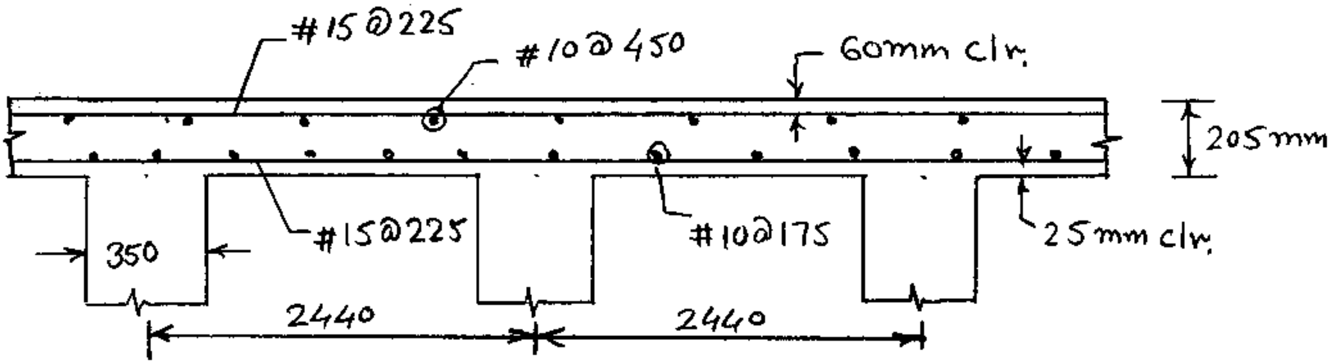
  Use #10 bars @ 250 mm c/c
- Max spacing = 450 mm c/c
- Straight bars only, hooks allowed, no truss bars
- Only lap splices, no welded or mechanical splices per
- Overhang designed for [A 9.7.2.2 and A 3.6.1.3.4]
  - wheel loads using equivalent strip method if barrier discontinuous
  - Equivalent line loads if barrier continuous
  - Collission loads using yield line failure mechanism. [A.A13.2]

Summary

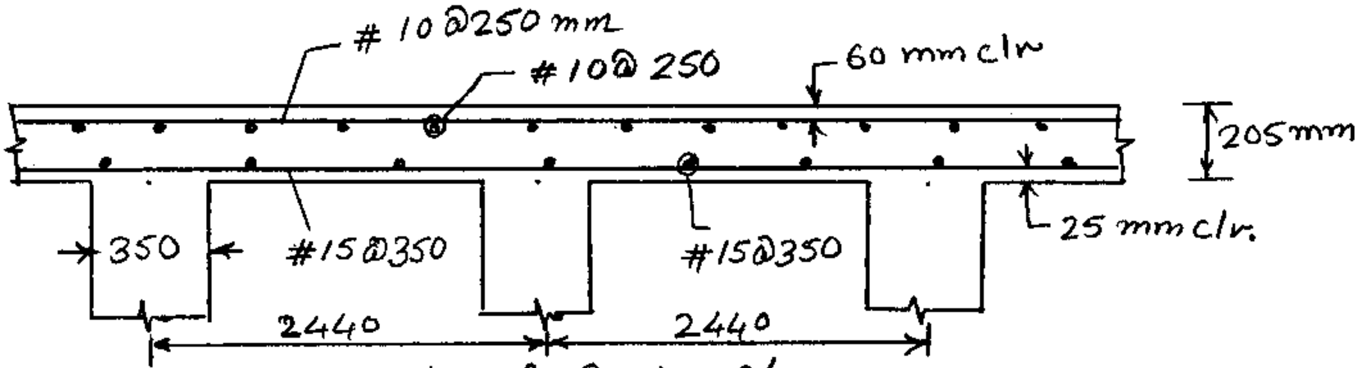
If requirements are met no design is needed and minimum reinforcement is provided.

Example 10.7.1 Barker & Puckett

Comparison of Design Based on Flexural Analysis of Strips and Empirical Design



Traditional Design Based on Flexure of Equivalent Strips



Empirical Design of Interior Deck panels