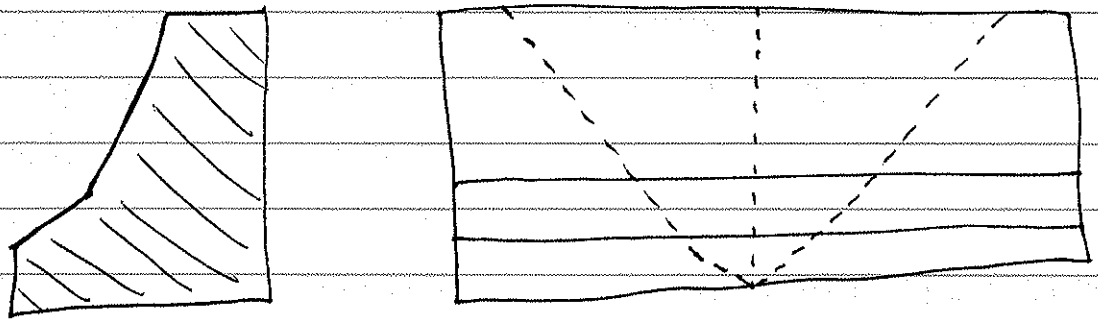
3-15-2013

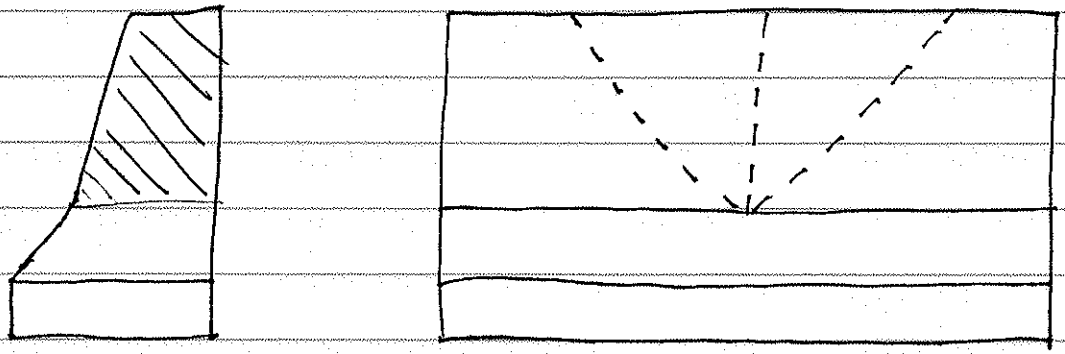
Yield Line Analysis of MN DOT Bridge Rail - Fig. 5-397.117.

* - 2 Possible Fracture Patterns Due to Geometry of Barrier (Safety Shape).

[1] - Full Section Bending/Yielding/Failure.



[2] Top Section Yielding/Failure



- Solve Yield Line For Both Failures.

M_c → Overturning Moment Resistance

1 - Full Section

Base width = 18"

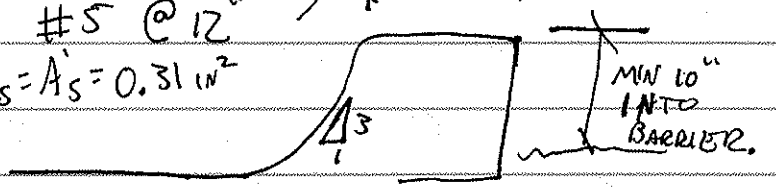
Clear cover (back) = 2 1/4"

$d = 18" - 2\frac{1}{4}" - (5/8)/2 = 15\frac{3}{8}"$

9"

Stirrup → #5 @ 12"

$A_s = A_s' = 0.31\ in^2$



Width of stirrup at deck/barrier interface.

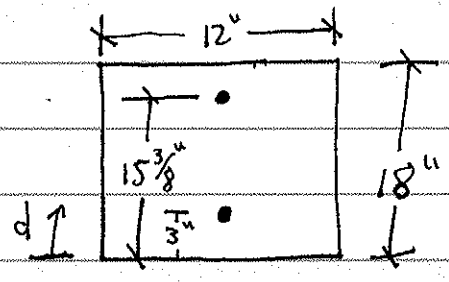
$= 9" + 10"/(3/1) \approx 12\frac{3}{8}"$

$d' = d - 12\frac{3}{8}" = 3"$

$f_y = 60\ ksi$

$f'_c = 4\ ksi$

Idealized shape →



$A_s = 0.31\ in^2$

$d = 15\frac{3}{8}"$

$d' = 3"$

$M_c = 325\ k\text{-}in$

$M_c = 27.1\ k\text{-}ft/ft$

2 - Top Section

Base Width = $10\frac{1}{2} + 2\frac{1}{2} = 13"$

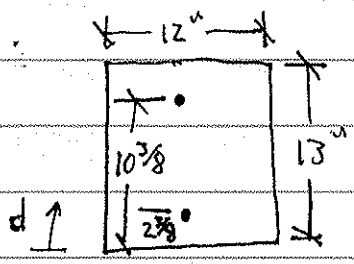
Clear Cover = 2 1/4"

$d = 13" - 2\frac{1}{4}" - (5/8)/2 = 10\frac{3}{8}"$

Front Cover = 2"

$d' = 2\frac{3}{8}"$

Simplified X-Section



$A_s = A_s' = 0.31\ in^2$

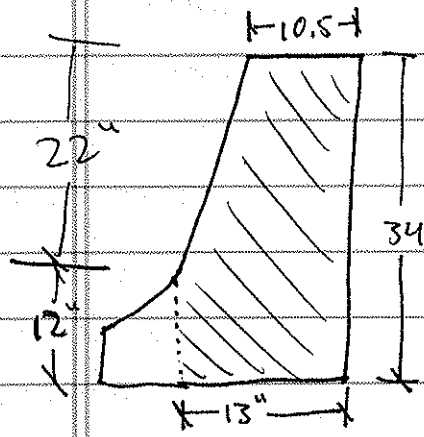
$M_c = 220\ k\text{-}in$

$M_c = 18.3\ k\text{-}ft/ft$

$M_W \rightarrow$ Wall Moment Resistance.

[1] Full Section

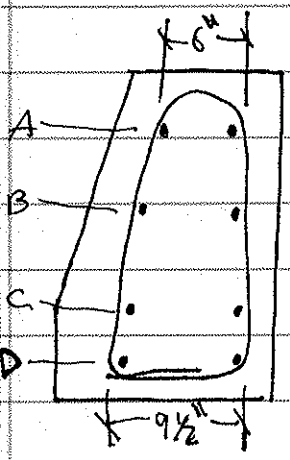
- Ignore Toe of Barrier (no steel anyway).



Ave Width (top) $= (10.5 + 13)/2 = 11\frac{3}{4}"$

Ave Width $= [(11\frac{3}{4} \times 22) + (13" \times 12)]/34 = 12\frac{1}{8}"$

Long. Steel = #4 Bars



Back Row of Steel → $d = 2\frac{1}{4} + \frac{5}{8} + (\frac{1}{2})/2$

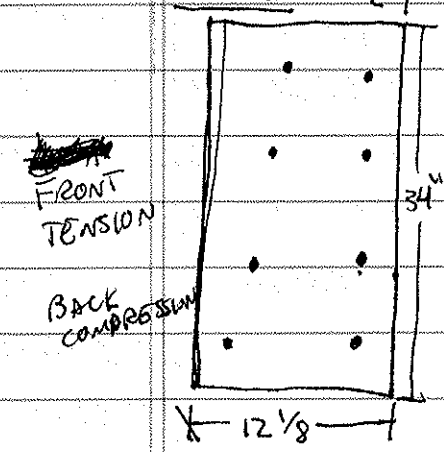
$d = 3\frac{1}{8}"$

$d_A = 3\frac{1}{8} + (6 - \frac{5}{8} - \frac{1}{2}) = 8"$

Assume Even Vert Distribution $\begin{cases} d_B = 9\frac{1}{8}" \\ d_C = 10\frac{3}{8}" \end{cases}$

$d_D = 3\frac{1}{8} + (9\frac{1}{2} - \frac{5}{8} - \frac{1}{2}) = 11\frac{1}{2}"$

Resistance I



$A_S = 0.20\ in^2/bar$

$d' = 3\frac{1}{8}"$ (4)

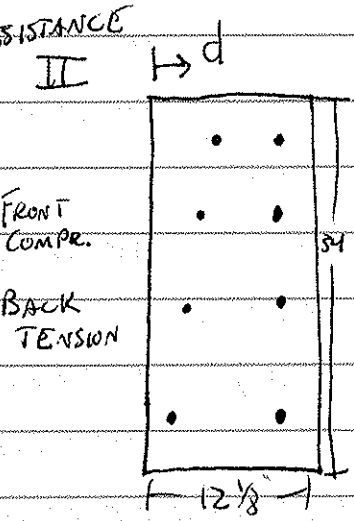
$d_A = 8"$ (1)

$d_B = 9\frac{1}{8}"$ (1)

$d_C = 10\frac{3}{8}"$ (1)

$d_D = 11\frac{1}{2}"$ (1)

Resistance II



$A_S = 0.20\ in^2/bar$

$d = 9"$ (4)

$d'_A = 4\frac{1}{8}"$ (1)

$d'_B = 3"$ (1)

$d'_C = 1\frac{3}{4}"$ (1)

$d'_D = \frac{5}{8}"$ (1)

Average

$M_W = 578$ k-in

$M_W = 17$ k-ft/ft

$M_W = 544$ k-in

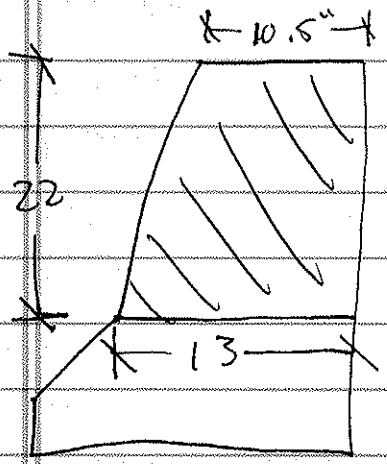
$M_W = 16$ k-ft/ft

$M_W = 510$ k-in

$M_W = 15$ k-ft/ft

M_W - CONTINUED.

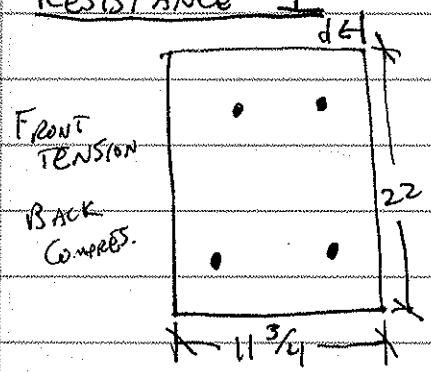
[2] TOP SECTION.



AVE WIDTH = $(10.5" + 13)/2 = 11\frac{3}{4}"$

☆ ONLY TOP 2 ROWS OF STEEL IN TOP PORTION. - SAME (d)s AS PREVIOUSLY CALCULATED.

RESISTANCE I



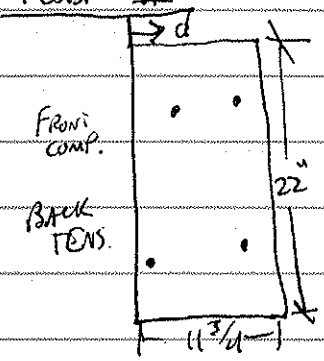
$A_S = 0.20\ in^2/BAR$

$d' = 3\frac{1}{8}"$ (2)

$d_A = 8"$ (1)

$d_B = 9\frac{1}{8}"$ (1)

RESIST II



$A_S = 0.20\ in^2/BAR$

$d = 8.625"$ (2)

$d'_A = 3\frac{3}{4}"$ (1)

$d'_B = 2\frac{5}{8}"$ (1)

AVE.

$M_W = 265$ K-IN

$M_W = 12.05$ K-FT/FT

$M_W = 266.5$ K-IN

$M_W = 12.1$ K-FT/FT

$M_W = 268$ K-IN

$M_W = 12.18$ K-FT/FT

INTERRIOR SECTION

YIELD LINE CALCULATIONS

$$L_{CR} = \frac{\ell}{2} + \sqrt{\left(\frac{\ell}{2}\right)^2 + 8H\frac{(M_B + M_W H)}{M_C}}$$

$$R_W = \frac{8M_B}{L_{CR} - \ell/2} + \frac{8M_W H}{L_{CR} - \ell/2} + \frac{M_C L_{CR}^2}{H(L_{CR} - \ell/2)}$$

LOAD LENGTH ℓ	TEST LEVEL
4 ft	TL-3
3.5 ft	TL-4
8 ft	TL-5

[1] FULL SECTION

$M_B = 0$
$M_C = 27.1$ k-ft/ft
$M_W = 16.0$ k-ft/ft
$H = 34" = 2.83$ ft
$\ell = 3.5$ ft

$L_{CR} = 8.15$ ft
$R_W = 155.9$ kips
$\phi R_W = 140$ kips

[2] TOP SECTION

$M_B = 0$
$M_C = 18.3$ k-ft/ft
$M_W = 12.1$ k-ft/ft
$H = 22" = 1.83$ ft
$\ell = 3.5$ ft

$L_{CR} = 6.31$ ft
$R_W = 126.3$ kips
$\phi R_W = 114$ kips

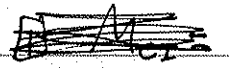
INTERRIOR WALL STRENGTH = 114 KIPS

$114 > 100$ KIPS → MEETS MASH TL-4 STRENGTH

END SECTION YIELD LINE CALCS

M_c VALUES: THE END SECTION (≈ 4 ft) HAS SAME STIRRUPS, BUT AT CONDENSED SPACING.
AVE SPACING ≈ 6" OR ½ OF PREVIOUS INT. SPACING.
• THUS, FOR SIMPLICITY, JUST MULTIPLY INT. M_c VALUES BY 2.

M_w VALUES:
• SINCE END SECTION BENDING ONLY HAS THE SINGLE YIELD LINE, MUST USE RESISTANCE I STRENGTHS.



[1]
$M_c = 27.1 \times 2$
$= 54.2$ k-ft/ft
$M_{w_I} = 17$ k-ft/ft

[2]
$M_c = 18.3 \times 2$
$= 36.6$ k-ft/ft
$M_{w_I} = 12.1$ k-ft/ft

• ALL H, l VALUES ARE THE SAME.

☆ END SECTION YIELD LINE EQUATIONS ☆

$$L_{CR} = l/2 + \sqrt{(l/2)^2 + H(M_B + M_w H)/M_c}$$

$$R_w = \frac{M_B}{L_{CR} - l/2} + \frac{M_w H}{L_{CR} - l/2} + \frac{M_c L_{CR}^2}{H(L_{CR} - l/2)}$$

RESULTS

[1] FULL SECTION
$L_{CR} = 4.1$ ft
$R_w = 156$ KIPS
$\phi R_w = 140$ KIPS

[2] TOP SECTION
$L_{CR} = 3.8$ ft
$R_w = 152$ KIPS
$\phi R_w = 136$ KIPS

END SECTION STRENGTH = 136 KIPS

COMMENTS.

★ THIS BARRIER HAS ENOUGH CAPACITY FOR TL-4 OF MASH.

- STIRRUP SPACING IN THE END SECTIONS IS VERY UNEVEN. I WOULD AIM FOR A CONSISTENT 6" SPACING. MAY HAVE TO CHANGE A FEW LOCATIONS TO AVOID GAURDRAIL CONNECTION BOLTS.
- TO ENSURE END SECTION STRENGTH, I WOULD USE 6" STIRRUP SPACING WITHIN 5 ft FROM END.

★ END SECTION REINFORCEMENT/STIRRUPS SHOULD BE USED AT ALL EXPANSION JOINTS, OR ANY OTHER DISCONTINUITY. CURRENT CONFIGURATION ONLY WITHIN 1 ft OF JOINT.

- BARRIER WIDTH : REINFORCEMENT COULD BE OPTIMIZED TO REDUCE MATERIALS AND STILL OBTAIN $\phi R_w \geq 100$ KIP.

- REMOVE DEFLECTION JOINT FROM STANDARD DRAWINGS. - NOT GOOD FOR STRENGTH.