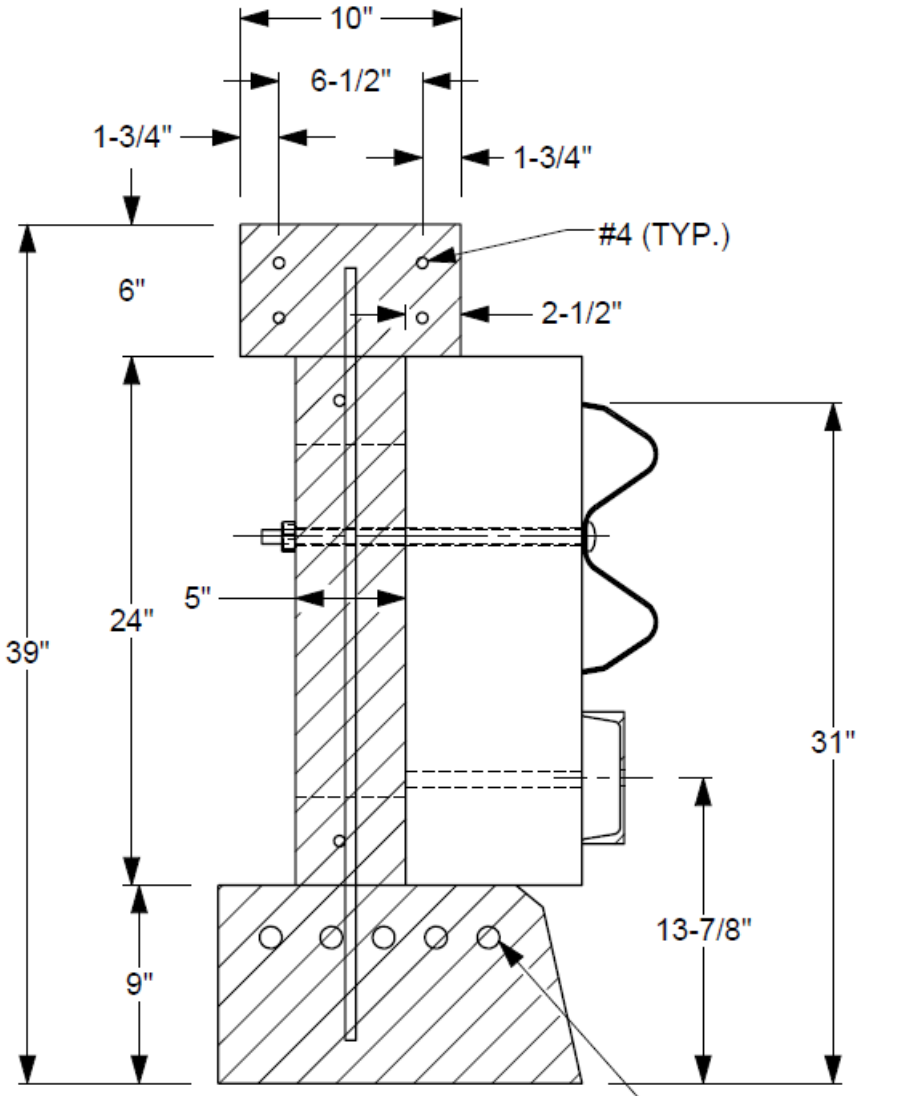
Texas A&M Transportation Institute

Project #: **602181** Sponsor: **PENNDOT**

By: William Williams, P.E.

Subject: **PENNDOT Barrier with Openings - LRFD Strength Analysis**

1.) Given Details: 1.) Given the Following PENNDOT Barrier Details.
2.) Find the Ultimate Resistance (R) for the Bridge Rail for Mid-Span in Accordance with AASHTO LRFD Section 13, 2010 Edition.

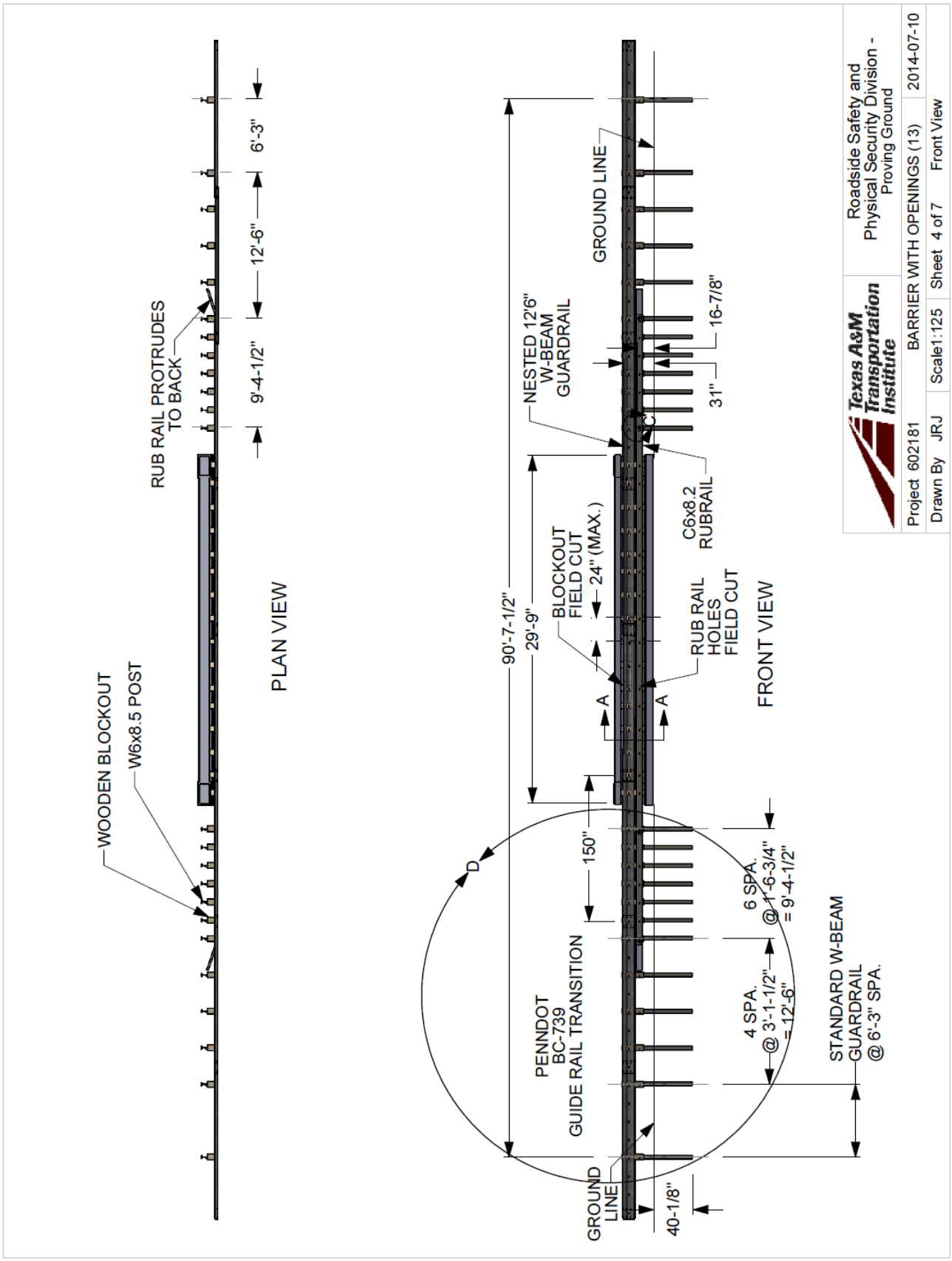


REINFORCING DETAILS

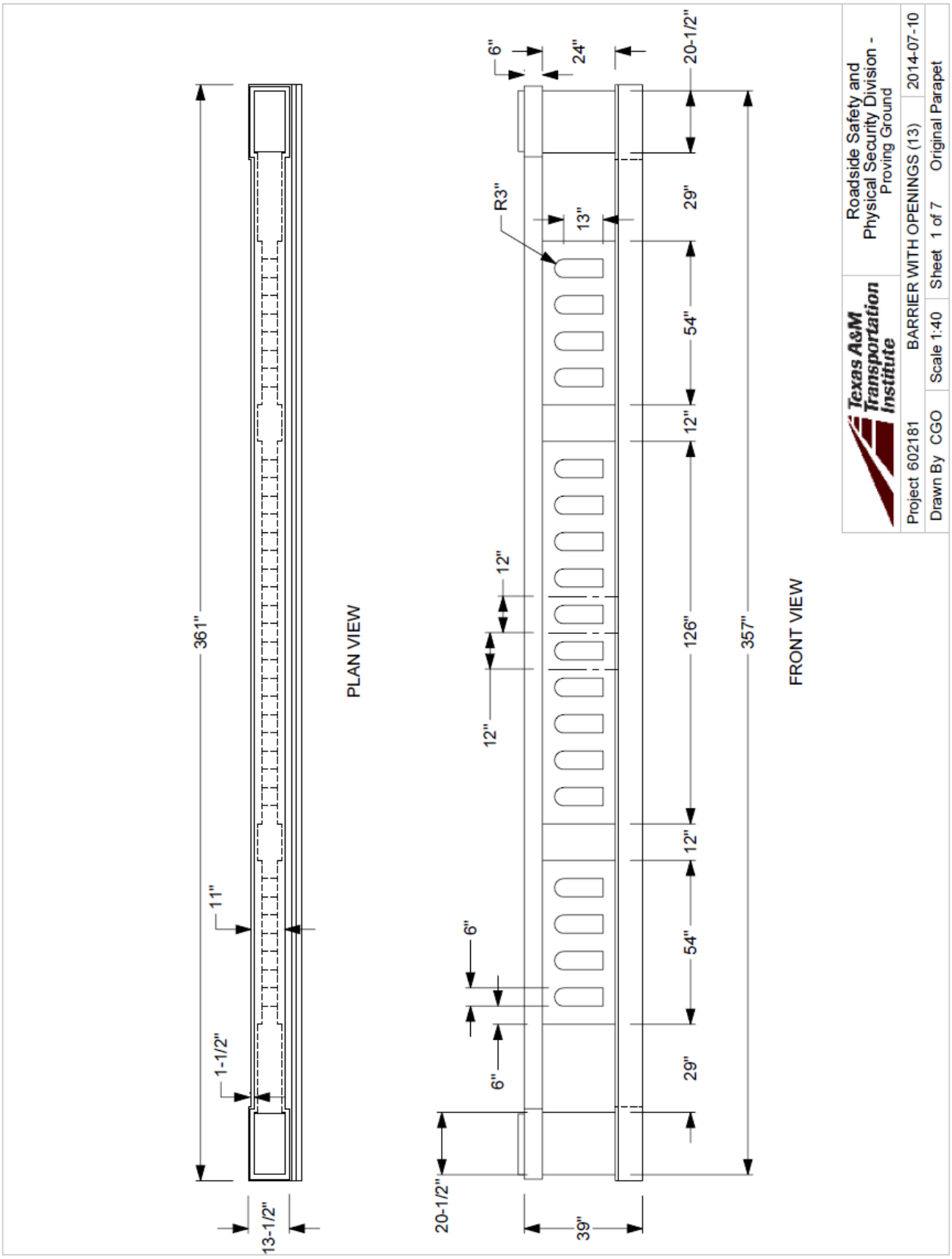
Section A-A

Scale 1 : 10

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2.) Given Input Design Information:

Rail Properties:

$b_{rail} := 6in$ .... Height of rail

$H_{rail} := 10in$ ... Thickness of rail (lateral direction)

$d_1 := 8.25in$

$d_1 = 8.25 \cdot in$ $A_{s1} := 2 \cdot 0.2in^2$

(2 ~ #4's Long. in extreme tension face)

$A_{slateral} := A_{s1}$ $A_{slateral} = 0.4 \cdot in^2$

$d_{rail} := d_1$

$d_{rail} = 8.25 \cdot in$ Avg. dist. to tension steel (8 bars)

Post Properties:

$Post_{width} := 5.0in$ Post Thickness (in.)

$b_{post} := 6in$ Post Width (ft.)

$d_{post} := 3.0in$

$d_{post} = 3 \cdot in$

1~#4 bars total on the tension face

$A_{spost} := 1 \cdot 0.20in^2$

$A_{spost} = 0.2 \cdot in^2$

Concrete Rail Material Properties:

$f'c := 4000psi$ Concrete Strength

$f_y := 60ksi$ Reinforcing Yield Strength

$\phi := 1.0$ Strength Reduction Factor

$\beta_1 := 0.85$

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3.) Check Concrete Rail Strength at Mid-Span in accordance with AASHTO LRFD Section 13 Specifications:

TL-3 Design Parameters from AASHTO & Rail Geometry

$H_e := 27in$ Minimum Height for analysis for TL-5

$L_t := 4.0ft$ Longitudinal length of distribution of impact force (feet).

$L := 1ft$ ..... Post Spacing (feet)

$\xi := 1.0$ Strength reduction factor for post

$H := 36in - 9in$ Height used for analysis (center of rail height)

$Curb_{ht} := 9in$ $H = 27\,in$

$kips \equiv kip$

$25MPa = 3625.94 \cdot \frac{lbf}{in^2}$

AASHTO TL-4 SECTION 13 REQUIREMENTS:

$F_t = 54$ kips

$F_L = 16$ kips

$F_v = 16$ kips

L_t and $L_L = 4.0$ feet

$L_v = 18$ feet

$H_e = 30$ inches (min.)

Min. Height = 30 inches for TL-3

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4.) Calculate the Strength of the Rail due to Lateral Impact Force (CONTINUED):

Calculate ρ:

$$\rho_{rail} := \frac{A_{slateral}}{b_{rail} \cdot d_{rail}} \qquad \rho_{rail} = 0.0081 \qquad A_{slateral} = 0.4 \cdot in^2$$

calculate ρ_{min}:

$$\rho_{min1} := \frac{3 \cdot \sqrt{f'c \cdot psi}}{f_y} \qquad \rho_{min1} = 0.00316$$

or

$$\rho_{min2} := \frac{200 \cdot psi}{f_y} \qquad \rho_{min2} = 0.00333$$

Calculate ρ_{bal}:

$$\rho_{bal} := \beta_1 \cdot \left(\frac{0.85 \cdot f'c}{f_y} \right) \cdot \left(\frac{87000psi}{87000psi + f_y} \right) \qquad \rho_{bal} = 0.0285$$

$$\rho_{max} := 0.75 \cdot \rho_{bal} \qquad \rho_{max} = 0.0214$$

$$\rho_{rail} = 0.0081 \quad << \quad \rho_{bal} = 0.029$$

.....Steel Ratio is O.K. .... steel yields!!

calculate "a":

$$a_{railhor} := \frac{A_{slateral} \cdot f_y}{0.85 \cdot f'c \cdot b_{rail}} \qquad a_{railhor} = 1.176 \cdot in$$

$$b_{rail} = 6 \cdot in$$

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Calculate Nominal Strength of Rail (Horizontal):

$A_{slateral} = 0.4 \cdot in^2$ (Area of 10 ~ #6 Bars) $f_y = 60 \cdot ksi$ $d_{rail} = 8.25 \cdot in$

$a_{railhor} = 1.176 \cdot in$ depth of the compression block

$$M_{urail} := \phi_{rail} \cdot A_{slateral} \cdot f_y \cdot \left(d_{rail} - \frac{a_{railhor}}{2} \right) \qquad \phi = 1 \qquad \phi_{rail} := 1.25$$

$M_{urail} = 19.154 \cdot kip \cdot ft$ $M_{nrail} := \frac{M_{urail}}{\phi}$ $M_{nrail} = 19.154 \cdot kip \cdot ft$

5.) Calculate the strength of the Mid-Span Posts:

$A_{spost} = 0.2 \cdot in^2$ $kips \equiv kip$

Calculate ρ_{post}: $\rho_{post} := \frac{A_{spost}}{d_{post} \cdot b_{post}}$ $\rho_{post} = 0.01111$ $d_{post} = 3 \cdot in$

$\rho_{min2} = 0.00333$

$\rho_{max} = 0.02138$ Steel Ratio O.K. ..... steel yields

Calculate Compression Block "a" for post:

with $b_{post} = 0.5 \cdot ft$ $a_{post} := \frac{A_{spost} \cdot f_y}{0.85 \cdot f'c \cdot b_{post}}$ $a_{post} = 0.588 \cdot in$

$\phi = 1$ $\phi_{post} := 1.10$

Calculate Nominal Strength M_n of Post section:

$A_{spost} = 0.2 \cdot in^2$ $f_y = 60 \cdot ksi$ $d_{post} = 3 \cdot in$ $a_{post} = 0.588 \cdot in$

$$M_{upost} := \phi_{post} \cdot A_{spost} \cdot f_y \cdot \left(d_{post} - \frac{a_{post}}{2} \right)$$

$M_{upost} = 2.976 \cdot kip \cdot ft$ $M_{npost} := \frac{M_{upost}}{\phi}$ $M_{npost} = 2.976 \cdot kip \cdot ft$

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6a.) Calculate P_p for the Mid-Span & End Posts @ center of rail (mid-point) 30.5 inches:

$M_{npost} = 2.976 \cdot kip \cdot ft$ $H = 27 \cdot in$

$$P_p := \frac{M_{npost}}{H - Curb_{ht}}$$

$P_p = 1.984 \cdot kips$

6b.) Re-summarize M_p of the Rail:

$M_p := M_{nrail}$

$M_p = 19.154 \cdot kip \cdot ft$

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8a.) Calculate the The total ultimate resistance "R", i.e. nominal resistance of the railing in kips for a single span:

$M_p = 19.154 \cdot kip \cdot ft$ $P_p = 1.984 \cdot kips$ $L_t = 4 \cdot ft$

$N_5 := 5$ ..... number of spans

$H_e = 27 \cdot in$

$H = 27 \cdot in$

$$R_5 := \frac{16 \cdot M_p + (N_5 - 1) \cdot (N_5 + 1) \cdot P_p \cdot L}{2 \cdot N_5 \cdot L - L_t} \cdot \frac{H}{H_e}$$

Post Spa. $L = 1 \cdot ft$

$H_e = 27 \cdot in$

$H = 27 \cdot in$

$\boxed{R_5 = 59.016 \cdot kips}$ ($R_1 > 54$ kips)

8b.) Calculate the The total ultimate resistance "R", i.e. nominal resistance of the railing in kips for two spans:

$N_6 := 6$ ..... number of spans $M_p = 19.154 \cdot kip \cdot ft$ $P_p = 1.984 \cdot kips$ $L_t = 4 \cdot ft$

$\frac{H}{H_e} = 1$

$$R_6 := \frac{16 \cdot M_p + N_6^2 \cdot P_p \cdot L}{2 \cdot N_6 \cdot L - L_t} \cdot \frac{H}{H_e}$$

Post Spa. $L = 1 \cdot ft$

$\boxed{R_6 = 47.238 \cdot kips}$ ($R_6 < 54$ kips min)

8c.) Calculate the The total ultimate resistance "R", i.e. nominal resistance of the railing in kips for three spans:

$M_p = 19.154 \cdot kip \cdot ft$ $P_p = 1.984 \cdot kips$ $L_t = 4 \cdot ft$ $H = 27 \cdot in$

$H_e = 27 \cdot in$

$N_7 := 7$ .... number of spans

$$R_7 := \frac{16 \cdot M_p + (N_7 - 1) \cdot (N_7 + 1) \cdot P_p \cdot L}{2 \cdot N_7 \cdot L - L_t} \cdot \frac{H}{H_e}$$

Post Spa. $L = 1 \cdot ft$

$\boxed{R_7 = 40.172 \cdot kips}$ ($R_3 < 38$ kips min)

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8d.) Calculate the The total ultimate resistance "R", i.e. nominal resistance of the railing in Kips for multiple spans:

$M_p = 19.154 \cdot kip \cdot ft$ $P_p = 1.984 \cdot kips$ $L_t = 4 \cdot ft$

$N_8 := 8$ .... number of spans $R_8 := \frac{16 \cdot M_p + N_8^2 \cdot P_p \cdot L}{2 \cdot N_8 \cdot L - L_t} \cdot \frac{H}{H_e}$ Post Spa. $L = 1 \cdot ft$

$R_8 = 36.122 \cdot kips$

.... 9 Spans:

$M_p = 19.154 \cdot kip \cdot ft$ $P_p = 1.984 \cdot kips$ $L_t = 4 \cdot ft$ $H = 27 \cdot in$

$H_e = 27 \cdot in$

$N_9 := 9$ .... number of spans

$R_9 := \frac{16 \cdot M_p + (N_9 - 1) \cdot (N_9 + 1) \cdot P_p \cdot L}{2 \cdot N_9 \cdot L - L_t} \cdot \frac{H}{H_e}$ Post Spa. $L = 1 \cdot ft$

$R_9 = 33.23 \cdot kips$ (R9 < 54 kips min)

.... 10 Spans:

$M_p = 19.154 \cdot kip \cdot ft$ $P_p = 1.984 \cdot kips$ $L_t = 4 \cdot ft$

$N_{10} := 10$ .... number of spans $R_{10} := \frac{16 \cdot M_p + N_{10}^2 \cdot P_p \cdot L}{2 \cdot N_{10} \cdot L - L_t} \cdot \frac{H}{H_e}$ Post Spa. $L = 1 \cdot ft$

$R_{10} = 31.556 \cdot kips$

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.... 12 Spans:

$M_p = 19.154 \cdot kip \cdot ft$ $P_p = 1.984 \cdot kips$ $L_t = 4 \cdot ft$

$N_{12} := 12$ .... number of spans

$$R_{12} := \frac{16 \cdot M_p + N_{12}^2 \cdot P_p \cdot L}{2 \cdot N_{12} \cdot L - L_t} \cdot \frac{H}{H_e}$$

Post Spa. $L = 1 \cdot ft$

$R_{12} = 29.611 \cdot kips$

.... 14 Spans:

$M_p = 19.154 \cdot kip \cdot ft$ $P_p = 1.984 \cdot kips$ $L_t = 4 \cdot ft$

$N_{14} := 14$ .... number of spans

$$R_{14} := \frac{16 \cdot M_p + N_{14}^2 \cdot P_p \cdot L}{2 \cdot N_{14} \cdot L - L_t} \cdot \frac{H}{H_e}$$

Post Spa. $L = 1 \cdot ft$

$R_{14} = 28.975 \cdot kips$

.... 16 Spans:

$M_p = 19.154 \cdot kip \cdot ft$ $P_p = 1.984 \cdot kips$ $L_t = 4 \cdot ft$

$N_{16} := 16$ .... number of spans

$$R_{16} := \frac{16 \cdot M_p + N_{16}^2 \cdot P_p \cdot L}{2 \cdot N_{16} \cdot L - L_t} \cdot \frac{H}{H_e}$$

Post Spa. $L = 1 \cdot ft$

$R_{16} = 29.088 \cdot kips$

In Summary: The concrete rail with the openings has approximately 30 kips capacity @ 27" Height.

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