LOADING DATA

design_load = HL93 Strength_limit := 1 wearing_surface := 6in

BRIDGE GEOMETERY

design_span := 50ft stringer_spacing := 53in $N_L := 2$ (number of lanes) $N_b := 6$ (number of beams)

roadway_width := 24ft deck_thickness := 5·in

dia_spacing := 12ft brg_lgt := 14in

STRINGER SIZE AND PROPERTIES & DESIGN VALUES:

beam width b := 8.5in

beam depth d := 44in

Glulam Comb. 24F-V3, Species SP (AASHTO Table 8.4.1.2.3-1)

$S_x := \frac{b \cdot d^2}{6}$ $I_x := \frac{b \cdot d^3}{12}$ $A := b \cdot d$ $A_b := b \cdot brg\_lgt$

$S_x = 2742.67 \cdot in^3$ $I_x = 60338.67 \cdot in^4$ $A = 374 \cdot in^2$ $A_b = 119 \cdot in^2$

$F_{bo} := 2.4 \cdot \frac{kip}{in^2}$ $F_{vo} := .72 \cdot .300 \frac{kip}{in^2}$ $F_{cpo} := .740 \frac{kip}{in^2}$ $E_o := 1800.000 \frac{kip}{in^2}$

WOOD ADJUSTMENT FACTORS - LRFD 8.4.4.1

Moisture Content Factor : LRFD Table 8.4.4.3-2 $C_{m\_b} := 1$ $C_{m\_v} := 1$

Stringers are assumed to have an in-service moisture content of 16% or less. All Cm values except Fcp shall equal 1 $C_{m\_cp} := .53$ $C_{m\_E} := 1$

Volume Factor : LRFD 8.4.4.5 $b_1 := 8.5in$ (note :widest board if staggered layup is used)

$$C_v := \left[\left(\frac{12in}{d}\right) \cdot \left(\frac{5.125in}{b_1}\right) \cdot \left(\frac{21ft}{design\_span}\right)\right]^{\frac{1}{20}}$$

$C_v = 0.875$

Time Effect Factor : LRFD 8.4.4.9 $C_\lambda := 0.8$

Beam Stability Factor :LRFD 8.6.2 $C_L := 1$

Assume compression zone is completely supported

Bearing Factor ; LRFD Table 8.8.3-1 $C_b := 1$

ADJUSTED DESIGN VALUES - LRFD 8.4.4.1

Resistance factors - LRFD Table 8.5.2.2 $\phi_m := 0.85$ $\phi_v := 0.75$ $\phi_{cp} := 0.9$

Conversion Factors : LRFD Table 8.4.4.2 $C_{KFb} := \frac{2.5}{\phi_m}$ $C_{KFv} := \frac{2.5}{\phi_v}$ $C_{KF\_CP} := \frac{2.1}{\phi_{cp}}$

$Fb := F_{bo} \cdot C_{KFb} \cdot C_{m\_b} \cdot C_v \cdot C_\lambda$ $Fb = 4.94 \cdot ksi$

$Fv := F_{vo} \cdot C_{KFv} \cdot C_{m\_v} \cdot C_\lambda$ $Fv = 0.576 \cdot ksi$

$Fcp := F_{cpo} \cdot C_{KF\_CP} \cdot C_{m\_cp} \cdot C_\lambda$ $Fcp = 0.732 \cdot ksi$

$E := E_o \cdot C_{m\_E}$ $E = 1800 \cdot ksi$

FACTORED RESISTANCE

Flexure

$M_n := Fb \cdot S_x \cdot C_L$ $M_n = 1129.22 \cdot ft \cdot kip$

$M_r := \phi_m \cdot M_n$ $M_r = 959.83 \cdot ft \cdot kip$

Shear

$V_n := \frac{Fv \cdot (b \cdot d)}{1.5}$ $V_n = 143.62 \cdot kip$

$V_r := \phi_v \cdot V_n$ $V_r = 107.71 \cdot kip$

Compression

$P_n := Fcp \cdot A_b \cdot C_b$ $P_n = 87.12 \cdot kip$

$P_r := \phi_{cp} \cdot P_n$ $P_r = 78.41 \cdot kip$

INTERIOR STRINGER DESIGN :

LRFD Table 3.5.1-1

$WT_{wood} := 50pcf$

$WT_{asphalt} := 140pcf$

Dead load and Moments for Components (deck, stiff, dia & misc DL)

$Deck_{dl} := stringer\_spacing \cdot deck\_thickness \cdot WT_{wood}$ $Deck_{dl} = 0.092 \cdot klf$

$Stringer_{dl} := b \cdot d \cdot WT_{wood}$ $Stringer_{dl} = 0.13 \cdot klf$

$Misc_{dl} := .2klf$

$DC := Deck_{dl} + Stringer_{dl} + Misc_{dl}$ $DC = 0.422 \cdot klf$

$M_{DC} := \frac{DC \cdot design\_span^2}{8}$ $M_{DC} = 131.84 \cdot ft \cdot kip$

$V_{DC} := \frac{DC \cdot design\_span}{2} - DC \cdot d$ $V_{DC} = 9 \cdot kip$

Dead load and Moments for Asphalt Wearing Surface

$DW := stringer\_spacing \cdot wearing\_surface \cdot WT_{asphalt}$ $DW = 0.309 \cdot klf$

$M_{DW} := \frac{DW \cdot design\_span^2}{8}$ $M_{DW} = 96.61 \cdot ft \cdot kip$

$V_{DW} := \frac{DW \cdot design\_span}{2} - DW \cdot d$ $V_{DW} = 6.6 \cdot kip$

Maximim HL93 Vehicle Moment : LRFD 3.6.1.2.2

$$M_{C1}(a_s, b_s) := \left(\frac{a_s \cdot ft \cdot b_s \cdot ft}{design\_span}\right)\left(8kip + 32kip \text{ if}\left(a_s > 14, \frac{a_s - 14}{a_s}, 0\right) + 32kip \text{ if}\left(a_s > 28, \frac{a_s - 28}{a_s}, 0\right)\right)$$

$$M_{C2}(a_s, b_s) := \left(\frac{a_s \cdot ft \cdot b_s \cdot ft}{design\_span}\right)\left(8kip \text{ if}\left(b_s > 14, \frac{b_s - 14}{b_s}, 0\right) + 32kip + 32kip \text{ if}\left(a_s > 14, \frac{a_s - 14}{a_s}, 0\right)\right)$$

$$M_{C3}(a_s, b_s) := \left(\frac{a_s \cdot ft \cdot b_s \cdot ft}{design\_span}\right)\left(25kip + 25kip \text{ if}\left(a_s > 4, \frac{a_s - 4}{a_s}, 0\right)\right)$$

$$M_{max}(a_s) := \max\left(M_{C1}\left(a_s, \frac{design\_span}{ft} - a_s\right), M_{C2}\left(a_s, \frac{design\_span}{ft} - a_s\right), M_{C3}\left(a_s, \frac{design\_span}{ft} - a_s\right)\right)$$

$$MMax_{LL} := \text{for } I \in 0, .1 .. \frac{design\_span}{ft}$$

$$MMax \leftarrow M_{max}(I) \text{ if } M_{max}(I - .1) < M_{max}(I)$$

$MMax_{LL} = 627.84 \cdot ft \cdot kip$

$$M_{laneload} := .64 \frac{kip}{ft} \frac{design\_span^2}{8}$$

$M_{laneload} = 200 \cdot ft \cdot kip$

$$M\_HL93 := MMax_{LL} + M_{laneload}$$

$M\_HL93 = 827.84 \cdot ft \cdot kip$

Distribution Factor LRFD Table 4.6.2.2.1-1

$$SP := \frac{stringer\_spacing}{12in}$$

One lane loaded $g_1 := \frac{SP}{10}$ $g_1 = 0.44$

Two or more lanes loaded $g_2 := \frac{SP}{10}$ $g_2 = 0.44$

$$DF := \begin{cases} g_1 & \text{if } g_1 \geq g_2 \\ g_2 & \text{otherwise} \end{cases}$$

$DF = 0.44$

$Dist\_M_{LL} := M\_HL93 \cdot DF$ $Dist\_M_{LL} = 365.63 \cdot ft \cdot kip$

Strength Limit States LRFD Table 3.4.1-1 $\gamma_{DC} := 1.25$ $\gamma_{DW} := 1.5$ $\gamma_{LL} := 1.75$

LRFD 1.3.3 Ductility $\eta_D := 1.0$

LRFD 1.3.4 Redundancy $\eta_R := 1.0$

LRFD 1.3.5 Operational Importance $\eta_I := 1.0$

LRFD 1.3.2.1-2 $\eta_i := \begin{cases} (\eta_D \cdot \eta_R \cdot \eta_I) & \text{if } \eta_D \cdot \eta_R \cdot \eta_I \geq 0.95 \\ 0.95 & \text{otherwise} \end{cases}$

$\eta_i = 1$

FLEXURE CHECK

$Q_{flexure} := \eta_i\left(\gamma_{DC}\cdot M_{DC} + \gamma_{DW}\cdot M_{DW} + \gamma_{LL}\cdot Dist\_M_{LL}\right)$ $Q_{flexure} = 949.57\cdot ft\cdot kip$

$Flexure\_check := \begin{cases} \text{"OK"} & \text{if } M_r \geq Q_{flexure} \\ \text{"RE-RUN"} & \text{otherwise} \end{cases}$ Flexure_check = "OK"

SHEAR CHECK

Critical Section location for Live Load Shear : LRFD 8.7 "d" from support $d = 3.67\,ft$

Maximum Shear Live Load placement

$Dist := if\left(3\cdot d < \frac{1}{4}\cdot design\_span, 3\cdot d, \frac{1}{4}\cdot design\_span\right)$ $Dist = 11\,ft$

$V_{C1}(a_s, b_s) := \left(1 - \frac{a_s\cdot ft}{design\_span}\right)\left(32kip + 32kip\, if\left(b_s > 14, \frac{b_s - 14}{b_s}, 0\right) + 8kip\, if\left(b_s > 28, \frac{b_s - 28}{b_s}, 0\right)\right)$

$V_{C2}(a_s, b_s) := \left(1 - \frac{a_s\cdot ft}{design\_span}\right)\left(25kip + 25kip\, if\left(b_s > 4, \frac{b_s - 4}{b_s}, 0\right)\right)$

$V_{max}(a_s) := \max\left(V_{C1}\left(a_s, \frac{design\_span}{ft} - a_s\right), V_{C2}\left(a_s, \frac{design\_span}{ft} - a_s\right)\right)$

$V_{max\_LL} := V_{max}\left(\frac{Dist}{ft}\right)$ $V_{max\_LL} = 42.72\cdot kip$

$V\_LaneLoad := .64\frac{kip}{ft}\cdot\left(\frac{design\_span}{2} - d\right)\cdot DF$ $V\_LaneLoad = 6.03\cdot kip$

$V\_HL93 := V_{max\_LL} + V\_LaneLoad$ $V\_HL93 = 48.75\cdot kip$

Horizontal Shear LRFD 4.6.2.2.2a-1

$V_{LL} := .5\cdot\left(.6V_{max\_LL} + DF\cdot V_{max\_LL}\right)$ $V_{LL} = 22.25\cdot kip$

$Q_{shear} := \eta_i\left[\gamma_{DC}\cdot V_{DC} + \gamma_{DW}\cdot V_{DW} + \gamma_{LL}\cdot\left(V_{LL} + V\_LaneLoad\right)\right]$ $Q_{shear} = 70.63\cdot kip$

Shear_Check := "OK" if $V_r \geq Q_{shear}$; "no good Re-run" otherwise — Shear_Check = "OK"

EXTERIOR STRINGER DESIGN

deck_overhang := 23.5in

Rail_Width := 12in

Dead load and Moments for Components (deck, stiff, dia, rail & misc DL)

$Deck_{dle} := \left(\frac{stringer\_spacing}{2} + deck\_overhang\right)\cdot deck\_thickness\cdot WT_{wood}$ $Deck_{dle} = 0.09\cdot klf$

Assume rail (misc DL) = .2 klf

$Misc_{dle} := .2klf$

$Stringer_{dl} = 0.13\cdot klf$

$DCe := Deck_{dle} + Stringer_{dl} + Misc_{dle}$ $DCe = 0.42\cdot klf$

$M_{DCe} := \frac{DCe\cdot design\_span^2}{8}$ $M_{DCe} = 130.21\cdot ft\cdot kip$

$V_{DCe} := \frac{DCe\cdot design\_span}{2} - DCe\cdot d$ $V_{DCe} = 8.89\cdot kip$

Dead load and Moments for Asphalt Wearing Surface

$DWe := \left(\frac{stringer\_spacing}{2} + deck\_overhang - Rail\_Width\right)\cdot wearing\_surface\cdot WT_{asphalt}$ $DWe = 0.22\cdot klf$

$M_{DWe} := \frac{DWe\cdot design\_span^2}{8}$ $M_{DWe} = 69.27\cdot ft\cdot kip$

$V_{DWe} := \frac{DWe\cdot design\_span}{2} - DWe\cdot d$ $V_{DWe} = 4.73\cdot kip$

Exterior Stringer Distribution : Lever Rule LRFD Table 4.6.2.2.2d-1

Lever Rule:

$L_r := .5\cdot\frac{3.375}{4.4167}$ $L_r = 0.382$

Rigid Section Rotation Check-Case 1 : one HS20 truck
Multiple Presence Factor (one lane) LRFD Table 3.6.1.1.2-1

$m_1 := 1.2$

$$DF_{c1} := \frac{1}{6} + \frac{11.0417 \cdot 7}{2\left(11.0417^2 + 6.625^2 + 2.208^2\right)}$$

$DF_{c1} = 0.39$

$$DF_{ca} := \begin{cases} \left(L_r \cdot m_1\right) & \text{if } L_r > DF_{c1} \\ \left(DF_{c1} \cdot m_1\right) & \text{otherwise} \end{cases} = 0.47$$

Rigid Section Rotation Check-Case 2 : two HS20 trucks
Multiple Presence Factor (two lane) LRFD Table 3.6.1.1.2-1

$m_2 := 1$

$$DF_{c2} := \frac{2}{6} + \frac{11.0417 \cdot (7 + -5)}{2\left(11.0417^2 + 6.625^2 + 2.208^2\right)}$$

$DF_{c2} = 0.4$

Distribution Factor exterior

$$DF_e := \begin{cases} DF_{ca} & \text{if } DF_{ca} > DF_{c2} \\ \left(DF_{c2}\right) & \text{otherwise} \end{cases} = 0.47$$

Flexure Check - Exterior Stringer :

$Dist\_M_{LLe} := M\_HL93 \cdot DF_e$

$Dist\_M_{LLe} = 390.49 \cdot ft \cdot kip$

$Q_{flexure\_ext} := \eta_i\left(\gamma_{DC} \cdot M_{DCe} + \gamma_{DW} \cdot M_{DWe} + \gamma_{LL} \cdot Dist\_M_{LLe}\right)$

$Q_{flexure\_ext} = 950.03 \cdot ft \cdot kip$

$$Flexure\_check_e := \begin{cases} \text{"OK"} & \text{if } M_r \geq Q_{flexure\_ext} \\ \text{"RE-RUN"} & \text{otherwise} \end{cases}$$

$Flexure\_check_e = \text{"OK"}$

Shear Check - Exterior Stringer :

$$V_{max\_LLe} := V_{max}\left(\frac{Dist}{ft}\right)$$

$V_{max\_LLe} = 42.72 \cdot kip$

$$V\_LaneLoad\_e := .64\frac{kip}{ft} \cdot \left(\frac{design\_span}{2} - d\right) \cdot DF_e$$

$V\_LaneLoad\_e = 6.44 \cdot kip$

$V\_HL93_e := V_{max\_LL} + V\_LaneLoad$

$V\_HL93_e = 48.75 \cdot kip$

$V_{LLe} := .5\left(.6 \cdot V_{max\_LLe} + DF_e \cdot V_{max\_LLe}\right)$

$V_{LLe} = 22.89 \cdot kip$

$$Q_{shear\_ext} := \eta_i\left[\gamma_{DC}\cdot V_{DCe} + \gamma_{DW}\cdot V_{DWe} + \gamma_{LL}\cdot\left(V_{LLe} + V\_LaneLoad\_e\right)\right]$$

$Q_{shear\_ext} = 69.54\cdot kip$

$$Shear\_Check_{ext} := \begin{cases} \text{"OK"} & \text{if } V_r \geq Q_{shear\_ext} \\ \text{"no good Re-run"} & \text{otherwise} \end{cases}$$

$Shear\_Check_{ext} = \text{"OK"}$

STRINGER DEFLECTION :

Live Load Deflection limited to L/425 LRFD 2.5.2.6.2

$$P_{EQ} := \frac{4\cdot MMax_{LL}\cdot DF}{design\_span}$$

$P_{EQ} = 22.18\cdot kip$

$$\Delta_{truck} := \frac{P_{EQ}\cdot design\_span^3}{48\cdot E\cdot I_x}$$

$\Delta_{truck} = 0.92\cdot in$

$$\Delta_{tandem} := \frac{DF\cdot 25\cdot kip}{24\cdot E\cdot I_x}\cdot\left(\frac{design\_span - 4ft}{2}\right)\cdot\left[3\cdot design\_span^2 - 4\left(\frac{design\_span - 4ft}{2}\right)^2\right]$$

$\Delta_{tandem} = 0.91\cdot in$

$$\Delta_{lane\_load} := \frac{DF\cdot .64\frac{kip}{ft}\cdot design\_span^4\cdot 5}{384\cdot E\cdot I_x}$$

$\Delta_{lane\_load} = 0.37\cdot in$

$$\Delta_{tr} := \begin{cases} \left(\Delta_{truck}\right) & \text{if } \Delta_{truck} \geq \Delta_{tandem} \\ \left(\Delta_{tandem}\right) & \text{otherwise} \end{cases}$$

$\Delta_{tr} = 0.92\cdot in$

$$\Delta_{LL} := \begin{cases} \left(.25\cdot\Delta_{tr} + \Delta_{lane\_load}\right) & \text{if } \left(.25\cdot\Delta_{tr} + \Delta_{lane\_load}\right) > \Delta_{tr} \\ \Delta_{tr} & \text{otherwise} \end{cases}$$

$\Delta_{LL} = 0.92\cdot in$

$$\Delta_{LL\_allow} := \frac{design\_span}{425}$$

$\Delta_{LL\_allow} = 1.41\cdot in$

$$\Delta_{ratio} := \frac{design\_span}{\Delta_{LL}}$$

$\Delta_{ratio} = 652.79$

$$Deflection\_Check := \begin{cases} \text{"Deflection is ok"} & \text{if } \Delta_{LL\_allow} \geq \Delta_{LL} \\ \text{"excessive deflection re-run"} & \text{otherwise} \end{cases}$$

$Deflection\_Check = \text{"Deflection is ok"}$

CAMBER REQUIRED:

Camber Timber Stringers two times dead load deflection LRFD 8.12.1

$$\Delta_{DLc} := \frac{5(DC + DW)\cdot design\_span^4}{384\cdot E\cdot I_x}\cdot 2$$

$\Delta_{DLc} = 1.893\cdot in$

$$Radius := \left(\frac{design\_span^2 + 4\Delta_{DLc}^2}{8\Delta_{DLc}}\right)$$

$Radius = 1980.99\ ft$

BEARING CHECK :

Maximum Shear reaction per lane at abutment

$$V\_LaneLoad1 := .64\frac{kip}{ft}\cdot\left(\frac{design\_span}{2}\right)$$

$V_{br} := \left(V_{max}\left(\frac{0}{ft}\right)\right) + V\_LaneLoad1 = 74.56\cdot kip$

$$V_{stringer} := \frac{V_{br}\cdot N_L}{N_b}$$

$V_{stringer} = 24.85\cdot kip$

$$Q_{cpo} := \eta_i\left[\left(\gamma_{DC}\cdot\frac{DC\cdot design\_span}{2} + \gamma_{DW}\cdot\frac{DW\cdot design\_span}{2}\right) + \gamma_{LL}\cdot V_{stringer}\right]$$

$Q_{cpo} = 68.27\cdot kip$

$$Bearing\_Check := \begin{cases} \text{"Bearing Check - OK"} & \text{if } P_r \geq Q_{cpo} \\ \text{"no good Re-Run"} & \text{otherwise} \end{cases}$$

$Bearing\_Check = \text{"Bearing Check - OK"}$