Bridge No.	CBC123	Analysis Method:	LRFR-LRFD	FDOT Bridge Load Rating Summary Form (Page 1 of 1)
Location	I-10 over Example Creek			
Description	Index 8030, 305' Triple 9'x3' Built 1972			

Rating Type	Rating Type	Gross Axle Weight (tons)	Moment/Shear/Service		Dead Load Factor	Live Load Factor	Live Load Distrib. Factor (axles)	Rating Factor	Span No. - Girder No., Interior/Exterior, %Span Length	RF·Weight (tons)
Level	**Vehicle**	**Weight**	**Reinf. Concrete**	**Limit**	**DC**	**LL**	**LLDF**	**RF**	**Governing Location**	**RATING**
Inventory	HL93	36	Reinf. Concrete	Strength, Moment	1.25/0.90	1.75	AREA DIST.	1.120	Top Slab at 1.40, D.fill = 2.00ft.	40.3
Operating	HL93	36	Reinf. Concrete	Strength, Moment	1.25/0.90	1.35	AREA DIST.	1.740	Top Slab at 1.40, D.fill = 2.00ft.	62.6
Permit	FL120	60	Reinf. Concrete	Strength, Moment	1.25/0.90	1.35	AREA DIST.	1.110	Top Slab at 1.40, D.fill = 2.00ft.	66.6
Permit Max Span	FL120	60	Reinf. Concrete	Strength, Moment	1.25/0.90	1.35	AREA DIST.	1.110	Top Slab at 1.40, D.fill = 2.00ft.	66.6
Legal	SU2	17	Reinf. Concrete	Strength, Moment	1.25/0.90	1.35	AREA DIST.	2.690	Top Slab at 1.40, D.fill = 2.00ft.	45.7
	SU3	33	Reinf. Concrete	Strength, Moment	1.25/0.90	1.35	AREA DIST.	2.030	Top Slab at 1.40, D.fill = 2.00ft.	67.0
	SU4	35	Reinf. Concrete	Strength, Moment	1.25/0.90	1.35	AREA DIST.	2.280	Top Slab at 2.00, D.fill = 2.00ft.	79.8
	C3	28	Reinf. Concrete	Strength, Moment	1.25/0.90	1.35	AREA DIST.	2.550	Top Slab at 1.40, D.fill = 2.00ft.	71.4
	C4	36.7	Reinf. Concrete	Strength, Moment	1.25/0.90	1.35	AREA DIST.	2.030	Top Slab at 1.40, D.fill = 2.00ft.	74.4
	C5	40	Reinf. Concrete	Strength, Moment	1.25/0.90	1.35	AREA DIST.	2.170	Top Slab at 1.40, D.fill = 2.00ft.	86.8
	ST5	40	Reinf. Concrete	Strength, Moment	1.25/0.90	1.35	AREA DIST.	2.410	Top Slab at 1.40, D.fill = 2.00ft.	96.4
Emergency Vehicle (EV)	EV2	28.75	Reinf. Concrete	Strength, Moment	1.25/0.90	1.30	AREA DIST.	1.830	Top Slab at 1.40, D.fill = 2.00ft.	52.6
	EV3	43	Reinf. Concrete	Strength, Moment	1.25/0.90	1.30	AREA DIST.	1.420	Top Slab at 1.40, D.fill = 2.00ft.	61.1

Original Design Load	HS20 or HS20-S16-44		Performed by:	Andrew DeVault	Date:	03/01/19
Rating Type, *Analysis*	LRFR-LRFD		Checked by:	Sarah Evans	Date:	03/04/19
Distribution Method	AASHTO Formula		Sealed By:	Andrew DeVault	Date:	03/11/19
Impact Factor	24.8%	(axle loading)	FL P.E. No.:	75976		
FL120 Gov. Span Length	9.6	(feet)	Cert. Auth. No.:	Government Agency		
Minimum Span Length	9.6	(feet)	Phone & email:	850-410-5531, andrew.devault@dot.state.fl.us		
Recommended Posting	At/Above legal loads. Posting Not Required.		Company:	FDOT		
Recommended SU Posting*	99	(tons)	Address:	2740 Centerview Dr. #1B, Tallahassee FL 32399		
Recommended C Posting	99	(tons)	*P.E. Seal, Comments by the Engineer*			
Recommended ST5 Posting	99	(tons)				
Owner	01 State Highway Agency					
Location	Carries interstate traffic.					
EV Posting	No. EV posting is not recommended. RF.EV2 >1.00 & RF.EV3 > 1.00					
Floor Beam Present?	No					
Segmental Bridge?	No					
Project No. & Reason	NA	Update with EV				
Plans Status	Built					

This 01-01-2022 summary follows the FDOT Bridge Load Rating Manual (BLRM), and the FDOT BMS Coding Guide.
*Recommended SU Posting levels for Florida SU trucks adequately restricts AASHTO SU trucks; see BLRM Chapter 7.

fdot.gov/maintenance/LoadRating.shtm

Narrative

HISTORY. In 1972, Proj. 50001-3401 constructed 305' Culvert No. CBC123 to carry I-10 over Example Creek. In 2001, Project 50001-3422 (FIN 222534-1) added riprap to the north end, and improved the geometry for the eastbound on-ramp to I-10, but 50001-3422 did not extend the culvert. This load rating is an update that includes Emergency Vehicles.

CONDITION. 01-08-2018, David Stump inspected, finding good condition overall (NBI Item Nos. 61 and 62 were both 7-Good). Among all walls, Stump noted "Vertical crack with efflorescence, corrosion bleed out and active water leakage in all sidewalls." However, the walls do not govern this structure, and the deterioration does not affect the carrying capacity at this time. Therefore, this analysis applies a condition factor of 1.00 and uses full sections.

DISCUSSION. This analysis was used to revise the "Hinged-End Culvert Example" published at https://www.fdot.gov/maintenance/LoadRating.shtm. Code citations were updated to LRFD 8th Ed., and FAST Act emergency vehicles were added.

CONCLUSION. Culvert No. 500112 is sufficient for all legal loads.

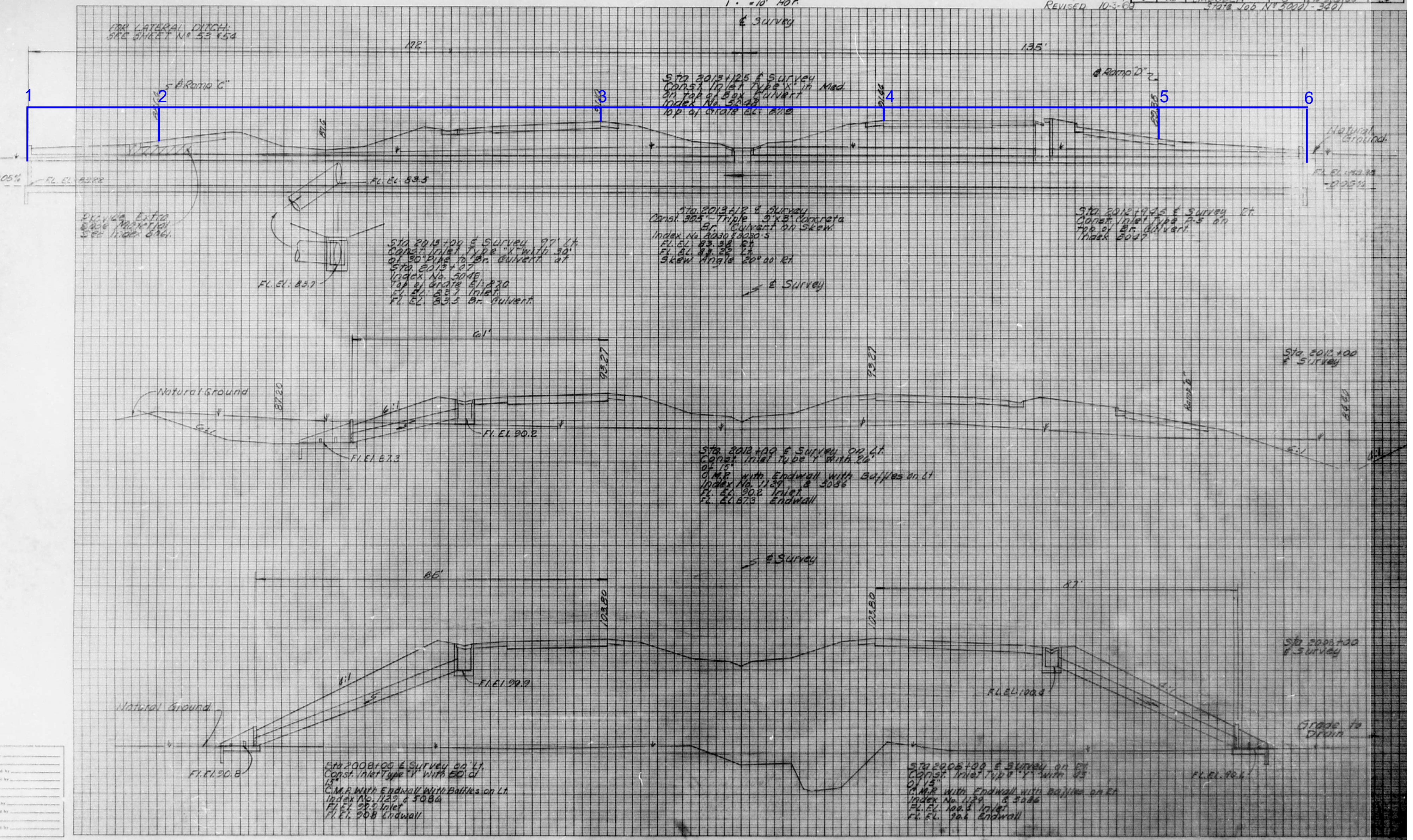
2019 leveling locations marked in blue.

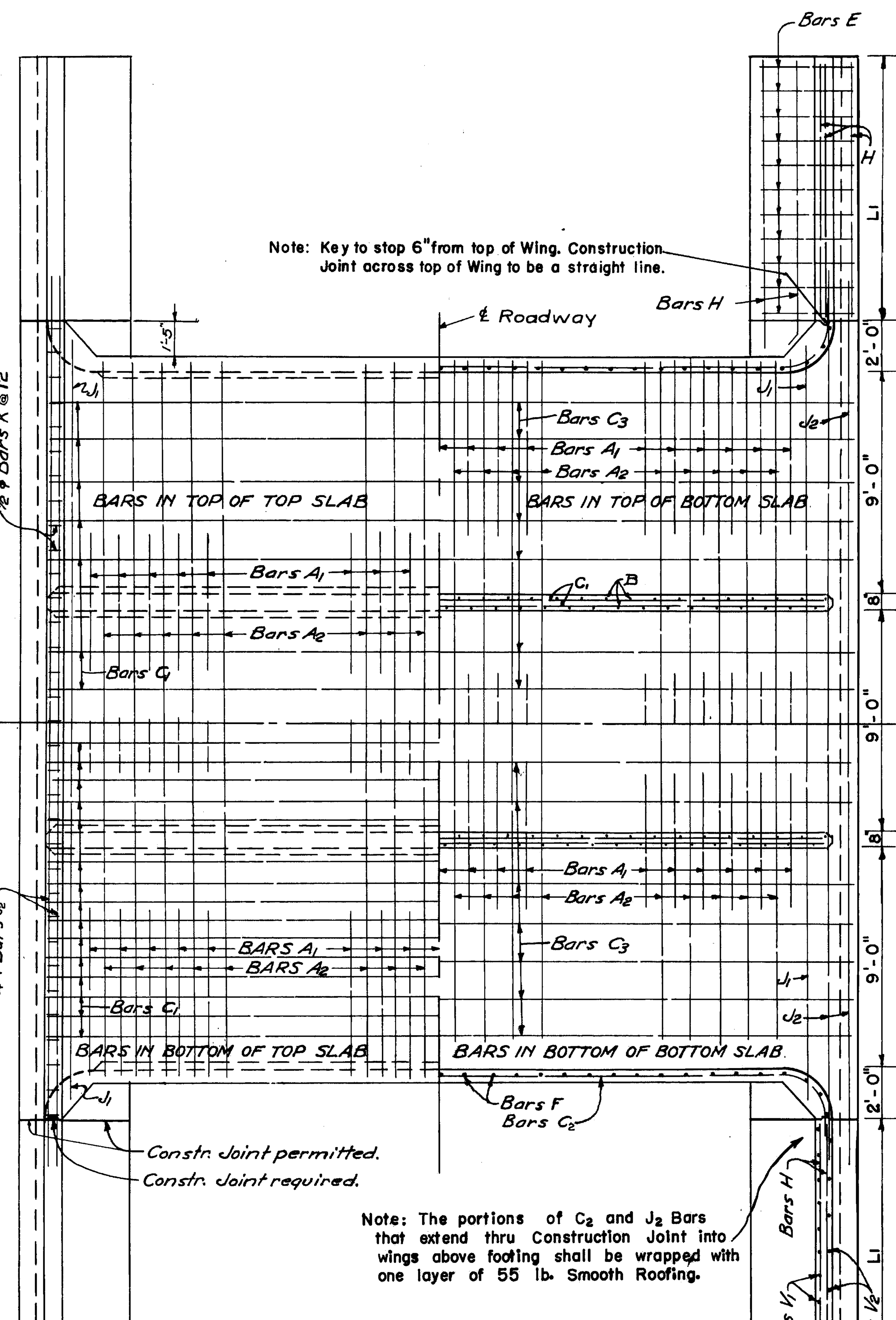
CROSS SECTIONS

Scale 1 inch = 5 feet Vert.
1" = 10' Hor.

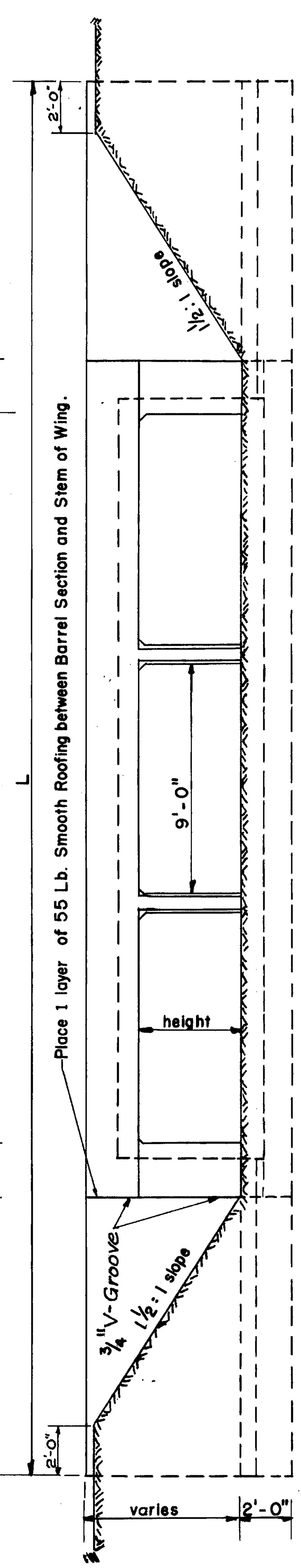
Fed. Road Div. No.	State	County	Route	Proj. No.	Sheet No.
3	Fla.	GADSDEN	8	I-10-3(18)188	22

Revised 10-3-62 State Job No 50001-3401

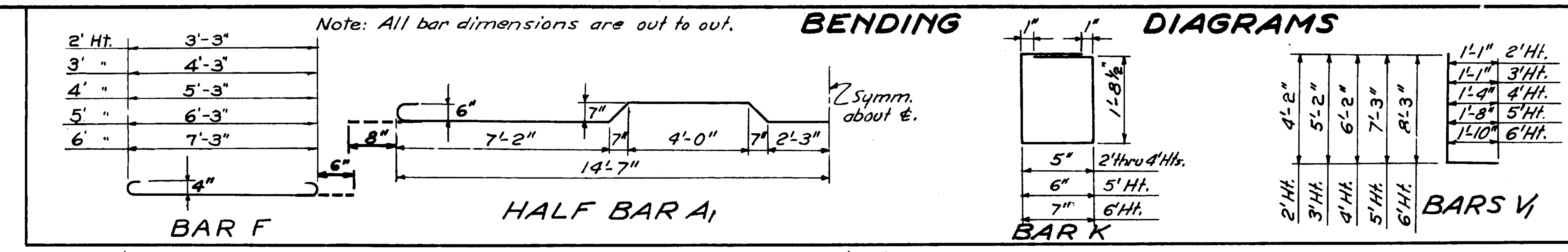


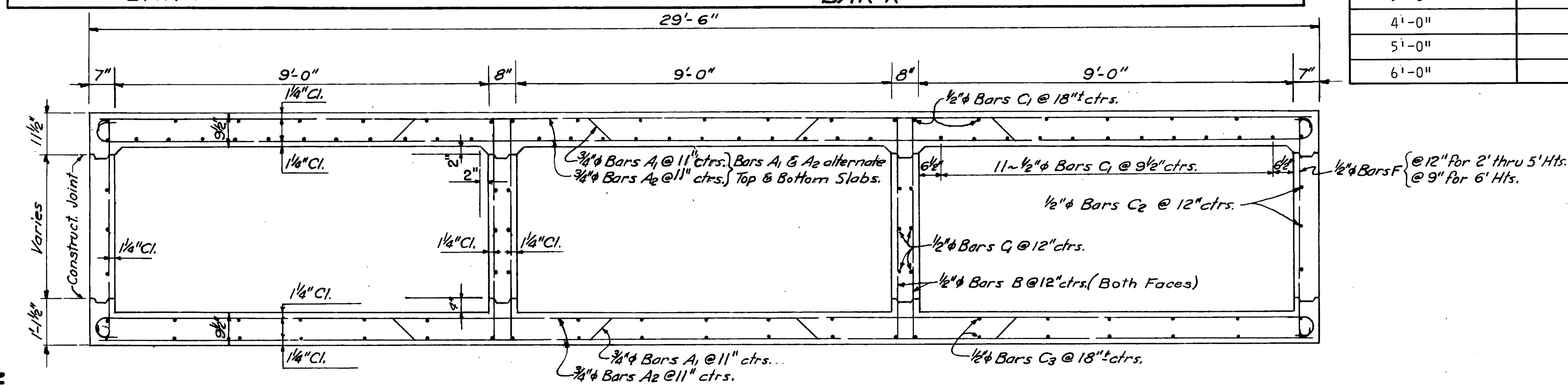


HALF PLAN   HALF SECTION

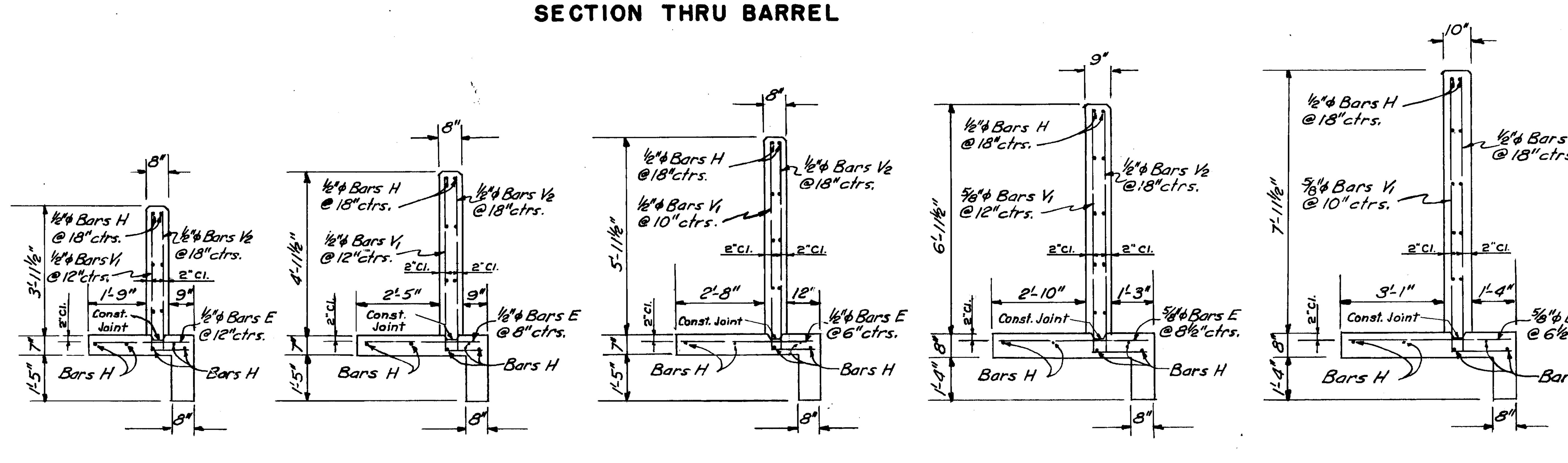


END ELEVATION





SECTION THRU BARREL



FOR 2 FT. HEIGHT CULVERT

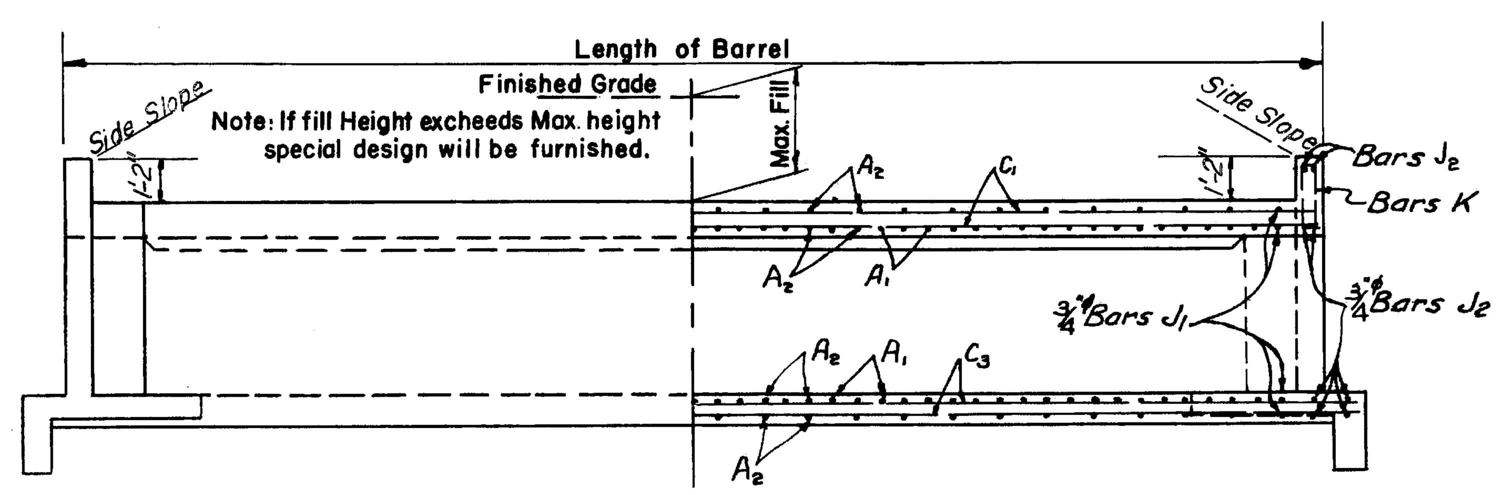
FOR 3 FT. HEIGHT CULVERT

FOR 4 FT. HEIGHT CULVERT

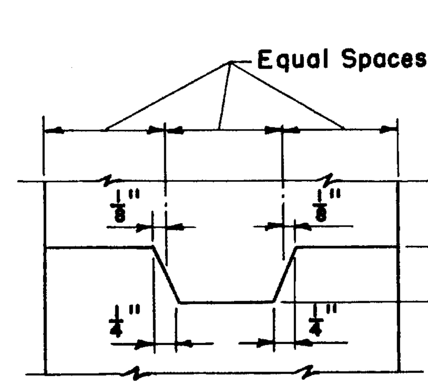
FOR 5 FT. HEIGHT CULVERT

FOR 6 FT. HEIGHT CULVERT

SECTIONS THRU WING WALLS



HALF ELEVATION   HALF SECTION



KEY DETAIL

FED. ROAD DIV. No.	STATE	SECTION	JOB No.	FISCAL YEAR	SHEET NO.	TOTAL SHEETS
3	FLA.					

WING TOE PRESSURE	
CULVERT HEIGHT (Ft.)	MAX. PRESSURE (Lbs. per sq. ft.)
2'-0"	650
3'-0"	800
4'-0"	950
5'-0"	1050
6'-0"	1250

REINFORCING STEEL

CULVERT HEIGHT	BAR A1		BAR A2		BAR B		BAR C1		BAR C2		BAR C3		BAR E		BAR F		BAR H		BAR J1		BAR J2		BAR K		BAR V1		BAR V2			
	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.
2'-0"	31'-6"	Varies with length of Barrel	29'-2"	Varies with length of Barrel	3'-3"	Varies with length of Barrel	Length of Barrel minus 4"	60	Length of Barrel Plus 4'-6"	2	Set bar length to clear face of concrete by 3"±	38	2'-10"	32	4'-3"	Varies with length of Barrel	7'-2"	44	30'-7"	8	34'-10"	16	4'-2"	66	5'-2"	32	4'-2"	20		
3'-0"	31'-6"		29'-2"		4'-3"			64		4		38	3'-6"	56	5'-3"		8'-8"	52	30'-7"	8	34'-10"	16	4'-2"	66	6'-2"	36	5'-2"	24		
4'-0"	31'-6"		29'-2"		5'-3"			68		6		38	4'-0"	84	6'-3"		10'-2"	52	30'-7"	8	34'-10"	16	4'-2"	66	7'-5"	52	6'-2"	28		
5'-0"	31'-6"		29'-2"		6'-3"			72		8		38	4'-6"	68	7'-3"		11'-8"	60	30'-7"	8	34'-10"	16	4'-5"	66	8'-10"	48	7'-3"	32		
6'-0"	31'-6"		29'-2"		7'-3"			76		10		38	4'-11"	100	8'-3"		13'-2"	68	30'-7"	8	34'-10"	16	4'-8"	66	10'-0"	64	8'-3"	36		

DIMENSIONS					QUANTITIES			
					32' BARREL LENGTH		ADDITIONAL LENGTH	
CULVERT HEIGHT	AREA OF OPENING	MAXIMUM FILL	L1	L	CONCRETE CU. YD.	REINF. STEEL LBS.	CONC. CU. YD. PER LIN. FT.	REINF. STEEL LBS. PER LIN. FT.
2'-0"	53.92	5'-0"	7'-6"	47'-4"	73.56	12,823	1.92	375.56
3'-0"	80.92	5'-0"	9'-0"	50'-4"	79.40	13,315	2.01	383.58
4'-0"	107.92	5'-0"	10'-6"	53'-4"	85.96	13,881	2.10	391.59
5'-0"	134.92	5'-0"	12'-0"	56'-4"	94.88	14,603	2.20	399.60
6'-0"	161.92	5'-0"	13'-6"	59'-4"	103.97	15,598	2.29	411.29

GENERAL NOTES

DESIGN SPECIFICATIONS: A.A.S.H.O. 1957
SURFACE FINISH:- The Class Surface Finish for all concrete surfaces shall be a general surface finish.
STRESSES: fs = 20,000 fc = 1,200.
CHAMFER: All edges and corners to be chamfered 3/4" unless otherwise noted.
LOADING: H20-S16-44 Modified for Military Loading as required.

STATE OF FLORIDA
STATE ROAD DEPARTMENT

TRIPLE 9 FT. SPAN CULVERT
2·3·4·5·6 FT. HEIGHTS

ROAD NO.	COUNTY	SECTION	JOB NO.

REVISIONS		
Names	Dates	Descriptions

	Names	Dates
Designed by	W.H.M.	1-51
Checked by	R.M.M.	2-51
Drawn by	W.H.W.	2-51
Checked by	J.L.W.	4-51
Quantities by	W.H.S.	2-51
Checked by	J.L.W.	4-51
Traced by	W.H.W.	2-51

T. W. Jennings

Drawing No.	Index No.
1 of 1	8030

Depth of Fill

On 02-28-2019, Andrew DeVault (rod) and Sarah Evans (instrument) shot levels to determine the depth of covering fill.

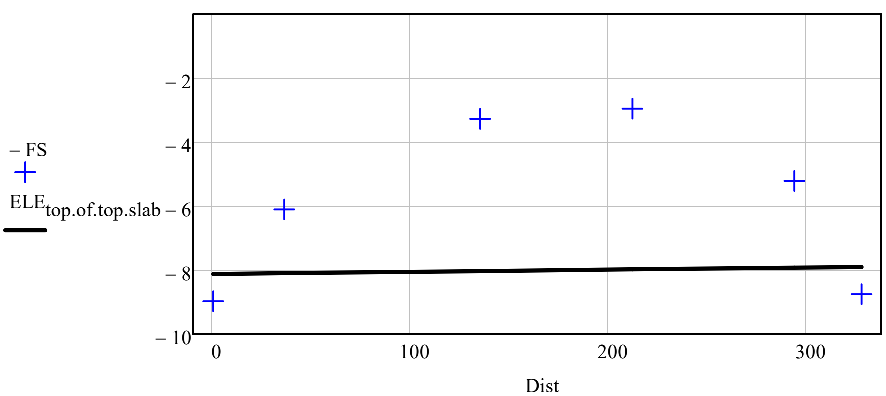
LOC - description of the height rod locations
Dist - approximate horizontal distance from culvert end to rod
FS - foresights, vertical rod readings
HI = 0 - say the height of instrument elevation is 0 feet

$$LOC = \begin{pmatrix} \text{"1. Bottom of top slab, north end................................"} \\ \text{"2. WB off-ramp, north white shoulder stripe................"} \\ \text{"3. I-10 WB, south white shoulder stripe......................"} \\ \text{"4. I-10 EB, north white shoulder stripe........................"} \\ \text{"5. EB ramp onto I-10, south white shoulder stripe........."} \\ \text{"6. Bottom of top slab, south end..............................."} \end{pmatrix} \qquad Dist := \begin{pmatrix} 0 \\ 36 \\ 135 \\ 212 \\ 294 \\ 328 \end{pmatrix} ft \qquad FS := \begin{pmatrix} 8.97 \\ 6.10 \\ 3.27 \\ 2.95 \\ 5.21 \\ 8.75 \end{pmatrix} ft$$

$$ELE_{top.of.top.slab} := -FS_1 + \frac{-FS_{rows(FS)} - \left(-FS_1\right)}{Dist_{rows(FS)}} \cdot Dist + 10.25in$$

$$Fill\_Heights := -FS - ELE_{top.of.top.slab} = \begin{pmatrix} -0.9 \\ 2.0 \\ 4.8 \\ 5.0 \\ 2.7 \\ -0.9 \end{pmatrix} ft$$

Traffic-carrying fill depths range from 2.0 to 5.0 feet.



Inputs

BridgeNo := "CBC123"

BridgeName := "I-10 over Example Creek"

BridgeDescription := "Index 8030, 305' Triple 9'x3' Built 1972"

VehSet :=

HL93+9TRUCKS	LRFR-LRFD
HL93+FL120	LRFR-LRFD
HS20+9TRUCKS	LOAD FACTOR
HS20	LOAD FACTOR

$\psi_c := 1.00$

ψ_c - condition factor

$D_{fills} := \begin{pmatrix} 2.0\text{ft} \\ 5.0\text{ft} \end{pmatrix}$

D_{fills} - covering fill depths, roadway surface to top of the top slab

cells := 3

cells - number of barrels

$W_c := 9\text{ft}$

W_c - barrel width, length of clear span

$t_{slab} := 9.5\text{in}$ $\quad t_{ExtWall} := 7\text{in}$ $\quad t_{IntWall} := 8\text{in}$

t_{slab} $t_{ExtWall}$ $t_{IntWall}$ - thicknesses: top slab, exterior wall, interior wall

$A_s := 0.44\text{in}^2 \cdot \dfrac{12\text{in}}{0.5 \cdot 11\text{in}} = 0.960 \cdot \text{in}^2$

A_s - area of tension reinforcement per strip foot, top slab

$d := t_{slab} - \left(1.25\text{in} + \dfrac{1}{2} \cdot \dfrac{6}{8}\text{in}\right) = 7.88 \cdot \text{in}$

d - distance from compression face to centroid of tension steel, top slab

$A_{s.wall} := 0.2\text{in}^2 \cdot \dfrac{12\text{in}}{12\text{in}} = 0.20 \cdot \text{in}^2$

$A_{s.wall}$ - area of positive moment reinforcement per strip foot, exterior wall

$d_{wall} := t_{ExtWall} - \left(1.25\text{in} + \dfrac{1}{2} \cdot \dfrac{4}{8}\text{in}\right) = 5.50 \cdot \text{in}$

d_{wall} - distance from compression face to centroid of tension steel, exterior wall

$f_y := 40\text{ksi}$ $\quad f_c := 3.0\text{ksi}$

f_y - steel yield and f_c - concrete strength (BLRM Tables 6A.5.2.1-1 and 6A.5.2.2-1)

$h_{clear} := 3\text{ft}$

h_{clear} - clear height of box opening

$h_{haunch.top} := 2\text{in}$ $\quad h_{haunch.bot} := 4\text{in}$

$h_{haunch.top}$ & $h_{haunch.bot}$ - haunch heights, top and bottom

$L_{wall} := h_{clear} - \left(h_{haunch.top} + h_{haunch.bot}\right) = 2.50\,\text{ft}$

L_{wall} - effective length of the exterior wall, pin-to-pin

Instructions

(1) INPUT. Adjust inputs on the 1st page. All primary inputs are confined to this one page.
(2) CALCULATE. This worksheet exports results to "1. SUMMARY.xlsm" sheet "DATA."
(3) PRINT this MathCAD worksheet.
(4) PRINT Excel file "FDOT HINGED-END CULVERT (YEAR MO-DD).xlsm" as follows:
Open sheet "SUMMARY." Review, adjust as necessary, and print.
Open sheet "SUMMARY_DETAILED," select print area, adjust page breaks, and print details.

Disclaimer

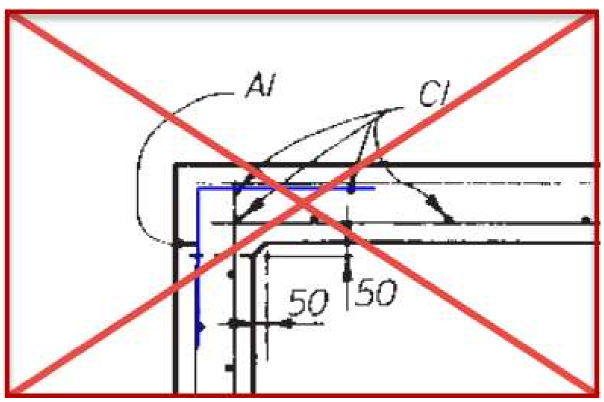
No warranty, expressed or implied, is made by the Florida Department of Transportation (FDOT) as to the accuracy and functioning of this program or the results it produces, nor shall the fact of distribution constitute any such warranty, and no responsibility is assumed by the Florida Department of Transportation in any connection there with.

References

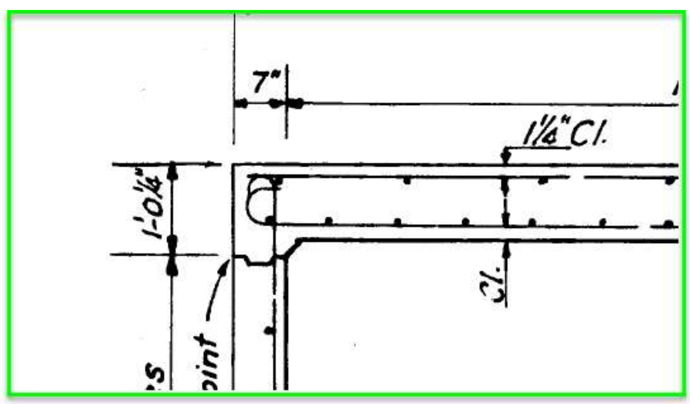
ACI 318, Current. Building Code Requirements for Structural Concrete (ACI)
FDOT Bridge Management System Coding Guide, 2018 (FDOT BMS Coding)
FDOT Bridge Load Rating Manual, 2019 (BLRM)
FDOT Structures Design Guidelines Volume 1, 2019 (SDG)
AASHTO LRFD Bridge Design Specifications, 8th Ed. 2017 (LRFD)
AASHTO Manual for Bridge Evaluation, 3rd Ed. 2018 with 2019 Interims (MBE)
AASHTO Standard Specifications for Highway Bridges, 17th Ed. 2002 with 2005 Interims (Std.Spec.)

Applicability

Inapplicable. Frame corners are reinforced.



Applicable. Outside corners are unreinforced; ends are hinged.



EXPAND THIS AREA TO PRINT

Discussion

APPLICABILITY. This program applies to typical old-style hinged-end cast-in-place box culverts in Florida built to Standard Indices prior to 1970, where (1) the outside corners omit reinforcement, (2) the top and bottom slabs are identically reinforced and uniformly thick, (3) positive moment reinforcement in the slabs is the same as negative moment reinforcement, thanks to "crank bars," (4) span lengths are less than 15 feet, and (5) the shoulder is adequate; the distance from any lane centerline to its nearest culvert end is greater than one half of the lateral distribution strip width.

ASSUMPTIONS, TOP SLAB. (1) Neglect the bottom slab. The bottom slab experiences less live load than the top slab, because the live load is distributed laterally through the walls before reaching the bottom slab. (2) Neglect top-slab-to-exterior-wall continuity. The outside face of the exterior wall omits reinforcement, which renders the connection pinned. Also neglect top-slab-to-interior-wall continuity. Minimal reinforcement, typically #4 at 12 in. OC, is insufficient to fix the connection. (3) Neglect mildly beneficial axial action onto the top slab, from horizontal earth pressures. (4) Approximate the governing location for positive moment as 40% span length for multi-span culverts, and 50% span length for single-span culverts. (5) For all top slab distribution calculations, take the effective span length as the clear span. Meanwhile for load calculations, take the effective span lengths as the distances between wall centerlines. (6) Use singly-reinforced flexural capacity, which is trivially less than doubly-reinforced capacity among typical 1.25 inch clear covers.

ASSUMPTIONS, EXTERIOR WALL. (1) Include axial loading, verify that ε.steel > ε.yield, and apply concepts from MBE Appendix G6A. (2) Reduce the effective span length to construction joint keys. (3) Adapt the HL93 Inventory Rating to all vehicles. Where γ = live load factor, GVW = gross vehicle weight, and GVW.HL93 is assumed to be 36 tons:
RF.Exterior.Wall.Vehicle = (RF.Exterior.Wall.HL93.Inventory)(γ.HL93.Inventory/γ.Vehicle)(GVW.HL93/GVW.Vehicle).

DISTRIBUTION. For LFR and LRFR lateral distribution through earth fill, consider one wheel-line and two wheel-lines (one truck). For LFR distribution through earth fill, additionally consider two adjacent trucks, and two trucks fully overlapped (two trucks), wherein adjacent truck spacing is 4 feet. For both LFR and LRFR, take the best of (slab distribution, earth distribution). For LFR tire distribution, use point loading (conservative); for LRFR, use tire patch loading (code). Apply longitudinal distribution, regardless of fill depth. For LFR, this controverts a narrow reading of Std.Spec 6.4.2, which specifies point loading for culverts under less than 2 feet of fill. However, Std. Spec. provides for alternate rational analyses at 1.1.1, and LRFD C4.6.2.10.2 provides that alternative when it explains why longitudinal distribution is reasonable and warranted, even for shallower fills.

LIVE LOAD. LFR appraisals use all axle effects, whereas LRFR ratings use extreme axle effects (LRFD C.3.6.1.3.1). LFR impact is interpolated to a linear, rather than step-wise, factor. LRFR lane loading does not apply to barrel widths less than 15 feet in length (LRFD 3.6.1.3.3), and lane loading has been removed from this worksheet.

SHEAR. Shear is taken at a distance "d" away from the face of the support. Reinforcement is assumed to be fully developed at d away from face, since FDOT hinged-end culvert indices used sensible bearing lengths and reinforcement details. For reference, the development length for a hooked 40ksi No. 7 bar in 3 ksi concrete is less than 12 inches (LRFD 5.10.8.2.4a-1); say 12 inches.

METHODOLOGY. All loading is interpolated to an influence matrix, whose precision is guided by "ips" (increments per span). A one foot equivalent strip is analyzed throughout. Consider minimum and maximum load factors to achieve the worst-case loading, however apply only one load factor per load case type at a time. For example, do not vary the vertical earth load factor across different span lengths.

Revision Notes

CHANGE NOTES, JULY 2013
(1) speeded up LL routine - dismissed needless increments
(2) added true coincidency shear capacity (previously vectorization conservatively took max moment for Vn equation)
(3) removed point load simulation; substituted area influence
(3) added check plots for select vehicle
(4) added explicit RF output for all vehicles
(6) LRFD 12.5.5.1 shear strength reduction factor to 0.85
(7) updated to 2013 LRFD Interim (adjust tire width to 20in. + 0.06*L)

CHANGE NOTES FEBRUARY 2015
(1) the program last verified 09-09-13; see #750083 review in EDMS, which compares independent calcs.
(2) excluded the Std.Spec. 24kip Military Tandem, as LFR evaluation omits this truck from HS20 evaluation (FDOT clarification for 2015)
(3) clarified that ϕV = 0.85 for all shear, even for LRFD slab-type fills less than 2feet.
(4) changed shear capacity note to cite simplified shear (LRFD - 5.8.3.4.3, which is by inference the $0.06 \cdot \sqrt{fc \cdot ksi} = 1.9 \cdot \sqrt{fc \cdot psi}$ terms in Vci Vcw)
(5) changed note for mpf = "...1.00 for FL120 routine permit (MBE 6A.4.5.4.2a-1, footnote a)," removing reference to 2011 FDOT Load Rating Manual.

CHANGE NOTES JULY - NOVEMBER 2015
(1) greatly simplify the governing output, only keeping what is needed to inform the Excel summary
(2) develop exterior wall assessment
(3) discard exact uniform load engine; use point approximations instead
(4) offer truly coincident loading with the possibility of varying load factors - min & max among same element.
(5) use one location per test, i.e. 1.40 for positive moment multi-cell or 1.50 for positive moment single-cell.
(6) reduce discussion, and make a separate LRFR code summary worksheet
(7) make companion Excel summary form and adjust for direct output
(8) adopt SDG and MBE DF - one lane only, mpf.legal = 1.00
(9) adopt General Method shear capacity for LRFD shallow fills

CHANGE NOTES JULY - JANUARY 2016
(1) edit preficial notes - disclaimer, intent and outline.
(2) update companion summary (Excel) and LRFR code summary

CHANGE NOTES - MARCH 2016
(1) in vehicle list CLVT_VEH_SET(L), row 3 column 2, subrow 2 subcol 1, change "HL93.OPR" to "HS20.OPR."
(2) remove calculations for depth of fill by auto-level; retain this as a separate worksheet
(3) change name from "FDOT OLD CBC" to "FDOT Hinged-End Culvert"
(4) re-arrange order of topics on Page 2
(5) include [quick-start] instructions, top of Page 2
(6) provide slider-bar on Page 6, to select the test vehicle, the vehicle to check on the last 8 pages
(7) move "applicability" section from Page 3 to Page 2
(8) add s.xe < 80in LRFD 8.5.3.4.2-5 (no change for d.v ~ 10in., but makes fidelity to code clearer)
(9) remove 3ksi hard code f.c at exterior wall "a" effective depth of the compression block; substitute with f.c (genuine change)
(10) add "Assumptions, Exterior Wall" section to Page 3
(11) add cartoon examples to Page 3, for inapplicable (frame) and applicable (hinged-end)

CHANGE NOTES - MARCH 2019
(1) Update the "References" section to BLRM 2019, etc.
(2) Update the "Discussion" section. Apply minor code number updates. Edit the shear subsection.
(3) Add emergency vehicles. Add live load category 5 - FAST Act Emergency Vehicles (EVs). Add trucks EV2 and EV3.
(4) Change the single-lane multiple presence factor for HL93 Operating to 1.00, per BLRM 6A.5.12.

Vehicles

$$\mathrm{HS20\_FT}(L) := \left|\begin{array}{l} \mathrm{SPACING} \leftarrow L_1\cdot(0.6+1+0.4) \\ \mathrm{SPACING} \leftarrow \max\left[14, L_1\cdot(0.6+1+0.4)\right] \\ \mathrm{SPACING} \leftarrow \min(30, \mathrm{SPACING}) \end{array}\right.$$

$$\mathrm{HS20}(L) := \left|\begin{array}{l} T \leftarrow \begin{pmatrix} 0 & 8 \\ 14 & 32 \\ 14 & 32 \end{pmatrix} \\ \text{return } T \text{ if } \mathrm{rows}(L) < 3 \\ \text{return } T \text{ if } \mathrm{HS20\_FT}(L) = 14 \\ \left[T \begin{pmatrix} 0 & 8 \\ 14 & 32 \\ \mathrm{HS20\_FT}(L) & 32 \end{pmatrix} \right]^T \end{array}\right.$$

$$\mathrm{HL93}(L) := \left|\begin{array}{l} \mathrm{HS20} \leftarrow \mathrm{HS20}(L) \\ \mathrm{TAND} \leftarrow \begin{pmatrix} 0 & 25 \\ 4 & 25 \end{pmatrix} \\ \text{return } (\mathrm{HS20}\ \ \mathrm{TAND})^T \text{ if } \mathrm{rows}(\mathrm{HS20}) = 3 \\ \mathrm{stack}[\mathrm{HS20}, (\mathrm{TAND})] \end{array}\right.$$

$$\begin{pmatrix} \mathrm{SU2} \\ \mathrm{SU3} \\ \mathrm{SU4} \\ \mathrm{ST5} \end{pmatrix} := \begin{bmatrix} \begin{pmatrix} 0 & 12 \\ 13 & 22 \end{pmatrix} \\ \begin{pmatrix} 0 & 22 \\ 11 & 22 \\ 4.17 & 22 \end{pmatrix} \\ \begin{pmatrix} 0 & 13.9 \\ 9.17 & 18.7 \\ 4.17 & 18.7 \\ 4.17 & 18.7 \end{pmatrix} \\ \begin{pmatrix} 0 & 8 \\ 27 & 18 \\ 4 & 18 \\ 12 & 18 \\ 24 & 18 \end{pmatrix} \end{bmatrix} \qquad \begin{pmatrix} \mathrm{C3} \\ \mathrm{C4} \\ \mathrm{C5} \\ \mathrm{FL120} \end{pmatrix} := \begin{bmatrix} \begin{pmatrix} 0 & 12 \\ 10 & 22 \\ 20 & 22 \end{pmatrix} \\ \begin{pmatrix} 0 & 7.3 \\ 10 & 22 \\ 21.83 & 22 \\ 4.17 & 22 \end{pmatrix} \\ \begin{pmatrix} 0 & 10 \\ 10 & 20 \\ 4.17 & 20 \\ 17.67 & 15 \\ 4.17 & 15 \end{pmatrix} \\ \begin{pmatrix} 0 & 13.334 \\ 14 & 53.333 \\ 14 & 53.333 \end{pmatrix} \end{bmatrix} \qquad \begin{pmatrix} \mathrm{EV2} \\ \mathrm{EV3} \end{pmatrix} := \begin{bmatrix} \begin{pmatrix} 0 & 24 \\ 15 & 33.5 \end{pmatrix} \\ \begin{pmatrix} 0 & 24 \\ 15 & 31 \\ 4 & 31 \end{pmatrix} \end{bmatrix}$$

$$\mathrm{CLVT\_VEH\_SET}(L) := \begin{bmatrix} 1 & \begin{pmatrix} \text{"HL93.INV"} & \mathrm{HL93}(L) & 1 \\ \text{"HL93.OPR"} & \mathrm{HL93}(L) & 2 \\ \text{"FL120"} & \mathrm{FL120} & 4 \\ \text{"SU2"} & \mathrm{SU2} & 3 \\ \text{"SU3"} & \mathrm{SU3} & 3 \\ \text{"SU4"} & \mathrm{SU4} & 3 \\ \text{"C3"} & \mathrm{C3} & 3 \\ \text{"C4"} & \mathrm{C4} & 3 \\ \text{"C5"} & \mathrm{C5} & 3 \\ \text{"ST5"} & \mathrm{ST5} & 3 \\ \text{"EV2"} & \mathrm{EV2} & 5 \\ \text{"EV3"} & \mathrm{EV3} & 5 \end{pmatrix} \\ 1 & \begin{pmatrix} \text{"HL93.INV"} & \mathrm{HL93}(L) & 1 \\ \text{"HL93.OPR"} & \mathrm{HL93}(L) & 2 \\ \text{"FL120"} & \mathrm{FL120} & 4 \end{pmatrix} \\ 0 & \begin{pmatrix} \text{"HS20.INV"} & \mathrm{HS20}(L) & 1 \\ \text{"HS20.OPR"} & \mathrm{HS20}(L) & 2 \\ \text{"SU2"} & \mathrm{SU2} & 3 \\ \text{"SU3"} & \mathrm{SU3} & 3 \\ \text{"SU4"} & \mathrm{SU4} & 3 \\ \text{"C3"} & \mathrm{C3} & 3 \\ \text{"C4"} & \mathrm{C4} & 3 \\ \text{"C5"} & \mathrm{C5} & 3 \\ \text{"ST5"} & \mathrm{ST5} & 3 \\ \text{"EV2"} & \mathrm{EV2} & 5 \\ \text{"EV3"} & \mathrm{EV3} & 5 \end{pmatrix} \\ 0 & \begin{pmatrix} \text{"HS20.INV"} & \mathrm{HS20}(L) & 1 \\ \text{"HS20.OPR"} & \mathrm{HS20}(L) & 2 \end{pmatrix} \\ 1 & \begin{bmatrix} \text{"CUSTM"} & \begin{pmatrix} 0.00 & 12.00 \\ 13.00 & 22.00 \end{pmatrix} & 4 \end{bmatrix} \end{bmatrix}$$

CLVT_VEH_SET(L) - standard vehicle sets
COL 1 = Method. 0 means LFR-Std.Spec.-Load Factor; 1 means LRFR-LRFD
COL 2 = Vehicle descriptions: Name, Trucks, Rating Level
Rating Level:
1 - Design Inventory
2 - Design Operating
3 - Legal Operating
4 - Permit
5 - Emergency Vehicle

NOTES
Trucks follow this format (ft spacing, kip axle loading).
No lane loading, for the HL93 (LRFD 3.6.1.3.3).
A vehicle can have one or more trucks (Truck and Tandem).

Dimensions

$$L := \begin{array}{|l} \text{for } i \in 1..\text{cells} \\ \quad L_i \leftarrow \begin{array}{|ll} 0.5 \cdot t_{ExtWall} + W_c + 0.5 \cdot t_{IntWall} & \text{if } i = 1 \vee i = \text{cells} \\ 0.5 \cdot t_{IntWall} + W_c + 0.5 \cdot t_{IntWall} & \text{otherwise} \end{array} \\ L \cdot ft^{-1} \end{array}$$

$L = \begin{pmatrix} 9.63 \\ 9.67 \\ 9.63 \end{pmatrix}$ - span lengths (feet)

$$\rho := \frac{A_s}{d \cdot 12in}$$

$\rho = 0.0102$ - steel/concrete ratio

$$B_c := t_{ExtWall} + \sum L \cdot ft$$

$B_c = 29.50\,ft$ - out-to-out bridge length parallel to the effective span lengths

Declare Vehicle Selection, Analysis Method, and Precision

$$D_{fills} := \overrightarrow{\text{round}\left(\frac{D_{fills}}{ft}, 2\right)} \cdot ft$$

$D_{fills} = \begin{pmatrix} 2.00 \\ 5.00 \end{pmatrix} ft$ - round fills to 0.01 ft.; standardize significant figures for check calcs

$$TRUCKS := \begin{array}{|l} T1 \leftarrow CLVT\_VEH\_SET(L)_{VehSet, 2} \\ T2(K) \leftarrow \text{if}[\text{cols}(K) = 2, (K), K] \\ \overrightarrow{T2(T1)} \end{array}$$

TRUCKS - select method and vehicles

$$LRFR := CLVT\_VEH\_SET(1)_{VehSet, 1}$$

$LRFR = 1.00$ - method is $Method := (\text{"LFR"} \quad \text{"LRFR"})_{1, LRFR+1} = \text{"LRFR"}$

$$AV := \begin{array}{|l} T \leftarrow TRUCKS^{\langle 1 \rangle} \\ \text{augment}(\text{matrix}(\text{rows}(T), 1, f(i,j) \leftarrow i + 1), T) \end{array}$$

$$AV^T = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 \\ \text{"HL93.INV"} & \text{"HL93.OPR"} & \text{"FL120"} & \text{"SU2"} & \text{"SU3"} & \text{"SU4"} & \text{"C3"} & \text{"C4"} & \text{"C5"} & \text{"ST5"} & \text{"E} \end{pmatrix}$$

select the test vehicle :

$testVEH = 2.00$ - check this vehicle, last 8 pages: $AV_{testVEH, 2} = \text{"HL93.OPR"}$

$ips := 20$

$ips = 20$ - precision, increments per span (10 is OK, 20 is good, and 40 is best)

$ips_{LL} := 50$

$ips_{LL} = 50$ - increments of truck travel (20 is OK, 50 is good, and 100 is best)

$$d_{AFF} := \begin{array}{|ll} 0.5 \cdot t_{ExtWall} + d & \text{if cells} = 1 \\ 0.5 \cdot t_{IntWall} + d & \text{otherwise} \end{array}$$

$d_{AFF} = 0.99\,ft$ - distance CL of bearing to "d" away from face, for shear RF location

Load Factors

$$\gamma_{LL\_MAT} := \begin{pmatrix} \text{"VEH TYPE"} & \text{"}\gamma\text{DESC"} & \text{"}\gamma\text{.LF"} & \text{"}\gamma\text{.LRFD"} \\ 1 & \text{"}\gamma\text{.INV "} & 2.17 & 1.75 \\ 2 & \text{"}\gamma\text{.OPR "} & 1.30 & 1.35 \\ 3 & \text{"}\gamma\text{.OPR "} & 1.30 & 1.35 \\ 4 & \text{"}\gamma\text{.PERM"} & 1.30 & 1.35 \\ 5 & \text{"}\gamma\text{.EV"} & 1.30 & 1.30 \end{pmatrix}$$

γ_{LL_MAT} - live load factor matrix (BLRM 6A.5.12)

$\gamma_{LLmin} := (1 \;\; 0)_{1,LRFR+1}$

$\gamma_{LLmin} = 0.00$ - for LFR, apply all effects; for LRFR, apply extreme effects

$\text{veh\_type}(iv) := \text{TRUCKS}_{iv,3}$

veh_type(iv) - vehicle type equation (1=Des.INV, 2=Des.OPR, 3=Legal.OPR, 4=PERMIT)

$\text{mpf\_eq}(iv) := \text{if}(\text{LRFR} = 1 \wedge \text{veh\_type}(iv) = 1, 1.20, 1.00)$

mpf_eq(iv) - single lane multiple presence factor equation

$\gamma\text{LL\_eq}(iv) := \gamma_{LL\_MAT_{\text{veh\_type}(iv)+1,\,3+\text{LRFR}}}$

γLL_eq(iv) - live load factor equation

$\gamma_{LL} := \overrightarrow{\gamma\text{LL\_eq}\left(AV^{\langle 1\rangle}\right)} \qquad \text{mpf} := \overrightarrow{\text{mpf\_eq}\left(AV^{\langle 1\rangle}\right)}$

γ_{LL} - live load factors, vector for all vehicles

$$\text{AV2} := \left| \begin{array}{l} (\text{LBL} \;\; \text{Nos}) \leftarrow \left[(\text{"\#"} \;\; \text{"VEH"} \;\; \text{"TYPE"} \;\; \text{"mpf"} \;\; \text{"}\gamma\text{.LL"}) \;\; AV^{\langle 1\rangle} \right] \\ \text{DAT} \leftarrow \text{augment}\left(AV, \overrightarrow{\text{veh\_type(Nos)}}, \overrightarrow{\text{mpf\_eq(Nos)}}, \overrightarrow{\gamma\text{LL\_eq(Nos)}}\right) \\ \text{stack(LBL, DAT)} \end{array} \right.$$

- available vehicles: No., name, type No., mpf, γ.LL

$\text{AV3} := \text{augment}\left(\text{AV2}^{\langle 2\rangle}, \text{AV2}^{\langle 4\rangle}, \text{AV2}^{\langle 5\rangle}\right)$

AV3 - available vehicles: name, mpf, γ.LL

$$\text{AV2} = \begin{pmatrix} \text{"\#"} & \text{"VEH"} & \text{"TYPE"} & \text{"mpf"} & \text{"}\gamma\text{.LL"} \\ 1.00 & \text{"HL93.INV"} & 1.00 & 1.20 & 1.75 \\ 2.00 & \text{"HL93.OPR"} & 2.00 & 1.00 & 1.35 \\ 3.00 & \text{"FL120"} & 4.00 & 1.00 & 1.35 \\ 4.00 & \text{"SU2"} & 3.00 & 1.00 & 1.35 \\ 5.00 & \text{"SU3"} & 3.00 & 1.00 & 1.35 \\ 6.00 & \text{"SU4"} & 3.00 & 1.00 & 1.35 \\ 7.00 & \text{"C3"} & 3.00 & 1.00 & 1.35 \\ 8.00 & \text{"C4"} & 3.00 & 1.00 & 1.35 \\ 9.00 & \text{"C5"} & 3.00 & 1.00 & 1.35 \\ 10.00 & \text{"ST5"} & 3.00 & 1.00 & 1.35 \\ 11.00 & \text{"EV2"} & 5.00 & 1.00 & 1.30 \\ 12.00 & \text{"EV3"} & 5.00 & 1.00 & 1.30 \end{pmatrix}$$

Dead Load

$$\begin{pmatrix} \gamma_{DCmin} \\ \gamma_{DCmax} \\ \eta\gamma_{EVmin} \\ \eta\gamma_{EVmax} \\ \eta\gamma_{EHmin} \\ \eta\gamma_{EHmax} \end{pmatrix} := \begin{pmatrix} 1.30 & 0.90 \\ 1.30 & 1.25 \\ 1.30 & 1.00\cdot 0.90 \\ 1.30 & 1.00\cdot 1.30 \\ 0.50\cdot 1.30 & 1.00\cdot 0.90 \\ 1.30 & 1.00\cdot 1.35 \end{pmatrix}^{\langle LRFR+1\rangle}$$

$$\begin{pmatrix} \gamma_{DCmin} \\ \gamma_{DCmax} \\ \eta\gamma_{EVmin} \\ \eta\gamma_{EVmax} \\ \eta\gamma_{EHmin} \\ \eta\gamma_{EHmax} \end{pmatrix} = \begin{pmatrix} 0.90 \\ 1.25 \\ 0.90 \\ 1.30 \\ 0.90 \\ 1.35 \end{pmatrix}$$ Load factors (Std.Spec. 3.22.1.A, BLRM 6A.5.12)

$\omega_{DC} := 150pcf\cdot 12in\cdot t_{slab}$

$\omega_{DC} = 0.119\cdot klf$ - component/slab load (SDG 3.15.4)

$\gamma_{soil} := 120pcf$

$\gamma_{soil} = 120\cdot pcf$ - unit weight of soil (SDG 3.15.4)

$F_{e.eq}(D) := \min\left(1.15, 1 + 0.20\cdot\frac{D}{B_c}\right)$

$\overrightarrow{F_{e.eq}(D_{fills})} = \begin{pmatrix} 1.014 \\ 1.034 \end{pmatrix}$ - soil interaction factor (Std.Spec.Eq. 16-16, LRFD 12.11.2.2.1-2)

$\omega_{EV}(D) := F_{e.eq}(D)\cdot D\cdot\gamma_{soil}\cdot ft$

$\overrightarrow{\omega_{EV}(D_{fills})} = \begin{pmatrix} 0.243 \\ 0.620 \end{pmatrix}\cdot klf$ - vertical earth loading

$\omega_{EH}(D) := \frac{\gamma_{soil}}{2}\cdot D\cdot ft$

$\overrightarrow{\omega_{EH}(D_{fills})} = \begin{pmatrix} 0.120 \\ 0.300 \end{pmatrix}\cdot klf$ - lateral earth pressure

$\omega_{DL}(D) := \left(\omega_{DC} + \omega_{EV}(D)\right)\cdot klf^{-1}$

$\overrightarrow{\omega_{DL}(D_{fills})} = \begin{pmatrix} 0.362 \\ 0.739 \end{pmatrix}$ - total unfactored vertical DL (klf)

Top Slab, Distribution & Impact (1 of 2)

DISTRIBUTION

$LRFR = 1.00$ Method = "LRFR"

$gage := 6ft$

gage - gage width, spacing between wheel lines (BLRM Appendix)

$lane_w := 12ft$

$lane_w$ - lane width (Std.Spec.17th Ed. Fig. 3.7.A, LRFD Fig. 3.6.1.2.2-1)

$tire_{width} := if(LRFR = 0, 0, 20in + 0.06 \cdot W_c)$

$tire_{width} = 26.48 \cdot in$ - tire width (Std.Spec.6.4.1, LRFD 3.6.1.2.6b)

$tire_{length} := if(LRFR = 0, 0, 10in)$

$tire_{length} = 10.00 \cdot in$ - tire length (Std.Spec. 3.30, LRFD 3.6.1.2.5)

$DF_{earth} := if(LRFR = 0, 1.75, 1.15)$

$DF_{earth} = 1.15$ distribution, earth (Std.Spec.17th Ed. 6.4.1, LRFD Table 3.6.1.2.6a-1)

Eq(mpf_1LANE, D_fill) - equivalent strip width for lateral distribution. mpf_1LANE - single-lane multiple presence factor, D - covering fill, from the roadway surface to the top of the top slab, (Slab distribution from Std.Spec. 3.24.3.2 & LRFD Eq. 4.6.2.10.2-1. Earth distribution from Std.Spec. 6.4 & LRFD 3.6.1.2.6). For effective span length, say clear span (Std.Spec. 3.24.1.1 & LRFD 4.6.2.10.2-1).

$$Eeq(mpf\_1LANE, D_{fill}) := \left| \begin{array}{l} E\_SLAB \leftarrow 8ft + 0.12 \cdot W_c \\ E\_EARTH\_1TRUCK \leftarrow \min\left[2 \cdot (tire_{width} + D_{fill} \cdot DF_{earth}), 1 \cdot (tire_{width} + DF_{earth} \cdot D_{fill} + gage)\right] \\ E\_EARTH\_2TRUCKS \leftarrow \min\left[1 \cdot (tire_{width} + D_{fill} \cdot DF_{earth} + 4ft), 0.5 \cdot (tire_{width} + D_{fill} \cdot DF_{earth} + 2 \cdot gage + 4ft)\right] \\ \begin{pmatrix} \max\left(\frac{E\_SLAB}{1.00}, \min\left(\frac{E\_EARTH\_1TRUCK}{1.00}, \frac{E\_EARTH\_2TRUCKS}{1.00}\right)\right) \\ \max\left(\frac{E\_SLAB}{mpf\_1LANE}, \min\left(\frac{E\_EARTH\_1TRUCK}{mpf\_1LANE}\right)\right) \end{pmatrix}_{LRFR+1} \end{array} \right.$$

$$E(D_{fill}) := \left| \begin{array}{l} T \leftarrow \left(concat\left("D.fill =", num2str(D_{fill} \cdot ft^{-1}), "ft"\right) \quad "mpf, 1\ lane" \quad "E\ (ft)"\right) \\ \text{return } stack\left[T, \left("INV/OPR" \quad 1 \quad Eeq(1, D_{fill}) \cdot ft^{-1}\right)\right] \text{ if } LRFR = 0 \\ \text{return } stack\left[T, \begin{pmatrix} "HL93" & 1.2 & Eeq(1.2, D_{fill}) \cdot ft^{-1} \\ "LGL/FL120" & 1 & Eeq(1, D_{fill}) \cdot ft^{-1} \end{pmatrix}\right] \text{ if } LRFR = 1 \end{array} \right.$$

$$\overrightarrow{E(D_{fills})} = \begin{bmatrix} \begin{pmatrix} "D.fill =2ft" & "mpf, 1\ lane" & "E\ (ft)" \\ "HL93" & 1.20 & 7.57 \\ "LGL/FL120" & 1.00 & 9.08 \end{pmatrix} \\ \begin{pmatrix} "D.fill =5ft" & "mpf, 1\ lane" & "E\ (ft)" \\ "HL93" & 1.20 & 11.63 \\ "LGL/FL120" & 1.00 & 13.96 \end{pmatrix} \end{bmatrix}$$

$$LLDFeq(mpf\_1LANE, D_{fill}) := \frac{ft}{Eeq(mpf\_1LANE, D_{fill})}$$

LLDFeq(mpf_1LANE, D_fill) - lateral distribution factor (axles per 1 foot strip)

$E_{long.eq}(D) := DF_{earth} \cdot D + tire_{length}$

$E_{long}(D)$ - longitudinal distribution length (Std.Spec. 1.1.1 & 6.4.1, LRFD 4.6.2.10.2-2)

IMPACT

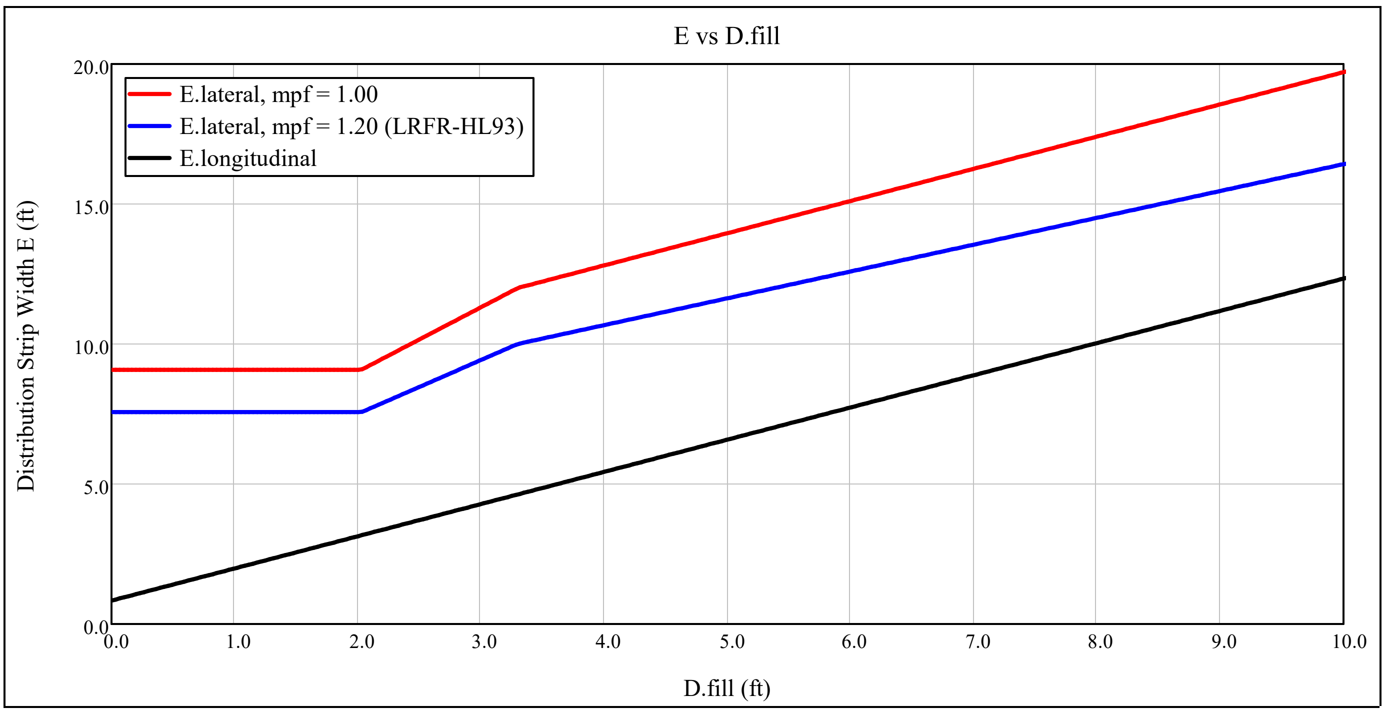
$LRFR = 1.00$ Method = "LRFR"

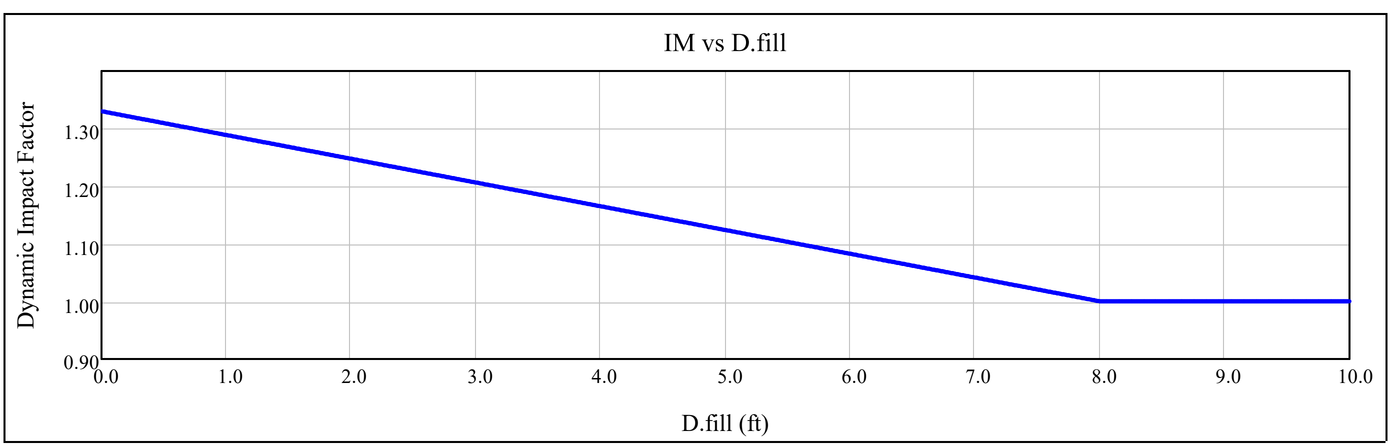
$$IM_{CLVT.Std.Spec.} := \begin{pmatrix} 0 & 1 & 1 & 2 & 2 & 3 & 3 & 20 \\ 1.3 & 1.3 & 1.2 & 1.2 & 1.1 & 1.1 & 1 & 1 \end{pmatrix}^T$$

$IM_{CLVT.Std.Spec.}$ - plot points, step-wise LFR impact(Std.Spec. 3.8.2.3)

$$IMeq(D_{fill}) := \begin{array}{|l} \text{if } LRFR = 0 \\ \quad \begin{array}{|l} IM \leftarrow \min\left[1.30, 1.30 - \frac{0.30}{3} \cdot \left(\frac{D_{fill}}{ft} - 0.5\right)\right] \\ \max(1.00, IM) \end{array} \\ \text{if } LRFR = 1 \\ \quad \begin{array}{|l} IM \leftarrow \min\left[1.33, 1 + 0.33 \cdot \left(1 - \frac{D_{fill}}{8ft}\right)\right] \\ \max(1.00, IM) \end{array} \end{array}$$

$IMeq(D_{fill})$ - live load impact (Std.Spec. 3.8.2.3 interpolated, LRFD 3.6.2.2-1)





Top Slab, Make Influence Table (1 of 8)

match2(n , M) - for exact match

$$\text{match2}(n,M) := \text{match}\left(n\cdot 10^{10}, M\cdot 10^{10}\right)_{1,1}$$

Vinc - shear check location at d away from face of bearing at Pier 2

$$\text{Vinc} := \min\left[1.999, \left(L_1 - \frac{d_{AFF}}{ft}\right)\cdot\left(L_1\right)^{-1} + 1\right] = 1.90$$

BrIncs_{eq1} BrIncs_{eq2} & BrIncs - bridge increments: span No. + % span length

$$\text{BrIncs}_{eq1}(L, ips) := \left|\begin{array}{l} r \leftarrow 0 \\ \text{for }\ \text{SpanNo} \in 1..\text{rows}(L) \\ \quad \text{for }\ i \in 1..ips + 1 \\ \qquad \left|\begin{array}{l} row \leftarrow i + (ips + 1)\cdot(\text{SpanNo} - 1) \\ T2 \leftarrow \left|\begin{array}{l} (i-1) + 10^{-9} \ \text{ if }\ i = 1 \\ i - 1 \ \text{ if }\ i > 1 \wedge i < ips + 1 \\ (i-1) - 10^{-9} \ \text{ if }\ i = ips + 1 \end{array}\right. \\ r \leftarrow r + 1 \\ T1_r \leftarrow \text{SpanNo} + \dfrac{T2}{ips} \end{array}\right. \\ T1 \end{array}\right.$$

$$\text{BrIncs}_{eq2}(L, ips) := \left|\begin{array}{l} \text{BrINCS} \leftarrow \text{csort}\left[\text{stack}\left[\begin{pmatrix} \text{Vinc} - 0.0001 \\ \text{Vinc} \\ \text{Vinc} + 0.0001 \end{pmatrix}, \text{BrIncs}_{eq1}(L, ips)\right], 1\right] \\ T \leftarrow \left(\text{BrINCS}_1\right) \\ \text{for }\ i \in 2..\text{rows}(\text{BrINCS}) \\ \quad T \leftarrow \text{if}\left(\text{BrINCS}_{i-1} = \text{BrINCS}_i, T, \text{stack}\left(T, \text{BrINCS}_i\right)\right) \\ T \end{array}\right.$$

$$\text{BrIncs} := \text{BrIncs}_{eq2}(L, ips)$$

RSIF_{eq} & RSIF - influence locations: (R)ow, (S)pan, (I)ncrement, (F)eet

$$\text{RSIF}_{eq}(L, \text{BrIncs}) := \left|\begin{array}{l} Lt \leftarrow \text{stack}[(0), L] \\ \text{for }\ i \in 1..\text{rows}(\text{BrIncs}) \\ \quad \left|\begin{array}{l} span \leftarrow \text{trunc}\left(\text{BrIncs}_i\right) \\ ft \leftarrow \left(\displaystyle\sum_{k=1}^{span} Lt_k\right) + \left[L_{span}\cdot\left(\text{BrIncs}_i - span\right)\right] \\ T^{\langle i \rangle} \leftarrow \left(i + 1 \quad span \quad \text{BrIncs}_i \quad ft\right)^T \end{array}\right. \\ T \leftarrow T^T \\ T2 \leftarrow \begin{bmatrix} 1 & \text{rows}(T) + 2 \\ 0 & \text{rows}(L) + 1 \\ \left(1 - \dfrac{0.001}{L_1}\right) & \left(\text{rows}(L) + 1 + \dfrac{0.001}{L_{\text{rows}(L)}}\right) \\ -0.001\cdot L_1 & \sum L + 0.001\cdot L_1 \end{bmatrix}^T \\ T \leftarrow \text{stack}(T, T2) \\ \text{csort}(T, 1) \end{array}\right.$$

$$\text{RSIF} := \text{RSIF}_{eq}(L, \text{BrIncs})$$

Top Slab, Make Influence Table (2 of 8)

RSIF_CHK_LOCS - check locations: (R)ow, (S)pan, (I)ncrement, (F)eet

```
RSIF_CHK_LOCS := | r(BrINC) ← match2(BrINC, RSIF^<3>)
                 |        ( match2( | 1.50  if  cells = 1 , RSIF^<3> ) )
                 |        (         | 1.40  otherwise                  )
                 | Get ←  ( match(2.00, RSIF^<3>)_1                    )
                 |        ( match2(Vinc, RSIF^<3>)                     )
                 |        ( match2(Vinc, RSIF^<3>)                     )
                 | for  i ∈ 1 .. rows(Get)
                 |   T2^<i> ← (RSIF^T)^<(Get_i)>
                 | T2^T
```

```
| HDR ← ("ROW"  "SPAN"  "INC"  "FT")
| stack(HDR, RSIF_CHK_LOCS)
```

=

"ROW"	"SPAN"	"INC"	"FT"
10.00	1.00	1.40	3.85
25.00	1.00	2.00	9.62
21.00	1.00	1.90	8.64
21.00	1.00	1.90	8.64

pM_{BrINC} - positive moment location

$$pM_{BrINC} := RSIF_{RSIF\_CHK\_LOCS_{1,1},3} = 1.40$$

pier location

```
SUML(L) := | for  i ∈ 1 .. rows(L)
           |   SUML_i ← Σ_{k=1}^{i} L_k
           | SUML
```

bridge length

$$ENDPIER(L) := \sum L$$

is x over a pier?

```
axlatpier(x, L) := | T_1 ← 1  if  x = 0
                   | T_1 ← 0  otherwise
                   | for  i ∈ 1 .. rows(L)
                   |   | T_{i+1} ← i + 1  if  x = Σ_{k=1}^{i} L_k
                   |   | T_{i+1} ← 0  otherwise
                   | max(T)
```

x is in what span?

```
axlspan(x, L) := | T ← 0  if  x < 0 ∨ x > ENDPIER(L)
                 | otherwise
                 |   | T ← 1
                 |   | while  x / (Σ_{k=1}^{T} L_k) > 1
                 |   |   T ← T + 1
                 | rows(L) + 1  if  x = Σ_{k=1}^{rows(L)} L_k
                 | T  otherwise
```

local distance to nearest left pier

```
a(x, L) := | x  if  axlspan(x, L) = 1 ∨ rows(L) = 1
           | x − Σ_{k=1}^{axlspan(x, L)−1} L_k  otherwise
```

EI - stiffness

$$EI := 10 \cdot 10^{4}$$

what's the sign of theta?

$$\text{signtheta}(x, L) := \left| \begin{array}{l} 1 \ \text{ if } \ \text{round}\left(\dfrac{\text{axlspan}(x, L)}{2}, 0\right) = 0 \\ -1 \ \text{ otherwise} \end{array} \right.$$

simple moment

$$MP(x, L) := \left| \begin{array}{l} \text{spanNo} \leftarrow \text{axlspan}(x, L) \\ \dfrac{L_{\text{spanNo}} - a(x, L)}{L_{\text{spanNo}}} \cdot a(x, L) \end{array} \right.$$

MEQ1 - unknown θ.1 & areas of moments

$$\text{MEQ1p}(x, L) := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(L) \\ \quad T_{i,1} \leftarrow \text{signtheta}(x, L) \cdot EI \cdot (-1) \\ \text{for } i \in 1..\text{rows}(L) \\ \quad \left| \begin{array}{l} 0 \ \text{ if } \ \text{rows}(L) = 1 \\ \text{otherwise} \\ \quad \left| \begin{array}{l} \text{for } j \in 2..\text{rows}(L) \\ \quad T_{i,j} \leftarrow \left| \begin{array}{l} 0 \ \text{ if } j > i \\ \text{otherwise} \\ \quad \left| \begin{array}{l} 0.5 \cdot L_{j-1} \ \text{ if } j = i \\ 0.5 \cdot \left(L_{j-1} + L_j\right) \ \text{ otherwise} \end{array} \right. \end{array} \right. \\ T \end{array} \right. \end{array} \right. \\ T \end{array} \right.$$

MEQ2 - unknown area moments * known distance

$$\text{MEQ2p}(x, L) := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(L) \\ \quad \text{for } j \in 1..\text{rows}(L) \\ \quad\quad \left| \begin{array}{l} \text{if } i = 1 \\ \quad \left| \begin{array}{l} AM_{i,j} \leftarrow \dfrac{L_i}{6} \ \text{ if } \vec{j} = 2 \\ AM_{i,j} \leftarrow 0 \ \text{ otherwise} \end{array} \right. \\ \text{otherwise} \\ \quad \left| \begin{array}{l} AM_{i,j} \leftarrow \dfrac{L_i}{6} \ \text{ if } j = i + 1 \\ \text{otherwise} \\ \quad \left| \begin{array}{l} AM_{i,j} \leftarrow \dfrac{L_i}{3} \ \text{ if } j = i \\ AM_{i,j} \leftarrow 0 \ \text{ otherwise} \end{array} \right. \end{array} \right. \end{array} \right. \\ AM \end{array} \right.$$

MEQ3p(x, L) - sum unknowns

$$\text{MEQSUMp}(x, L) := \text{MEQ1p}(x, L) + \text{MEQ2p}(x, L)$$

MEQ3ap - known simple point load area

$$\text{MEQ3ap}(x, L) := \left| \begin{array}{l} T_{1,1} \leftarrow 0 \ \text{ if } \ \text{rows}(L) = 1 \\ \text{otherwise} \\ \quad \left| \begin{array}{l} \text{row} \leftarrow \text{axlspan}(x, L) \\ \text{for } i \in 1..\text{rows}(L) \\ \quad \left| \begin{array}{l} T_{i,1} \leftarrow \dfrac{L_{\text{row}}}{2} \ \text{ if row} < i \\ T_{i,1} \leftarrow -0 \ \text{ otherwise} \end{array} \right. \\ T \end{array} \right. \\ T \end{array} \right.$$

MEQbp - known simple point load moment

$$\text{MEQ3bp}(x, L) := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(L) \\ \quad T_{i,1} \leftarrow 0 \\ \text{row} \leftarrow \text{axlspan}(x, L) \\ T_{\text{row},1} \leftarrow \dfrac{L_{\text{row}}}{3} - \dfrac{a(x, L)}{6} \\ T \end{array} \right.$$

MEQ3p(x, L) - sum knowns, and multiply by point moment

$$\text{MEQ3p}(x, L) := (\text{MEQ3ap}(x, L) + \text{MEQ3bp}(x, L)) \cdot MP(x, L) \cdot \text{signtheta}(x, L)$$

Top Slab, Make Influence Table (4 of 8)

MeqGO(x, L) whether moment solution can run

$$\mathrm{MeqGO}(x, L) := \begin{cases} 0 & \text{if } x \le 0 \lor x \ge \mathrm{ENDPIER}(L) \\ 1 & \text{otherwise} \end{cases}$$

SOLNp(x, L) - theta, pier moments

```
SOLNp(x, L) := | if MeqGO(x, L) = 0
               |   | for i ∈ 1 .. rows(L)
               |   |   T_i ← 0
               |   | T
               | MEQSUMp(x, L)^(−1)·MEQ3p(x, L)   otherwise
```

axlspanpier(x, L) - get span No. if on endpier, report last span. else if on pier, report pier no.

```
axlspanpier(x, L) := | SPA ← axlspan(x, L)
                     | PIER ← axlatpier(x, L)
                     | min(rows(L), max(SPA, PIER))
```

ReturnAXLonPIER(xaxl, L, xtst, OnPier, span) - if the axle is on a pier, report influence (M,V+,V-)

$$\mathrm{ReturnAXLonPIER}(xaxl, L, xtst, OnPier, span) := \left| \begin{array}{l} \text{return} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \quad \text{if } OnPier = 1 \land xaxl = xtst = 0 \\ \text{return} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \quad \text{if } OnPier = span \land xaxl = xtst \\ \text{return} \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix} \quad \text{if } OnPier = span + 1 \land xaxl = xtst \\ \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \end{array} \right.$$

Top Slab, Make Influence Table (5 of 8)

$R3_{local}(xaxl, L, xtst)$ - simple span influence (moment, positive shear, negative shear) at xtst span, from 1 kip load at xaxl)

```
R3_local(xaxl, L, xtst, span) := | SPANnoAXL ← axlspanpier(xaxl, L)
                                  | SPANnoTST ← span
                                  | return (0, 0, 0)^T  if SPANnoAXL ≠ SPANnoTST ∨ SPANnoTST = 0
                                  | XlocAXL ← | xaxl  if SPANnoAXL = 1
                                  |           | xaxl − SUML(L)_(SPANnoAXL−1)  otherwise
                                  | XlocTST ← | xtst  if SPANnoTST = 1
                                  |           | xtst − SUML(L)_(SPANnoTST−1)  otherwise
                                  | R_left ← (L_SPANnoAXL − XlocAXL) / L_SPANnoAXL
                                  | R_right ← XlocAXL / L_SPANnoAXL
                                  | if XlocTST < XlocAXL
                                  |   | M_local ← XlocTST·R_left
                                  |   | V_local_pos ← R_left
                                  |   | V_local_neg ← R_left
                                  | if XlocTST > XlocAXL
                                  |   | M_local ← (L_SPANnoAXL − XlocTST)·R_right
                                  |   | V_local_pos ← −R_right
                                  |   | V_local_neg ← −R_right
                                  | if XlocTST = XlocAXL
                                  |   | M_local ← XlocTST·R_left
                                  |   | V_local_pos ← R_left
                                  |   | V_local_neg ← −R_right
                                  | (M_local, V_local_pos, V_local_neg)^T
```

Top Slab, Make Influence Table (6 of 8)

R3a(xaxl, L, xtst, span) - get simple and pier influence

$$
R3a\left(L, T_{SOLNp}, xtst, span\right) := \left|
\begin{array}{l}
SPANnoTST \leftarrow span \\
\text{return } (0\ \ 0\ \ 0)^{T} \text{ if } SPANnoTST < 1 \vee SPANnoTST > \text{rows}(L) \\
XlocTST \leftarrow \left| \begin{array}{ll} xtst & \text{if } SPANnoTST = 1 \\ xtst - SUML(L)_{SPANnoTST-1} & \text{otherwise} \end{array} \right. \\
\left(M_{left}\ \ M_{right}\ \ V_{pier}\right) \leftarrow (0\ \ 0\ \ 0) \\
\text{return} \left| \begin{array}{l}
M_{right} \leftarrow T_{SOLNp_2} \cdot \dfrac{XlocTST}{L_1} \\
V_{pier} \leftarrow \left(\dfrac{T_{SOLNp_2}}{L_1}\right) \\
\left[\left(M_{left} + M_{right}\right)\ \ V_{pier}\ \ V_{pier}\right]^{T}
\end{array} \right. \text{ if } SPANnoTST = 1 \\
\text{return} \left| \begin{array}{l}
M_{right} \leftarrow 0 \\
Ltemp \leftarrow L_{\text{rows}(L)} \\
T \leftarrow \left| \begin{array}{ll} 0 & \text{if } SPANnoTST = \text{rows}(L) + 1 \\ 1 & \text{otherwise} \end{array} \right. \\
M_{left} \leftarrow T_{SOLNp_{\text{rows}(L)}} \cdot \left(1 - \dfrac{XlocTST}{Ltemp}\right) \cdot T \\
V_{pier} \leftarrow -\left(\dfrac{T_{SOLNp_{\text{rows}(L)}}}{Ltemp}\right) \\
\left[\left(M_{left} + M_{right}\right)\ \ V_{pier}\ \ V_{pier}\right]^{T}
\end{array} \right. \text{ if } SPANnoTST \ge \text{rows}(L) \\
\text{return} \left| \begin{array}{l}
M_{left} \leftarrow T_{SOLNp_{(SPANnoTST)}} \cdot \left(1 - \dfrac{XlocTST}{L_{SPANnoTST}}\right) \\
M_{right} \leftarrow T_{SOLNp_{(SPANnoTST+1)}} \cdot \left(\dfrac{XlocTST}{L_{SPANnoTST}}\right) \\
V_{pier} \leftarrow \dfrac{-T_{SOLNp_{(SPANnoTST)}} + T_{SOLNp_{(SPANnoTST+1)}}}{L_{SPANnoTST}} \\
\left[\left(M_{left} + M_{right}\right)\ \ V_{pier}\ \ V_{pier}\right]^{T}
\end{array} \right. \text{ if } 1 < SPANnoTST < \text{rows}(L)
\end{array} \right.
$$

MVVa(L, xaxl, xtst, span, SLN) - if 1 span, use simple solution; otherwise use continuous

$$
MVVa(L, xaxl, xtst, span, SLN) := \left|
\begin{array}{l}
R3local \leftarrow R3_{local}(xaxl, L, xtst, span) \\
\text{return } R3local \text{ if } \text{rows}(L) = 1 \\
R3a(L, SLN, xtst, span) + R3local
\end{array} \right.
$$

MVVb(xaxl, xtst) - get +M +V -V for one test location and one axle location

$$
MVVb(xaxl, xtst) := \left|
\begin{array}{l}
span \leftarrow axlspan(xtst, L) \\
SLN \leftarrow SOLNp(xaxl, L) \\
MVVa(L, xaxl, xtst, span, SLN)
\end{array} \right.
$$

Top Slab, Make Influence Table (7 of 8)

$R4(xaxl, L)$ - influence (+M, +V, -V) from 1kip load at location $xaxl$ in bridge feet, when $RSIF$ (bridge geometry matrix) is known.

$$R4(xaxl, L, RSIF) := \left| \begin{array}{l} SLN \leftarrow SOLNp(xaxl, L) \\ MVV(xtst, span) \leftarrow MVVa(L, xaxl, xtst, span, SLN) \\ \text{for } j \in 1..rows(RSIF) \\ \quad \left| \begin{array}{l} (span \;\; xtst) \leftarrow \left(RSIF_{j,2} \;\; RSIF_{j,4}\right) \\ T^{\langle j \rangle} \leftarrow MVV(xtst, span) \\ T^{\langle j \rangle} \leftarrow (0 \;\; 0 \;\; 0)^T \text{ if } xtst < 0 \vee xtst > \sum L \end{array} \right. \\ T \end{array} \right.$$

$INF2_{eq}$ & $INF2$ -- regular influence table (+M, -M, +V, -V)

$$INF2_{eq}(L, RSIF) := \left| \begin{array}{l} \text{for } i \in 1..rows(RSIF) \\ \quad \left| \begin{array}{l} T \leftarrow R4\left(RSIF_{i,4}, L, RSIF\right)^T \\ \left(M^{\langle i \rangle} \;\; Vp^{\langle i \rangle} \;\; Vn^{\langle i \rangle}\right) \leftarrow \left(T^{\langle 1 \rangle} \;\; T^{\langle 2 \rangle} \;\; T^{\langle 3 \rangle}\right) \end{array} \right. \\ \left(M^T \;\; M^T \;\; Vp^T \;\; Vn^T\right) \end{array} \right.$$

$$INF2 := INF2_{eq}(L, RSIF)$$

INF_{show} - an abbreviated influence matrix, with few increments, for display.

$$INF_{show} := \left| \begin{array}{l} L \leftarrow L \\ ips \leftarrow 5 \\ RSIF \leftarrow RSIF_{eq}\left(L, BrIncs_{eq2}(L, ips)\right) \\ S(r) \leftarrow matrix(r, 1, f(i,j) \leftarrow "") \\ I \leftarrow INF2_{eq}(L, RSIF) \\ SIDE \leftarrow stack[("\#" \;\; "SPAN" \;\; "BrINC" \;\; "FT"), RSIF] \\ DAT \leftarrow augment\left(diag\left(I_{1,3}\right), diag\left(I_{1,4}\right), I_{1,1}\right) \\ LBL \leftarrow ("V+" \;\; "V-") \\ HDR \leftarrow augment\left(LBL, RSIF^{\langle 3 \rangle T}\right) \\ T \leftarrow augment(SIDE, stack(HDR, DAT)) \end{array} \right.$$

Top Slab, Make Influence Table (8 of 8)

ABBREVIATED INFLUENCE TABLE , FOR CHECKING

#	SPAN	BrNC	FT	V+	V−	0.9999	1.0000	1.2000	1.4000	1.6000	1.8000	1.8971	1.8972	1.8973	2.0000
1	0	**1.00**	0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	1	**1.00**	0.0	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	1	**1.20**	1.9	0.7489	−0.2511	0.0000	0.0000	1.4416	0.9582	0.4749	−0.0085	−0.2431	−0.2434	−0.2436	−0.4919
4	1	**1.40**	3.9	0.5106	−0.4894	0.0000	0.0000	0.9828	1.9657	1.0235	0.0814	−0.3760	−0.3765	−0.3769	−0.8608
5	1	**1.60**	5.8	0.2978	−0.7022	0.0000	0.0000	0.5732	1.1465	1.7197	0.3680	−0.2882	−0.2889	−0.2895	−0.9838
6	1	**1.80**	7.7	0.1233	−0.8767	0.0000	0.0000	0.2374	0.4749	0.7123	0.9497	0.1306	0.1297	0.1289	−0.7378
7	1	**1.90**	8.6	0.0563	−0.9437	0.0000	0.0000	0.1084	0.2167	0.3251	0.4335	0.4861	0.4852	0.4843	−0.4487
8	1	**1.90**	8.6	0.0562	−0.9438	0.0000	0.0000	0.1083	0.2165	0.3248	0.4330	0.4855	0.4856	0.4847	−0.4483
9	1	**1.90**	8.6	0.0562	−0.9438	0.0000	0.0000	0.1081	0.2163	0.3244	0.4325	0.4850	0.4851	0.4851	−0.4480
10	1	**2.00**	9.6	0.0000	−1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	2	**2.00**	9.6	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	2	**2.20**	11.6	0.8321	−0.1679	0.0000	0.0000	−0.1240	−0.2480	−0.3719	−0.4959	−0.5561	−0.5562	−0.5562	−0.6199
13	2	**2.40**	13.5	0.6160	−0.3840	0.0000	0.0000	−0.1550	−0.3099	−0.4649	−0.6198	−0.6950	−0.6951	−0.6952	−0.7748
14	2	**2.60**	15.4	0.3840	−0.6160	0.0000	0.0000	−0.1239	−0.2479	−0.3718	−0.4957	−0.5559	−0.5559	−0.5560	−0.6196
15	2	**2.80**	17.4	0.1679	−0.8321	0.0000	0.0000	−0.0619	−0.1239	−0.1858	−0.2478	−0.2778	−0.2778	−0.2779	−0.3097
16	2	**3.00**	19.3	0.0000	−1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	3	**3.00**	19.3	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	3	**3.20**	21.2	0.8767	−0.1233	0.0000	0.0000	0.0370	0.0739	0.1109	0.1479	0.1658	0.1658	0.1659	0.1849
19	3	**3.40**	23.1	0.7022	−0.2978	0.0000	0.0000	0.0493	0.0986	0.1479	0.1972	0.2211	0.2211	0.2212	0.2465
20	3	**3.60**	25.1	0.4894	−0.5106	0.0000	0.0000	0.0431	0.0863	0.1294	0.1725	0.1935	0.1935	0.1935	0.2157
21	3	**3.80**	27.0	0.2511	−0.7489	0.0000	0.0000	0.0246	0.0493	0.0739	0.0986	0.1106	0.1106	0.1106	0.1232
22	3	**4.00**	28.9	0.0000	−1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	4	**4.00**	28.9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

$$\left(\text{matrix}(40,20,f(i,j) \leftarrow \text{""}) \quad \text{INF}_{\text{show}}\right)$$

Top Slab, Influence Vectors (1 of 2)

While LRFR does apply simultaneous minimum and maximum live load factors among a given element or span (extreme effects, neglecting axles not contributing to the force under consideration, and patch lane loading), LRFR does not vary minimum and maximum permanent load factors for one load type, within the same calculation. "In the application of permanent loads, force effects for each of the specified six load types should be computed separately. It is unnecessary to assume that one type of load varies by span, length, or component within a bridge" (LRFD C3.4.1). At a two-span culvert, for example, when considering positive moment in the top slab of span 1, maximize vertical dead load throughout the entire top slab. Consistently apply maximum component (DC) and vertical earth (EV) load factors to both spans. However use the minimum horizontal earth (EH) pressure, if its effects benefit the top slab with axial force.

$iMpos := \left(INF2_{1,1}\right)^{\langle RSIF\_CHK\_LOCS_{1,1}\rangle}$ (1) iMpos - unfactored influence vector at $pM_{BrINC} = 1.40$ for positive moment (+M)

$iMneg := \left(INF2_{1,1}\right)^{\langle RSIF\_CHK\_LOCS_{2,1}\rangle}$ (2) iMneg - unfactored influence vector at 2.00 for negative moment (-M)

$iVneg := \left(INF2_{1,4}\right)^{\langle RSIF\_CHK\_LOCS_{3,1}\rangle}$ (3) iVneg - unfactored influence vector at $Vinc = 1.90$ for negative shear (-V)

$iMv := \left(INF2_{1,1}\right)^{\langle RSIF\_CHK\_LOCS_{4,1}\rangle}$ (4) iMv - unfactored influence vector at $Vinc = 1.90$ for M coincident with V (Mv)

$maxINF(INF,\gamma_{max},\gamma_{min}) := if(INF \ge 0, \gamma_{max}\cdot INF, \gamma_{min}\cdot INF)$ $maxINF(INF,\gamma_{max},\gamma_{min})$ - apply γ_{max} or γ_{min} to emphasize positive influence

$minINF(INF,\gamma_{max},\gamma_{min}) := if(INF \le 0, \gamma_{max}\cdot INF, \gamma_{min}\cdot INF)$ $minINF(INF,\gamma_{max},\gamma_{min})$ - apply γ_{max} or γ_{min} to emphasize negative influence

$COINC(Vneg,\gamma_{max},\gamma_{min}) := if(Vneg < 0, \gamma_{max}, \gamma_{min})$ $COINC(Vneg,\gamma_{max},\gamma_{min})$ - use Vneg as guidance on whether to use γ_{max} or γ_{min}

$INF\_LL\_Mpos := \overrightarrow{maxINF(iMpos, 1, \gamma_{LLmin})}$ (1) INF_LL_Mpos - live load (LL) influence vector at $pM_{BrINC} = 1.40$ for +M

$INF\_LL\_Mneg := \overrightarrow{minINF(iMneg, 1, \gamma_{LLmin})}$ (2) INF_LL_Mneg - LL influence vector at 2.00 for -M

$INF\_LL\_Vneg := \overrightarrow{minINF(iVneg, 1, \gamma_{LLmin})}$ (3) INF_LL_Vneg - LL influence vector at $Vinc = 1.90$ for -V

$INF\_LL\_Mv := \overrightarrow{COINC(iVneg, iMv, 0\cdot iMv)}$ (4) INF_LL_Mv - LL influence vector at $Vinc = 1.90$ for Mv

$INF\_\gamma DC\_Mpos := \gamma_{DCmax}\cdot iMpos$ (1) INF_γDC_Mpos - factored (γ) component DL (DC) infl. at $pM_{BrINC} = 1.40$ for +M

$INF\_\gamma DC\_Mneg := \gamma_{DCmax}\cdot iMneg$ (2) INF_γDC_Mneg - γDC influence vector at 2.00 for -M

$INF\_\gamma DC\_Vneg := \gamma_{DCmax}\cdot iVneg$ (3) INF_γDC_Vneg - γDC influence vector at $Vinc = 1.90$ for -V

$INF\_\gamma DC\_Mv := \gamma_{DCmax}\cdot iMv$ (4) INF_γDC_Mv - γDC influence vector at $Vinc = 1.90$ for Mv

$INF\_\gamma EV\_Mpos := \eta\gamma_{EVmax}\cdot iMpos$ (1) INF_γEV_Mpos - factored (γ) vertical earth (EV) influence at $pM_{BrINC} = 1.40$ for +M

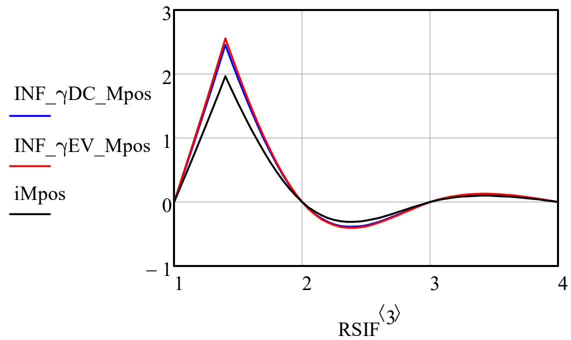
$INF\_\gamma EV\_Mneg := \eta\gamma_{EVmax}\cdot iMneg$ (2) INF_γEV_Mneg - γEV influence vector at 2.00 for -M

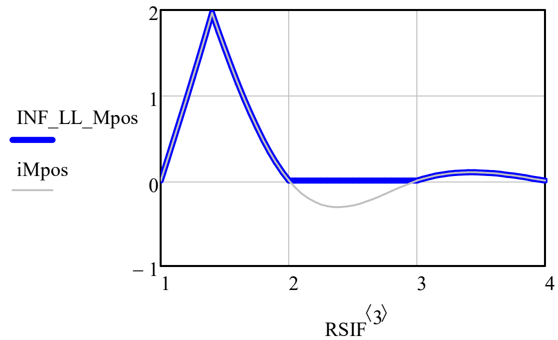
$INF\_\gamma EV\_Vneg := \eta\gamma_{EVmax}\cdot iVneg$ (3) INF_γEV_Vneg - γEV influence vector at $Vinc = 1.90$ for -V

$INF\_\gamma EV\_Mv := \eta\gamma_{EVmax}\cdot iMv$ (4) INF_γEV_Mv - γEV influence vector at $Vinc = 1.90$ for Mv

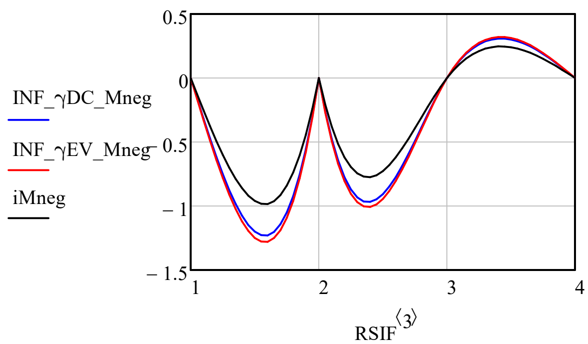
Top Slab, Influence Vectors (2 of 2)

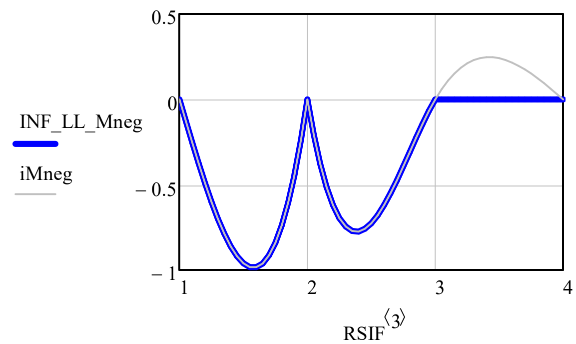
POSITIVE MOMENT



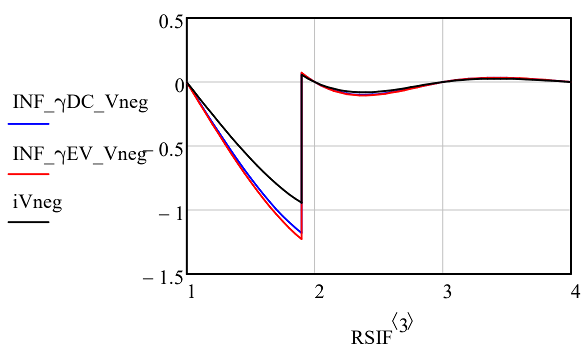


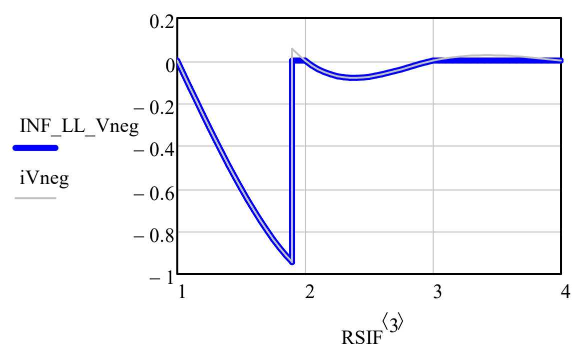
NEGATIVE MOMENT



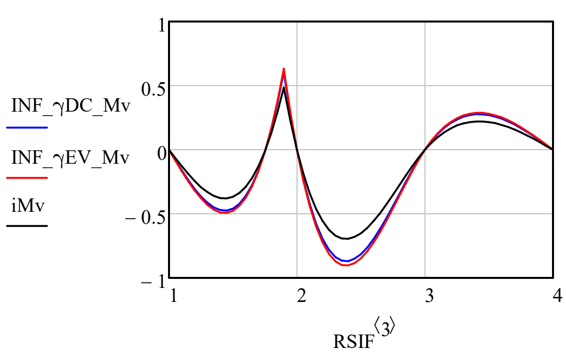


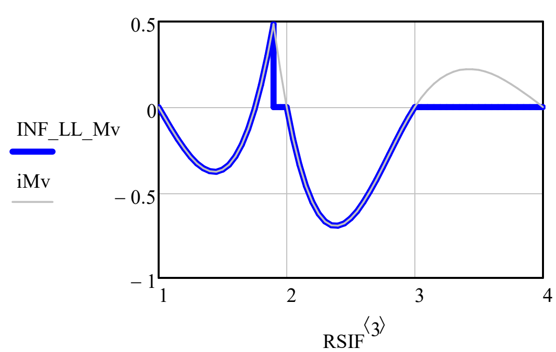
SHEAR





MOMENT ASSOCIATED WITH SHEAR





Top Slab, Apply Load to Influence (1 of 4)

UTILITIES

iftoi(FT) - given FEET, get Brinc

$\text{iftoi}(FT) := \text{linterp}\left(RSIF^{\langle 4\rangle}, RSIF^{\langle 3\rangle}, FT\right)$

iioft(BrINC) - given BrINC, get FEET

$\text{iioft}(BrINC) := \text{linterp}\left(RSIF^{\langle 3\rangle}, RSIF^{\langle 4\rangle}, BrINC\right)$

iftor(FT) - given FEET, get NODE No.

$\text{iftor}(FT) := \text{linterp}\left(RSIF^{\langle 4\rangle}, RSIF^{\langle 1\rangle}, FT\right)$

APPLY ω TO AN INFLUENCE VECTOR

INFx1x2a - add four nodes to an influence vector, one pair of new nodes adjacent to x1, and another new pair adjacent to x2. Add a column with bridge feet location. Output is (feet, influence).

```
INFx1x2(I, x1, x2) := | "if the load is not on the bridge, return 0"
                      | return (0   0; 0.1  0)  if x1 ≥ ΣL ∨ x2 ≤ 0
                      | "x1 can't be less than 0; x2 can't be greater than ΣL"
                      | (x1  x2) ← (max(0, x1)  min(x2, ΣL))
                      | "add 2 new nodes, before and after x1 &x2"
                      | FTadd ← stack[(x1 − 10^−6; x1 + 10^−6), (x2 − 10^−6; x2 + 10^−6)]
                      | "get influence for all nodes, including FTadd"
                      | for j ∈ 1..cols(I)
                      |   | T(x) ← linterp(RSIF<4>, I<j>, x)
                      |   | INFt<j> ← stack(I<j>, vectorize(T(FTadd)))
                      | "combine FT & INFLUENCE, sort by FT"
                      | ftINF ← augment(stack(RSIF<4>, FTadd), INFt)
                      | ftINF ← csort(ftINF, 1)
                      | "zero out any increment not within the range x1 to x2"
                      | ZeroLeftRight(x, INF) ← if(x < x1 ∨ x > x2, 0, INF)
                      | for j ∈ 2..cols(ftINF)
                      |   ftINF<j> ← vectorize(ZeroLeftRight(ftINF<1>, ftINF<j>))
                      | ftINF
```

INFx1x2ω(INF, x1x2ω) - for each row in x1x2ω, apply ω (klf) to influence from x1 to x2 (ft). Output is the force effect of the loading.

```
INFx1x2ω(INF, x1x2ω) := | T1 ← matrix(1, cols(INF), f(i, j) ← 0)
                        | for i ∈ 1..rows(x1x2ω)
                        |   | T2 ← INFx1x2(INF, x1x2ω[i,1], x1x2ω[i,2])
                        |   | Δ(k) ← T2[k,1] − T2[k−1,1]
                        |   | I(k, j) ← (T2[k,j] + T2[k−1,j]) / 2
                        |   | ω ← x1x2ω[i,3]
                        |   | for j ∈ 2..cols(T2)
                        |   |   | T3 ← Σ_{k=2}^{rows(T2)} [Δ(k)·(I(k, j)·ω)]
                        |   |   | T1[1,j−1] ← T1[1,j−1] + T3
                        | T1
```

DEAD LOAD

$$DLeq(INF, \omega) := INFx1x2\omega\left[INF, \left(0 \quad \sum L \quad \frac{\omega}{klf}\right)\right]$$

$$DL(D) := \begin{pmatrix} DLeq\left(iMpos, \omega_{DC}\right) + DLeq\left(iMpos, \omega_{EV}(D)\right) \\ DLeq\left(iMneg, \omega_{DC}\right) + DLeq\left(iMneg, \omega_{EV}(D)\right) \\ DLeq\left(iVneg, \omega_{DC}\right) + DLeq\left(iVneg, \omega_{EV}(D)\right) \\ DLeq\left(iMv, \omega_{DC}\right) + DLeq\left(iMv, \omega_{EV}(D)\right) \end{pmatrix}^T$$

$$\gamma DL(D) := \begin{pmatrix} DLeq\left(INF\_\gamma DC\_Mpos, \omega_{DC}\right) + DLeq\left(INF\_\gamma EV\_Mpos, \omega_{EV}(D)\right) \\ DLeq\left(INF\_\gamma DC\_Mneg, \omega_{DC}\right) + DLeq\left(INF\_\gamma EV\_Mneg, \omega_{EV}(D)\right) \\ DLeq\left(INF\_\gamma DC\_Vneg, \omega_{DC}\right) + DLeq\left(INF\_\gamma EV\_Vneg, \omega_{EV}(D)\right) \\ DLeq\left(INF\_\gamma DC\_Mv, \omega_{DC}\right) + DLeq\left(INF\_\gamma EV\_Mv, \omega_{EV}(D)\right) \end{pmatrix}^T$$

$$DL := \left| \begin{array}{l} \text{for } iD \in 1..rows\left(D_{fills}\right) \\ \quad T^{\langle iD \rangle} \leftarrow DL\left(D_{fills_{iD}}\right)^T \\ T^T \end{array} \right.$$

$$\gamma DL := \left| \begin{array}{l} \text{for } iD \in 1..rows\left(D_{fills}\right) \\ \quad T^{\langle iD \rangle} \leftarrow \gamma DL\left(D_{fills_{iD}}\right)^T \\ T^T \end{array} \right.$$

$$DL = \begin{bmatrix} (2.68) & (-3.36) & (-1.73) & (-1.47) \\ (5.47) & (-6.86) & (-3.54) & (-2.99) \end{bmatrix}$$

$$\gamma DL = \begin{bmatrix} (3.44) & (-4.31) & (-2.22) & (-1.88) \\ (7.07) & (-8.86) & (-4.57) & (-3.87) \end{bmatrix}$$

DISTRIBUTED TRUCK

OLAPTRK2(TRK, D) - given a truck (ft kip), make a longitudinally distributed truck (x_start x_end klf). Where axle distribution lengths overlap, the tributary axles are uniformly distributed over the net length (Std.Spec. 6.4.2 & LRFD MBE C6A.5.12.10.3a). When axle overlapping does occur, heavy axle areas may be irrationally distributed to light axle areas. However, such overlapping occurs under deep fills, where DL supercedes LL.

$$OLAPTRK2(TRK, D) := \left| \begin{array}{l} E_{long} \leftarrow E_{long.eq}(D) \cdot ft^{-1} \\ \text{return } \left(-0.5 \cdot E_{long} \quad 0.5 \cdot E_{long} \quad \dfrac{TRK_{1,2}}{E_{long}}\right) \text{ if } rows(TRK) = 1 \\ (T \quad CL\_AXLE) \leftarrow \left[\left(-0.5 \cdot E_{long} \quad 0.5 \cdot E_{long} \quad TRK_{1,2}\right) \quad (0)\right] \\ \text{for } i \in 2..rows(TRK) \\ \quad \left| \begin{array}{l} (r \quad CL\_AXLE) \leftarrow \left[rows(T) \quad \left(CL\_AXLE - TRK_{i,1}\right)\right] \\ T \leftarrow \left| \begin{array}{l} stack\left[T, \left[\left(CL\_AXLE - 0.5 \cdot E_{long}\right) \quad \left(CL\_AXLE + 0.5 \cdot E_{long}\right) \quad TRK_{i,2}\right]\right] \text{ if } TRK_{i,1} > E_{long} \\ \left(T_{r,1} \quad T_{r,2} \quad T_{r,3}\right) \leftarrow \left[\left(CL\_AXLE - 0.5 \cdot E_{long}\right) \quad \left(T_{r,2}\right) \quad \left(T_{r,3} + TRK_{i,2}\right)\right] \text{ otherwise} \end{array} \right. \end{array} \right. \\ \text{for } i \in 1..rows(T) \\ \quad T_{i,3} \leftarrow \dfrac{T_{i,3}}{T_{i,2} - T_{i,1}} \\ T \end{array} \right.$$

Top Slab, Apply Load to Influence (3 of 4)

MAKE DISTRIBUTED TRUCKS

TKLOCS2 - (x_start, x_end, unfactored pressure) and (locations of first wheel in bridge feet), no lateral distribution, no IM, and no load factor)

$$
\mathrm{TKLOCS2}(TK, D) := \left|
\begin{array}{l}
T \leftarrow \mathrm{OLAPTRK2}(TK, D) \\
TRK\_LEN \leftarrow \max\left(T^{\langle 2 \rangle}\right) - \min\left(T^{\langle 1 \rangle}\right) \\
RUN\_LEN \leftarrow TRK\_LEN + 1.2 \cdot L_1 \\
\text{for } i \in 1 .. ips_{LL} + 1 \\
\quad x_i \leftarrow \dfrac{RUN\_LEN}{ips_{LL}} \cdot (i - 1) + 0.4 \cdot L_1 \\
\text{for } i \in 1 .. \mathrm{rows}(x) \\
\quad T2_i \leftarrow \mathrm{augment}\left(T^{\langle 1 \rangle} + x_i, T^{\langle 2 \rangle} + x_i, T^{\langle 3 \rangle}\right) \\
T2
\end{array}
\right.
$$

MIRROR(TRK) - reverse the truck for two-way traffic

$$
\mathrm{MIRROR}(TRK) := \left|
\begin{array}{l}
\text{for } i \in 1 .. \mathrm{rows}(TRK) \\
\quad \left|
\begin{array}{l}
T2_{i,1} \leftarrow \left| \begin{array}{ll} 0 & \text{if } i = 1 \\ TRK_{\mathrm{rows}(TRK)-i+2,1} & \text{otherwise} \end{array} \right. \\
T2_{i,2} \leftarrow TRK_{\mathrm{rows}(TRK)-i+1,2}
\end{array}
\right. \\
\text{return } T2 \text{ if } \mathrm{cols}(TRK) = 2 \\
\mathrm{augment}\left(T2, TRK^{\langle 3 \rangle}\right)
\end{array}
\right.
$$

Top Slab, Apply Load to Influence (4 of 4)

RUN LIVE LOAD

γLLwLBL(D) - factored live load with distribution and impact for one fill depth. 1 vehicle per row.

Main columns are:
(1) LL details
(2) M.positive
(3) M.negative
(4) V.negative
(5) M.coincident.with.Vnegative

Submatrix (1) LL detail columns:
(1) Row No.
(2) Veh No.
(3) Veh Name
(4) Truck No.
(5) Forward/Reverse 0/1
(6) 0
(7) Factored Truck

Submatrix (7) Factored Truck Columns are:
(1) x.start - the place in bridge feet at which the loading begins
(2) x.end - the place in bridge feet at which the loading ends
(3) klf loading - γ.LL*DF*IM*(AXLE, or ΣAXLES for overlapped axles)

```
γLLwLBL(D) := | VEHS ← TRUCKS
              | IM ← IMeq(D)
              | for iv ∈ 1..rows(VEHS)
              |   | VEH ← VEHS_(iv,1)
              |   | DF ← LLDFeq(mpf_iv, D)
              |   | (Mp  Mn  Vn  M_Vn  row) ← (0  0  0  0  0)
              |   | for iTRK ∈ 1..rows(VEHS_(iv,2))
              |   |   | TRK1 ← (TRUCKS_(iv,2))_(iTRK,1)
              |   |   | for iMIRR ∈ 1..2
              |   |   |   | TRK2 ← | TRK1  if iMIRR = 1
              |   |   |   |        | MIRROR(TRK1)  otherwise
              |   |   |   | TKS ← TKLOCS2(TRK2, D)
              |   |   |   | for itrk ∈ 1..rows(TKS)
              |   |   |   |   | r ← r + 1
              |   |   |   |   | x_lead ← (TKS_itrk)_(rows(TKS_itrk), 3)
              |   |   |   |   | (TKS_itrk)^<3> ← γLL_iv·DF·IM·(TKS_itrk)^<3>
              |   |   |   |   | TK ← TKS_itrk
              |   |   |   |   | T^<r> ← (r  iv  VEH  iTRK  iMIRR − 1  0  TKS_itrk)^T
              |   |   |   |   | ( Mp^<r>   )    ( INFx1x2ω(INF_LL_Mpos, TK)^T )
              |   |   |   |   | ( Mn^<r>   ) ←  ( INFx1x2ω(INF_LL_Mneg, TK)^T )
              |   |   |   |   | ( Vn^<r>   )    ( INFx1x2ω(INF_LL_Vneg, TK)^T )
              |   |   |   |   | ( M_Vn^<r> )    ( INFx1x2ω(INF_LL_Mv, TK)^T   )
              |   | γLL^<iv> ← (T^T  Mp^T  Mn^T  Vn^T  M_Vn^T)^T
              |   | (T  Mp  Mn  Vn  McφoincVn) ← (0  0  0  0  0)
              |   | r ← 0
              | γLL^T
```

Top Slab, Capacity

MOMENT, LFR OR LRFR

$Mn := f_y \cdot A_s \cdot \left(d - \frac{1}{2} \cdot \frac{f_y \cdot A_s}{0.85 \cdot f_c \cdot ft}\right)$

$Mn = 23.19 \cdot kip \cdot ft$ - nominal flexural capacity (Std.Spec. Eq.8-16, LRFD Eq. 5.6.3.2.2-1)

$\phi_M := 0.90$

$\phi_M = 0.90$ - flexural strength reduction (Std.Spec. 8.16.1.2.2, LRFD Table 12.5.5-1)

$\psi\phi Mn := \psi_c \cdot \phi_M \cdot Mn$

$\psi\phi Mn = 20.87 \cdot kip \cdot ft$ - factored flexural strength; condition factor is $\psi_c = 1.00$

SHEAR, LFR OR LRFR D.FILL > 2 FEET

$$Vn_{DeepFills}(Mu, Vu) := \left| \begin{array}{l} \sigma \leftarrow \text{if}\left(cells = 1, 2.5 \cdot \sqrt{f_c \cdot psi}, 0\right) \\ \sigma \leftarrow \max\left(\sigma, 2.14 \cdot \sqrt{f_c \cdot psi} + 4600 \cdot psi\ \rho \cdot \min\left(1, \frac{|Vu| \cdot d}{|Mu|}\right)\right) \\ \min\left(\sigma, 4.0 \cdot \sqrt{f_c \cdot psi}\right) \cdot ft \cdot d \end{array} \right.$$

- nominal shear strength, D.fill > 2 feet (Std.Spec. 8.16.6.7.1, LRFD 5.12.7.3)

SHEAR, LFR D.FILL < 2 FEET

$$Vn_{LFR\_Shallow}(Mu, Vu) := \left| \begin{array}{l} \sigma \leftarrow 1.9 \cdot \sqrt{f_c \cdot psi} + 2500 \cdot psi\ \rho \cdot \min\left(1, \frac{|Vu| \cdot d}{|Mu|}\right) \\ \min\left(\sigma, 3.5 \cdot \sqrt{f_c \cdot psi}\right) \cdot ft \cdot d \end{array} \right.$$

- nominal shear strength for LFR when D.fill < 2 feet (Std.Spec. Eq. 8-48)

SHEAR, LRFR D.FILL < 2 FEET

For LRFR D.fill < 2 feet, use LRFD 5.7.3.4.1. For box culverts that neglect axial loading, LRFD reduces to:

$d_v := \frac{Mn}{A_s \cdot f_y}$

$d_v = 7.25 \cdot in$ - distance between tension and compression centroids at full strength

$$\varepsilon_{s.min}(Mu, Vu) := \frac{\frac{\max\left(|Mu|, |Vu| \cdot d_v\right)}{d_v} + |Vu|}{29000ksi \cdot A_s}$$

$\varepsilon_{s.min}(Mu, Vu)$- strain at the centroid of reinforcement

$$s_{xe} := \min\left(\max\left(12in, d_v \cdot \frac{1.38}{0.375 + 0.63}\right), 80in\right)$$

$s_{xe} = 12.00 \cdot in$ - crack spacing parameter, assuming max aggregate size = 3/8in.

$$\beta(Mu, Vu) := \frac{4.8}{1 + 750 \cdot \min\left(\varepsilon_{s.min}(Mu, Vu), 6 \cdot 10^{-3}\right)} \cdot \frac{51in}{39in + s_{xe}}$$

$\beta(Mu, Vu)$- shear capacity factor

$Vn_{LRFR\_Shallow}(Mu, Vu) := \beta(Mu, Vu) \cdot \sqrt{f_c \cdot psi} \cdot ft \cdot d_v$

$Vn_{LRFR\_Shallow}(Mu, Vu)$ - concrete shear capacity

FACTORED SHEAR CAPACITY

$\phi_V := 0.85$ - strength reduction factor for shear (Std.Spec. 8.16.1.2.2, LRFD Table 12.5.5-1. Neglect LRFD 5.5.4.2 ϕ.V = 0.90 for slabs & shallow fills.

$$\psi\phi Vn(Mu, Vu, D) := \left| \begin{array}{l} \text{return } \psi_c \cdot \phi_V \cdot Vn_{DeepFills}(Mu, Vu) \text{ if } D \ge 2ft \\ \text{return } \psi_c \cdot \phi_V \cdot Vn_{LFR\_Shallow}(Mu, Vu) \text{ if } LRFR = 0 \\ \text{return } \psi_c \cdot \phi_V \cdot Vn_{LRFR\_Shallow}(Mu, Vu) \text{ if } LRFR = 1 \\ \text{"ERROR"} \end{array} \right.$$

- factored shear strength; condition factor is $\psi_c = 1.00$

EXTERIOR WALL (1 OF 6)

$D_{fill} := \max(D_{fills})$ — $D_{fill} = 5.00\,ft$ - covering fill

$\gamma_{LL.Inventory} := \gamma_{LL_1}$ — $\gamma_{LL.Inventory} = 1.75$ - live load factor, Inventory Level

$\omega_{DC} = 0.119 \cdot klf \quad \gamma_{soil} = 120 \cdot pcf$ — ω_{DC} & γ_{soil} - previously defined terms

$\omega_{EV.Wall} := \omega_{EV}(D_{fill})$ — $\omega_{EV.Wall} = 0.620 \cdot klf$ - vertical earth (EV) loading for exterior wall

VERTICAL LOADS

Axial loads, designated by "P," are positive for tension, and negative for compression.

$INF\omega := (0.5000 \;\; 0.3750 \;\; 0.4000 \;\; 0.3928)_{1,\min(cells,4)} \cdot L_1 \cdot \frac{kip}{klf}$ — $INF\omega = 3.85 \cdot \frac{kip}{klf}$ - influence, klf (ω) top slab to ext. wall rxn: +Area, -Area, ΣArea

$INFp := (0 \;\; -0.096 \;\; -0.08 \;\; -0.0789)_{1,\min(cells,4)}$ — $INFp = -0.08 \cdot \frac{kip}{kip}$ - uplifting influence, kip onto exterior wall per 1 kip axle in span 2

$DC_P := -\omega_{DC} \cdot INF\omega$ — $DC_P = -0.46 \cdot kip$ - slab component load (DC), axial compression (P) onto exterior wall

$\gamma DC_P := -\gamma_{DCmin} \cdot \omega_{DC} \cdot INF\omega$ — $\gamma DC_P = -0.41 \cdot kip$ - minimized factored DC_P

$EV_P := -\omega_{EV.Wall} \cdot INF\omega$ — $EV_P = -2.39 \cdot kip$ - vertical earth (EV) axial comp. (P) onto ext wall. $F_{e.eq}(D_{fill}) = 1.03$

$\gamma EV_P := -\eta \gamma_{EVmin} \cdot \omega_{EV.Wall} \cdot INF\omega$ — $\gamma EV_P = -2.15 \cdot kip$ - minimized factored EV_P

$LV_P := -IMeq(D_{fill}) \cdot LLDFeq(mpf_1, D_{fill}) \cdot (32kip \cdot INFp)$ — $LV_P = 0.25 \cdot kip$ - vertical live load (LV) axial tension (P), 32 kip axle load, where:
$IMeq(D_{fill}) = 1.124 \quad mpf_1 = 1.20 \quad LLDFeq(mpf_1, D_{fill}) = 0.0860$

$\gamma LV_P := \gamma_{LL.Inventory} \cdot LV_P$ — $\gamma LV_P = 0.43 \cdot kip$ - minimized factored LV_P.

$F_s := A_{s.wall} \cdot f_y = 8.00 \cdot kip$ — F_s - force of steel at yield

$$a := \frac{F_s + (\gamma DC_P + \gamma EV_P + \gamma LV_P)}{0.85 \cdot f_c \cdot 12in}$$

$a = 0.19 \cdot in$ - effective depth of the compression block

$$d_{ax.to.c} := \frac{d_{wall}}{2} - \frac{a}{2}$$

$d_{ax.to.c} = 2.65 \cdot in$ - axial load to CG compression

$DC_M := DC_P \cdot d_{ax.to.c} \qquad \gamma DC_M := \gamma DC_P \cdot d_{ax.to.c}$ — $DC_M = -0.10 \cdot kip \cdot ft$ & $\gamma DC_M = -0.09 \cdot kip \cdot ft$
Unfactored and factored moment from slab component load (DC)

$EV_M := EV_P \cdot d_{ax.to.c} \qquad \gamma EV_M := \gamma EV_P \cdot d_{ax.to.c}$ — $EV_M = -0.53 \cdot kip \cdot ft$ &
Unfactored and factored moment from vertical earth (EV)

$LV_M := LV_P \cdot d_{ax.to.c} \qquad \gamma LV_M := \gamma LV_P \cdot d_{ax.to.c}$ — $LV_M = 0.05 \cdot kip \cdot ft$ & $\gamma LV_M = 0.10 \cdot kip \cdot ft$
Unfactored and factored moment from vertical live load (LV)

$\psi c \phi Mn\_wall := \psi_c \cdot \phi_M \cdot F_s \cdot \left(d_{wall} - \frac{a}{2}\right)$ — $\psi c \phi Mn\_wall = 3.24 \cdot kip \cdot ft$ - factored flexural capacity, exterior wall

Exterior Wall (2 of 6)

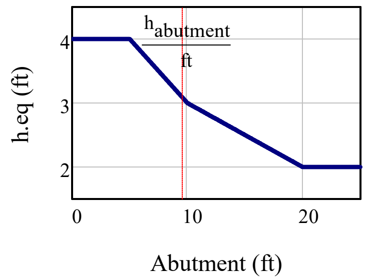
EQUIVALENT HEIGHT

$h_{abutment} := D_{fill} + 2 \cdot t_{slab} + h_{clear}$

$h_{abutment} = 9.58\,ft$ - overall height of the abutment

$$h_{eq.equation}(h_{abutment}) := \left| \begin{array}{l} h \leftarrow h_{abutment} \\ \text{return } 2ft \text{ if } LRFR = 0 \\ \text{return } 4ft \text{ if } h < 5ft \\ \text{return } 2ft \text{ if } h > 20ft \\ \text{linterp}\left[\begin{pmatrix} 5 \\ 10 \\ 20 \end{pmatrix} ft, \begin{pmatrix} 4 \\ 3 \\ 2 \end{pmatrix} ft, h\right] \end{array} \right.$$

$h_{eq.equation}$ - equivalent surcharge for LL (Std.Spec. 3.20.3, LRFD 3.11.6.4-1)



$h_{eq} := h_{eq.equation}(h_{abutment})$

$h_{eq} = 3.08\,ft$ - equivalent surcharge height for live load

SIMPLE SPAN EQUATIONS

$$\omega_{\omega1.\omega2.eq}(\omega_{start}, \omega_{end}, L, x) := \text{if}\left[0 \le x \le L, \omega_{start} + (\omega_{end} - \omega_{start}) \cdot \left(\frac{x}{L}\right), 0\right]$$

$ix := 1..41$

$$V_{\omega1.\omega2.eq}(\omega_{start}, \omega_{end}, L, x) := \text{if}\left[0 \le x \le L, \left[\omega_{start} \cdot \left(\frac{L}{2} - x\right) + (\omega_{end} - \omega_{start}) \cdot \left(\frac{L}{6} - \frac{x^2}{2 \cdot L}\right)\right], 0\right]$$

$$FT_{ix} := \frac{ix - 1}{40} \cdot L_{wall}$$

$$M_{\omega1.\omega2.eq}(\omega_{start}, \omega_{end}, L, x) := \text{if}\left[0 \le x \le L, \left[\omega_{start} \cdot \left(\frac{L}{2} \cdot x - \frac{x^2}{2}\right)\right] + (\omega_{end} - \omega_{start}) \cdot \left(\frac{L \cdot x}{6} - \frac{x^3}{6 \cdot L}\right), 0\right]$$

$$FT := \text{stack}\left[\left(-10^{-3} \cdot ft\right), FT, \left(\max(FT) + 10^{-3} \cdot ft\right)\right]$$

$x_{origin} := h_{abutment} - t_{slab} - h_{haunch.bot}$

$x_{origin} = 8.46\,ft$ - the depth of "x origin," at the bottom construction joint

HORIZONTAL EARTH (EH)

$\omega_{EH.start} := \omega_{EH}(x_{origin}) = 0.508 \cdot klf$

$\omega_{EH.end} := \omega_{EH}(x_{origin} - L_{wall}) = 0.358 \cdot klf$

$EH_{\omega} := \overrightarrow{\omega_{\omega1.\omega2.eq}(\omega_{EH.start}, \omega_{EH.end}, L_{wall}, FT)}$

$EH_V := \overrightarrow{V_{\omega1.\omega2.eq}(\omega_{EH.start}, \omega_{EH.end}, L_{wall}, FT)}$

$EH_M := \overrightarrow{M_{\omega1.\omega2.eq}(\omega_{EH.start}, \omega_{EH.end}, L_{wall}, FT)}$

$\gamma EH_M := \eta \gamma_{EHmax} \cdot EH_M \quad \max(\gamma EH_M) = 0.46 \cdot kip \cdot ft$

HORIZONTAL LL FROM SURCHARGE (LS)

$\omega_{LS.start} := \omega_{EH}(h_{eq}) = 0.185 \cdot klf$

$\omega_{LS.end} := \omega_{EH}(h_{eq}) = 0.185 \cdot klf$

$LS_{\omega} := \overrightarrow{\omega_{\omega1.\omega2.eq}(\omega_{LS.start}, \omega_{LS.end}, L_{wall}, FT)}$

$LS_V := \overrightarrow{V_{\omega1.\omega2.eq}(\omega_{LS.start}, \omega_{LS.end}, L_{wall}, FT)}$

$LS_M := \overrightarrow{M_{\omega1.\omega2.eq}(\omega_{LS.start}, \omega_{LS.end}, L_{wall}, FT)}$

$\gamma LS_M := \gamma_{LL.Inventory} \cdot LS_M \quad \max(\gamma LS_M) = 0.25 \cdot kip \cdot ft$

Exterior Wall (3 of 6)

APPROXIMATE RATING FACTOR, DESIGN INVENTORY

$\psi c\phi Mn\_wall = 3.24 \cdot kip \cdot ft$

$DC_M = -0.10 \cdot kip \cdot ft$ $\quad \gamma DC_M = -0.09 \cdot kip \cdot ft$ $\quad DC_M$ - component dead load, reduces the wall moment (-)

$EV_M = -0.53 \cdot kip \cdot ft$ $\quad \gamma EV_M = -0.48 \cdot kip \cdot ft$ $\quad EV_M$ - vertical earth, reduces the wall moment (-)

$\max(EH_M) = 0.34 \cdot kip \cdot ft$ $\quad \max(\gamma EH_M) = 0.46 \cdot kip \cdot ft$ $\quad EH_M$ - horizontal earth, increases the wall moment (+)

$LV_M = 0.05 \cdot kip \cdot ft$ $\quad \gamma LV_M = 0.10 \cdot kip \cdot ft$ $\quad LV_M$ - vertical live load uplift, from axle in span 2, increases the wall moment (+)

$\max(LS_M) = 0.14 \cdot kip \cdot ft$ $\quad \max(\gamma LS_M) = 0.25 \cdot kip \cdot ft$ $\quad LS_M$ - horizontal LL from a vertical surcharge increases wall moment (+)

$$RF_{approx} := \frac{\psi c\phi Mn\_wall - \left(\gamma DC_M + \gamma EV_M + \max(\gamma EH_M)\right)}{\gamma LV_M + \max(\gamma LS_M)} = 9.615$$

RF_{approx} - approximate the Design Vehicle RF at the Inventory Level

RATING FACTOR, DESIGN INVENTORY

$DL_{wall} := DC_M + EV_M + EH_M$ $\quad \gamma DL_{wall} := \gamma DC_M + \gamma EV_M + \gamma EH_M$ $\quad DL_{wall}$ & γDL_{wall} - unfactored and factored DL

$LL_{wall} := LV_M + LS_M$ $\quad \gamma LL_{wall} := \gamma LV_M + \gamma LS_M$ $\quad LL_{wall}$ & γLL_{wall} - unfactored and factored LL

$$RFs := \left| \begin{array}{l} mx(A,B) \leftarrow \max(A,B) \\ \overrightarrow{\dfrac{\psi c\phi Mn\_wall - \gamma DL_{wall}}{mx\left(10^{-6} kip \cdot ft, \gamma LL_{wall}\right)}} \end{array} \right.$$

$RF_{Des.Inv} := \min(RFs)$

$RF_{Des.Inv} = 9.616$ - exterior wall rating factor, Design Inventory

$$ROW\_ExtWall := \left| \begin{array}{l} T \leftarrow RF_{Des.Inv} \\ match2(T, RFs) \end{array} \right.$$

$ROW\_ExtWall = 22.00$ - governing row No.

$$\frac{LL_{wall_{ROW\_ExtWall}}}{DL_{wall_{ROW\_ExtWall}}} = -0.68$$

EXTERIOR WALL (4 OF 6)

VERIFY ϕ.M = 0.90

$\beta_{1.eq}(f_c) := \text{if}\left(f_c \le 4ksi, 0.85, \max\left(0.65, 0.85 - 0.20\cdot\frac{f_c - 4ksi}{4ksi}\right)\right)$

$\beta_1 := \beta_{1.eq}(f_c) = 0.85$ - a/c (LRFD 5.6.2.2)

$c := \frac{a}{\beta_1} = 0.23\cdot in$

c - distance to the neutral axis, under factored loading

$\varepsilon_t := 0.003\cdot\frac{d - c}{c} = 0.102$

ε_t - steel tension when $\varepsilon_{conc} = 0.003$

$CHECK := \text{if}\left(\varepsilon_t \ge \frac{f_y}{29000ksi}, \text{"OK: } \varepsilon\text{.steel} > \varepsilon\text{.yield"}, \text{"ERROR: } \varepsilon\text{.steel} < \varepsilon\text{.yield; revise calculations "}\right)$ ... CHECK = "OK: ε.steel > ε.yield"

$RF_{Des.Inv} := \text{if}\left(CHECK = \text{"OK: } \varepsilon\text{.steel} > \varepsilon\text{.yield"}, RF_{Des.Inv}, 0\right) = 9.62$

$RF_{Des.Inv} = 9.62$ - if ε.steel < ε.yield, revise the rating factor to 0

$\phi eq(\varepsilon_t, \varepsilon_{cl}, \varepsilon_{tl}) := \text{if}\left(\varepsilon_t \le \varepsilon_{cl}, 0.75, \min\left(0.90, 0.75 + 0.15\cdot\frac{\varepsilon_t - \varepsilon_{cl}}{\varepsilon_{tl} - \varepsilon_{cl}}\right)\right)$

$\phi eq(\varepsilon_t, \varepsilon_{cl}, \varepsilon_{tl})$ - flexural resistance factor equation (LRFD 5.5.4.2-1)

$\varepsilon_{cl} := \frac{f_y}{29000ksi} = 0.0014$

ε_{cl} - compression controlled limit; when $\varepsilon_{conc} = 0.003$ and $\varepsilon_t = \varepsilon_{yield}$

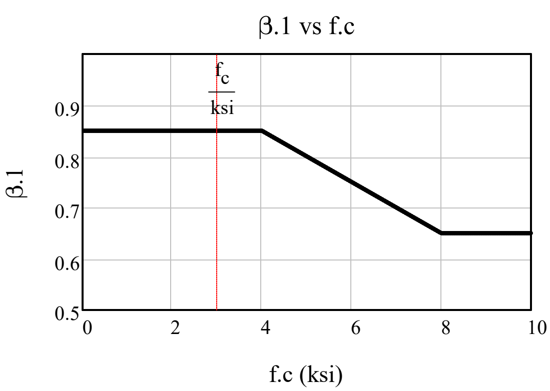
$\varepsilon_{tl} := 0.005$

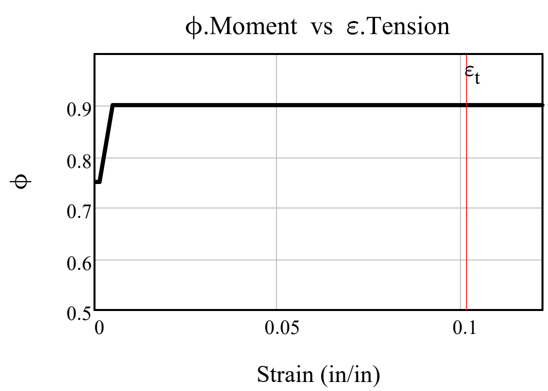
ε_{tl} - tension controlled limit; when $\varepsilon_{conc} = 0.003$ and $\varepsilon_t = 0.005$

$\phi := \phi eq(\varepsilon_t, \varepsilon_{cl}, \varepsilon_{tl}) = 0.90$

$\phi = 0.90$ - flexural resistance/reduction factor (also see Std.Spec. 8.16.1.2.2)

Also see Std.Spec. 8.16.1.2.2, and ACI 10.3.5. For factored axial loading less than n $0.1\cdot f_c\cdot t_{ExtWall}\cdot ft = 25.20\cdot kip$, if ε.t > 0.004, then ϕ=0.90.





Exterior Wall (5 of 6)

DRAW EXTERIOR WALL

$$KEY := \begin{pmatrix} 0 & 0 \\ 0.333\cdot t_{ExtWall} - 0.125in & 0 \\ 0.375in & -1.625in \\ 0.333\cdot t_{ExtWall} - 0.375in & 0 \\ 0.375in & 1.625in \\ 0.333\cdot t_{ExtWall} - 0.125in & 0 \end{pmatrix}$$

$$DRAWxy(xy) := \left| \begin{array}{l} T \leftarrow \left(xy^T\right)^{\langle 1 \rangle} \\ \text{for } i \in 2..\text{rows}(xy) \\ \quad T^{\langle i \rangle} \leftarrow T^{\langle i-1 \rangle} + \left(xy^T\right)^{\langle i \rangle} \\ T^T \end{array} \right.$$

$$MIRRORX(MATRX) := \left| \begin{array}{l} T \leftarrow MATRX \\ \text{for } i \in 1..\text{rows}(T) \\ \quad T_{i,1} \leftarrow -T_{i,1} \\ T \end{array} \right.$$

$$CBC := \left| \begin{array}{l} T \leftarrow \text{stack}\left[\left[\begin{array}{cc} 0 & 0 \\ \left(t_{ExtWall} + 0.5\cdot W_c\right) & 0 \\ -\left(t_{ExtWall} + 0.5\cdot W_c\right) & 0 \\ 0 & \left(t_{slab} + 4in\right) \end{array}\right], KEY, \begin{pmatrix} 0 & -4in \\ 0.5\cdot W_c & 0 \\ -0.5\cdot W_c & 0 \end{pmatrix}\right] \\ DRAWxy\left[\text{stack}\left[T, \left[\begin{array}{cc} 0 & \left(h_{clear} - 2in\right) \\ 2in & 2in \\ \left(0.5\cdot W_c - 2in\right) & 0 \\ -\left(0.5\cdot W_c - 2in\right) & 0 \\ -2in & -2in \end{array}\right], MIRRORX(KEY), \left[\begin{array}{cc} 0 & \left(2in + t_{slab}\right) \\ \left(0.5\cdot W_c + t_{ExtWall}\right) & 0 \\ -\left(0.5\cdot W_c + t_{ExtWall}\right) & 0 \\ 0 & -\left(h_{clear} + t_{slab}\right) \end{array}\right]\right]\right] \end{array} \right.$$

$$CBC^{\langle 2 \rangle} := CBC^{\langle 2 \rangle} - \left(h_{abutment} - x_{origin}\right)$$

DRAW ROADWAY SURFACE

$$ROAD := \left| \begin{array}{l} T \leftarrow (-2 \;\; 0) \\ \text{for } i \in 1..200 \\ \quad \left| \begin{array}{l} (Tx \;\; Ty) \leftarrow \left(T_{\text{rows}(T),1} \;\; T_{\text{rows}(T),2}\right) \\ T \leftarrow \text{stack}\left[T, \begin{pmatrix} Tx + 0.5 & Ty \\ Tx + 0.25 & Ty - 0.5 \\ Tx + 0.5 & Ty \end{pmatrix}\right] \end{array} \right. \\ T^{\langle 2 \rangle} \leftarrow T^{\langle 2 \rangle} + \dfrac{x_{origin}}{ft} \\ T^{\langle 1 \rangle} \leftarrow T^{\langle 1 \rangle} - 40 \\ T \end{array} \right.$$

DRAW CULVERT TOP SLAB

$$CBC2 := \left| \begin{array}{l} T \leftarrow \text{stack}[(0), SUML(L)]\cdot ft \\ T2 \leftarrow (0 \;\; 0) \\ LEG(t,x) \leftarrow \begin{pmatrix} x - 0.5\cdot t & 0 \\ x - 0.5\cdot t & -2ft \\ x - 0.5\cdot t & 0 \\ x + 0.5\cdot t & 0 \\ x + 0.5\cdot t & -2ft \\ x + 0.5\cdot t & 0 \end{pmatrix} \\ \text{for } i \in 1..\text{rows}(T) \\ \quad T2 \leftarrow \text{stack}\left(T2, LEG\left(\left| \begin{array}{ll} t_{ExtWall} & \text{if } i = 1 \vee i = \text{rows}(T) \\ t_{IntWall} & \text{otherwise} \end{array} \right., T_i\right)\right) \\ T2 \leftarrow \text{stack}\left[T2, \begin{pmatrix} \max\left(T2^{\langle 1 \rangle}\right) & t_{slab} \\ -0.5\cdot t_{ExtWall} & t_{slab} \\ -0.5\cdot t_{ExtWall} & 0 \end{pmatrix}\right] \\ T2^{\langle 2 \rangle} \leftarrow T2^{\langle 2 \rangle} - \max\left(T2^{\langle 2 \rangle}\right) \\ T2 \end{array} \right.$$

PLOT RANGES

$plt\_\omega min := 1.2\cdot\min\left(-EH_{\omega}, -LS_{\omega}\right) = -0.61\cdot klf$

$plt\_Vmin := 1.2\cdot\min\left(-EH_V, -LS_V\right) = -0.69\cdot kip$

$plt\_Vmax := 1.2\cdot\max\left(-EH_V, -LS_V\right) = 0.61\cdot kip$

$plt\_Mmin := 1.2\cdot\min\left(-EH_M, -LS_M\right) = -0.41\cdot kip\cdot ft$

$FT\_ExtWall := FT$

Exterior Wall (6 of 6)

RATING FACTOR DETAILS

n2s(N, DP) - number to string; show trailing zeroes

$$
\text{n2s}(N,DP) := \left|\begin{array}{l}
\text{N2str} \leftarrow \text{num2str}(\text{round}(N,DP)) \\
\text{N2str} \leftarrow \text{concat}(\text{N2str}, \text{"."}) \quad \text{if} \;\; \text{search}(\text{N2str}, \text{"."}, 0) = -1 \\
\text{while} \;\; \text{strlen}(\text{N2str}) - \text{search}(\text{N2str}, \text{"."}, 0) < DP + 1 \\
\quad \text{N2str} \leftarrow \text{concat}(\text{N2str}, \text{"0"}) \\
\text{N2str}
\end{array}\right.
$$

GVW - gross vehicle weights in tons

$$
\text{GVW} := \left|\begin{array}{l}
\text{GVWeq1}(\text{TRK}) \leftarrow 0.5\cdot\sum \text{TRK}^{\langle 2\rangle} \\
\text{GVWeq2}(\text{TRKS}) \leftarrow \max\left(\overrightarrow{\text{GVWeq1}(\text{TRKS})}\right) \\
\text{augment}\left(\text{TRUCKS}^{\langle 1\rangle}, \overrightarrow{\text{GVWeq2}\left(\text{TRUCKS}^{\langle 2\rangle}\right)}\right)
\end{array}\right.
$$

RF_ExtWall(iv) -exterior wall rating factor details for each vehicle No.' iv"

$$
\text{RF\_ExtWall}(iv) := \left|\begin{array}{l}
r \leftarrow \text{ROW\_ExtWall} \\
\text{RF} \leftarrow \dfrac{\gamma\text{LL\_eq}(1)}{\gamma\text{LL\_eq}(iv)}\cdot\dfrac{\text{mpf\_eq}(1)}{\text{mpf\_eq}(iv)}\cdot\dfrac{\text{GVW}_{1,2}}{\text{GVW}_{iv,2}}\cdot\text{RF}_{\text{Des.Inv}} \\
\text{MSSG}_{\text{RF}} \leftarrow \left|\begin{array}{l}
T \leftarrow \text{concat}(\text{"RF = ["}, \text{n2s}(\gamma\text{LL\_eq}(1),2), \text{"/"}, \text{n2s}(\gamma\text{LL\_eq}(iv),2), \text{"]["}, \text{n2s}(\text{mpf\_eq}(1),2), \text{"/"}, \text{n2s}(\text{mpf\_eq}(iv),2), \text{"]["}) \\
T \leftarrow \text{concat}\left[T, \text{num2str}\left(\text{GVW}_{1,2}\right), (\text{"/"}), \text{num2str}\left(\text{GVW}_{iv,2}\right), \text{"][("}\right] \\
\text{concat}\left[T, \text{n2s}\left(\dfrac{\psi c\phi\text{Mn\_wall}}{\text{kip}\cdot\text{ft}}, 2\right), \text{" - "}, \text{n2s}\left(\dfrac{\gamma\text{DC}_M + \gamma\text{EV}_M + \gamma\text{EH}_{M_r}}{\text{kip}\cdot\text{ft}}, 2\right), \text{") / ("}, \text{n2s}\left(\dfrac{\gamma\text{LV}_M + \gamma\text{LS}_{M_r}}{\text{kip}\cdot\text{ft}}, 2\right), \text{")] = "}, (\text{n2s}(\text{RF},2))\right]
\end{array}\right. \\
\text{MSSG}_{\text{LOC}} \leftarrow \text{concat}\left(\text{"Ext Wall at "}, \text{n2s}\left(\dfrac{\text{FT}_r}{L_{\text{wall}}}, 2\right), \text{", D.fill = "}, \text{n2s}\left(\dfrac{\max\left(D_{\text{fills}}\right)}{\text{ft}}, 2\right), \text{"ft."}\right) \\
\begin{bmatrix}
1 & \text{"GOV (row\#)"} & 1 \\
2 & \text{"VEH (\#)"} & iv \\
3 & \text{"VEH (name)"} & \text{TRUCKS}_{iv,1} \\
4 & \text{"TRUCK (\#)"} & 1 \\
5 & \text{"TRUCK mirror"} & 0 \\
6 & \text{"TRUCK, (ft, kip)"} & \left(\text{TRUCKS}_{iv,2}\right)_1 \\
7 & \text{"TRUCK (h.eq, 0, 0)"} & \begin{pmatrix}\dfrac{h_{eq}}{\text{ft}} & 0 & 0\end{pmatrix} \\
8 & \text{"LOC (inc)"} & \dfrac{\text{FT}_r}{L_{\text{wall}}} \\
9 & \text{"LOC (ft)"} & \dfrac{\text{FT}_r}{\text{ft}} \\
10 & \text{"TEST"} & \text{"M.wall"} \\
11 & \text{"LOC message, Excel"} & \text{MSSG}_{\text{LOC}} \\
12 & \text{"RF message"} & \text{MSSG}_{\text{RF}} \\
13 & \text{"RF"} & \text{RF} \\
14 & \text{"RATING (tons)"} & \text{RF}\cdot\text{GVW}_{iv,2} \\
15 & \text{"LL/DL"} & \dfrac{\text{GVW}_{iv,2}}{\text{GVW}_{1,2}}\cdot\dfrac{\text{LV}_M + \text{LS}_{M_r}}{\text{DC}_M + \text{EV}_M + \text{EH}_{M_r}} \\
16 & \text{"LOC message, CAD"} & \text{concat}\left(\text{n2s}\left(\dfrac{t_{\text{slab}} + h_{\text{haunch.bot}} + \text{FT}_r}{\text{ft}}, 2\right), \text{" from the bottom of the slab"}\right)
\end{bmatrix}
\end{array}\right.
$$

$$
\text{RFs5EXTWALL} := \left|\begin{array}{l}
\text{for} \;\; iv \in 1..\text{rows}(\text{TRUCKS}) \\
\quad T^{\langle iv\rangle} \leftarrow \text{RF\_ExtWall}(iv)^{\langle 3\rangle} \\
T^{T}
\end{array}\right.
$$

Top Slab Rating Factors (1 of 2)

$RFpos(Mr, \gamma DL, \gamma LL)$ & $RFneg(Mr, \gamma DL, \gamma LL)$ - rating factor equations for positive and negative loads

$$RFpos(C, DL, LL) := \begin{vmatrix} \text{return } 99 \text{ if } LL < 0.001 \\ \min\left(99, \dfrac{C - DL}{LL}\right) \end{vmatrix}$$

$$RFneg(C, DL, LL) := \begin{vmatrix} \text{return } 99 \text{ if } LL > -0.001 \\ \min\left(99, \dfrac{C - DL}{LL}\right) \end{vmatrix}$$

$RFs1(iD)$ - run rating factors for one depth of fill

$$RFs1(iD) := \begin{vmatrix} \gamma LL \leftarrow \gamma LLwLBL\left(D_{fills_{iD}}\right) \\ \text{for } iv \in 1..rows(TRUCKS) \\ \quad \begin{vmatrix} RF\_Mp(\gamma LLMp) \leftarrow RFpos\left(\dfrac{\psi\phi Mn}{kip \cdot ft}, \gamma DL_{iD,1}, \gamma LLMp\right) \\ RF\_Mn(\gamma LLMn) \leftarrow RFneg\left(\dfrac{-\psi\phi Mn}{kip \cdot ft}, \gamma DL_{iD,2}, \gamma LLMn\right) \\ V(\gamma LLV, \gamma LLM) \leftarrow \begin{vmatrix} Mu \leftarrow \left(\gamma LLM + \gamma DL_{iD,4}\right) \cdot kip \cdot ft \\ Vu \leftarrow \left(\gamma LLV + \gamma DL_{iD,3}\right) \cdot kip \\ C \leftarrow \dfrac{-\psi\phi Vn\left(Mu, Vu, D_{fills_{iD}}\right)}{kip} \\ RFneg\left(C, \gamma DL_{iD,3}, \gamma LLV\right) \end{vmatrix} \\ RF_{iv,1} \leftarrow \overrightarrow{RF\_Mp\left(\gamma LL_{iv,2}\right)} \\ RF_{iv,2} \leftarrow \overrightarrow{RF\_Mn\left(\gamma LL_{iv,3}\right)} \\ RF_{iv,3} \leftarrow \overrightarrow{V\left(\gamma LL_{iv,4}, \gamma LL_{iv,5}\right)} \end{vmatrix} \\ augment(\gamma LL, RF) \end{vmatrix}$$

$RFs2(iD)$ - run rating factors for one depth of fill, and report the governing row

$$RFs2(iD) := \begin{vmatrix} T \leftarrow RFs1(iD) \\ \text{for } iRF \in 1..3 \\ \quad \text{for } iv \in 1..rows(TRUCKS) \\ \qquad \begin{vmatrix} minRF_{iv,iRF} \leftarrow \min\left(T_{iv,iRF+5}\right) \\ MATCH_{iv,iRF} \leftarrow match2\left(minRF_{iv,iRF}, T_{iv,iRF+5}\right) \\ R_{iv,iRF} \leftarrow MATCH_{iv,iRF} \end{vmatrix} \\ augment(T, minRF, R) \end{vmatrix}$$

$\gamma DFIMshow(iv, D, \gamma LL)$ - show live load factors (γ.LL, DF, IM, and LL)

$$\gamma DFIMshow\left(iv, D_{fill}, \gamma LL\right) := \begin{vmatrix} (DF \;\; IM) \leftarrow \left(\dfrac{ft}{Eeq\left(mpf_{iv}, D_{fill}\right)} \;\; IMeq\left(D_{fill}\right)\right) \\ concat\left(n2s\left(\gamma LL_{iv}, 2\right), \text{"* "}, n2s(DF, 4), \text{"*"}, n2s(IM, 3), \text{"*"}, n2s\left(\dfrac{\gamma LL}{\gamma LL_{iv} \cdot DF \cdot IM}, 1\right)\right) \end{vmatrix}$$

Top Slab Rating Factors (2 of 2)

RFdetails1(iv, MMV, DL, γDL, LL, γLL, C, RF, BrINC, D) - show rating factor details for one vehicle and one depth of fill

$$\text{RFdetails1}(iv, MMV, DL, \gamma DL, LL, \gamma LL, C, RF, BrINC, D) := \left| \begin{array}{l} MMV \leftarrow (\text{"M.pos"} \;\; \text{"M.neg"} \;\; \text{"V.neg"})_{1, MMV} \\ RFeq \leftarrow \text{concat}[\text{"RF = ("}, \text{n2s}(C, 2), \text{" - "}, \text{n2s}(\gamma DL, 2), \text{") / ("}, \gamma\text{DFIMshow}(iv, D, \gamma LL), \text{") = "}, (\text{n2s}(RF, 2))] \\ LOC \leftarrow \text{concat}\left(\text{"Top Slab at "}, \text{n2s}(BrINC, 2), \text{", D.fill = "}, \text{n2s}\left(\frac{D}{ft}, 2\right), \text{"ft."}\right) \\ \left(MMV \;\; LOC \;\; RFeq \;\; RF \;\; RF \cdot GVW_{iv, 2} \;\; \frac{LL}{DL} \;\; \text{concat}\left(\text{n2s}\left(\text{iioft}(BrINC) + \frac{t_{ExtWall}}{ft}, 1\right), \text{"ft. to face of Ext Wall"}\right)\right) \end{array} \right.$$

RFs3(iD) - show rating factors for all vehicles, for depth of fill $D_{fills_{iD}}$

$$\text{RFs3}(iD) := \left| \begin{array}{l} T1 \leftarrow \text{RFs2}(iD) \\ T3 \leftarrow \text{matrix}(1, 16, f(i,j) \leftarrow 0) \\ \text{for } iv \in 1..\text{rows}(TRUCKS) \\ \quad \text{for } MMV \in 1..3 \\ \quad\quad \left| \begin{array}{l} (ROW \;\; COL) \leftarrow \left[\left(T1_{iv, 11+MMV}\right) \;\; (1)\right] \\ (DLt \;\; \gamma DLt \;\; LLt \;\; \gamma LLt) \leftarrow \left[\left(DL_{iD, MMV}\right)_{1,1} \;\; \left(\gamma DL_{iD, MMV}\right)_{1,1} \;\; \frac{\left(T1_{iv, 1+MMV}\right)_{ROW}}{\gamma LL\_eq(iv)} \;\; \left(T1_{iv, 1+MMV}\right)_{ROW}\right] \\ C \leftarrow \left[\left(\frac{\psi\phi Mn}{kip \cdot ft}\right) \;\; \left(\frac{-\psi\phi Mn}{kip \cdot ft}\right) \;\; \left[\frac{-\psi\phi Vn\left[\left[\left[\left(T1_{iv, 5}\right)_{ROW} + \left(\gamma DL_{iD, 4}\right)_{1,1}\right] \cdot kip \cdot ft\right], \left[\left[\left(T1_{iv, 4}\right)_{ROW} + \left(\gamma DL_{iD, 3}\right)_{1,1}\right] \cdot kip\right], D_{fills_{iD}}\right]}{kip}\right]\right]_{1, MMV} \\ T2 \leftarrow \text{RFdetails1}\left[iv, MMV, DLt, \gamma DLt, LLt, \gamma LLt, C, \left(T1_{iv, 8+MMV}\right), RSIF\_CHK\_LOCS_{MMV, 3}, D_{fills_{iD}}\right] \\ DET\_LABEL \leftarrow \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 \\ \text{"ROW\#"} & \text{"VEH\#"} & \text{"NAME"} & \text{"TRUCK\#"} & \text{"MIRROR"} & 0 & \text{"x1x2}\gamma\omega\text{"} \end{pmatrix} \\ DET \leftarrow \left(T1_{iv, 1}{}^{T}\right)^{\langle ROW \rangle} \\ (DLt \;\; \gamma DLt) \leftarrow \left[\left[\left(DL_{iD, MMV}\right)_{1, COL}\right] \;\; \left[\left(\gamma DL_{iD, MMV}\right)_{1, COL}\right]\right] \\ (LLt \;\; \gamma LLt) \leftarrow \left[\left[\frac{\text{IMeq}\left(D_{fills_{iD}}\right) \cdot ft}{\text{Eeq}\left(mpf_{iv}, D_{fills_{iD}}\right)} \cdot \text{INFx1x2}\omega\left[(iMpos \;\; iMneg \;\; iVneg)_{1, MMV}, DET_{7}\right]\right] \;\; \left[\left(T1_{iv, 1+MMV}\right)_{ROW, COL}\right]\right] \\ TRUCK \leftarrow \text{if}\left[DET_{5} = 0, \left(TRUCKS_{iv, 2}\right)_{DET_{4}}, \text{MIRROR}\left[\left(TRUCKS_{iv, 2}\right)_{DET_{4}}\right]\right] \\ \left(DET_{6} \;\; DET_{8} \;\; DET_{9}\right) \leftarrow \left(TRUCK \;\; RSIF\_CHK\_LOCS_{MMV, 3} \;\; RSIF\_CHK\_LOCS_{MMV, 4}\right) \\ T3 \leftarrow \text{stack}\left(T3, \text{augment}\left(DET^{T}, T2\right)\right) \end{array} \right. \\ \text{submatrix}(T3, 2, \text{rows}(T3), 1, \text{cols}(T3)) \end{array} \right.$$

RFs5 - run all rating factors for all depths of fill, and stack on top of the exterior wall rating factors

$$\text{RFs5} := \left| \begin{array}{l} \text{RFs4} \leftarrow \left| \begin{array}{l} \text{for } i \in 1..\text{rows}\left(D_{fills}\right) \\ \quad T1 \leftarrow \left| \begin{array}{ll} \text{RFs3}(i) & \text{if } i = 1 \\ \text{stack}(T1, \text{RFs3}(i)) & \text{otherwise} \end{array} \right. \\ T1 \end{array} \right. \\ (r \;\; RowsPerDfill) \leftarrow \left(0 \;\; \frac{\text{rows}(RFs4)}{\text{rows}\left(D_{fills}\right)}\right) \\ \text{for } i \in 1..RowsPerDfill \\ \quad \text{for } iD \in 1..\text{rows}\left(D_{fills}\right) \\ \quad\quad \left| \begin{array}{l} r \leftarrow r + 1 \\ T2^{\langle r \rangle} \leftarrow \left(RFs4^{T}\right)^{\langle (iD-1) \cdot RowsPerDfill + i \rangle} \end{array} \right. \\ \text{stack}\left(T2^{T}, RFs5EXTWALL\right) \end{array} \right.$$

Rating Factor Assembly (2 of 4)

MAKE OUTPUT SUMMARIES

```
DESIGN_ROW_minRF(iv, MorV) := | (minRF  minRFrow) ← (999  1)
                              | for  i ∈ 1 .. rows(RFs5)
                              |   if  substr(RFs5[i,10], 0, 1) = MorV ∧ iv = RFs5[i,2]
                              |     | minRF ← min(minRF, RFs5[i,13])
                              |     | minRFrow ← i  if  minRF = RFs5[i,13]
                              | minRFrow
```

```
OUT_CAD := | DET(MorV) ← | for  iv ∈ 1 .. rows(TRUCKS)
           |             |   T<iv> ← | r ← DESIGN_ROW_minRF(iv, MorV)
           |             |           | (RFs5[r,15]  RFs5[r,13]  RFs5[r,14]  RFs5[r,11]  RFs5[r,16])^T
           |             | T
           | HDR ← ("LL/DL"  "RF"  "TONS"  "LOCATION"  "DIMENSION")
           | R1 ← augment[stack[("TEST:"  "VEH")^T, TRUCKS<1>], stack(matrix(1, 5, f(i, j) ← "MOMENT"), HDR, DET("M")^T)]
           | R3 ← augment[stack[("TEST:"  "VEH")^T, TRUCKS<1>], stack(matrix(1, 5, f(i, j) ← "SHEAR"), HDR, DET("V")^T)]
           | stack(R1, matrix(1, 6, f(i, j) ← ""), R3)
```

```
OUT_Excel_Verbose := | for  r ∈ 1 .. rows(RFs5)
                     |   T<r> ← (RFs5[r,3]  RFs5[r,13]  RFs5[r,11]  RFs5[r,10]  RFs5[r,12])^T
                     | stack[("VEH"  "RF"  "LOCATION"  "TEST"  "RF.equation"), T^T]
```

```
RFsGOV := | row(iv) ← | (minRF  minRFrow) ← (999  1)
          |           | for  i ∈ 1 .. rows(RFs5)
          |           |   if  iv = RFs5[i,2]
          |           |     | minRF ← min(minRF, RFs5[i,13])
          |           |     | minRFrow ← i  if  minRF = RFs5[i,13]
          |           | minRFrow
          | for  iv ∈ 1 .. rows(TRUCKS)
          |   T<iv> ← | r ← row(iv)
          |           | (RFs5[r,3]  RFs5[r,13]  RFs5[r,11]  RFs5[r,10]  RFs5[r,12])^T
          | stack[("VEH"  "Gov.RF"  "Governing.LOCATION"  "Gov.TEST"  "Governing.RF.equation"), T^T]
```

Rating Factor Assembly (3 of 4)

SHOW DETAILED RESULTS

```
CHECKeq(iv) := | for MMVE ∈ 1..4
               |   | TEST ← ("M.pos"  "M.neg"  "V.neg"  "M.wall")_(1,MMVE)
               |   | RF ← 999
               |   | for i ∈ 1..rows(RFs5)
               |   |   if RFs5_(i,13) ≤ RF ∧ RFs5_(i,2) = iv ∧ RFs5_(i,10) = TEST
               |   |     | RF ← RFs5_(i,13)
               |   |     | T^<MMVE> ← (RFs5^T)^<i>
               | T^T
```

```
CHECKallD(iv) := | c ← 0
                 | for MMVE ∈ 1..4
                 |   | TEST ← ("M.pos"  "M.neg"  "V.neg"  "M.wall")_(1,MMVE)
                 |   | for i ∈ 1..rows(RFs5)
                 |   |   if RFs5_(i,2) = iv ∧ RFs5_(i,10) = TEST
                 |   |     | c ← c + 1
                 |   |     | T^<c> ← (RFs5^T)^<i>
                 | T^T
```

```
CHECK_DeGook(T) := | T ← augment(T^<3>, T^<6>, T^<7>, submatrix(T, 1, rows(T), 10, 12))
                   | for i ∈ 1..rows(T)
                   |   | T_(i,2) ← stack[("ft"  "kip"), T_(i,2)]
                   |   | T_(i,3) ← stack[("start(ft)"  "end(ft)"  "klf"), T_(i,3)]
                   |   | T_(i,5) ← (T_(i,5)  T_(i,6))^T
                   | T_(rows(T),3) ← [ "h.eq(ft)"                 ""  ""
                   |                   (T_(rows(T),3))_(2,1)      ""  "" ]
                   | submatrix(T, 1, rows(T), 1, 5)
```

CHECKeq(iv) := CHECK_DeGook(CHECKeq(iv))

CHECKallD(iv) := CHECK_DeGook(CHECKallD(iv))

QCHECK := CHECKeq(testVEH)

Rating Factor Assembly (4 of 4)

RF TABLE, ALL TESTS AT THE GOVERNING FILL

```
RFs := | HDR ← ( "+M.slab"  "-M.slab"  "V.slab"  "M.wall" )
       | T1(iv) ← | for j ∈ 1..4
       |          |   | RFt ← 999
       |          |   | for i ∈ 1..rows(RFs5)
       |          |   |   RFt ← min(RFt, RFs5[i,13]) if RFs5[i,2] = iv ∧ RFs5[i,10] = ( "M.pos"  "M.neg"  "V.neg"  "M.wall" )[1,j]
       |          |   | RF[j] ← RFt
       |          | RF^T
       | for iv ∈ 1..rows(TRUCKS)
       |   T2^⟨iv⟩ ← T1(iv)^T
       | augment(AV2^⟨2⟩, stack(HDR, T2^T))
```

RF & TONS, ALL TESTS AT THE GOVERNING FILL

```
TONS := | HDR ← ( "+M.slab"  "-M.slab"  "V.slab"  "M.wall" )
        | T1(iv) ← submatrix(RFs, iv + 1, iv + 1, 2, 5)·GVW[iv,2]
        | for iv ∈ 1..rows(TRUCKS)
        |   T2^⟨iv⟩ ← T1(iv)^T
        | augment(AV2^⟨2⟩, stack(HDR, T2^T))
```

```
RF_TN := | SUB(M) ← submatrix(M, 1, rows(M), 2, 5)
         | HDR(LBL) ← matrix(1, 4, f(i,j) ← LBL)
         | C1 ← stack[( "VEH"  "VEH"  "VEH" ), AV3]
         | C2 ← stack(HDR("RF"), SUB(RFs))
         | C3 ← stack(HDR("TON"), SUB(TONS))
         | augment(C1, C2)
```

EXPAND SUB-MATRICES FOR EXCEL OUTPUT

DeFunk1(M, Rows) - add some blank rows to matrix M

```
DeFunk1(M, Rows) := | S(r, c) ← matrix(r, c, f(i,j) ← "")
                    | rM ← rows(M)
                    | return stack[(M), S(Rows − 1, 1)] if rM = 0
                    | return M if rM = Rows
                    | stack(M, S(Rows − rows(M), cols(M)))
```

DeFunk2(M) - expand submatrices in matrix M with stack and augment

```
DeFunk2(M) := | for i ∈ 1..rows(M)
              |   for j ∈ 1..cols(M)
              |     T1[i] ← if(j = 1, M[i,1], augment(T1[i], M[i,j]))
              | for i ∈ 1..rows(T1)
              |   T2 ← if(i = 1, T1[1], stack(T2, T1[i]))
              | T2
```

DeFunk3 - governing details for one vehicle

```
DeFunk3(M) := | for itest ∈ 1..rows(M)
              |   | ROWS ← max(vectorize(rows(M^T)))
              |   | for j ∈ 1..cols(M)
              |   |   T1[itest,j] ← DeFunk1(M[itest,j], ROWS)
              | DeFunk2(T1)
```

DeFunkCheck_4- details for all vehicles and all fill depths

```
DeFunk4(M) := | for iv ∈ 1..rows(M)
              |   T ← | DeFunk3(M[iv]) if iv = 1
              |       | stack(T, DeFunk3(M[iv])) otherwise
              | T
```

CHECK - details for testVEH at the governing fill depths

```
CHECK := DeFunk3(CHECKeq(testVEH))
```

Details_Verbose- details for all vehicles and all fill depths

```
OUT_Verbose := DeFunk4(vectorize(CHECKallD(AV^⟨1⟩)))
```

Prepare Export to Excel

$$\text{Description} := \begin{bmatrix} \text{"Bridge No"} & \text{BridgeNo} \\ \text{"Name"} & \text{BridgeName} \\ \text{"Description"} & \text{BridgeDescription} \\ \text{"Method"} & \begin{pmatrix} \text{"LFR - Load Factor"} \\ \text{"LRFR-LRFD"} \end{pmatrix}_{LRFR+1} \\ \text{"Impact"} & \left| \begin{array}{l} n \leftarrow \text{search}\left(\text{RFsGOV}_{3,3}, \text{"D.fill"}, 1\right) \\ \left(\text{IMeq}\left(\text{str2num}\left(\text{substr}\left(\text{RFsGOV}_{3,3}, n+9, 4\right)\right)\cdot \text{ft}\right) - 1\right) \end{array} \right. \\ \text{"Span Length"} & L_1 \end{bmatrix} = \begin{pmatrix} \text{"Bridge No"} & \text{"CBC123"} \\ \text{"Name"} & \text{"I-10 over Example Creek"} \\ \text{"Description"} & \text{"Index 8030, 305' Triple 9'x3' Built 1972"} \\ \text{"Method"} & \text{"LRFR-LRFD"} \\ \text{"Impact"} & 0.25 \\ \text{"Span Length"} & 9.63 \end{pmatrix}$$

$$\text{NULL}(r,c) := \text{matrix}(r,c,f(i,j) \leftarrow \text{""})$$

$$\text{maxROWS\_maxCOLS}(\text{Matrices}) := \left| \begin{array}{l} \text{mx}(M) \leftarrow \max(M) \\ \left(\text{mx}\left(\overrightarrow{\text{rows}(\text{Matrices})}\right) \quad \text{mx}\left(\overrightarrow{\text{cols}(\text{Matrices})}\right) \right) \end{array} \right.$$

AugmentFill(Names, Matrices) - combine Matrices, horizontal direction

$$\text{AugmentFill}(\text{Names}, \text{Matrices}) := \left| \begin{array}{l} \text{MaxRows} \leftarrow \text{maxROWS\_maxCOLS}(\text{Matrices})_{1,1} \\ \text{STACK}(\text{Matrix}) \leftarrow \text{Matrix} \;\text{ on error }\; \text{stack}(\text{Matrix}, \text{NULL}(\text{MaxRows} - \text{rows}(\text{Matrix}), \text{cols}(\text{Matrix}))) \\ \text{for } i \in 1..\text{rows}(\text{Matrices}) \\ \quad \left| \begin{array}{l} \text{HEADER} \leftarrow \text{Names}_i \;\text{ on error }\; \text{augment}\left(\text{Names}_i, \text{NULL}\left(1, \text{cols}\left(\text{Matrices}_i\right) - 1\right)\right) \\ T \leftarrow \text{stack}\left(\text{HEADER}, \text{STACK}\left(\text{Matrices}_i\right)\right) \;\text{ on error }\; \text{augment}\left(T, \text{NULL}(\text{MaxRows}+1, 1), \text{stack}\left(\text{HEADER}, \text{STACK}\left(\text{Matrices}_i\right)\right)\right) \end{array} \right. \\ T \end{array} \right.$$

StackFill(Names, Matrices) - combine Matrices, vertical direction

$$\text{StackFill}(\text{Names}, \text{Matrices}) := \left| \begin{array}{l} \text{MaxCols} \leftarrow \text{maxROWS\_maxCOLS}(\text{Matrices})_{1,2} \\ \text{AUGMENT}(\text{Matrix}) \leftarrow \text{augment}(\text{Matrix}, \text{NULL}(\text{rows}(\text{Matrix}), \text{MaxCols} - \text{cols}(\text{Matrix}) + 1)) \\ \text{for } i \in 1..\text{rows}(\text{Matrices}) \\ \quad \left| \begin{array}{l} \text{HEADER} \leftarrow \text{augment}\left(\text{Names}_i, \text{NULL}(1, \text{MaxCols})\right) \\ T \leftarrow \text{stack}\left(\text{HEADER}, \text{AUGMENT}\left(\text{Matrices}_1\right)\right) \;\text{ on error }\; \text{stack}\left(T, \text{NULL}(1, \text{MaxCols}+1), \text{HEADER}, \text{AUGMENT}\left(\text{Matrices}_i\right)\right) \end{array} \right. \\ T \end{array} \right.$$

WRITE_DATA_TO_EXCEL (Name_of_Worksheet) - write all output matrices to one Excel sheet. Use Excel formulas to link that data to secondary sheets formatted for printing. To force Excel formula updating, apply a VBA macro: Private Sub Workbook_Open(), Application.CalculateFull, End Sub.

$$\text{WRITE\_DATA\_TO\_EXCEL}(\text{Name\_of\_Worksheet}) := \left| \begin{array}{l} \text{Worksheet} \leftarrow \text{Name\_of\_Worksheet} \\ \text{WRITEEXCEL}(\text{matrix}(500, 50, f(i,j) \leftarrow \text{""}), \text{Worksheet}, \text{"DATA!A1"}) \\ \text{WRITEEXCEL}\left[\text{AugmentFill}\left[\begin{pmatrix} \text{"Decription"} \\ \text{"RFs"} \\ \text{"RFs.GOV"} \\ \text{"RFs.VERBOSE"} \\ \text{"CAD"} \end{pmatrix}, \begin{pmatrix} \text{Description} \\ \text{RFs} \\ \text{RFsGOV} \\ \text{OUT\_Verbose} \\ \text{OUT\_CAD} \end{pmatrix}\right], \text{Worksheet}, \text{"DATA!A1"}\right] \end{array} \right.$$

Quick Check Setup (1 of 2)

MAKE INFLUENCE MATRIX, AND ASSIGN RF CHECK OUTPUTS

$RF\_Mpos := \left(QCHECK^{T}\right)^{\langle 1\rangle T}$ $RF\_Mneg := \left(QCHECK^{T}\right)^{\langle 2\rangle T}$ $RF\_Vneg := \left(QCHECK^{T}\right)^{\langle 3\rangle T}$ $RF\_ExtWall := \left(QCHECK^{T}\right)^{\langle 4\rangle T}$

$ips := 20$ $RSIF\_check := RSIF_{eq}\left(L, BrIncs_{eq2}(L, ips)\right)$ $INF2\_check := INF2_{eq}(L, RSIF\_check)$

$ROWS := RSIF\_check^{\langle 1\rangle}$ $BrINCS := RSIF\_check^{\langle 3\rangle}$ $FT := RSIF\_check^{\langle 4\rangle} \cdot ft$ $TK := TRUCKS_{testVEH,1}$

$(MpCol\ \ MnCol\ \ VnCol) := \left(match2\left(pM_{BrINC}, RSIF\_check^{\langle 3\rangle}\right)\ \ match\left(2.00, RSIF\_check^{\langle 3\rangle}\right)_1\ \ match2\left(Vinc, RSIF\_check^{\langle 3\rangle}\right)\right) = (10\ \ 25\ \ 21)$

$Mpos := \left(INF2\_check_{1,1}\right)^{\langle MpCol\rangle} \cdot \frac{kip \cdot ft}{kip}$ $Mneg := \left(INF2\_check_{1,1}\right)^{\langle MnCol\rangle} \cdot \frac{kip \cdot ft}{kip}$ $Vneg := \left(INF2\_check_{1,4}\right)^{\langle VnCol\rangle} \cdot \frac{kip}{kip}$ $Mv := \left(INF2\_check_{1,1}\right)^{\langle VnCol\rangle} \cdot \frac{kip \cdot ft}{kip}$

$\gamma LL_{show}\left(\gamma_{LL}, DF, IM, LL\right) := concat\left["(", n2s\left(\gamma_{LL}, 2\right), ")(", n2s(DF, 4), ")(1+", n2s[(IM - 1) \cdot 100, 0], "\%)(", n2s(LL, 1), ") = ", n2s\left(\gamma_{LL} \cdot DF \cdot IM \cdot LL, 2\right)\right]$ - show live load

STATE VARIABLES COMMON TO ALL RF CHECKS FOR TEST VEHICLE $TK = "HL93.OPR"$

$$Dfilleq(CHK) := \begin{array}{|l} T \leftarrow \left(CHK_{1,5}\right)_1 \\ (start\ \ end) \leftarrow (search(T, "=", 1)\ \ search(T, "ft", 1)) \\ str2num(substr(T, start + 1, end - start - 1)) \cdot ft \end{array}$$

$Dfilleq(CHK)$ - extract depth of fill from a check output

$mpf := mpf_{testVEH}$

$mpf = 1.00$ - single-lane multiple presence factor

$\gamma_{LL} := \gamma_{LL_{testVEH}} = 1.35$

$\gamma_{LL} = 1.35$ - live load factor

Quick Check Setup (2 of 2)

MAKE PLOTS

PLTCIRCLE(r, θ) - plot a circle: r - radius, θ - starting angle

$$\text{PLTCIRCLE}(r,\theta) := \left| \begin{array}{l} \text{for } i \in 1..13 \\ \quad \left| \begin{array}{l} \theta 2 \leftarrow \theta + \dfrac{360\text{deg}}{12}\cdot(i-1) \\ \left(T_{i,1} \;\; T_{i,2}\right) \leftarrow r\cdot(\cos(\theta 2) \;\; \sin(\theta 2)) \end{array} \right. \\ T \end{array} \right.$$

PLTAXL(x, r, P, CIRCLE) - plot an axle weight P at location x

$$\text{PLTAXL}(x,r,P,\text{CIRCLE}) := \left| \begin{array}{l} \text{Scale} \leftarrow 0.1768\cdot\sqrt{P} \\ \text{CIRCLE} \leftarrow \text{CIRCLE}\cdot\text{Scale} \\ \text{augment}\left(\text{CIRCLE}^{\langle 1\rangle} + x, \text{CIRCLE}^{\langle 2\rangle} + r\cdot\text{Scale}\right) \end{array} \right.$$

PLTaxles(TKr, TRKdist, D) - plot the truck axles, and scale for size

$$\text{PLTaxles}(\text{TKr},\text{TRKdist},D) := \left| \begin{array}{l} \text{CIRCLE} \leftarrow \text{PLTCIRCLE}(18\text{in}, -90\text{deg}) \\ \text{AXL}(x,P) \leftarrow \text{PLTAXL}(x, 18\text{in}, P, \text{CIRCLE}) \\ x \leftarrow \min\left(\text{TRKdist}^{\langle 1\rangle}\right)\cdot\text{ft} + 0.5\cdot\left(D\cdot\text{DF}_{\text{earth}} + \text{tire}_{\text{length}}\right) \\ \text{TRKraw} \leftarrow \text{MIRROR}(\text{TKr}) \\ T \leftarrow \text{AXL}\left(x, \text{TRKraw}_{1,2}\right) \\ \text{for } i \in 1..\text{rows}(\text{TRKraw}) \\ \quad \left| \begin{array}{l} x \leftarrow x + \text{TRKraw}_{i,1}\cdot\text{ft} \\ T \leftarrow \left| \begin{array}{ll} T & \text{if } i = 1 \\ \text{stack}\left(T, \text{AXL}\left(x, \text{TRKraw}_{i,2}\right)\right) & \text{otherwise} \end{array} \right. \end{array} \right. \\ T^{\langle 2\rangle} \leftarrow T^{\langle 2\rangle} + D \\ T \end{array} \right.$$

PLTdist(TKd, D) - plot longitudinal distribution

$$\text{PLTdist}(\text{TKd},D) := \left| \begin{array}{l} \text{Side} \leftarrow 0.5\cdot D\cdot\text{DF}_{\text{earth}} \\ \text{PLT1DIST}(x1,x2) \leftarrow \begin{pmatrix} x1+\text{Side} & D \\ x1 & 0 \\ x1+\text{Side} & D \\ x2-\text{Side} & D \\ x2 & 0 \\ x2-\text{Side} & D \end{pmatrix} \\ T \leftarrow \text{PLT1DIST}\left(\text{TKd}_{1,1}\cdot\text{ft}, \text{TKd}_{1,2}\cdot\text{ft}\right) \\ \text{return } T \text{ if } \text{rows}(\text{TKd}) = 1 \\ \text{for } i \in 2..\text{rows}(\text{TKd}) \\ \quad T \leftarrow \text{stack}\left(T, \text{PLT1DIST}\left(\text{TKd}_{i,1}\cdot\text{ft}, \text{TKd}_{i,2}\cdot\text{ft}\right)\right) \\ T \end{array} \right.$$

PLTTRK (CHECK) - plot axles and longitudinal distribution for a RF check output, which contains details for the governing location

$$\text{PLTTRK}(\text{CHECK}) := \left| \begin{array}{l} D \leftarrow \text{Dfilleq}(\text{CHECK}) \\ (T1 \;\; T2) \leftarrow \left(\text{CHECK}_{1,2} \;\; \text{CHECK}_{1,3}\right) \\ (\text{TRKraw} \;\; \text{TRKdist}) \leftarrow (\text{submatrix}(T1, 2, \text{rows}(T1), 1, 2) \;\; \text{submatrix}(T2, 2, \text{rows}(T2), 1, 2)) \\ (\text{PLTaxles} \;\; \text{PLTdist}) \leftarrow (\text{PLTaxles}(\text{TRKraw}, \text{TRKdist}, D) \;\; \text{PLTdist}(\text{TRKdist}, D)) \\ \text{TRUCK} \leftarrow \text{stack}(\text{PLTdist}, \text{PLTaxles})\cdot\text{ft}^{-1} \\ \text{range} \leftarrow \max\left(\text{TRUCK}^{\langle 1\rangle}, \sum L\cdot 1.1\right) - \min\left(\text{TRUCK}^{\langle 1\rangle}, -0.1\cdot\sum L\right) \\ \text{PlotRatio} \leftarrow 3 \\ (\text{Xmin} \;\; \text{Xmax} \;\; \text{Ymax}) \leftarrow \left[\left(\min\left(\text{TRUCK}^{\langle 1\rangle} - \dfrac{\text{range}}{10}, -0.1\cdot\sum L\right)\right) \;\; \left(\max\left(\text{TRUCK}^{\langle 1\rangle} + \dfrac{\text{range}}{10}, \sum L\cdot 1.1\right)\right) \;\; \left(\dfrac{\text{range}}{\text{PlotRatio}} - 2\right)\right] \\ \text{ROAD} \leftarrow \text{augment}\left(\text{ROAD}^{\langle 1\rangle}, \text{ROAD}^{\langle 2\rangle} - \max\left(\text{ROAD}^{\langle 2\rangle}\right) + D\cdot\text{ft}^{-1}\right) \\ \text{if } \text{Ymax} < 1.1\cdot\max\left(\text{TRUCK}^{\langle 2\rangle}\right) \\ \quad \left| \begin{array}{l} \Delta Y \leftarrow 1.1\cdot\max\left(\text{TRUCK}^{\langle 2\rangle}\right) - \text{Ymax} \\ (\text{range} \;\; \text{Xmin} \;\; \text{Xmax} \;\; \text{Ymax}) \leftarrow \left[(\text{range} + \text{PlotRatio}\cdot\Delta Y) \;\; \left(\text{Xmin} - \dfrac{\text{PlotRatio}}{2}\cdot\Delta Y\right) \;\; \left(\text{Xmax} + \dfrac{\text{PlotRatio}}{2}\cdot\Delta Y\right) \;\; (\text{Ymax} + \Delta Y)\right] \end{array} \right. \\ (\text{range} \;\; \text{Xmin} \;\; \text{Xmax} \;\; \text{Ymax} \;\; \text{TRUCK} \;\; \text{ROAD}) \end{array} \right.$$

EXPAND THIS AREA TO PRINT

Results

Z := WRITE_DATA_TO_EXCEL("1. SUMMARY.xlsm") - output to Excel, to a sheet named DATA.

RF_TN =

"VEH"	"VEH"	"VEH"	"RF"	"RF"	"RF"	"RF"
"VEH"	"mpf"	"γ.LL"	"+M.slab"	"-M.slab"	"V.slab"	"M.wall"
"HL93.INV"	1.20	1.75	1.12	1.51	1.27	9.62
"HL93.OPR"	1.00	1.35	1.74	2.34	1.97	14.96
"FL120"	1.00	1.35	1.11	1.57	1.37	8.97
"SU2"	1.00	1.35	2.69	3.84	3.33	31.68
"SU3"	1.00	1.35	2.03	2.31	2.24	16.32
"SU4"	1.00	1.35	2.35	2.28	2.49	15.39
"C3"	1.00	1.35	2.55	3.16	3.29	19.23
"C4"	1.00	1.35	2.03	2.73	2.33	14.69
"C5"	1.00	1.35	2.17	2.66	2.46	13.46
"ST5"	1.00	1.35	2.41	3.09	2.69	13.46
"EV2"	1.00	1.30	1.83	2.92	2.29	19.45
"EV3"	1.00	1.30	1.42	1.96	1.64	13.00

$$\begin{pmatrix} \gamma_{DCmin} \\ \gamma_{DCmax} \\ \eta\gamma_{EVmin} \\ \eta\gamma_{EVmax} \\ \eta\gamma_{EHmin} \\ \eta\gamma_{EHmax} \end{pmatrix} = \begin{pmatrix} 0.90 \\ 1.25 \\ 0.90 \\ 1.30 \\ 0.90 \\ 1.35 \end{pmatrix}$$

$$L = \begin{pmatrix} 9.63 \\ 9.67 \\ 9.63 \end{pmatrix}$$

RFsGOV =

"VEH"	"Gov.RF"	"Governing.LOCATION"	"Gov.TEST"	"Governing.RF.equation"
"HL93.INV"	1.12	"Top Slab at 1.40, D.fill = 2.00ft."	"M.pos"	"RF = (20.87 - 3.44) / (1.75* 0.1322*1.248*54.0) = 1.12"
"HL93.OPR"	1.74	"Top Slab at 1.40, D.fill = 2.00ft."	"M.pos"	"RF = (20.87 - 3.44) / (1.35* 0.1101*1.248*54.0) = 1.74"
"FL120"	1.11	"Top Slab at 1.40, D.fill = 2.00ft."	"M.pos"	"RF = (20.87 - 3.44) / (1.35* 0.1101*1.248*84.8) = 1.11"
"SU2"	2.69	"Top Slab at 1.40, D.fill = 2.00ft."	"M.pos"	"RF = (20.87 - 3.44) / (1.35* 0.1101*1.248*34.9) = 2.69"
"SU3"	2.03	"Top Slab at 1.40, D.fill = 2.00ft."	"M.pos"	"RF = (20.87 - 3.44) / (1.35* 0.1101*1.248*46.3) = 2.03"
"SU4"	2.28	"Top Slab at 2.00, D.fill = 2.00ft."	"M.neg"	"RF = (-20.87 - -4.31) / (1.35* 0.1101*1.248*-39.2) = 2.28"
"C3"	2.55	"Top Slab at 1.40, D.fill = 2.00ft."	"M.pos"	"RF = (20.87 - 3.44) / (1.35* 0.1101*1.248*36.8) = 2.55"
"C4"	2.03	"Top Slab at 1.40, D.fill = 2.00ft."	"M.pos"	"RF = (20.87 - 3.44) / (1.35* 0.1101*1.248*46.2) = 2.03"
"C5"	2.17	"Top Slab at 1.40, D.fill = 2.00ft."	"M.pos"	"RF = (20.87 - 3.44) / (1.35* 0.1101*1.248*43.2) = 2.17"
"ST5"	2.41	"Top Slab at 1.40, D.fill = 2.00ft."	"M.pos"	"RF = (20.87 - 3.44) / (1.35* 0.1101*1.248*39.0) = 2.41"
"EV2"	1.83	"Top Slab at 1.40, D.fill = 2.00ft."	"M.pos"	"RF = (20.87 - 3.44) / (1.30* 0.1101*1.248*53.3) = 1.83"
"EV3"	1.42	"Top Slab at 1.40, D.fill = 2.00ft."	"M.pos"	"RF = (20.87 - 3.44) / (1.30* 0.1101*1.248*68.9) = 1.42"

CHECK =

"HL93.OPR"	"ft"	"kip"	"start(ft)"	"end(ft)"	"klf"	"M.pos"	"Top Slab at 1.40, D.fill = 2.00ft."
""	0.00	25.00	5.27	8.41	1.48	""	"RF = (20.87 - 3.44) / (1.35* 0.1101*1.248*54.0) = 1.74"
""	4.00	25.00	1.27	4.41	1.48	""	""
""	""	""	""	""	""	""	""
"HL93.OPR"	"ft"	"kip"	"start(ft)"	"end(ft)"	"klf"	"M.neg"	"Top Slab at 2.00, D.fill = 2.00ft."
""	0.00	25.00	5.65	8.78	1.48	""	"RF = (-20.87 - -4.31) / (1.35* 0.1101*1.248*-38.1) = 2.34"
""	4.00	25.00	1.65	4.78	1.48	""	""
""	""	""	""	""	""	""	""
"HL93.OPR"	"ft"	"kip"	"start(ft)"	"end(ft)"	"klf"	"V.neg"	"Top Slab at 1.90, D.fill = 2.00ft."
""	0.00	25.00	5.65	8.78	1.48	""	"RF = (-13.17 - -2.22) / (1.35* 0.1101*1.248*-30.0) = 1.97"
""	4.00	25.00	1.65	4.78	1.48	""	""
""	""	""	""	""	""	""	""
"HL93.OPR"	"ft"	"kip"	"h.eq(ft)"	""	""	"M.wall"	"Ext Wall at 0.50, D.fill = 5.00ft."
""	0.00	8.00	3.08	""	""	""	"RF = [1.75/1.35][1.20/1.00][36/36][(3.24 - -0.11) / (0.35)] = 14.96"
""	14.00	32.00	""	""	""	""	""
""	14.00	32.00	""	""	""	""	""

QUICK CHECK (1 OF 8), POSITIVE MOMENT

$$RF\_Mpos = \left[\text{"HL93.OPR"} \quad \begin{pmatrix} \text{"ft"} & \text{"kip"} \\ 0.00 & 25.00 \\ 4.00 & 25.00 \end{pmatrix} \quad \begin{pmatrix} \text{"start(ft)"} & \text{"end(ft)"} & \text{"klf"} \\ 5.27 & 8.41 & 1.48 \\ 1.27 & 4.41 & 1.48 \end{pmatrix} \quad \text{"M.pos"} \quad \begin{pmatrix} \text{"Top Slab at 1.40, D.fill = 2.00ft."} \\ \text{"RF = (20.87 - 3.44) / (1.35* 0.1101*1.248*54.0) = 1.74"} \end{pmatrix}\right]$$

$\psi c\phi Mn := \psi_c \cdot 0.90 \cdot f_y \cdot A_s \cdot \left(d - \frac{1}{2} \cdot \frac{f_y \cdot A_s}{0.85 \cdot f_c \cdot 12in}\right)$ $\psi c\phi Mn = 20.87 \cdot kip \cdot ft$ - factored capacity; $\psi_c = 1.00$, $d = 7.88 \cdot in$, $A_s = 0.960 \cdot in^2$

$D_{fill} := Dfilleq(RF\_Mpos)$ $D_{fill} = 2.00\,ft$ - depth of fill, roadway surface to top of top slab

$F_e := \min\left(1.15, 1 + 0.20 \cdot \frac{D_{fill}}{\sum L \cdot ft + t_{ExtWall}}\right)$ $F_e = 1.014$ - earth interaction factor

$\gamma\omega DLmax := \gamma_{DCmax} \cdot t_{slab} \cdot 150pcf \cdot ft + F_e \cdot \eta\gamma_{EVmax} \cdot D_{fill} \cdot 120pcf \cdot ft$ $\gamma\omega DLmax = 0.465 \cdot klf$ - maximum factored DL, $\gamma_{DCmax} = 1.25$ $\eta\gamma_{EVmax} = 1.30$

$\gamma DL_{pM} := \int_{0ft}^{\sum L\,ft} linterp(FT, Mpos, x) \cdot \gamma\omega DLmax\, dx$ $\gamma DL_{pM} = 3.44 \cdot kip \cdot ft$ - factored dead load

$DF := LLDFeq(mpf, D_{fill})$ $DF = 0.1101$ - live load distribution factor, axles per strip foot

$IM := IMeq(D_{fill})$ $IM = 1.248$ - dynamic impact factor

$E_{long} := DF_{earth} \cdot D_{fill} + tire_{length}$ $E_{long} = 3.13\,ft$ - longitudinal distribution, where $DF_{earth} = 1.15$ $tire_{length} = 10.00 \cdot in$

$x\omega := submatrix\left(RF\_Mpos_{1,3}, 2, rows\left(RF\_Mpos_{1,3}\right), 1, 3\right)$ $start := x\omega^{\langle 1 \rangle} \cdot ft = \begin{pmatrix} 5.3 \\ 1.3 \end{pmatrix} ft$ $end := x\omega^{\langle 2 \rangle} \cdot ft = \begin{pmatrix} 8.4 \\ 4.4 \end{pmatrix} ft$ $\omega := \frac{x\omega^{\langle 3 \rangle} \cdot klf}{\gamma_{LL} \cdot DF \cdot IM} = \begin{pmatrix} 7.98 \\ 7.98 \end{pmatrix} \cdot klf$

$LL_{pM} := \sum \overrightarrow{\left(\omega \cdot \int_{start}^{end} \max(linterp(FT, Mpos, x), 0 \cdot klf)\, dx\right)}$ $LL_{pM} = 54.0 \cdot kip \cdot ft$ - raw live load (no γ_{LL}, no DF, no IM)

$\gamma LL_{show}\left(\gamma_{LL}, DF, IM, \frac{LL_{pM}}{kip \cdot ft}\right) = \text{"(1.35)(0.1101)(1+25.%)(54.0) = 10.02"}$ $\left(\psi c\phi Mn \quad \gamma DL_{pM} \quad \gamma_{LL} \cdot DF \cdot IM \cdot LL_{pM}\right) = (\,20.87 \quad 3.44 \quad 10.02\,) \cdot kip \cdot ft$

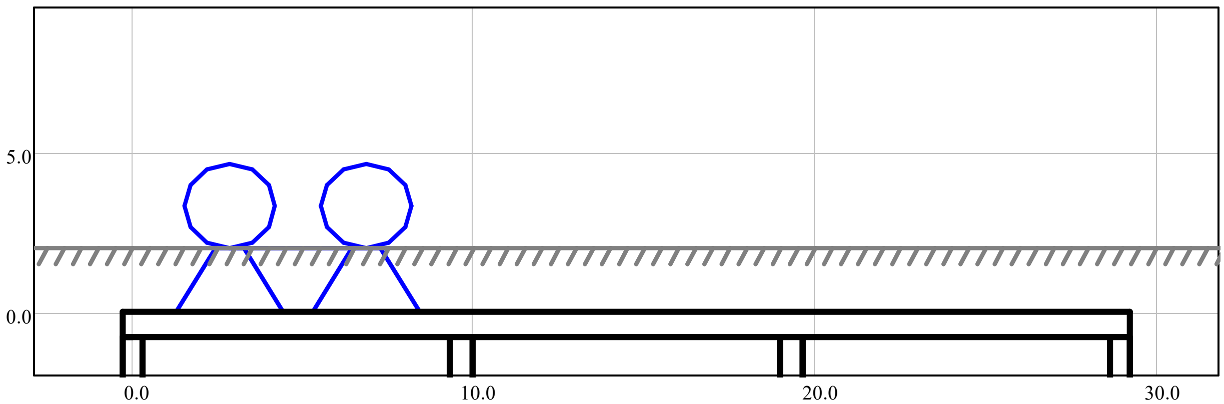
$$\frac{\psi c\phi Mn - \gamma DL_{pM}}{\gamma_{LL} \cdot DF \cdot IM \cdot LL_{pM}} = 1.74$$

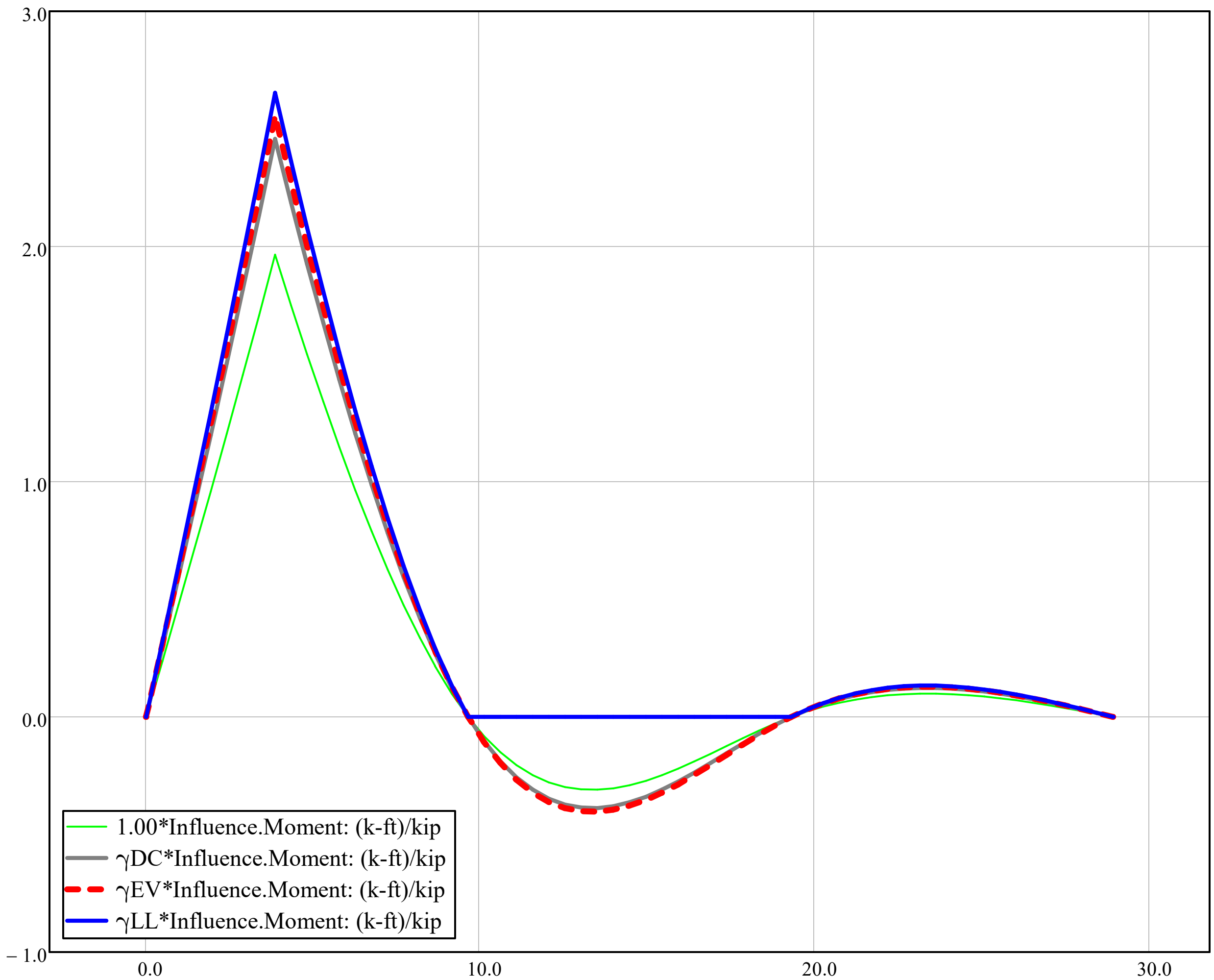
Unfactored ratio LL/DL: $LL := DF \cdot IM \cdot LL_{pM} = 7.42 \cdot kip \cdot ft$ and $DL := \left(DL_{match\left(D_{fill}, D_{fills}\right)1,1}\right)_1 \cdot kip \cdot ft = 2.68\,ft \cdot kip$, so $= \frac{LL}{DL} = 2.77$

Quick Check (2 of 8), Positive Moment Plot

$$RF\_Mpos = \left[\begin{array}{cccc} \text{"HL93.OPR"} & \begin{pmatrix} \text{"ft"} & \text{"kip"} \\ 0.00 & 25.00 \\ 4.00 & 25.00 \end{pmatrix} & \begin{pmatrix} \text{"start(ft)"} & \text{"end(ft)"} & \text{"klf"} \\ 5.27 & 8.41 & 1.48 \\ 1.27 & 4.41 & 1.48 \end{pmatrix} & \text{"M.pos"} & \begin{pmatrix} \text{"Top Slab at 1.40, D.fill = 2.00ft."} \\ \text{"RF = (20.87 - 3.44) / (1.35* 0.1101*1.248*54.0) = 1.74"} \end{pmatrix} \end{array}\right]$$

PLT_truck := PLTTRK(RF_Mpos)





Quick Check (3 of 8), Negative Moment

$$RF\_Mneg = \left[\text{"HL93.OPR"} \quad \begin{pmatrix} \text{"ft"} & \text{"kip"} \\ 0.00 & 25.00 \\ 4.00 & 25.00 \end{pmatrix} \quad \begin{pmatrix} \text{"start(ft)"} & \text{"end(ft)"} & \text{"klf"} \\ 5.65 & 8.78 & 1.48 \\ 1.65 & 4.78 & 1.48 \end{pmatrix} \quad \text{"M.neg"} \quad \begin{pmatrix} \text{"Top Slab at 2.00, D.fill = 2.00ft."} \\ \text{"RF = (-20.87 - -4.31) / (1.35* 0.1101*1.248*-38.1) = 2.34"} \end{pmatrix} \right]$$

$\psi c\phi Mn := -\psi c\phi Mn$

$\psi c\phi Mn = -20.87 \cdot kip \cdot ft$ - factored capacity; $\psi_c = 1.00$, $d = 7.88 \cdot in$, $A_s = 0.960 \cdot in^2$

$D_{fill} := Dfilleq(RF\_Mneg)$

$D_{fill} = 2.00\,ft$ - depth of fill, roadway surface to top of top slab

$$F_e := \min\left(1.15, 1 + 0.20 \cdot \frac{D_{fill}}{\sum L \cdot ft + t_{ExtWall}}\right)$$

$F_e = 1.014$ - earth interaction factor

$\gamma\omega DLmax := \gamma_{DCmax} \cdot t_{slab} \cdot 150pcf \cdot ft + F_e \cdot \eta\gamma_{EVmax} \cdot D_{fill} \cdot 120pcf \cdot ft$

$\gamma\omega DLmax = 0.465 \cdot klf$ - max factored dead load, $\gamma_{DCmax} = 1.25$ $\quad \eta\gamma_{EVmax} = 1.30$

$$\gamma DL_{nM} := \int_{0ft}^{\sum L\,ft} linterp(FT, Mneg, x) \cdot \gamma\omega DLmax\, dx$$

$\gamma DL_{nM} = -4.31 \cdot kip \cdot ft$ - factored dead load

$DF := LLDFeq(mpf, D_{fill})$

$DF = 0.1101$ - live load distribution factor, axles per strip foot

$IM := IMeq(D_{fill})$

$IM = 1.248$ - dynamic impact factor

$E_{long} := DF_{earth} \cdot D_{fill} + tire_{length}$

$E_{long} = 3.13\,ft$ - longitudinal distribution, where $DF_{earth} = 1.15$ $\quad tire_{length} = 10.00 \cdot in$

$x\omega := submatrix(RF\_Mneg_{1,3}, 2, rows(RF\_Mneg_{1,3}), 1, 3)$

$start := x\omega^{\langle 1 \rangle} \cdot ft = \begin{pmatrix} 5.6 \\ 1.6 \end{pmatrix} ft \qquad end := x\omega^{\langle 2 \rangle} \cdot ft = \begin{pmatrix} 8.8 \\ 4.8 \end{pmatrix} ft \qquad \omega := \frac{x\omega^{\langle 3 \rangle} \cdot klf}{\gamma_{LL} \cdot DF \cdot IM} = \begin{pmatrix} 7.98 \\ 7.98 \end{pmatrix} \cdot klf$

$$LL_{nM} := \sum \overrightarrow{\left(\omega \cdot \int_{start}^{end} \min(linterp(FT, Mneg, x), 0 \cdot klf)\, dx\right)}$$

$LL_{nM} = -38.1 \cdot kip \cdot ft$ - raw live load (no γ_{LL}, no DF, no IM)

$\gamma LL_{show}\left(\gamma_{LL}, DF, IM, \frac{LL_{nM}}{kip \cdot ft}\right) = \text{"(1.35)(0.1101)(1+25.\%)(-38.1) = -7.07"}$

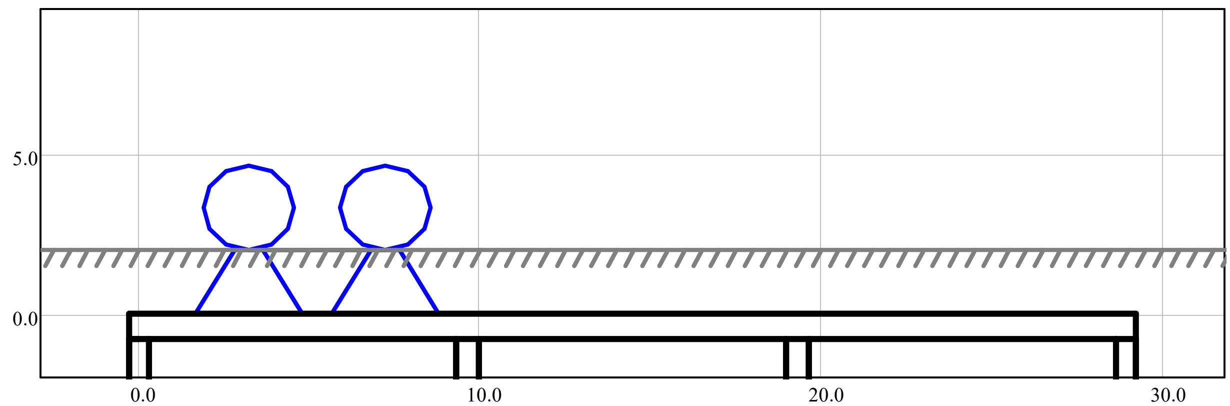
$\left(\psi c\phi Mn \quad \gamma DL_{nM} \quad \gamma_{LL} \cdot DF \cdot IM \cdot LL_{nM}\right) = \left(-20.87 \quad -4.31 \quad -7.07\right) \cdot kip \cdot ft$

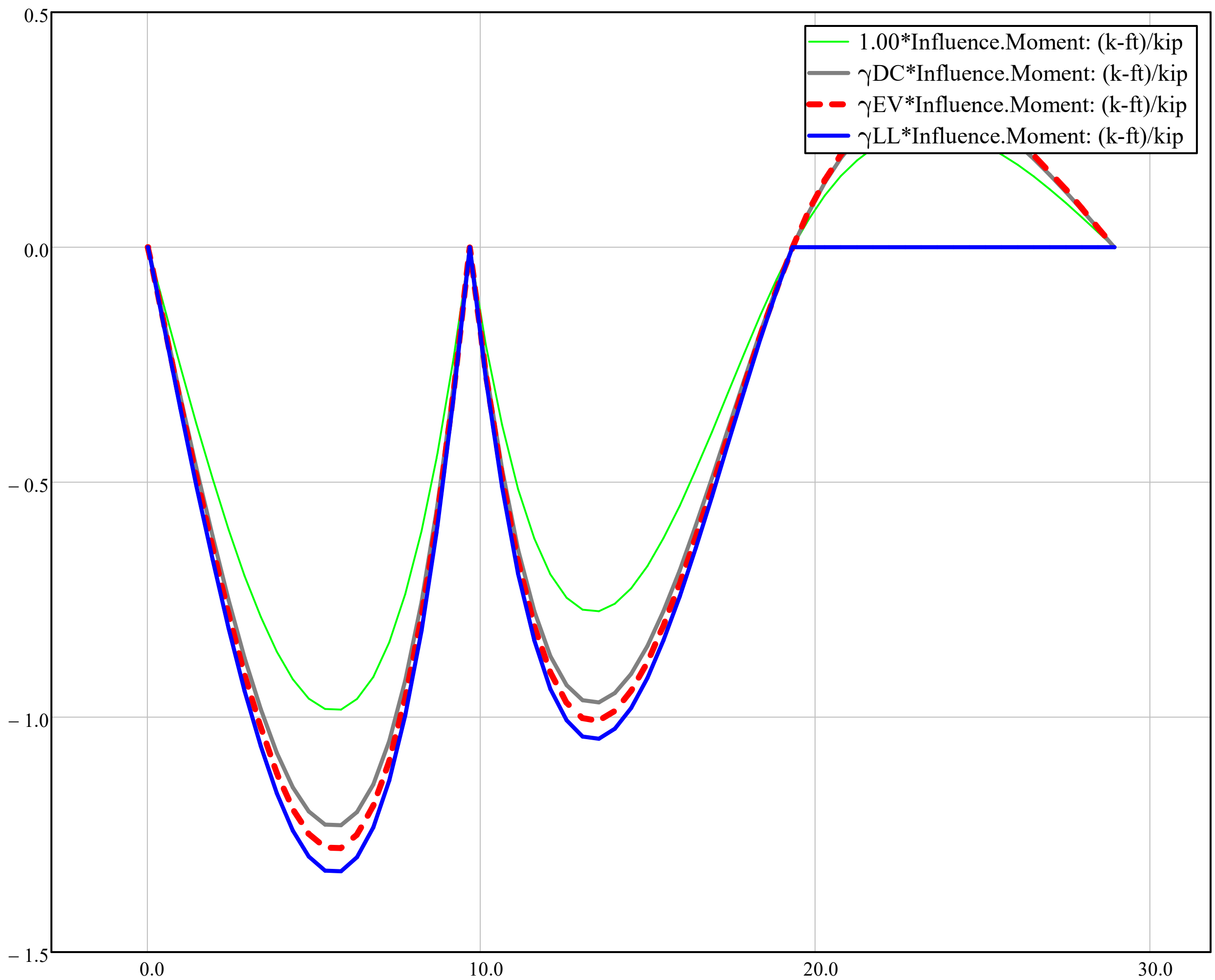
$$\frac{\psi c\phi Mn - \gamma DL_{nM}}{\gamma_{LL} \cdot DF \cdot IM \cdot LL_{nM}} = 2.34$$

Unfactored ratio LL/DL: $LL := DF \cdot IM \cdot LL_{nM} = -5.24 \cdot kip \cdot ft$ and $DL := \left(DL_{match(D_{fill}, D_{fills}), 1, 2}\right)_1 \cdot kip \cdot ft = -3.36\,ft \cdot kip$, so $= \frac{LL}{DL} = 1.56$

$$RF\_Mneg = \left[\text{"HL93.OPR"} \quad \begin{pmatrix} \text{"ft"} & \text{"kip"} \\ 0.00 & 25.00 \\ 4.00 & 25.00 \end{pmatrix} \quad \begin{pmatrix} \text{"start(ft)"} & \text{"end(ft)"} & \text{"klf"} \\ 5.65 & 8.78 & 1.48 \\ 1.65 & 4.78 & 1.48 \end{pmatrix} \quad \text{"M.neg"} \quad \begin{pmatrix} \text{"Top Slab at 2.00, D.fill = 2.00ft."} \\ \text{"RF = (-20.87 - -4.31) / (1.35* 0.1101*1.248*-38.1) = 2.34"} \end{pmatrix} \right]$$

PLT_truck := PLTTRK(RF_Mneg)





Quick Check (5 of 8), Shear

$$RF\_Vneg = \left[\text{"HL93.OPR"} \quad \begin{pmatrix} \text{"ft"} & \text{"kip"} \\ 0.00 & 25.00 \\ 4.00 & 25.00 \end{pmatrix} \quad \begin{pmatrix} \text{"start(ft)"} & \text{"end(ft)"} & \text{"klf"} \\ 5.65 & 8.78 & 1.48 \\ 1.65 & 4.78 & 1.48 \end{pmatrix} \quad \text{"V.neg"} \quad \begin{pmatrix} \text{"Top Slab at 1.90, D.fill = 2.00ft."} \\ \text{"RF = (-13.17 - -2.22) / (1.35* 0.1101*1.248*-30.0) = 1.97"} \end{pmatrix} \right]$$

$D_{fill} := Dfilleq(RF\_Vneg) = 2.00\,ft$ $\quad F_e := \min\left(1.15, 1 + 0.20\cdot\frac{D_{fill}}{\sum L\cdot ft + t_{ExtWall}}\right) = 1.014$ $\quad COINC(Vneg, \gamma MAX, \gamma MIN) := if(Vneg < 0, \gamma MAX, \gamma MIN)$

$$\gamma DLM := \int_0^{\sum L\cdot ft} linterp\left(FT, \gamma_{DCmax}\cdot Mv, x\right)\cdot\left(t_{slab}\cdot 150pcf\cdot ft\right) + linterp\left(FT, \eta\gamma_{EVmax}\cdot Mv, x\right)\cdot\left(F_e\cdot D_{fill}\cdot 120pcf\cdot ft\right) dx \qquad \gamma DLM = -1.88\cdot kip\cdot ft$$

$$\gamma DLV := \int_0^{\sum L\cdot ft} linterp\left(FT, \gamma_{DCmax}\cdot Vneg, x\right)\cdot\left(t_{slab}\cdot 150pcf\cdot ft\right) + linterp\left(FT, \eta\gamma_{EVmax}\cdot Vneg, x\right)\cdot\left(F_e\cdot D_{fill}\cdot 120pcf\cdot ft\right) dx \qquad \gamma DLV = -2.22\cdot kip$$

$\gamma_{LL} = 1.35$ $\quad mpf := mpf\_eq(testVEH) = 1.00$ $\quad DF := LLDFeq\left(mpf, D_{fill}\right) = 0.1101$ $\quad IM := IMeq\left(D_{fill}\right) = 1.248$

$x\omega := submatrix\left(RF\_Vneg_{1,3}, 2, rows\left(RF\_Vneg_{1,3}\right), 1, 3\right)$ $\quad start := x\omega^{\langle 1\rangle}\cdot ft = \begin{pmatrix} 5.65 \\ 1.65 \end{pmatrix} ft$ $\quad end := x\omega^{\langle 2\rangle}\cdot ft = \begin{pmatrix} 8.78 \\ 4.78 \end{pmatrix} ft$ $\quad \omega := \frac{x\omega^{\langle 3\rangle}\cdot klf}{\gamma_{LL}\cdot DF\cdot IMeq\left(D_{fill}\right)} = \begin{pmatrix} 7.98 \\ 7.98 \end{pmatrix}\cdot klf$

$$LL_M := \left| \begin{array}{l} McoincVLL \leftarrow \overrightarrow{COINC(Vneg, Mv, 0\cdot Mv)} \\ \overrightarrow{\sum\left(\omega\cdot\int_{start}^{end} linterp(FT, McoincVLL, x)\, dx\right)} \end{array} \right. = -8.00\cdot kip\cdot ft \qquad \gamma LL_M := \gamma_{LL}\cdot DF\cdot IM\cdot LL_M = -1.48\cdot kip\cdot ft \qquad Mu := \gamma DLM + \gamma LL_M = -3.37\cdot kip\cdot ft$$

$$LL_V := \left| \begin{array}{l} VnegLL \leftarrow \overrightarrow{COINC(Vneg, Vneg, 0\cdot Vneg)} \\ \overrightarrow{\sum\left(\omega\cdot\int_{start}^{end} linterp(FT, VnegLL, x)\, dx\right)} \end{array} \right. = -29.95\cdot kip \qquad \gamma LL_V := \gamma_{LL}\cdot DF\cdot IM\cdot LL_V = -5.56\cdot kip \qquad Vu := \gamma DLV + \gamma LL_V = -7.78\cdot kip$$

$$Vn_{DeepFill} := -\min\left(\max\left(2.5\cdot\sqrt{f_c\cdot psi}, 2.14\cdot\sqrt{f_c\cdot psi} + 4600\cdot psi\,\rho\cdot\min\left(1, \frac{|Vu|\cdot d}{|Mu|}\right)\right), 4.0\cdot\sqrt{f_c\cdot psi}\right)\cdot(ft\cdot d) = -15.49\cdot kip \qquad \rho = 0.0102 \qquad d = 7.88\cdot in$$

$$Vn_{LFR\_ShallowFill} := -\min\left(1.9\cdot\sqrt{\frac{f_c}{psi}} + 2500\rho\cdot\min\left(1, \frac{|Vu|\cdot d}{|Mu|}\right), 3.5\cdot\sqrt{\frac{f_c}{psi}}\right)\cdot ft\cdot d\cdot psi = -12.23\cdot kip \qquad f_c = 3.0\cdot ksi$$

$$Vn_{LRFR\_ShallowFill} := \frac{-4.8}{1 + 750\cdot\frac{\max\left(\frac{A_s\cdot f_y}{Mn}\cdot|Mu|, |Vu|\right) + |Vu|}{29000ksi\cdot A_s}}\cdot\frac{51in}{39in + \max\left(12in, d_v\cdot\frac{1.38in}{0.375in + 0.63in}\right)}\cdot\left[\sqrt{f_c\cdot psi}\cdot ft\cdot\left(d - \frac{1}{2}\cdot\frac{f_y\cdot A_s}{0.85\cdot f_c\cdot 12in}\right)\right] = -16.11\cdot kip$$

$$\psi c\phi Vn := \left| \begin{array}{l} \text{return } \psi_c\cdot 0.85\cdot Vn_{DeepFill} \text{ if } D_{fill} \ge 2ft \\ \text{return } \psi_c\cdot 0.85\cdot Vn_{LFR\_ShallowFill} \text{ if } LRFR = 0 \\ \psi_c\cdot 0.85\cdot Vn_{LRFR\_ShallowFill} \end{array} \right.$$

$\gamma LL_{show}\left(\gamma_{LL}, DF, IM, \frac{LL_V}{kip}\right) = $ "(1.35)(0.1101)(1+25.%)(-30.0) = -5.56"

$\left(\psi c\phi Vn \quad \gamma DLV \quad \gamma_{LL}\cdot DF\cdot IM\cdot LL_V\right) = (-13.17 \quad -2.22 \quad -5.56)\cdot kip$ $\qquad \frac{\psi c\phi Vn - \gamma DLV}{\gamma_{LL}\cdot DF\cdot IM\cdot LL_V} = 1.97$

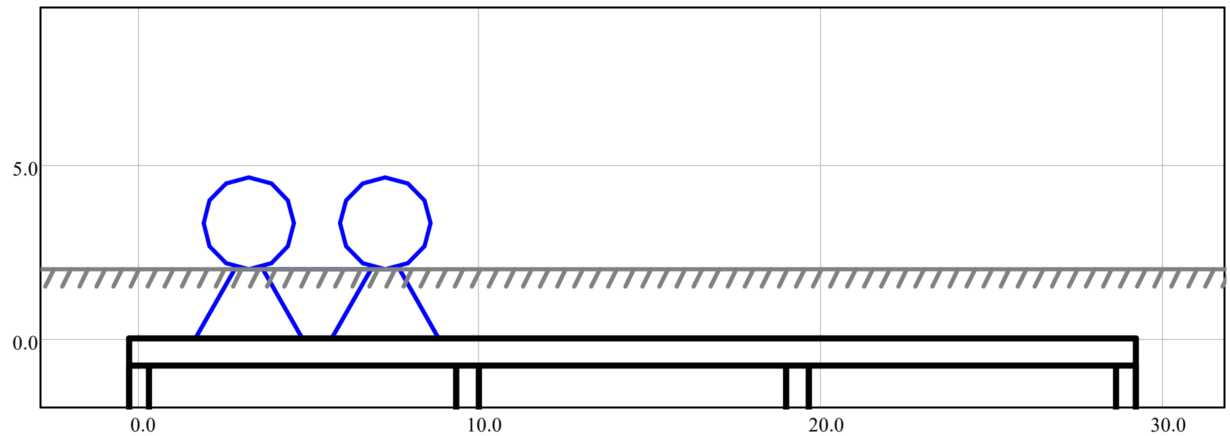
Unfactored ratio LL/DL: $LL := DF\cdot IM\cdot LL_V = -4.12\cdot kip$ and $DL := \left(DL_{match\left(D_{fill}, D_{fills}\right)1,3}\right)_1\cdot kip = -1.73\cdot kip$, so $= \frac{LL}{DL} = 2.37$

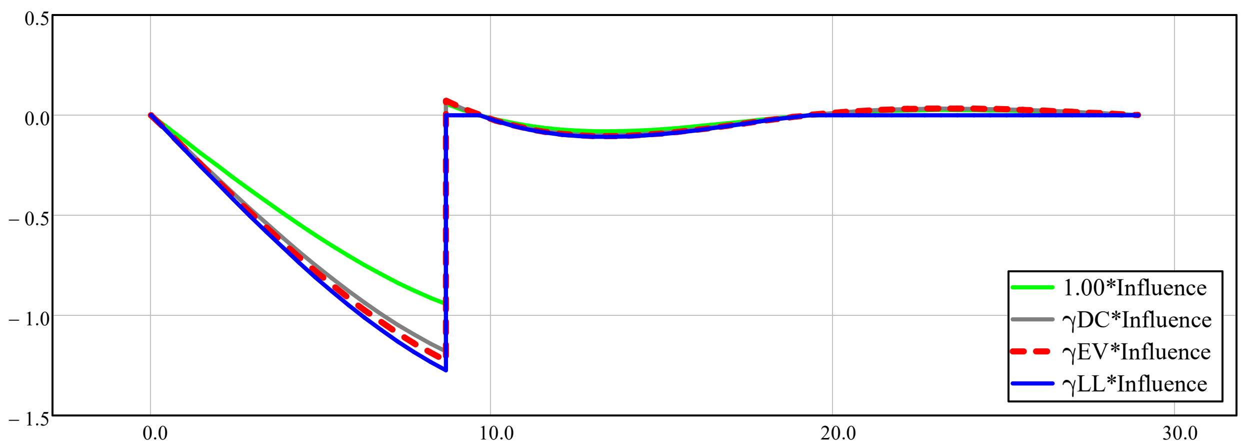
Quick Check (6 of 8), Shear Plots

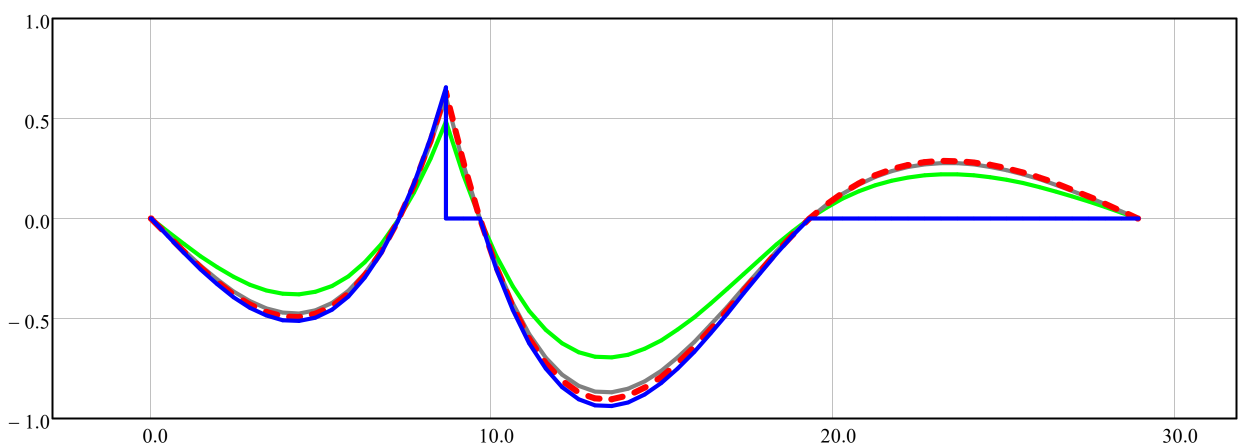
$$\text{RF\_Vneg} = \left[\begin{array}{cccc} \text{"HL93.OPR"} & \begin{pmatrix} \text{"ft"} & \text{"kip"} \\ 0.00 & 25.00 \\ 4.00 & 25.00 \end{pmatrix} & \begin{pmatrix} \text{"start(ft)"} & \text{"end(ft)"} & \text{"klf"} \\ 5.65 & 8.78 & 1.48 \\ 1.65 & 4.78 & 1.48 \end{pmatrix} & \text{"V.neg"} & \begin{pmatrix} \text{"Top Slab at 1.90, D.fill = 2.00ft."} \\ \text{"RF = (-13.17 - -2.22) / (1.35* 0.1101*1.248*-30.0) = 1.97"} \end{pmatrix} \end{array}\right]$$

PLT_truck := PLTTRK(RF_Vneg)

For LRFR, neglect live load not contributing to the force under consideration ($\gamma_{LL.LRFR.min}$ = 0). Meanwhile for LFR, apply all axles.







QUICK CHECK (7 OF 8), EXTERIOR WALL

$$\text{RF\_ExtWall} = \begin{bmatrix} \text{"HL93.OPR"} & \begin{pmatrix} \text{"ft"} & \text{"kip"} \\ 0.00 & 8.00 \\ 14.00 & 32.00 \\ 14.00 & 32.00 \end{pmatrix} & \begin{pmatrix} \text{"h.eq(ft)"} & \text{""} & \text{""} \\ 3.08 & \text{""} & \text{""} \end{pmatrix} & \text{"M.wall"} & \begin{pmatrix} \text{"Ext Wall at 0.50, D.fill = 5.00ft."} \\ \text{"RF = [1.75/1.35][1.20/1.00][36/36][(3.24 - -0.11) / (0.35)] = 14.96"} \end{pmatrix} \end{bmatrix}$$

$D_{fill} := \max(D_{fills}) = 5.00\,ft$ $\quad F_e := \min\left(1.15, 1 + 0.20\cdot\frac{D_{fill}}{\sum L\cdot ft + t_{ExtWall}}\right) = 1.034$ $\quad \gamma_{soil} = 120\cdot pcf$

$INF_\omega := (0.5\ \ 0.375\ \ 0.4\ \ 0.3928)_{1,\min(4,cells)}\cdot L_1\cdot ft = 3.850\cdot\frac{kip}{klf}$ - axial force onto wall from uniform DL on top slab $\quad A_{s.wall} = 0.20\cdot in^2$

$INF_P := (0\ \ 0.096\ \ 0.080)_{1,\min(3,cells)} = 0.080\cdot\frac{kip}{kip}$ - uplifting axial force onto wall from point load on top slab $\quad f_y = 40\cdot ksi$

$\gamma P_{DC} := -\gamma_{DCmin}\cdot(150pcf\cdot t_{slab}\cdot ft)\cdot INF_\omega = -0.41\cdot kip$ $\quad \gamma P_{EV} := -\eta\gamma_{EVmin}\cdot(F_e\cdot\gamma_{soil}\cdot D_{fill}\cdot ft)\cdot INF_\omega = -2.15\cdot kip$ $\quad f_c = 3.0\cdot ksi$

$P_{LL} := 32kip$ $\quad DF := LLDFeq(mpf\_eq(1), D_{fill}) = 0.0860$ $\quad IM := IMeq(D_{fill}) = 1.124$ $\quad \gamma P_{LV} := \gamma_{LL.Inventory}\cdot DF\cdot IM\cdot P_{LL}\cdot INF_P = 0.43\cdot kip$

$F_{s.wall} := A_{s.wall}\cdot f_y = 8.00\cdot kip$ $\quad a := \frac{F_{s.wall} + \gamma P_{DC} + \gamma P_{EV} + \gamma P_{LV}}{0.85\cdot f_c\cdot ft} = 0.19\cdot in$ $\quad M\_arm := \frac{d_{wall}}{2} - \frac{a}{2} = 2.65\cdot in$ - axial force to CG comp.

$h_{abutment} := D_{fill} + 2\cdot t_{slab} + h_{clear} = 9.58\,ft$ $\quad h_{LL.surcharge} := h_{eq.equation}(h_{abutment}) = 3.08\,ft$ - LL surcharge

$x_{origin} := D_{fill} + t_{slab} + h_{clear} - h_{haunch.bot} = 8.46\,ft$ $\quad ix := 1, 2..41$ $\quad x_{ix} := L_{wall}\cdot\frac{ix-1}{40}$

$$\gamma EH := \left| \begin{array}{l} \omega_{EH}(x) \leftarrow \eta\gamma_{EHmax}\cdot\frac{\gamma_{soil}}{2}\cdot(x_{origin} - x)\cdot ft \\ \overrightarrow{\int_0^x \int_0^{L_{wall}} \frac{\omega_{EH}(x)\cdot(L_{wall} - x)}{L_{wall}}\,dx - \int_0^x \omega_{EH}(x)\,dx\,dx} \end{array} \right. \qquad \gamma LS := \left| \begin{array}{l} \omega_{LH}(x) \leftarrow \gamma_{LL.Inventory}\cdot\frac{\gamma_{soil}}{2}\cdot h_{eq}\cdot ft \\ \overrightarrow{\int_0^x \int_0^{L_{wall}} \frac{\omega_{LH}(x)\cdot(L_{wall} - x)}{L_{wall}}\,dx - \int_0^x \omega_{LH}(x)\,dx\,dx} \end{array} \right.$$

$\psi\phi Mn_{wall} := \psi_c\cdot 0.90\cdot A_{s.wall}\cdot f_y\cdot\left(d_{wall} - \frac{a}{2}\right) = 3.24\cdot kip\cdot ft$

$\gamma DC := \gamma P_{DC}\cdot M\_arm = -0.091\cdot kip\cdot ft$ - factored component slab load, axial compression (-) reduces moment

$\gamma EV := \gamma P_{EV}\cdot M\_arm = -0.475\cdot kip\cdot ft$ - factored vertical earth load, axial compression (-) reduces moment

γEH: $\max(\gamma EH) = 0.46\cdot kip\cdot ft$ - maximum factored horizontal earth (+) increases moment

$\gamma LV := \gamma P_{LV}\cdot M\_arm = 0.096\cdot kip\cdot ft$ - factored vertical LL, uplift for multi-cell CBCs, axial tension (+) increases moment

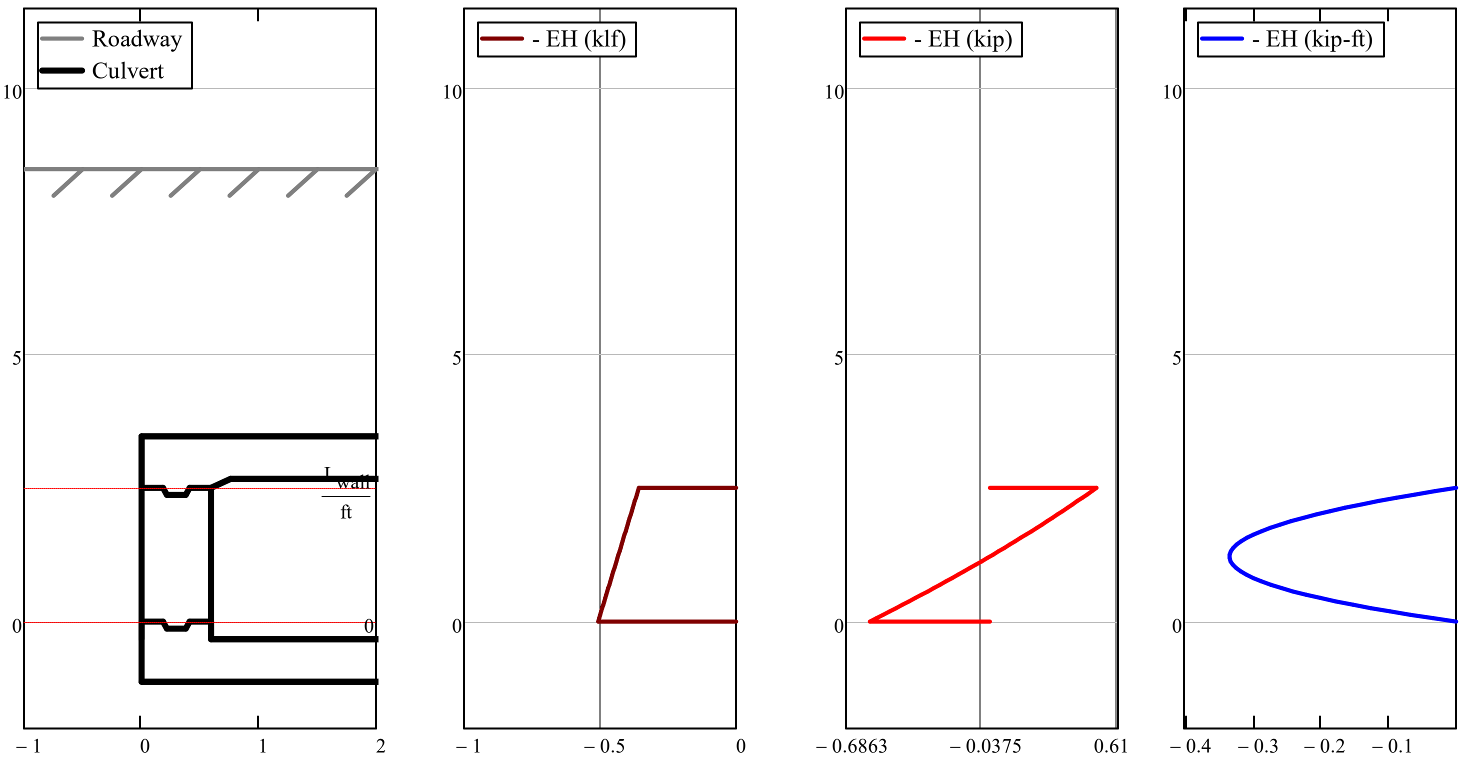
γLS: $\max(\gamma LS) = 0.25\cdot kip\cdot ft$ - maximum factored LL surcharge (+) increases moment

$RF_{Inv} := \frac{\psi\phi Mn_{wall} - (\gamma DC + \gamma EV + \gamma EH)}{\gamma LV + \gamma LS}$ $\quad r := match(\min(RF_{Inv}), RF_{Inv})_1 = 21$ $\quad RF := \frac{\gamma_{LL.Inventory}}{\gamma_{LL}}\cdot\frac{mpf\_eq(1)}{mpf}\cdot\frac{36}{GVW_{testVEH,2}}\cdot RF_{Inv_r}$ $\quad RF = 14.96$

$\left[\psi\phi Mn_{wall}\ \ \left((\gamma DC + \gamma EV + \gamma EH_r)\right)\ \ \max(\gamma LV + \gamma LS_r)\right] = (3.24\ \ -0.11\ \ 0.35)\cdot kip\cdot ft$ $\quad \gamma_{LL} = 1.35$ $\quad mpf\_eq(1) = 1.20$ $\quad mpf = 1.00$ $\quad GVW_{testVEH,2} = 36$

Quick Check (8 of 8), Exterior Wall Plots

HORIZONTAL EARTH LOAD (EH)



HORIZONTAL LIVE LOAD WITH IMPACT (LH)