

Bridge Load Rating

Prepared for

Maine Department of Transportation

Waldo County

Stower Brook Bridge

Bridge No. 5928

Route 1

Over

Stower Brook

WIN: 21831.00P – Revision 2

Date of Rating: March 16, 2020

Prepared By: Ian Riley, PE, SE

Calculations Reviewed By: _____

Adam Pearson, PE, SE, P.Eng

FOSCADH
[faw-skuh] CONSULTING ENGINEERS



American Concrete Industries

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Tel: 207-947-8334

Fax: 207-947-3580

Stamp



Bridge No: <u>5928</u>	Bridge Name: <u>Stower Brook Bridge</u>
Town/City: <u>Waldo County</u>	Owner: <u>MaineDOT</u>
Route Carried: <u>Route 1</u>	Year Built: <u>2020</u>
Crosses: <u>Stower Brook</u>	Year(s) Rebuilt/Rehab: _____

SUMMARY OF BRIDGE RATING

Vehicle Type		Load Rating Factor	RT (TONS)	POSTING LOAD (TONS)
HL-93	INVENTORY	1.23	36.00	
	OPERATING	1.59	36.00	
HL-93 Modified (125%)	INVENTORY	N/A	45.00	
	OPERATING	N/A	45.00	
CONFIGURATION 1		N/A	50.00	
CONFIGURATION 2		N/A	47.00	
CONFIGURATION 3		N/A	44.00	
CONFIGURATION 4		N/A	44.00	
CONFIGURATION 5		N/A	44.00	
CONFIGURATION 6		N/A	37.95	
CONFIGURATION 7		N/A	29.50	
CONFIGURATION 8		N/A	18.70	

Group 1 Posting Analysis (Configuration 1)

Governing Posting: _____

Governing Load Model: _____

Group 2 Posting Analysis (Configurations 2 – 5)

Governing Posting: _____

Governing Load Model: _____

Group 3 Posting Analysis (Configurations 6 – 8)

Governing Posting: _____

Governing Load Model: _____

LRFR Evaluation Factors:

Live Load Distribution Factor:	<u>1.15</u>
Impact Factor:	<u>1.00</u>
Governing Condition Factor, ϕ_c :	<u>1.00</u>
System Factor, ϕ_s :	<u>1.00</u>
ADTT (one-way):	_____

Please check all the boxes that apply:

- ☐ Bridge load rating is governed by substructure rating
- ☐ Exterior girder controls load rating
- ☐ As-built load rating
- ☐ As-inspected load rating
- ☒ As-designed load rating
- ☐ One lane loaded
- ☐ Advanced analysis used
- ☐ Actual measurements taken
- ☐ Finite fatigue life ____ years

BREAKDOWN OF BRIDGE RATING

Town/City: Waldo County

Route Carried: Route 1

Bridge No: 5928

Crosses: Stower Brook

LOAD RATING POINTS OF INTEREST

[illegible]

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Project : Stockton Springs Box Culvert

Task : Clamshell Culvert Design

Job No. : WIN: 21831.00P

Client: American Concrete

File: Mid Seam Clamshell Culvert.etcx

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Spec.: LRFD 8th ed.

Type of Culvert: Precast

Physical Dimensions

Clear Span:	21'-0"
Clear Height:	10'-0"
Top Slab:	1'-6"
Bottom Slab:	1'-6"
Ext. Wall:	1'-0"
Fill Depth:	18.00 ft
Length:	6'-8"
Skew Angle:	51.00 deg
Bottom Slab Support:	Full Slab
Top Haunch, Width:	8"
Top Haunch, Height:	8"
Bottom Haunch, Width:	8"
Bottom Haunch, Height:	8"

Material Properties

Concrete	
Strength, f _c :	5.000 ksi
Density:	0.150 kcf
Elasticity, E _c :	4592 ksi
Type:	Normal wt

Steel	
Yield, f _y :	75 ksi
Allow Stress:	45 ksi
Elasticity, E _s :	29000 ksi

Soil	
Density:	0.125 kcf

Exposure Factor
Class 2 Exposure

Reinforcement Covers

Ext. Cover Top Slab:	2"
Ext. Cover Bottom Slab	2"
Ext. Cover Walls	2"
Int. Cover Walls	1 1/2"
Int. Cover Top Slab	1 1/2"
Int. Cover Bottom Slab	1 1/2"

Loads

Live Load

Vehicle Names:	125% HL-93
	HL-93
Traffic Direction:	Parallel
Eq. Height of Soil:	2.00 ft (Calc'd)
Max No. of Lanes:	1

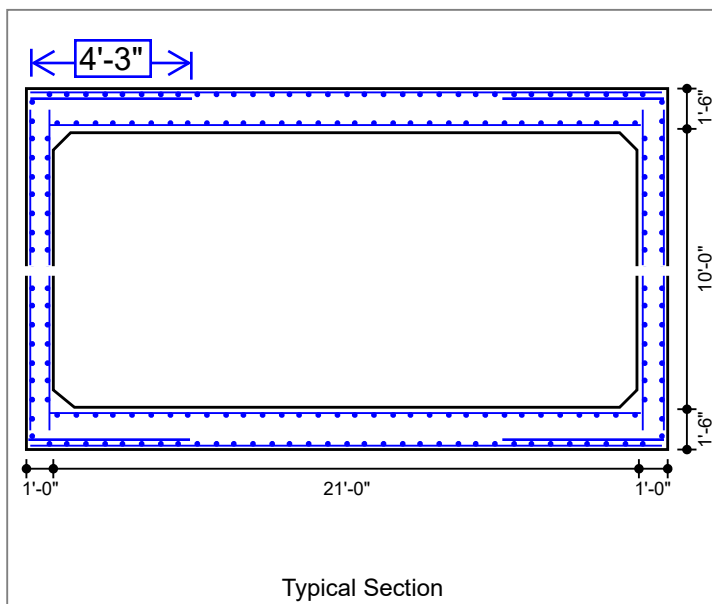
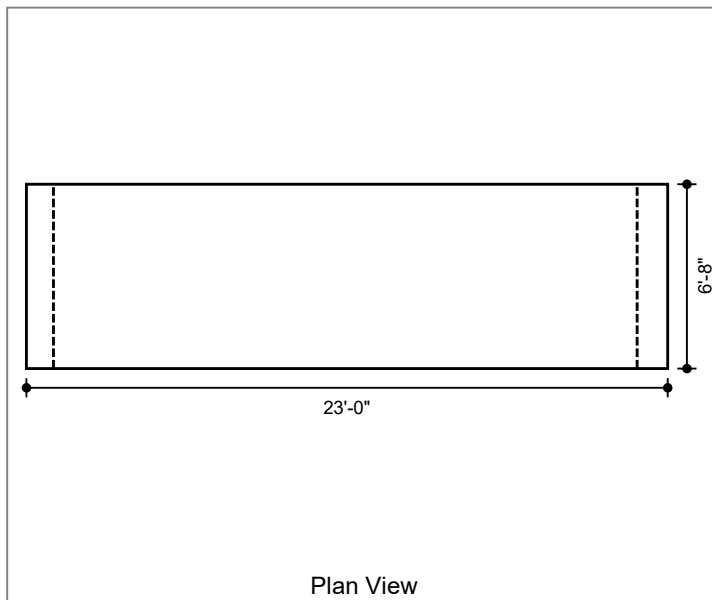
Dead Load

Future Wearing Surface:	0.000 klf
Additional Dead Load:	0.000 klf
Concentrated Loads:	none

Lateral Soil Loads

Eq. Fluid Press. Max:	93.70 pcf
Eq. Fluid Press. Min:	30.00 pcf

Consider Int. Water Press.: no



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Project : Stockton Springs Box Culvert

Task : Clamshell Culvert Design

Client: American Concrete

Job No. : WIN: 21831.00P

File: Mid Seam Clamshell Culvert.etcx

Concrete Summary

Volume of Concrete: 3.329 cy/ft Total Volume of Concrete: 22.195 cy

Reinforcing Steel Bar Schedule (lb)

Location	Mark	Sheets Included	As Provided
Top Slab(Int)	A100	Top	3.240
Bot Slab(Int)	A200	Bot	3.240
Top Slab(Ext)	A300	Top	0.435
Bot Slab(Ext)	A400	Bot	0.435
Corner(Top)	A1	Top	0.480
Corner(Bot)	A2	Bot	0.480
Wall(Int)	B1	L&R	0.300
Wall(Ext)	B2	L&R	0.480
Longit. Top (Int)	C100	Top	0.150
Longit. Bot (Int)	C200	Bot	0.150
Longit. Top (Ext)	C1	Top	0.075
Longit. Bot (Ext)	C1	Bot	0.075
Longit. Wall (Ext)	C1	L&R	0.075
Longit. Wall (Int)	C1	L&R	0.075

Project: Stockton Springs Box Culvert
 Task : Clamshell Culvert Design
 Client : American Concrete
 Job No.: WIN: 21831.00P

CULVERT PROPERTIES

Type of Culvert: Precast Specification : LRFD 8th Edition
 Operating Mode : Analysis

Physical Dimensions

No. of Boxes: 1 Name: Stower Brook Bridge
 Clear Span : 21.0000 ft Fill Depth : 18.00ft
 Clear Height: 10.0000 ft Skew Angle : 51.00 deg
 Length : 6.6667 ft Bottom Slab Support: Full Slab
 Haunches: Top, Length: 8.0000 in Height: 8.0000 in
 Bottom, Length: 8.0000 in Height: 8.0000 in
 Member Thicknesses: Top Slab: 18.0000 in Bot Slab: 18.0000 in
 Ext wall: 12.0000 in
 Wall Joint: 0 in. from culvert center line, deflection not restrained

Material Properties

Concrete, Bot: Strength: 5.000 ksi Density: 0.150 kcf Elasticity: 4592 ksi
 Concrete, Top: Strength: 5.000 ksi Density: 0.150 kcf Elasticity: 4592 ksi
 Concrete, All: Type: Normal weight Density Modification Factor : 1.00
 Fr Factor : 0.24 Gamma1 : 1.20 Gamma3 : 0.94
 Steel: Yield,fy : 75.00 ksi fss Limit : 0.6fy Elasticity,Es: 29000 ksi
 Yield,fyv : 60.00 ksi Diameter : 0.500 in Type : Mesh
 Soil: Density : 0.125 kcf Slope Factor: 1.150 (B1 Installation)
 Poisson's : 0.5
 Fe Factor : 1.150 (Maximum for Compacted Fill)
 Serviceability, Gamma-e: 0.75

Loads

Live Load: Vehicle: (AA) 125% HL-93 - Design Vehicle
 Axle No. weight(k) Dist. From Previous(ft)
 1 10.00 0.00
 2 40.00 14.00
 3 40.00 14.00
 Gage width: 6.00 ft, Tread width: 20.00 in, Tread Length: 10.00 in
 Include Tandem: yes
 Tandem: Axle 1: 25.00 k, Axle 2: 25.00 k, Axle Spacing: 4.00 ft
 Lane Load: 0.64 klf, P-Moment: 0.00 k, P-Shear: 0.00 k
 Combine: Truck Or Tandem Or Lane
 Inventory Rating Load Factor: 1.75 Operating Rating Load Factor: 1.35
 Design Load Combinations: Strength I
 Override MPF: no
 Override DLA: no
 Vehicle: (AB) HL-93 - Design Vehicle
 Axle No. weight(k) Dist. From Previous(ft)
 1 8.00 0.00
 2 32.00 14.00
 3 32.00 14.00
 Gage width: 6.00 ft, Tread width: 20.00 in, Tread Length: 10.00 in
 Include Tandem: yes
 Tandem: Axle 1: 25.00 k, Axle 2: 25.00 k, Axle Spacing: 4.00 ft
 Lane Load: 0.64 klf, P-Moment: 0.00 k, P-Shear: 0.00 k
 Combine: Truck + Lane Or Tandem + Lane
 Inventory Rating Load Factor: 1.75 Operating Rating Load Factor: 1.35
 Design Load Combinations: Strength I
 Override MPF: no
 Override DLA: no
 Include Lane Load : no Max. No. of Lanes: Computed by Program
 Traffic Direction** : Lanes Parallel to Main Reinforcement
 Neglect Live Load for Large Fill Depths: yes
 Apply Surcharge at Fill Depths > 2 ft : yes
 Compute Surcharge Depth: yes
 Dead Load: Future wearing Surface : 0.00 klf Add. Dead Load : 0.00 klf
 Concentrated Loads : none
 Lateral Soil Loads: Max. Equiv. Fluid Press.: 93.70 pcf Min. Equiv. Fluid Press. : 30.00 pcf
 Buoyancy Check : no
 Fluid Pressures : Apply Water Press. : no
 Foundation Model : Rigid

Load and Resistance Factors

Max Min

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Filename: Mid Seam Clamshell Culvert.etcx
DC: 1.250 0.900
DW: 1.500 0.650
EV: 1.300 0.900
EH: 1.350 0.900
WA: 1.000
EQ: 1.000

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LL I : 1.750 LL II : 1.350
Ductility: 1.000 Importance: 1.000 Redundancy, non-earth: 1.000 Redundancy, earth: 1.050
Condition: 1.000 System : 1.000
Phi Shear: 0.900 Phi Moment: 1.000 PM Compression: 0.750 PM Tension : 0.900
Load Factor Multipliers, Design Mode: 1.00 Analysis Mode: 1.00

Reinforcement

Reinforcement Covers : Exterior Interior
Top Slab: 2.0000 in 1.5000 in
Walls : 2.0000 in 1.5000 in
Bot Slab: 2.0000 in 1.5000 in

Assigned reinforcement:			Spacing	# of
Location	Mark	Size	(in)	Layers
Top Slab Inside	A100 (AS2)	D27	2.0000	2
Bottom Slab Inside	A200 (AS3)	D27	2.0000	2
Top Slab Outside	A300 (AS7)	D14.5	4.0000	1
Bottom Slab Outside	A400 (AS8)	D14.5	4.0000	1
Top Corner	A1 (AS1)	D8	2.0000	1
Bottom Corner	A2 (AS1)	D8	2.0000	1
Ext. wall Inside	B1 (AS4)	D10	4.0000	1
Ext. wall Outside	B2 (AS1)	D8	2.0000	1
Longitudinal	C1 (AS6)	D5	8.0000	1
Top Distribution	C100 (AS5)	D5	8.0000	2
Bottom Distribution	C200	D5	8.0000	2

Analysis Options

LL Analysis : Automatically Set Traffic Direction to Account for Skew Effects: yes (**will override previous)
Limit Distribution width to Culvert Length for Fills < 2 ft: no
Limit Distribution width to Culvert Length for Fills > 2 ft: no
Combine Longitudinal Axle Overlaps for Fills > 2 ft: yes
Combine Transverse Axle Overlaps for Fills > 2 ft: no
Axle Placement Increment for Moving Load Analysis: 20
Include Impact on Bottom Slab: yes
Always Distribute Wheel Load: yes
Reinforcement: Always Include Distribution Steel: no
Distribution Slab Provided: no
User Defined Longitudinal Steel: yes
Max. AS used in Vc Calcs: 2.00 in²/ft
Distribute Minimum Reinforcement per Face: yes
Use individual Member Thicknesses for Min Steel: yes
Epoxy coat steel: no
Slenderness : Checked K Factor: 2.00
Analysis Modeling : Use Haunches in the Structural Analysis Model: yes
Crit. Section: Consider Haunches when Selecting Critical Section Locations: yes
Extend Critical Section for Shear Beyond the End of the Haunch: yes
Use Max. Moment with Max. Shear at the Critical Section for Shear: yes
Flexure : Ignore Axial Thrust: no
Use Eq. 12.10.4.2.4a-1: no
Shear : Always Check Iterative Beta Method
Environmental: Apply environmental durability factors: no
Live Load Deflection Criteria: 1/800

ANALYSIS RESULTS
 =====

Top Slab Thickness = 18.00 in
 Bottom Slab Thickness = 18.00 in
 Exterior Wall Thickness = 12.00 in

Modular Ratio (N) = 6.32 Max. Steel Ratio = 0.018
 Design Span = 22.00 ft Design Height = 11.50 ft
 Design Fill Depth = 18.00 ft

Volume of Concrete: 3.329 cy/ft

M dimension = 2.52 ft (method of equivalent capacity)
 = 4.30 ft (method of contraflexure - ASTM)

Reinforcing Steel Schedule

Location	Mat Mark	Sheets Included	Layers	As,prv (in2/ft)
Top Slab (int)	A100 (AS2)	Top	2	3.240
Bot Slab (int)	A200 (AS3)	Bot	2	3.240
Top Slab (ext)	A300 (AS7)	Top	1	0.435
Bot Slab (ext)	A400 (AS8)	Bot	1	0.435
Corner Top-U	A1 (AS1)	Top	1	0.480
Corner Bottom-U	A2 (AS1)	Bot	1	0.480
Ext wall (int)	B1 (AS4)	L&R	1	0.300
Ext wall (ext)	B2 (AS1)	L&R	1	0.480
Top slab (int- 1)	C100 (AS5)	Top	2	0.150
Bot Slab (int- 1)	C200	Bot	2	0.150
Temperature (1)	C1 (AS6)	Top	1	0.075
Temperature (1)	C1 (AS6)	Bot	1	0.075
Temperature (1)	C1 (AS6)	L&R	1	0.075
Temperature (1)	C1 (AS6)	L&R	1	0.075

Note: A denotes flexural steel, B denotes vertical steel, C denotes longitudinal steel

AS Bar Marks

Location	As prv in2/ft
Transverse Side Wall - Outside Face (AS1)	0.480
Transverse Top Slab - Inside Face (AS2)	3.240
Transverse Bottom Slab - Inside Face (AS3)	3.240
Transverse Side Wall - Inside Face (AS4)	0.300
Distribution Top Slab - Inside Face (AS5)	0.150
Distribution Top Slab - Outside Face (AS6)	0.075
Transverse Top Slab - Outside Face (AS7)	0.435
Transverse Bottom Slab - Outside Face (AS8)	0.435

Notes: 1.) Final areas of steel provided must be checked in analysis mode

Sheet Inventory

Interior sheets - 4 sheet layout with no laps

Sheet Loc.	Mat Mark	Zone	Size	Spac. (in)	Length (ft-in)	Area (in2/ft)	H leg (ft-in)	V leg (ft-in)	-Cross wires(L,tot= 6- 7)-	Mat Mark	Size	Spac. (in)	Area (in2/ft)	wgt (lbs)
Top	A100	Base	D27	2.00	21- 9	0.810				C100	D5	8.00	0.038	1710
										(1) sheets, Total weight: 1710				
L&R	B1	Base	D10	4.00	10- 9	0.300		10- 9		C1	D5	8.00	0.075	111
										(1) sheets, Total weight: 111				
Bot	A200	Base	D27	2.00	21- 9	0.810				C200	D5	8.00	0.038	1710
										(1) sheets, Total weight: 1710				

Exterior sheets - 4 sheet layout with laps located in the slab

Sheet Loc.	Mat Mark	Zone	Size	Spac. (in)	Length (ft-in)	Area (in2/ft)	H leg (ft-in)	V leg (ft-in)	-Cross wires(L,tot= 6- 7)-	Mat Mark	Size	Spac. (in)	Area (in2/ft)	wgt (lbs)
Top	A300	Base	D14.5	4.00	22- 8	0.435				C1	D5	8.00	0.075	235
										(1) sheets, Total weight: 235				
L&R	B2	Base	D8	2.00	21- 2	0.480	4- 3	12- 8		C1	D5	8.00	0.075	280
	A1	Base	D8	2.00	21- 2	0.480	4- 3	12- 8		C1	D5	8.00	0.075	-----
	A2	Base	D8	2.00	21- 2	0.480	4- 3	12- 8		C1	D5	8.00	0.075	-----
										(2) sheets, Total weight: 560				

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 Bot A400 Base D14.5 4.00 22- 8 0.435

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 0.075 305
 (1) sheets, Total weight: 305

Weight of Steel: 695 lb/ft

Total weight of all sheets: 4631

Notes:

Epoxy coating may be needed for A1, A300, and some C1 reinforcement, check with governing agency.
 L&R - left and right, TC - top corner, BC - bottom corner, INT - interior walls, EXT - exterior walls
 Nested line wires are additive to the base line wires, but nested cross wires replace base cross wires.
 Adder sheets may require cross wires, check with mesh supplier.

Splice Lengths Table:

Bar Mark	Size	Splice Length (ft-in)
B1	D10	1- 4
C1	D5	1- 4
CE1	D5	0- 0
C100	D5	1- 4
C200	D5	1- 4

Summary of Ratings Table:

Truck	Flexure					Shear				
	Fill	Member	Location	IR	OR	Fill	Member	Location	IR	OR
(AA) 125% HL-	18.00	1	TOP	1.23	1.59	18.00	4	LT	1.31	1.70
(AB) HL-93	18.00	1	TOP	1.23	1.59	18.00	4	LT	1.53	1.98

Critical Sections Summary: Flexure

Member 1: (Exterior wall), Thickness = 12.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings		Truck	Fill Depth (ft)
										IR	OR		
BOT	17.00	-35.76	44.55	28.46	9.84	39.55	0.90	0.48	14.53	8.25	10.69	AB	18.00
MID	69.00	2.67	26.70	18.94	10.32	25.52	0.90	0.30	14.53	50.18	65.04	AA	18.00
MID-	69.00	-4.50	44.96	28.46	9.84	39.68	0.90	0.48	14.53	99.99	99.99	AA	18.00
TOP	17.00	-32.65	26.70	28.46	9.84	33.97	0.90	0.48	14.53	1.23	1.59	AA	18.00

Member 2: (Top Slab), Thickness = 18.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings		Truck	Fill Depth (ft)
										IR	OR		
LT	14.00	-27.67	18.51	46.46	15.84	50.52	0.90	0.48	32.69	3.56	4.61	AA	18.00
MID	132.00	234.06	4.46	271.63	15.80	243.19	0.89	3.24	32.69	1.57	2.04	AA	18.00
RT	14.00	-27.67	18.51	46.46	15.84	50.52	0.90	0.48	32.69	3.56	4.61	AA	18.00

Member 4: (Bottom slab), Thickness = 18.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings		Truck	Fill Depth (ft)
										IR	OR		
LT	14.00	-33.33	22.76	46.46	15.84	52.52	0.90	0.48	32.69	11.22	14.54	AA	18.00
MID	132.00	239.46	6.37	271.63	15.80	242.90	0.89	3.24	32.69	1.23	1.59	AA	18.00
RT	14.00	-33.33	22.76	46.46	15.84	52.52	0.90	0.48	32.69	11.22	14.54	AA	18.00

Critical Sections Summary: Vertical Shear

Member 1: (Exterior wall), Thickness = 12.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn	Beta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings		Truck	Fill Depth (ft)
												IR	OR		
BOT	25.77	13.74	-35.8	44.96	9.49	14.48	2.000	16.09b	0.00	0.00	0.00	2.27	2.94	AA	18.00
MID	69.00	0.33	2.7	26.70	10.10	38.77	5.030	43.08a	0.00	0.00	0.00	62.46	80.97	AA	18.00
MID-	69.00	0.33	-4.5	44.96	9.49	37.27	5.147	41.41a	0.00	0.00	0.00	99.99	99.99	AA	18.00
TOP	25.77	-12.14	-32.7	26.70	9.49	14.48	2.000	16.09b	0.00	0.00	0.00	2.08	2.69	AA	18.00

Member 2: (Top Slab), Thickness = 18.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn	Beta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings		Truck	Fill Depth (ft)
												IR	OR		
LT	31.77	34.11	-27.7	18.51	15.84	36.26	n/a	40.29c	0.00	0.00	0.00	1.96	2.53	AA	18.00
MID	132.00	0.44	234.1	4.46	15.80	36.16	n/a	40.18c	0.00	0.00	0.00	81.70	99.99	AA	18.00
RT	31.77	34.11	-27.7	18.51	15.84	36.26	n/a	40.29c	0.00	0.00	0.00	1.96	2.53	AA	18.00

Member 4: (Bottom slab), Thickness = 18.00 in

Design Corr. Corr. Max. Load Ratings Fill

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Loc	Dist. (in)	Shear (k)	Moment (k-ft)	A. F. (k)	Dv (in)	phi*Vn	Beta	Vc (k)	Vs (k)	Av (in2)	Spac (in)	IR	OR	Truck	Depth (ft)
LT	31.77	35.62	-33.3	22.76	15.84	36.26	n/a	40.29c	0.00	0.00	0.00	1.31	1.70	AA	18.00
MID	132.00	0.00	239.5	6.37	15.80	36.16	n/a	40.18c	0.00	0.00	0.00	NC	NC	AA	18.00
RT	31.77	35.62	-33.3	22.76	15.84	36.26	n/a	40.29c	0.00	0.00	0.00	1.31	1.70	AA	18.00

Vc Calculation By: a - Iterative Beta, b - Constant Beta, c - Box Culvert, d - Standard/Arema

Analysis Results: Fill Depth = 18.00 ft

Load Parameters:

Fe = 1.15 Surcharge Depth : 2.00 ft

Applied Horizontal Loads: (k/ft)

Load Description	Bottom of wall	Top of wall
Horizontal Earth Load	2.834	1.757
Live Load Surcharge	0.187	0.187
Internal Water Pressure	0.000	0.000

Unfactored Moments due to All Loads: (k-ft)

M-PT	Mdc	Mev	Mdw	Meh	Mls	Mwa
Member 1: (Exterior wall)						
Bottom						
1- 0	-0.99	0.00	0.00	-42.32	-1.08	0.00
1- 1	-0.79	0.00	0.00	-26.93	-0.37	0.00
1- 2	-0.60	0.00	0.00	-15.14	0.09	0.00
1- 3	-0.40	0.00	0.00	-6.82	0.31	0.00
1- 4	-0.20	0.00	0.00	-1.81	0.28	0.00
1- 5	0.00	0.00	0.00	0.01	0.00	0.00
1- 6	0.20	0.00	0.00	-1.21	-0.53	0.00
1- 7	0.40	0.00	0.00	-5.31	-1.30	0.00
1- 8	0.60	0.00	0.00	-12.17	-2.32	0.00
1- 9	0.79	0.00	0.00	-21.63	-3.59	0.00
1-10	0.99	0.00	0.00	-33.56	-5.11	0.00
Top						

Member 2: (Top Slab)

Left						
2- 0	0.99	0.00	0.00	-33.58	-5.11	0.00
2- 1	5.93	56.36	0.00	-33.58	-5.11	0.00
2- 2	9.74	100.19	0.00	-33.58	-5.11	0.00
2- 3	12.47	131.50	0.00	-33.58	-5.11	0.00
2- 4	14.10	150.28	0.00	-33.58	-5.11	0.00
2- 5	14.64	156.54	0.00	-33.58	-5.11	0.00
2- 6	14.10	150.28	0.00	-33.58	-5.11	0.00
2- 7	12.47	131.50	0.00	-33.58	-5.11	0.00
2- 8	9.74	100.19	0.00	-33.58	-5.11	0.00
2- 9	5.93	56.36	0.00	-33.58	-5.11	0.00
2-10	0.99	0.00	0.00	-33.58	-5.11	0.00
Right						

Member 4: (Bottom Slab)

Left						
4- 0	-0.99	0.00	0.00	-42.32	-1.08	0.00
4- 1	7.49	56.36	0.00	-42.32	-1.08	0.00
4- 2	14.09	100.19	0.00	-42.32	-1.08	0.00
4- 3	18.80	131.50	0.00	-42.32	-1.08	0.00
4- 4	21.62	150.28	0.00	-42.32	-1.08	0.00
4- 5	22.57	156.54	0.00	-42.32	-1.08	0.00
4- 6	21.62	150.28	0.00	-42.32	-1.08	0.00
4- 7	18.80	131.50	0.00	-42.32	-1.08	0.00
4- 8	14.09	100.19	0.00	-42.32	-1.08	0.00
4- 9	7.49	56.36	0.00	-42.32	-1.08	0.00
4-10	-0.99	0.00	0.00	-42.32	-1.08	0.00
Right						

Unfactored Shears due to All Loads: (k)

M-PT	Vdc	Vev	Vdw	Veh	Vls	Vwa
Member 1: (Exterior wall)						
Bottom						
1- 0	0.17	0.00	0.00	14.99	0.73	0.00
1- 1	0.17	0.00	0.00	11.80	0.51	0.00
1- 2	0.17	0.00	0.00	8.72	0.30	0.00
1- 3	0.17	0.00	0.00	5.77	0.08	0.00
1- 4	0.17	0.00	0.00	2.95	-0.13	0.00
1- 5	0.17	0.00	0.00	0.24	-0.35	0.00
1- 6	0.17	0.00	0.00	-2.33	-0.57	0.00
1- 7	0.17	0.00	0.00	-4.79	-0.78	0.00
1- 8	0.17	0.00	0.00	-7.12	-1.00	0.00
1- 9	0.17	0.00	0.00	-9.32	-1.21	0.00
1-10	0.17	0.00	0.00	-11.41	-1.43	0.00
Top						

Member 2: (Top Slab)

Left						
2- 0	2.56	28.46	0.00	0.00	0.00	0.00
2- 1	1.98	22.77	0.00	0.00	0.00	0.00
2- 2	1.49	17.08	0.00	0.00	0.00	0.00
2- 3	0.99	11.39	0.00	0.00	0.00	0.00
2- 4	0.50	5.69	0.00	0.00	0.00	0.00
2- 5	0.00	0.00	0.00	0.00	0.00	0.00
2- 6	-0.50	-5.69	0.00	0.00	0.00	0.00
2- 7	-0.99	-11.39	0.00	0.00	0.00	0.00
2- 8	-1.49	-17.08	0.00	0.00	0.00	0.00
2- 9	-1.98	-22.77	0.00	0.00	0.00	0.00
2-10	-2.56	-28.46	0.00	0.00	0.00	0.00
Right						

Member 4: (Bottom Slab)

Left						
4- 0	4.28	28.46	0.00	0.00	0.00	0.00
4- 1	3.43	22.77	0.00	0.00	0.00	0.00
4- 2	2.57	17.08	0.00	0.00	0.00	0.00
4- 3	1.71	11.39	0.00	0.00	0.00	0.00
4- 4	0.86	5.69	0.00	0.00	0.00	0.00
4- 5	0.00	0.00	0.00	0.00	0.00	0.00
4- 6	-0.86	-5.69	0.00	0.00	0.00	0.00
4- 7	-1.71	-11.39	0.00	0.00	0.00	0.00
4- 8	-2.57	-17.08	0.00	0.00	0.00	0.00
4- 9	-3.43	-22.77	0.00	0.00	0.00	0.00
4-10	-4.28	-28.46	0.00	0.00	0.00	0.00
Right						

Unfactored Thrusts due to All Loads: (k)

Member	Pdc	Pev	Pdw	Peh	Pls	Pwa
1	2.56	28.46	0.00	0.00	0.00	0.00
2	-0.17	0.00	0.00	11.41	1.43	0.00
4	0.17	0.00	0.00	14.99	0.73	0.00

Analysis Truck, 125% HL-93

Vehicle	Axle No.	Weight (k/ft)	Length (ft)	Dist. From Previous (ft)
Truck	1	0.077	28.37	
	2	0.077	28.37	10.00
Tandem	1	0.066	28.37	
	2	0.066	28.37	10.00

Traffic Direction is Perpendicular to Main Reinforcement
Distribution width : 36.79 ft
Impact Factor : 1.00
Distribution width : 0.00 ft
Lane Load: 0.000 k/ft

Maximum +Moment in Top Slab				
Vehicle	Axle No.	weight (k)	Length (ft)	Dist. From Left End (ft)
Truck	1	0.077	28.37	16.38
	2	0.077	28.37	6.38
Maximum +Moment	:		9.08	k-ft
Corresponding Moment at End	:		-0.06	k-ft
Coincident Bottom Slab Load	:		0.14	k/ft

Maximum +Shear in Top Slab				
Truck	1	0.077	28.37	14.18
	2	0.077	28.37	4.18
Maximum +Shear			:	1.66 k
Corresponding Shear at Mid			:	-0.02 k
Coincident Bottom Slab Load			:	0.14 k/ft

Maximum +Moment in Top Slab			
Tandem	1	0.066	28.37
	2	0.066	28.37
Maximum +Moment	:		7.80 k-ft
Corresponding Moment at End	:		-0.05 k-ft
Coincident Bottom Slab Load	:		0.12 k/ft

Maximum +Shear in Top Slab			
Tandem	1	0.066	28.37
	2	0.066	28.37
Maximum +Shear			1.43 k
Corresponding Shear at Mid			-0.02 k
Coincident Bottom Slab Load			0.12 k/ft

Maximum -Moment in Top Slab				
Vehicle	Axle No.	weight (k)	Length (ft)	Dist. From Left End (ft)
Truck	1	0.077	28.37	16.38
	2	0.077	28.37	6.38
Maximum -Moment			:	-0.06 k-ft
Corresponding Moment at Mid			:	9.08 k-ft
Coincident Bottom Slab Load			:	0.14 k/ft

Maximum -Shear in Top Slab			
Truck	1	0.077	28.37
	2	0.077	28.37
Maximum -Shear			-1.66 k
Corresponding Shear at Mid			0.02 k
Coincident Bottom Slab Load			0.14 k/ft

Maximum -Moment in Top Slab			
Tandem	1	0.066	28.37 16.38
	2	0.066	28.37 6.38
Maximum -Moment	:		-0.05 k-ft
Corresponding Moment at Mid	:		7.80 k-ft
Coincident Bottom Slab Load	:		0.12 k/ft

Maximum -Shear in Top Slab				
Tandem	1	0.066	28.37	17.82
	2	0.066	28.37	7.82
Maximum -Shear	:		-1.43	k
Corresponding Shear at Mid	:		0.02	k
Coincident Bottom Slab Load	:		0.12	k/ft

[illegible][illegible]

Member 4: (Bottom slab)
Left

Eriksson Culvert v4.4.4
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 Filename: Mid Seam Clamshell Culvert.etcx

Sht:____of____
 By:IRR Chk:____
 3/17/2020 7:44:47 PM
 Culvert p. 8 of 13

4- 0	0.06	-0.05	1.55	0.00	0.05	-0.05	1.33	0.00	0.00	0.00	0.00	0.00
4- 1	3.12	0.00	1.24	0.00	2.68	0.00	1.06	0.00	0.00	0.00	0.00	0.00
4- 2	5.50	0.00	0.93	0.00	4.72	0.00	0.80	0.00	0.00	0.00	0.00	0.00
4- 3	7.21	0.00	0.62	0.00	6.18	0.00	0.53	0.00	0.00	0.00	0.00	0.00
4- 4	8.23	0.00	0.31	0.00	7.06	0.00	0.27	0.00	0.00	0.00	0.00	0.00
4- 5	8.57	0.00	0.00	0.00	7.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4- 6	8.23	0.00	0.00	-0.31	7.06	0.00	0.00	-0.27	0.00	0.00	0.00	0.00
4- 7	7.21	0.00	0.00	-0.62	6.18	0.00	0.00	-0.53	0.00	0.00	0.00	0.00
4- 8	5.50	0.00	0.00	-0.93	4.72	0.00	0.00	-0.80	0.00	0.00	0.00	0.00
4- 9	3.12	0.00	0.00	-1.24	2.68	0.00	0.00	-1.06	0.00	0.00	0.00	0.00
4-10	0.06	-0.05	0.00	-1.55	0.05	-0.05	0.00	-1.33	0.00	0.00	0.00	0.00

Right

Note: Unfactored live load results computed at 18.00 ft and 0 ft fill depths, per LRFD 3.6.1.2.6

Serviceability Check: Crack Control

Bar Mark	Location	Moment (k-ft)	Thrust (k)	Fss (ksi)	Spacing (in)	Allow (in)
A1	Top Corner Bar	-22.0	32.68	25.37	2.00	11.43
A2	Bot Corner Bar	-25.2	32.68	33.61	2.00	7.57
A100	Top Slab (int)	169.5	3.47	43.64	2.00	6.80
A200	Bot Slab (int)	174.1	4.96	44.64	2.00	6.57

Strength Limit State at Critical Sections: Flexure

Member 1: (Exterior wall), Thickness = 12.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	OR
BOT	17.00	-35.77	44.96	28.46	9.84	39.68	0.90	0.48	14.53	8.33	10.80
MID	69.00	-2.67	26.70	18.94	10.32	25.52	0.90	0.30	14.53	50.18	65.04
MID-	69.00	-4.50	44.96	28.46	9.84	39.68	0.90	0.48	14.53	99.99	99.99
TOP	17.00	-32.65	26.70	28.46	9.84	33.97	0.90	0.48	14.53	1.23	1.59

Member 2: (Top Slab), Thickness = 18.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	OR
LT	14.00	-27.67	18.51	46.46	15.84	50.52	0.90	0.48	32.69	3.56	4.61
MID	132.00	234.06	4.46	271.63	15.80	243.19	0.89	3.24	32.69	1.57	2.04
RT	14.00	-27.67	18.51	46.46	15.84	50.52	0.90	0.48	32.69	3.56	4.61

Member 4: (Bottom Slab), Thickness = 18.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings IR	OR
LT	14.00	-33.33	22.76	46.46	15.84	52.52	0.90	0.48	32.69	11.22	14.54
MID	132.00	239.46	6.37	271.63	15.80	242.90	0.89	3.24	32.69	1.23	1.59
RT	14.00	-33.33	22.76	46.46	15.84	52.52	0.90	0.48	32.69	11.22	14.54

Notes: Mu - Resisting moment under pure flexure, Ma - Allowable moment under applied axial load

Strength Limit State at Critical Sections: Vertical Shear

Member 1: (Exterior wall), Thickness = 12.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	OR
BOT	25.77	13.74	-35.8	44.96	9.49	14.48	2.000	45.00	16.09b	0.00	0.00	0.00	2.27	2.94
MID	69.00	0.33	2.7	26.70	10.10	38.77	5.030	29.04	43.08a	0.00	0.00	0.00	62.46	80.97
MID-	69.00	0.33	-4.5	44.96	9.49	37.27	5.147	28.55	41.41a	0.00	0.00	0.00	99.99	99.99
TOP	25.77	-12.14	-32.7	26.70	9.49	14.48	2.000	45.00	16.09b	0.00	0.00	0.00	2.08	2.69

Member 2: (Top Slab), Thickness = 18.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	OR
LT	31.77	34.11	-27.7	18.51	15.84	36.26	n/a	n/a	40.29c	0.00	0.00	0.00	1.96	2.53
MID	132.00	0.44	234.1	4.46	15.80	36.16	n/a	n/a	40.18c	0.00	0.00	0.00	81.70	99.99
RT	31.77	34.11	-27.7	18.51	15.84	36.26	n/a	n/a	40.29c	0.00	0.00	0.00	1.96	2.53

Member 4: (Bottom Slab), Thickness = 18.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings IR	OR
LT	31.77	35.62	-33.3	22.76	15.84	36.26	n/a	n/a	40.29c	0.00	0.00	0.00	1.31	1.70
MID	132.00	0.00	239.5	6.37	15.80	36.16	n/a	n/a	40.18c	0.00	0.00	0.00	NC	NC
RT	31.77	35.62	-33.3	22.76	15.84	36.26	n/a	n/a	40.29c	0.00	0.00	0.00	1.31	1.70

Vc Calculation By: a - Iterative Beta, b - Constant Beta, c - Box Culvert, d - Standard/Arema

Load Combination Results at Tenth Points: (k-ft, k)

M-PT	+Moment	-Moment	+Axial	-Axial	+Shear	-Shear
Member 1: (Exterior wall)						
Bottom						
1- 0	-18.560	-63.228	42.049	44.960	22.758	6.370
1- 1	-11.996	-39.891	42.049	44.960	17.848	5.054
1- 2	-6.915	-22.100	42.049	44.960	13.114	3.788
1- 3	-3.261	-9.653	42.049	44.960	8.556	2.574
1- 4	-0.973	-2.346	42.049	44.960	4.173	1.411
1- 5	0.021	0.006	26.699	44.960	0.333	-0.111
1- 6	-0.231	-2.458	42.049	26.699	-0.729	-4.142
1- 7	-1.654	-9.452	42.049	26.699	-1.739	-7.998
1- 8	-4.209	-20.779	42.049	26.699	-2.698	-11.678
1- 9	-7.837	-36.237	42.049	26.699	-3.606	-15.183
1-10	-12.481	-55.624	42.049	26.699	-4.463	-18.512
Top						
Member 2: (Top Slab)						
Left						
2- 0	-12.487	-55.645	4.463	18.512	44.960	26.699
2- 1	76.200	-2.893	4.463	18.512	35.925	21.299
2- 2	145.266	38.108	4.463	18.512	26.997	15.974
2- 3	194.612	67.394	4.463	18.512	18.091	10.650
2- 4	224.208	84.966	4.463	18.512	9.215	5.325
2- 5	234.064	90.823	4.463	18.512	0.443	-0.443
2- 6	224.205	84.966	4.463	18.512	-5.325	-9.215
2- 7	194.604	67.394	4.463	18.512	-10.650	-18.091
2- 8	145.266	38.108	4.463	18.512	-15.974	-26.997
2- 9	76.200	-2.893	4.463	18.512	-21.299	-35.925
2-10	-12.487	-55.645	4.463	18.512	-26.699	-44.960
Right						
Member 4: (Bottom Slab)						
Left						
4- 0	-18.560	-63.228	6.370	22.758	46.913	28.251
4- 1	74.327	-6.848	6.370	22.681	37.530	22.601
4- 2	146.573	36.659	6.370	22.681	28.148	16.951
4- 3	198.177	67.735	6.370	22.681	18.765	11.301
4- 4	229.139	86.381	6.370	22.681	9.383	5.650
4- 5	239.460	92.597	6.370	22.681	0.000	0.000
4- 6	229.139	86.381	6.370	22.681	-5.650	-9.383
4- 7	198.177	67.735	6.370	22.681	-11.301	-18.765
4- 8	146.573	36.659	6.370	22.681	-16.951	-28.148
4- 9	74.327	-6.848	6.370	22.681	-22.601	-37.530
4-10	-18.560	-63.228	6.370	22.758	-28.251	-46.913
Right						

Analysis Truck, HL-93				
Vehicle	Axle No.	weight (k/ft)	Length (ft)	Dist. From Previous (ft)
Truck	1	0.061	28.37	
	2	0.061	28.37	10.00
Tandem	1	0.066	28.37	
	2	0.066	28.37	10.00

Live Load Parameters:

Traffic Direction is Perpendicular to Main Reinforcement
 Distribution width : 36.79 ft
 Impact Factor : 1.00
 Distribution width : 0.00 ft
 Lane Load: 0.000 k/ft

Truck Positions That Cause Maximum Results:

Maximum +Moment in Top Slab					Maximum -Moment in Top Slab				
Vehicle	Axle No.	weight (k)	Length (ft)	Dist. From Left End (ft)	Vehicle	Axle No.	weight (k)	Length (ft)	Dist. From Left End (ft)
Truck	1	0.061	28.37	16.38	Truck	1	0.061	28.37	16.38
	2	0.061	28.37	6.38		2	0.061	28.37	6.38
Maximum +Moment : 7.27 k-ft					Maximum -Moment : -0.05 k-ft				
Corresponding Moment at End : -0.05 k-ft					Corresponding Moment at Mid : 7.27 k-ft				
Coincident Bottom Slab Load : 0.11 k/ft					Coincident Bottom Slab Load : 0.11 k/ft				

Maximum +Shear in Top Slab
 Truck 1 0.061 28.37 14.18
 2 0.061 28.37 4.18
 Maximum +Shear : 1.33 k
 Corresponding Shear at Mid : -0.02 k
 Coincident Bottom Slab Load : 0.11 k/ft

Maximum +Moment in Top Slab
 Tandem 1 0.066 28.37 16.38
 2 0.066 28.37 6.38
 Maximum +Moment : 7.80 k-ft
 Corresponding Moment at End : -0.05 k-ft
 Coincident Bottom Slab Load : 0.12 k/ft

Maximum +Shear in Top Slab
 Tandem 1 0.066 28.37 14.18
 2 0.066 28.37 4.18
 Maximum +Shear : 1.43 k
 Corresponding Shear at Mid : -0.02 k
 Coincident Bottom Slab Load : 0.12 k/ft

Maximum -Shear in Top Slab
 Truck 1 0.061 28.37 17.82
 2 0.061 28.37 7.82
 Maximum -Shear : -1.33 k
 Corresponding Shear at Mid : 0.02 k
 Coincident Bottom Slab Load : 0.11 k/ft

Maximum -Moment in Top Slab
 Tandem 1 0.066 28.37 16.38
 2 0.066 28.37 6.38
 Maximum -Moment : -0.05 k-ft
 Corresponding Moment at Mid : 7.80 k-ft
 Coincident Bottom Slab Load : 0.12 k/ft

Maximum -Shear in Top Slab
 Tandem 1 0.066 28.37 17.82
 2 0.066 28.37 7.82
 Maximum -Shear : -1.43 k
 Corresponding Shear at Mid : 0.02 k
 Coincident Bottom Slab Load : 0.12 k/ft

Unfactored Moments and Shears due to Truck Loads: (k-ft, k)

M-PT	Truck				Tandem				Lane			
	M11+	M11-	V11+	V11-	M11+	M11-	V11+	V11-	M11+	M11-	V11+	V11-
Member 1: (Exterior wall)												
Bottom												
1- 0	0.05	-0.04	0.01	-0.01	0.05	-0.05	0.01	-0.01	0.00	0.00	0.00	0.00
1- 1	0.04	-0.03	0.01	-0.01	0.04	-0.04	0.01	-0.01	0.00	0.00	0.00	0.00
1- 2	0.03	-0.03	0.01	-0.01	0.03	-0.03	0.01	-0.01	0.00	0.00	0.00	0.00
1- 3	0.02	-0.02	0.01	-0.01	0.02	-0.02	0.01	-0.01	0.00	0.00	0.00	0.00
1- 4	0.01	-0.01	0.01	-0.01	0.01	-0.01	0.01	-0.01	0.00	0.00	0.00	0.00
1- 5	0.00	0.00	0.01	-0.01	0.00	0.00	0.01	-0.01	0.00	0.00	0.00	0.00
1- 6	0.01	-0.01	0.01	-0.01	0.01	-0.01	0.01	-0.01	0.00	0.00	0.00	0.00
1- 7	0.02	-0.02	0.01	-0.01	0.02	-0.02	0.01	-0.01	0.00	0.00	0.00	0.00
1- 8	0.03	-0.03	0.01	-0.01	0.03	-0.03	0.01	-0.01	0.00	0.00	0.00	0.00
1- 9	0.03	-0.04	0.01	-0.01	0.04	-0.04	0.01	-0.01	0.00	0.00	0.00	0.00
1-10	0.04	-0.05	0.01	-0.01	0.05	-0.05	0.01	-0.01	0.00	0.00	0.00	0.00
Top												
Member 2: (Top Slab)												
Left												
2- 0	0.04	-0.05	1.33	0.00	0.05	-0.05	1.43	0.00	0.00	0.00	0.00	0.00
2- 1	2.60	0.00	1.08	-0.01	2.79	0.00	1.16	-0.01	0.00	0.00	0.00	0.00
2- 2	4.64	0.00	0.84	-0.03	4.98	0.00	0.90	-0.03	0.00	0.00	0.00	0.00
2- 3	6.11	0.00	0.60	-0.07	6.55	0.00	0.64	-0.08	0.00	0.00	0.00	0.00
2- 4	6.98	0.00	0.38	-0.13	7.49	0.00	0.41	-0.14	0.00	0.00	0.00	0.00
2- 5	7.27	0.00	0.20	-0.20	7.80	0.00	0.22	-0.22	0.00	0.00	0.00	0.00
2- 6	6.98	0.00	0.13	-0.38	7.49	0.00	0.14	-0.41	0.00	0.00	0.00	0.00
2- 7	6.10	0.00	0.07	-0.60	6.55	0.00	0.08	-0.64	0.00	0.00	0.00	0.00
2- 8	4.64	0.00	0.03	-0.84	4.98	0.00	0.03	-0.90	0.00	0.00	0.00	0.00
2- 9	2.60	0.00	0.01	-1.08	2.79	0.00	0.01	-1.16	0.00	0.00	0.00	0.00
2-10	0.04	-0.05	0.00	-1.33	0.05	-0.05	0.00	-1.43	0.00	0.00	0.00	0.00
Right												
Member 4: (Bottom Slab)												
Left												
4- 0	0.05	-0.04	1.24	0.00	0.05	-0.05	1.33	0.00	0.00	0.00	0.00	0.00
4- 1	2.50	0.00	0.99	0.00	2.68	0.00	1.06	0.00	0.00	0.00	0.00	0.00
4- 2	4.40	0.00	0.74	0.00	4.72	0.00	0.80	0.00	0.00	0.00	0.00	0.00
4- 3	5.76	0.00	0.50	0.00	6.18	0.00	0.53	0.00	0.00	0.00	0.00	0.00
4- 4	6.58	0.00	0.25	0.00	7.06	0.00	0.27	0.00	0.00	0.00	0.00	0.00
4- 5	6.85	0.00	0.00	0.00	7.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4- 6	6.58	0.00	0.00	-0.25	7.06	0.00	0.00	-0.27	0.00	0.00	0.00	0.00
4- 7	5.76	0.00	0.00	-0.50	6.18	0.00	0.00	-0.53	0.00	0.00	0.00	0.00
4- 8	4.40	0.00	0.00	-0.74	4.72	0.00	0.00	-0.80	0.00	0.00	0.00	0.00
4- 9	2.50	0.00	0.00	-0.99	2.68	0.00	0.00	-1.06	0.00	0.00	0.00	0.00
4-10	0.05	-0.04	0.00	-1.24	0.05	-0.05	0.00	-1.33	0.00	0.00	0.00	0.00
Right												

Note: Unfactored live load results computed at 18.00 ft and 0 ft fill depths, per LRFD 3.6.1.2.6

Serviceability Check: Crack Control

Bar Mark	Location	Moment (k-ft)	Thrust (k)	Fss (ksi)	Spacing (in)	Allow (in)
A1	Top Corner Bar	-22.0	32.45	25.58	2.00	11.31
A2	Bot Corner Bar	-25.2	32.45	33.83	2.00	7.50
A100	Top Slab (int)	168.2	3.47	43.31	2.00	6.88
A200	Bot Slab (int)	172.9	4.96	44.32	2.00	6.64

Strength Limit State at Critical Sections: Flexure

Member 1: (Exterior wall), Thickness = 12.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings	
										IR	OR
BOT	17.00	-35.76	44.55	28.46	9.84	39.55	0.90	0.48	14.53	8.25	10.69
MID	69.00	-2.67	26.70	18.94	10.32	25.52	0.90	0.30	14.53	50.46	65.42
MID-	69.00	-4.46	44.55	28.46	9.84	39.55	0.90	0.48	14.53	99.99	99.99
TOP	17.00	-32.65	26.70	28.46	9.84	33.97	0.90	0.48	14.53	1.23	1.59

Member 2: (Top Slab), Thickness = 18.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings	
										IR	OR
LT	14.00	-27.67	18.51	46.46	15.84	50.52	0.90	0.48	32.69	3.56	4.61
MID	132.00	231.81	4.47	271.63	15.80	243.19	0.89	3.24	32.69	1.83	2.38
RT	14.00	-27.67	18.51	46.46	15.84	50.52	0.90	0.48	32.69	3.56	4.61

Member 4: (Bottom Slab), Thickness = 18.00 in

Loc	Dist. (in)	Design Moment (k-ft)	Corr. A. F. (k)	Mu (k-ft)	ds (in)	Ma (k-ft)	phi	As (in2)	Mcr (k-ft)	Load Ratings	
										IR	OR
LT	14.00	-33.32	22.76	46.46	15.84	52.52	0.90	0.48	32.69	11.22	14.54
MID	132.00	237.34	6.37	271.63	15.80	242.90	0.89	3.24	32.69	1.43	1.86
RT	14.00	-33.32	22.76	46.46	15.84	52.52	0.90	0.48	32.69	11.22	14.54

Notes: Mu - Resisting moment under pure flexure, Ma - Allowable moment under applied axial load

Strength Limit State at Critical Sections: Vertical Shear

Member 1: (Exterior wall), Thickness = 12.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings	
													IR	OR
BOT	25.77	13.74	-35.8	44.55	9.49	14.48	2.000	45.00	16.09b	0.00	0.00	0.00	2.27	2.95
MID	69.00	0.33	2.7	26.70	10.10	38.77	5.030	29.04	43.08a	0.00	0.00	0.00	62.46	80.97
MID-	69.00	0.33	-4.5	44.55	9.49	37.25	5.145	28.55	41.39a	0.00	0.00	0.00	99.99	99.99
TOP	25.77	-12.14	-32.7	26.70	9.49	14.48	2.000	45.00	16.09b	0.00	0.00	0.00	2.08	2.70

Member 2: (Top Slab), Thickness = 18.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings	
													IR	OR
LT	31.77	33.79	-27.7	18.51	15.84	36.26	n/a	n/a	40.29c	0.00	0.00	0.00	2.28	2.95
MID	132.00	0.38	231.8	4.47	15.80	36.16	n/a	n/a	40.18c	0.00	0.00	0.00	95.19	99.99
RT	31.77	33.79	-27.7	18.51	15.84	36.26	n/a	n/a	40.29c	0.00	0.00	0.00	2.28	2.95

Member 4: (Bottom Slab), Thickness = 18.00 in

Loc	Dist. (in)	Design Shear (k)	Corr. Moment (k-ft)	Corr. A. F. (k)	Dv (in)	phi*Vn (k)	Beta	Theta	Vc (k)	Vs (k)	Av (in2)	Max. Spac (in)	Load Ratings	
													IR	OR
LT	31.77	35.33	-33.3	22.76	15.84	36.26	n/a	n/a	40.29c	0.00	0.00	0.00	1.53	1.98
MID	132.00	0.00	237.3	6.37	15.80	36.16	n/a	n/a	40.18c	0.00	0.00	0.00	NC	NC
RT	31.77	35.33	-33.3	22.76	15.84	36.26	n/a	n/a	40.29c	0.00	0.00	0.00	1.53	1.98

Vc Calculation By: a - Iterative Beta, b - Constant Beta, c - Box Culvert, d - Standard/Arema

M-PT	+Moment	-Moment	+Axial	-Axial	+Shear	-Shear
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Member 1: (Exterior wall)

Bottom						
1- 0	-18.575	-63.214	42.049	44.547	22.756	6.372
1- 1	-12.007	-39.881	42.049	44.547	17.846	5.056
1- 2	-6.924	-22.092	42.049	44.547	13.112	3.791
1- 3	-3.266	-9.647	42.049	44.547	8.554	2.577
1- 4	-0.976	-2.344	42.049	44.547	4.171	1.413
1- 5	0.021	0.006	26.699	44.547	0.330	-0.111
1- 6	-0.234	-2.458	42.049	26.699	-0.731	-4.142
1- 7	-1.659	-9.452	42.049	26.699	-1.741	-7.998
1- 8	-4.217	-20.779	42.049	26.699	-2.700	-11.678
1- 9	-7.848	-36.237	42.049	26.699	-3.609	-15.183
1-10	-12.494	-55.624	42.049	26.699	-4.466	-18.512
Top						

Member 2: (Top Slab)

Left						
2- 0	-12.501	-55.645	4.466	18.512	44.547	26.699
2- 1	75.395	-2.893	4.466	18.512	35.590	21.299
2- 2	143.827	38.108	4.466	18.512	26.737	15.974
2- 3	192.719	67.394	4.466	18.512	17.905	10.650
2- 4	222.044	84.966	4.466	18.512	9.098	5.325
2- 5	231.811	90.823	4.466	18.512	0.380	-0.380
2- 6	222.042	84.966	4.466	18.512	-5.325	-9.098
2- 7	192.712	67.394	4.466	18.512	-10.650	-17.905
2- 8	143.827	38.108	4.466	18.512	-15.974	-26.737
2- 9	75.395	-2.893	4.466	18.512	-21.299	-35.590
2-10	-12.501	-55.645	4.466	18.512	-26.699	-44.547
Right						

Member 4: (Bottom Slab)

Left						
4- 0	-18.575	-63.214	6.372	22.756	46.529	28.251
4- 1	73.553	-6.848	6.372	22.681	37.223	22.601
4- 2	145.208	36.659	6.372	22.681	27.917	16.951
4- 3	196.390	67.735	6.372	22.681	18.612	11.301
4- 4	227.099	86.381	6.372	22.681	9.306	5.650
4- 5	237.335	92.597	6.372	22.681	0.000	0.000
4- 6	227.099	86.381	6.372	22.681	-5.650	-9.306
4- 7	196.390	67.735	6.372	22.681	-11.301	-18.612
4- 8	145.208	36.659	6.372	22.681	-16.951	-27.917
4- 9	73.553	-6.848	6.372	22.681	-22.601	-37.223
4-10	-18.575	-63.214	6.372	22.756	-28.251	-46.529
Right						

CULVERT DESIGN FOR BOX CULVERTS AND 3-SIDED CULVERTS PER AASHTO LRFD BRIDGE DESIGN SPECIFICATION, 8th ED.

CULVERT LOCATION AND PROJECT NUMBER

Culvert description:	Stockton Springs Box Culvert	10.0	X	21.0
Project number:	WIN: 21831.00	(height)	X	(span)
	Hand Verification of Top Slab			
Date of design:	Wednesday, March 4, 2020			
Designed By:	Ian Riley, P.E., S.E.			
	Foscadh Consulting Engineers			

CALCULATION GUIDE AND LAYOUT

These calculations are designed to be both an efficient design tool and an effective guide to the calculations for summary review. The calculations are arranged in 6 sections:

- SECTION 1 - GENERAL DESIGN INFORMATION
- SECTION 2 - FACTORED LOADS PER AASHTO ARTICLE 3.4
- SECTION 3 - DESIGN OF TOP SLAB FOR FLEXURE AND SHEAR
- SECTION 4 - DESIGN OF CULVERT WALLS FOR COMBINED LOADING
- SECTION 5 - DESIGN OF BOTTOM SLAB or DESIGN OF 3-SIDED CULVERT FOOTING
- SECTION 6 - RISA-3D STRUCTURE MODEL REPORT

Section 1 shows the general design inputs and gives a summary of the designed culvert reinforcement sizes and loads. Section 2 shows the calculation of the factored loads to be input into the RISA-3D model. Section 3 shows the design of the top slab of the culvert. Section 4 shows the design of the walls of the culvert. Section 5 shows the design of the bottom slab or the 3-sided culvert footing (depending on which is applicable) with Section 5a showing footing sliding (if applicable). Section 6 shows the output from the RISA-3D model showing load locations and values.

SECTION 1 - GENERAL DESIGN INFORMATION

This culvert design spreadsheet is programmed to simplify design calculations for box and 3-sided culverts designed per AASHTO LRFD bridge specs. It is designed to take dimension and load inputs, which are applied to a RISA-3D.pro model with given load factors, and output design checks for all structural members per AASHTO specifications. It will only design single span culverts with traffic parallel to the span. It is advised that the user of this spreadsheet verify all calculations and inputs for errors or limitations. Design assumptions are also made and must be verified by the user as acceptable for the design. Additional design checks may be required for unusual culvert designs.

SECTION 1 - GENERAL DESIGN INFORMATION

The following cell is an input cell, to be modified by the user: **SAMPLE INPUT CELL** (units)
The following cell is a calculation cell, to be verified by the user: **SAMPLE CALC CELL** (units)

GENERAL INPUTS FOR CULVERT TO BE DESIGNED

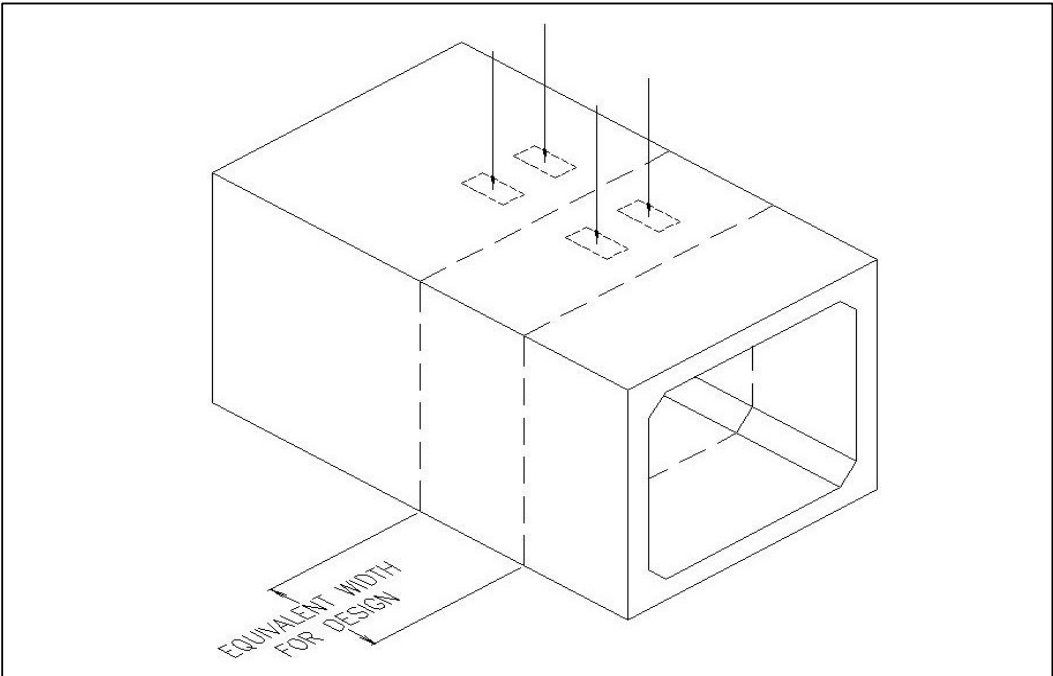
Location and soil information:

<i>ys</i>	Weight of soil:	Use 125 pcf for typical soils if weight is unknown.	125	pcf
			MIN	MAX
<i>Hmin & H</i>	Soil cover over culvert:		18	18 ft
<i>Dw</i>	Depth of water table (typically assume top of culvert):			18 ft
<i>Qserv</i>	Allowable SERVICE soil bearing pressure			2,000 psf
<i>Qstr</i>	Allowable STRENGTH soil bearing pressure			3,000 psf

Designed culvert dimensions:

<i>S</i>	Span (clear span from wall to wall):	21	ft
<i>Hc</i>	Height of culvert walls (clear height, slab to slab):	10	ft
<i>t</i>	Top slab thickness:	18	in
<i>tw</i>	Wall thickness:	12	in
<i>tb or tbf</i>	Bottom slab or 3-sided footing thickness:	18	in
	WARNING! Culvert span is greater than 20 ft and is considered a bridge.		
<i>tf</i>	Corner fillet width/height:	8	in
<i>Ls</i>	Culvert segment length:	6.67	ft
<i>E</i>	Equivalent width of slab for design (calculated):	213.76	in

The culvert will be divided into "equivalent width" sections and designed for those sections. Each section will be calculated as the area of culvert "engaged" per wheel load. See Section 2 for calculations of E.



SECTION 1 - GENERAL DESIGN INFORMATION

Basic culvert component information:

F_c	28 day compressive strength of concrete:	5,000	psi
F_y	Yield strength of reinforcement:	75,000	psi
d_{ci} & d_{co}	Reinforcement cover from edge of bar to face of concrete:	Inside face 1.5	Outside face 2.0
Minimum cover to the outside face is 2 in (if $H < 2$ ft) per Article 12.11.4.4.			in
Minimum cover to the outside face is 2.5 in if top slab is used as a driving surface per Article 5.12.3			2.0 in (top)

DESIGN SUMMARY OF CULVERT

The following is a summary of the dimensions, thickness, and rebar sizes and spacings for the culvert.

Culvert dimensions:

Span:	21 ft	Development length per Article 5.11.2.1 and calculated in each individual section.
Height:	10 ft	
Top slab thickness:	18 in	
Wall thickness:	12 in	
Bottom slab/footing thickness:	18 in	

Top slab reinforcement:

	Trans. Spacing	Long. Spacing	Wire Size/Wire Size	Development Length Required
Interior (positive) rebar:	A-100	Wire Mesh: 2 x 8	D27/D5 WWR	15.92 inches
Exterior (negative) rebar:	A-300	Wire Mesh: 4 x 8	D14.5/D5 WWR	15.79 inches
Longitudinal (T&S) rebar:	C-100	Longitudinal bars of A-100/300	WWR	12 inches

SUMMARY OF CULVERT FACTORED LOADS FROM RISA-3D MODEL

The designed culvert will be modeled in RISA-3D as a concrete frame with fixed member ends and pin-roller connections at the base. The culvert is loaded with the loads calculated in the next section of this spreadsheet. These loads are added into RISA-3D as individual, unfactored loads. We then use three sets of load combinations to calculate the maximum stresses in the culvert.

The first set of load cases are the combined unfactored Service I cases, used to check for deflection limits. The second set of load cases are the combined, factored Strength I cases, used to check for stress limits. The third set of load cases are also combined, factored Strength I cases, but are used to check for maximum shear.

These load cases are analyzed in RISA-3D and the worst case of both the STRENGTH I and SERVICE I AASHTO load cases are chosen for each member. The maximum factored moments of the top and bottom slabs and walls used for design are listed below. For further details please see the RISA-3D output report following these spreadsheets (Section 6).

Top slab factored loads:

Mup (Positive FACTORED moment)	4,465,030	lb-ft
Mun (Negative FACTORED moment)	136,500	lb-ft
Vu (FACTORED shear load in slab)	623,300	lb
Vu (FACTORED shear load in fillet)	623,300	lb

SECTION 1 - GENERAL DESIGN INFORMATION

SECTION 2 - FACTORED LOADS PER AASHTO ARTICLE 3.4

APPLIED LIVE LOADS PER 3.6

LOADS ARE PER EQUIVALENT WIDTH (PER WHEEL) OF CULVERT LENGTH

$$\text{EQUIVALENT WIDTH} = E = 213.8 \text{ in} = 17.813 \text{ ft}$$

Equivalent width is calculated in Section 3 (Top Slab Design)

Live loads applied, see Article 3.6.1.2.2 for HL-93 loading

Axle load (2x wheel load) per Article 3.6.1.2.2	Single axle load:	32.0 kip
Width between wheel loads per Article 3.6.1.2.2	Typical axle width:	6.0 ft
Design tandem load per Article 3.6.1.2.3	Design tandem axle load:	25.0 kip
Tandem spacing per Article 3.6.1.2.3	Design tandem axle spacing:	4.0 ft spacing
Per MDOT Section 534.30:	Configuration 6:	21.3 21.4 21.3 axle load
<i>Include an 11.9 kip axle (9 ft. spacing) for long spans</i>		kip kip kip
<i>Lane load does not apply per Article 3.6.1.3.3</i>		
	Manual live load increase factor (applied to HL-93 loads only):	1.25 (unitless)
Bd = width of excavation trench, for earth vertical load below	Bd:	28 ft

Load factors per Article 3.4.1:

AASHTO Article	Description	Factor
1.3.2.1	η_i - Load modifier for ductility and redundancy	1.05 (unitless)
Table 3.4.1-1	γ_l - Live load (and related loads)	1.75 (unitless)
<i>Fatigue loading is not required per Article 5.5.3.1</i>		
Table 3.4.1-2	γ_p - Components	Max 1.25 Min 0.90 (unitless)
<i>These AASHTO load factors</i>		
<i>should not need to be modified</i>		
<i>unless desired.</i>		
	γ_p - At-rest earth pressure	1.35 0.90 (unitless)
	γ_p - Vertical earth pressure	1.30 0.90 (unitless)
	WA - Water load	1.00 0.00 (unitless)
Table 3.6.1.1.2-1	m - Multiple presence factor	1.2 (unitless)
<i>Culverts shall be designed for single lane loading per Article 12.11.2.1.</i>		
Table 3.6.2.1-1	IM - Impact factor	1.33 (unitless)
3.6.2.2	IMb - Modified impact factor for buried components	1.000 (unitless)
<i>Seismic loads are not required for single span bridges and culverts.</i>		

Factored load and general design methodology per Article 3.4.1

Total factored load shall be: $Q = \sum \eta_i \gamma_i Q_i$

Culverts shall be designed for Strength I loads, checked for deflection and bearing under Service I

SECTION 2 - FACTORED LOADS PER AASHTO ARTICLE 3.4

loads. Fatigue design is not required per Article 5.5.3.1. See Risa-3D output for all designed load cases.

Design limit states: Per Article 1.3.2.1: $Q = \sum \eta_i \gamma_i Q_i \leq \phi R_n = R_r$

Deflection limit per Article 2.5.2.6.2

The deflection limits in AASHTO are meant for above-grade bridges and not **buried culverts**. Therefore we shall limit **buried culvert live load deflections** to **L/360** unless otherwise required. For culverts with **less than 4 feet of cover** deflections shall be limited to **L/800** unless there are pedestrian loads applied directly to the culvert (and then shall be **L/1000**) per Article 2.5.2.6.2.

Live Load Deflection limit: $S / \boxed{360} = \boxed{0.7}$ in
Total Service Deflection limit: $S / \boxed{160} = \boxed{1.575}$ in

Top slab deflections shall be checked per Article 2.5.2.6.2 and also per the Risa-3D model calculated deflections. See section 3 for top slab deflection calculations.

CALCULATE SOIL PRESSURE ON CULVERT

This program will not check for pressure from ice, seismic, swelling & temperature changes as they typically will not control the design. Perform additional calculations if required.

γ_w (density of water, typically 62.4 pcf) $\gamma_w = \boxed{62.4}$ pcf
 K_o (at-rest earth pressure coefficient, use 0.500 if unknown) $K_o = \boxed{0.500}$ (unitless)
 $K_o = 0.5$ is a conservative value. Alternatively, calculate per Article 3.11.5.2.
At-rest earth pressure is assumed over active pressure as culvert is a buried, rigid structure.

Live load surcharge per Article 3.11.6.4

Height of culvert wall (outside face) $H_w = H + (t+tb)/12$ $H_w = \boxed{13.00}$ ft
Earth surcharge due to live load per Table 3.11.6.4-1 $heq = \boxed{2.70}$ ft
Live load can be neglected at depths greater than 8 ft and the span length per Article 3.6.1.2.6.
 $\Delta p = k_o \gamma_s heq$ (eq. 3.11.6.4-1) $\Delta p = \boxed{168.75}$ psf

Vertical earth pressure per Article 12.11.2.2

For embankment installations, per Article 12.11.2.2.1

$B_c = S + 2 \cdot t_w$ Assumed compacted fill, thus $F_e \leq 1.15$. $B_c = \boxed{23.000}$ ft
 $F_e = 1 + 0.20 \cdot (H/B_c) < \text{or} = 1.15$ (eq. 12.11.2.2.1-2) $F_e = \boxed{1.150}$ (unitless)
 $W_E = F_e \gamma_s B_c H$ (eq. 12.11.2.2.1-1) W_e (embankment) = $\boxed{59,513}$ lb/ft

For trench installations, per Article 12.11.2.2.1

$C_d = \frac{1 - e^{-2K_\mu' \frac{H}{B_d}}}{2K_\mu'}$ (see Figure 12.11.2.2.1-3) $C_d = \boxed{0.592005}$ (unitless)
 B_d (width of trench) $B_d = \boxed{28}$ ft
We will assume that $B_d = B_c + 5$ ft (more is conservative)

SECTION 2 - FACTORED LOADS PER AASHTO ARTICLE 3.4

$$F_t = \frac{C_d B_d^2}{H B_c} \leq F_s$$

$K\mu'$ (see Figure 12.11.2.2.1-3) $K\mu' = 0.130$ (unitless)
We will assume that $K\mu' = 0.130$ (conservative)
 (eq. 12.11.2.2.1-4) $F_t = 1.121$ (unitless)

$$W_E = F_t \gamma_s B_c H$$

(eq. 12.11.2.2.1-3) W_E (trench) = 58,016 lb/ft

Selected W_E for design, input W_E if installation conditions are known

As installation conditions are rarely known we will assume the worst case of the above calculated values. If installation conditions are known then one can manually select the W_E from above and input it below.

W_E (maximum of values calculated above) $W_E' = 59,513$ lb/ft width
 W_E is in lb/ft of width of culvert, multiply by E and divide by B_c to get lb/ft along span.

Distributed vertical soil load on top slab of culvert: $W_E = 48,187$ lb/ft

Lateral pressure per Article 3.11

Lateral earth pressure per Article 3.11.5.1

z = depth below surface, take as $H_w + H$ $z = 31.00$ ft
 $p = k \gamma_s z$ with $k = 0.500$ and $\gamma_s = 125$ pcf $p = 1937.5$ psf
 (eq. 3.11.5.1-1) (at bottom of culvert wall)

Hydrostatic pressure per Article 3.11.3

Water table depth (from general inputs) $D_w = 18$ ft
 $P_w = \gamma_w ((H_w + H) - D_w)$ (at bottom of culvert wall) $P_w = 811.2$ psf

In load cases where we combine hydrostatic pressure with the horizontal earth pressure we will reduce the horizontal earth pressure by the density of water. See Figure C3.11.3-1.

Buoyancy is assumed to not control the design and will be checked separately.

UNFACTORED LOADS FOR RISA-3D MODEL

FOLLOWING LOADS WILL BE INPUT INTO THE CULVERT MODEL IN RISA-3D

LOADS ARE PER EQUIVALENT WIDTH (PER WHEEL) OF CULVERT LENGTH

EQUIVALENT WIDTH = 213.76 in = 17.813 ft

DEAD LOADS:

UNFACTORED - SERVICE I

ALL COMPONENTS:

Self-weight of concrete:

Self-weight load

Selfweight

Self-weight load is calculated in Risa-3D or entered in Risa-3D manually.

TOP SLAB:

SECTION 2 - FACTORED LOADS PER AASHTO ARTICLE 3.4

Vertical soil pressure:

Distributed load

$$W_e = 48187.1 \text{ lb/ft}$$

WALLS:

Lateral earth pressure:

Linear varying load

Lateral earth pressure reduced for hydrostatic pressure:

Exterior lateral hydrostatic pressure:

Linear varying load

Interior lateral hydrostatic pressure:

Linear varying load

$$EH/E_{hw} \text{ Ratio: } 0.501$$

	BOTTOM	TOP
EH =	34513.3	20040.0
E _{hw} =	17284.3	10036.0
W _w =	14450.2	0.0
W _w =	11115.5	0
	lb/ft	lb/ft

BOTTOM SLAB:

Vertical water pressure:

Distributed load

$$W_w = 16117.5 \text{ lb/ft}$$

Add internal soil load manually if present.

HL-93 SINGLE AXLE LOAD:

UNFACTORED - SERVICE I

TOP SLAB:

Centered on span

		START	STOP
HL-93 wheel load:	Distributed at	-81.2	345.2
		in	in

$$W_l = 450.3 \text{ lb/ft}$$

WALLS: *Taking 0 at bottom of wall*

		START	STOP
Live load surcharge:	Distributed at	120.0	138.0
		in	in

$$W_l = 3006.0 \text{ lb/ft}$$

HL-93 TANDEM AXLE LOAD:

UNFACTORED - SERVICE I

TOP SLAB:

		START	STOP
First wheel load:	Distributed at	0.0	333.2
Second wheel load:	Distributed at	-45.2	264.0
		in	in

$$W_l = 351.8 \text{ lb/ft}$$

$$W_l = 351.8 \text{ lb/ft}$$

WALLS: *Taking 0 at bottom of wall*

		START	STOP
Live load surcharge:	Distributed at	120.0	138.0
		in	in

$$W_l = 3006.0 \text{ lb/ft}$$

MDOT TRI-AXLE LOAD:

UNFACTORED - SERVICE I

TOP SLAB:

		START	STOP
First wheel load:	Distributed at	0.0	297.2
Second wheel load:	Distributed at	-81.2	345.2
Third wheel load:	Distributed at	-33.2	264.0
		in	in

$$W_l = 299.7 \text{ lb/ft}$$

$$W_l = 301.1 \text{ lb/ft}$$

$$W_l = 299.7 \text{ lb/ft}$$

WALLS: *Taking 0 at bottom of wall*

		START	STOP
Live load surcharge:	Distributed at	120.0	138.0
		in	in

$$W_l = 3006.0 \text{ lb/ft}$$

SECTION 3 - DESIGN OF TOP SLAB FOR FLEXURE AND SHEAR

This program has the following limitations:

1. This program does not compute selfweight, it must be added to the dead loads manually
2. This program limits the beam design to tension-controlled only for maximum ductility
3. This program will not design shear reinforcement (but will indicate if it's required)
4. This program is for precast culverts only, modify minimum reinforcement spacing for cast-in-place.

INPUT TOP SLAB FACTORED LOADS FROM RISA-3D OUTPUT

Input factored loads only! This program will not factor the loads that are input.

Negative moments shall be taken at the intersection of the walls and slabs at haunches per Article 12.11.4.2.

Mup (Positive FACTORED moment)	4,465,030	lb-ft	(See RISA-3D output)
Mun (Negative FACTORED moment)	136,500	lb-ft	(See RISA-3D output)
Vu (FACTORED shear load in slab)	623,300	lb	(See RISA-3D output)
Vu (FACTORED shear load in fillet)	623,300	lb	(See RISA-3D output)
Mp (Positive UNFACTORED moment)	2,976,687	lb-ft	For crack control calculation.
Mnp (Negative UNFACTORED end moment from Mp's load case)	1,488,343	lb-ft	
Mdnpc (Positive dead load moment)	1,488,343	lb-ft	For deflection calculations.
Mnd (Negative UNFACTORED dead load end moment, from Mp's case)	744,172	lb-ft	
Mnp and Mnd are to be taken from the load case of Mp above, for deflection calculations.			
Mn (Negative UNFACTORED moment)	91,000	lb-ft	For crack control calculation.

INPUT REINFORCEMENT SIZES AND SPACING

$$\text{EQUIVALENT WIDTH} = E = 213.8 \text{ in} = 17.813 \text{ ft}$$

Interior (positive moment) circumferential reinforcement:

Area of steel: $\left(\frac{E}{\text{spacing}}\right) 2A_{\text{bar}} =$		57.715	in ² /E	2 WWR sheets assumed
Stress ratio:		91.5%	< 1.0 OK!	Diameter: 0.586 in
Basic development length:		12.00	in	Spacing: 2.0 in
Required length past cutoff =		15.91	in	Max. spacing = 6.91 in
Development length calculated elsewhere				

Exterior (negative moment) circumferential reinforcement:

Area of steel: $\left(\frac{E}{\text{spacing}}\right) A_{\text{bar}} =$		7.749	in ² /E	Diameter: 0.430 in
Stress ratio:		18.2%	< 1.0 OK!	Spacing: 4.0 in
Basic development length:		12.00	in	Max. spacing = 18.00 in
Required length past cutoff =		15.79	in	Development length calculated elsewhere

Temperature and shrinkage (longitudinal) distribution reinforcement:

Max. spacing =		18.00	in	Top	Bottom
Diameter:		0.252		0.252	in

SECTION 3 - DESIGN OF TOP SLAB FOR FLEXURE AND SHEAR

Basic development length: 12.00 in

Development length calculated elsewhere

Spacing: 8.0 8.0 in

Area per foot = 0.075 0.075 in²/ft

Area required = 0.030 0.030 in²/ft

CALCULATE EQUIVALENT STRIP WIDTH PER WHEEL

Tire contact area per Article 3.6.1.2.5:

Tire contact area is entered for HL-93 loads. Modify if other than the typical contact area for the design truck wheel load.

Length: 10 in

Width: 20 in

Load distribution per Article 3.6.1.2.6:

LLDF per Table 3.6.1.2.6a-1:

LLDF = 1.15 unitless

Minimum height of soil cover = H = 18.00 ft

Minimum axle spacing used (conservative):

s_a = axle spacing = 14 ft

$$H_{int-t} = \frac{s_w - \frac{w_t}{12} - \frac{0.06D_i}{12}}{LLDF}$$

s_w = wheel spacing = 6 ft

l_t = tire patch length = 10 in

$$H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF}$$

w_t = tire patch width = 20 in

D_i = clear span of culvert = 252 in

H_{int-t} = wheel interaction depth transverse to culvert span = 2.67 ft

H_{int-p} = wheel interaction depth parallel to culvert span = 11.45 ft

Check if equation 3.6.1.2.6b-2 or 3.6.1.2.6b-3 applies:

Is $H < H_{int-t}$? NO

ww per equation 3.6.1.2.6b-3:

Perp. to span:

Width of distributed load applied to top slab = w_w = 29.63 ft

Check if equation 3.6.1.2.6b-5 or 3.6.1.2.6b-6 applies:

Is $H < H_{int-p}$? NO

lw per equation 3.6.1.2.6b-6:

Along span:

Length of distributed load parallel to span = l_w = 35.53 ft

Equivalent width per Article 4.6.2.10:

This equivalent width is for both wheel loads on an axle.

$E = 96 + 1.44S$ (eq. 4.6.2.10.2-1)

Per axle:

E = 126 in

$E_{span} = L_T + LLDF(H)$

E_{span} = 258.4 in

Check if AASHTO article 3.6.1.2.6 applies:

Is depth of soil cover 2 ft or greater?

YES

If 'yes' then use AASHTO Article 3.6.1.2.6, otherwise use Article 4.6.2.10:

Equivalent width and length for design calculated for single wheel load:

l_w = 426.40 in

w_w = 355.52 in

This design will be based off of a single wheel load, NOT for the full axle load and width.

Check for overlap of loaded widths:

Do wheel loads overlap?

YES

Reduction for overlap, if any: 141.76 in

All structural calculations will use this equivalent width.

Equivalent width to use for design:

E = 213.76 in

SHEAR DESIGN PER ARTICLE 5.7 AND ARTICLE 5.12.7**Vu (FACTORED shear load) at ds away from the end of the fillet**

Vu @ dv from start of fillet (from inputs above)

Vu for slab design = **623.30** kip*We will check the shear at a distance dv away from the start of the fillet.***Design for shear at ds away from the end of the fillet**

Use the lesser of:

$$V_n = V_c + V_s + V_p \quad (\text{eq. 5.7.3.3-1})$$

or

$$V_n = 0.25f'_c b_v d_v + V_p \quad (\text{eq. 5.7.3.3-2})$$

*Use the procedure for shear in slabs of box culverts per Article 5.12.7.3.**Otherwise use the simplified procedure of Article 5.6.7.1:*

Is the culvert soil cover less than 24 in. per Article 5.12.7.3:

NO*Per Article 5.7.2.8:*

b = bv = E = **213.76** in

No transverse reinforcement is needed per Article 5.7.2.3.

SQRT(F'c) = **2.236** ksi

Per Article 5.12.7.3:

As = **57.715** in²

$$V_c = \left(0.0676\sqrt{f'_c} + 4.6 \frac{A_s V_u d_e}{b d_e M_u} \right) b d_e \quad (\text{eq. 5.12.7.3-1})$$

Mu (below) = **53580.4** kip-in

$$d_e = \frac{A_s f_y d_s}{A_s f_y} \quad (\text{eq. 5.7.2.8-2})$$

de = **15.91** in

$$d_v = \frac{M_n}{A_y f_y} \geq \text{MAX}(0.9d_e \text{ or } 0.72h) \quad (\text{eq. C5.7.2.8-1})$$

(Vu*de)/Mu not greater than 1.0

dv = **14.32** in

(Vu*de)/Mu = **2.222** unitless

Vc = **779.70** kip

Therefore, take (Vu*de)/Mu = 1.0*For single cell box culvert slabs cast monolithic with walls per 5.12.7.3:*

Vc need not be less than 0.0948*SQRT(f'c)*bv*de

Vc min = **721.11** kip

Vc not to exceed 0.126*SQRT(f'c)*bv*de

Vc max = **958.43** kip

Simplified procedure per Article 5.6.7.1 (not used if soil cover is 2 ft or more):

Check that thickness < 16 in for simplified design:

NO**OK! Box culvert slab shear design per 5.12.7.3 applies, ignore simplified shear.***Per Article 5.6.7.1:*

β = **2.0** (unitless)

θ = **45** degrees

$$V_c = 0.0316\beta\sqrt{f'_c} b_v d_v \quad (\text{eq. 5.7.3.3-3})$$

Vc = **432.66** kip

Vc to be used = **779.70** kip

Vn (from the lesser of eq. 5.7.3.3-1 and 5.7.3.3-2)

Vn = **779.70** kip

φ = **0.9** (unitless) *Per Table 12.5.5-1*

Vr = φVn = **701.73** kip

OK! One-way shear strength in slab is sufficient.**Vu (FACTORED shear load) though fillet at distance ds from wall face**

Vu @ dv from face of wall (from inputs above)

Vu for fillet design = **623.30** kip*We will check the shear at a distance dv away from the face of the support.***Design for shear through corner fillets**

SECTION 3 - DESIGN OF TOP SLAB FOR FLEXURE AND SHEAR

No transverse reinforcement is needed per Article 5.7.2.3.

$$d_v = \left\{ \begin{array}{l} (d_s + t_{haunch}) - \left(\frac{C}{2}\right) \geq \\ MAX[0.9(d_e + t_{haunch}) \\ or (0.72t + t_{haunch})] \end{array} \right\}$$

Per Article 5.6.7.1:

$$V_c = 0.0316\beta\sqrt{f'_c}b_vd_v \quad (eq. 5.7.3.3-3)$$

Vn (from the lesser of eq. 5.7.3.3-1 and 5.7.3.3-2)

$$\phi = 0.9 \text{ (unitless) } \text{ Per Table 12.5.5-1}$$

OK! One-way shear strength in fillet is sufficient.

$$\begin{array}{ll} b_v = & 213.76 \text{ in} \\ ds \text{ (below)} = & 15.914 \text{ in} \\ dv = & 21.523 \text{ in} \\ \beta = & 2.0 \text{ (unitless)} \\ \theta = & 45 \text{ degrees} \end{array}$$

$$\begin{array}{ll} V_c = & 721.11 \text{ kip} \\ V_n = & 721.11 \text{ kip} \\ V_r = \phi V_n = & 649.00 \text{ kip} \end{array}$$

FLEXURAL DESIGN PER ARTICLE 5.6

Mup (FACTORED positive moment)

Mup (from inputs above)

$$M_{up} = 4,465,030 \text{ lb-ft}$$

Mun (FACTORED negative moment)

Mun (from inputs above)

$$M_{un} = 136,500 \text{ lb-ft}$$

β_1 (Ratio of depth of the rectangular stress block) per Article 5.6.2.2

f'_c (ksi)	β_1
$2.2 \leq f'_c \leq 4.0$	0.85
$4.0 < f'_c < 8.0$	$0.85 - 0.05(f'_c - 4)$
$8.0 \leq f'_c$	0.65

$$\beta_1 = 0.800 \text{ (unitless)}$$

Compute the POSITIVE moment capacity for the selected reinforcement per Article 5.6.3.2

Take compression force to equal tension force.

$$C = (0.85 \cdot f'_c) \cdot b \cdot a \quad \text{and} \quad T = A_s \cdot f_s$$

C = T

Therefore:

$$a = \frac{A_s f_s}{0.85 f'_c b}$$

$$\frac{c}{d_s} \leq \frac{0.003}{0.003 + \epsilon_{cl}} \quad eq. 5.6.2.1-1$$

$$\epsilon_{cl} = 0.003 \text{ in/in}$$

$$0.003 / (0.003 + \epsilon_{cl}) = 0.522 \text{ in/in}$$

Assume $f_s = f_y$

$$a = 4.764706 \text{ in}$$

with

$$f_s = f_y = 75,000 \text{ psi}$$

Per Article 5.6.3.2.2:

$$a = \beta_1 c$$

Therefore: $c = a / \beta_1$

$$c = 5.955882 \text{ in}$$

SECTION 3 - DESIGN OF TOP SLAB FOR FLEXURE AND SHEAR

$$d_s = 15.91 \text{ in (extreme compression fiber to centroid of steel)}$$

$$c/d_s = 0.37 \text{ (unitless)}$$

OK! $c/d_s < \text{or} = \text{eq. 5.6.2.1-1}$, use F_y for F_s .

Per Article 5.6.3.2.3 we can use eq. 5.6.3.2.1-1 and eq. 5.6.3.2.2-1 with $b_w = b$.

We will ignore the negative moment reinforcement and the compressive forces (conservative).

$$M_n = A_s f_s \left(d_s - \frac{a}{2} \right) \quad (\text{eq. 5.6.3.2.1-1}) \quad M_n = 4,881,136 \text{ ft-lb}$$

$$M_r = \phi M_n \quad (\text{eq. 5.6.3.2.1-1}) \quad \text{Per Table 12.5.5-1:} \quad \phi = 1.00 \text{ (unitless)}$$

We will assume that the section is tension controlled. This assumption is to have an efficient and ductile section and will be checked below.

$$M_r = 4,881,136 \text{ ft-lb} \quad \text{OK! Positive moment capacity is sufficient.}$$

Check for tension controlled section (assumed above)

$$a = \beta_1 c \quad c = 5.955882 \quad \epsilon_c = 0.003 \quad \text{Per Article 5.6.2.1}$$

$$\epsilon_t = \frac{d_s - c}{c} \epsilon_c \quad d_s \text{ (calculated above)} = 15.91 \text{ in} \quad \epsilon_t = 0.005 \text{ (unitless)}$$

$$f_y = 75 \text{ ksi}$$

$$\epsilon_{ti} = 0.005 \text{ (unitless)}$$

Assumption OK if $\epsilon_t \geq \epsilon_{ti}$ *etl per Table C5.6.2.1-1*

OK! Section is tension controlled.

Check minimum required reinforcement per Article 5.6.3.3

$$M_{cr} = \gamma_3 \left[(\gamma_1 f_r + \gamma_2 f_{cpe}) S_c - M_{dnc} \left(\frac{S_c}{S_{nc}} - 1 \right) \right] \quad (\text{eq. 5.6.3.3-1})$$

fcpe = comp. stress due to prestress	No prestress.	fcpe = 0 ksi
fr = modulus of rupture	Per Article 5.4.2.6:	fr = 0.24*SQRT(Fc) = 0.54 ksi
Snc = section modulus for non-composit section		Snc = 11,543 in^3
Sc = Snc per article 5.6.3.3 for non-composite flexure		Sc = Snc = 11,543 in^3
Mdnc = total unfactored dead load moment, from above		Mdnc = N/A kip-in
γ1 = flexural cracking variability factor	For precast sections	γ1 = 1.20 (unitless)
γ2 = prestress variability factor	For bonded tendons	γ2 = N/A (unitless)
γ3 = Fy/Fu of reinforcement	For A1064, grade 70	γ3 = 0.938 (unitless)

$$M_r \geq \text{MIN}(M_{cr}, 1.33 * M_{up}) \quad M_{cr} = 580,748 \text{ lb-ft}$$

$$1.33 * M_{up} = 5,938,490 \text{ lb-ft}$$

$$M_r = 4,881,136 \text{ lb-ft} \quad A_{smin} = 7.630 \text{ in}^2 \text{ (min. area of steel)}$$

OK! Reinforcement area more than minimum required.

Check minimum required reinforcement per Article 12.11.5.3.2

$$\text{Min. reinforcement} = 0.002 \times \text{gross concrete area} \quad A_g = 216 \text{ in}^2/\text{ft}$$

SECTION 3 - DESIGN OF TOP SLAB FOR FLEXURE AND SHEAR

Min. reinforcement area = **0.432** in²/ft
 Reinforcement area provided = **3.24** in²/ft

OK! Reinforcement area more than minimum required.

Check minimum reinforcement spacing per Article 5.10.3.1

Diameter of selected bar d_{bar} = **0.586** in
 Selected spacing of reinforcement Spacing = **2.00** in
 Maximum size of course aggregate Max size of aggregate = **0.75** in
 Min. spacing (per Article 5.10.3.1.2) Min. spacing = **1.59** in

This is for precast sections only, modify if using cast-in-place.

OK! Reinforcement spacing > min. bar spacing.

Check maximum reinforcement spacing per Article 5.10.3.2 and Article 5.6.7

Selected spacing of bars Spacing = **2.00** in
 Max. spacing (per Article 5.10.3.2) Max. spacing = **18.00** in

Also, check maximum spacing for crack control per Article 5.6.7:

$$\beta_s = 1 + \frac{d_c}{0.7(h - d_c)} \quad d_c \text{ need not be taken } > 2 \text{ in.} + d_b/2$$

d_c = **1.793** in
 β_s = **1.1580** (unitless)

Calculate f_{ss}: *Assume j = 0.9*

$$f_{ss} = \frac{M}{\phi A_s j d_s}$$

f_{ss} = **43.2** ksi

Max. spacing (per Article 5.6.7)

$$s \leq \frac{700\gamma_e}{\beta_s f_{ss}} - 2d_c \quad \gamma_e = 0.75 \text{ for Class 2 exposure (corrosion)} \quad \gamma_e = **0.75** \text{ (unitless)}$$

Max. spacing for crack control = **6.91** in

max. spacing, s, need not be taken < 5 in.

OK! Bar spacing < max. bar spacing.

Max. spacing = **6.91** in

POSITIVE flexural reinforcement development length per Article 5.10.8.2.1

Basic tension development length per Article 5.10.8.2.1a:

development length calculated elsewhere

From inputs above:

Minimum cutoff length of 12 inches, 15d_{bar}, (1/20)span, and d_s

Required reinforcement length past theoretical cutoff:

d_{bar} = **0.586** in
 A_{bar} = **0.27** in²
 l_d = **12.00** in
 l_{cutoff} = **15.91** in

Compute the NEGATIVE moment capacity for the selected reinforcement per Article 5.6.3.2

Take compression force to equal tension force.

$$C = (0.85 \cdot f'_c) \cdot b \cdot a \quad \text{and} \quad T = A_s \cdot F_s$$

C = T

Therefore:

$$a = \frac{A_s f_s}{0.85 f'_c b}$$

SECTION 3 - DESIGN OF TOP SLAB FOR FLEXURE AND SHEAR

$$\frac{c}{d_s} \leq \frac{0.003}{0.003 + \epsilon_{cl}} \quad \text{eq. 5.6.2.1-1}$$

Assume $f_s = f_y$

$a = 0.639706$ in with $f_s = f_y = 75,000$ psi

$\epsilon_{cl} = 0.003$ in/in
 $0.003/(0.003 + \epsilon_{cl}) = 0.522$ in/in

Per Article 5.6.3.2.2: $a = \beta_1 c$

Therefore: $c = a / \beta_1$ $c = 0.799632$ in

$d_s = 15.79$ in (extreme compression fiber to centroid of steel)
 $c/d_s = 0.05$ (unitless)

OK! $c/d_s < \text{or} = \text{eq. 5.6.2.1-1}$, use F_y for F_s .

We will ignore the negative moment reinforcement and the compressive forces (conservative).

Per Article 5.6.3.2.3 we can use eq. 5.6.3.2.1-1 and eq. 5.6.3.2.2-1 with $b_w = b$.

$$M_n = A_s f_s \left(d_s - \frac{a}{2} \right) \quad (\text{eq. 5.6.3.2.1-1}) \quad M_n = 748,977 \text{ ft-lb}$$

$$M_r = \phi M_n \quad (\text{eq. 5.6.3.2.1-1}) \quad \text{Per Table 12.5.5-1: } \phi = 1.00 \text{ (unitless)}$$

We will assume that the section is tension controlled. This assumption is to have an efficient and ductile section and will be checked below.

$M_r = 748,977$ ft-lb **OK! Negative moment capacity is sufficient.**

Check for tension controlled section (assumed above)

$a = \beta_1 c$ $c = 0.799632$ $\epsilon_c = 0.003$ Per Article 5.6.2.1

$$\epsilon_t = \frac{d_s - c}{c} \epsilon_c \quad d_s \text{ (calculated above)} = 15.79 \text{ in} \quad \epsilon_t = 0.056 \text{ (unitless)}$$

Assumption OK if $\epsilon_t \geq \epsilon_{tl}$ ϵ_{tl} per Table C5.6.2.1-1 $f_y = 75$ ksi $\epsilon_{tl} = 0.005$ (unitless)

OK! Section is tension controlled.

Check minimum required reinforcement per Article 5.6.3.3

$$M_{cr} = \gamma_3 \left[(\gamma_1 f_r + \gamma_2 f_{cpe}) S_c - M_{dnc} \left(\frac{S_c}{S_{nc}} - 1 \right) \right] \quad (\text{eq. 5.6.3.3-1})$$

f_{cpe} = comp. stress due to prestress No prestress. $f_{cpe} = \text{N/A}$ ksi
 f_r = modulus of rupture Per Article 5.4.2.6: $f_r = 0.24 \cdot \text{SQRT}(F_c) = 0.54$ ksi
 S_{nc} = section modulus for non-composit section $S_{nc} = 11,543$ in³
 S_c = S_{nc} per article 5.6.3.3 for non-composite flexure $S_c = S_{nc} = 11,543$ in³
 M_{dnc} = total unfactored dead load moment, from above $M_{dnc} = \text{N/A}$ kip-in
 γ_1 = flexural cracking variability factor For precast sections $\gamma_1 = 1.20$ (unitless)
 γ_2 = prestress variability factor For bonded tendons $\gamma_2 = \text{N/A}$ (unitless)
 γ_3 = F_y/F_u of reinforcement For A1064, grade 70 $\gamma_3 = 0.938$ (unitless)

$M_r > \text{or} = \text{MIN}(M_{cr}, 1.33 \cdot M_{un})$ $M_{cr} = 580,748$ lb-ft

SECTION 3 - DESIGN OF TOP SLAB FOR FLEXURE AND SHEAR

$$M_r = 748,977 \text{ lb-ft} \quad 1.33 * M_{un} = 181,545 \text{ lb-ft}$$

$$A_{smin} = 2.087 \text{ in}^2 \text{ (min. area of steel)}$$

OK! Reinforcement area more than minimum required.

Check minimum required reinforcement per Article 12.11.5.3.2

$$\text{Min. reinforcement} = 0.002 \times \text{gross concrete area}$$

$$A_g = 216 \text{ in}^2/\text{ft}$$

$$\text{Min. reinforcement area} = 0.432 \text{ in}^2/\text{ft}$$

$$\text{Reinforcement area provided} = 0.435 \text{ in}^2/\text{ft}$$

OK! Reinforcement area more than minimum required.

Check minimum reinforcement spacing per Article 5.10.3.1

$$\begin{aligned} \text{Diameter of selected bar} & \quad d_{bar} = 0.430 \text{ in} \\ \text{Selected spacing of reinforcement} & \quad \text{Spacing} = 4.00 \text{ in} \\ \text{Maximum size of course aggregate} & \quad \text{Max size of aggregate} = 0.75 \text{ in} \\ \text{Min. spacing (per Article 5.10.3.1.2)} & \quad \text{Min. spacing} = 1.43 \text{ in} \end{aligned}$$

This is for precast sections only, modify if using cast-in-place.

OK! Reinforcement spacing > min. bar spacing.

Check maximum bar spacing per Article 5.10.3.2 and Article 5.6.7

$$\begin{aligned} \text{Selected spacing of bars} & \quad \text{Spacing} = 4.00 \text{ in} \\ \text{Max. spacing (per Article 5.10.3.2)} & \quad \text{Max. spacing} = 18.00 \text{ in} \end{aligned}$$

Also, check maximum spacing for crack control per Article 5.6.7:

$$\beta_s = 1 + \frac{d_c}{0.7(h - d_c)} \quad d_c \text{ need not be taken} > 2 \text{ in.} + d_b/2$$

$$\begin{aligned} d_c & = 2.215 \text{ in} \\ \beta_s & = 1.2005 \text{ (unitless)} \end{aligned}$$

Calculate f_{ss} : Assume $j = 0.9$

$$f_{ss} = \frac{M}{\phi A_s j d_s} \quad f_{ss} = 9.9 \text{ ksi}$$

Max. spacing (per Article 5.6.7)

$$s \leq \frac{700\gamma_e}{\beta_s f_{ss}} - 2d_c \quad \gamma_e = 0.75 \text{ for Class 2 exposure (corrosion)}$$

$$\begin{aligned} \gamma_e & = 0.75 \text{ (unitless)} \\ \text{Max. spacing for crack control} & = 39.66 \text{ in} \end{aligned}$$

max. spacing, s, need not be taken < 5 in.

OK! Bar spacing < max. bar spacing.

$$\text{Max. spacing} = 18.00 \text{ in}$$

NEGATIVE flexural reinforcement development length per Article 5.10.8.2.1

Basic tension development length per Article 5.10.8.2.1a:

development length calculated elsewhere

From inputs above:

Minimum cutoff length of 12 inches, $12d_{bar}$, $(1/16)\text{span}$, and d_s

Required reinforcement length past theoretical cutoff:

$$\begin{aligned} d_{bar} & = 0.430 \text{ in} \\ A_{bar} & = 0.15 \text{ in}^2 \\ l_d & = 12.00 \text{ in} \\ l_{cutoff} & = 15.79 \text{ in} \end{aligned}$$

DESIGN SLAB FOR PUNCHING SHEAR

Check two-way shear of slab @ ds/2 away from loaded area per Article 5.12.8.6.3

Does two-way shear apply?

NO

(Will apply if loaded width + ds < E)

Vu = Maximum factored wheel load

Culvert segment length = 80 in

Vu = 44.1 kip

Per Table 12.5.5-1:

 $\phi = 0.9$ (unitless)

b0 (length of shear perimeter) = 2*(ww+lw+(2*ds))

b0 = 1627.496 in

 β_c = long side of load/short side of load $\beta_c = 1.1993699$ (unitless)

Vn per eq. 5.12.8.6.3-1:

dv = 15.914 in

$$V_n = \left(0.063 + \frac{0.126}{\beta_c} \right) \sqrt{f'_c} b_o d_v \leq 0.126 \sqrt{f'_c} b_o d_v$$

Vn = 7297.18 kip

 $\phi V_n = 6,567.46$ kip

OK! Two-way shear does not apply.

CHECK MINIMUM LONGITUDINAL REINFORCEMENT

For a precast section, per Article 12.11.5.3.2:

As required per face = 0.030 in²/ftLong. reinforcement not less than 0.03 in²/ft at each face.

Ast = selected area of longitudinal steel

Interior Ast selected = 0.075 in²/ftExterior Ast selected = 0.075 in²/ft

OK! Longitudinal reinforcement is acceptable.

Check minimum temperature and shrinkage reinforcement per Article 5.10.6

Applies if fabricated length exceeds 16 feet. Per Article 5.10.6, for $f_y \leq 75$ ksi:

$$A_s \geq \frac{1.30bh}{2(b+h)f_y}$$

$$0.11 \leq A_s \leq 0.60$$

b = 276 in

h = 18 in

As required per face = 0.030 in²/ftTotal As required, both faces = 1.380 in²

Ast = selected area of steel

Ast selected = 3.400 in²

OK! Precast sections length 16 ft or less, temp. & shrinkage check not required.

Check minimum distribution reinforcement per Article 9.7.3.2

For primary reinforcement parallel to traffic:

100/sqrt(S) = 21.82% percent

Required percentage of positive reinforcement area = Asp * 0.2182

0 in²/ft

Percent area need not be more than 50%.

Ast selected = 0.075 in²/ft

The selected area of steel only considers the interior reinforcement.

OK! Distribution reinforcement is not required as soil cover is 2 ft or greater.

Check minimum reinforcement spacing per Article 5.10.3.1

Diameter of selected bottom bar

dbar (interior) = 0.252 in

Selected spacing of reinforcement

Spacing = 8.00 in

Maximum size of course aggregate

Max size of aggregate = 0.75 in

SECTION 3 - DESIGN OF TOP SLAB FOR FLEXURE AND SHEAR

Min. spacing (per Article 5.10.3.1.2)	Min. spacing =	1.25	in
Diameter of selected top bar	d _{bar} (exterior) =	0.252	in
Selected spacing of reinforcement	Spacing =	8.00	in
Maximum size of coarse aggregate	Max size of aggregate =	0.75	in
Min. spacing (per Article 5.10.3.1.2)	Min. spacing =	1.25	in

This is for precast sections only, modify if using cast-in-place.

OK! Reinforcement spacing > min. bar spacing.

Check maximum reinforcement spacing per Article 5.10.3.2

Selected spacing of reinforcement	Spacing =	8.00	in
Max. spacing (per Article 5.10.3.2)	Max. spacing =	18.00	in

OK! Reinforcement spacing < max. bar spacing.

Longitudinal reinforcement development length per Article 5.10.8.2.1

Basic tension development length per Article 5.10.8.2.1a:

development length calculated elsewhere

From inputs above:

d _{bar} =	0.252	in
A _{bar} =	0.050	in ²
l _d =	12.00	in

CHECK FOR EDGE BEAM OR EDGE SHEAR REQUIREMENT PER ARTICLE 12.11.2

For cast-in-place box culverts or for precast box culverts with top slabs having span to thickness ratios (s/t) > 18 or segment lengths < 4.0 ft, edge beams OR shear transfer between sections shall be provided as specified in Article 4.6.2.10.4 as follows:

--

At ends of culvert runs where wheel loads travel within 24.0 in. from the end of culvert,

-- *At expansion joints of cast-in-place culverts where wheel loads travel over or adjacent to the expansion joint.*

S/t = 14 (unitless) Segment length = 6.666667 ft

OK! Edge beams are not required per Article 4.6.2.10.4

CHECK FOR DEFLECTION IN TOP SLAB PER ARTICLE 2.5.2.6.2

Deflection limit from Section 2: Deflection limit = Span/360 = 0.700 in
We will check deflections per AASHTO article 5.6.3.5.

$E_c = 33,000 K_1 w_c^{1.5} \sqrt{f'_c}$ Per Article 5.4.2.4

Modular ratio = $E_s / E_c = n$

$E_s = 29,000$ ksi

$E_c = 4291$ ksi

$n = 6.76$ (unitless)

Transformed areas of steel for calculating gross moment of inertia:

SECTION 3 - DESIGN OF TOP SLAB FOR FLEXURE AND SHEAR

Transformed area = (n - 1) * area of steel

Bottom: $A_{sp\ trans} = 332.326\ in^2$
 Top: $A_{sn\ trans} = 44.618\ in^2$
 $I_{g\ conc} = 103887.36\ in^4$

Gross moment of inertia of concrete only = $I_g = (E * t^3) / 12$

Calculate gross moment of inertia of the transformed section:

Part	Area (in ²)	y _{top} (in)	Ay _{top} (in ³)	y (in)	I _{self} (in ⁴)	Ay ² (in ⁴)	I _{part} (in ⁴)
Concrete	3847.68	9.00	34629.12	-0.472	103887.4	858.02	104745.4
Top Steel	44.618	2.22	98.83	-7.257	-	2349.90	2349.90
Bottom Steel	332.326	15.91	5288.64	6.442	-	13790.37	13790.37
$\Sigma\ (total) = 4224.6\ (in^2)$		40017 (in ³)		$\Sigma I_{part} = I_g\ (in^4) =$		120885.7	

Centroid of uncracked section:

$$y_{uncr} = \Sigma Ay_{top} / \Sigma Area$$

$$y_{uncr} = 9.472\ in$$

Transformed areas of steel for calculating gross moment of inertia:

Transformed area in cracked section = (n) * A_s

$$A_{sp\ trans} = 390.042\ in^2$$

Transformed area in uncracked section = (n - 1) * A_s

$$A_{sn\ trans} = 44.618\ in^2$$

We will assume that the bottom steel is in a cracked area and the top steel is not.

Calculate properties of the cracked, transformed section:

Part	Area (in ²)	y _{top} (in)	Ay _{top} (in ³)	y (in)	I _{self} (in ⁴)	Ay (in ³)	I _{part} (in ⁴)
Concrete	-	9.00	-	2.956	3681.5	3736.09	14726.1
Top Steel	44.618	2.22	98.83	3.697	-	164.97	609.95
Bottom Steel	390.042	15.91	6207.12	-10.002	-	-3901.06	39017.00
$\Sigma\ (total) = 434.66\ (in^2)$		6305.95 (in ³)		$\Sigma I_{part} = I_{cr}\ (in^4) =$		54353.0	

Depth to the neutral axis = c *c is solved for with $\Sigma Ay = 0$.*

OK! ΣAy is equal to or near zero. Use calculated value of c.

$$\Sigma Ay = 0.00\ in^3$$

$$c = \frac{-\Sigma A_s \pm \sqrt{(\Sigma A_s)^2 + 2(E)(\Sigma Ay_{top})}}{E}$$

$$c = 5.9124\ in$$

Calculate the dead load deflection:

Cracking moment for positive moment (calculated above):

$$M_{cr} = 580748\ lb-ft$$

$$I_e = \left(\frac{M_{cr}}{M_a} \right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_a} \right)^3 \right] I_{cr}$$

M_a = positive dead load moment = 1488343.3 lb-ft

$$I_e \leq I_g$$

$$I_e = 58306\ in^4$$

eq. 5.6.3.5.2-1 and 5.6.3.5.2-2

$$\Delta_{MIDSPAN} = \frac{5}{48} \frac{l_n^2}{EI} [M_{mid} + 0.1(2M_{end})]$$

$$M_{mid} = 1488343\ lb-ft$$

$$M_{end} = -744172\ lb-ft$$

$$\Delta D_{midspan} = 0.425\ in$$

Calculate the total dead + live load deflection:

SECTION 3 - DESIGN OF TOP SLAB FOR FLEXURE AND SHEAR

Cracking moment for positive moment (calculated above):

$$M_{cr} = 580748 \text{ lb-ft}$$

$$I_e = \left(\frac{M_{cr}}{M_a} \right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_a} \right)^3 \right] I_{cr}$$

$$I_e \leq I_g$$

$$M_a = \text{total positive moment} = 2976686.7 \text{ lb-ft}$$

$$I_e = 54847 \text{ in}^4$$

eq. 5.6.3.5.2-1 and 5.6.3.5.2-2

$$\Delta_{\text{MIDSPAN}} = \frac{5}{48} \frac{l_n^2}{EI} [M_{\text{mid}} + 0.1(2M_{\text{end}})]$$

$$M_{\text{mid}} = 2976687 \text{ lb-ft}$$

$$M_{\text{end}} = -1488343 \text{ lb-ft}$$

$$\Delta D+L_{\text{midspan}} = 0.904 \text{ in}$$

Calculate the total long term deflection:

$$\Delta D_{\text{midspan}} = 0.425 \text{ in}$$

$$\Delta L_{\text{midspan}} = \Delta D+L - \Delta D = 0.479 \text{ in}$$

$$\Delta_{\text{Total}} = [(M_D / M_{D+L}) * \Delta D+L] + \Delta D+L$$

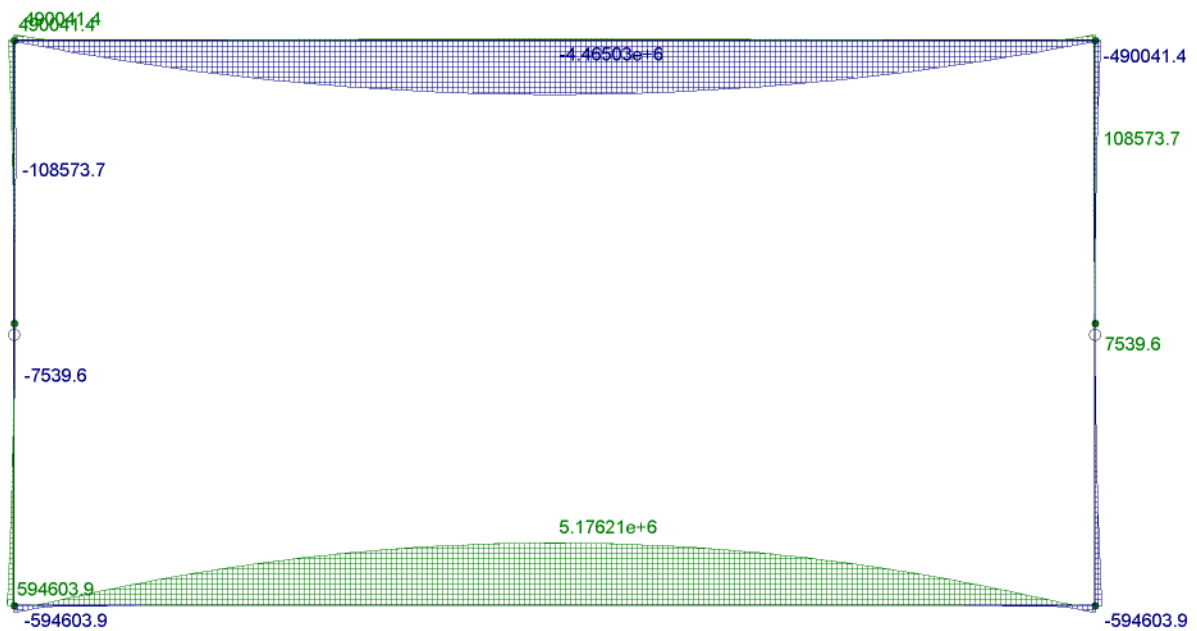
$$\Delta_{\text{Total}} = 1.355 \text{ in}$$

$$\text{Live Load Deflection limit} = \text{Span}/360 = 0.700 \text{ in}$$

$$\text{Total Service Load Deflection limit} = \text{Span}/160 = 1.575 \text{ in}$$

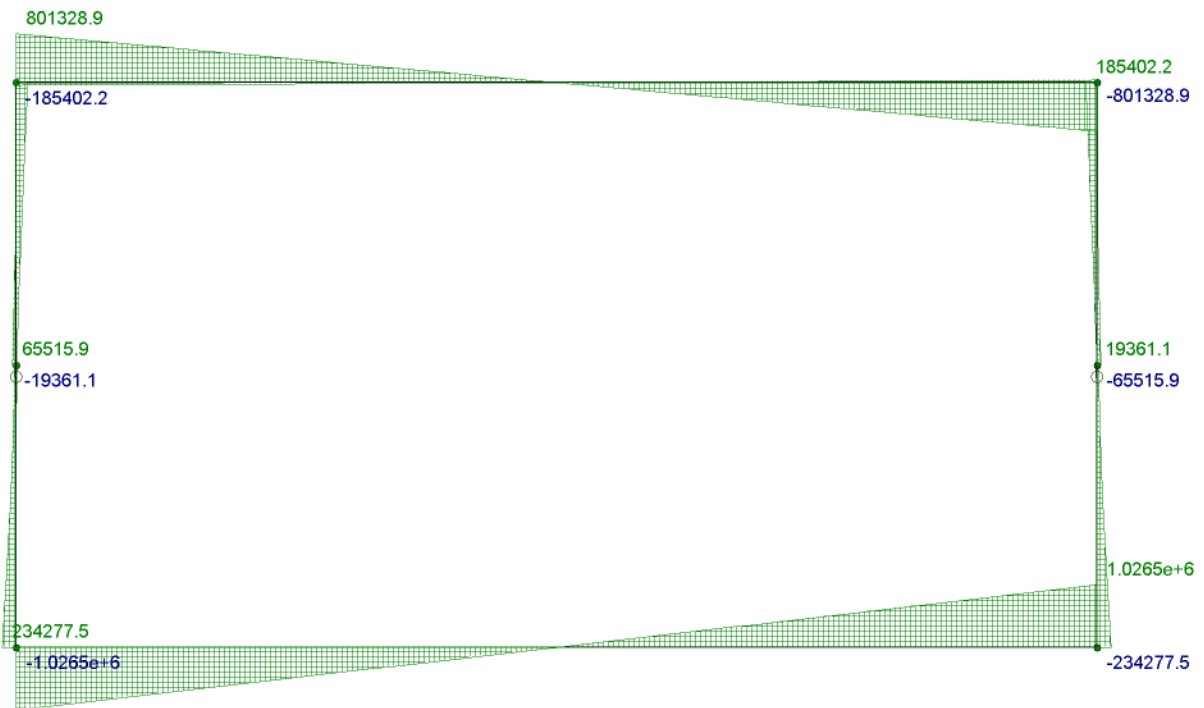
OK! Live load deflection of top slab is within allowable limits.

OK! Total service load deflection of top slab is within allowable limits.



Member z Bending Moments (lb-ft) (Enveloped)

American Concrete Industri...	Stockton Springs Box Culvert STRENGTH-I Flexural Envelope	SK - 1
Ian Riley, PE, SE		Feb 19, 2020 at 6:45 PM
WIN: 21831.00		Clamshell Box Culvert Model.r3d

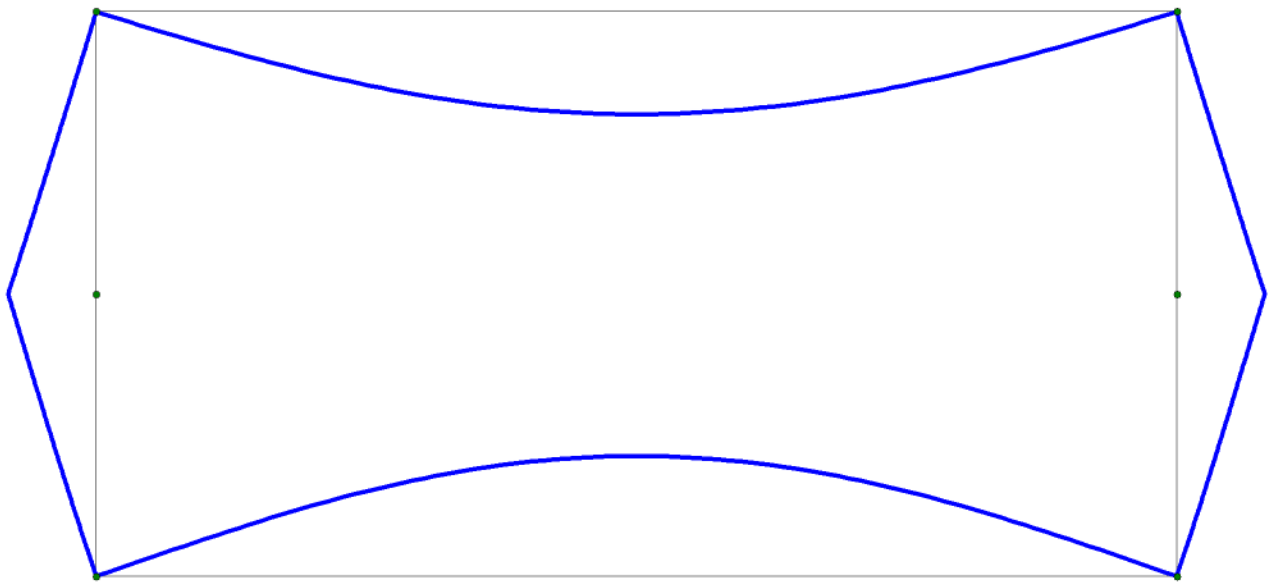


Member y Shear Forces (lb) (Enveloped)

American Concrete Industri...	Stockton Springs Box Culvert STRENGTH-I Shear Envelope	SK - 2
Ian Riley, PE, SE		Feb 19, 2020 at 6:45 PM
WIN: 21831.00		Clamshell Box Culvert Model.r3d



Section Sets
■ na



Results for LC 26, Service I (Dead only)

American Concrete Industri...	Stockton Springs Box Culvert Deflected Shape	SK - 3
Ian Riley, PE, SE		Feb 19, 2020 at 6:45 PM
WIN: 21831.00		Clamshell Box Culvert Model.r3d