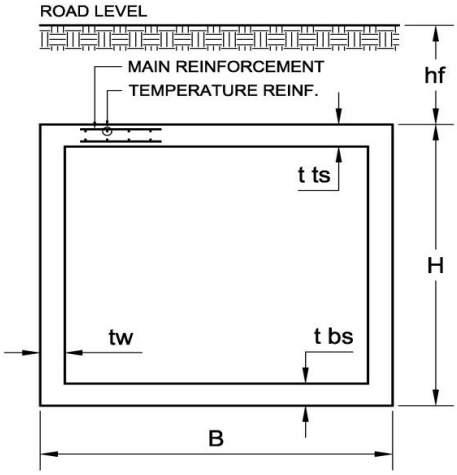
STRUCTURAL DESIGN OF SINGLE CELL BOX CULVERT

Based on AASHTO LRFD Bridge Design 2007 SI

Client:		**Designed By:**	*Ali Akbar Shaikhzadeh*	**Date:**	*31-Jul-21*
Job Name/Station:		**Verified By:**		**Revision:**	

INPUT DATA

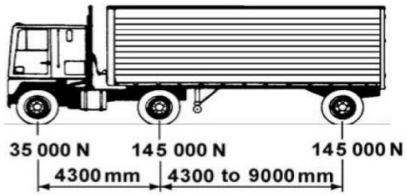
CONCRETE COMPRESSIVE STRENGTH, f'c	28	MPA
REBAR YIELD STRENGTH, fy	420	MPA
CONCRETE UNIT WEIGHT, γ_c	24	kN/cum
SATURATED SOIL UNIT WEIGHT, γ_s	18	kN/cum
HEIGHT OFCULVERT, H	1500	mm
WIDTH OF CULVERT, B	2000	mm
THICKNESS OF SIDE WALLS, t_w	350	mm
THICKNESS OF TOP SLAB, t_{ts}	350	mm
THICKNESS OF BOTTOM SLAB, t_{bs}	350	mm
DEPTH OF FILL, h_f	2000	mm
IMPOSED SERVICE DEAD LOADS, w_d	0	KPa
ALLOWABLE SOIL PRESSURE, Q_a	144	KPa
SOIL ANGLE OF FRCITION, ϕ	30	Deg.
PREFERRED REBAR SIZE	12	mm
CONCRETE COVER TO REBAR CENTER	75	mm
NO. OF REINFORCEMENT LAYERS	2	
MAIN REINFORCEMENT SPACING	200	mm
SHRINKAGE & TEMP. REINFOR. SPACING	200	mm



Design Summary	
Shear Status	**O.K.**
Flexure Status	**O.K.**
Soil Pressure Status	**O.K.**

LOADS ON THE CULVERT

For the design purposes a one-meter length of the culvert is considered.



Top Slab

Vehicular Live Loads (HS 20 AASHTO Truck)

Include live loads if h_f < 2400mm	h_f =	2000	mm	**LL considered.** Design Based on →	(AASHTO 3.6.1.2.6)
Multiple presence factor		1.20		Traffic travelling parallel to span	(AASHTO 3.6.1.1.2)
Width of distributed load (parallel to span)		2250	mm		(AASHTO 3.6.1.2.6)
Length of distributed load (perpend. to span)		4510	mm	**Equiv. wheel loads don't overlap.**	(AASHTO 3.6.1.2.6)
Pressure intensity at the specified depth of fill		7.14	KPa	Wheel Load = 72.5 KN	
Linear load on the top slab		7.14	KN/m		

Dynamic Load Allowance (Impact Factor) (AASHTO 3.6.2.2)

IM = 33(1 - 0.00041 h_f) > 0%	5.94	%	Factor for increasing live load due to impact effects
Increased linear live load	9.08	KN/m	Impact and multiple presence factor included.

Weight of earth fill

Linear weight of fill on the slab	36.00	KN/m

Imposed dead loads

Linear imposed dead loads on the slab	0	KN/m

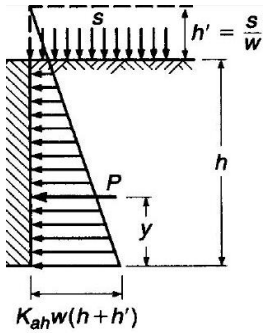
Selfweight

Linear selft weight of the slab	8.4	KN/m

Side Walls

Soil pressure

k_{ah} = (1 - sinϕ) / (1 + sinϕ)	0.333	
Surcharge on side walls due to top soil	36.0	KPa



$$y = \frac{h^2 + 3hh'}{3(h+2h')}$$

$$P = \frac{1}{2} K_{ah} w h (h + 2h')$$

Height of surcharge ($h' = s / \gamma_s$)	2.0	m
Linear pressure at the bottom of the side wall	21.0	kN/m

Selfweight

Two side walls = $t_w (H - t_{bs} - t_{ts}) \gamma_c$	13.4	KN

Bottom Slab

Self weight of the whole structure

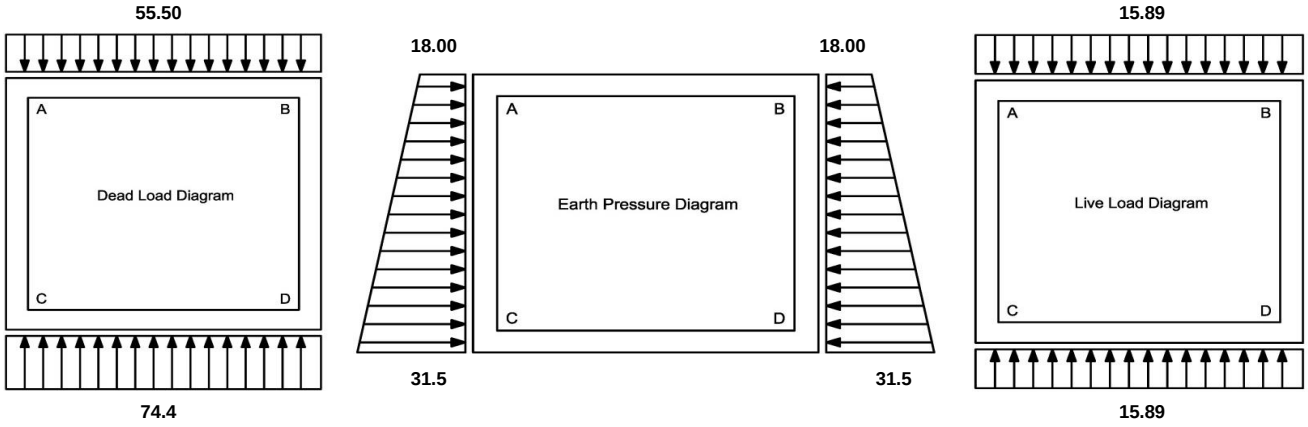
Linear soil pressure due to stru. selfweight	59.52	kN/m	See note 1

Vehicular Live Loads (HS 20 AASHTO Truck)

Linear soil pressure due to live loads	9.08	KN/m	See note 1

FACTORED LOAD DIAGRAMS

Load factor for dead load	1.25	(AASHTO 3.4.1)
Load factor for horizontal earth pressure	1.50	(AASHTO 3.4.1)
Load factor for live load	1.75	(AASHTO 3.4.1)



ANALYSIS OF THE STRUCTURE

The structure is analyzed using the moment distribution method.

The fixed-end moment at each joint is the superposition of the fixed-end moments due to dead, live and earth pressure loads.

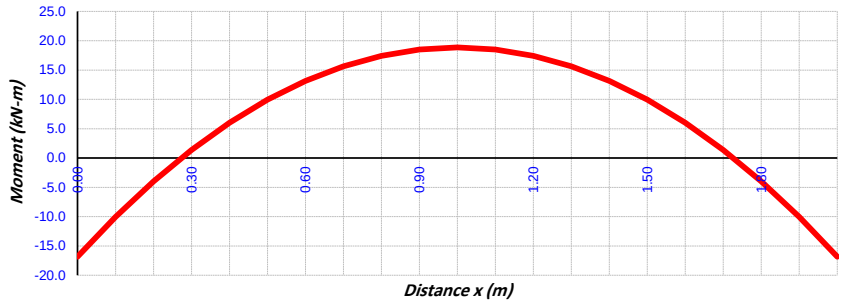
Joint	A		B		D		C	
Member	AC	AB	BA	BD	DB	DC	CD	CA
Length	0.80	2.00	2.00	0.80	0.80	2.00	2.00	0.80
Moment of Inertia	0.0292	0.0292	0.0292	0.0292	0.0292	0.0292	0.0292	0.0292
Distrib. Factor	0.71	0.29	0.29	0.71	0.71	0.29	0.29	0.71
FEM	1.25	-23.80	23.80	-1.25	1.39	-30.10	30.10	-1.39
Distribution	16.11	6.44	-6.44	-16.11	20.50	8.20	-8.20	-20.50
Carry Over	-10.25	-3.22	3.22	10.25	-8.05	-4.10	4.10	8.05
Distribution	9.62	3.85	-3.85	-9.62	8.68	3.47	-3.47	-8.68
Carry Over	-4.34	-1.92	1.92	4.34	-4.81	-1.74	1.74	4.81
Distribution	4.48	1.79	-1.79	-4.48	4.68	1.87	-1.87	-4.68
Carry Over	-2.34	-0.90	0.90	2.34	-2.24	-0.94	0.94	2.24
Distribution	2.31	0.92	-0.92	-2.31	2.27	0.91	-0.91	-2.27
Carry Over	-1.13	-0.46	0.46	1.13	-1.15	-0.45	0.45	1.15
Distribution	1.14	0.46	-0.46	-1.14	1.15	0.46	-0.46	-1.15
Carry Over	-0.57	-0.23	0.23	0.57	-0.57	-0.23	0.23	0.57
Distribution	0.57	0.23	-0.23	-0.57	0.57	0.23	-0.23	-0.57
Carry Over	-0.29	-0.11	0.11	0.29	-0.29	-0.11	0.11	0.29
Distribution	0.29	0.11	-0.11	-0.29	0.29	0.11	-0.11	-0.29
Moment Sum	16.84	-16.84	16.84	-16.84	22.41	-22.41	22.41	-22.41

SHEAR MOMENT DIAGRAMS

Top Slab

$M_{max\ (+)}$	18.86	kN/m
$M_{max\ (-)}$	-16.84	kN/m
Design Moment	18.86	kN/m

Top Slab Moment Diagram



$V_{max\ (+)}$	71.39	kN
$V_{max\ (-)}$	-64.26	kN
Design Shear	26.77	kN

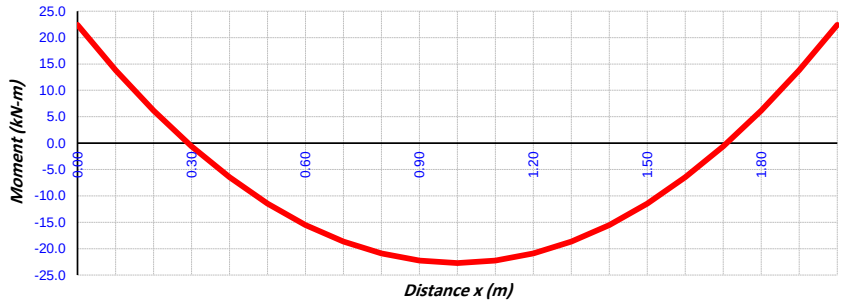
At distance d from the face of the support

Top Slab Shear Diagram

Bottom Slab

$M_{max\ (+)}$	22.41	kN/m
$M_{max\ (-)}$	-22.73	kN/m
Design Moment	22.73	kN/m

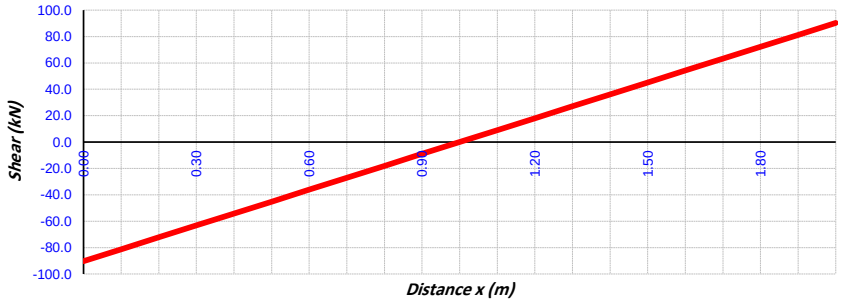
Bottom Slab Moment Diagram



$V_{max\ (+)}$	90.29	kN
$V_{max\ (-)}$	-90.29	kN
Design Shear	33.86	kN

At distance d from the face of the support

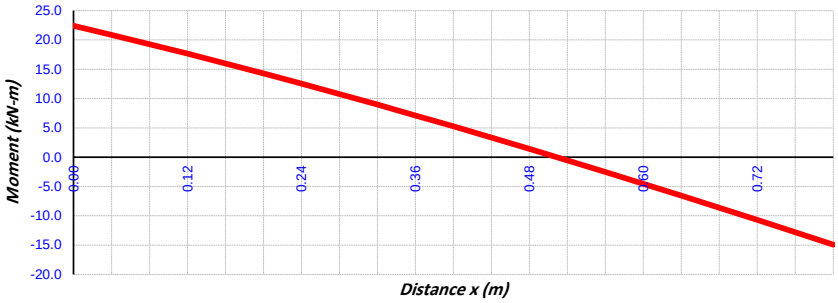
Bottom Slab Shear Diagram



Side Walls

$M_{max\ (+)}$	22.41	kN/m
$M_{max\ (-)}$	-14.92	kN/m
Design Moment	22.41	kN/m

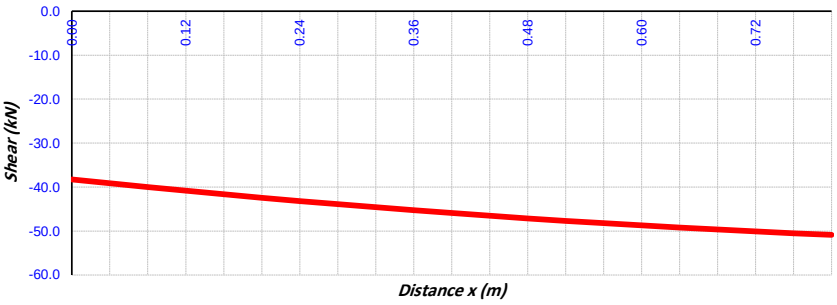
Side Walls Moment Diagram



$V_{max\ (+)}$	-38.26	kN
$V_{max\ (-)}$	-50.86	kN
Design Shear	49.03	kN

At distance d from the face of the support

Side Walls Shear Diagram



THICKNESS CHECK

Shear strength provided by concrete = $\phi V_c = \phi 0.17 (f'_c)^{0.5} b_w d$ (ACI 11.2.1.2)

Component	d (mm)	ϕV_c (kN)	V_d (kN)	Status
Top slab	275	185.5	26.8	**O.K.**
Bottom slab	275	185.5	33.9	**O.K.**
Side walls	275	185.5	49.0	**O.K.**

REINF. CALCULATIONS

Minimum ratio for main reinforcement, ρ_{min}	0.0007		See note 2	(AASHTO 5.10.8)
Minimum ratio for shrinkage & temperature reinforcement, ρ_{min}	0.0008		See note 2	(AASHTO 5.10.8)
Maximum center to center spacing of reinforcement, s_{max}	525	mm	Max (1.5 t, 450)	(AASHTO 5.10.3.2)

Component	MAIN REINFORCEMENT							TEMPRATURE REINF.		
	d (mm)	M_u(kN-m)	A_s (mm^2)	$A_{s\ prov}$	ρ_{act}	ρ_{min}	Status	ρ_{act}	ρ_{min}	Status
Top slab	275	21.0	202	1131	0.0032	0.0013	**O.K.**	0.0032	0.0015	**O.K.**
Bottom slab	275	25.3	243	1131	0.0032	0.0013	**O.K.**	0.0032	0.0015	**O.K.**
Side walls	275	24.9	240	1131	0.0032	0.0013	**O.K.**	0.0032	0.0015	**O.K.**

SOIL PRESSURE CHECK

Pressure on soil	68.60	KPa
Allowable soil pressure	144.00	KPa
Status	**O.K.**	

1- In reality, the uplift soil pressure on the bottom slab may not be uniform. However, for simplicity, it shall be assumed to be uniform.

2- Minimum reinforcement ratio found is for one layer of reinforcement and shall be multiplyed by 2 if there are 2 layers of reinforcement.

3- Clear distance between two layers of reinforcement shall not be more than 150mm and less than 25mm.

4- All soil has been assumed to be saturated soil.

5- It has been assumed that only one axle of the design truck comes on the culvert at a time. This is true for culvert width up to 4300. For more widths

this design spreadsheet can not be used since it is possible that two axle loads come on the culvert.