Box Culvert

A **culvert** is a structure that allows water to flow under a road, railroad, or similar obstruction from one side to the other side. Typically embedded so as to be surrounded by soil, a culvert may be made from a pipe, reinforced concrete or other material.

box Culverts consist of top slab, bottom slab and two vertical side walls. The top of the box section can be at the road level or can be at a depth below road level with a fill depending on site conditions.

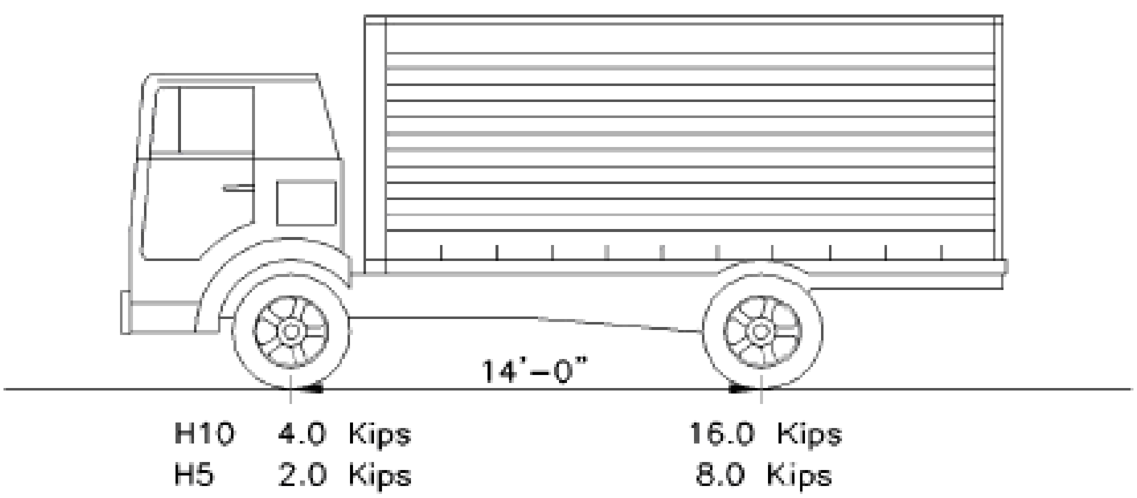
box culverts are reinforced concrete closed rigid frames which must support vertical earth and truck loads and lateral earth pressure. They may be either single or multi-cell based on the hydraulic requirements.

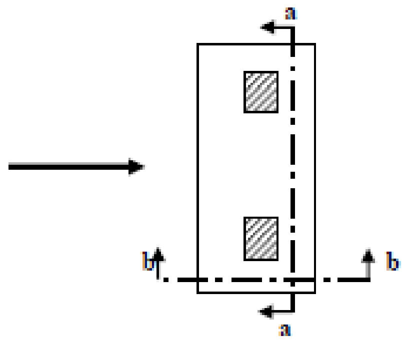
Loads

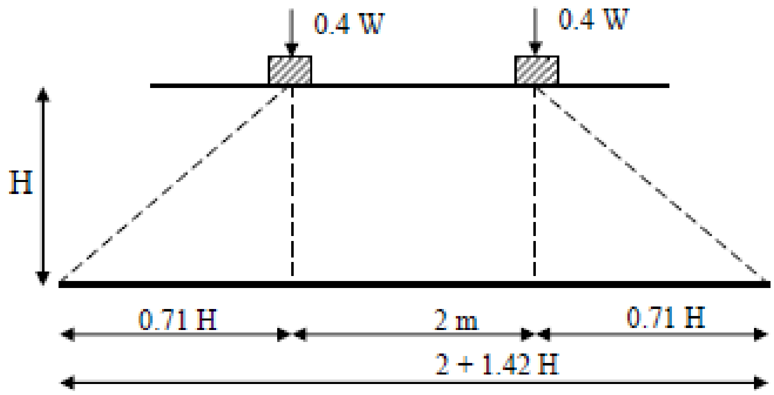
- Self weight of the culvert
- Pavement
- Backfill weight
- Lateral soil pressure
- Live load: the vehicular live load consists set of wheel loads moving on top slab of culvert. These loads are distributed through the top slab of the culvert.

Loads are calculated and factored according to AASHTO LRFD Bridge Design Specifications.

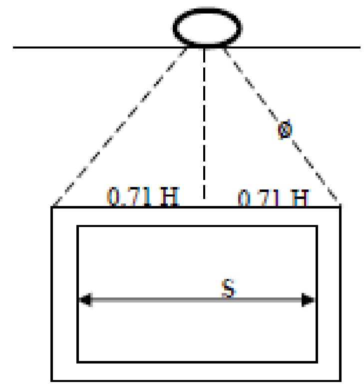
AASHTO: American Association of State Highway and Transportation Officials
LRFD: Load and Resistance Factor Design







Section (a-a)

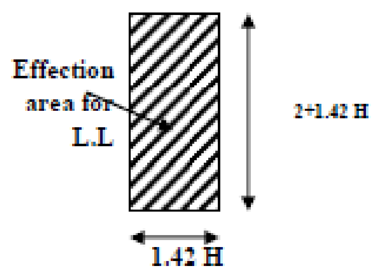


Sec b-b

$$L.L = \frac{0.8\,W}{(2+1.42H)(1.42H)}$$

$$Impact \quad I\% = \frac{16}{S+40} \leq 50\%$$

Impact load = $I\% \times L.L$



Note: "*For single-span culverts, the effects of live load may be neglected where the depth of fill is more than 2400 mm and exceeds the span length; for multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between faces of end walls.*"

Culvert Design

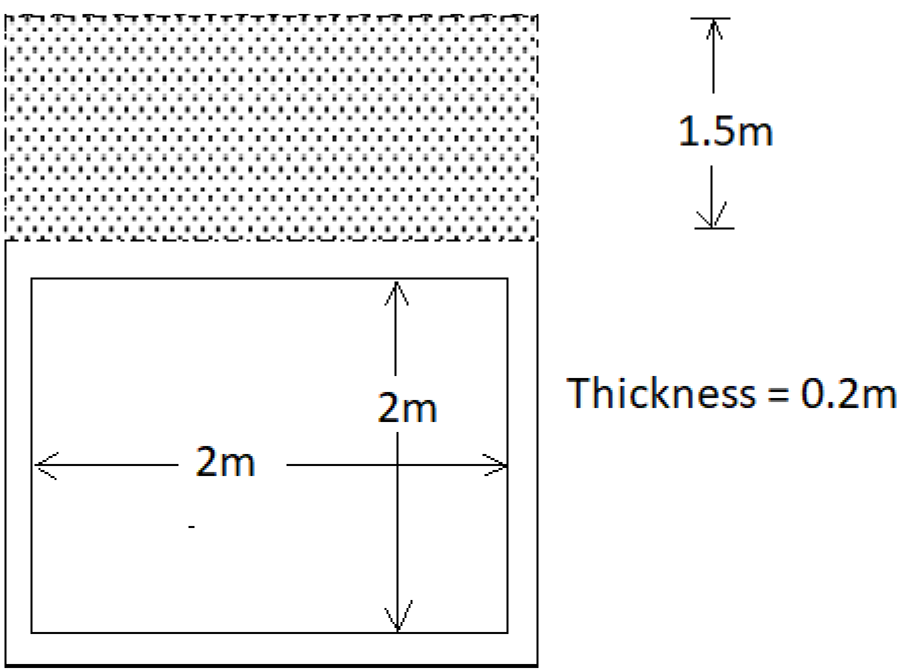
Example 3:

Design the box culvert shown in the figure, using the following information:

$f'c$ = 25MPa

fy = 420 MPa

Use AASHTO H-10 Truck for the live load



Top Slab

Self weight = 24 *0.2 = 4.8 kN/m^2
Backfill load = 1.5 *18 = 27 KN/m^2

Live load (L.L) = 0.8 w / [(1.42 H +2)(1.42H)]
*= 0.8 *100 / [(1.42* 1.5 + 2)(1.42 * 1.5)] = 9.09 kN/m²*

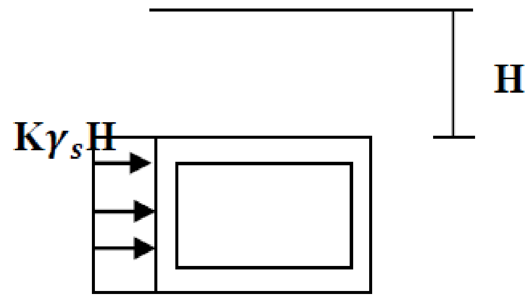
Impact Load I% = 16/(S+40) = 16 / (2+40) = 38% < 50% OK
*= 38% * 9.09 = 3.45 kN/m²*

LL + Impact = 9.09 + 3.45 = 12.54 kN/m²

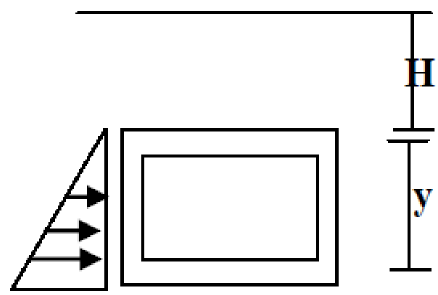
Factored total load =4.8*1.25 + 27*1.35 + 12.54*1.75 = 64.395 kN/m^2

Sides of Culvert

Lateral homogenous pressure on sides of culvert = $k * \gamma_s * H$
= 0.333 *18 * 1.5 = 8.991 kN/m^2



The value of k depends on soil characteristics, k = 1/3 = 0.333 for cohesive and non-cohesive soil.

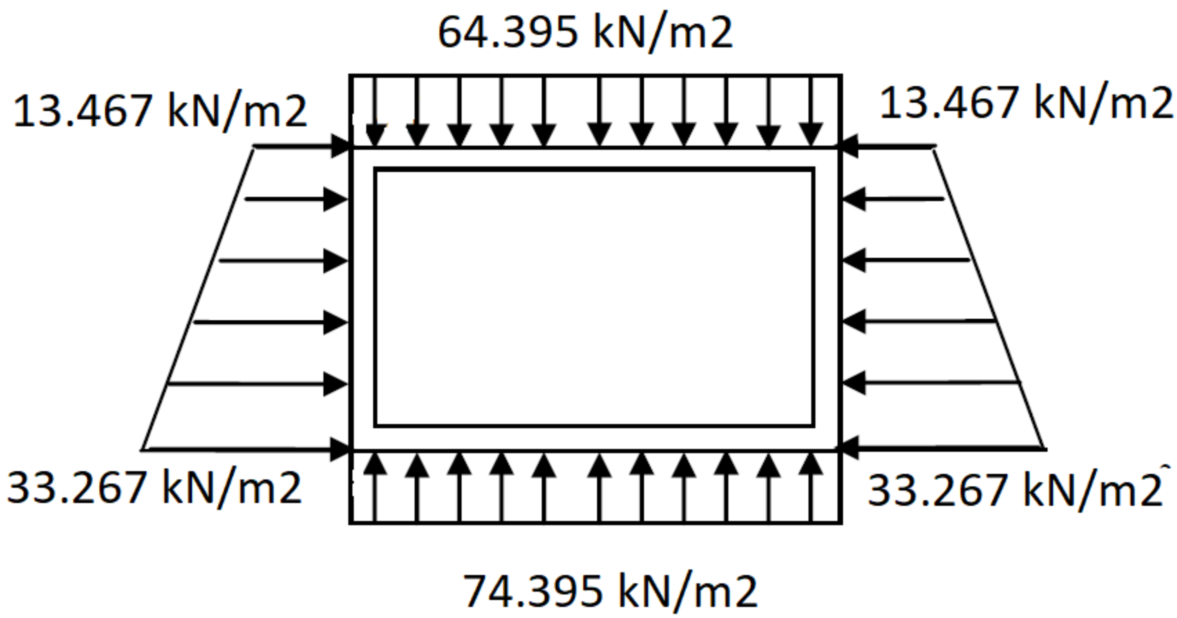


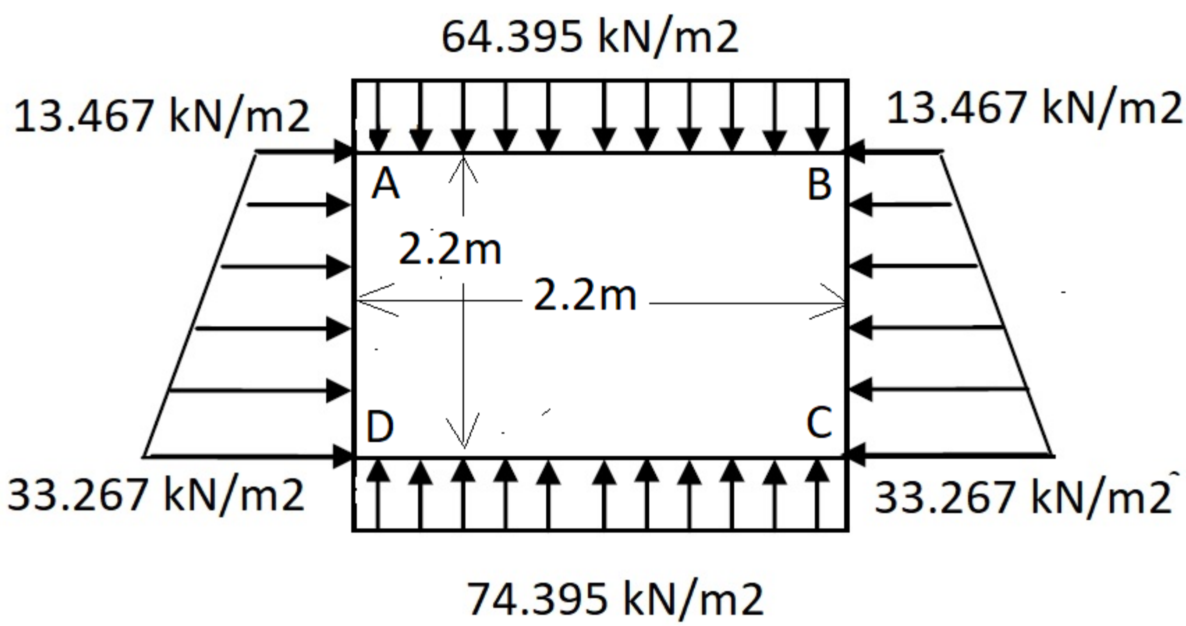
Triangular lateral soil pressure on sides = $k * \gamma_s * y$
= 0.333 *18 * 2.2 = 13.187 kN/m^2
y = 2 + t = 2 + 0.2 = 2.2 m

Total lateral pressure at top = 8.991 $kN.m^2$
Total lateral pressure at bottom = 8.991+ 13.187= 22.178 $kN.m^2$
Factored lateral pressure at top E_H = 1.5 * 8.991 = 13.467 $kN.m^2$
Factored lateral pressure at bottom E_H = 1.5 * 22.178
= 33.267 $kN.m^2$

Bottom slab

Factored Self weight of walls = 2 x 24 x 2 x 0.2 x 1.25 / 2.4
= 10 kN/m^2
Factored load from top slab = 64.395 KN/m^2
Total factored loads = 10 + 64.395 = 74.395 KN/m^2

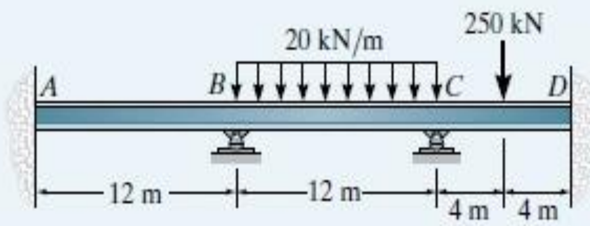

64.395 kN/m2
13.467 kN/m2
13.467 kN/m2
33.267 kN/m2
33.267 kN/m2
74.395 kN/m2


64.395 kN/m2
13.467 kN/m2
13.467 kN/m2
A
B
2.2m
2.2m
D
C
33.267 kN/m2
33.267 kN/m2
74.395 kN/m2

Moment Distribution Method

Example 1:

Determine the internal moments at each support of the beam shown



K=4EI/L

DF=K/∑K

$$K_{AB} = \frac{4EI}{12} \qquad K_{BC} = \frac{4EI}{12} \qquad K_{CD} = \frac{4EI}{8}$$

Therefore,

$$DF_{AB} = DF_{DC} = 0 \qquad DF_{BA} = DF_{BC} = \frac{4EI/12}{4EI/12 + 4EI/12} = 0.5$$

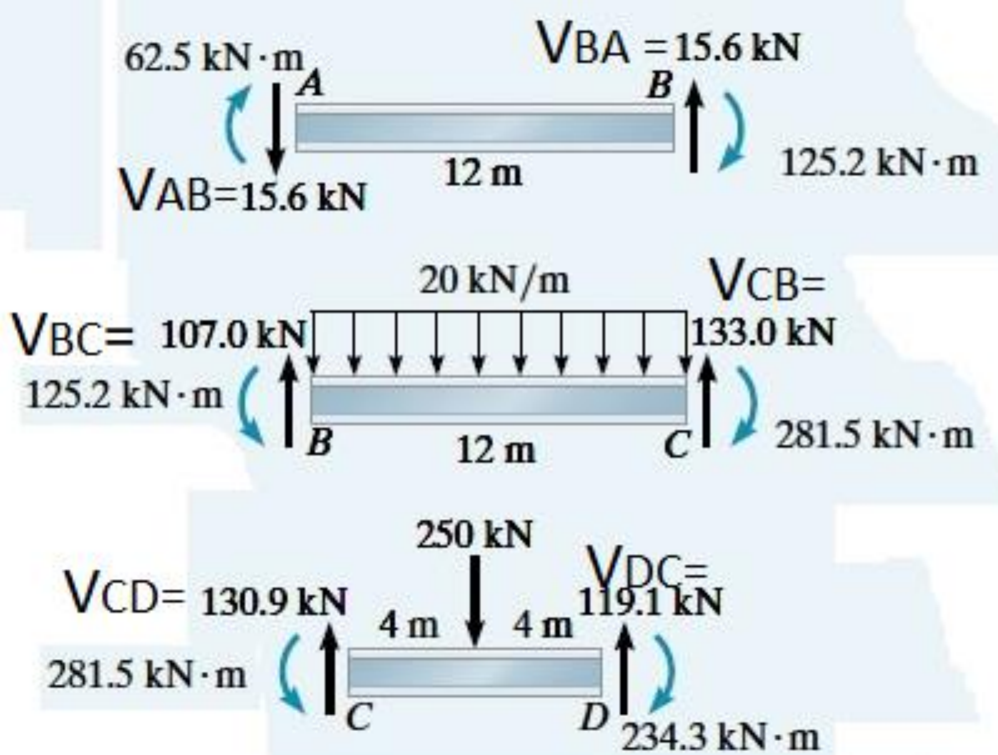
$$DF_{CB} = \frac{4EI/12}{4EI/12 + 4EI/8} = 0.4 \quad DF_{CD} = \frac{4EI/8}{4EI/12 + 4EI/8} = 0.6$$

The fixed-end moments are

$$(FEM)_{BC} = -\frac{wL^2}{12} = \frac{-20(12)^2}{12} = -240\ \text{kN}\cdot\text{m} \qquad (FEM)_{CB} = \frac{wL^2}{12} = \frac{20(12)^2}{12} = 240\ \text{kN}\cdot\text{m}$$

$$(FEM)_{CD} = -\frac{PL}{8} = \frac{-250(8)}{8} = -250\ \text{kN}\cdot\text{m} \qquad (FEM)_{DC} = \frac{PL}{8} = \frac{250(8)}{8} = 250\ \text{kN}\cdot\text{m}$$

Joint	A	B		C		D
Member	AB	BA	BC	CB	CD	DC
DF	0	0.5	0.5	0.4	0.6	0
FEM			−240	240	−250	250
Dist.		120	120	4	6	
CO	60		2	60		3
Dist.		−1	−1	−24	−36	
CO	−0.5		−12	−0.5		−18
Dist.		6	6	0.2	0.3	
CO	3		0.1	3		0.2
Dist.		−0.05	−0.05	−1.2	−1.8	
CO	−0.02		−0.6	−0.02		−0.9
Dist.		0.3	0.3	0.01	0.01	
ΣM	62.5	125.2	−125.2	281.5	−281.5	234.3



$\sum M_B = 0$

$-V_{AB} * 12 + 125.2 + 62.5 = 0$

$V_{AB} = 15.6$ kN

$\sum fy = 0$

$V_{BA} - 15.6 = 0$

$V_{BA} = 15.6$ kN

$\sum Mc = 0$

$V_{BC} * 12 - 125.2 + 281.5 - 20 * 12 * 6 = 0$

$V_{BC} = 107$ kN

$\sum fy = 0$

$107 + V_{CB} - 20 * 12 = 0$

$V_{CB} = 133$ kN

$\sum M_D = 0$

$V_{CD} * 8 + 234.3 - 281.5 - 250 * 4 = 0$

$V_{CD} = 130.9$ kN

$\sum fy = 0$

$130.9 + V_{DC} - 250 = 0$

$V_{DC} = 119.1$ kN

Example 2

supports at A and D are fixed and B and C are fixed connected. EI is constant.

$K_{AB} = 4EI/15$ $K_{BC} = 4EI/24$ $K_{CD} = 4EI/15$

$$(DF)_{AB} = (DF)_{DC} = 0$$

$$(DF)_{BA} = (DF)_{CD} = \frac{I/15}{I/15 + I/24} = 0.6154$$

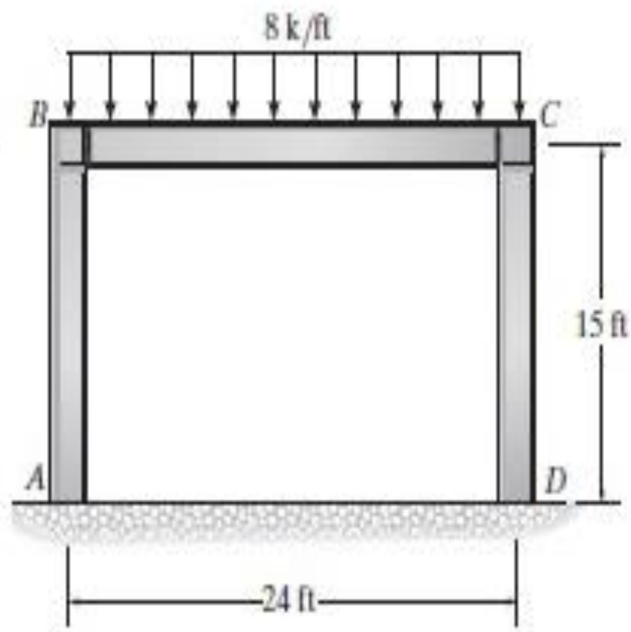
$$(DF)_{BC} = (DF)_{CB} = 0.3846$$

$$(FEM)_{AB} = (FEM)_{BA} = 0$$

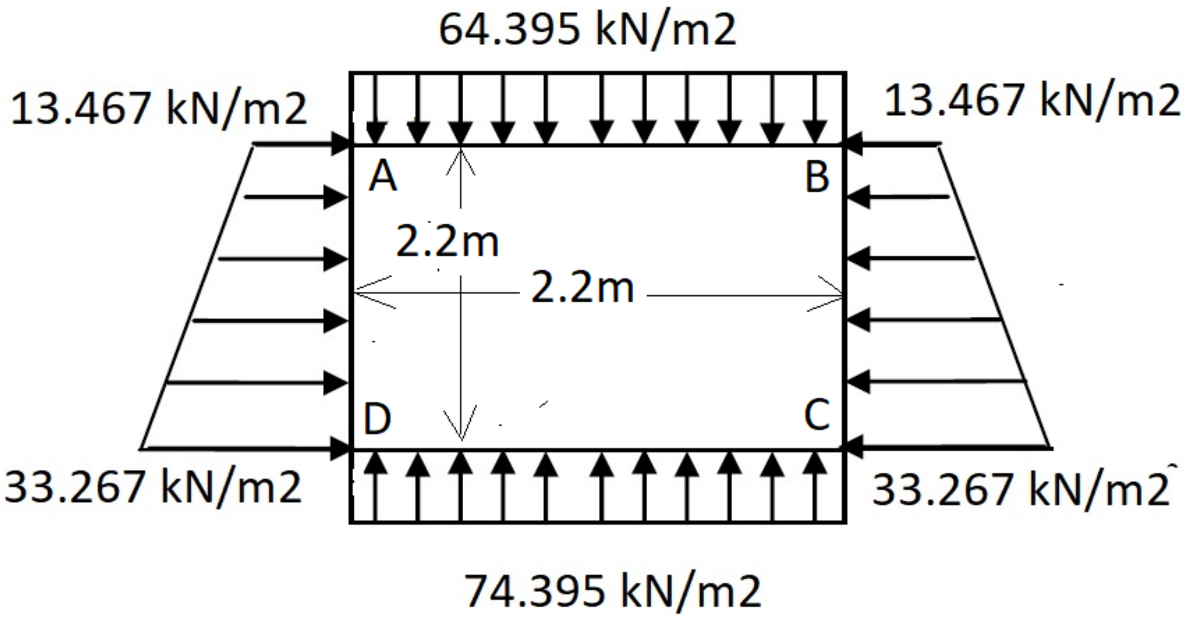
$$(FEM)_{BC} = \frac{-8(24)^2}{12} = -384 \text{ k} \cdot \text{ft}$$

$$(FEM)_{CB} = 384 \text{ k} \cdot \text{ft}$$

$$(FEM)_{CD} = (FEM)_{DC} = 0$$



Joint	*A*	*B*		*C*		*D*
Mem.	*AB*	*BA*	*BC*	*CB*	*CD*	*DC*
DF	0	0.6154	0.3846	0.3846	0.6154	0
FEM			−384	384		
DM		236.31	147.69	−147.69	−236.31	
COM	118.16		−73.84	73.84		−118.16
DM		45.44	28.40	−28.40	−45.44	
COM	22.72		−14.20	14.20		−22.72
DM		8.74	5.46	−5.46	−8.74	
COM	4.37		−2.73	2.73		−4.37
DM		1.68	1.05	−1.05	−1.68	
COM	0.84		−0.53	0.53		−0.84
DM		0.32	0.20	−0.20	−0.33	
COM	0.16		−0.10	0.10		−0.17
DM		0.06	0.04	−0.04	−0.06	
COM	0.03		−0.02	0.02		−0.03
DM		0.01	0.01	−0.01	−0.01	
$\sum M$	146.28	292.57	−292.57	292.57	−292.57	−146.28



FEM_{AB} = - $wL^2/12$ =- 64.395 * $2.2^2/12$ = -25.973 kN.m

FEM_{BA} = $wL^2/12$ = 64.395 * $2.2^2/12$ = 25.973 kN.m

FEM_{BC} = - $w1L^2/12$+ (w2-w1) $L^2/30$ = 13.467 * $2.2^2/12$ + (33.267-13.467)*$2.2^2/30$ = -11.342 kN.m

FEM_{CB} = $w1L^2/12$+ (w2-w1) $L^2/20$ = 13.467 * $2.2^2/12$ + (33.267-13.467)*$2.2^2/20$ = -12.939 kN.m

FEM_{CD} = - $wL^2/12$ =- 74.395 * $2.2^2/12$ = -30.006 kN.m

FEM_{DC} = $wL^2/12$ = 74.395 * $2.2^2/12$ = 30.006 kN.m

FEM_{DA} = - $w1L^2/12$+ (w2-w1) $L^2/20$ = 13.467 * $2.2^2/12$ + (33.267-13.467)*$2.2^2/20$ = -12.939 kN.m

FEM_{AD} = $w1L^2/12$+ (w2-w1) $L^2/30$ = 13.467 * $2.2^2/12$ + (33.267-13.467)*$2.2^2/30$ = 11.342 kN.m

	A		B		C		D	
	AD	AB	BA	BC	CB	CD	DC	DA
DF	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
FEM	11.342	-25.973	25.973	-11.342	12.939	-30.006	30.006	-12.939
DM	7.32	7.32	-7.32	-7.32	8.53	8.53	-8.53	-8.53
COM	-4.27	-3.66	3.66	4.27	-3.66	-4.27	4.27	3.66
DM	3.96	3.96	-3.96	-3.96	3.96	3.96	-3.96	-3.96
COM	-1.98	-1.98	1.98	1.98	-1.98	-1.98	1.98	1.98
DM	1.98	1.98	-1.98	-1.98	1.98	1.98	-1.98	-1.98
COM	-0.99	-0.99	0.99	0.99	-0.99	-0.99	0.99	0.99
DM	0.99	0.99	-0.99	-0.99	0.99	0.99	-0.99	-0.99
COM	-0.50	-0.50	0.50	0.50	-0.50	-0.50	0.50	0.50
DM	0.50	0.50	-0.50	-0.50	0.50	0.50	-0.50	-0.50
COM	-0.25	-0.25	0.25	0.25	-0.25	-0.25	0.25	0.25
DM	0.25	0.25	-0.25	-0.25	0.25	0.25	-0.25	-0.25
COM	-0.12	-0.12	0.12	0.12	-0.12	-0.12	0.12	0.12
Total M	18.23	-18.48	18.48	-18.23	21.65	-21.90	21.90	-21.65

Mid-span moments

$M^{+}_{AB} = wL^2/8 – (M^{-}_{1} + M^{-}_{2})/2$

$= 64.395 * 2.2^2/8 – (18.48+18.48)/2 = 20.48$ kN.m

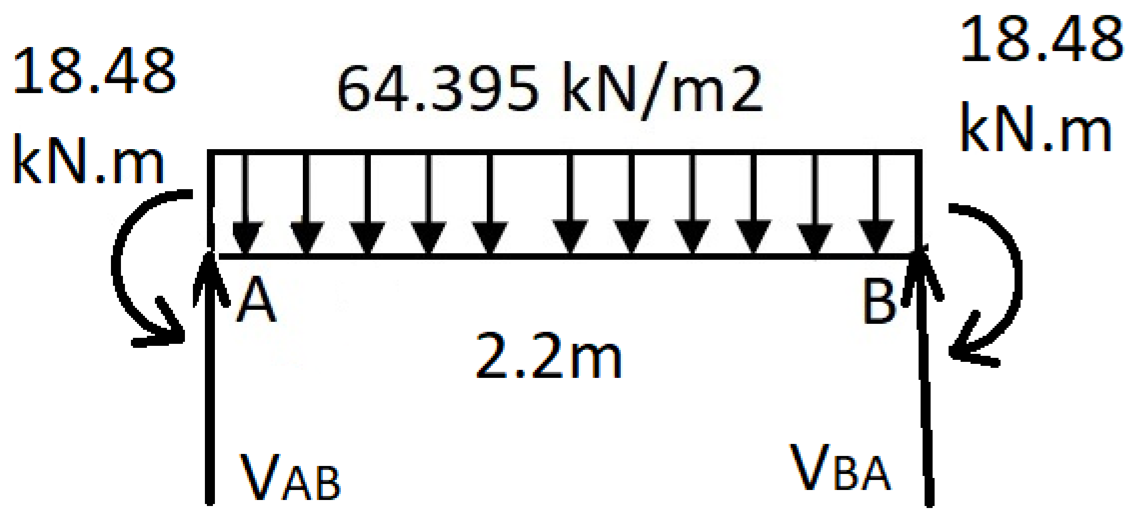
$M^{+}_{CD} = wL^2/8 – (M^{-}_{1} + M^{-}_{2})/2$

$= 74.395 * 2.2^2/8 – (21.9+21.9)/2 = 23.11$ kN.m

$M^{+}_{BC} = M^{+}_{AD} = [w_1L^2/8 + (0.128 * (w_2 – w_1) * L^2)] – (M^{-}_{1} + M^{-}_{2})/2$

$= [13.467*2.2^2/8 + (0.128 * (33.267-13.467) * 2.2^2)] – (18.23+21.65)/2 = 0.47$ kN.m

Checking Shear



$\sum M_B = 0$

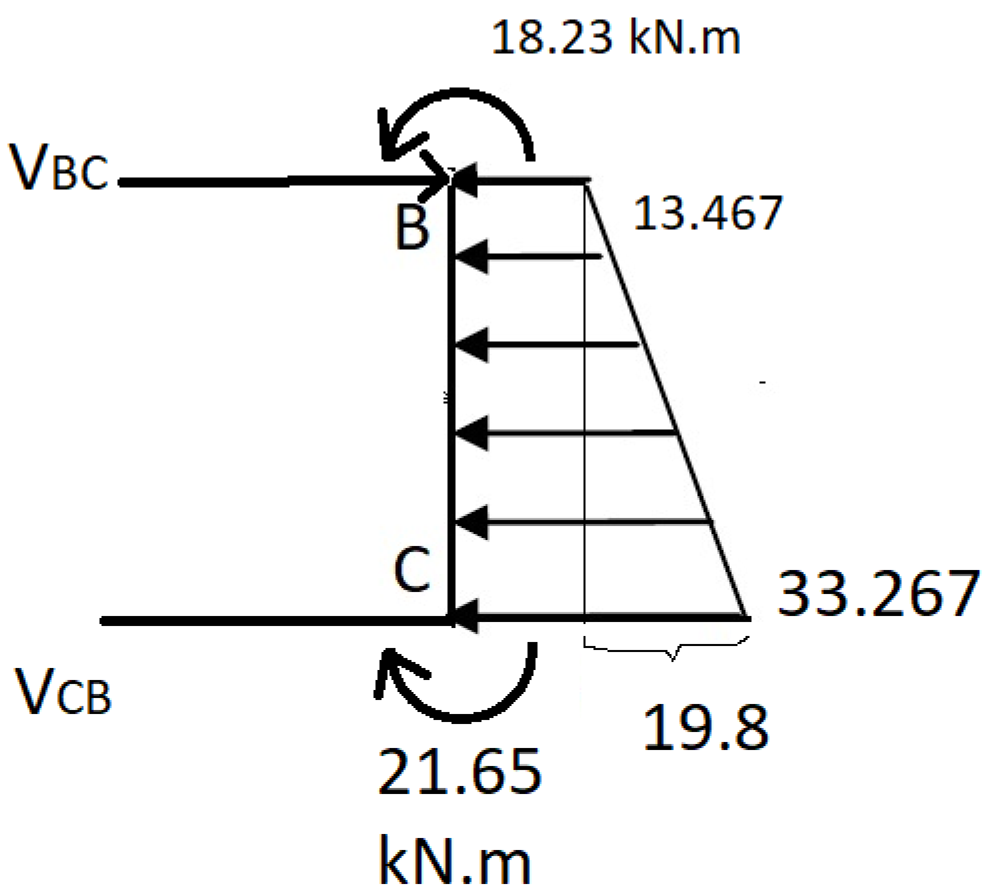
$V_{AB} * 2.2 - 18.48 + 18.48 - 64.395 * 2.2 * 1.1 = 0$

$V_{AB} = 70.8\ kN$

$\sum fy = 0$

$70.8 - 64.395 * 2.2 + V_{BA} = 0$

$V_{BA} = 70.8\ kN$



$\sum M_c = 0$

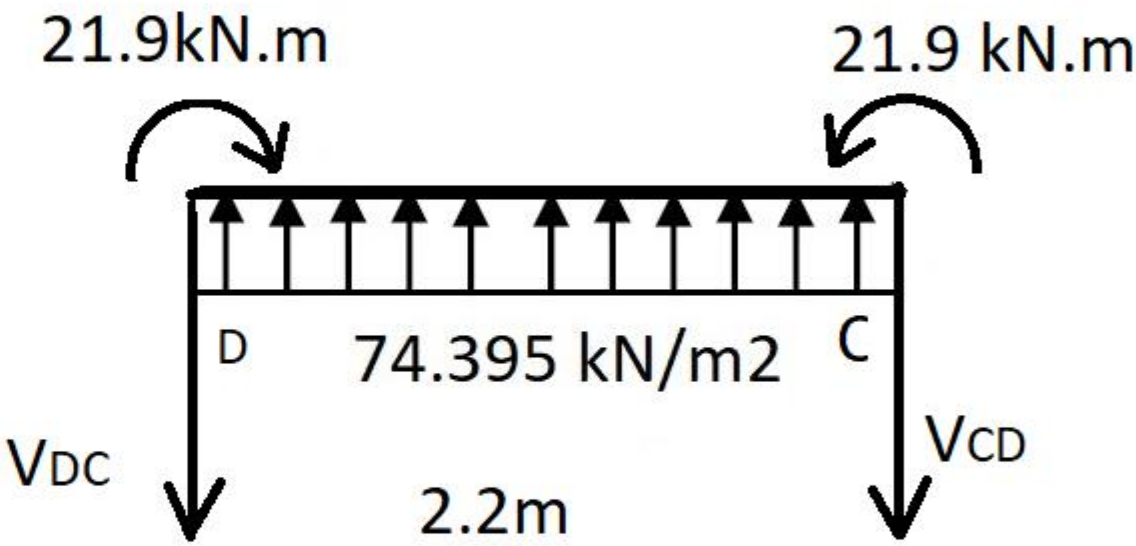
$V_{BC}*2.2 - 18.23 + 21.65 - 13.467*2.2*1.1 - 19.8*2.2/2*2.2/3 = 0$

$V_{BC} = 20.5\ kN$

$\sum fX = 0$

$20.5 + V_{CB} - 13.467*2.2 - 19.8 * 2.2/2 = 0$

$V_{CB} = 30.9\ kN$



$\sum M_C = 0$

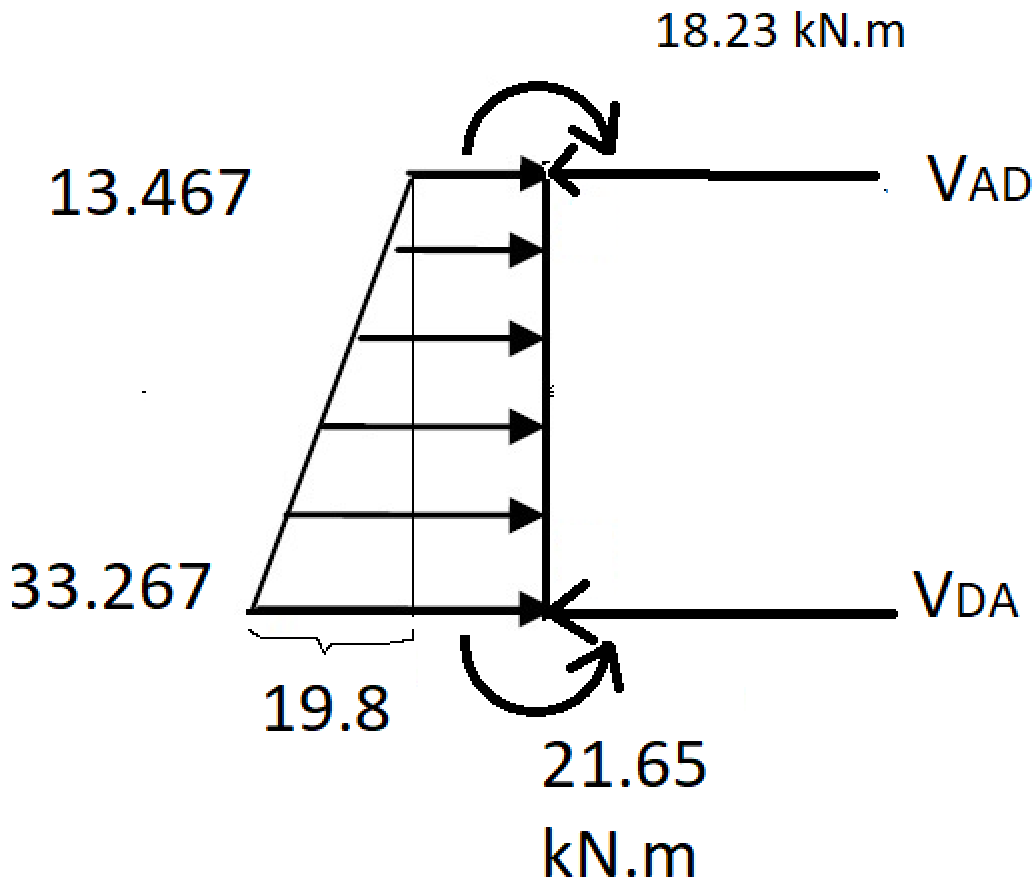
$-V_{DC} * 2.2 + 21.9 - 21.9 + 74.395*2.2*1.1 = 0$

$V_{DC} = 81.8\ kN$

$\sum fy = 0$

$-81.8 - V_{CD} + 74.395*2.2 = 0$

$V_{CD} = 81.8\ kN$



$\sum M_D = 0$

$-V_{AD}*2.2 +18.23 - 21.65 + 13.467*2.2*1.1 +19.8*2.2/2*2.2 /3= 0$

$V_{AD} = 20.5\ kN$

$\sum fX = 0$

$-20.5 - V_{DA} +13.467*2.2 + 19.8 * 2.2/2= 0$

$V_{DA} = 30.9\ kN$

$$\emptyset Vc = \emptyset\ 0.17\ \lambda \sqrt{f'c}\ bw\ d$$

λ = modification factor according to the type of concrete. In case of normal concrete, it equals 1.
bw = width of the concrete section

$d = h - cover - \emptyset/2$

= 200 − 75 −12/2
= 119 mm

$$\emptyset Vc = 0.75 * \ 0.17\ \sqrt{30} * 1000 * 119\ * 10^{-3} = 83.1\ kN$$

Max V is V_{DC} and $V_{CD} = 81.8\ kN < 83.1$ OK

$$R = \frac{Mu}{\phi bd^2}$$

$$m = \frac{f_y}{0.85 f'_c}$$

$$\rho = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2mR}{f_y}}\right)$$

Ø = 0.9

$A_s = \rho bd$

For Mu = 23.11 kN.m :

$R = 23.11*10^6/(0.9 * 1000* 119^2) = 1.81$

*m = 400 / (0.85 * 30) = 15.69*

p = 1/15.69 [1- $\sqrt{1 - \frac{2*15.69*1.81}{400}}$] = 0.0047

$As = 0.0047 * 1000*119 = 560\ mm^2/m$

Member	Joint	Mu kN.m	m	R	p	As mm^2/m
AB	A	18.48	15.69	1.45	0.0037	444
	Mid-Span	20.48	15.69	1.61	0.0042	494
	B	18.48	15.69	1.45	0.0037	444
BC	B	18.23	15.69	1.43	0.0037	438
	Mid-Span	0.47	15.69	0.04	0.0001	11
	C	21.65	15.69	1.70	0.0044	523
CD	C	21.9	15.69	1.72	0.0045	530
	Mid-Span	23.11	15.69	1.81	0.0047	560
	D	21.9	15.69	1.72	0.0045	530
DA	D	21.65	15.69	1.70	0.0044	523
	Mid-Span	0.47	15.69	0.04	0.0001	11
	A	18.23	15.69	1.43	0.0037	438

$A_{s\,min} = 0.0018 * 420 / fy * Ag \geq 0.0014\, Ag$

$A_{s\,min} = 0.0018 * 420 / 400 * 200 * 1000 = 378\ mm^2/m$

$\geq 0.0014\, Ag = 0.0014 * 200 * 1000 = 280\ mm^2/m$

$A_{s\,min} = 378\ mm^2/m$

For As = 560 mm²/m

Use Ø12@20 cm As = 113 5= 565 > 560 mm²/m OK*

Max spacing (Smax) = 3h ≤ 450mm

*=3*200 = 600 mm > 450 mm*

Smax = 450 mm

S = 200 mm < 450 mm OK

Use Ø12@20 cm as flexural reinforcement for all parts of the culvert

Shrinkage and temperature reinforcement

$A_{s\ min}$ = 0.0018 * 420 /fy * Ag ≥ 0.0014 Ag

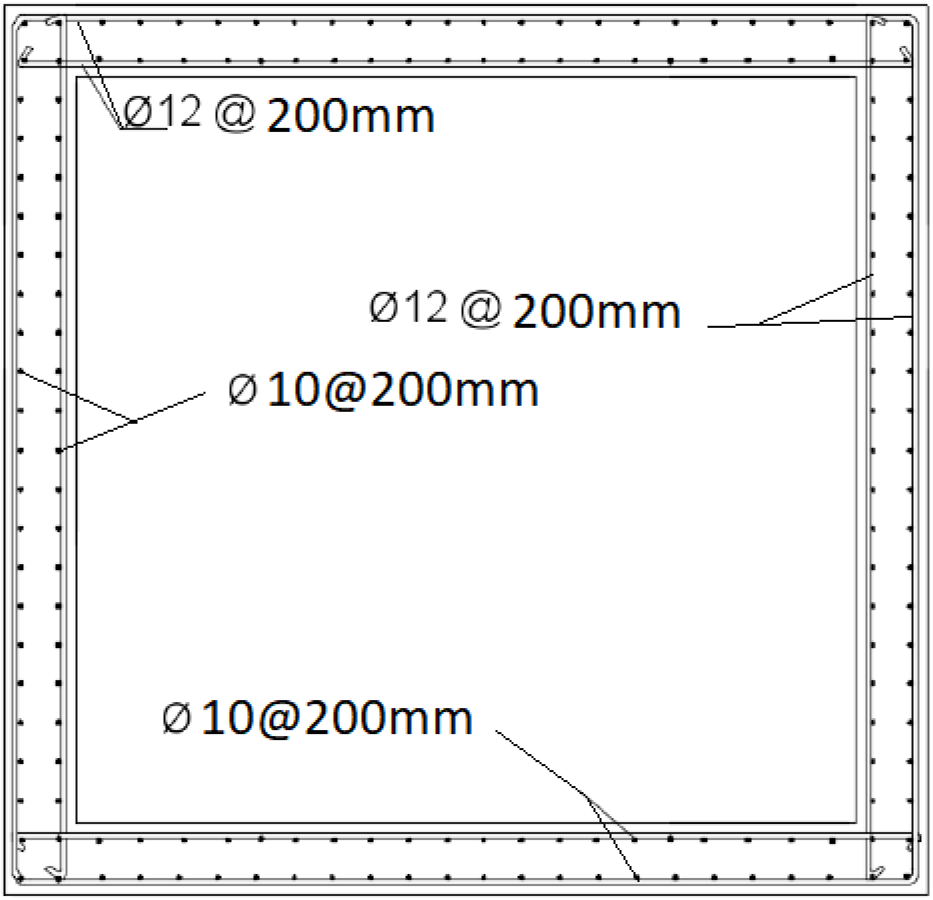
$A_{s\ min}$ = 378 mm²/m

Max spacing (Smax) = 5h ≤ 450mm

*=5*200 = 1000 mm > 450 mm*

Smax = 450 mm

*Use Ø10@20 cm As = 79 * 5= 395 > 378 mm²/m OK*


Ø12 @ 200mm
Ø12 @ 200mm
Ø 10@200mm
Ø 10@200mm