The Structural Design of a Reinforced Concrete Box Culverts

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ABSTRACT

Box – Culverts are an important part and an indispensable structural component in civil engineering, especially when it comes to making this part a link between nature and concrete structures by making box culverts as a bridge to cross vehicles or pedestrians or both and other uses as they are cheap and economical Compared to the construction of a bridge for this purpose. We can see these box culverts in different shapes and types in terms of the materials used for them or the way they are built, where some of them are bricks, stone or concrete, but their types, for example, are in the form of surface bridges or tube or box channels with square walls or triple walls and others depend This depends on the place of use and the loads and loads resulting from the effect of water or the reaction resulting from the soil. To design the box culverts, consideration must be given to the state of the structure, whether it is full or empty, the amount of forces exerted on it, the amount of reactions resulting from the soil and the forces resulting from the movement of water inside the box culverts, as well as the amount of forces applied to the live loads resulting from movement over the box culverts As well as the amount of dead loads for box culverts. All these limitations and others lead to one result, which is the design of box culverts that are characterized by their resistance to conditions and safe for users. The aim of this study is to design reinforced concrete box culverts based on the highest value of positive moments and the highest value of negative moments, in addition to taking the highest amount of shear strength and designing box culverts that can be used well for the purpose of resisting all live and dead loads as well as all forces resulting from water or the soil . All results are manual results and no programs were used in order to achieve the greatest benefit in terms of the accuracy and acceptability of the results during the design

Keywords: Box–Culverts, lateral forces, Moments, thrust , shear force , concrete , slab

1. Introduction

Box culverts consist of two side walls and two upper and lower roofs, and are used for the purpose of crossing people or vehicles or transporting water through them and constructing roads and railways over them, as they have a very high resistance to loads, whether vertical loads or lateral loads, they are always suitable for all places due to the low cost of construction Compared to bridges or tunnels and the speed of their construction, and it can be with a single or multiple openings depending on the place and type of use, noting that the ground roof does not need special treatment when it is built, because the ground roof acts as a raft over the soil, which increases its resistance to pressures and loads. One of the most important places in which box culverts are used are areas that collect rainwater in depressions and form dangerous torrents and conflict with roads, residential areas and river areas through which transportation methods such as railways and paved roads pass. And the areas through which water needs to cross to the other side, these are the most important areas in which the box culverts need to work[1]

An important note: When designing box culverts, the strength of the water flow must be taken into account at the moment it enters the box culverts, because the movement of water will be strong and will sometimes be destructive to the structure. From the above mentioned were the most important advantages of box culverts

As for its downsides, it exposes the reinforced concrete to the attack of salts and chlorides as a result of water contact with the concrete, which will negatively affect the rebar used in box culverts. One of the best solutions is to use reinforced concrete with GRFP bars[2] The culverts are also clogged as a result of sediment, stones or cutting down trees, which leads to a problem in the drainage process. In some cases, the construction of box culverts with more than one drainage holes is required for the purpose of draining the water, knowing that this case is done in the case of abundant water that requires its drainage quickly so as not to affect the roads or the facilities adjacent to it. The function of the transmission of forces in this structure is based around the side walls and the upper ceiling, since the loads are transmitted directly from it to the lower ceiling of the box culverts, so care must be taken when designing the box culverts and providing an appropriate safety factor for it so that we do not face any problems such as cracks or failure in the future. Concrete

2. Literature Review

1. Mr. Afzal Hanif Sharif July (2016)

Worked on a study using the torque distribution method and matching the results with the STAAD PRO program method in order to come up with the best way for the purpose of designing a box culvert that is suitable and safe in the best way[3]

2. Ajay R. Polra, Pro. P. Chandresha, Dr. K.B Parikh (2017)

Where this topic dealt with the values of box culverts determinants, the aim of which is to observe the effect of stresses, moments, dispersion angles and soil strength on the origin in the case of cushioning or without cushioning[4]

3. Sujata Shreedhar, R. Shreedhar (2017)

The study was on designing factors for each case of box culverts, starting from single to dual box culverts, where the study included the moments and shear forces and their development in each axis, after which each case of force loading was studied for them[5].

4. Sravanthi, G. Ramakrishna Rao, Dr. M. Kameshwara Rao (2015)

The study was also represented on the topic of designing a structure manually using transactions with linking work using the STAAD PRO program, where the study showed that the possibility of using box culverts with one or more openings depends on the length of the facility, the quantity and strength of water flow, in addition to other factors[6]

3. Cases To Be Solved & Parameters Used:

For this work, box- culverts of reinforced concrete in a prismatic shape with dimensions shown in the Figure 1 over which a highway pass. Description for Parameters used for designing in Table 1as shown below

Table 1 Parameters Used for Designing

Parameters	Values
The dead load	9 KN/m²
the live load	50 KN/m²
Density of the soil	18 KN/m³
angle of repose of the soil is	30°
Adopting concrete	M-20 grade
Adopting for steel	Fe-415 grade

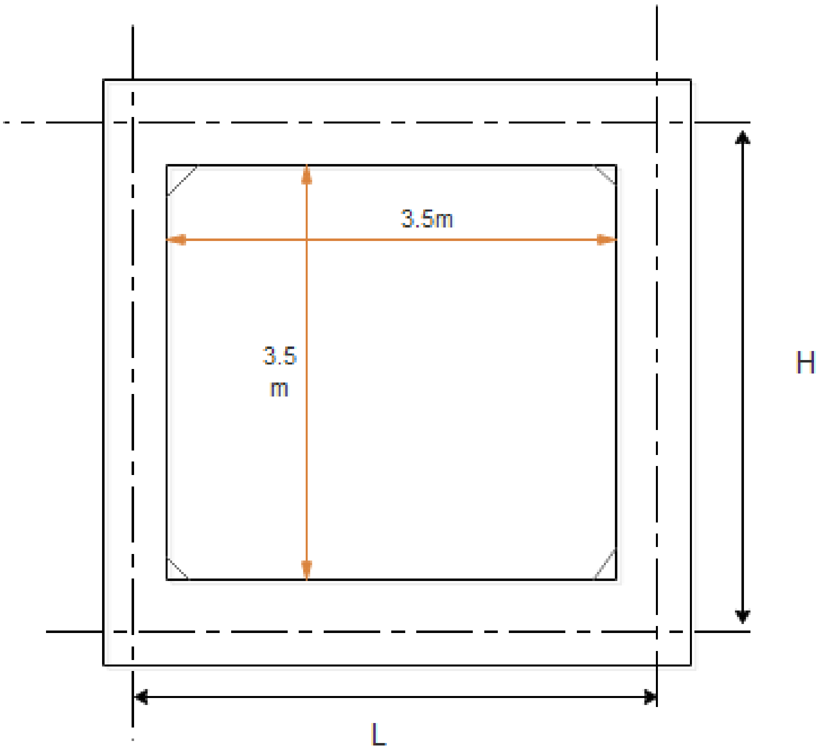

Figure 1Box Culvert Dimensions

3.1. Design

3.2. Loads

The structural design of the box culverts for reinforced concrete includes the analysis of the steel frame when applying shear forces, moments and thrust caused by different types of loading forces imposed on the structure [7,8]as follows:-

W= concentrated load on the slab
P= wheel load
I= impact factor
E = effective width of dispersion
Then:

$$\mathrm{W} = \frac{P \times I}{e} \quad (1)$$

Case 1 :Concentrated Loads This situation is caused by the movement of vehicles on the upper ceiling, assuming that the reactions of the earth to them are equal over the entire area of the lower ceiling of the box culverts., as shown in the Figure 2below

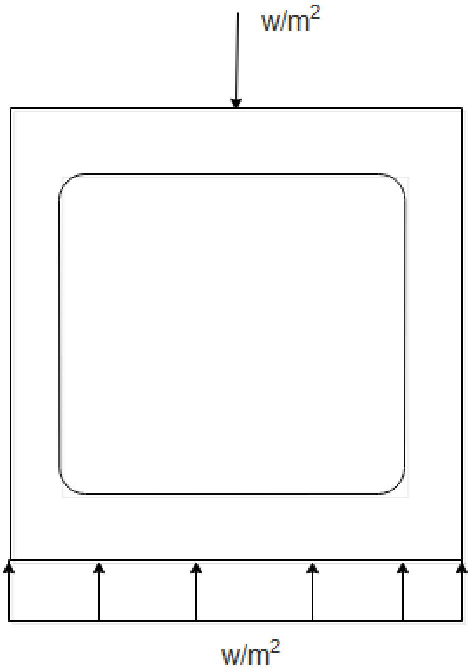

Figure 2. concentrated load

Case 2 :Uniform distributed load In this case, we consider that the vehicle loads with the weight of the upper roof and all the ends that are attached to the roof as loads are evenly distributed over all parts of the upper roof, as shown in the Figure 3below

γ_c = Density of concrete (kN/m^3) = 24b

t_s = Thickness of span (m)

$$\text{Self-weight of top slab} = ts \times \gamma c \times 1m = wc \times 1m \quad (2)$$

$$\text{Super imposed dead load}(w_{S.I.D}) := wS.I.D \times 1m \quad (3)$$

Live load: = Wlive × 1m (4)

$$W\ total = Eq\ no.2 + Eq\ no.3 + Eq\ no.4 \quad (5)$$

Moment (M) =WL^2
Thrust (N) =W
Shear (V) =WL

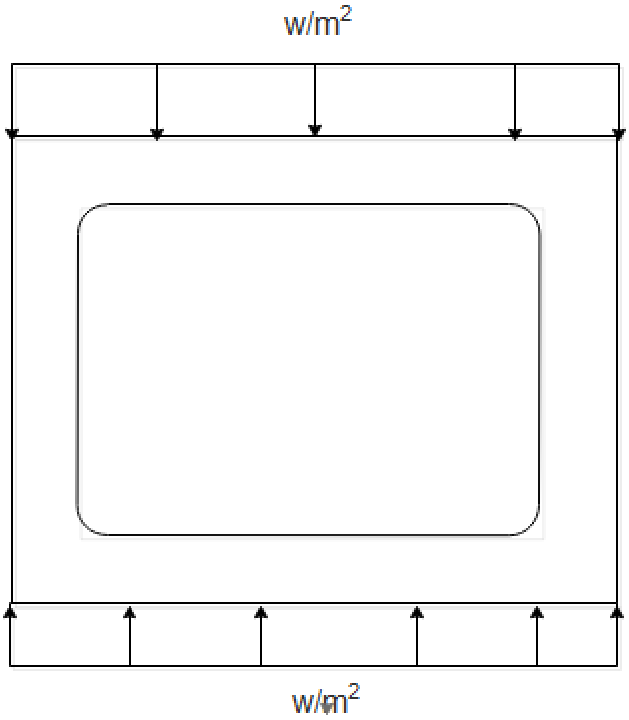

Figure 3. Uniform distributed load

Case 3: Weight of vertical side wall Assuming that the weight of the side walls are loads placed on all the box culverts of its lower slab, as shown in the Figure 4below

γ_c = Density of concrete (kN/m³) = 24

t_w = Thickness of web (m)

H= t_w + h

$$W = tw \times H \times \gamma c \times 1m \qquad (6)$$

Moment (M) =WL

Thrust (N) =W

Shear (V) =W

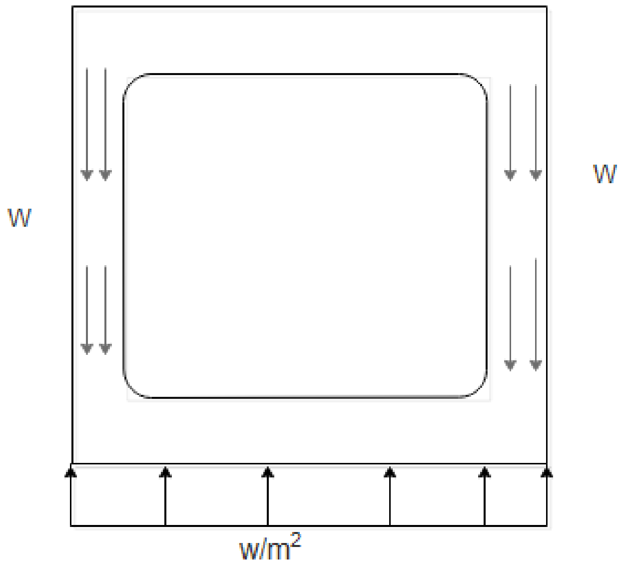

Figure 4. Weight of vertical side wall

Case 4 :Water pressure inside culvert When the box culverts are filled with water, lateral forces are formed on the walls of the canal, the maximum force in it at the bottom forming a pyramidal shape along the wall, as shown in the Figure 5below

γ_c = Density of concrete (kN/m^3) = 24
γ_w = Density of water (kN/m^3) = 10
t_w = Thickness of web (m)
H= t_w + h

$$P = \gamma w \times H \times 1m \quad (7)$$

Moment (M) =PL^2
Thrust (N) =PL
Shear (V) =PL

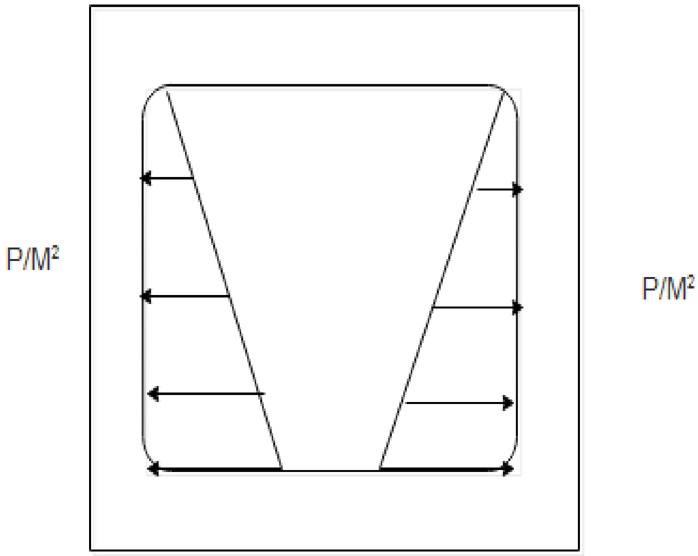

Figure 5. Water pressure inside culvert

Case 5: Earth (soil) pressure on vertical side wall The soil pressure on the retaining walls of box culverts is calculated according to Coulomb's theorem and according to the Figure 6 below

θ°= Angle of repose
γ_s = Density of soil (kN/m^3) = 18
t_w = Thickness of web (m)
H= t_w + h

$$P = \gamma S \times H \times \frac{1 - \sin\theta}{1 + \sin\theta} \times \frac{\pi}{180} \times 1m \quad (8)$$

Moment (M) =PL^2
Thrust (N) =PL
Shear (V) =PL

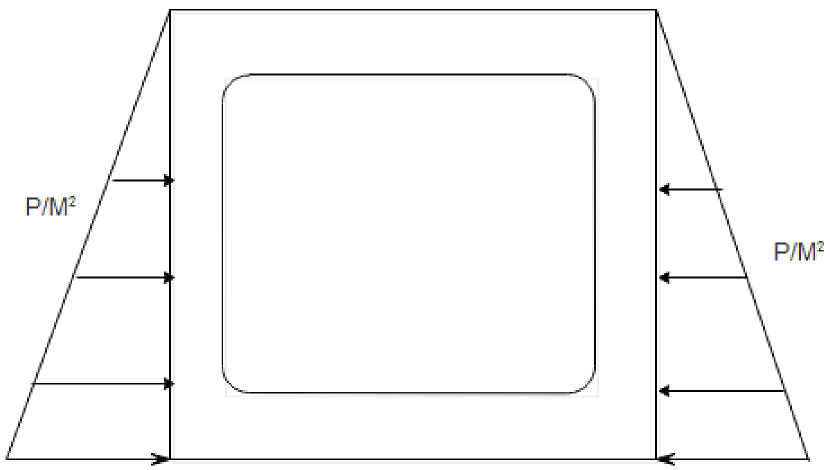

Figure 6. Earth (soil) pressure on vertical side wall

Case 6a **:**Uniform lateral load effected of live and super imposed : They are the lateral forces equally distributed over the area of the side walls of the box culverts, which are pressing on the walls and resulting from the pressure of the soil for them., as shown in the Figure 7 below

$$P = (\text{Wlive} + \text{WS.I.D}) \times \frac{1-\sin\theta}{1+\sin\theta} \times \frac{\pi}{180} \times 1\text{m} \quad (9)$$

Moment (M) =PL^2
Thrust (N) =PL
Shear (V) =PL

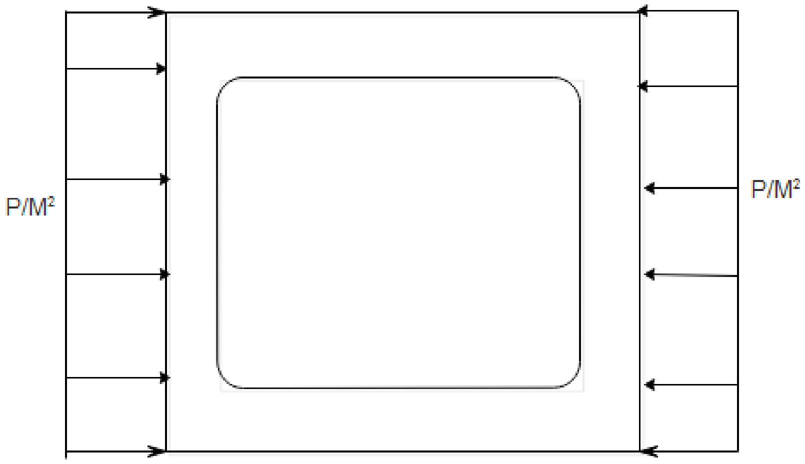

Figure 7. Uniform lateral load effected of live and super imposed

Case 6b :Uniform lateral load effected of super imposed dead loads on side wall They are the lateral forces distributed in the form of an uneven trapezoid over the entire area of the side walls of the box culverts, which are pressing on the walls and resulting from the pressure of the soil for them., as shown in the Figure 8below

$$P = \text{WS.I.D} \times \frac{1-\sin\theta}{1+\sin\theta} \times \frac{\pi}{180} \times 1\text{m} \quad (10)$$

Moment (M) =PL^2
Thrust (N) =PL
Shear (V) =PL

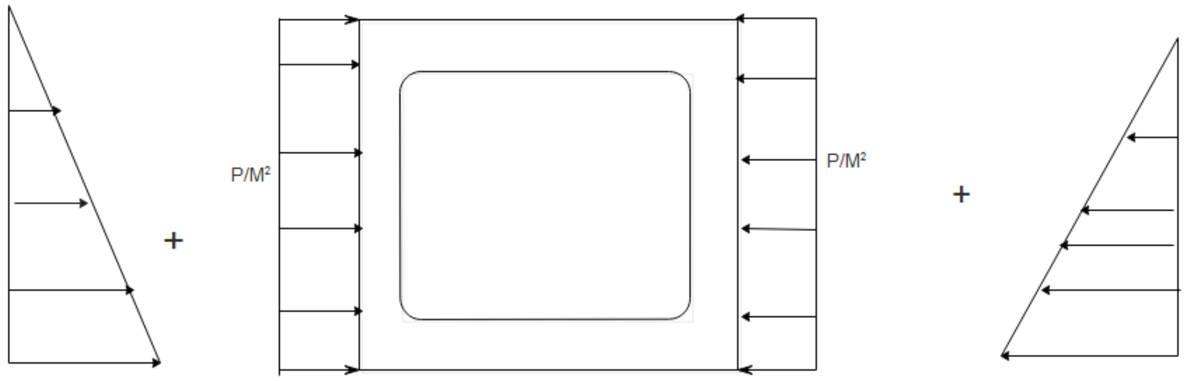

Figure 8. Uniform lateral load effected of super imposed dead loads on side wall

Therefore, Table 2represents the results of the values of the previous cases that we touched on, which included obtaining the values of moments, shear forces and thrust for each of them, which came by multiplying each coefficient[1,3]. with the value of each w or p and according to each case. Figure 9 represents the locations of the sections for which we found the values of moments, shear forces, and thrust.The results of the design loads will be as follows:

Table 2. values of design loads in each section

$(length)^2$	L2	14.8225					
Length	L	3.85					
	W	67.4	32.34	38.5	23.1	19.67	3
case numbers.		2	3	4	5	6A	6B
Moment (M)		999.0365	124.509	570.6663	342.3998	291.5586	44.4675
Thrust (N)		259.49	32.34	148.225	88.935	75.7295	11.55
Shear (V)		259.49	32.34	148.225	88.935	75.7295	11.55
b-1	M	82.92003	2.614689	10.84266	-6.5056	-12.2455	-1.86764
	N	0	0	-24.7536	14.85215	37.86475	5.775
A-2	M	-41.9595	2.614689	10.84266	-6.5056	-12.2455	-1.86764
	N	0	0	-24.7536	14.85215	-37.8648	-5.775
	V	129.745	0	0	0	0	0
A-3	M	-41.9595	2.614689	10.84266	-6.5056	-12.2455	-1.86764
	N	129.745	0	0	0	0	0
	V	0	0	24.75358	-14.8521	-37.8648	-5.775
E-4	M	-41.9595	-5.22938	-24.5386	14.72319	24.19936	3.690803
	N	129.745	16.17	0	0	0	0
D-5	M	-41.9595	-0.49804	13.12532	-7.87519	-12.2455	-1.86764
	N	129.745	32.34	-49.3589	29.61536	0	0
	V	0	0	0	0	37.86475	5.775

D-6	M	-41.9595	-12.9489	13.12532	-7.87519	-12.2455	-1.86764
	N	0	0	0	0	37.86475	5.775
	V	-129.745	-32.9868	-49.3589	29.61536	0	0
C-7	M	82.92003	18.17831	13.12532	-7.87519	-12.2455	-1.86764
	N	0	0	-49.3589	29.61536	37.86475	5.775

3.3. Analysis of moments, shear and thrust

Table 3 represents the sum of the results for each value in the same section and the same type. The values were moments or shear forces or thrust from the previous Table 2 and as indicated by[7],Figure 9 shows the locations of the clips for each case

Table 3. loading combination for each section

SECTION	LOADING COMBINATION CASES	SITUATION
D-6	2+3+5+6a	Support of down slab
A-2	2+3+5+6a	Support of top slab
B-1	2+3+4+5+6b	Center of top slab
C-7	2+3+4+5+6b	Center of down slab
E-4	2+3+4+5+6b	Center of side slab

After determining the values, the values are grouped according to what was mentioned in Table 3 where the values were as follows in Table 4 as follows:

Table 4. Values of Loading Combination

	Moment (M)		Thrust (N)		Shear (V)
D-6	-75.0291		37.86475		-133.116
A-2	-58.0959		-23.0126		129.745
B-1	88.00415		-4.12643		0
C-7	104.4808		-13.9686		0
E-4	-53.3136		145.915		0

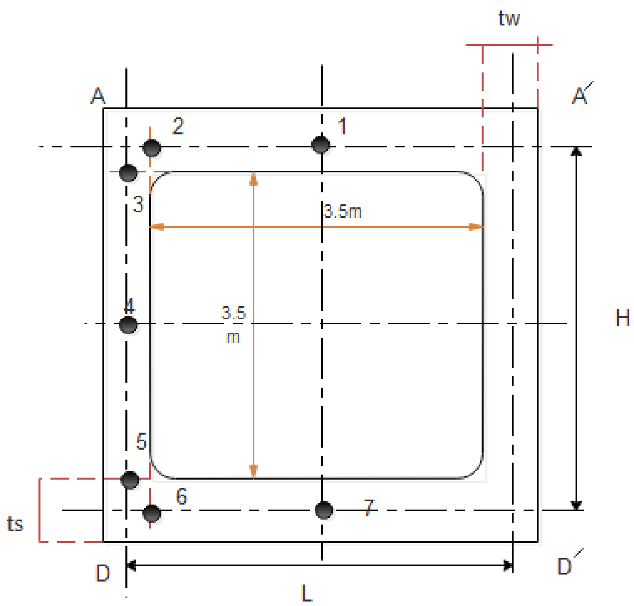

Figure 9. The locations of the sections of the box culverts

Figure 10 shows the ends to be taken care of and designed for the purpose of making a good and safe design, since these places are characterized by their permanent danger towards loads and soil reactions to the design, where[7] shows how to design this paragraph and according to the equations mentioned in the Table 5Fixed End Moments in Box Culverts

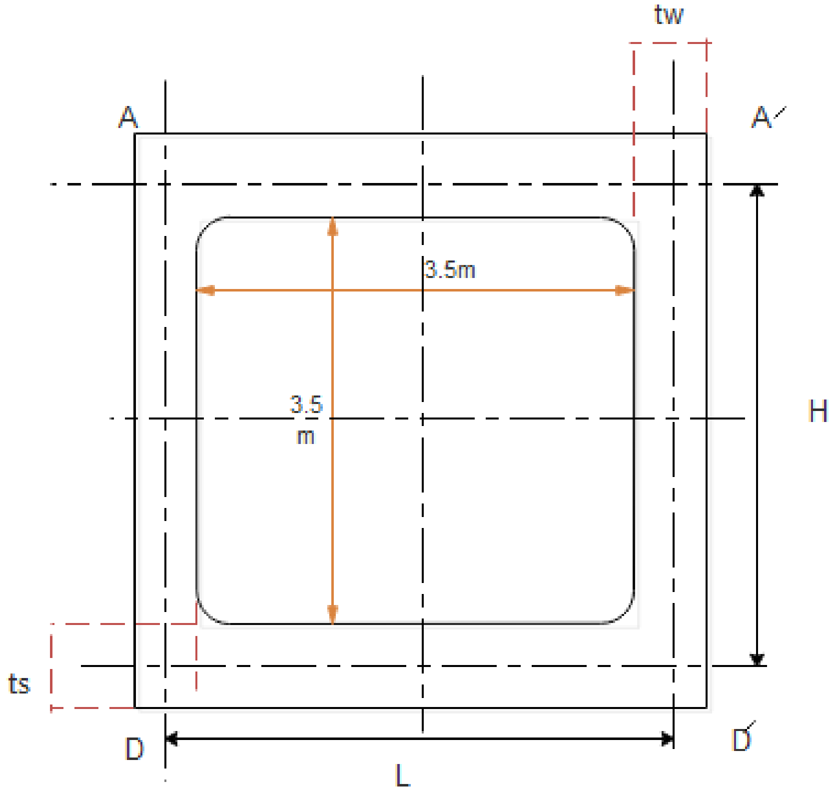

Figure 10. for edge box culvert

Table 5. Fixed End Moments in Box Culverts

Loading case	Fixed end moments	
	MA = MA/	MD = MD/
1	$-\frac{WL}{12}[\frac{2K+4.5}{(K+3)(K+1)}]$	$-\frac{WL}{24}[\frac{2K+4.5}{(K+3)(K+1)}]$
2	$-\frac{WL^2}{12(K+1)}$	$-\frac{WL^2}{12(K+1)}$
3	$+\frac{WL}{6}[\frac{K}{(K+3)(K+1)}]$	$-\frac{WL}{6}[\frac{3+2K}{(K+3)(K+1)}]$
4	$+\frac{PH^2}{60}[\frac{K(2K+7)}{(K+3)(K+1)}]$	$+\frac{PH^2}{60}[\frac{K(3K+8)}{(K+3)(K+1)}]$
5	$-\frac{PH^2}{60}[\frac{K(2K+7)}{(K+3)(K+1)}]$	$-\frac{PH^2}{60}[\frac{K(3K+8)}{(K+3)(K+1)}]$
6	$-\frac{PKH^2}{12(K+1)}$	$-\frac{PKH^2}{12(K+1)}$

3.4. Results, discussions and Design of reinforcement

We find area steel (AST) (mm2)

$$(\text{AST}) = \frac{MP \times 10^6}{\sigma ST \times J \times (ts - d)} \quad (11)$$

Then we find

$$\text{S} = \frac{1000 \times A\emptyset}{(\text{AST})} \quad (12)$$

So now we most find Distribution steel

$$\text{DST (mm2)} = \frac{0.3}{100} \times \text{ts} \times 1000 \quad (13)$$

Note :(S) must be smaller than

$$\frac{1000 \times area\ \emptyset 10 \times 2}{\text{DST}} \quad (14)$$

Through the above equations No. 11, 12, 13 and 14 and Table 2.2.2 which includes the values of load combination and the results of Table 2.2.3 which includes fixed end moments in box culverts[7], it turns out that the area of the armature of the C-7 section is 2571 mm2. Use rebar of diameter 20 to equal this area and resist forces and external loads. The distance between each piece of rebar is 122 mm for each two sides of the box culverts. As for the section D-6, the area of the rebar is 1640 mm 2. Therefore, rebar with a diameter of 16 must be used to resist any An effective load on the structure. The distance between each piece of rebar is 122 mm, and this is in relation to the center of the middle of each part of the box culverts. As for the E-4 section, the rebar area was 2800 mm 2, where it is possible to use rebar with a diameter of 16 to resist all forces And the torques acting on it, but the distance between each piece and the other is 70 mm. All values have been included in Table 6 below with the inclusion of the final form of the design process that was done and concluded here in this paper in Figure 11.

1- The utmost need of this type lies in the drainage of rainwater, especially in mountainous areas, to prevent the erosion or the occurrence of mountain avalanches of soil or rocks.
2- Because of its resistance to high loads, box culverts succeeded in draining water or using it for other purposes on highways and subjected to high and continuous loads[10].
3- The largest positive torque in the box culverts occurs at the center of the lower slab
4- The largest negative moment of the box culverts occurs at the edges of the lower slab when there are loads on the upper slab.
5- Due to the resistance of the box culverts to loads, so they do not consume a lot of rebar,[11] and therefore it is considered very ideal for being economical in cost
6- You do not need to take care or make a great effort to provide solid foundations under the box culverts, as they are suitable for all conditions.
7- It is possible to increase the length of the box culverts when increasing the width of the road and this does not affect its durability and the work of the box culverts

Table 6. results of area steel and distribution steel

Section	**Area steel mm²**	**Distribution steel mm²**	**Final**
C-7	2571	1050	20∅at 122mm on both faces
D-6	1640	1050	16∅ at 122mm centers
E-4	2800	1050	16∅ at 70 mm

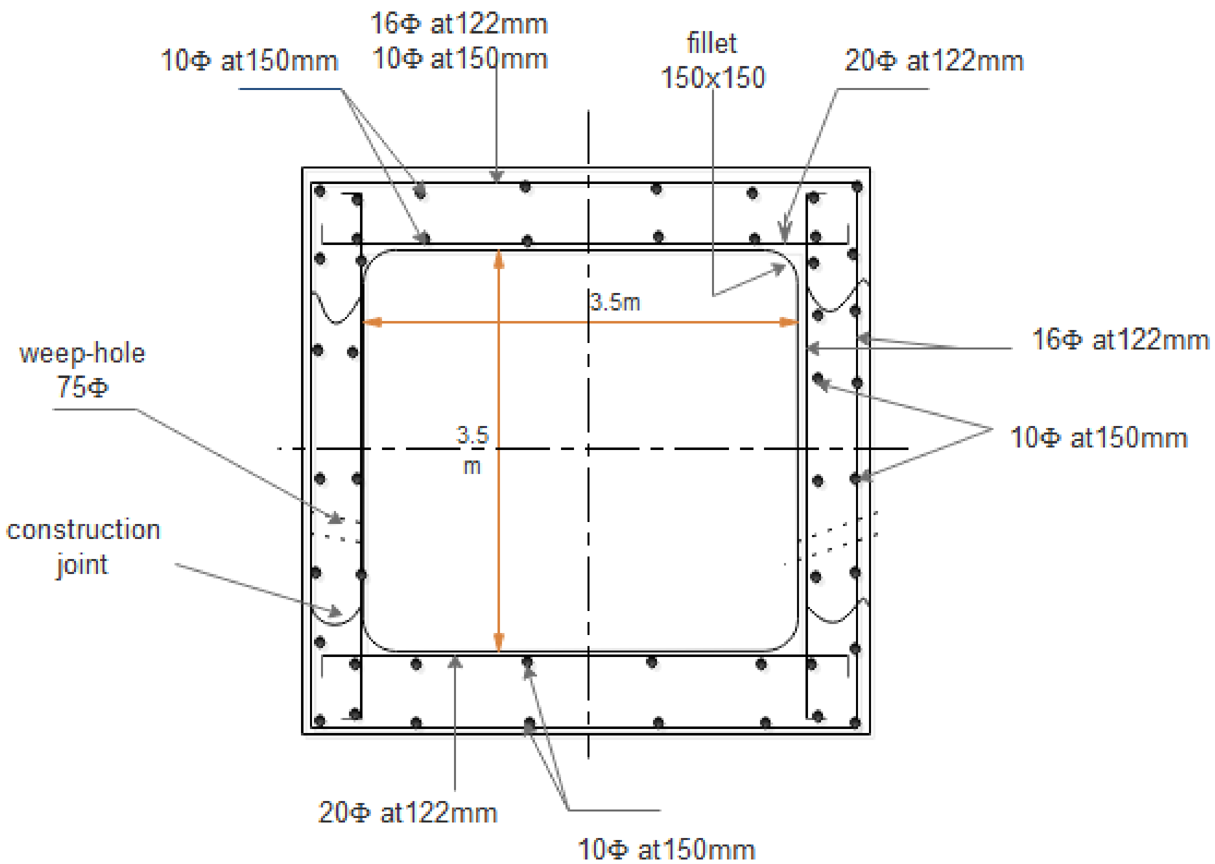

Figure 11. Final Shape for Design Box Culverts

Figure 12. Some forms of Box Culverts

3.5. Conclusion

1- The above study included working on the moments, thrust and shear forces at the critical state to apply forces to it.

2- The design is not restricted as it can be changed to two or more openings according to the data of the site and the urgent need to drain the water flow according to what the designer sees.

3- The sections D-6, E-4, C-7, and A-2 are critical sections on which the design depends.

4- The maximum torque is when a live lamb and a dead lamb dominate, but the canal is dry of water, and vice versa when it is completely submerged in water.

5- The largest positive torque is formed at the middle of the upper and lower ceiling of the box culverts

6- The largest negative torque is formed at the middle of the walls of the box culverts

7-We conclude that the greater the number of box culverts slots, the greater the resistance to the forces exerted, and therefore we do not need to support the design in a large way, and therefore it is more economic than the single slot of the box culverts

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