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Design of Culvert using Suitable Software

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ABSTRACT

At the time when required, there is a water canal or the natural stream which intersects the road or the carriageway width, the big problem for us is to know how to keep this stream of water flows away from the road so that the roadway should not get affected by such situations. And the vehicles which pass near that stream in the flood situations, should also not get affected by this natural disaster. So, looking at this purpose, the Culverts are must be constructed across these intersections. A Culvert is nothing but a structure that is designed for passing the water which is overflowing through the streams. In this research work, we discussed aspects of culverts required at the different locations. And the designs are done both manually as well as by taking the help of the design software. The Standard codes of the design of Bridges and Roads are used in this research work for compiling the design of the culvert part. Different software's are used for designing a culvert. From the results, for the design engineer, this research will offer to optimize saving of effort and also the time, by looking into effectiveness or accuracy.

Keywords: Stream, Culverts, Carriage Way, Disaster

1. INTRODUCTION

The hydraulic structure is the structure that is partially submerged or fully submerged in any water body, which eventually obstructs the flow of water. These structures are used to disrupt, completely stop, or divert the flow. This type of hydraulic structure is built in a sea, rivers, or at any water body where the change in water flow is needed.

Culvert is a structure i.e. hydraulic structure which allows flowing water under a road, trail, railroad, or from any other obstruction from one to another side. Which is typically embedded with the soil surroundings. Construction of culverts can be done with a variety of materials which include precast concrete or cast in Plane.

Culverts are used commonly both to pass water below the road or as cross drains as relief ditches for the stream crossing and also as natural drainage. Culverts are basically like bridge structures which are designed to pass the vehicle or traffic pedestrian to pass over the waterway with giving adequate passage for water to flow. There are many shapes and sizes of the culverts which include elliptical, box-like, and round constructions. Various factors are seen while shape selections and the culvert types which include, the height of roadway embankment, upstream limitation of water surface, and performances of hydraulic actions.

The consideration for structural design are load cases (full, surcharge loads, box empty, etc.) and initial factors like effective width, impact factor, load through fill dispersal, braking force, earth pressure co-efficient, etc. structural elements need to be designed by looking into bending moment (Maximum) and shear force. Referrals of various relevant codes are required.

Objectives: Nowadays there has been a large development in the building and construction in major parts of the country. And this development has given a large significance in the construction and design of the culverts. Great attention is to be made in the field of design of the box culvert, which in future there will be a part in the manual design for the bridges and road. Looking at above, this research work is examined to establish the following objectives:

- Hydraulically design of the box culvert
- To know all the loads acting on the culvert
- Appropriate design of box culvert
- Reinforcement design for box culvert
- Analysis of the box culvert with the help of Etabs Software

2. LITERATURE REFERENCES

Cremer (2007) in his research paper he introduces the use of various types of culverts to be established and that to be used for the passing of the water or the stream under the roadways, railways, etc. Normally the optimized selection of the culverts is dependent on the previous year's hydraulic data collected and the total catchment area volume which is estimated, looking at these factors the selection is made. From this research paper, he concluded the general basic shapes and segments of the culverts [1].

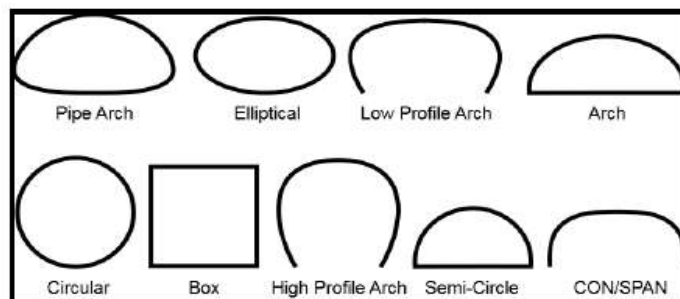


Fig. 1 Typical design of various culverts [1]

Kilgore et.al. (2012) in their research he made the consideration looking as per the economic behavior of the design. The author calculated all the data related to hydrology i.e. Catchment area, the total flow of water at that particular area, etc. Then the author made the comparison between the structures to be constructed at the site location. He estimated the bridge and culvert at that particular examined area. And at last, the author compared the difference in the economy relating to the bridge and the culvert [2].

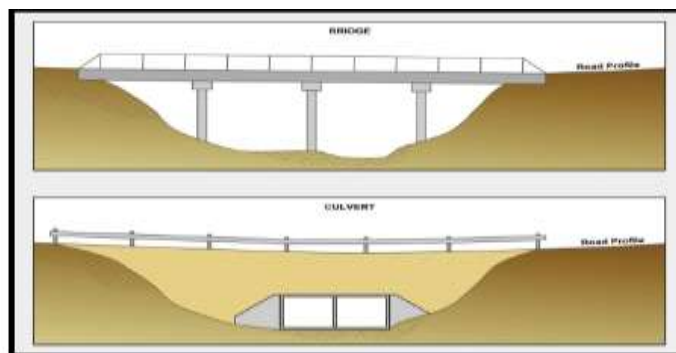


Fig. 2 Culvert and Bridge at same location [2]

Bolden et.al. (2016) in their research he mentioned that the design of culverts begins only when the design structure unit receives the report of hydraulic design of culverts. This report is used for containing the design fill, culvert length, and many other parameters which lead to the completion of culvert plan [3].

Garg (2007) reports that the design of box culverts is way similar to the design of bridges, and in current days the design for the bridge is based on Resistance factor design and loads which are invented by AASHTO. The four sides of the box culverts are cast monolithically and they are also provided by the haunch at corners to minimize the effect of water pressure. Since the bottom slab of Box culvert acts as a foundation so there is no need for providing any extra foundation [4].

3. METHODOLOGY

3.1 Design consideration for culvert as per hydrological data

A. Design peak flood estimation by the rational formula

Hydrological design for culvert is examined by hydrology response for catchment to rainfall design over it. Different factors which adverse the effect for peak runoff over drainage basin is: Cover condition, antecedent moisture condition, permeability, the magnitude of rainfall, time of concentration, etc. Because the catchment area for the culvert are small, so peak flood is normally calculated using Rational Formula:

$$Q=0.028f pm Ic A$$

Where, Q= Peak flood discharge

Pm= average runoff coefficient for catchment area

f= Fraction, depends on area and curve constructed by statistical analysis

Ic= Critical rainfall intensity as in Cm/hr

A= Catchment area calculated in Hec.

B. Hydraulic Design for culverts:

Flow through culverts: Looking at the magnitude flow through Culvert, outlet and inlet geometry, shape and size, bed slope, length, culvert may run full or part full as shown in fig. If $HW/D < 1.2$, the Culvert run as part full and no submergence of inlet. If $HW/D > 1.2$, the Culvert can run still as part full but there will be submergence of inlet.

C. Flow equation and control Types:

a. Inlet Control: For inlet Control the culvert considered to be submerged inlet, there is orifice type flow and culvert discharge can be obtained as, $Q = C_o A_o (2gHW)^{1/2}$,

Q= Discharge,

C_o= constant

A_o= area of orifice

b. Outlet control: For outlet control, the head losses are governed by head water elevation at entry (H_e), Headloss for outlet (H_o) and head loss caused by friction (H_f), as shown in fig. The depth of headwater is obtained as:

$$HW = H_o + H - L S_o$$

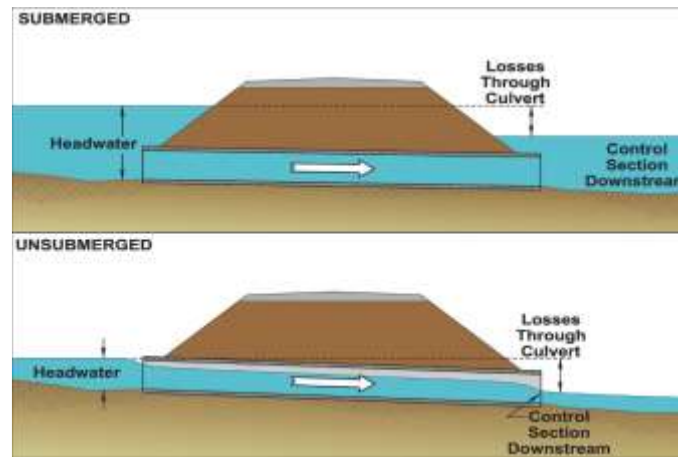


Fig.3 Typical outflow section

c. Software used for hydrological design of Culvert: Due to large complexity and lots of time is required to analysis culvert for hydraulics, Software used is ArcGIS, Which is now a days used widely all over to estimate the Catchment area, Stream length, Difference in the contour intervals.

3.2 Analysis and design method

After completion of the hydraulic design of the box culvert, the dimension of the culvert is taken considering the discharge capacity. The culverts are designed and analyzed considering the rigid frame and the bending moments are taken for end support. The moment distribution method is normally used to determine the final moments for the frame.

The culvert is to be analyzed considering the conditions of critical loading. For structural elements, the design is done as per the Limit state Principles.

A. Design principles for the Structural elements

The concrete elements structural design is in BS 5400: Part 4 and is implemented as BD 24 (Manual design for bridges and road volume 1) it will provide us with the proper design principles we need to adopt while designing.

B. Design principles for foundation design

1. Sliding: The failure possibility for the structure against sliding for base can be investigated by ULS (Ultimate limit state method).

2. Settlement and bearing failure for Foundation: The net bearing maximum pressure below the base for the structure below nominal loads can be checked against safe bearing pressure for the foundation to know that there will be adequate safety factor against bearing failure for the foundation and prevent differential settlement and excessive settlement.

C. Design principles for loads

1. Loads should be considered: Permanent load (superimposed Dead load, hydrostatic pressure, buoyancy and dead load).

Vertical Live Load (loads for carriage way i.e. HA or HB (vehicle which cover upto 44 tons load), cycle track loading and footway). **Horizontal live load** (Traction, Live load surcharge, Parapet collision, temperature effect, centrifugal load and accidental skidding).

2. Load combinations: Combination 1 (vertical live load, horizontal live load and permanent loads), Combination 2 (Temperature effect plus Combination 1 loads), Combination 3(Horizontal live load and permanent load, plus one among these: Traction, centrifugal loads).

4. RESULTS AND DISCUSSION

A. Calculation of Catchment area, Stream flow, Stream length, Contour intervals: The equation mention below for the culvert and the equation we have discussed in the methodology section are used to design the hydraulics of culverts.

$$\Delta H = \left(\frac{12.7 \times n^2 \times g \times l}{D^3} + k_{inlet} + k_{outlet} \right) \times \frac{Q^2}{D^4} \times \frac{1}{2g}$$

Hydraulics calculations by ArcGIS software: To determine catchment area manual recommends the use of standard maps to be used for hydrology are normally the 1:50000 topographical scale maps or 1:10000 orthophotos scale. If the catchment area at the particular location is less than 10 km², normally we made the use of latter. To calculate the catchment area, determination of manual procedures are entailed that the desired catchment boundary from the map is to be copied in graph paper, after that the number of squares which are seen in the catchment area is to be counted by looking at the squares which are more than the halfway onto the catchment. And then the conversion factor is made use for converting several squares onto the catchment area as in km². To measure the catchment area manually the planimeters are still in use.

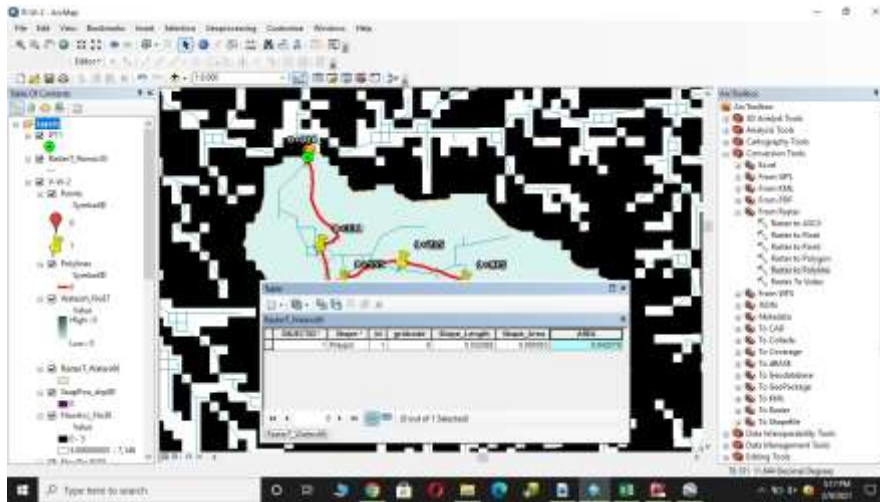


Fig. 4 Practical example of calculation for Catchment area, Contour intervals, Stream length as per ARCGIS Software

In the above example the points represents the culverts at the roadways, the polygon shape near the culvert points represent the catchment area on that particular points respectively, Blue lines indicates the flow of the stream at that particular area, red color lines indicates the contour form near the roadway and the culverts. To find the stream length we need to stretch the Blue lines conceding with the culverts, to know the contour difference we need to find the highest and the lowest contour at that specific culvert point, catchment area is automatically calculated by the watershed tool in ArcGIS.

Structural design of culvert using Etabs: Once the hydraulics design for the culvert location is completed we need to carry forward with the design and analysis part. From hydrology we get the dimensions of the culvert to be proposed as shown below :

Table.1 Identifying Culvert dimensions

| Drain Design Discharge (m ³ /s) | Size of Barrel (m) | Roof, wall and floor thickness (m) |
|--|--------------------|------------------------------------|
| 1.5 - 2.1 | 1.2 | 0.25 |
| 2.1 - 2.8 | 1.4 | 0.25 |
| 2.8 - 3.6 | 1.6 | 0.25 |
| 3.6 - 4.6 | 1.8 | 0.30 |
| 4.6 - 5.7 | 2.0 | 0.30 |
| 5.7 - 6.9 | 2.2 | 0.30 |
| 6.9 - 8.2 | 2.4 | 0.30 |
| 8.2 - 10.4 | 2.7 | 0.35 |
| 10.4 - 12.8 | 3.0 | 0.35 |

Once the dimension are set we need to make the model in Etabs. The model is prepared looking at the site conditions i.e. whether there will be cushion or not. If cushion is available then the loads on the culverts are change, since we have to examine the soil load also. So considering no cushion at location we will assign the loads that are given in the manual as shown below. The use of code SP IRC 13(mostly used for considering the loading cases) is also made in use to provide the loading. Once the loads are assign then it's time to do the analysis of that structure. After analysis we come across the maximum shear force and maximum bending moments.

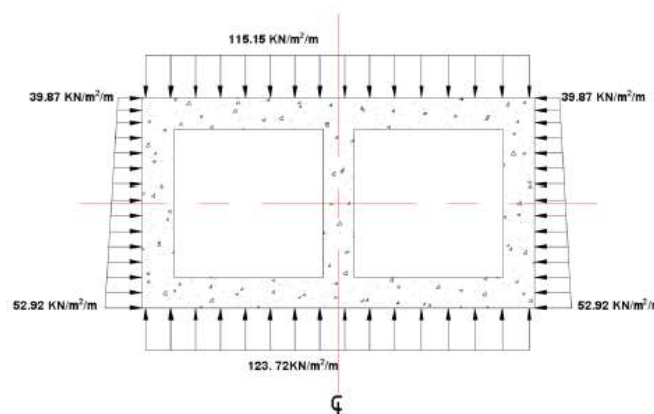


Fig. 5 Factor load distribution

Once the analysis is completed then next step is to go for the design of reinforcement. To calculate the reinforcement we have to fix the moments at the structure and by moment distribution method we come across the final moments. And this moments are used for the calculating the area of steel required. Manually we can do this by the moment distribution method and can find the area of steel required. But through Etabs software we just need to give the Grade of concrete and type of steel to be used then automatically the reinforcement is design in the software and we can get in the output file. We have also cross check the manual calculations with the software base calculation, at last we get that the results from both manually and software are almost same. The reinforcement details are as follow:

Table. 2 Etabs design reinforcement details

| Reinforcement/m | Walls | Top slab | Floor slab |
|---------------------------|---------------------|--------------|--------------|
| Flexural | Ø16 @ 300 mm (EF/V) | Ø12 @ 250 mm | Ø12 @ 250 mm |
| Shrinkage and temperature | Ø12 @ 250 mm (EF/H) | Ø12 @ 250 mm | Ø12 @ 250 mm |

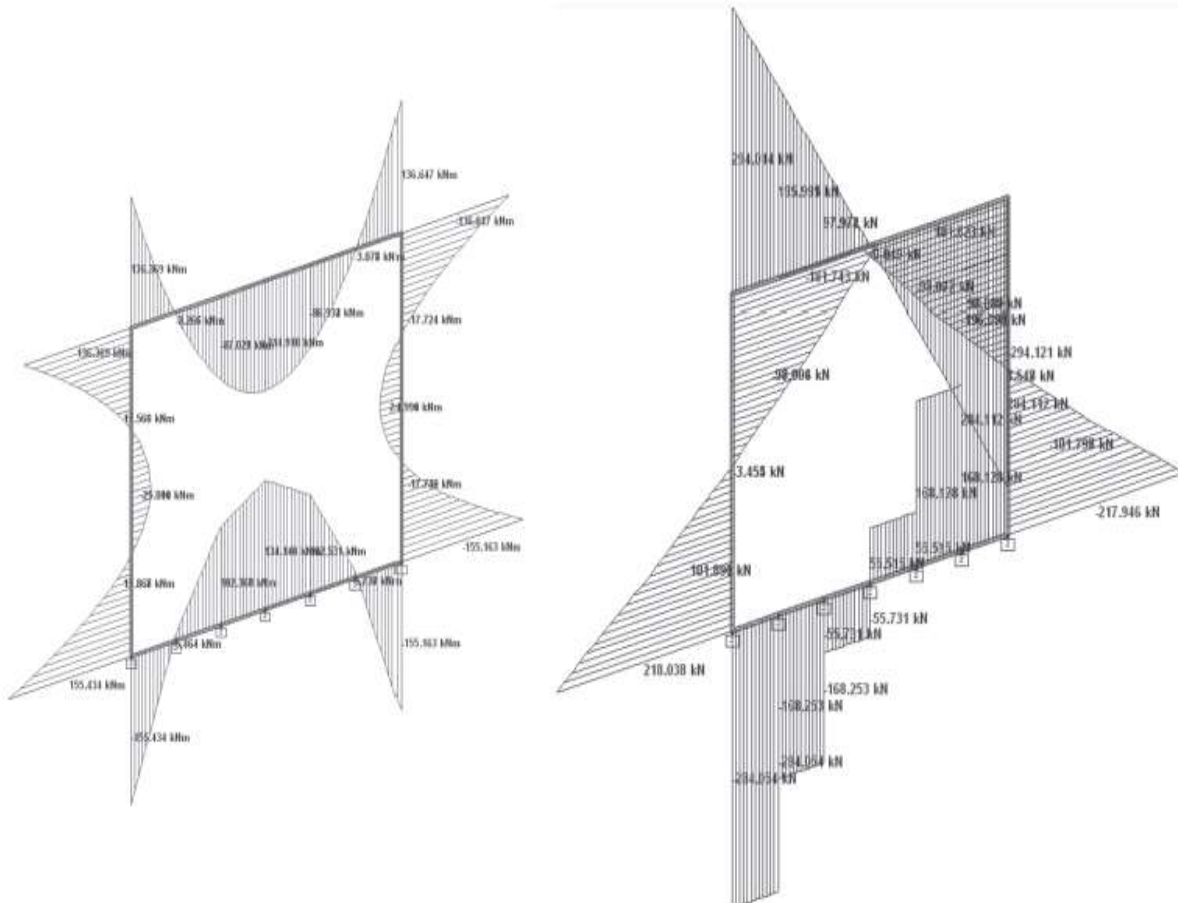


Fig.6 Bending Moment and Shear Force Calculation (for single spans)

Table 3 Moment and Shear values by Manual Calculation and STAAD. Pro.

| Item | Location | Members | By Manual Calculation | Computer Output ETABS | Remarks |
|----------------------|---|---|-----------------------|-----------------------|---------|
| Bending Moment (kNm) | Support | M _{AB} , M _{BA} , M _{AD} , M _{BC} | 82.50 | 83.05 | |
| | | M _{DC} , M _{CD} , M _{DA} , M _{CB} | 95.52 | 94.66 | |
| | Mid span | M _{AB} , M _{BA} | 69.32 | 69.99 | |
| | | M _{DC} , M _{CD} , M _{AD} , M _{BC} | 79.34 15.06 | 81.70 15.22 | |
| Shear Force (kN) | At d _{eff} from support for slabs | A & B D & C | 112.93 133.06 | 113.88 102.46 | |
| | At d _{eff} from top slab for wall | A & B | 76.51 | 75.95 | |
| | At d _{eff} from bottom slab for wall | D & C | 78.40 | 78.96 | |

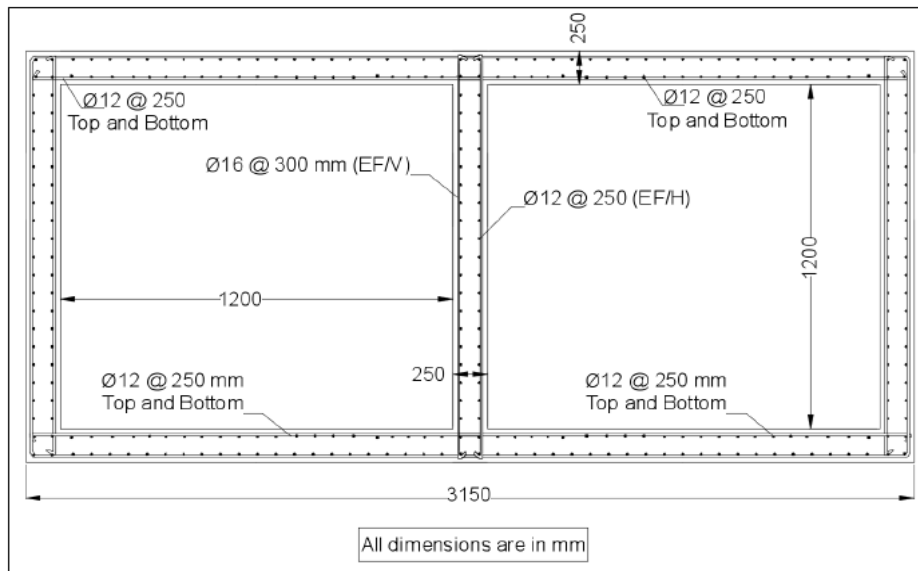


Fig. 7 reinforcement details of culvert

5. CONCLUSION

1. From the hydraulics analysis, the dimensions of box culvert were obtained. The designed culvert is of two spans which have full length as 26 m and width as 3.15.
2. The elements of box culvert includes floor slab, top slab, one interior wall and two exterior wall (side). In each element of the culvert the maximum shear force and the maximum bending moment is carried out.
3. The structure design and analysis was carried out by using the Etabs software, and the results are manually cross-checked. The reinforcement provided for the structure are :
 - Ø16@300mm c/c for EF/V and Ø12@250mm c/c for EF/H for walls.
 - Ø12mm@250mm c/c for bottom and floor slab
4. This design procedure are applied to design various culverts. The normal software which we use for analysis and design is Etabs. And this software gives the very close result as compared to the manual calculations.
5. For designing the various culverts this tool can be used to implement for various culverts at other location with different catchment areas. This tool can be implemented in design manual for small bridges and roads for improving the road management.
6. With the help of this formulation we can design the box culvert in an appropriate mannar and it will also save money and time for the structural engineers.

6. REFERENCES

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