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HYDRAULIC DESIGN OF BOX CULVERT FOR HIGHWAY AT COASTAL REGION

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ABSTRACT

The primary purpose of a culvert is to convey surface water across the roadway, railroad or other embankments. In addition to the hydraulic function, a culvert must also support the embankment and roadway for traffic conveyance, and protect the traveling public and adjacent property owners from flood hazards to the extent practicable and in a reasonable and prudent manner. In the coastal region a highway is crossing through many hydrologically important locations, and consists of several pipe and box culverts. The road is passing through a natural drainage. In the present study, an attempt has been made for the hydraulic design of a culvert for the drainage area in the coastal region.

INTRODUCTION

Culverts are structures used to convey surface runoff through embankments. Culverts are usually covered with embankment and composed of structural material around the entire perimeter, although some are supported on spread footings with the streambed serving as the bottom of the culvert. For economy and hydraulic efficiency, culverts should be designed to operate with the inlet submerged during flood flows, if conditions permit. Cross-drains are those culverts and pipes that are used to convey runoff from one side of a roadway to another.

The design of a culvert is influenced by cost, hydraulic efficiency, purpose, and the topography at the proposed culvert site. Thus physical data must be integrated with engineering and economic considerations. Primary considerations for the final selection of any drainage structure are that its design be based upon appropriate hydraulic principles, economy, and minimized effects on adjacent property by the resultant headwater depth and outlet velocity.

In addition to sound hydraulic design, sound structural design, site design, and construction practices are necessary for a culvert to function properly. The allowable headwater elevation is that elevation above which damage may be caused to adjacent property and/or the roadway. It is this allowable headwater depth that is the primary basis for sizing a culvert.

To ensure safety during major flood events, access and egress routes to developed areas shall be checked for the 20-50 year flood to determine if these streets will provide safe access for emergency vehicles and local residents.

DESIGN GUIDELINES

2.1 Catchment Area

When the catchment as seen from the 'topo' sheet is less then about 1.25 sq.km in area a traverse should be made along the watershed with a chain and compass. Larger catchment can be read from 1cm = 5oo m topo maps of the Survey of India by marking the watershed in pencil and reading the included area by placing over a piece of transparent square paper.

2.2 Cross-sections

As a rule for a sizable stream , three cross-sections should be taken , namely one at the selected site, one upstream and another downstream of the site, all to the horizontal scale of not less then 1 cm to 10 m. Approximate distances, upstream and downstream of the selected site of crossing at which cross-sections should be taken are as under :

Catchment area	Distance at which cross-section should be taken
1. 2.5 sq.km	150 m
2. From 2.5 to 10 sq.km	300 m
3. Over 10 sq.km	400 to 1600 m

The cross section at the proposed site of the crossing should show levels at close interval and indicate outcrops of rocks, pools, etc.

2.3 In the case of very small streams (catchment of 40 hectare or less) one cross section may do, but it should be carefully plotted so as to represent truly the normal size and shape of the channel on a straight reach.

2.4 The maximum HFL

The maximum HFL should be ascertained by intelligent local observation , supplemented by local enquiry, and marked on the cross-sections.

2.5 Longitudinal Sections

The longitudinal section should extend upstream and downstream of the proposed site for the distances indicated in the **table** and should show levels of the bed , the low water surface and the HFL.

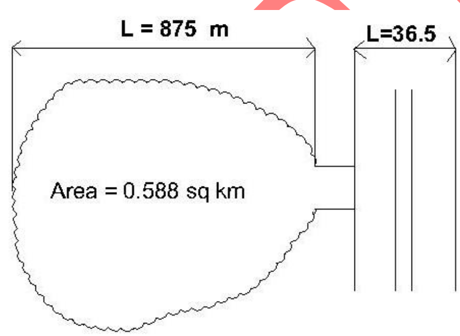
2.6 Velocity Observations

Attempts should be made to observe the velocity during an actual flood and, if that flood is smaller than the maximum flood , the observed velocity should be suitably

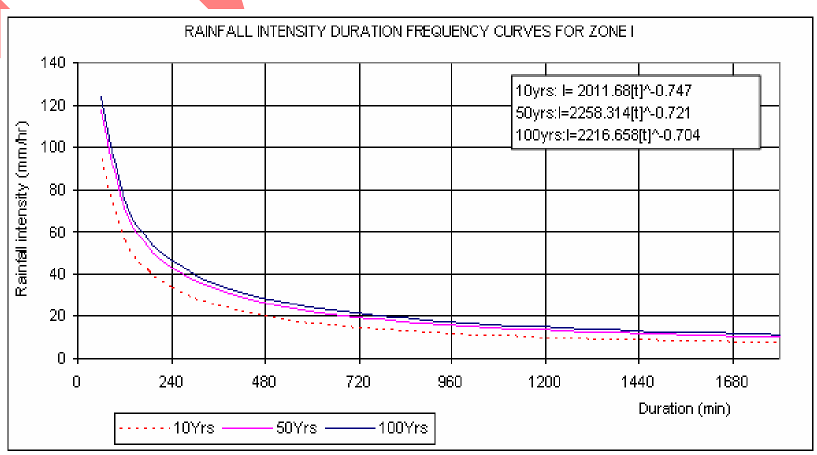
increased. The velocity thus obtained is a good check on the accuracy of that calculated theoretically.

HYDRAULIC DESIGN OF CULVERT

In the road stretch of verugal region, there are many hydrologically important locations, and consists of several pipe and box culverts. The road is passing through a natural drainage, the details are as given below.



The details of the drainage and its characteristics were obtained from various reports pertaining to the area. The drainage area corresponding to this loaction is 0.588 km^2 and length of drainage is 875 m. The drainage area is lying in the region of Hydrological zone I. The intensity duration curve (IDF) for this zone is available as given in the following Fig-5 and hence the same is being used in the present study.



Step 1. Estimate of Peak discharge

The peak discharge is estimated using rational formula and other empirical relationships developed for specific regions.

(a) Rational formula

Q = 0.028 P A Ic (IRC-SP13, 1998) .

tc = L/0.4572+5 min

For the given drainage characteristics, t_c is calculated as

=875/0.457+5=160.34 minutes

The value of I_c corresponding to t_c = 160.34 minutes from IFD figure is obtained as

Ic = 120 min/hr

= 12 cm/hr

The value of P is taken from IRC-SP 13 and is taken as 0.4 that corrresponds to loam, lightly cultivated or covered area.

Now the value of Q may be estimated by using the rational formula.

$Q = (0.028*0.4*(0.588*10^5)/10^3)*12$

$= 7.90\ m^3/s$

(b) Using Emiprical Formula

- **Dicken's Formuls**

$Q = CM^{3/4}$

M = catchement area in km^2

C = 22 for western ghats (IRC-SP13, 1998)

$Q = 22*(0.588)^{3/4}$

$=14.76\ m^3/s$

- **Ryve's Formula**

$Q = CM^{2/3}$

C = 6.8 for areas within 25 km of the coast (IRC-SP13, 1998)

M = Area of catchement in km^2

$Q = 6.8*(0.588)^{2/3}$

$Q = 4.77\ m^3/s$

The peak discharges obtained by Ryve's formula is 4.77 m^3/s is the lowest while the discharge 14.76 m^3/s obtained by Dicken's formula is the largest. If compared with the rational formula (discharge 7.90 m^3/s), the discharge by Dicken's is about twice while discharge by Ryve is about half of rational formula. So, the discharge obtained by rational formula appears to be more appropriate reppresenting the median value. Hence, in the present study, peak design discharge **Q = 7.90 m^3/s** was adopted as obtained by rational formula.

STEP 2 - Cross section water ways

Provided a stream is truly alluvial, it is destined to come to regime according to Lacey. It will be stable and have a section and slope conforming to this equation.

$W = 4.8\ Q^{1/2}$

$= 4.8\ \sqrt{7.90}$

$= 13.49$ m say 13.50 m

Scour depth of culvert;

The normal depth of scour D on a straight and unobstructed part of a wide stream may be taken as :

$D = (0.473Q^{1/3}) / f^{1/3}$

Taking f = 0.850 (for medium silt) (IRC-SP13, 1998)

$D = 0.473*7.90^{1/3}\ /\ 0.850^{1/3}$

= 0.998m say 1 m

Peak design discharge, Q = 7.90 m3/s ,

Culvert length (L) = 36.5m

Natural waterway invert levels:

Inlet : R.L. 2.544 m

Outlet : R.L. 2.544 m

STEP 3 - Determining the suitable Size of Culvert

Average upstream flood level: R.L. 3.782 m
Desirable road pavement level: R.L. 4.749 (= 3.249+1.5)
Minimum height of pavement above head water: 0.30 m

Estimated downstream tail water level : R.L. 3.049 m (flood level)

Maximum headwater height, (MHW), is the lesser (i) & (ii)

i) Maximum headwater height:

MHW = RL of road level – freeboard – Tailwater level

MHW= 4.749 - 0.30- 2.544 = 1.905m

ii) MHW = Flood level – RL of Tailwater level

= 3.782-2.544 = 1.238 m

MHW = maximum of (i) & (ii)

= 1.905 m

Step 4 : Case - Inlet Control

Assume permissible velocity in the culvert at inlet as per IRC-SP13,

V = 2.0 m/s (range = 2.0 - 2.5 m/s)
Then area A = Q/V = 7.90/2 = 3.95 m^2

Provide 2000 mm (wide) x 2000 mm (high) box culvert (A = 4 m^2 > 3.95 m^2, calculated velocity = 7.90/4 = 1.975 m/s ≈ 2 m/s)

Calculation of HW

The available HW is calculated using Inlet control nomogram for box culvert. The nomogram.

For the calculation of HW, depth of box culvert, discharge intensity and condition of u/s wing wall is required which are presented as below.

Q = 7.90 m3/s

Q/NB = 7.90/2 = 3.95 m^3/s/m

As per the discussion with the practicing engineers, the present practice is to provide the wing wall at 90^0 from the direction of flow for the benefit of economy and land constraint. Therefore, in the present case, the same is adopted.

Therefore, using nomogram for inlet control, for Q/NB = 3.95 $m^3/s/m$, Depth = 2 m, wingwall flare at 90^0, (draw line as shown and obtain HW/D = 0.94)

HW/D obtained is = 0.94

Hence, $HW = 0.94 \times 2 = 1.88$ m < the Max HW = 1.905 m ok

Since, the available headwater is less than the maximum headwater and hence it is acceptable.

STEP 5 : Check for Outlet Control

TW = 3.049-2.544 = 0.505

TW = 0.505 < 2.0m This corresponds to culvert flowing full for part of the length.

Calculation of critical depth (h_c)

The critical depth h_c is calculated using the nomogram given in Fig-2 . For culvert width B and discharge Q, the critical depth is calculated as shown in the nomogram.

The value of critical depth obtained is

$h_c = 1.2$ m

Then $(h_c + D)/2 = (1.2+2)/2 = 1.6$ m > TW = 0.505 m

For this, the calculation of HW is required which is calculated as follows.

HW= hc + D/2 + H - Ls

The value of H is calculated using the outlet control nomograph as shown in the figure.-3

L = 36.5 m
A = 2 x 2 = 4 m^2
$k_e = 0.5$

Draw line with Q = 7.90 m^3/s then draw the other line which gives

H = 0.35 m

Fall of culvert invert,

Ls = 2.544-2.344

= 0.200 = 0.2 m hence

HW= (hc + D)/2 + H - Ls = (1.2+2)/2 + 0.35 - 0.2 = 1.75 < 1.88m ok

HW (inlet control) = 1.88 m which is greater than HW (outlet control) = 1.75 m Therefore inlet control governs the culvert flow.

Step 6 : Flow Velocity

Hydraulic radius R = area/ wetted perimeter

R= 7.90/2(2+2) = 0.5m

Equivalent R= D/4

D = 4 x 0.5 = 2.0m and

s = 1/36.5

for k_e= 0.5mm we get:

V_f = 4.4m/s Value of Vf (full velocity) is obtained from the design chart

$Q_f = A_f * V_f$ = 4 x 4.4 = 17.6 m3/s

Q/Qf =7.90/17.6=0.448

B/D = 1

The value of B/D is obtained from the design chart

V /Vf =0.92 and

The value of V/Vf is obtained from the design chart

V= 0.92 x 4.4 = 4.048 m/s

y/D= 0.45 and

the value of y/D is obtained from the design chart

y = 0.45 x 2 = 0.90 <hc = 1.2m ok

the value of depth (y) is less than the critical depth (hc), hence it is acceptable

Length Of Apron

$F_r = V/(g*y_1)^{1/2} = 4.4/(9.81*0.90)^{1/2} = 1.48 \text{ m} > 1 \text{ m}$ **(supercritical)**

(Undular jump : 1.0 < Fr <= 1.7)

Therefore :

$$y_2/y_1 = 1/2\,(-1 + (1 + 8F^2)^{1/2})$$

$$y_2 = 0.90 * 0.5\,(-1 + (1 + 8*1.48^2)^{1/2})$$

$$= 1.48 \text{ m}$$

Height of the jump :

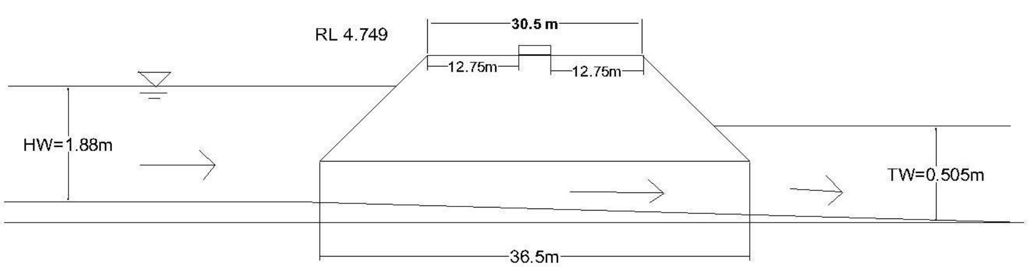
Ht. of the jump = $y_2 - y_1$ = 1.48 – 0.90= 0.58 m

Length of the jump :

$= 4.5\,(y_2 - y_1) = 4.5 * 0.58 = 2.61$ m

CONCLUSION

The culvert is designed with a peak discharge of 7.90 m^3/s with a cross section waterway width of 13.50 m. Scour depth of culvert is 1m .Providing 2000 x 2000 mm concrete box culvert . The culvert will flow with inlet control with a HW height of 1.88 m and outlet control with a HW height of 1.75 m. Therefore inlet control governs the culvert flow. The culvert will flow with a velocity of 2 m/s. The value of critical depth is 1.2 m and depth of culvert is 0.90 m . The length of apron is 2.61 m with a hydraulic jump of 0.58 m and Froude number = 1.48 m , which forms an undular jump by the following condition as **: (1.0 < Fr <= 1.7) .** The following diagram shows the dimensions of the culvert .



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