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"Research Note"

THE EFFECT OF ENTRANCE GEOMETRY ON DISCHARGE COEFFICIENT IN CULVERTS *

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Abstract– The effect of the entrance geometry of a culvert on the discharge coefficient is studied. The experimental results of a sharp edge model, which is compared with Bodhaine's, are taken as the comparison base. The curved up edge model and the curved edge of a side walls model, was shown to be effective on increasing the discharge coefficient. In addition, the bottom slope, culvert length, and discharge variation have no effect on the coefficient of discharge for flow types 1, 2, and 3.

Keywords– Culvert, discharge coefficient, entrance geometry

1. INTRODUCTION

The geometry of culvert entrance, discharge, bottom slope, upstream and downstream head and the rapid contraction of flow entering are effective on the loss of energy in culverts .The variation of these parameters and their combinations make different hydraulic conditions in free or pressurized culverts. Bodhaine presented six types of flow based on the hydraulic condition upstream and downstream of a culvert [1]. Yanqing Lain and Ben Chie Yen studied the comparison of risk calculation methods for culverts [2]. They found most of these methods being computationally simpler than the Monte Carlo simulation. In the present research, the effects of entrance geometry, the length of a culvert, bottom slope, and variation of discharge are studied and the results are presented.

2. THE HYDRAULICS OF FLOW IN CULVERTS

Many factors such as viscosity, the turbulence of flow and entrance condition affect the discharge coefficient of culverts. Bodhaine [1] has done several experiments and has divided the flow through culverts into six different categories based on the relative heights of head and tail water (Fig. 1). Equations used to estimate the discharge for various types of flow are presented in the same figure. In this figure, z = elevation of the culvert entrance relative to a datum through the culvert exit , h = depth of flow relative to the datum, A_c= flow area of critical depth (h_c), V_1= mean flow velocity of the approach section, α = kinetic energy correction coefficient for the approach section, $h_{1-2} = L_wQ^2/K_1K_2$, $h_{2-3} = LQ^2/K_2K_3$, K= the conveyance of the related section, and Lw= distance from the approach section to the culvert entrance. The other parameters are shown in Fig. 1.

More details for the value of discharge coefficient C, which have been established by laboratory tests, are summarized in reference [1]; also some of them are presented in Table 1.

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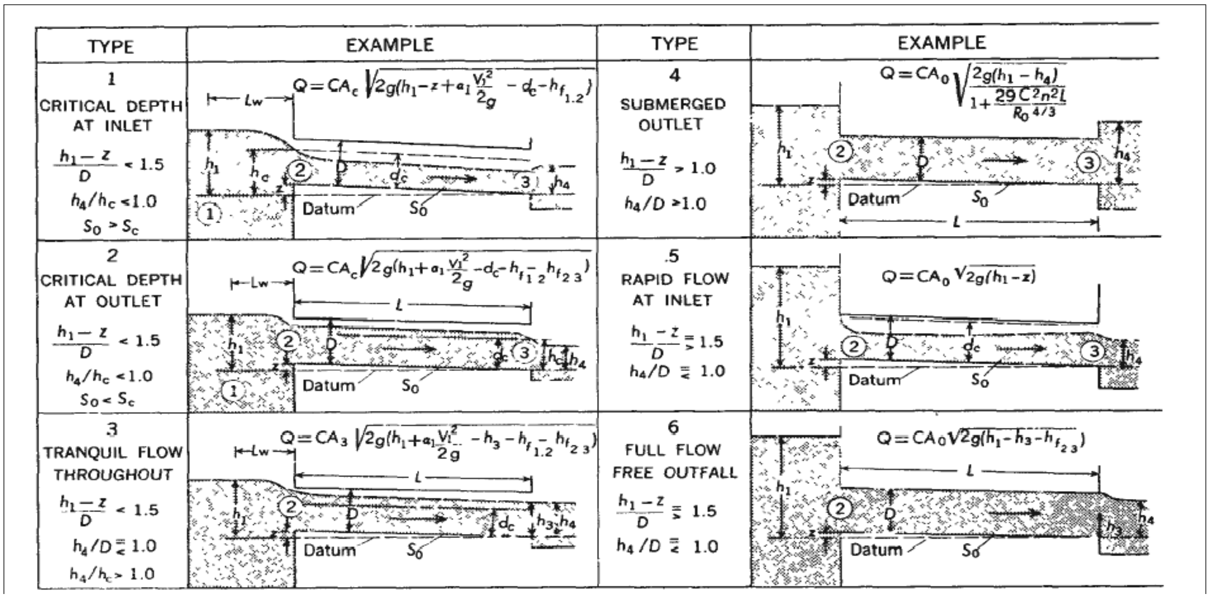

Fig. 1. Classification of culvert flow [1]

Table 1. The values of C for model 1

Flow type	Bodhaine 's results	Bottom slope			
		0.02	0.01	0.001	Total average
1	0.95	0.935	0.926	-	0.931
2	0.95	-	-	0.941	0.941
4	0.84	0.832	0.804	0.785	0.807
6	0.84	0.798	0.753	0.729	0.760

3. EXPERIMENTAL WORK

The experiments were conducted using a rectangular channel. The channel was 10 m long, 0.3 m wide and 0.5 m deep. To improve the condition of the approach flow to the culvert, porous walls at the upstream pool were used. The channel contained a plexiglass box culvert with dimensions of 0.1 m*0.1 m, two lengths of 2m and 3.65m, and three types of bottom slopes of 0.02, 0.01, and 0.001 .Three classifications of entrance geometry are also considered (Fig. 2), model 1 (with set flush sharp at the edge of the side walls), model 2 (with set flush rounded at the edge of the up side), and model 3 (with set flush rounded at the edge of the side walls). The models were based on the equation $(X/d)^2+9.81(Y/d)^2=1$ (where X= 0.65d in the indirection of central axis form water level at culvert entrance and Y=0.5d normal to X direction and d the dimension of each side of square culvert section), which is applied for some outlets of dams.

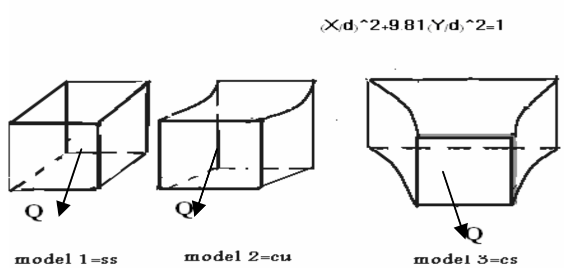

Fig. 2. Schematic of entrance models

With a combination of the three bottom slopes, two culvert lengths, and three models of entrance, 300 experiments were performed. The main purpose of this study was to highlight the effect of a rounded edge entrance on the loss of energy in the vicinity of the culvert entrance and its discharge coefficient.

4. EXPERIMENTAL RESULTS

The following symbols are used to present the results:

c: curve, u: up, s: side, ss: sharp edge, L_1:culvert length = 3.65m, L_2:culvert length = 2m, and the first number shows the value of slope.

The results of the preliminary experiments for model 1, which are summarized in Table 1, are in good agreement with those of Bodhaine [1].This assures the operation of the laboratory set up. Therefore, these results were considered for comparison with other models.

Type 1: This type of flow, which is supercritical in the culvert, cannot be performed at the bottom slope of 0.001. Figure 3 shows observations in a culvert for different conditions. It can be seen that the variation of discharge, culvert length, and bed slope do not have much of an effect on the value of C, which is nearly 0.931 for model 1, 0.939 for model 2, and 0.95 for model 3.

Other types of flow: The experimental results for the other types of flows, which have figures similar to Fig. 3, are summarized in Table 2.

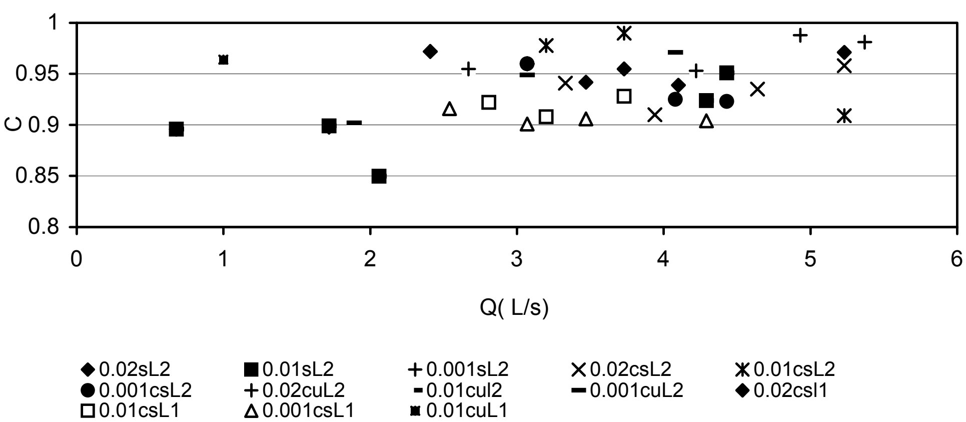

Fig. 3. Relationship between Q and C for different models of entrance, bed slopes and length of culverts for type 1 flow

Table 2. The value of average discharge coefficient for different models and for different type of flows

Type of flow		1	2	3	4	5						6
						(h1-z)/d						
						1.4	1.5	1.6	1.7	1.8	1.9	
Model 1	C	0.931	0.941	-	0.807	0.412	0.427	0.44	0.452	0.462	0.472	0.760
Model 2	C	0.939	0.942	-	0.828	0.425	0.459	0.492	0.525	0.558	0.591	0.768
	Increase%	0.860	0.11	-	2.6	3.2	7.5	11.8	16.2	20.8	25.2	1.1
Model 3	C	0.950	0.947	-	0851	0.501	0.537	0.573	0.609	0.645	0.676	0.786
	Increase%	2.1	0.64		5.5	21.6	25.8	30.2	34.7	39.6	43.2	3.4

Because of the subcritical flow in Type 2, no data exist for slopes of 0.01 and 0.02. Also, C is not so affected by discharge variations and culvert lengths in this type of flow. For Type 4, the increase of slope and discharge increases the value of C (which can not be seen in Bodhaine's results), but culvert length has no effect on it. In Type 5, C is a function of h_1/d (d =width of culvert) and Bodhaine has spotted the effect of the discharge. A linear regression is derived between C and $(h_1\text{-}z)/d$, and the discharge coefficient is obtained for each model. For this type, changing the discharge, the bed slope, and the culvert length would change the value of C. For Type 6, the value of C was found to be constant for models 1 and 3 (as Bodhaine's), but model 2, shows C increasing as the bed slope and discharge increase, while culvert length has no effect on C .

5. CONCLUSION

A series of laboratory experiments were carried out to determine the discharge coefficient for different entrance geometry of culverts. Culvert length does not affect the discharge coefficient (but does influence the loss of energy along the culvert) unless for Type 5 which has a significant effect. The variation of the bed slope and discharge vary the value of C unless for Types 1 and 2. The influence of entrance geometry is quite clear. The suggested curves for the side edges and the top edge increase the discharge coefficient and the ability of culverts to convey water, sometimes up to 43% (Type 5). As a summary of the present results, the discharge coefficient for the mentioned curved entrance can be found from Table 2 and Figs. 4, 5, and 6.

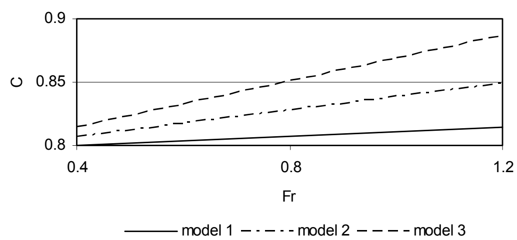

Fig. 4. Suggested discharge coefficient for type 4 flow

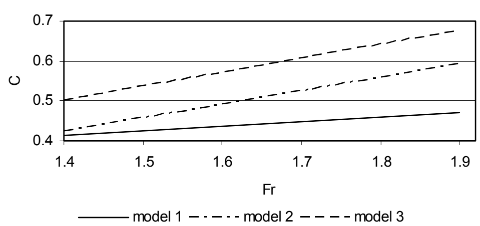

Fig. 5. Suggested discharge coefficient for type 5 flow

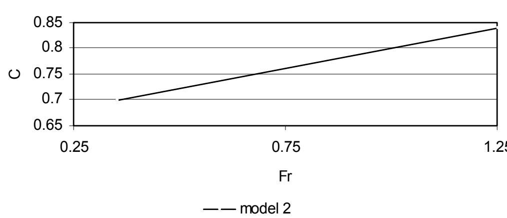

Fig. 6. Suggested discharge coefficient for type 6 flow, model 2

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