EIJEST

The Egyptian Int. J. of Eng. Sci. and Technology
Vol.14, No. 2 (May 2011)

INTEGRATION BETWEEN CULVERT AND EMBANKMENT FOR PROTECTION AGAINST FLOODS*

Maha R. F. El-zawalatry**

Water Engineering Department., Zagazig University, Egypt

ABSTRACT

Culvert is considered one of the main available solutions to avoid failure due to flooding. It's constructed at intersection of a wadi with highway to remove excess water from upstream of highway to downstream to avoid failure of road above culvert. All over the world, we have problems due to the different construction failure across the path of flood. In this paper, we modified the construction of highway above culvert to work as a broad crested weir and integrated with culvert to pass the discharge increases over the culvert. Extensive experimental works were conducted to pipe culvert. Different parameters are studied such as highway height above culvert (h=3.5cm, 7.50cm, and 10.5cm), upstream and downstream side slopes of highway which are 0H:1V, 1H:1V, 1.5H:1V, 2H:1V, and 2.5H:1V. The length of highway above culvert was also studied at different ratios: 30%, 44%, 58%, 72%, and 100%. Finally, all parameters were measured at different bed channel slopes: 0.0, 0.002, 0.004 and 0.006. This study aims to obtain the optimum design of the highway to work as a broad crested weir above culvert with submerged flow to remove the excessive discharge from upstream to downstream of highway. Different figures, and developed empirical equations-to help engineering in design- are also presented.

KEY WORDS: Culvert, Embankment, Weir, Flood, Highway, Broad crested weir

INTEGRATION ENTRE PONCEAU ET LE REMBLAI POUR LA PROTECTION CONTRE LES INONDATIONS

RÉSUMÉ

Ponceau est considéré comme l'un des principales solutions disponibles pour éviter l'échec à cause des inondations. C'est construit à l'intersection d'un oued avec des autoroutes pour enlever l'excès d'eau de l'amont à l'aval de l'autoroute pour éviter l'échec de la route au-dessus du ponceau. Partout dans le monde, nous avons des problèmes à cause de l'échec de la construction différents à travers le chemin de la crue. Dans ce papier, nous avons modifié la construction de l'autoroute au-dessus du ponceau pour travailler comme un large déversoir à crête et intégré avec ponceau à passer la décharge augmente au fil du ponceau. D'importants travaux expérimentaux ont été menés pour ponceau. Différents paramètres sont étudiés tels que la hauteur au-dessus de l'autoroute ponceau (h = 3.5cm, 7.50cm, et 10.5cm), les pentes en amont et en aval de la route qui sont 0H: 1V, 1H: 1V, 1,5 H: 1V, 2H: 1V, et 2.5h: 1V. La longueur de la route au-dessus du ponceau a également été étudiée dans des proportions différentes: 30%, 44%, 58%, 72% et 100%. Enfin, tous les paramètres ont été mesurés à différentes pentes de canal lit: 0,0, 0,002, 0,004 et 0,006. Cette étude vise à obtenir la conception optimale de l'autoroute à travailler comme un large déversoir à crête au-dessus du ponceau avec un débit submergée pour supprimer la décharge excessive de l'amont à l'aval de l'autoroute. Chiffres différents, et développé les équations empiriques à l'aide d'ingénierie en conception-sont également présentées.

Mots-Clés: le ponceau, Berge, Weir, Flood, autoroute, large crête du déversoir

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* Received: 27/4/2011, accepted: 28/5/2011 (Original Paper)

** Contact author (maha205066@yahoo.com)

1. INTRODUCTION

This research combined between culvert and embankment to pass the maximum discharge of wadi or waterway. It also suggested modification of embankment to work as weir by changing the geometry of slope in upstream and downstream. Referring to: The overtopping flow above embankment discussed by Scholl, B. N., et al. (2000, 2009), U.S. Department of transportation (2005), and Taxes Department of Transportation (2004) in which they discussed the equations of overtopping and the design chart for the different parameters. Additionally, the design of culvert equations and the energy dissipaters discussed by U.S. Department of Transportation in (2006), Cordes, K. E. and Hotchkiss, R.H (1993). Thus, the optimal culverts sizes were developed to estimate the design floods by taking the critical storm duration into consideration to design discharge by Kang, M.S. et al.(2009), Najafi, M. and Bhattachar, V.(2010), Masada, T. et al(2007). They discussed risk assessment method developed by the ODOT approach. Charbeneau, R. J.et al. (2006) presented a versatile two-parameter model describing the hydraulic performance of highway culverts operating under inlet control for both un-submerged and submerged conditions. Dasika, B. (1995) presented new approach to design culverts under inlet control. He recommended that the culvert is designed to flow under outlet-control conditions. Sargison, J. E. and Percy, A.(2009) investigated the flow of water over a sloped broad crested weir in upstream and downstream. He developed empirical equation to determine the discharge coefficient that was written as $C_{dw}=0.43+0.06\sin[\pi(\varepsilon-0.55)]-0.0396\theta+0.0039$, in which $\varepsilon=(H_r/(H_r+L)$, for $0<\varepsilon<1$ and θ is the influence upstream face angle. Fritz H. M. and Hager W. H.(1998) discussed the design of overtopping embankment for upstream and downstream slopes 2H : 1V. They determined the discharge coefficient $C_{dw}=0.43+0.06\sin[\pi(\varepsilon-0.55)]$ and drew the streamlines profile above weirs for free and submerged flow. The hydraulic characteristics for rapidly varying flow over oblique weirs were studied by Wlos B., et al.(2006). Saker. M. A. and Rhodes D. G.(2004) measured the flow surface profile above broad crested weir and compared it with results of numerical models. The hydraulic performance curves for highway culverts in case of inlet control for both submerged and un-submerged were presented by Charbeneay R. J., et al.(2006). Masada T. et al. (2007) presented a risk assessment method to compute the overall structural health rating for any inspected culvert. Measelhe, E. A., et al.(2007), Hager W. H.and Del Giudice G.(1998) discussed the generalized design culvert and the flow measurements through culverts.

2. MATHEMATICAL APPROACH

Flow through culvert and weirs is functioned in different parameters. These parameters are upstream head above the crest in upstream (H_r), downstream(h_r), horizontal length of highway(B), height of highway above culvert(p), upstream and downstream side slope(S_s), channel bed slope (S_e), Length of highway above culvert (L), discharge coefficient of culvert (C_{dc}), discharge coefficient of highway above culvert(C_{dw}), culvert length(L_c), upstream water depth(y_o), tail water depth(y_t),and culvert discharge(Q_c),discharge above highway(Q_w), total discharge (Q_T). These parameters are combined with flow characteristics, fluid characteristics and boundary characteristics to deduce the dimensional function used for the analysis of the phenomena. Figure 1 shows a diagram to the tested model.

2.1 Culvert Discharge

By applying the principles of continuity and energy equations, the discharge equation for the culvert and overtopping highway above culvert can be written as follows (Richard F.(1985) and Ven Te Chow (1959)):

For sloped channel

$$Q_c = c_{dc} A_o \sqrt{\frac{2g(y_0 - y_t) + S_e L_c}{1 + \left(k.c_{dc}^2.n^2 L_c / R^{4/3}\right)}} \qquad (1)$$

For horizontal channel

$$Q_c = c_{dc} A_o \sqrt{\frac{2g(y_0 - y_t)}{1 + \left(k.c_{dc}^2.n^2 L_c / R^{4/3}\right)}} \qquad (2)$$

In which:

A_o=culvert cross-section, k=coefficient equals 29 for English system and 19.65 for international system, and R=hydraulic radius., L_c=length of culvert, y_o=upstream water depth, y_t=tail water depth, c_{dc}=culvert discharge coefficient, g=gravitational acceleration, n=roughness Manning coefficient

Equations (1) and (2) are valid for submerged outlet,

$$\left((y_o - p)/d\right) \succ 1, and \quad y_t / d \succ 1.$$

2.2 Highway Overtopping Discharge

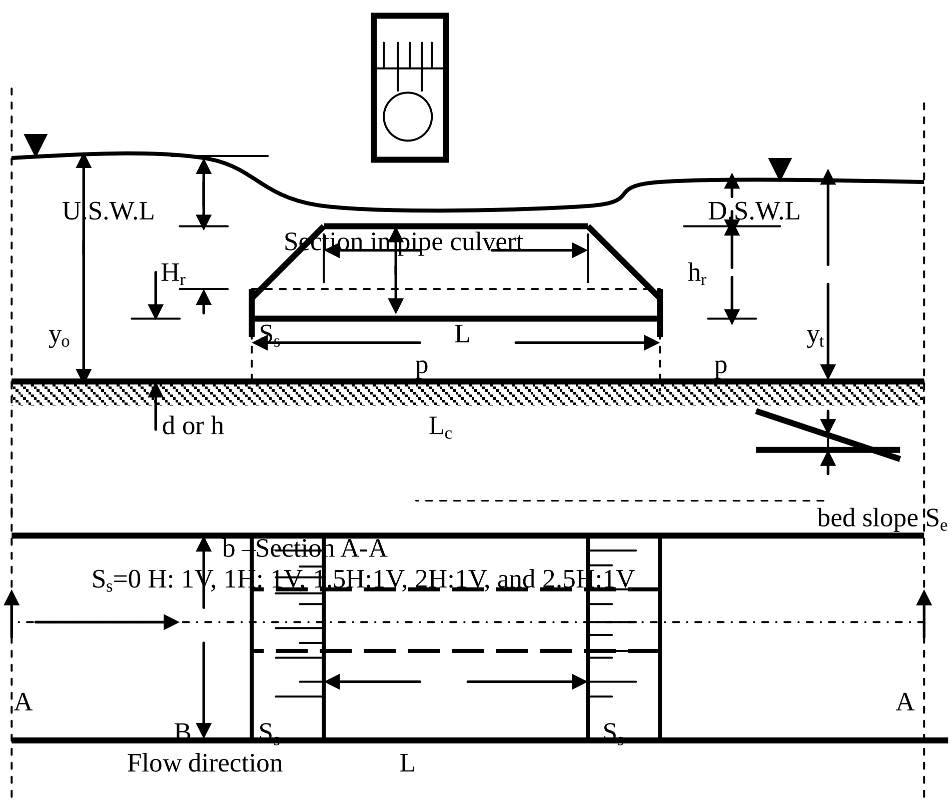
The discharge of highway overtopping can be computed by the following equation:

$$Q_w = K_1.C_{dw}.B.H_r^{1.5} \qquad (3)$$

In which

Q_w= discharge overtopping highway, C_{dw} =discharge coefficient equal 1.66 for SI and 3 for English system, B=horizontal length of overflow perpendicular of the flow direction, k_1=over-embankment factor, and H_r=upstream head above crest of highway.

The total discharge passes from the channel Q_T=Q_c+Q_w, then



S_e=0.00, 0.002, 0.004 and 0.006

Plan of the tested model

Fig. (1): Schematic Diagram to Tested Models

The parameters of the equations 1, 2, and 3 can be written in the following function:

$f(\rho, g, \mu, Q_t, Q_c, Q_w, H_r, h_r, p, B, L_c, L, y_o, y_t, S_s, S_e, C_{dc}, C_{dw}) = 0.0$ (4)

By using the dimension analysis theory, the equation 4 can be formulated as follows:

The discharge coefficient of highway crest can be written as follows:

$$\therefore C_{dw} = f\left(\frac{Q_w}{Q_T}, \frac{Q_c}{Q_T}, \frac{H_r}{P}, \frac{h_r}{H_r}, \frac{H_r}{y_o - y_t}, \frac{H_r}{L}, \frac{y_o - y_t}{y_o}, S_e, S_s\right) \quad (5)$$

3. EXPERIMENTAL WORK

Experiments were conducted to study the modification of highway above culvert to work as weir to remove the exceeded discharge. Experiments were conducted in a rectangular channel with a smooth bottom and two-glass wall 10cm wide, 31cm deep, and 300cm long. The tailgate is fixed nearly at the end of the working section. It is an aluminum plate provided with a rubber cover at both sides to prevent leakage.

The flume support includes a jacking system, which allows positive and negative bed slopes to be achieved. The flume is a re-circulating type and the flow system is a closed circuit. The flume takes its water from the 50mm feeding a P.V.C. pipe, which is connected to a mild steel sump tank, which is sited below the working section. At the outlet of the working section of the flume, the water falls vertically into the sump tank and is re-circulated by the pump. The discharge is measured by means of a pre-calibrated electronic flow meter and calibrated orifice meter connected in the middle of the feeding pipe. The upstream water depth, initial depth, sequent depth and tail water depth are measured by point gages. Different tested models at highway heights (3.5cm, 7.5cm, and 10.5cm) are tested with channel slopes 0.0, 0.002, 0.004, and 0.006. The highway is tested with changing upstream and downstream slopes 0:0, 1:1, 1.5:1 , 2:1, and 2.5:1. Photo1, and 2 show the test models under operation.

Photo (1): Vertical Angle Highway above Culvert

Photo (2): Upstream and Downstream-Sloped Highway above Culvert

4.DATA ANALYSIS

4.1. Discharge Coefficient of Culvert

To determine the pipe culvert parameters to separate between culvert discharge and weir discharge, some of the experimental data are conducted in case of culvert only. From equation 1, the C_{dc} can be deduced as follows:

$$C_{dc} = \frac{Q_c}{\sqrt{A_o^2.2g.((y_0 - y_1 + S_e.L_c) - \left(Q_c^2.k.n^2.L_c / R^{4/3}\right)}} \qquad (6)$$

In which: A_o=20.25cm^2, L_c=75cm, R=1.27cm, and S_e=0.00, 0.002, 0.004, and 0.006., k= constant (29 for English system, and 19.65 for SI).

From data analysis, the C_{dc} range is between 0.91 and 1.00 depening on channel bed slope. It can be determined from the empirical equation:

$$C_{dc} = -2500\,S_e - 0.05S_e + 1.0015, \qquad (7)$$

$$for \quad \text{Re}\,gression \quad coeff.R^2 = 0.9914$$

4.2.Effect of Hr/L on Discharge Coefficient C_{dw}

Figs. (2), (3), (4), and (5) show the correlation between the discharge coefficient C_{dw} and the ratio of H_r/L. The relationship is drawn with different bed channel slopes S_e=0.00, 0.002, 0.004 and 0.006. Also the highway upstream and downstream slopes are 0.00, 1H:1V, 1.5H:1V, 2H:1V, and 2.5H:1V. The figure indicated that the discharge coefficient decreases as the ratio H_r/L increases. It also increases as the highway slope increases. The relations are represented for 0.02<H_r/P<0.38. To show the effect of the channel bed slope on the highway discharge coefficient, we take H_r/L=0.06, and S_s=0.00, we fined C_{dw}= 1.75 at S_e=0.00, 1.80 at Se=0.002, 1.95 at S_e=0.004, 2 at S_e=0.006. The amount of increase in C_{dw}=12.50%, when Se increases by 100%. Also, the discharge coefficient increases by 16.6% at Ss=1H: 1V, 30% at Ss=1.5H: 1V, 41.7% at Ss=2H: 1V, 128.5% when Ss= 2.5H: 1V. This means that the effect of highway slope in upstream and downstream is more effective if compared with channel bed slope. Also, the amount of increase in upstream and downstream slope causes increases in removing discharge from flood of wadi.

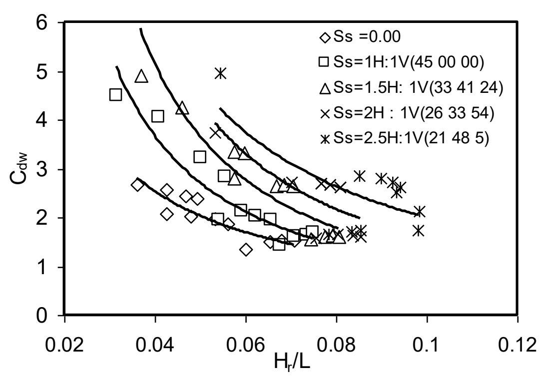


Fig. 2 Highway discharge coefficient Cdw versus H_r/L at channel bed slope S_e=0.00, 0.02<H_r/P<0.38

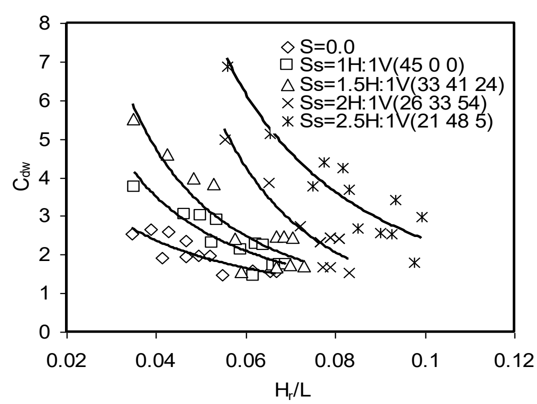


Fig. 3 Highway discharge coefficient C_{dw} versus H_r/L for channel bed slope S_e=0.002, 0.02<H_r/P<0.38

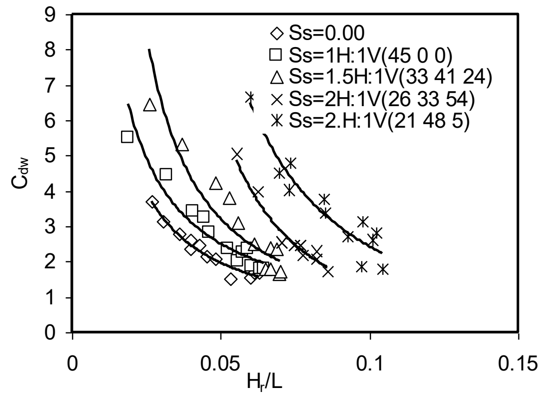


Fig. 4 Highway discharge coefficient C_{dw} versus H_r/L at chaneel bed slope S_e=0.004, 0.02<H_r/P<0.38

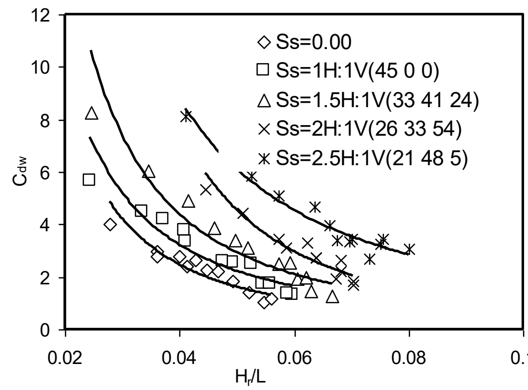


Fig. 5 Highway discharge coefficient C_{dw} versus H_r/L at bed channel slope S_e=0.006,0.02<H_r/P<0.38

4.3. Effect of Hr/P on Discharge Coefficient (C_{dw})

From the previous studies, the heights of highway which work as broad crested weir affect on the flow characteristics. The ratio of H_r/P is ranged between 0.02 and 0.38. Figs. (6), (7), (8), and (9) show the relationship between C_{dw} and the ratio of H_r/P. All figures indicated that the discharge coefficient decreases as the ratio H_r/P increases. The average percentage of C_{dw} decreases is 60% when H_r/P increases by 90%. At H_r/p equals 0.2, the increases in the discharge coefficient occurred relative to S_s=0.0 due to change in upstream and downstream highway slopes which are 28.57% at S_s=1H: 1V, 60% at S_s=1.5H : 1V, 80% at S_s=2H:1V, 105% at S_s=2.5H:1V. The amount of increase in the channel bed slope S_e from 0.00 to 0.006 causes an amount of increase in the discharge C_{dw} by 10%.

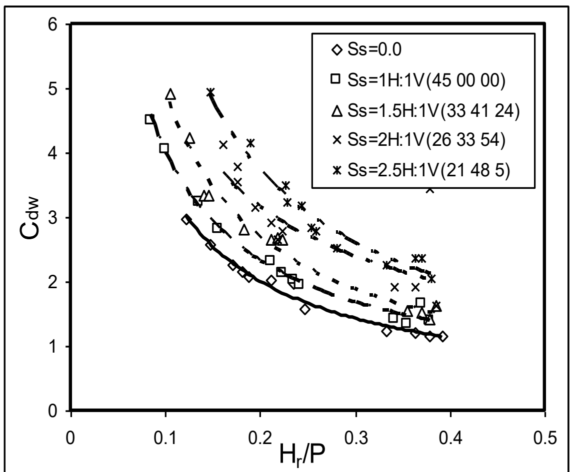


Fig.6 Relationship between Cdw and Hr/P at channel bed slope Se=0.00

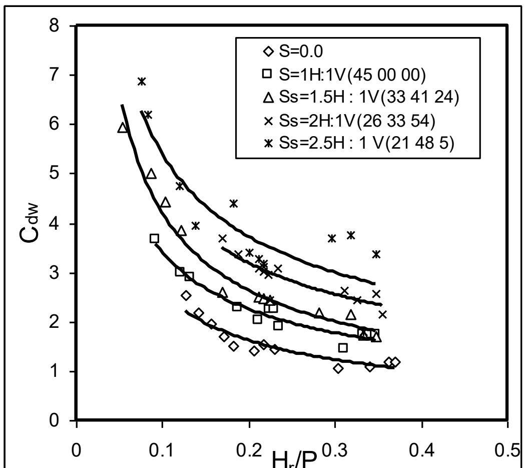


Fig. 7 Relationship between C_{dw} and H_r/P at bed channel slope Se=0.002

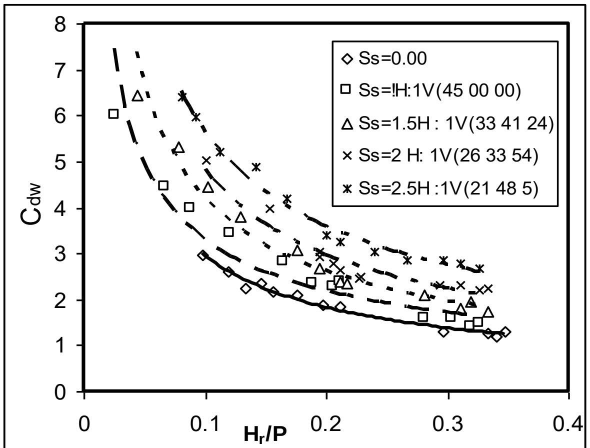


Fig. 8 Relationship between C_{dw} and H_r/P at channel bed slope Se=0.004

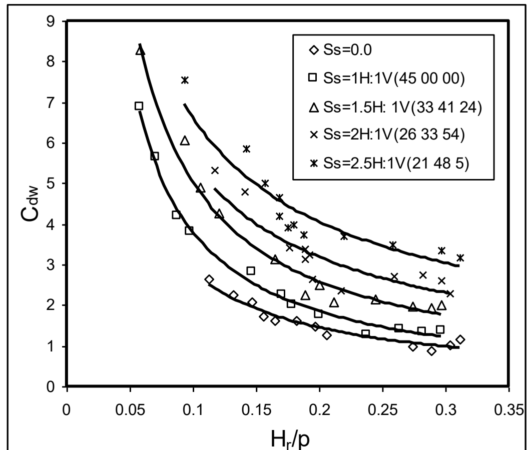


Fig. 9 Relationship between C_{dw} and H_r/P at channel bed slope Se=0.006

4.4. Relationship between the Ratios of Q_w/Q_T, y_o-y_t/y_o and Q_c/Q_T

The relationship between Q_c/Q_T versus Q_w/Q_T is shown in fig. 10. The figure indicated that the ratio of Q_c/Q_T increases of the ratio of Q_w/Q_T decreases at all tested ratios of H_r/p, H_r/L, Se and Ss. The relation deduced from regression analysis is $(Q_w/Q_T)=0.9998-0.9997(Q_c/Q_T)$, at R^2 =0.9998. Fig. (11) shows the effect of the submergence factor on the culvert discharge. It shows that the submergence ratio y_t/y_o increases as the ratio of Q_c/Q_T decreases. This means that the rising in downstream water level causes a decrease in the efficiency of the culvert for increases in y_t/y_o by 30%, and the Q_c/Q_T decreases by 47%. The co-relation between Q_c/Q_T and y_t/y_o is $Q_c/Q_T=0.719-0.489(y_t/y_o)$ which is deduced by regression analysis.

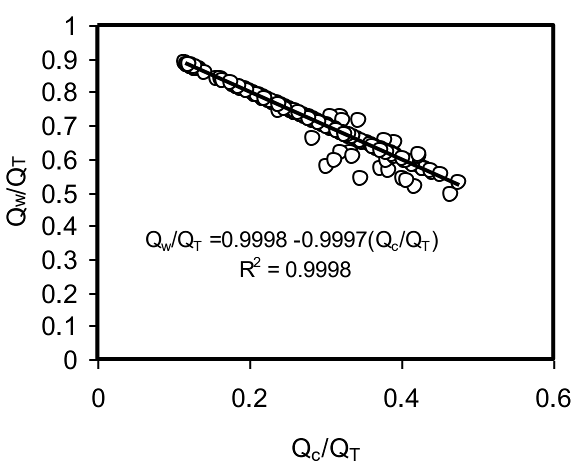


Fig. 10 Relationship between Q_c/Q_T and Q_w/Q_T, $0.02<h_r/P<0.38$, $0.00<S_e<0.006$, 21^o 48" 5'$<S_s<90^o$

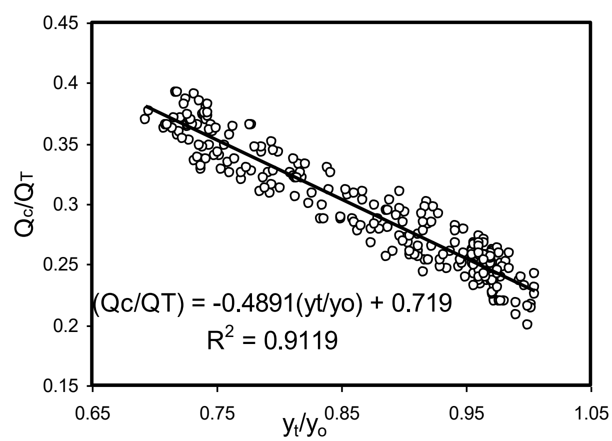


Fig. 11 Relationship between submerged ratio y_t/y_o and Q_c/Q_T, 0.02<hr/P<0.38, 0.00<Se<0.006, 21o 48" 5'<Ss<90o

5. Developed Empirical Equations for C_{dw}

Three empirical equations are developed to compute the discharge coefficient of highway above the culvert. Fig. (11) shows the co-relation between C_{dw} versus H_r/L and the empirical equation can be written as follows:

$C_{dw}=0.0145*(H_r/L)-1.8591$ at
$0.00<S_e<0.006$, $21\ 48\ 5<S_s<90$, $R^2=90.78\%$ (8)

The relationship between C_{dw} and H_r/P is shown in Fig. (12) and can be written as follows:

$C_{dw}=0.8021*(H_r/p)-0.7748$ at
$0.00<S_e<0.006$, $21\ 48\ 5<S_s<90$, $R^2=98.24\%$ (9)

and, the relationship between discharge coefficient C_{dw} and upstream and downstream slopes Ss of the highway above culvert have been co-related due to regression analysis and can be written as follows:

$C_{dw}=10.657(\sin S_s)2-18.48(\sin S_s)+9.6698$
$R^2=94.37\%$ (10)

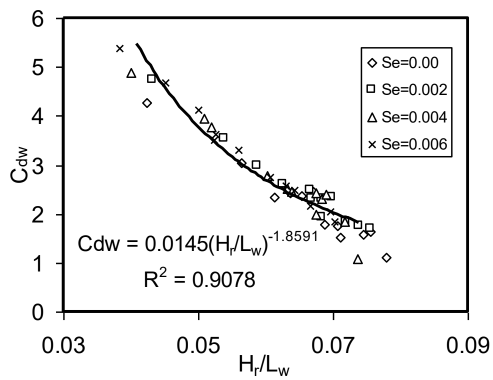


Fig. 12 Relationship between C_{dw} and H_r/L_w at different bed channel slope S_e, (21^o 48' 5"<Ss<90^o)

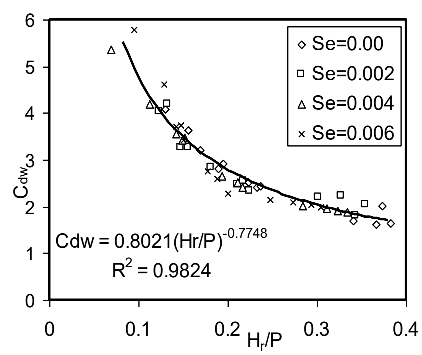


Fig. 13 Relationship between average C_{dw} and H_r/p at different bed channel slope S_e and different S_s(21^o 48' 5" and 90^o)

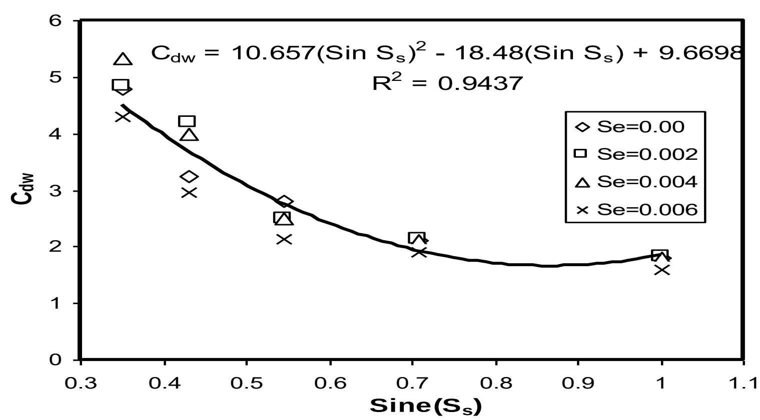


Fig. 14 Discharge cofficient C_{dw} versus highway sloped $S_s$at $0.03<H_r/L<0.08$, $0.01<H_r/P<0.40$

6. CONCLUSIONS

Extensive experimental work is conducted for submerged flow of culvert to study the hydraulic performance and characteristics of flow over highway above culvert to help in removing excess flow. The new shape of highway works as broad crested weir to be protected against failure. The main conclusion can be summarized as follows:

1. The increases in channel bed slope and weir side slopes resulted in increasing the discharge coefficients of culvert and broad crested weir above culvert.
2. For submerged flow, the discharge coefficients decrease as the ratio H_r/L, and H_r/P increase.
3. Developing three empirical equations used to determine discharge coefficient of broad crested weir as a function of Hr/L, Hr/P and upstream and downstream weir slopes.
4. The ratio of (Q_c/Q_T) decreases as the submerged ratio (yo/yt) increases, and the ratio of (Q_w/Q_T) increases for integrating weir with culvert to remove excess flow.

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