CHARACTERISTICS OF FLOW IN CULVERT WITH TRIANGULAR SHAPE CROSS SECTION

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ABSTRACT

In this paper, the culvert of a triangular shape cross section is presented as a new shape. Such a shape can be used in practice since it possesses higher uplift resistance. The characteristics of flow through triangular culvert are extensively investigated. Different cases of culvert operations are studied. The limits of each case of flow are fixed. The discharge equations with the required coefficients are predicted for; weir, orifice, combined, and pipe flow using the experimental results. Experiments were conducted on culvert models with different dimensions. The prsented study shows a slightly higher inlet resistance to flow for triangular shape culvert compared with circular and box shape culverts. Results are presented in the form of tables, curves, and formulas.

Keywords: Culvert, Culvert with triangular shape cross section, Discharge measurement.

Notations

A_o	Culvert cross sectional area,
A	flow cross sectional area at the contracted depth y,
a	Height of culvert,
B	Total width of culvert base,
b	Clear width of culvert base,
$\bar{b}$	Average width of flow at inlet in case of weir flow,
C_A	Combined, vertical and lateral contraction coefficient,
C_c	Coefficient of vertical contraction,
C	Chezy coefficient,
C_d	Discharge coefficient for case of pressurized flow,
C_{do}	Discharge coefficient for case of orifice flow,
C_{dp}	Discharge coefficient for case of pipe flow,
C_v	Coefficient of velocity,
C_{dw}	Discharge coefficient for case of weir flow,
d	Depth of earth fill measured from culvert base,
g	Gravitational acceleration,
H	Headwater depth,
H_o	Total energy at the approach section o-o, $H_o = H + h_a$,
H_t	Tailwater depth,
h_a	kinetic head, $h_a = \alpha \dfrac{v_a^2}{2g}$,
h_i, h_f, h_o,	The loss of head refers to inlet, friction, and outlet, respectively,
k_p	Coefficient of pressure,
L	The entire length of culvert,
ℓ_n	Length of pressurized flow,
P_n	Pressure on culvert base at the end of pressurized flow,
Q	Discharge through culvert,
R	Hydraulic radius,
U	Uplift force,
v_a	Approaching velocity,
v	Mean velocity in culvert,
y	Contracted depth in case of orifice flow,
η_1, η_f, η_o	The coefficients of head loss refer to inlet, friction, and outlet, respectively,
γ	The specific weight of water.

1. INTRODUCTION

A culvert is a conduit through which water is flowing from one side of an embankment to the other to satisfy the following functions and practical problems:

(i) cross drainage for highways,

(ii) regulation of flow at canal's intakes,
(iii) stream flow measurements in open channel, and
(iv) crossing bridges on small streams.

Two aspects are considered to design a culvert; the hydraulic and structural design. The present work deals with the hydraulic design only. The hydraulic design mainly depends on the type of flow through a culvert and its performance. Once the type of flow has been determined, the well known equation for weir flow, orifice flow, pipe flow, and water surface profile can be applied to determine the head-discharge relationship.

Culvert may have cross section of circular, Box (square or rectangular) or arched shapes. These shapes are commonly constructed in a wide range of application in engineering practical situations.

In the present work a nontraditional shape, for the culvert cross section, is presented. It is the triangular shape. From the hydraulic viewpoint, culvert with triangular shape may not be the best compared with other conventional shapes. However, triangular shape provides more stability for the culvert barrel, than box or circular shapes. Culvert with triangular shape possesses greater uplift resistance against uplift forces, exerted on the culvert base, due to seepage flow in culvert zone. In fact, the base of the triangular shape behaves as an anchor plate when subjected to uplift forces. For any type of soil and anchor shape, tests performed on anchors installed to shallow depths (d/B<5), at ultimate uplift resistance, showed a major crack incorporate a curved surface, slightly inclined outward as it approaches the soil surface, as shown in Figure (1-a), [1,2,3,4].

Referring to Figure (1-b), the vertical surfaces of the box shape control the plane of failure to extend vertically up to the soil surface. The comparison between the behaviors of planes of rupture for triangular and box shapes, if they subjected to the same uplift force, U shows higher uplift resistance possessive by the triangular shape as shown in Figure (1). Furthermore, for deep culverts, the arching effect, occurring in the earth fill covering the culvert, takes place for a lower depths in case of culvert with triangular shape. This leads to smaller vertical loads and lower cost for culvert construction.

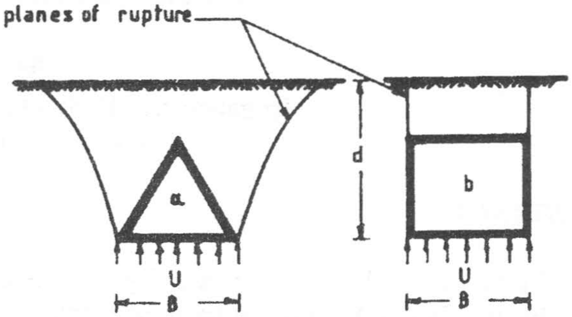


Figure 1. Behaviour of planes of failure due to uplift ferce, U, exerted on; a-triangular shape, and b- Box shope

The characteristics of flow through culvert depend on various factors; shape, size and geometry of inlet and outlet, length, slope and roughness of barrel, and both head and tailwater depths. The effect of the above factors on the discharge and flow characteristics in both pipe and box culvert have been studied in different ways of approach.

In some literature [5,6,7,8] great attention was turned to classify types of flow through culvert. Accordingly, the flow through culverts was hydraulically classified into the following items:

1) *Inlet and outlet control*

Flow through culvert may be under inlet or outlet control. The flow is under inlet control if the culvert has mild or steep slopes with tailwater levels below the top of culvert. In this case, the discharge and the depth of headwater depend only on the size and shape of culvert cross section and the entrance conditions (such as square, rounded or splayed-edged). In such case, the characteristics of culvert barrel (such as length slope, type of surface, etc.,) do not have any effect on the flow rate.

Flow through culvert is under outlet control when both inlet and outlet are submerged, or when the inlet is free and the outlet is unsubmerged with tailwater depth greater than the end depth. In this case, the flow rate would depend on the depth of flow at the outlet, size, shape, length, slope of the barrel and the inlet shape.

2) *Full and partly full flow through culvert*

Culvert may act with running full or partly full flow with respect to its cross section. The culvert acts with full flow when the inlet is submerged and the outlet either submerged or unsubmerged. In this case,the flow through culvert is considered to be pipe flow.

Culvert is operated with partly full flow when the inlet is submerged and the outlet is unsubmerged. In this case, the flow at the inlet simulates orifice or weir flow according to the ratio of headwater depth to culvert height. In such a case, culvert acts as an open channel.

3) *Short and long culvert*

With respect to its length, culvert may called hydraulically short or long. In case of orifice flow, if the culvert is not sufficiently long to allow the expanding depth of flow below the contraction to rise and fill the barrel, the culvert will never flow full. such a culvert is considered hydraulically short. Otherwise, the culvert is hydraulically long, for it will flow like a pipe.

Several investigators [9,10,11,12] were interested by improvement culvert inlet by providing hood inlet to pipes. Smooth pipes, when equipped with this inlet, flow full at relatively low heads regardless of the conduit slope. In rough pipes, the hood inlet caused the entrance to fill once the inlet was submerged, but full flow occurred at higher heads.

Other investigators studied the factors affecting flow in culverts; shape, geometry, roughness, slope, etc. Lawton, et al. [13] presented a report contains a list of 69 references, including the influence of the above factors, up to 1964. The friction head loss, in box culvert having different side and bed roughness, was experimentally studied for the cases when the culvert is running full, partly full, and as an open channel [14]. As a result, semi-empirical equations was obtained to describe the flow characteristics through box culvert.

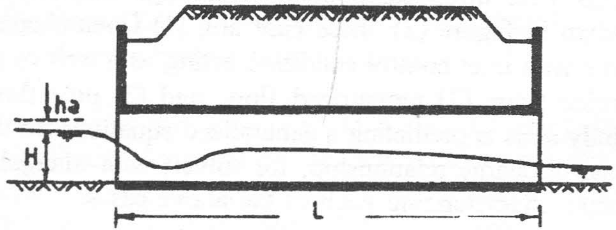
Recently, the flow through pipe culvert with square-edged entrance was experimentally investigated [15]. New generalized relations, between the headwater and the discharge, are presented for inlet-control conditions.

In the present paper, the characteristics of flow through triangular shape culvert are investigated. Study deals with three cases of flow through culvert. As shown in Figure (2), these case are; (1) Open channel flow with inlet control condition acting as a weir or an orifice flow, (2) pressurized flow, and (3) pipe flow. Study aims at predicting a generalized equations for the head-discharge relationship, for culvert with triangular shape, characterizing each of the above cases.

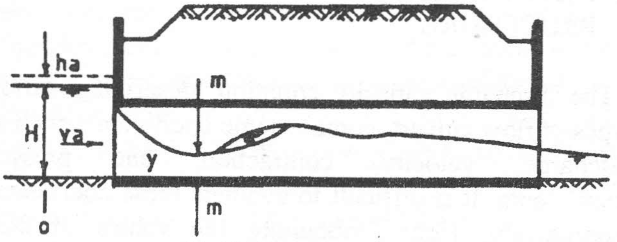
2. EXPERIMENTAL SETUP AND TEST PROCEDURE

The discharge capacity equation, describing various types of flow culvert, contain some coefficients such as; discharge, velocity, contraction, and pressure coefficients. It is difficult to evaluate these coefficients theoretically. Hence, obtaining the values of these coefficients experimentally is considered to be the only approach. Experimental work aims also at fixing limits of the relative head H/a within which the discharge equations of weir flow, orifice flow, pressurized flow, and pipe flow could be valid.

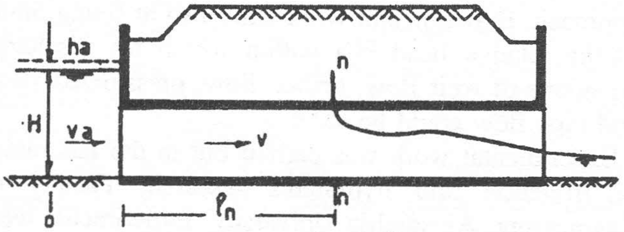
Experimental work was carried out in the laboratory of irrigation and hydraulics research, Faculty of Engineering, Alexandria University. Experiments were conducted in rectangular horizontal channel having 9.0 length 0.395 m width, and 0.50 m height. The channel was fabricated from 8 mm perespex sheets supported by a steel frame. Two models for the triangular shape culvert were prepared from 4.0 mm perespex sheet. The two models have the same length of 1.50 m., but with different dimensions for the cross section shape. The first shape is of equilateral triangle 10x10x10 cm, while the other has 15x15x15 cm triangle lengths. The culvert height a = 8.7 cm for the first model, while it equals 13.0 cm for the second one. The pressure distribution was measured by piezometers. Sixteen piezometers were installed along the center line of culvert base. The first and last piezometers were located just after and before the inlet and the outlet, respectively. In addition, two piezometers were provided just before and after the inlet and outlet, respectively. Piezometers have opens of 1.0 mm diameter, and connected with polythene tubes to open tube manometers mounted on a vertical board. The passing discharges thorough culvert were measured by a V-notch weir. The tailwater depth was controlled by adjusting a sliding gate located at the channel end.



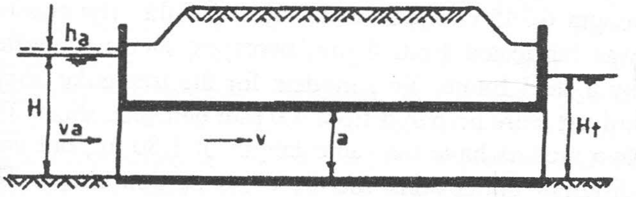
(a) Weir flow



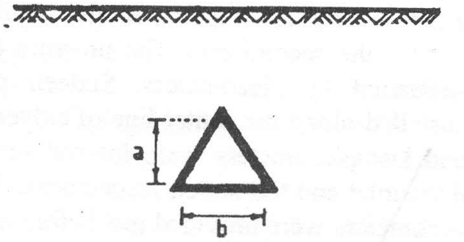
(b) Orifice flow



(c) Pressurized flow



(d) Pipe flow



(e) Cross section (equilateral triangle)

Figure 2. Types of culvert flow control.

A set of experiments were firstly conducted to fix the limits of the relative headwater H/a defining each type of flow. Once these limits were fixed, a sets of experiments of different discharges were performed for each type of flow.

Experiments were conducted on horizontally positioned culvert. The culvert outlet was kept free from tailwater for cases of weir, orifice, and pressurized flow, as shown in Figure (2-a, b,c), respectively. In case of pipe flow only, the culvert outlet was submerged by tailwater, as shown in Figure (2-d).

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. *Limits defining types of flow through culvert*

Keeping the culvert horizontally and the outlet free, the headwater depth H was slightly raised. It is found that, the flow surface touches the soffit of culvert entry when the headwater-culvert height ratio $H/a \simeq 1.05$. For values of H/a up to 1.05 the inlet is considered unsubmerged and the culvert runs partly full (open channel flow), Figure (2-a). In this case the inlet acts as a weir with crest height equals zero.

When $H/a > 1.05$, the water surface touches the soffit, and for this and higher values of H, the culvert entry becomes submerged and acts essentially as a sluice gate, Figure (2-b). The flow is contracted, below the entrance, for a few distance and rise again through a hydraulic jump. When $H/a \simeq 1.28$, the end depth of the jump starts to touch the culvert crown. However, when $H/a \geq 1.3$ approximately, the flow typically takes the form indicated in Figure (3), in which the flow contacts the crown to a short length inclosing an air pool just below the entrance. For any further increase in the headwater depth H, the contact length increases and moves upward. Hence, the air bubbles moves with the flow to the exit of culvert. When $H/a \simeq 1.45$, the air pool thoroughly disappear and the culvert prime itself and thus runs with flow full to a length ℓn, then the flow separates from the top of culvert as shown in Figure (2-c). For values of $H/a > 1.45$ the culvert is partly equipped with full flow with respect to its length. In this case, flow in culvert may called pressurized flow. Further increase in the headwater H increases the length of the pressurized flow ℓn.

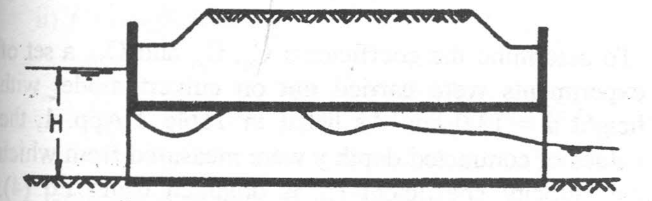


Figure 3. Transition flow case.

Noting that, using the culvert model with height a = 13 cm, self priming did not occur, and the flow still like orifice flow for values of H/a up to 3.5. The culvert, in this case, considered hydraulically short. This confirms that, the culvert length is not the only factor defining short or long culvert, but also the culvert height.

Blaisdells experiments [10] which related only to circular culverts with hood inlet, established that the culvert would prime and run full if H/D> 1.25 for slopes up to 0.361, where D is the pipe diameter. According to Blaisdells results, the inlet is unsubmerged whenever H/D< 1.25.

As for box culvert, when H/a < 1.2 the water surface at the entry does not touch the soffit and the inlet is considered submerged when H/a > 1.2 [6]. Chow [5] expanded this limit, that is the entrance will not be submerged if H/a varies from 1.2 to 1.5 depending on the entrance geometry. However, a lower limits have been given by shvainshteim [16], that is inlet will be submerged if H/a ranges from 1.15 to 1.25. Lower limit is for round edged entrance, while the upper limit is for sharp edged one.

3.2. *Operation of culvert with weir flow*

In the condition when the culvert entrance is unsubmerged, i.e. H/a ≤ 1.0 5, the flow surface falls at the entrance and rises again. Here, the inlet acts as a weir with crest height equals zero. In this case culvert is under control inlet and the governing head-discharge relation is the weir equation in the form,

$$Q = C_{dw} \cdot \bar{b} \, \sqrt{2g} \, H_o^{3/2} \qquad (1)$$

where,

C_{dw} is the weir coefficient of discharge,

$\bar{b}$ is the average width, for equilateral triangle,

$$\bar{b} = b - \frac{H}{\sqrt{3}}, \text{ and}$$

b is the clear base width of the triangular shape.

To determine the discharge coefficient, a set of experiments were conducted on the culvert model of height a = 13.0 cm to allow for wide range of discharges. The discharge coefficient was calculated using Eq. (1) within the range of H/a < 1.05. Results are given in Table 1 App. 1. The discharge coefficient increases as H/a increases as shown in Figure (4). The relation between the discharge coefficient C_{dw} and H/a can be described by the following empirical equation,

$$C_{dw} = 0.25 \left(\frac{H}{a}\right)^3 - 0.45\left(\frac{H}{a}\right)^2 + 0.395\left(\frac{H}{a}\right) + 0.21, \qquad (2)$$

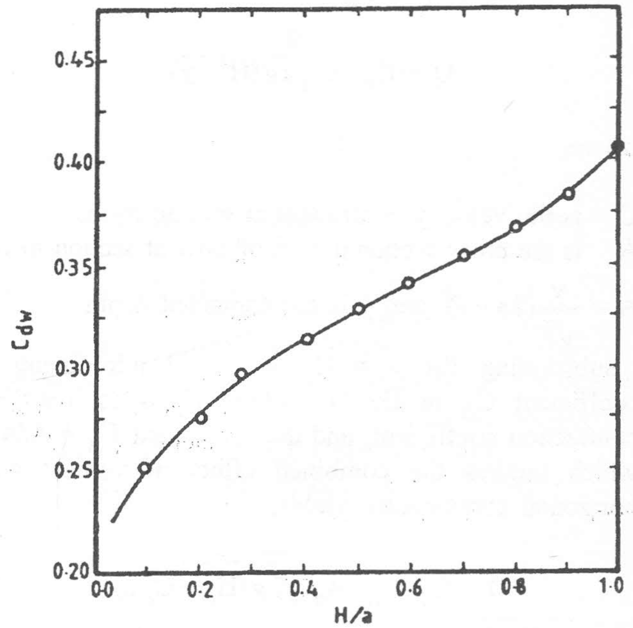


Figure 4. Relation between coefficient of discharge C_{dw} and the ratio H/a.

with correlation coefficient R = 0.9996. However a simple relation can be written as,

$$C_{dw} = 0.24 \left(\frac{H}{a}\right) + 0.16 \qquad (3)$$

In Eqs. (2) and (3) $0 < H/a \leq 1.05$

For box culvert, the coefficient C_{dw} ranges from 0.3 to 0.5. However, these values are given for H/a up to 1.2 [5]. Assuming critical flow at the entrance, the coefficient C_{dw} equals 0.35 for sharp edged box culvert [6]. For square-ended culvert with circular shape C_{dw} ranges between 0.5 and 0.6 [17].

3.3. *Operation of culvert with orifice flow*

In this case the inlet is submerged and the outlet is unsubmerged, for which $1.05 < H/a \leq 1.30$. Under these conditions, the flow entering the culvert will be contracted to a depth y, less than the height of the culvert barrel, a, in a manner very similar to the contraction of flow in the form of a jet under a sluice gate. In this case, culvert is under inlet control. Considering the orifice flow condition, the application of the energy-equation to sections 0-0 and m-m, as shown in Figure (2-b), gives

$$Q = C_V . A \sqrt{2g(H_o - y)} \tag{4}$$

where,

C_V is the velocity coefficient at section m-m,
A is the cross sectional area of flow at section m-m,

$A = \frac{y}{\sqrt{3}}(2a - y)$, and y is the contacted depth.

Substituting for $y = C_c . a$ and introducing a coefficient C_A in Eq (4), where C_c is the vertical contraction coefficient, and the coefficient $C_A = A/A_o$, which implies the combined effect of vertical and horizontal contractions, yields,

$$Q = C_V . C_A . A_o \sqrt{2g(H_o - C_c . a)} \tag{5}$$

where, A_o is the culvert cross sectional area, and

$$A_o = \frac{\sqrt{3}}{2} . a^2$$

Substituting for A and A_o, the coefficient C_A can be related to the coefficient C_c since,

$$C_A = \frac{A}{A_o} = 2C_c - C_c^2 \tag{6}$$

To determine the coefficients C_c, C_A and C_V, a set of experiments were carried out on culvert model with height a = 13.0 cm. As listed in Table 2 App. 1, the values of contracted depth y were measured from which the velocity coefficient C_v is obtained using Eq (4). The average value of the coefficient $C_v \sim 0.90$. The values of C_c and C_A are computed as $C_c = y/a$ and $C_A = A/A_o$. The values of C_c and C_A are plotted against H/a values as shown in Figures (5) and (6). These two coefficients C_c and C_A are correlated to H/a as follows;

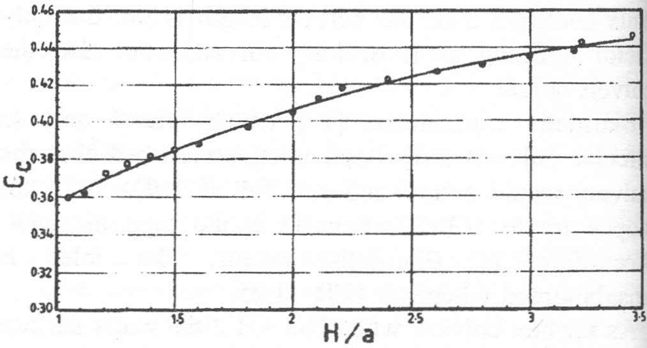


Figure 5. Relation between coefficient of vertical contraction C_c and H/a.

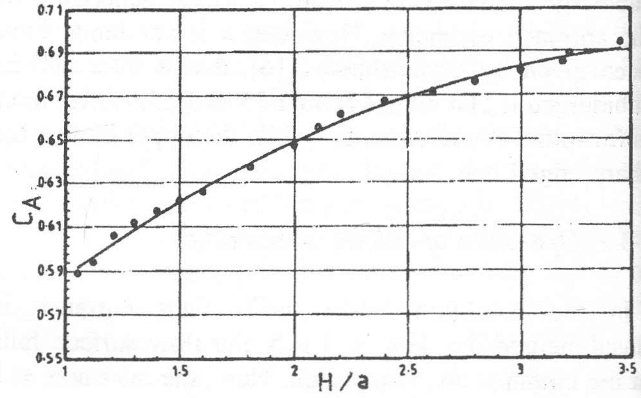


Figure 6. Relation between coefficient of combined contraction C_A and H/a.

i) *for coefficient* C_c,

$$C_c = -0.0096\left(\frac{H}{a}\right)^2 + 0.0778\left(\frac{H}{a}\right) + 0.2894, \tag{7}$$

with correlation coef. $R = 0.998$, and

ii) *for coefficient* C_A,

$$C_A = -0.0126\left(\frac{H}{a}\right)^2 + 0.098\left(\frac{H}{a}\right) + 0.5029. \qquad (8)$$

with correlation coef. $R = 0.998$

Introducing a discharge coefficient, $C_{do} = C_v \cdot C_A$, Eq (5) becomes,

$$Q = C_{do} \cdot A_o \sqrt{2g(H_o - C_c . a)}, \qquad (9)$$

where $C_v \sim 0.90$.

The values of C_{do} are plotted versus H/a as shown in Figure (7). An empirical equation, expressing this relation, can be written in the form,

$$C_{do} = 0.015\left(\frac{H}{a}\right)^3 - 0.12\left(\frac{H}{a}\right)^2 + 0.33\left(\frac{H}{a}\right) + 0.29, \qquad (10)$$

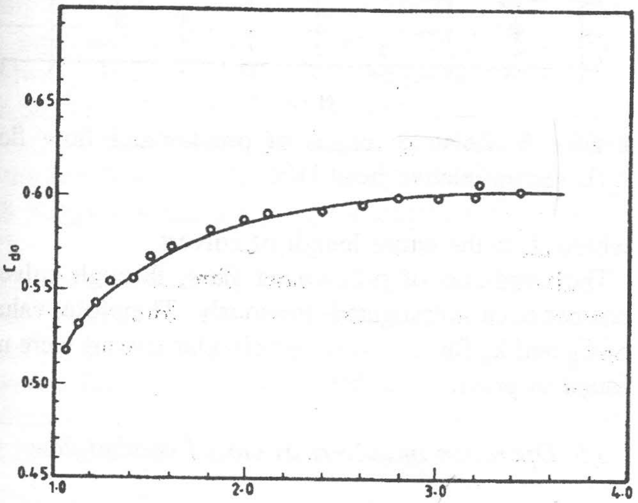


Figure 7. Relation beween coefficient of discharge C_{do} and ratio H/a.

For case of orifice flow, the discharge coefficient, given by Chow [5], varies from 0.45 to 0.75. Both coefficients C_c and C_{do}, are replaced by one coefficient equals 0.8 and 0.6 for rounded and square edges, respectively [6]. For values of H/a ranges from 1.4 to 5.0, the discharge coefficient varies from 0.44 to 0.59, and from 0.46 to 0.73 for square and rounded edges, respectively [17]. As for the coefficient of velocity C_v, it equals 0.94 for box culvert [16],

3.4. *Condition of pressurized flow through culvert*

For free outlet culvert when the headwater-culvert height ratio H/a exceeds 1.45, a part of the culvert length is equipped with full flow, while the other runs partly full. The culvert in this case has a combined action of pipe and open channel flows. The length of pressurized flow ℓ_n mainly depends on the shape and roughness of culvert barrel as well as on the headwater depth.

The discharge equation, governing this case of flow, can be obtained by applying the energy equation at sections 0-0 and n-n (section at which flow separates from the culvert crown). Considering the energy correction coefficient α equals unity, the energy equation can be written as,

$$H_o = \frac{P_n}{\gamma} + \frac{v^2}{2g}(1 + \eta_i) \qquad (11)$$

where,

H_o, is the total heat at section 0-0, $H_o = H + h_a$,

h_a, is the kinetic head, $h_a = \frac{v_a^2}{2g}$,

v_a, is the approaching velocity,

P_n is the pressure value on culvert base at section n-n,

v is the flow velocity through pressurized flow part,

γ is the specific weight of water, and

η_i is the coefficient of head loss at inlet,

Equation (11) can be written as,

$$Q = C_d \cdot A_o \sqrt{2g\left(H_o - \frac{P_n}{\gamma}\right)} \qquad (12)$$

where,

C_d is the discharge coefficient, it equals $\frac{1}{\sqrt{1 + \eta_i}}$ since the contraction coefficient equals unity in this case.

It was found from the experimental measurements of pressure that the values of P_n/γ, at section n-n, are always lower than the culvert height a. This refers to that the pressure distribution at section n-n deviates from the linear distribution. Therefore, a pressure coefficient k_p is introduced in the discharge equation to express the nonlinearity of pressure distribution, where

$$k_p = (\frac{P_n}{\gamma})/a. \text{ Hence,}$$

$$Q = C_d \cdot A_o \sqrt{2g(H_o - k_p.a)} \tag{13}$$

To evaluate the discharge coefficient C_d, the coefficient of head loss due to inlet, η_i, is evaluated using Weisbach equation where,

$$h_i = \eta_i \frac{v^2}{2g} \tag{14}$$

where h_i is the loss of head at the culvert inlet.

Table (3). App. 1 shows the values of η_i for a set of experiments conducted on culvert model of height a = 8.7 cm. From Table (3). The average values of C_d and k_p are 0.736 and 0.90, respectively.

In equation (13) the head loss due to friction along the length of pressurized flow was not taken into account. In order to account for the friction head loss, the discharge coefficient may be expressed as

$$C_d = \frac{1}{\sqrt{1 + \sum \eta}} \tag{15}$$

where

$$\sum \eta = \eta_i + \eta_f, \text{ and}$$

η_f is the coefficient of head loss due to friction. The coefficient η_f can be computed using Darcy-Weisbach equation:

$$\eta_f = \frac{2g.l_n}{C^2 R} \tag{16}$$

where,

ℓ_n is the length of pressurized flow,
C chezy coefficient ($m^{1/2}$/sec), and
R is the hydraulic radius.

The length of pressurized flow ℓ_n was experimentally measured and plotted versus H/a as shown in Figure (8). An empirical equation expressing this relationship can be written as follows:

$$\ell_n/L = = -0.0025(\frac{H}{a})^6 + 0.061(\frac{H}{a})^5 - 0.605(\frac{H}{a})^4 + 3.16(\frac{H}{a})^3$$

$$-9.26(\frac{H}{a})^2 + 14.5(\frac{H}{a}) - 8.624 \tag{17}$$

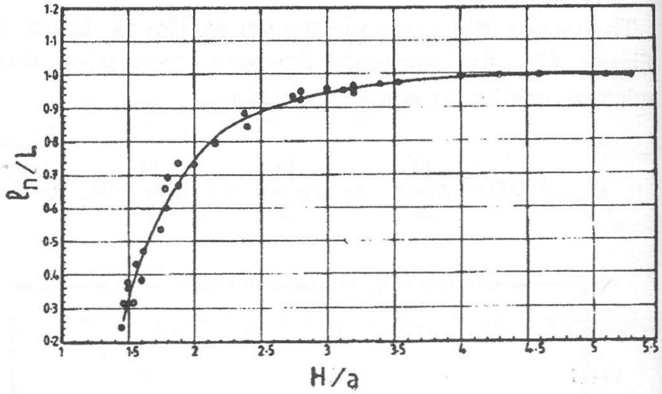


Figure 8. Relative length of pressurozed flow flow ℓ_n/L versus relative head H/a.

where L is the entire length of culvert.

The condition of pressurized flow, through culvert, has not been investigated previously. Therefore, values of C_d and k_p for both box and circular culvert were not found in previous studies.

3.5. *Operation of culvert as closed conduit flow*

If both inlet and outlet of the culvert are submerged, the culvert runs full. In this case the culvert is considered as closed conduit and acts as a pipe.

The discharge of the culvert, in this case, can be determined by the application of the continuity and energy equations between the approach and downstream sections, Then,

$$Q = C_{dp} \cdot A_o \sqrt{2g(H_o - H_t)} \tag{18}$$

where,

C_{dp} is the discharge coefficient of pipe flow,
H_t is the tailwater depth.

The discharge coefficient C_{dp} can be expressed as,

$$C_{dp} = \frac{1}{\sum \eta}, \tag{19}$$

where $\sum \eta = \eta_i + \eta_f + \eta_o$, and

η_o is the coefficient of head loss due to outlet.

Using the experimental measurements, conducted on the two culvert's models of heights, a equals 8.7 and 13.0 cm, the values of η_i, η_f and η_o are evaluated as shown in Tables (4) App.1. The average values obtained as follows; η_i=0.62, η_f=0.21, and η_o=1.02. Consequently, the average value of the discharge coefficient C_{dp} = 0.735.

Noting that the value of C_{dp} for ordinary cost iron pipe of 15 cm internal diameter has been found to be nearly 0.74 [18]. However, the coefficient of discharge for pipe and box culverts, set flush in a vertical headwall, equals 0.84 for square-edged entrance [17]. The addition of wingwalls to the entrance of a circular culvert set flush with a vertical headwall has no effect on the coefficient of discharge, while for box culverts with wingwalls and a square top entrance C_{dp} = 0.75 [17].

It is obvious that, the shape of entrance edges has a great influence on the discharge coefficient. Square-edges causes separation distance of flow from the culvert soffit, then the culvert runs full. The contraction of flow at the entrance increases the head loss at inlet and in turn decreases the discharge coefficient.

4. CONCLUSIONS

The characteristics of flow through a culvert of triangular shape cross section are extensively studied. A Comprehensive description for the culvert performance with different types of flow is presented. As a result, the obtained conclusions can be summarized as follows;

i) *weir flow*

The culvert will be under inlet control with weir flow when the outlet is unsubmerged and 0<H/a < 1.05. The discharge can be calculated using Eq (1).

ii) *Orifice flow*

When the culvert outlet is ûnsubmerged, hydraulically long culvert will be under inlet control with orifice flow when 1.05 < H/a < 1.30. For hydraulically short culvert, inlet acts with orifice flow for higher values of H/a (up to 3.5 in the present study for L/a = 11.5). For both cases, the culvert discharge is determined using Eq. (9).

iii) *pressurized flow condition*

If the culvert outlet is unsubmerged, and H/a>1.45, the upper part of the culvert length runs with full flow, while it runs partly full in the lower length. The discharge can be estimated using Eq (13).

(iv) *Pipe flow condition*

For both submerged inlet and outlet, culvert acts as a closed conduit. The discharge, in this case, is evaluated as in pipe using Eq. (18).

(v) For all the above cases the required coefficients of; discharge, velocity, contraction, and pressure are empirically evaluated.

The comparison between the obtained results for triangular shape culvert, in this paper, and the reported previously for both box and circular culvert indicated that entrance losses are slightly higher for triangular shape culvert.

Finally, culvert with triangular shape cross section may be recommended to be used in practical situations since it possesses greater stability against uplift forces.

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APPENDIX (I)

Table 1. Measured and Calculated Data for case of weir Flow through culvert, a = 13.0 cm.

No	Q ℓ/sec.	H_o, cm.	$\frac{H}{a}$	$\bar{b}$ cm	C_{dw}
1	0.294	1.49	0.114	14.15	0.258
2	0.697	2.62	0.200	13.50	0.272
3	1.209	3.70	0.282	12.89	0.286
4	2.040	5.31	0.405	11.96	0.305
5	2.747	6.53	0.498	11.27	0.320
6	3.543	7.91	0.603	10.47	0.337
7	4.256	9.17	0.700	9.75	0.353
8	4.989	10.48	0.800	9.00	0.369
9	5.690	11.80	0.902	8.23	0.385
10	6.393	13.08	1.00	7.94	0.401
11	6.629	13.52	1.034	7.24	0.407

Table 2. Measured and calculated Data for case of Orifice Flow through Culvert, a = 13.0 cm

No	Q, ℓ/sec.	H_o, cm.	$\frac{H}{a}$	y, cm.	A, cm^2.	$C_A=\frac{A}{A_o}$	$C_c = \frac{y}{a}$	C_{do}	C_v
1	6.74	13.77	1.05	4.67	57.46	0.589	0.359	0.518	0.879
2	7.25	14.66	1.12	4.71	57.84	0.594	0.362	0.533	0.897
3	7.79	15.87	1.21	4.84	59.08	0.606	0.372	0.544	0.898
4	8.30	17.04	1.30	4.90	59.64	0.612	0.377	0.552	0.902
5	8.77	18.28	1.40	4.95	60.10	0.617	0.381	0.557	0.903
6	9.36	19.63	1.50	5.00	60.57	0.622	0.385	0.567	0.912
7	9.85	20.87	1.60	5.05	61.03	0.626	0.388	0.574	0.917
8	10.78	23.64	1.81	5.16	62.03	0.637	0.397	0.581	0.912
9	11.53	26.06	2.00	5.27	63.02	0.647	0.405	0.586	0.906
10	12.00	27.48	2.11	5.36	63.81	0.655	0.412	0.591	0.902
11	12.33	28.79	2.21	5.43	64.43	0.661	0.418	0.591	0.894
12	12.99	31.26	2.40	5.49	64.95	0.667	0.422	0.593	0.889
13	13.72	33.97	2.61	5.55	65.47	0.672	0.427	0.596	0.887
14	14.35	36.45	2.8	5.60	65.89	0.676	0.431	0.599	0.886
15	14.92	38.95	3.00	5.65	66.32	0.681	0.435	0.599	0.880
16	15.49	41.46	3.19	5.70	66.74	0.685	0.438	0.600	0.876
17	15.78	41.91	3.22	5.75	67.16	0.689	0.442	0.608	0.882
18	16.32	44.95	3.45	5.80	67.58	0.694	0.446	0.604	0.870