OPTIMUM HYDRAULIC DESIGN FOR INVERTED SIPHON

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Abstract

In this research, optimum hydraulic design for siphon has been studied depending on the method of optimization **(Modified Hooke and Jeeves)** with some modifications. Some modifications on this method have done. These modifications are: 1- Modification on the assumed initials base points 2- Modification on the value of step length 3- Modification on the value of the reduced step length at each trial. The siphon shapes that used in this study are pipe, square, and rectangular. The materials that used are concrete and steel for designing inverted siphon.

A computer program depending on the method of (**Modified Hooke and Jeeves)** has written for optimum hydraulic design of inverted siphon structure with **"Quick- Basic"** language. Many examples solved by using this program to make insure the accuracy of it.

Keywords: Optimum, hydraulic, inverted siphon

التصميم الهيدروليكي الامثل للسيفون المعكوس

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الخلاصة

في هذا البحث تم دراسة التصميم الهيدروليكي الامثل بالاعتماد على طريقة **(Modified Hooke and (Jeeves** مع بعض التعديلات التي أجريت عليها خلال هذا البحث.أن تلك التعديلات على هذه ألطريقة يمكن تلخيصها للاتي:1- تعديلات على النقطة الابتدائية المفروضة 2- تعديلات على قيمة الخطوة 3- تعديلات على قيمة الخطوة المخفضة المضافة في كل محاولة.
لقد تم عمل برنامج حاسب بلغة **"Quick- Basic"**بالاعتماد على طريقة **(Modified Hooke and Jeeves)** للتصميم الهيدروليكي الامثل للسيفون، وتم تطبيق عدة أمثلة محلولة باستخدام هذا البرنامج للتأكد من دقته.

Nomenclature

S: the slope of siphon (dimensionless).
V: the velocity of the flow through the siphon barrel (m/s).
h_f : the total head losses which equals to the difference between the upstream and downstream water level (m).
b: span of siphon (m).
d: height of siphon (m).
Y: elevation of water (m).
Z_s: cost of construction per unit meter for steel pipe (I.D).
Z_{cp}: cost of construction per unit meter for concrete pipe (I.D).
Z_{cb}: cost of construction per unit meter for concrete box (I.D).

D: diameter of pipe for siphon (m).
L: length of the barrel (m).
R: hydraulic mean radius of the barrel (m).
V: velocity of flow through the barrel (m/s).
Va : velocity of approach and is often neglected (m/s).
f_2 : is a coefficient such that the losses of head through the barrel due to surface friction,
F1: constant for elbows losses.
F2: constant for bend losses
R_1: Depth of scour below water level (m).
q: Discharge / meter width (m^3/m.s).
Ca: constant for showing irrigation canal (Ca=1) or drainage canal (Ca=2).
Q: discharge (m^3/sec).
L: length of inverted siphon (m).
Ke: entrance coefficient.
Ko: outlet coefficient.
Ks: screen coefficient.
Kel: elbows coefficient
Kex: expansion coefficient
Kcon: contraction coefficient
Vc: velocity of canal (m/sec)
Ye: depth of water in canal (m).
b::span of box section (m)
D:Diameter of pipe (m)
d:height of box section (m)
f:Lacey silt factor (m)
f_1:coefficient of head losses at entry (m)
K_1:Entrance coefficient (m)
K_2:Outlet coefficient (m)
K_{con}:Contraction coefficient (m)
K_{ex}:expansion coefficient (m)
L:length of the barrel (m)
q:Discharge / meter width (m^3/m.s)
R:hydraulic mean radius of the barrel (m)
R_1:Depth of scour below water level (m)
V:velocity of flow through the barrel (m/s)
Va:velocity of approach and is often neglected (m/s)
Z_{cb}:cost of construction for concrete box (I.D)
Z_{cp}:cost of construction for concrete pipe (I.D)
Z_s:cost of construction for steel pipe (ID).

Introduction

Highways and railroads traversing the land cut across individual watersheds. To allow the flow from each watershed across the embankment, culverts, siphons and aqueducts are used. Although these structures simple in appearance, their hydraulic design is no easy matter. The operation of these structures under the various possible discharge conditions presents a somewhat complex problem that cannot be classified either as flow under pressure or as free surface flow. The actual conditions involve both of these concepts.

Hydraulic structures employed to convey, control, measure and protect the flow of water at various locations in an irrigation and drainage system. There are many different types of structures can be used for these purposes though individually they may be small or large. Structures can contribute to a large part of the overall capital cost of an irrigation project; hence, a proper design of these facilities is a major factor in making the scheme efficient and keeping capital costs to a minimum. The final design must take into consideration the practices and farming methods in vogue and should endeavor to meet the requirements of the farmer and thereby enlist his co-operation. This will minimize maintenance costs by minimizing mis-use and vandalism. Other factors that affect the design and operation of irrigation structures include site conditions, the methods employed for the conveyance of water and the availability of construction materials. Only the smaller sizes of structure are amenable to having the design procedure standardized.

Purpose and Description of Inverted Siphons

Inverted siphons used to convey canal water by gravity under roads, railroads, other structures, various types of drainage channels, and depressions. A siphon is a closed conduit designed to run full and under pressure (Aisenbrey, et al., 1974). The structure should operate without excess head when flowing at design capacity.

A-Application

Economics and other considerations determine the feasibility of using a siphon or another type of structure to accomplish the previous objectives. The use of an elevated flume would be an alternative to a siphon crossing a depression, drain channel or another manmade channel. The use of bridge over a canal would be an alternative to a siphon under a road or a railroad.

B-Advantages and Disadvantages of Inverted Siphons

Inverted siphons are economical, easily designed and built, and have proven a reliable means of water conveyance. Normally, canal erosion at the ends of the siphon is inconsequential if the structures in earth waterways have properly designed and constructed transitions and erosion protection.

Costs of design, construction, and maintenance are factors that may make an inverted siphon more feasible than another structure that might used for the same purpose. There may be, however, instances where the value of the head required to operate a siphon may justify the use of another structure such as a bridge (Aisenbrey, et al., 1974) .

An inverted siphon may present a hazard to life, especially in high population density areas.

Structure Components

The siphon profile is determined in such a way as to satisfy certain requirements of cover, siphon slopes, bend angles, and submergence of inlet and outlet. Siphon cover requirements are (Aisenbrey, et al., 1974) :

1) At all, siphons crossing under roads other than farm roads and siphons crossing under railroads, a minimum of (0.91 m) of earth cover should provided. Farm roads require only (0.61 m) of earth cover and are frequently ramped using 10 to 1 slopes (10 percent grade) when necessary to provide minimum cover requirements. If roadway ditches exist and extended over the siphon, the minimum distance from the ditch to the top of the pipe should be (0.61 m).
2) At siphons crossing under cross-discharge channels, a minimum of (0.91 m) of earth cover should provided unless studies indicate more cover is required because of projected future retrogressions of the channel.
3) At siphons crossing under an earth canal, a minimum of (0.61 m) of earth cover should provide.
4) At siphons crossing under a lined canal, a minimum of (0.15 m) of earth cover should provide between the canal lining and the top of siphon.

Roadway widths and side slopes at road and railroad siphon crossings should match existing roadway widths and side slopes, or as otherwise specified. Side slopes should not be steeper than (1-1/2 to 1).

Siphon slopes should not be steeper than (2 to 1) and should not be flatter than a slope of (0.005).

Hydraulic Design Considerations

Available head, economy, and allowable siphon velocities determine the size of the siphon. Thus, it is necessary to assume internal dimensions for the siphon and compute head losses such as entrance, friction, bend, and exit. The sum of all the computed losses should approximate the difference in energy grade elevation between the upstream and downstream ends of the siphon (available head).

In general, siphon velocities should range from (1.07 m/s) to (3.05 m/s), depending on available head and economic considerations (Aisenbrey, et al., 1974) **.**

The following velocity criteria may use in determining the dimensions of the siphon:

1- (1.07 m/s) or less for a relatively short siphon with only earth transitions provided at entrance and exit.
2- (1.52 m/s) or less for a relatively short siphon with either a concrete transition or a control structure provided at the inlet and a concrete transition provided at the outlet.
3- (3.05 m/s) or less for a relatively long siphon with either a concrete transition or a control structure provided at the inlet and a concrete transition provided at the outlet.

Where there is reasonable, confidence that a good standard of construction will achieve the upper limit of velocity through a siphon may take as (3 m/s), where doubts exist as to construction quality this figure may be reduced to (2 m/s),(Jawad, Kanaan, 1983) . To avoid sedimentations, the minimum velocity that considered is (0.6 m/s).

For discharges up to about (2.5 m^3/s), pipes can be used but for larger discharges a box section is preferred, (Jawad, Kanaan, 1983) .

For future increase in demand, it is usual to design all canal structures for (1.2 Q) where Q is the design flow during the period of maximum demand. The minimum design flow is usually taken as (0.7 Q), blow this value, there is the risk that sedimentation will occur due to low velocities. For drainage structures, the maximum flow taken as (1.5) times the design flow. Minimum flow does not apply to drainage structures, (Jawad, Kanaan, 1983) .

The most common materials used for culverts are concrete and corrugated steel. The roughness in both cases usually assumed constant for any flow depth. On hilly terrains where the culvert slope expected to be relatively steep and the flow through the culvert gains considerable energy, corrugated steel pipes offer energy-dissipating advantages. On flat terrains, energy loss through a culvert is undesirable; hence, concrete pipes are more suitable (Simon, 1997). For design purposes in Iraq, concrete and steel pipes considered with roughness coefficient (n) equal to (0.014) and (0.01) respectively(Jawad, Kanaan, 1983).

Drainage structures must checked against piping, uplift pressure, erosion at upstream, downstream, and protected against sulphate attack on concrete. The protection consist of ($0.4\times0.4\times0.2$ thick m) concrete blocks over (0.1 m) gravel bedding for length ($2\times D$) of the barrel for upstream. Downstream is similar for length ($3\times D$). Depth of scour in unlined canal can be calculated from Lacey formula and compared with ($2\times D$) and ($3\times D$) (Jawad, Kanaan, 1983).

$$R_1=1.35\times (q^2/f)^{0.33} \qquad (1)$$

Where:
f: Lacey silt factor can obtained from **Table (1)** which used for Iraq.

$$Ds = 1.5 \times R_1 - \text{Depth of flow} \tag{2}$$

$$\text{Length of protection} = 1.5 \times Ds \tag{3}$$

To ensure inlet submergence the invert of the siphon section should be dropped so that D greater than the elevation of water at the canal with the drop at the siphon entrance with slope (1 to 5 V: H) which generally equal to (0.5 m). So the discharge will divided into 2,3,4,….etc, to satisfy the previous condition, and that means the siphon sections equal to 2,3,4,…etc.

Reinforced concrete rigid frame box culverts with square or rectangular opening are use up to spans of (4 m). The height of the vent generally does not exceed (3 m). Adopting thickness of slab as (100 mm/ meter span) (Simon,1997).

Head Losses of Inverted Siphon

Total head losses equal to the sum of the friction, entrance, exit, screens, elbows, transitions and bends losses. The minimum overall head loss for inverted siphons is (0.2 m) (Jawad, Kanaan,.1983) . Losses through siphon can calculate by using the following formula (Garg, Santosh , 1978) **:**

$$\Delta H = \left[1 + f1 + f2 \times \frac{L}{R} + F1 + F2 + Ks\right]\frac{V^2}{2g} - \frac{Va^2}{2g} + h_{ex} + h_{con} \tag{4}$$

A briefly, discussions about these losses can illustrate as follows:

Friction Losses

Friction losses through the barrels of siphon can calculate by using the following formula.

$$hf = \left[f2 \times \frac{L}{R}\right]\frac{V^2}{2g} \tag{5}$$

Where:

$$f_2 = a\left(1 + \frac{b}{R}\right) \tag{6}$$

Where the values of **a** and **b** for different materials may be taken as given in **Table (2)**.

Entrance and Exit Losses

Entrance losses can calculate from the following equation (Jawad, Kanaan,1983) :

$$h_e = K_1 \frac{V^2}{2g} \tag{7}$$

Where:

K_1: Entrance coefficient, which obtained from the following table.

Exit losses can calculate from the following equation[(5)]:

$$h_o = K_2 \frac{V^2}{2g} \tag{8}$$

Where:
K_2: Outlet coefficient which taken as 1.0 for most outlets.

Screen Losses

Losses through screens and trash racks are related the velocity head of the approach flow and the geometry of the rack (spacing, thickness and shape of bars and inclination to the horizontal). Screens used at entry and exit on inverted siphons as a safety precaution to prevent children and unauthorized personal from gaining access. The head loss can related to the percentage of waterway area that the bars take up as shown in **Table (4)** below:

$$h_s = K_s \frac{V^2}{2g} \tag{9}$$

Elbows and Bends Losses

It remains now to consider the effect of elbows and bends, on the discharge of the siphon. The losses in an elbow or a bend in a pipe appear to be due to secondary circulation and to contraction of the flow, which occur, in, and immediately downstream of, the cause of the disturbance.

Weisbach gives the following formula for the loss of head in elbows[6] **.**

$$h_{el} = F_1 \frac{V^2}{2g} \tag{10}$$

Where:

$$F_1 = 0.9457 \sin^2 \frac{\vartheta}{2} + 2.047 \sin^4 \frac{\vartheta}{2} \tag{11}$$

According to this theory, if the radius of curvature R does not change, the length ℓ_b of the bent portion of the pipe, and angle ϑ, have very little effect (if any) on the total loss of head attributable to the bend. The formula was therefore as follows **(**Leliavsky, Serrge, 1979**).**

$$h_b = F_2 \frac{V^2}{2g} \tag{12}$$

Where:

$$F_2 = (0.13 + 0.16\left[\frac{D}{R}\right]^{7/2}) \frac{\vartheta}{90^\circ} \tag{13}$$

D: Diameter of pipe.

Transitions Losses

A channel transition may define, as a local change is cross section, which produces a variation in flow from one uniform state to another. In many hydraulic structures the main reason for constricting or fluming the flow at the inlet is to reduce, the costs of construction of the structure and in some cases can provide an expedient device for measurement of discharges in the main body of the structure. It is important that transitions to and from structures is properly designed when head losses are critical. Transitions can serve several other functions, namely:

1- To minimize canal erosion.
2- To increase the seepage path and thereby provide additional safety against piping.
3- To retain earth fill at the ends of structures.

All transitions may classify as either inlet (contraction) or outlet (expansion) transition. Expansion and contraction losses can be finding from the following equations (Jawad, 1983):

$$h_{ex} = K_{ex}\left(\frac{V^2}{2g} - \frac{Vc^2}{2g}\right) \qquad \text{(For canal structures)} \qquad (14)$$

$$h_{con} = K_{con}\left(\frac{V^2}{2g} - \frac{Vc^2}{2g}\right) \qquad \text{(For canal structures)} \qquad (15)$$

$$h_{ex} = K_{ex}\left(1.2\frac{V^2}{2g} - \frac{Vc^2}{2g}\right) \qquad \text{(For drainage structures)} \qquad (16)$$

$$h_{con} = K_{con}\left(1.2\frac{V^2}{2g} - \frac{Vc^2}{2g}\right) \qquad \text{(For drainage structures)} \qquad (17)$$

Where:

K_{ex} & K_{con}: are the expansion and contraction coefficient respectively, which can obtained from **Table (5)** depending on the discharge values (depending on the reference of **[5]**).

Angle of contraction at the upstream is preferred as equal as or less than 27.5^o, and the optimum contraction angle is 14^o, while the angle of the expansion at the downstream is equal or less than 22.5^o (Varshney,1972).

Optimization Method For Designing the Inverted Siphon

The purpose of optimization is to find the best possible solution among the many potential solutions satisfying the chosen criteria. Designers often based their designs on the minimum cost as an objective, safety and serviceability.

A general mathematical model of the optimization problem can represent in the following form [(2)]:

A certain function (Z), called the objective function,

$$Z = f\} X_i\} \quad i = 1, 2 \ldots n \tag{18}$$

Which is usually the expected benefit (or the involved cost), involves (n) design variable {X}? Such function is to be maximized (or minimized) subject to certain equality or inequality constraints in their general forms:

$$gi\ \{X_i\} = bi \qquad i = 1, 2, \ldots\ldots\ldots, i \tag{19}$$

$$qi\ \{X_j\} \geq bj \qquad j = 1, 2, \ldots\ldots\ldots, j \tag{20}$$

The constraint reflects the design and functional requirements. The vector {X} of the design variables will have optimum values when the objective function reaches its optimum value.

Objectives Functions

The objective function (Z_s) of the present research for steel pipes siphons involves the cost of transportation, cutting, constructions, and filling as ($Z_s = C \times D$) (Raju,1986), (Zs: total cost per unit meter, C: constant, D: diameter of siphon)

. The following equation estimated by **(STATISTICA)** program with a regression coefficient of (R = 0.996):

$$Z_s = 248791.9 \times D^{0.469596} \tag{21}$$

In addition, the objective functions for concrete pipe and box siphons shown below. Data for this formula obtained from the reference(7) **.**

$$Z_{cp} = 177798.44 \times D^2 \tag{22}$$

$$Z_{cb} = 514500\ (\frac{b^2}{3} + \frac{d^2}{3}) \tag{23}$$

The following **Figure** shows the relationships between the costs and the dimensions of concrete siphon (pipe and box) and steel siphons, depending on the previous formulas.

Constraints for the optimization Technique

The following constraints that considered for the optimizations technique in this research was as follows:

1- $0.005 \leq S \leq 0.5$
2- $0.6 \leq V \leq 3.0$
3- $h_f \geq 0.2$
4- $b \leq 4.0$
5- $d \leq 3.0$
6- $d \leq (Y+0.5)$

Modefied Hooke and Jeeves

This method dates back to 1961(3) but is nonetheless a very efficient and ingenious procedure. The search consists of a sequence of exploration steps about a base point, which if successful followed by pattern moves. The procedure is as follows:

A) Choose an initial base point $\mathbf{b_1}$ and a step length $\mathbf{h_j}$ for each variable X_j, j = 1, 2… n. The program given later uses a fixed step h for each variable, but the modification indicated can be useful.

B) Carry out an exploration about $\mathbf{b_1}$. The purpose of this is to acquire knowledge about the local behavior of the function. This knowledge used to find a likely direction for the pattern move by which it hoped to obtain an even greater reduction in the value of the function. The exploration about $\mathbf{b_1}$ proceeds as indicated.
i) Evaluate f ($\mathbf{b_1}$).
ii) Each variable now changed in turn, by adding the step length. Thus f ($\mathbf{b_1} + \mathbf{h_1}\ \mathbf{e_1}$) can be calculated where e_1 is a unit vector in the direction of the X_1-axis. If this reduces the function, replace $\mathbf{b_1}$ by (b1 $+\mathbf{h_1}\ \mathbf{e_1}$). If not find f ($\mathbf{b_1} - \mathbf{h_1}\ \mathbf{e_1}$) and replace $\mathbf{b_1}$–by ($\mathbf{b_1} - \mathbf{h_1}\ \mathbf{e_1}$) if the function–is reduced. If neither step gives a reduction leave $\mathbf{b_1}$ unchanged and consider changes in X_2, i.e. find f ($\mathbf{b_1} + \mathbf{h_2}\ \mathbf{e_2}$) etc. When it has considered all n variables, a new base point $\mathbf{b_2}$ can obtained.
iii) If $\mathbf{b_2} = \mathbf{b_1}$ i.e. no function reduction has been achieved, the exploration is repeated about the same base point $\mathbf{b_1}$ but with a reduced step length. Reducing the step length(s) to one tenth of its former value appears to be satisfactory in practice.
iv) If $\mathbf{b_2} \neq \mathbf{b_1}$ make a pattern move.
C) Pattern moves utilize the information acquired by exploration, and accomplish the function minimization by moving in the direction of the establish "pattern". The procedure is as follows.
i) It seems sensible to move further from the base point $\mathbf{b_2}$ in the direction $\mathbf{b_2} - \mathbf{b_1}$ since that move has already led to a reduction in the function value. Therefore, the evaluation of the function at the next pattern point can do.

$$\mathbf{P_1 = b_2 + 2\ (b_2 - b_1)} \tag{24}$$

In general:

$$\mathbf{P_i = b_i + 2\ (b_{i+1} - b_i)} \tag{25}$$

ii) Then continue with exploratory moves about P_1 (P_i).
iii) If the lowest value at step C (ii) is less than the value at the base point $\mathbf{b_2}$ (bi_{+1} in general) then a new base point $\mathbf{b_3}$ ($\mathbf{b_{i+2}}$) has been reached. In this case, repeat C (i). Otherwise abandon the pattern move from $\mathbf{b_2}$ ($\mathbf{bi_{+1}}$) and continue with an exploration about $\mathbf{b_2}$ ($\mathbf{b_{i+1}}$).
D) Terminate the process when the step length(s) has reduced to a predetermined small value.

In this research some modifications on this method has achieved, since this method is not able to move along the constraint and converges on the first point on the constraint that it locates as the solution. With a certain initial point and certain step length, a certain solution has obtained, while with another initial point or another step length another different solution has obtained. These modifications reduce the difference between the two obtained solutions. These modification in this research as follows:
1- Assume the initial base point within the range of constraints.
2- Reduce the step length to a lower value such as (0.00001).
3- Reducing the step length(s) to (1/1.001) of its former value appears to be more satisfactory in practice instead of one tenth at step B (iii).

Computer Program for Optimum Hydraulic Design

In this research, the program was writing with "Quick- Basic" Language depending on **(Modified Hook and Jeeves)** method with some modifications -since **(SUMT)** method cannot be used due to the fractional powers of constrains- to find the optimum hydraulic design for the inverted siphon. Many examples applied by using this program to check the accuracy of it. The following example solved without the optimization technique and with the optimization technique by using this program.

The input data for this program were:(Ca, Cs, L, Ke, K_0, Ks, Cel, Kex, …)
X(i): initial dimension for siphon (i=1 for pipe siphon, i= loop from 1 to 2, for box and rectangular siphon).

H: step length.

Many examples applied using the program and compared with the design without optimization as follow:

The following figure shows a typical section for inverted siphon:

The following **Table** (8) shows the dimensions of siphon with variable discharges, constant velocity (0.82 m/s) and variable elevation for the same canal.

The following **Table** (9) shows the dimensions of siphon with variable discharges, variable velocity and constant elevation (1.5 m) for the same canal.

The following **Figure** (3) shows the relationship between the cost of siphon construction and discharge.

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Table (1): Silt Factor [5].

Region	f
Northern	**0.7-1.0**
Central	**0.6**
Southern	**0.5**

Table (2): Values of a and b for different materials [4].

Materials of the surface of the barrel	a	b
Smooth iron pipe	0.00497	0.025
Encrusted pipe	0.00996	0.025
Smooth cement plaster	0.00316	0.030
Ashlars or brick work	0.00401	0.070
Rubble masonry or stone pitching	0.00507	0.250

Table (3): Entrance coefficient [5].

Description	K_1
For square edged inlet flush with vertical walls	0.5
For rounded inlets, radius r where $r/D \leq 0.15$	0.1
For grooved or socket ended pipes	0.15
For projecting concrete pipes	0.2
For projecting steel pipes	0.85

Table (4): Loss coefficients for screens and trash racks [5].

Bar area/waterway area %	5	10	15	20	25	30
Loss coefficient (Ks)	**0.12**	**0.25**	**0.42**	**0.62**	**0.86**	**1.15**

Table (5): Expansion and contraction coefficients

Siphon section	Discharge m^3/s	K_{ex}	K_{con}
Box	**2.5-5**	**0.6**	**0.3**
	> 5	**0.2**	**0.1**
Pipe	**< 0.5**	**1.0**	**0.5**
	0.5-2.5	**0.7**	**0.4**

Table(6): Data for optimum hydraulic design for inverted siphon

	Q(m3/s)	Vc(m/s)	Elev. Of water(m)	Length of siphon(m)	Kent	Kext	Ks	Kelb
Case 1	4	0.82	1.50	41.3	0.2	0.3	0.2	0.05
Case 2	5	1.0	2.0	50	0.2	0.3	0.2	0.05
Case 3	10	1.50	2.0	70	0.2	0.3	0.2	0.05
Case 4	20	1.50	2.0	70	0.2	0.3	0.2	0.05

Table (7): Output of the above input data with and without optimization technique.

Case		No. of Sections	Dimension (m)
1	Without optimization	1	1.45 x 1.45
	With optimization	1	1.15 x 1.15
2	Without optimization	1	1.54 x 1.54
	With optimization	1	1.29 x 1.29
3	Without optimization	1	2.13 x 2.13
	With optimization	1	1.83 x 1.83
4	Without optimization	2	2.13 x 2.13
	With optimization	2	1.83 x 1.83

Table (8): Dimension of siphon and its number of sections for constant velocity.

$Q(m^3/s)$	4	8	10	12	15	18	20	25	30
Y(m) / V(m/s)	1.5	3.0	3.75	4.5	5.63	6.75	7.5	9.38	11.3
0.82	1.12 × 1.12	1.64 × 1.64	1.82 × 1.82	2 × 2	2.23 × 2.23	2.45 × 2.45	2.58 × 2.58	2.88 × 2.89	2.23 × 2.24
Section No.	1	1	1	1	1	1	1	1	2

Table (9): Dimension of siphon and its number of sections for constant elevation.

$Q (m^3/s)$	4	8	10	12	15	18	20	25	30
V(m/s) / Y(m)	0.82	1.64	2.05	2.46	3.08	3.69	4.10	5.13	6.15
1.50	1.12 × 1.12	1.58 × 1.58	1.76 × 1.77	1.93 × 1.94	1.58 × 1.58	1.73 × 1.73	1.82 × 1.83	1.66 × 1.67	1.82 × 1.83
Section No.	1	1	1	1	2	2	2	3	3

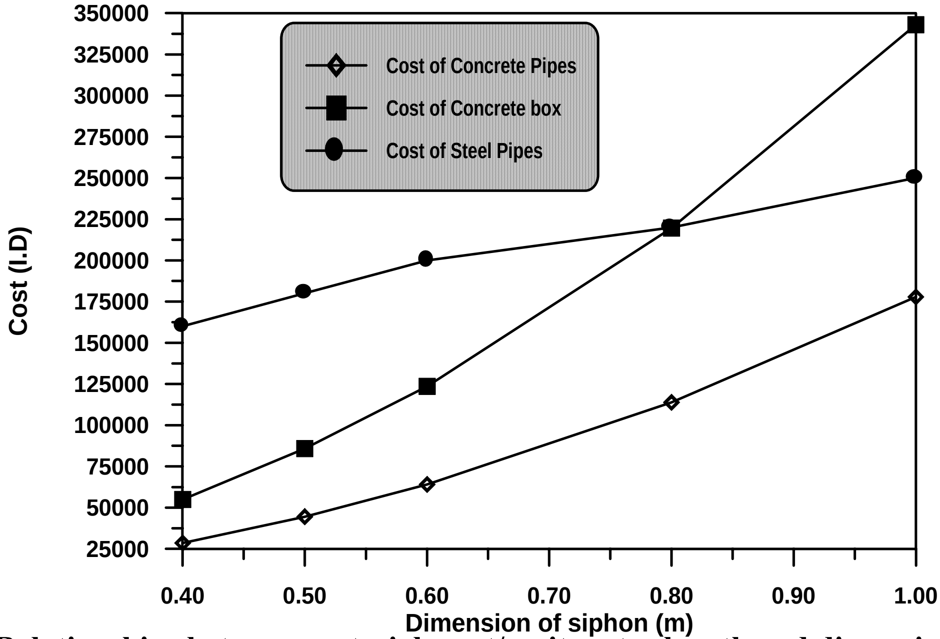

Fig. (1): Relationships between materials cost/ unit meter length and dimensions of inverted siphon.

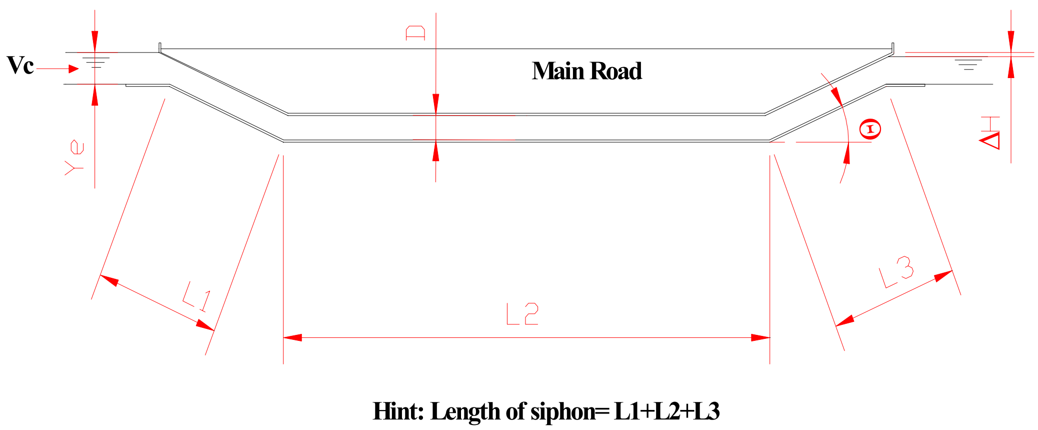

Fig. (2): Typical section for inverted siphon.

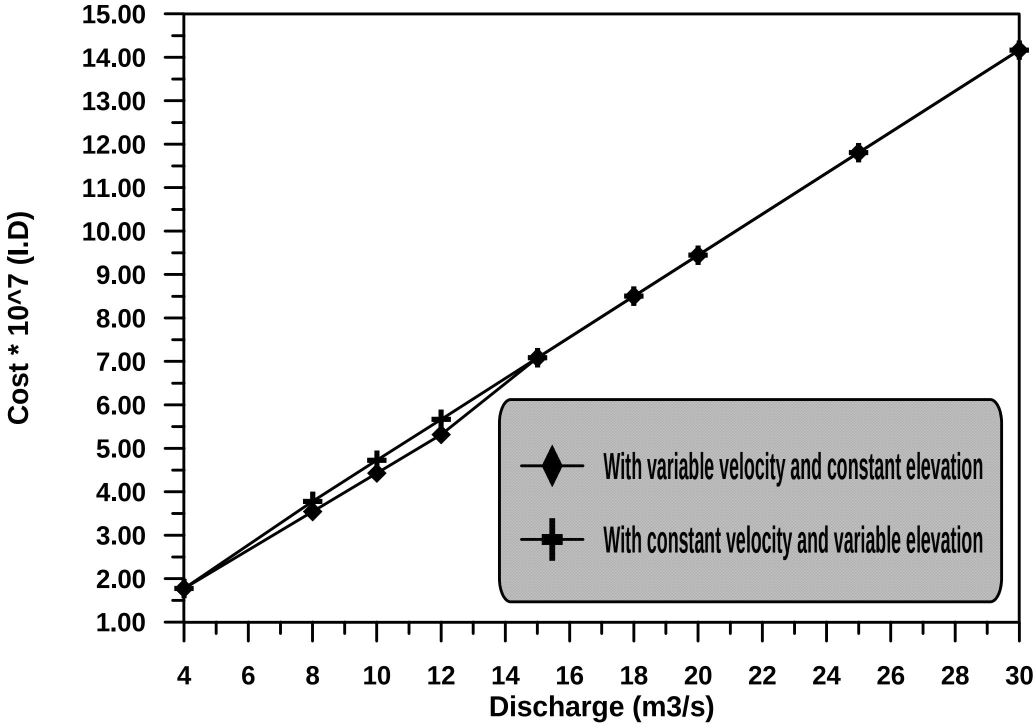

Fig. (3): Relationships between cost and discharge of inverted siphon.