A BROKEN HEADWALL FOR INCREASING THE WORKING EFFICIENCY OF BOX CULVERTS

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ABSTRACT

Since inclined headwalls proved promising good results in increasing the performance efficiency of the under-desert road culverts, and so protecting such roads against overtopping and flooding (Ashour et al., 2016). Using headwalls with inclination angle less than 45° will be so expensive due to its big length for reaching the water levels. So in this experimental study, an economical solution for using such inclined headwalls is introduced, to score the two needed goals (more culvert performance efficiency, and at the same time, with minimum cost). The technical idea tested here is to use a broken headwall consists of two parts; the first part is an inclined part just over the top point of the culvert, while the second part which will be over that inclined part will be vertical and extends some distance over the water surface. This study is divided into two trends. The first one is focusing on obtaining the optimum inclination angle (θ), of the inclined lower part of the tested headwall. The second trend concerns with the length (L) of that inclined part (as a function of the culvert inside height "d") after which the vertical part begins. Six angles of inclination ranging from 15° to 90° were tested in addition to the culvert without any headwalls (projected culvert) as a reference. Meanwhile five models of broken headwalls of lower inclined part of length ranging as L/d = 0.5, 1.0, 1.5, 2.0, and 2.5 were examined with the recommended inclination angle. Experiments carried out using the introduced new shape of the headwall in both upstream and downstream sides (at the entrance and exit of the culvert). Through a total of 315 experimental runs, 30° inclination angle for the introduced headwall in both culvert's entrance and exit, proved the best among all the tested angles. Also, the relative length of the inclined part (L/d) =2.5 showed the best economic relative length for the lower inclined part among all the tested relative lengths.

Keywords: Culvert efficiency, Inclined headwall, Outlet control, Box culverts, Broken headwall.
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1 INTRODUCTION

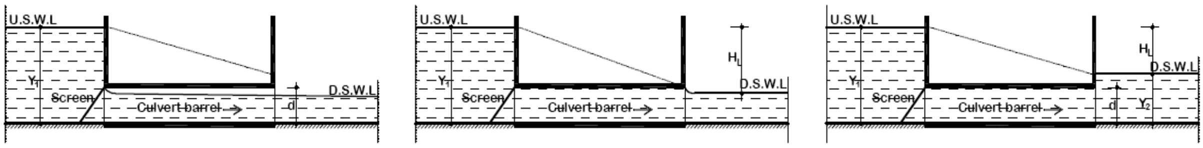
The present research is a trial for introducing an efficient, and economic way to protect desert-road box culverts against the expected attack of the flash flooding or torrents by improving and increasing their performance efficiency. After reviewing the available previous studies and discussing their main results, the following main technical points can be highlighted:

- The performance of culverts is significantly affected by the inlet shape and configurations(French, 1969).
- The best inlet shape for the box culverts, is the tapered shape with slope 5:1 and has rounded sides (R=0.5 cm), which gives the minimum head loss and the best performance (El-Bahar, 1996).
- Using the vertical headwall at the upstream side improves the hydraulic performance, and maintains the same discharge with low water height at the upstream side (Smith and Oak, 1995).
- Using the beveled or the rounded edge barrels improves the hydraulic performance of culverts compared with the sharp edge barrels (Lorenz et al., 1953).
- The worst shape for box culverts is the conventional sharp edged without any modifications (Khalil and Zein, 1995).
- Equipping a headwall of inclination angle 15° in the U.S. side of the box culvert gave the best hydraulic efficiency (Ashour et al. 2016)

From reviewing the available literature, it was clear that there are many tools for enhancing the discharge capacity of the box culverts such as using rounded inlets, beveled-edge inlets, side or slopes tapered inlets (James et al., 2012; Metwally, 1998; Harrison et al., 1972).However there is no attempt for studying the effect of using inclined headwall as a tool for improving the desert road culvert performance. Ashour et al. (2016) studied the effect of the inclined headwall on the hydraulic efficiency of the box culvert, where they examined an inclined headwall equipped only in the U.S. side of the culvert. Since the flush floods, and torrents may attack the desert roads from any sides of the culverts which means great importance of using the needed improving tools for such under desert road culverts to reach the maximum possible working efficiency, which means more safety for the road over such culverts. So, in this work we tried to test the influence of equipping a modified headwall with different inclination angles in both sides of the box culvert.

2 THEORETICAL APPROACH

There are two conditions of flow through culverts, where culverts can operate with inlet or outlet control depending on the location of the control section (Norman, 1995) In case of inlet control, the culvert barrel is running partially full while the U.S. is submerged, the culvert in this case behaves as an orifice as shown in figure (1-a),while in case of outlet control, the culvert barrel is running full and the culvert is acting as a pipe flow, as shown in figure (1-b) for free outlet and figure (1-c) for submerged outlet.



(a). Inlet control **(b). Free outlet control** **(c). Submerged outlet control**

Figure1.Conditions of flow through culverts.

The present study focuses on the effect of the inclined headwall equipped in the U.S. and D.S. sides of box culvert on the hydraulic efficiency, so all the experiments were carried out in case of the submerged outlet condition and the relationship between the head loss and the discharge can be written as follows (Younan N. A., 1991):

$$H_L = \left[K_{in} + K_{sc} + K_{fr} + K_{ex}\right]\frac{V^2}{2g} \quad (1)$$

$$\left[K_{in} + K_{ex}\right] = H_L \frac{2g}{V^2} - \left[K_{sc} + K_{fr}\right] \quad (2)$$

Where the headwall type effects on the value of the entrance and the exit losses coefficient, (K_{in} and K_{ex}).

3 EXPERIMENTAL SET-UP

The experiments of this research were performed in a re-circulation rectangular open flume at the Irrigation and Hydraulic Laboratory of Civil Engineering Department at Assiut University, as shown in figure (2).

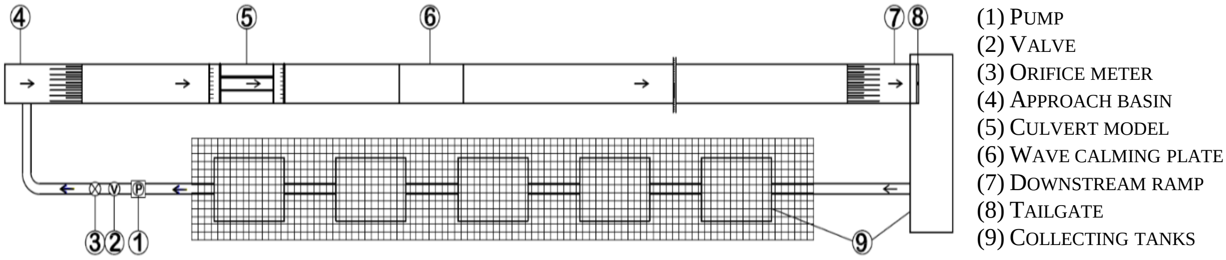
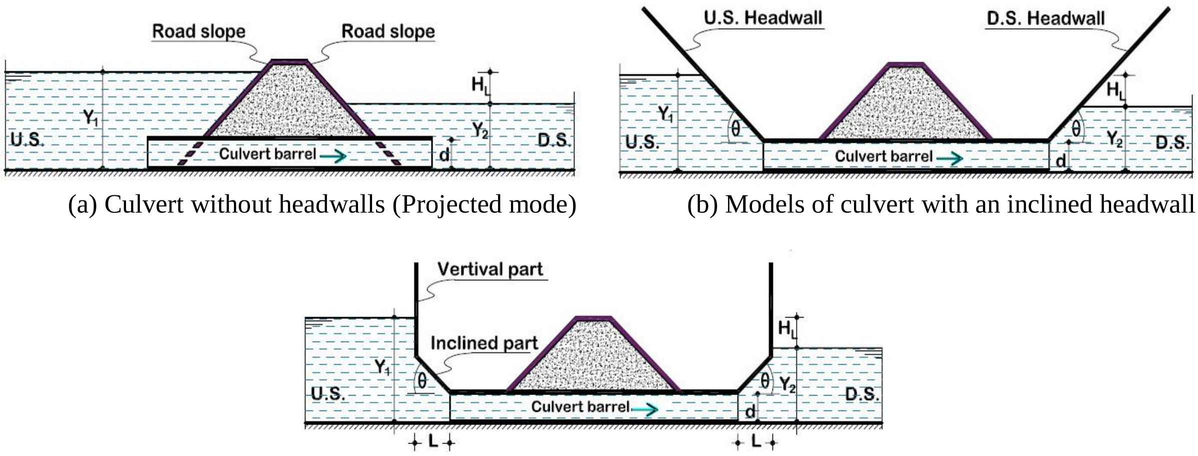


Figure 2. Experimental Set-Up.

The flume is 20 m long, 30 cm wide and 50 cm depth, with an adjustable slope. A tail gate was located at the end of the flume to control the downstream water depth. The discharge was delivered by a pump and measured using a calibrated orifice meter with a manometer. Measurements of the U.S. and D.S. water depths (Y_1 and Y_2), were recorded using Vernier point gauge and electrical point gauge. A Perspex barrel of an inner cross section 9.0x 9.0 cm, 0.6 cm wall thickness, and 100 cm length was used for testing the conventional box culvert as shown in figure (3).



(a) Culvert without headwalls (Projected mode)

(b) Models of culvert with an inclined headwall

(c) Modelsof culvert with a broken headwall

Figure 3. Types of tested headwall models

4 EXPERIMENTAL APPROACH

The experiments were carried out for recommending the most efficient inclination angle of the headwall for permitting a passage of maximum discharge with minimum headloss and economical shape of headwall at the same time. The types of the tested headwall models are shownin photo (1).

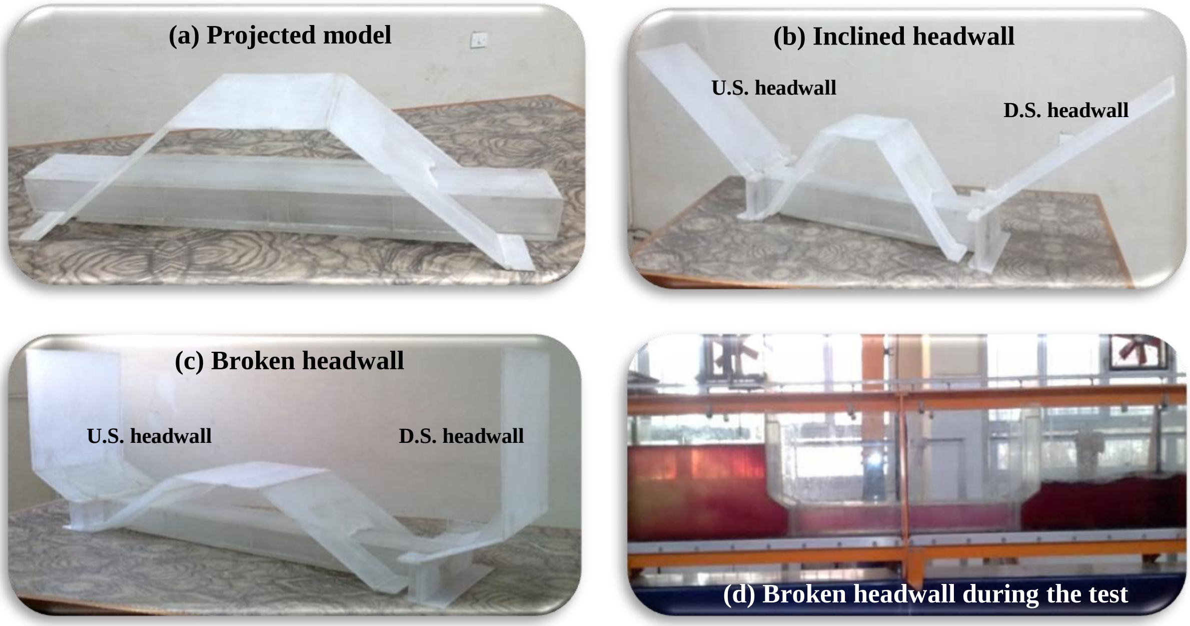


Photo 1. Types of used experimental models.

The experiments of the present study were divided into two trends. The first one was determining the effect of equipping a headwall with inclination angle (θ) ranges from 15° to 90°, in both sides of the box culvert on the head loss, and comparing the results with the case of the projected culvert, which is the usual case in most of the Egyptian desert road culverts. In this stage, six models of headwalls with different inclination angles were used in addition to the projected model. With each model, sixvaluesof the discharge were used, rangingfrom 8.2 to 14.6 L/s to obtain velocities ranging from 1.0 to 1.8 m/s, and fivevalues of relative submersion (Y_2/d) were used rangingfrom1.50to 2.50. In this trend, 30 runs were carried out for each headwall model with a total of 210 runs. The second trendof the studydepended on the results of the first one after obtaining the recommended inclination angle for the headwall equipped in both sides of the box culvert, a trial to get an economical headwall length was done. In this stage,five models of broken headwalls were used, where the headwall consists of two parts, a vertical part and a lower inclined part has an inclination angle based on the results of the first trend, and of length (L) rangingfrom 0.5 d to 2.5d, and comparing the results with the completely inclined headwallrecommended in the first trend.For each model, five values of the discharge were used,varied between 8.46 and 14.48 L/s to get velocities ranging from 1.04 to 1.79 m/s, and three values of relative submersion (Y_2/d) equal to 1.75,2.0 and 2.25 were used. In this stage of experiments 15 runs were carried out for each broken headwall model with a total of 105 runs.

5 ANALYSIS AND DISCUSSION

All the headwall models were prepared to be tested for determining the head loss. The experiments were carried out for the following two purposes:

1) Testing the effect of the headwall inclination angle on the hydraulic efficiency of the box culvert,
2) Reducing the cost of constructing the introduced inclined headwall by getting the optimum length of the inclined part of the headwall (using a broken headwall).

5.1 Effect of the headwall inclination angle on the hydraulic efficiency of the box culvert

To investigate the effect of the headwall inclination angle on the hydraulic efficiency of the box culvert, six models of headwall of an inclination angle 15°, 22.5°, 30°, 45°, 60° and 90°, were equipped at the barrel entrance and exit of the box culvert, in addition to the projected one as a reference. Figure (4) shows the relation between the velocity and the head loss in case of arelative submersion value (Y_2/d) equals 1.5.

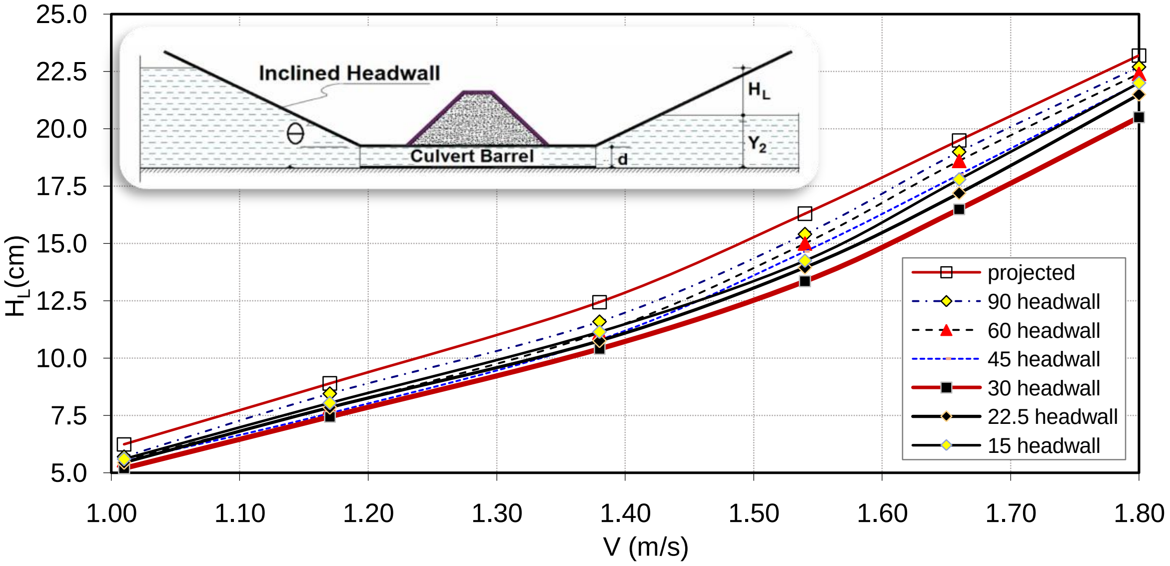


Figure4. The relation between the head loss and the velocity (at Y_2/d =1.5)

From figure (4) it can be noticed that the best inclination angle for the headwall, used in both sides of the box culvert is 30°, where the head loss decreases with the decrease of the headwall inclination angle till it reaches 30° then the head loss increases again, which differsfrom that given by (Ashour et al., 2016)who stated that, the headwall of inclination angle 15° in the opposite direction of the flow gives the best hydraulic efficiency for the box and the circular culvert.This is due to that, the present study depends on using the same headwall model in both sides of the box culvert but (Ashour et al 2016)studied the effect of using headwall in the U.S. of the culvert only, where using the headwall in the D.S. side has a negative effect on the hydraulic efficiency of culvert, but we have to use the headwall in both sides of desert- road culverts in case of flow has a changeable directions.

Figures (5) through (8) clear this note for the used relative submersion value rangingbetween 1.75 and 2.50, from which it could be proved clearly that the best inclination angle for using headwalls in both sides of the box culvert is 30°, which enhanced the head loss in case of submersion ratios (Y_2/d) equals 1.5 with about 15.5 %, with respect to the projected culvert, and increases with the increase of the relative submersion value till it reaches 16.5 % at (Y_2/d) equals 2.5, or it can be concluded that, for all used relative submersion value (from 1.5 to 2.5), the average value of decreasing the head loss in case of using 30° inclined headwall model is 16 % with respect to the projected culvert.

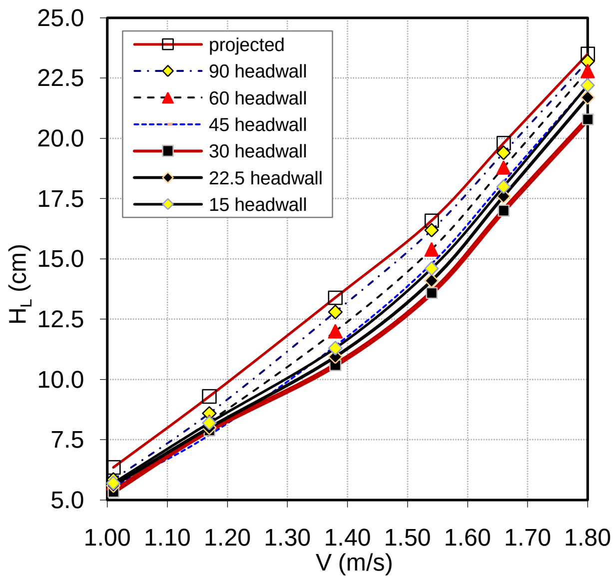


Figure 5. The relation between the head loss and the velocity (at Y_2/d =1.75)

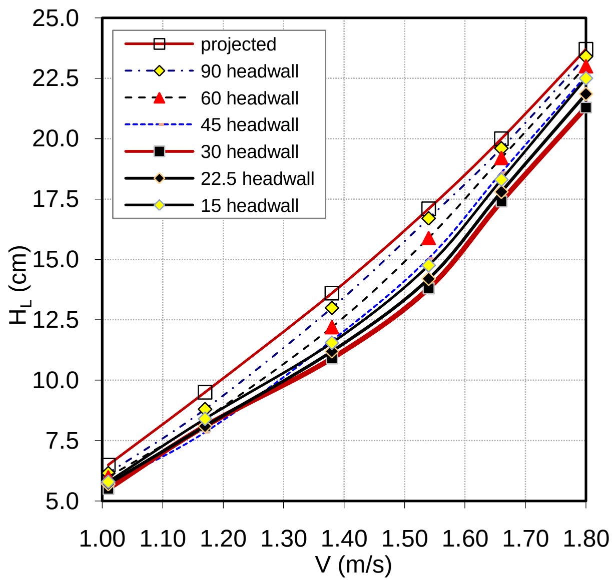


Figure 6. The relation between the head loss and the velocity (at Y_2/d =2.0)

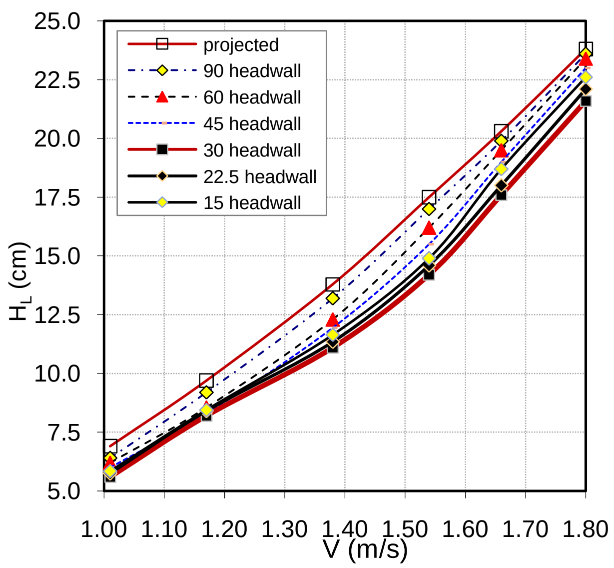


Figure 7. The relation between the head loss and the velocity (at Y_2/d =2.25)

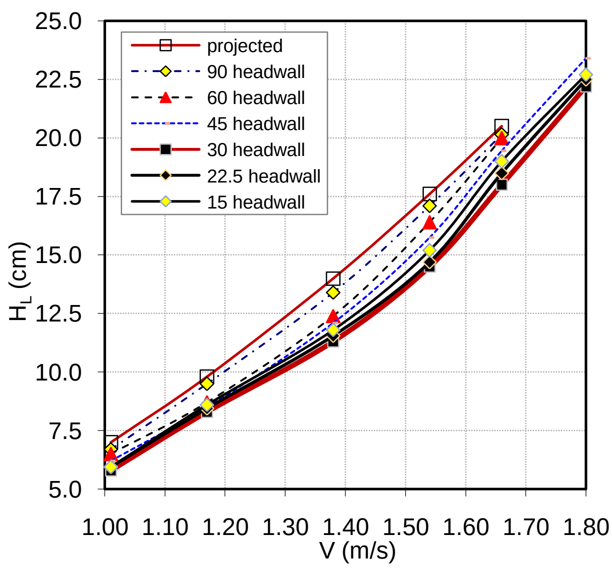


Figure 8. The relation between the head loss and the velocity (at Y_2/d =2.5)

Table (1) shows the effect of equipping 30° inclined headwall at both sides of the box culvert, on the entrance and the exit losses coefficient(K_{in} + K_{ex}), from which it can be noticed that, for the range of the used velocities (from 1.0 to 1.8 m/s), and the range of the used relative submersion value (from 1.50 to 2.50),using the headwall of inclination angle 30°decreased the values of (K_{in} + K_{ex}) from 1.26 to 1.04, with an average value 17.5% compared with the projected model.

Table (1) Values of the entrance and the exit losses coefficient(K_{in} +K_{ex}) for the projected culvert model and 30° headwall model.

Relative submersion value (Y_2/d)	1.5		1.75		2		2.25		2.5		Average	
Headwall model	Projected	30°	Projected	30°	Projected	30°	Projected	30°	Projected	30°	Projected	30°
(K_{in} +K_{ex})	1.2	0.99	1.24	1.03	1.27	1.05	1.30	1.07	1.31	1.08	1.26	1.04

Figure (9) shows the relation between the inclination angle (θ) and the head loss for a relative submersion value (Y_2/d) equals 2.0, from which it can be proved clearly that the best inclination angle for using headwall in both sides of box culverts is 30°.

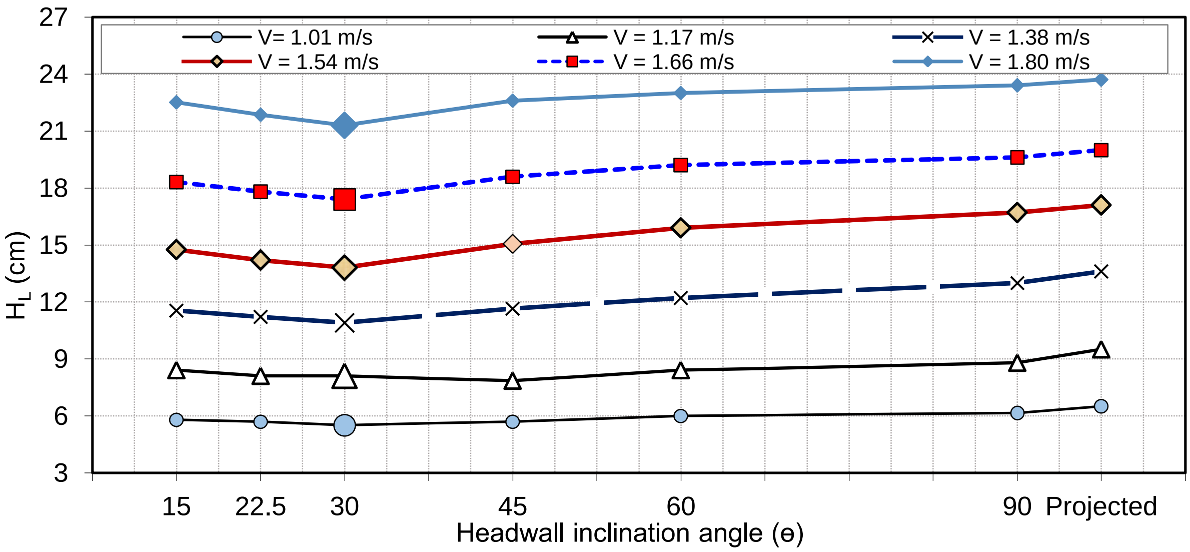


Figure 9. The relation between the head loss and the headwall inclinationangle (at Y_2/d =2.0)

5.2 Reducing the cost of constructing the inclined headwall by using a modified one(Broken headwall)

The first part of this study concluded that, using a headwall of an inclination angle 30° increases the hydraulic efficiency of the box culvert with an average value reaches 16 %. But this recommended (30°) inclined headwall may have a big length, which increases the cost of the construction, especially if the box culvert is subjected to high water levels in the entrance and exit.In this study, the length of the completely inclined headwall was taken as L=7.5d which means the length of the inclined part is extended above the U.S. water level.

So, in the second part of the study, the length of the recommended (30°) inclined headwall will be reduced by using a modified shape, may called broken headwall, in which it consists of two parts, the lower one is inclined with the recommended inclination angle (30°) while the other part is vertical. The length of that lower inclined part was tested with length equals0.5 d, 1.0 d, 1.5 d, 2.0 d and 2.5 d.

Figure (10) shows the relationbetween the velocity and the head loss for the used broken headwall models at (Y_2/d) equals 1.75.It is clear that, the head loss decreases with the increase of the length of the inclined part, and the same results can be proved for relative submersion values equal 2.0 and 2.25 as shown in figure (11) and figure (12) respectively.

Figure (13) shows the effect of the introduced partially inclined headwall (Broken headwall) on the head loss for a relative submersion value (Y_2/d) equals 2.0. The figure shows clearly that, using the introduced broken headwall with length of inclined part equals 2.5d decreases the head loss with about 14.5% with respect to projected culvert, which presents 90 % of that (16 %)obtained by using the completely inclined headwall having the same inclination angle equals 30°.

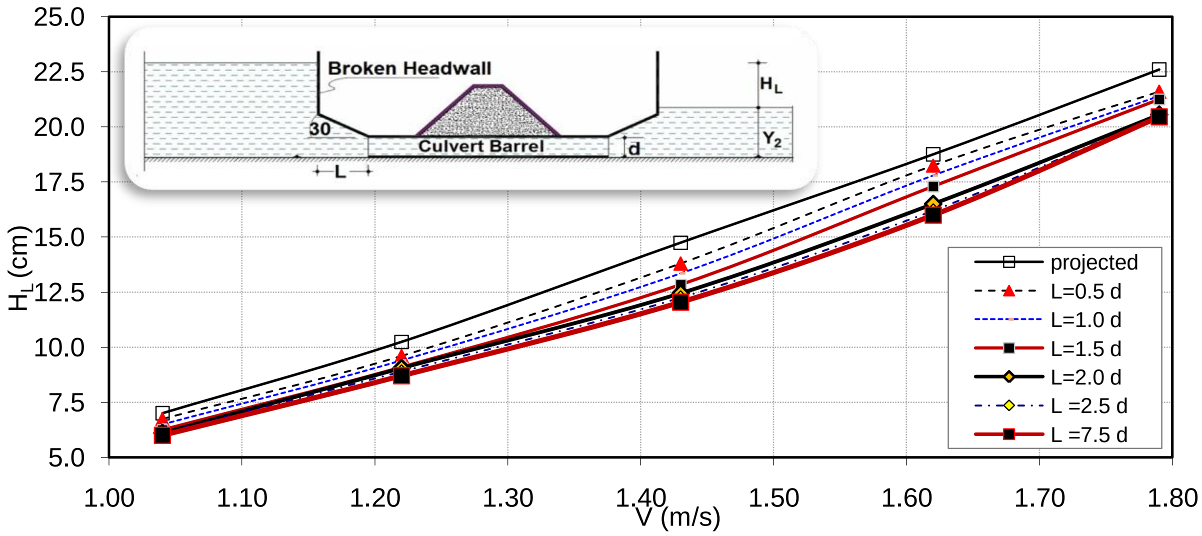


Figure 10. The relation between the head loss and the velocity (at Y_2/d =1.75)

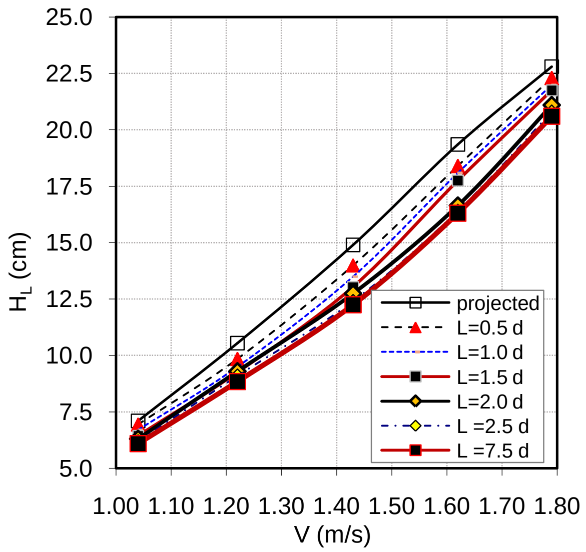


Figure 11. The relation between the head loss and the velocity (at Y_2/d =2.0)

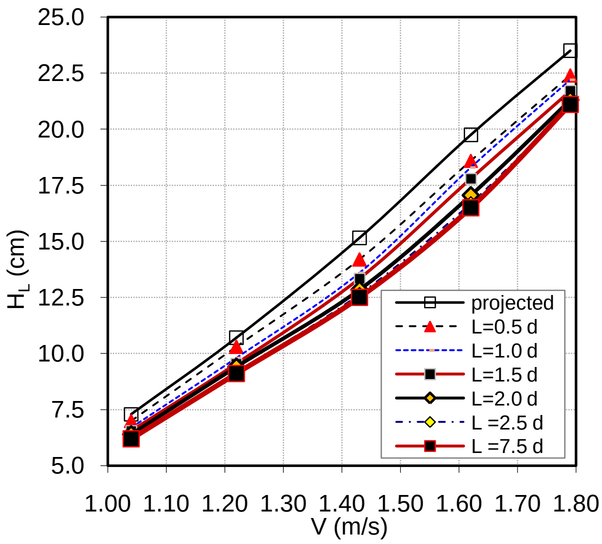


Figure 12. The relation between the head loss and the velocity (at Y_2/d =2.25)

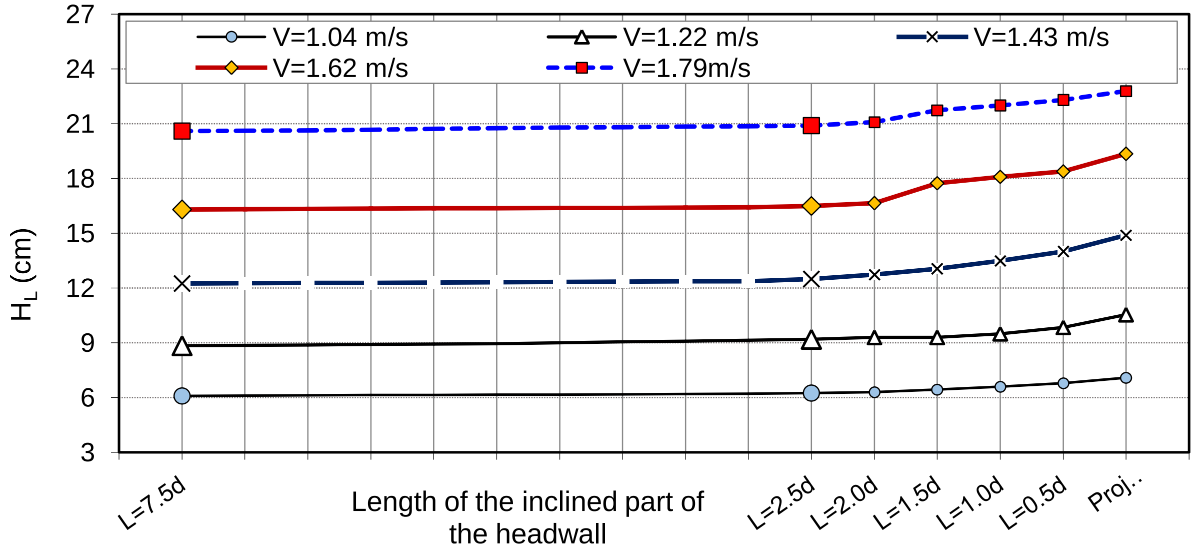


Figure 13.The relation between the head loss and the length of the inclined part (at Y_2/d =2.0)

6 CONCLUSIONS

Through the experimental results and discussion, the following conclusions can be introduced:

- Many methods and tools examined by several authors for improving the under-desert road culverts performance, while no one examined the inclined headwall as an efficient tool, according to author knowledge.
- A new shape of headwalls, such called broken headwall, is introduced as an efficient and economic tool for significantly improving the under-desert road box culvert efficiency.
- Among all the tested values of the headwall inclination angles, 30° was the best, which improved the head loss with an average value equals 16% with respect to the projected culvert.
- Using the modified partially inclined headwall (broken headwall) with a length of the lower inclined part equals 2.5 d enhanced the hydraulic efficiency of the box culvert with about 90 % of that obtained by using completely inclined headwall.
- For the most efficient, safe, and economic design of the under-desert road box culverts, we strongly recommend using the introduced broken inclined headwall in both sides.

NOTATION

The following symbols are used in this paper:

A: Culvert cross sectional area;
C_d : Discharge coefficient;.
d: Inside height of the culvert;
g : Gravitational acceleration;.
H_L: Head loss;
h : U.S. water depth measured from the axis of the culvert;
K: Coefficient of head loss;
K_{ex} : Exit losses coefficient;
K_{fr}: Fiction losses coefficient;
K_{sc} : Screen losses coefficient;.
K_{in}: Inlet losses coefficient.
L: Length of the headwall inclined part;
Q : Discharge;
Y_1 : U.S. water depth measured from the bottom of the culvert; and
Y_2 : D.S. water depth measured from the bottom of the culvert.

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