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Experimental Investigation about the Effects of Blockage on Upstream Box Culverts

Duaa Amir H. Al-kmoly[1,*], Hayder Q. Majeed[2]

Department of Water Resources Engineering, College of Engineering, University of Baghdad, Bagdad, Iraq
doaa.abd2110m@coeng.uobaghadad.edu.iq[1], hmajeed@coeng.uobaghdad.edu.iq[2]

ABSTRACT

This experimental study focuses on scouring in box culvert inlets under steady-state conditions and at different percentages of blockage ranging from 0% to 65%, and also looks at the hydraulics of water in the culvert. The investigation shows that the blockage of the culverts has influenced the scouring pattern at the blocked culverts' entrances. Ten experiments were carried out at the laboratory to see how blockage impacts the scouring pattern upstream of a box culvert during steady flow. Both partially blocked and unblocked cases were implemented in this study. The experimental tests were done until the equilibrium scour occurred, which took about 3.5 hours of water flow to reach equilibrium conditions. The results revealed that the blockage will increase the water depth at the inlet by about 30%–50%, which may affect the safety of structures or cause culvert failure. In addition, the results discovered that the maximum scour depth, which inversely correlated with the obstruction upstream of the box culvert, increased with increasing discharge.

Keywords: Box culvert, Steady flow, Blockage, Scour depth.

*Corresponding author
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تحريات مختبرية عن تأثير ألانسداد في مقدمة العبّارات الصندوقية

دعاء عامر حمدي[1]،*، حيدر قيس مجيد[2]

قسم هندسة الموارد المائية، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

تبحث هذه الدراسة التجريبية في كميات الحفر في مداخل العبارات الصندوقية في ظل ظروف جريان مستقر وبنسب مختلفة من الانسداد 25٪ ، 45٪ ، 65٪، وايضا تبحث عن هيدروليكية الجريان في العبارة الصندوقية. أظهر التحقيق أن نمط النحر عند مدخل العبارات الصندوقية المسدودة قد تأثر بشكل كبير بانسداد العبارات. تم استخدام قناة مختبرية في المختبر لإجراء عشرة اختبارات تجريبيًا لتحديد كيفية تأثير الانسداد على نمط النحر في أعلى المجرى عند وجود جريان مستقر. تم استخدام كل من حالات الانسداد الجزئي وحالات عدم الانسداد للاختبارات التجريبية. تم إجراء الاختبارات التجريبية حتى حدوث التوازن في عمق النحر، والتي استغرقت حوالي 3.5 ساعة من تدفق الماء للوصول إلى ظروف التوازن. اكتشفت النتائج أن الانسداد سيؤثر على عمق المياه عند المدخل بحوالي 30٪ –50٪ أكثر مما قد يؤثر على سلامة الهياكل أو يسبب فشل المجاري. اكتشف أيضًا أن الحد الأقصى لعمق النحر يرتبط عكسيًا بالانسداد في أعلى المجرى الصندوقي ، ويزداد مع زيادة التصريف .

الكلمات المفتاحية: عبّارة صندوقية، جريان مستقر، انسداد ،عمق النحر.

1. INTRODUCTION

Culverts are covered with conveyance and regulation structures. Most culverts comprise three components: the diffuser (exit), the barrel, and the intake (entrance). The culvert may be controlled at the inlet or outlet **(Hotchkiss et al., 2008; Jaeger et al., 2019)**. The only factors in inlet management that affect a culvert's hydraulic capacity are its entry design and headwater depth **(Maatooq et al., 2020). (Rigby et al., 2002)** studied in response to the flood that hit Wollongong in 1998 and found that when culvert hole diameters are less than 6 m, culvert obstruction, and flooding are a considerable danger. It was emphasized that more holes, even little ones, would be less likely to be blocked than just one. According to reports, the obstruction is unrelated to other factors such as material type, land use, stream slope, contributing catchment area, and culvert count**.** The culvert is constructed according to various parameters, including the height of the roadway and the hydraulic water surface elevation. They are used to regulate water flow **(Thompson and Kilgore, 2006; Schall, 2012)**. Culverts are built and intended to be hydraulically effective in passing flood flows without going over the top of the road embankment. Compared to the approach channel flow, flow passing through a culvert often experiences an increase in velocity because the cross-sectional flow area has decreased **(Tullis, 2012). (Crookston and Tullis, 2012)** used different types of bed materials. Four substrate materials were put to the test. These substances were chosen to stand in for fortified, non-cohesive streambeds. For each substrate type, sieving and density analyses were carried out. A 0.61-meter-wide bottomless arch culvert with a range of entrance configurations and pressured and non-pressurized flow conditions were used to test four substrate materials. The culvert was scoured over its entire length, with the entrance and exit areas experiencing the worst scour. At the culvert entry, flow contraction resulted in localized pier-style scour holes. Additionally, the bed near the culvert entry eroded under pressure. Because there was no regulated tailwater at the culvert exit, the fastest speeds and deepest scour were observed there. The amount of scour inside the culvert barrel was lessened by angularity and gradation compared to rounder cobbles, which would be more usual for streambed modeling and bridge obstruction. Culverts pass the flow underneath an impediment, such as railroad tracks or highways. The complexity of the flow through culverts depends on all the design factors, including size, form, length, slope, roughness, and depth of head and tail waters. Culverts are sites in water channels where the water flow is impeded, increasing the likelihood of a blockage of some type. The significance of culvert structures and their functional needs is underlined by considering the number of culverts **(Sorourian, 2015)**. All around the world, there are numerous bridges and modest-sized canals in both urban and rural settings. culverts are placed where rivers are constrained during flood occurrences, and debris is likely to fully or partially block them. Debris obstructed most of the canals, bridges, waterways, and clogged sewers caused damage. Due to this obstruction, flood levels rise upstream of railroads and highways, diverting the flow from its intended course and into overland flow routes, causing more damage during floods. Sewers and embankments get clogged from a functional standpoint. Damage to both private property and public assets is quite likely as a result. **(Sorourian et al., 2016)** the connection between the culvert's blockage ratios, maximum scour depth, and flow parameters was examined. In the experimental studies, partially blocked and unblocked circumstances were explored. The results show that blockage significantly affects the flow structure and overall form at the culvert outflow. It was found that the average turbulence intensity was three times greater than in the non-blocked scenario when rapid changes in the velocity distribution occurred in the culvert barrel to clear the blocked section. The maximum scouring depth in the partially blocked condition was higher than the findings obtained in a non-blocked scenario downstream of the culvert, as shown when the study's maximum scouring depth data were compared with some earlier investigations in non-blocked settings. Scour is the term used to describe the lowering of a riverbed caused by water erosion, a condition that frequently exposes bridge foundations. The scour or scour depth refers to the amount of this drop below an estimated natural level. **(Ahmad et al., 2018)** also reported that a wide range of other factors may influence scour at the culvert, including flow rate, discharge, size of the particles, depth of the tailwater, culvert design, and slope. **(Taha et al., 2020)** analyzed the scour characteristics downstream of obstructed culverts using mathematics. The study's objective was to statistically explain how a blockage in a box culvert affects the water surface and scour. For this purpose, a sediment transport model has been investigated using FLOW 3D v11.1.0. Studies on various blockage ratios via box culverts have been conducted. The FLOW 3D model was calibrated with experimental data. Due to the culvert blockage, when the culvert was halted at the same outflow, they found that the upstream water level in B70 was 2.3 times higher than in the alternative scenario, which might be dangerous for the stability of the roadways above. The depth-averaged velocity rose three times higher through the culvert barrel than it did in the unblocked situation. While many studies did not account for the amount of scour and the water in the culvert's intake at the time of blockage, the reported study took each affecting aspect into account. In general, there are numerous studies about the effect of scour around hydraulic structures and erosion of soil, such as **(Al-Hassani and Mohammad, 2021**; **Majeed et al., 2021; Khwairakpam and Mazumdar, 2009; Rasool**

and Mohammed, 2023), and many others. **(Majeed et al., 2022)** reported that the effect of spacing on the scour pattern and the maximum scour depth in open channel flow was examined using the computation fluid dynamic (CFD) method. **(Miranzade et al., 2022)** studied how blockage is affected by culvert form under flood event conditions, including an experimental investigation of temporal fluctuations in the blockage caused by woody debris upstream of culverts under erratic flow circumstances. A lab-created synthetic flow hydrograph was designed to resemble flood conditions. To imitate the movement of woody debris during flood events, two different-diameter wooden dowels that were cylindrical were used. The box and circular pipe culverts are two culvert forms that are examined in their article. The pipe culvert was found to be more susceptible to blockage than the culvert in a box. Regression analysis is presented as a method for developing predictive equations to determine the proportion of culvert blockage during flood events. According to these earlier researches, the main variables affecting the maximum scour depth of a culvert (size or form) are sediment characteristics, such as median particle size and geometrical standard deviation, flow conditions, and culvert type. According to some studies, the design and slope of the culvert have an impact on how the scour hole forms. As a result, it can be notice that, there are very few studies that consider the impact of scour caused by debris upstream of the culverts.

Therefore, the purpose of this study is to investigate the effect of debris with different percentages of blockage at the maximum scour depth and the volume of sediment removed upstream of the box culvert, as well as the flow properties at the inlet and outlet of the culvert, and how much energy loss dose the blockage caused.

2. EXPERIMENTAL SET-UP

In Baghdad University's hydraulics lab was the test setup, which included a rectangular flume powered by static tanks. This flume's longitudinal profile and plan view are seen in **Fig. 1**. The 4-meter-long flume measures 600 mm in width and 200 mm in depth. The test section had to be positioned 1 m from the flume's inlet to guarantee that a fully developed flow would reach it. The test area was a one m-long, 72 mm-deep, wide sand basin. The flume's valve controls water flow. The testing box-culvert model was installed in the flume on a sand bed. **Fig. 2** displays the finer characteristics of the culvert model.

The culvert's entrance measures 80 mm × 80 mm, and the culvert length is 750 mm. At the culvert's entrance and outlet, there are transitions with a 30° flare. A plate was placed at the culvert entrance to mimic a blockage at the inflow. In the experimental tests, three sizes of plates (80×20mm, 80× 36 mm, and 80 × 52 mm) were used to generate various blockage ratios. The non-uniform, non-cohesive sand utilized in this investigation has median grain diameters (d_{50}) of 0.48 mm. An electromagnetic flow meter with the model code SPE-LDGDN40 was used to measure discharges and velocities, as shown in **Fig. 3**. A flow meter can be used to measure linear, non-linear, mass, or volumetric flow rates to determine how much liquid is flowing through a pipe or conduit **(Stone and Wright, 1994; Pereira, 2009)**. (Sometimes referred to as a flow sensor).

Figure 1. Laboratory for Experimental Testing in Hydraulics: Plan View of the flume.

Figure 2. Setup the Box Culvert in the Flume.

Figure 3. Flow meter device

Table 1 shows the calibration and maintenance done on this device, which is accurate to ±0.3% before each test. This device was calibrated using the volumetric method for discharges, and for depths abroad-crested weir was used. The result of the calibration is shown in **Fig. 4.** (ha) is the head of water calculated from the curve of calibration operation in (mm), and (h) is the head of water above the weir in (mm).

Table 1. Flow meter calibration

(ha) (mm)	(h) (mm)	(Q) (m^3/h)
27.3	24.8	12
23.2	20.4	11.6
17.3	16.4	10.54
13.0	12	8.73
8.0	8.7	7.1
5.9	5.9	6.55
5.1	4	6.31
2.6	3	5.45
2.1	1.9	5.034

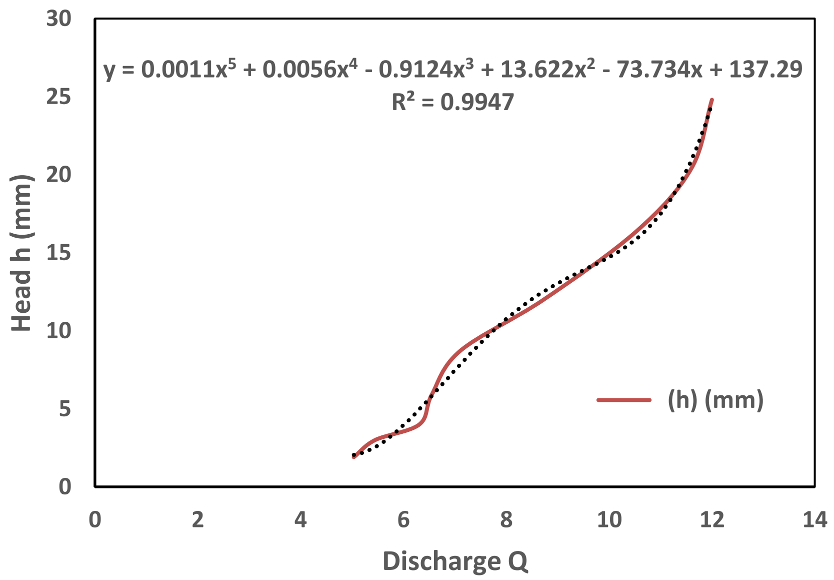

Figure 4. Flow meter calibration curve and equation.

In a steady-state environment, the depths of water upstream of the cannel, at the inlet of the culvert, at the outlet of the culvert, and the soil depths were measured by the points gauge shown in **Fig. 5**. with an accuracy of ±1 mm checked by **(Al-Jassim and Al-Hadidi, 2020; Nkad et al., 2022)**. Experimental testing was carried out, and the flow rate ranged from 3.6 to 9.2 m^3/hr. The test periods were long enough to verify that the scouring process had reached equilibrium. Tests were carried out using free surface flow. Blockage condition (B) is the term used to describe each run. B25, B45, and B65 are used for tests in partially blocked situations, while B0 is used in unblocked settings. h_w stands for the upstream water level. σ_g the sediment's geometric standard deviation, which was found =1.7, which is greater than 1.3, indicates the sediment is non-uniform **(Chiew, 1991; Melville and Coleman,**

2000). The definition of the symbol B is (h_B/h_w), where h_B is the height of the plate that serves as the obstruction in the culvert's intake.

Figure 5. Points gage device.

3. RESULTS AND DISCUSSION

Due to flume limitations, the flow discharges in the channel ranged from 3.6 m^3/h to 9.2 m^3/h. These discharges were used to study the scour pattern at the inlet of the culverts in four different blockage cases. The first scenario is used as a model for three experiments that examined the impact of an unblocking inlet (B0) on the maximum scour depth and sediment removal volume. The other three stages (B25, B45, and B65) were applied to investigate the effect of 25%, 45%, and 65% inlet blockage, respectively, on the scour properties. All the experiments were done under the same flow conditions. In each experiment, the sediment movement continued until it reached equilibrium, and the time for each experiment to reach equilibrium was approximately 3.5 hours, where no significant changes occurred in the bed profile. **Fig. 6** shows the relationship between the maximum scour depths and discharge. It is found that there is practically an inverse relation between the blockage and the greatest depth of scour upstream of the culvert. In the case of 9.2 m^3/h flow discharge, it is noticed that at B0, the maximum scour depth is equal to 40 mm. Whereas at B25%, the results decreased compared to B0 by about 12%, and the maximum scour depth reached is 35mm. In the cases of B45 and B65%, the results were eliminated due to overflow in the water when the discharge was equal to or higher than 6.2 m^3/h. In the case of a flow discharge of 3.6 m^3/h, the difference in maximum scour depth between B0% and B25% can be neglected, but with B45% and B65%, the maximum scour depth decreased gradually by about 8% and 22%, respectively as shown in **Fig. 6 (a-d)**.

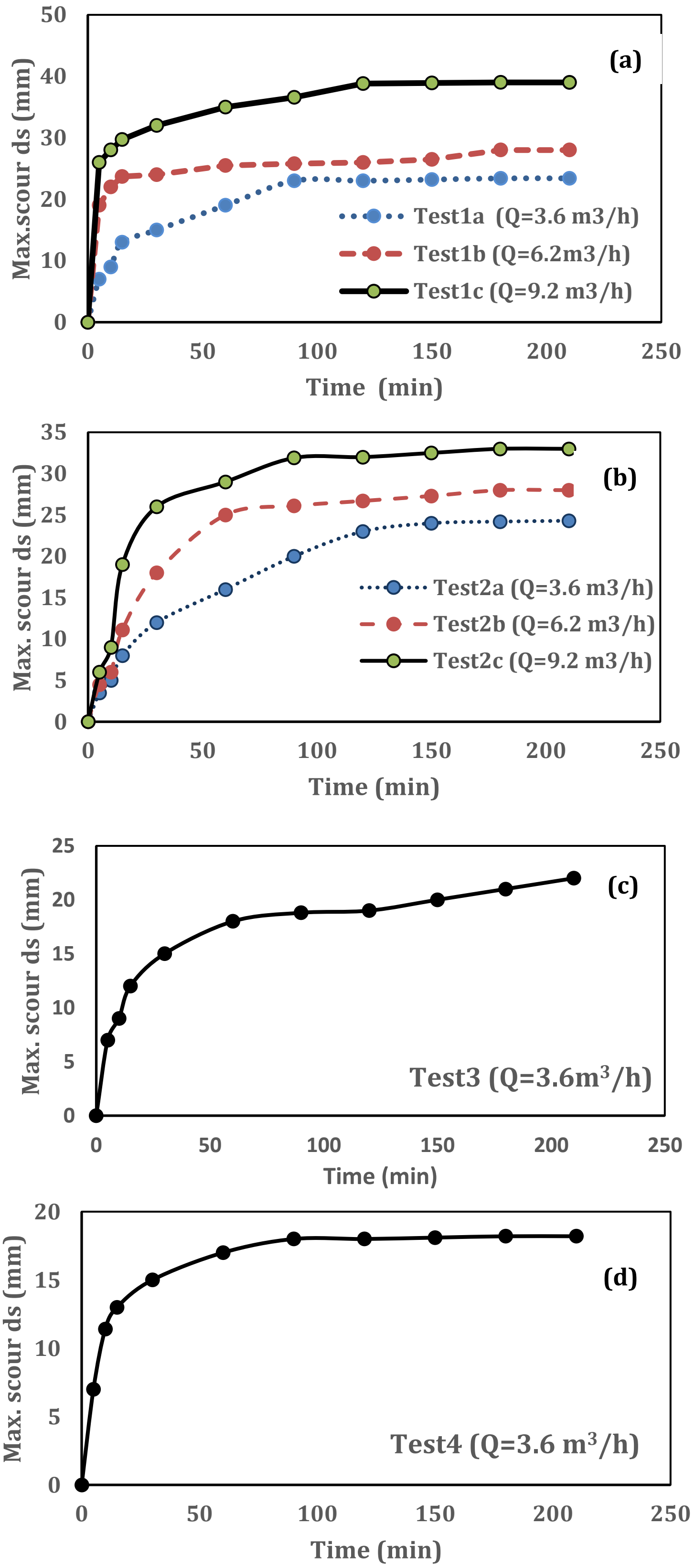

Figure 6. The maximum scour depths and time for B =:
a) 0%, b) 25%, C) 45%), and d) 65%.

Figs. 7 to 10 shows the top view of the soil profile in two dimensions upstream of the culvert model for different percentages of scour drawn in Surfer 13 software. In contrast, the horizontal and vertical axes of these figures represent the lateral and longitudinal sections of the channel, respectively, in millimeters. **Table 2.** presents the volume of sediment removed from the scour hole upstream of the box culvert; the results show that the total volume of residue removed is also influenced by the percentage of debris accumulated at the culvert inlet. It can be seen that in the case of non-blockage B0%, the rate of sediment removed will be increased by about 40%, and with a blockage rate of 25%, the rate of total sediment removed will be increased by about 60% when the flow rate upstream the box culvert increases by about three times. Otherwise, for the same flow rate of 3.6 m^3/h the quantity of total sediment removed decreased by 45-55% in the case of B25% and B45%, respectively, and by about 20% in the case of B65%.

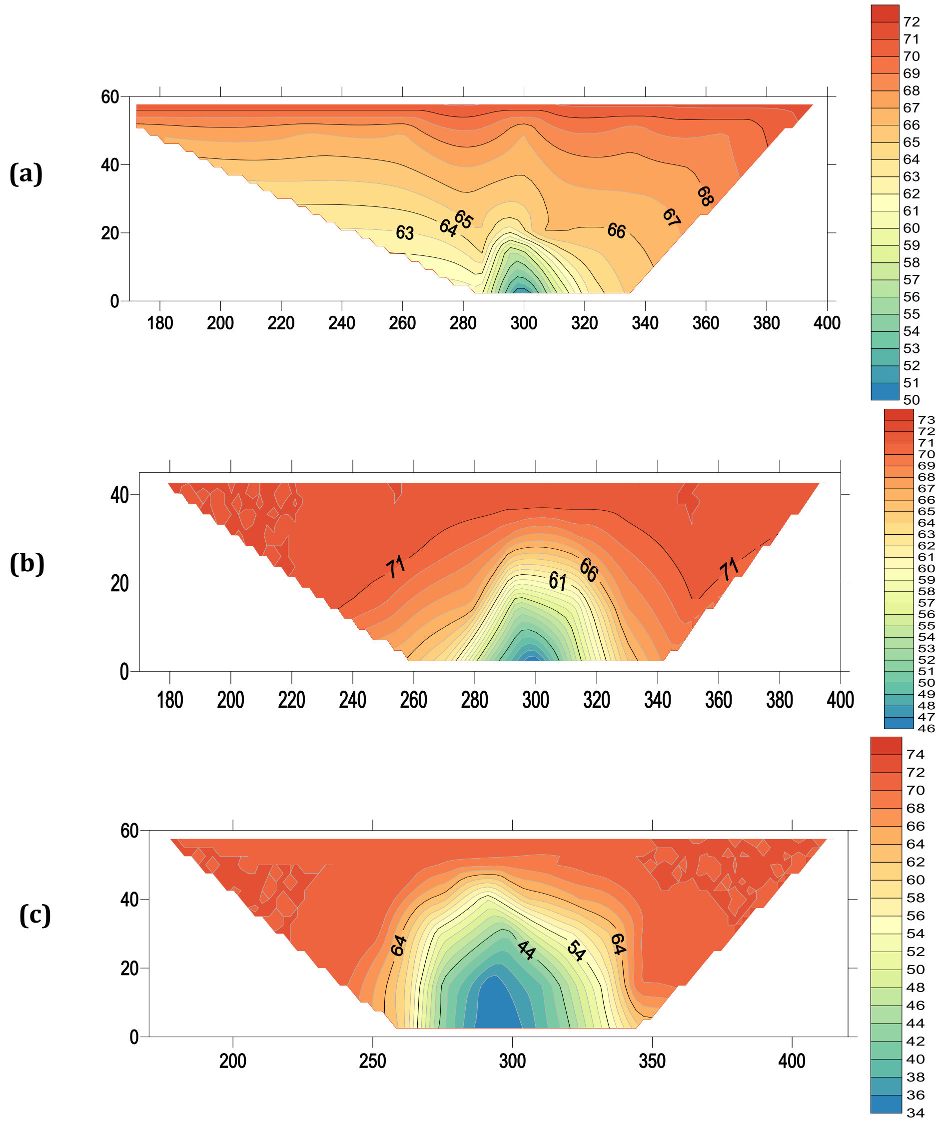

Figure 7. Two-dimensional top view of the soil profile upstream of the culvert model with no blockage B=0% for (a) Q=3.6 m^3/h, (b) Q=6.2m^3/h, and (c) Q=9.2 m^3/h.

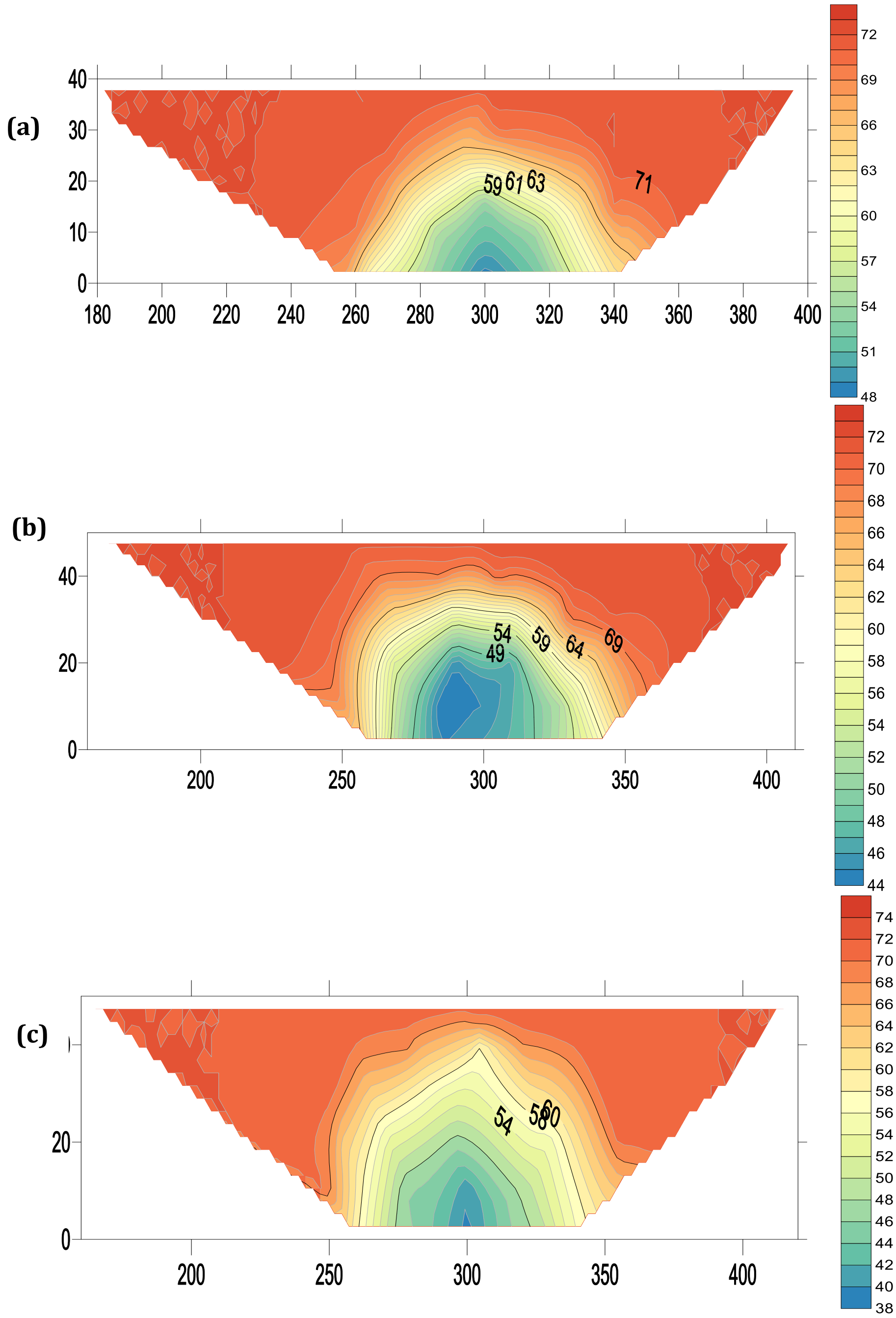

Figure 8. Two-dimensional top view of the soil profile upstream of the culvert model when there is blockage B=25% for (a) Q=3.6 m^3/h, (b) Q=6.2m^3/h, (c) Q=9.2 m^3/h.

The results show that the scour hole and maximum scour depth have a reverse effect by increasing the percentage of debris at the inlet of the culvert in case of a steady flow rate, but in flood circumstances when the flow becomes faster and unsteady, the rate of sediment removed will be increased.

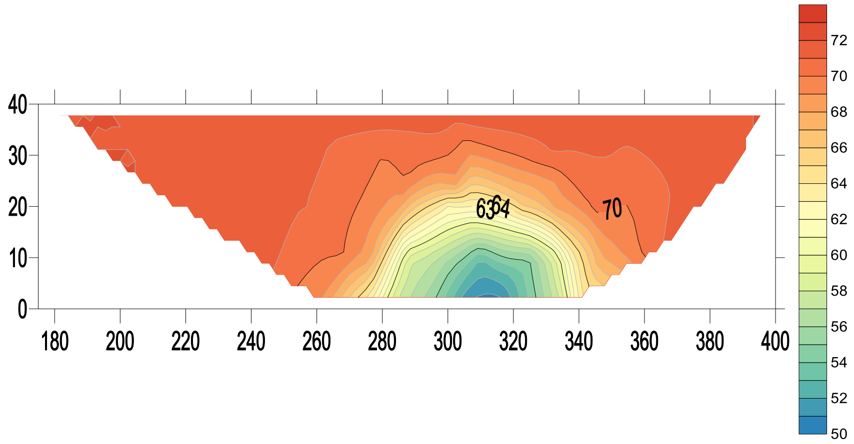

Figure 9. Two-dimensional top view of the soil profile upstream of the culvert model when there is blockage B=45% for (Q=3.6 m^3/h).

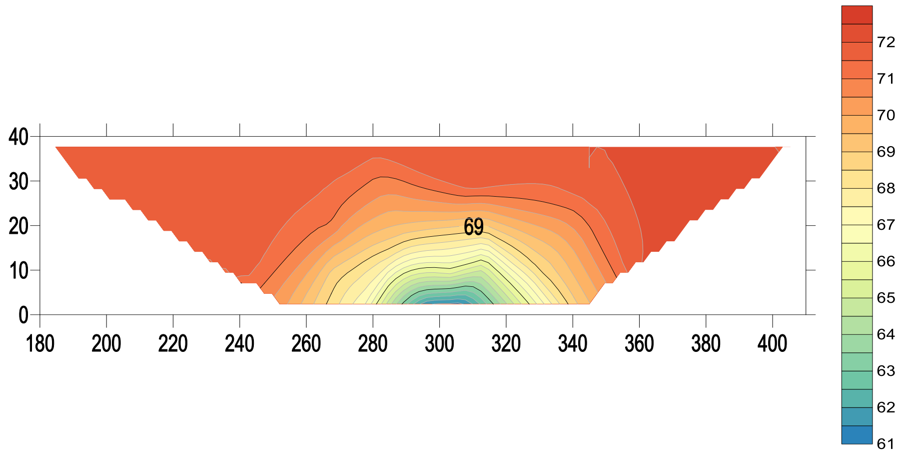

Figure 10. Two-dimensional top view of the soil profile upstream of the culvert model when there is blockage B=65% for (Q=3.6 m^3/h).

Table 2 The volume of sediment removed.

Blockage B%	Q (m^3/h)	The volume of scour vs. (mm^3)
0	3.6	46,563.17
0	6.2	63,650.24
0	9.2	80,273.05
25	3.6	25,010.35
25	6.2	56,792.15
25	9.2	63,147.44
45	3.6	21,840.89
65	3.6	37,180.46

Water depths were measured at the examined distances for each experiment to investigate the effect of debris on the flow of hydraulic properties. The results show that the water depth at the inlet and outlet of the culvert significantly changed from the non-blockage case to partial blockage. It was shown that the flow becomes stronger downstream at partial obstruction, and a hydraulic jump forms, shifting the flow from supercritical to subcritical

(Hager and Bretz, 1986). The depth of the water upstream increases as the proportion of blockage increases. With a direct relationship, this is sometimes dangerous because it causes the water to rise past the structure's design capacity. This leads to the sinking of the structure and the creation of some problems, and in many cases, this leads to the failure of the structure. As given in **Tables 3 and 4,** the Reynolds number, Weber number, and Froude number have all been determined for each discharge unit in several different situations. In addition, the water levels at the culvert with the head losses caused by blockage and the depths inside the culvert where hydraulic jumps happen, called subsequent depths, were calculated.

Table 3. The characteristics of flow at the physical model.

Blockage B%	Q (m^3/s) 10^{-3}	$h_{u/s}$ (m)	width w(m)	area A (m^2) 10^{-3}	Wetted perimeter P	Hydraulic Radius (m)	Velocity (m/s)	Weber number W	Reynolds number Re
0	1	3.4	0.08	3	0.148	0.02	0.37	138.01	5988.02
0	1.7	5.1	0.08	4	0.182	0.02	0.42	216.22	9686.61
0	2.5	6.7	0.08	5	0.214	0.03	0.47	302.71	13623.98
0	1.5	4.7	0.08	4	0.174	0.02	0.40	191.06	8645.53
0	2.1	5.8	0.08	5	0.196	0.02	0.45	269.40	11731.84
0.25	1	5.2	0.08	4	0.184	0.02	0.24	72.58	5681.82
0.25	1.7	6.7	0.08	5	0.214	0.03	0.32	139.97	9264.31
0.25	2.5	7.8	0.08	6	0.236	0.03	0.40	235.78	13227.51
0.45	1	6.3	0.08	5	0.206	0.02	0.20	53.51	5509.64
0.65	1	7.6	0.08	6	0.232	0.03	0.16	39.39	5319.15

The point located 10 cm upstream of the culvert was also tacked into account to show the characteristics of flow in the canal far from the steady area, and it was found that at the depth of water= 0.070 m and discharge=0.0026 m^3/s Weber no. = 20.2075and Reynolds no. = 17627.12, and the point located 5 cm upstream of the culvert with the same discharge and water depth shows that Weber no. = 55.0265 and Reynolds No. equals to 26666.67that is acceptable for these results because the flow is turbulence due to the result of Reynolds number >2000 and Weber number> 11 to prevent viscous effects; this often necessitates avoiding surface tension and viscous effects, Weber numbers for intake models should be higher than 11 **(Novak et al., 2001; Sturm, 2001; Novak et al., 2017)**

1. Data processing

The equations were used in the calculation above in **Table 3**:

Reynolds number **(Rott, 1990)**

$$Re = \frac{\rho V L}{\mu} \quad (1)$$

where ρ is the density of water =1000 kg/m^3.

V is the velocity of water in a culvert (m/s).

μ is the dynamic viscosity of water in the laboratory temperature (10^{-3} Pa.s or kg/ (m.s)).

L is a characteristic linear dimension (m).

Here it is calculated by hydraulic radius (L=4R); it equation is **(Mohammadi, 1997)**:

Table 4. The water depths during water flow for each experiment with different percentages of blockage %, different discharges and head losses.

Test No.	Q (m^3/s)	q ($m^3/s/m$)	$y_{u/s}$ (m)	$V_{u/s}$ (m/s)	$y_{2\,D/s}$ (m)	V_2 (m/s)	Fr_2	y_1 (m)	V_1 (m/s)	Fr_1
T1B0	0.0010	0.013	0.034	0.37	0.029	0.43	0.81	0.02	0.58	1.25
T2B0	0.0017	0.021	0.051	0.42	0.036	0.59	0.99	0.04	0.60	1.01
T3B0	0.0025	0.031	0.067	0.47	0.048	0.65	0.95	0.04	0.70	1.05
T4B25	0.0010	0.013	0.052	0.24	0.027	0.46	0.90	0.02	0.53	1.11
T5B25	0.0017	0.021	0.067	0.32	0.036	0.59	0.99	0.04	0.60	1.01
T6B25	0.0025	0.031	0.078	0.40	0.047	0.66	0.98	0.05	0.68	1.02
T7B45	0.0010	0.013	0.063	0.20	0.026	0.48	0.95	0.02	0.51	1.05
T8B65	0.0010	0.013	0.076	0.16	0.027	0.47	0.93	0.02	0.52	1.08

Test No.	E_1 (m)	$E_{u/s}$ (m)	Head loss HL (m)
T1B0	0.039	0.041	0.0023
T2B0	0.054	0.060	0.0061
T3B0	0.070	0.078	0.0085
T4B25	0.038	0.055	0.0170
T5B25	0.054	0.072	0.0184
T6B25	0.070	0.086	0.0166
T7B45	0.038	0.065	0.0272
T8B65	0.038	0.077	0.0395

$$R = \frac{A}{P} = \frac{B*h_{u/s}}{B+2h_{u/s}} \quad (2)$$

where R is the hydraulic radius.
A is a culvert area (m^2).
P is the wetted parameter (m).
B is the width of the culvert (m).
$h_{u/s}$ is the water depth upstream of the box culvert (m).

Weber number **(Jain et al., 2015)**

$$W = \frac{\rho VL}{\sigma} \quad (3)$$

where ρ is the density of water =1000 kg/m^3.
V is the velocity of water in a culvert (m/s).
L is a characteristic linear dimension (m). It is calculated by hydraulic radius (L=4R).

σ is surface tension in 25 ^{o}C (0.072 N/m) **(Rivera et al., 2021)**.

The equations were used in the calculation above in **Table 4**:

Froude number **(Smith, 1970)**

$$Fr = \frac{V}{\sqrt{g\,y}} \quad (4)$$

where g is the gravity acceleration in (9.8 m/s²).

Energy head **(Jianhua et al., 2010)**

$$E = y + \frac{V^2}{2g} \quad (5)$$

Head losses **(French, 1986)**

$$HL = E_{u/s} - E_1 \quad (6)$$

4. CONCLUSIONS

In this study, the effect of scour upstream of the box culvert has been experimentally done using different values of discharges and different percentages of blockage (from 25% to 65%). According to studies on the impact of blockage on the scour upstream of the culvert, the maximum scour depth and the volume of material transported at the culvert entry decrease as the blockage percentage increases. On the other hand, these blockages result in a rise in the water depth of approximately 50% and 25% in the case of a flow discharge of 3.6, 6.2, and 9.2, respectively, and consequently cause culvert submergence. Findings show that obstruction has a significant impact on the flow structure, the design of the scouring hole, and the water depths at the intake and departure of the culvert. Compared to blocked conditions, the non-blocked culverts had scoured areas that were 50–80% larger, while partially blocked situations saw scouring width and length reduce by up to 20%. Also, the blockage affects design discharges. When the blockage is 0% and 25%, all the design discharges in this artificial canal from 3.6 m^3/h to 9.2 m^3/h can pass through this culvert. But when the blockage is 45% or more, the maximum discharge that can pass is 3.6 m^3/h. Also, inside the culvert, the flow of water forms an undulating hydraulic jump $1 < Fr1 < 2.5$, and several little rollers are produced on the water's surface, with y1 and y2 almost equal.

NOMENCLATURE

Symbol	Description	Symbol	Description
E1	Energy head inside the culvert before the hydraulic jump (m).	V2	Hydraulic jump SPEED downstrea at the culvert outlet (m/s).
E_1	Energy head inside the culvert before the hydraulic jump (m).	$E_{u/s}$	Energy head at the culvert inlet (m).
V_2	The speed of the hydraulic jump downstream at the culvert outlet (m/s) .	$V_{u/s}$	The velocity at the culvert's inflow (m/s).
W	Canal width (m).	V_1	The hydraulic jump's upstream velocity was measured (m/s).
$y_{D/S}$	The water depth at the culvert's outflow downstream of the hydraulic jump that occurs inside the culvert (m) .	y_1	The water depth within the culvert upstream of the hydraulic jump (m).
h_w	=The canal's upstream water level (m) .	$y_{u/s}$	Water depth at the culvert's inlet (m).
Q	Discharge in (m^3/s).	q	Discharge per unit width in the culvert in ($m^3/s/m$)

REFERENCES

Ahmad, N., Melville, B.W., Mohammad, T., and Suif, Z., 2018. Evaluation of pier-scour predictions for wide piers using field data. *GEOMATE Journal*, 14(42), pp. 140-145. Doi:10.21660/2018.42.3516.

Al-Hassani, N.Z., and Mohammad, T.A., 2021. Impact of the weir slit location, the flow iintensity and the bed sand on the scouring area and depth at the dam upstream. *Journal of Engineering*, 27(5), pp. 49-62. Doi:10.31026/j.eng.2021.05.04.

Al-Jassim, W.S., and Al-Hadidi, M.T., 2020. Impact of rationing on the properties of cement-treated gypsum canals. *Association of Arab Universities Journal of Engineering Sciences*, 27(3), pp. 15-30. Doi:10.33261/jaaru.2020.27.3.00.

Chiew, Y., 1991. Bed features in nonuniform sediments. *Journal of Hydraulic Engineering,* 117(1), pp. 116-120. Doi:10.1061/(ASCE)0733-9429(1991)117:1(116).

Crookston, B., and Tullis, B., 2012. Scour prevention in bottomless arch culverts. *International Journal of Sediment Research*, 27(2), pp. 213-225. Doi:10.1016/S1001-6279(12)60029-8.

FRENCH, R.H., 1986. Open channel hydraulics.

Hager, W.H., and Bretz, N.V., 1986. Hydraulic jumps at positive and negative steps. *Journal of hydraulic research,* 24(4), pp. 237-253. Doi:10.1080/00221688609499303.

Hotchkiss, R.H., Thiele, E.A., Nelson, E.J., and Thompson, P.L., 2008. Culvert hydraulics: comparison of current computer models and recommended improvements. *Transportation Research Record,* 2060(1), pp. 141-149. Doi:10.3141/2060-16.

Jaeger, R., Tondera, K., Pather, S., Porter, M., Jacobs, C., and Tindale, N., 2019. Flow control in culverts: A performance comparison between inlet and outlet control. *Water,* 11(7), pp. 1408. Doi:10.3390/w11071408.

Jain, M., Prakash, R.S., Tomar, G., and Ravikrishna, R., 2015. Secondary breakup of a drop at moderate Weber numbers. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences,* 471(2177), P. 20140930. Doi:10.1098/rspa.2014.0930.

Jianhua, W., Wanzheng, A., and Qi, Z., 2010. Head loss coefficient of orifice plate energy dissipator. *Journal of hydraulic research,* 48(4), pp. 526-530. Doi:10.1080/00221686.2010.507347.

Khwairakpam, P., and Mazumdar, A., 2009. Local scour around hydraulic structures. *International Journal of Recent Trends in Engineering,* 1(6), P. 59. Doi:10.1201/9781315644479-199.

Maatooq, J., Omran, H., and Taha, M., 2020. Generalize new method to determine the location of the control setion in the box culvert under inlet control. Paper presented at the IOP Conference Series: *Materials Science and Engineering*. Doi :10.1088/1757-899X/737/1/012155.

Majeed, H.Q., Abed, B.S., and Ibrahim, A.K., 2022. Countermeasure of Riverbanks Local Scour and Deposition Using Different Shapes of Multiple Groynes with Different Spacing. *Mathematical Modelling of Engineering Problems*, 9(5), pp. 1277-1281. Doi:10.18280/mmep.090619.

Majeed, H.Q., Abed, B.S., and Shamkhi, M.S., 2021. CFD simulation for the operation effect of gates openings of al-hay regulator on the local erosion. *Journal of Engineering Science and Technology,* 16(2), pp. 1098-1109. Doi:10.18280/mmep.090515.

Melville, B.W., and Coleman, S.E., 2000. Bridge scour: Water Resources Publication LLC. 1-887 201-18-01.

Miranzadeh, A., Keshavarzi, A., and Hamidifar, H., 2022. Blockage of box-shaped and circular culverts under flood event conditions: a laboratory investigation. *International Journal of River Basin Management*, pp. 1-10. Doi:10.1080/15715124.2022.2064483.

Mohammadi, M., 1997. Shape effects and definition of hydraulic radius in manning\'s equation in open channel flow. *International Journal of Engineering,* 10(3), pp. 127-142. https://www.ije.ir/article_71181.html.

Nkad, N.Z., Mohammad, T.A., and Hammoodi, H.M., 2022. Experimental investigations on scour volume upstream of a slit weir. *Pertanika Journal of Science & Technology*, 30(3). Doi:10.47836/pjst.30.3.09.

Novak, P., Moffat, A., Nalluri, C., and Narayanan, R., 2001. Hydraulic Structures. *Spon Press.* Doi:10.4324/9781482267754.

Novak, P., Moffat, A., Nalluri, C., and Narayanan, R., 2017. Hydraulic structures: *CRC Press.* Doi:10.1201/9781315274898

Pereira, M. 2009. Flow meters: part 1. *IEEE Instrumentation & Measurement Magazine*, 12(1), pp. 18-26. Doi: 10.1109/MIM.2009.4762948.

Rasool, H., and Mohammed, T.A., 2023. Checking the accuracy of selected formulae for both clear water and live bed bridge Scour. *Journal of Engineering*, 29(2), pp. 99-111. Doi:10.31026/j.eng.2023.02.07.

Rigby, E., Boyd, M., Roso, S., Silveri, P., and Davis, A., 2002. Causes and effects of culvert blockage during large storms. In Global solutions for urban drainage, pp. 1-16. Doi:10.1061/40644(2002)298.

Rivera, Y., Muñoz-Cobo, J.L., Cuadros, J.L., Berna, C., and Escrivá, A., 2021. Experimental study of the effects produced by the changes of the liquid and gas superficial velocities and the surface tension on the interfacial waves and the film thickness in annular concurrent upward vertical flows. *Experimental Thermal and Fluid Science*, *120*, P. 110224. Doi:10.1016/j.expthermflusci.2020.110224.

Rott, N., 1990. Note on the history of the Reynolds number. *Annual review of fluid mechanics,* 22(1), pp. 1-12. Doi:10.1146/annurev.fl.22.010190.000245.

Schall, J.D., 2012. Hydraulic design of highway culverts, United States. *Federal Highway Administration*.

Smith, G.L., 1957. Scour and energy dissipation below culvert outlets, *Colorado State University. Libraries* .CERNo.57GLS16.

Sorourian, S., 2015. Study of blockage effects on scouring pattern downstream of box culverts. *(Doctoral dissertation) Universoty of Technologu Sydney*. http://hdl.handle.net/10453/44198

Sorourian, S., Keshavarzi, A., and Ball, J.E., 2016. Scour at partially blocked box-culverts under steady flow. *Proceedings of the Institution of Civil Engineers-Water Management.* Doi:10.1680/jwama.15.00019

Stone, C., and Wright, S., 1994. Non-linear and unsteady flow analysis of flow in a viscous flowmeter. *Transactions of the Institute of Measurement and Control* 16(3), pp. 128-141. Doi:10.1177/014233129401600302.

Sturm, T.W., 2001. Open channel hydraulics, *McGraw-Hill New York*.

Taha, N., El-Feky, M.M., El-Saiad, A.A., and Fathy, I., 2020. Numerical investigation of scour characteristics downstream of blocked culverts. *Alexandria Engineering Journal*, 59(5), pp. 3503-3513. Doi:10.1016/j.aej.2020.05.032.

Thompson, P.L., and Kilgore, R.T., 2006. Hydraulic design of energy dissipators for culverts and channels: Hydraulic Engineering circular number 14, *National Highway Institute (US).* https://rosap.ntl.bts.gov/view/dot/44356.

Tullis, B.P., 2012. *Hydraulic* loss coefficients for culverts. National Academies of Sciences, Engineering, and Medicine; Transportation Research Board; National Cooperative Highway Research Program*.*