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Investigation of Blockage Upstream Box Coverage on the Scour Pattern in the Open Channel

Emam A. Osman

Abstract: ***Under sub-critical flow conditions, the presence of blockage (solid wastes and weeds) upstream of box coverage and the scours pattern downstream of the coverage was explored in this study. The upstream blocking was simulated using 48 runs in an artificial trapezoidal cross-section with three square box coverages of side dimensions 8.80, 10.40, and 12.90 cm, four water flows of 2, 5, 8, and 11 L/s, and four blockage ratios of 0, 10, 20, and 30% relative to the coverage cross-section area. To estimate the scour hole characteristics, a 2.00 m long, 0.60 m bed width, and 0.30 m deep sand basin filled with D_{50} = 0.50 mm bed material was constructed directly downstream of the coverage outlet. In each run, the water level, velocity, and scoured hole parameters downstream of the coverage were measured. According to the analysis, the Non-blocked coverage has less scour depth and length than the partially blocked coverage, where the maximum scour depths and length of the Non- blocked coverage for cases 1, 2, and 3 at the discharge of 11 l/s were 73, 72, and 17 % respectively, and 77.56, 77.34, and 83.66 % respectively relative to the maximum scour depth and length of partially blocked coverage at the discharge of 11 l/s and blockage ratio 30 %. The depth and length of the scour hole downstream coverage are increased with the increment of the coverage's blockage ratio and discharge and are reversely proportional to the inlet area of coverage. Increased relative scour depth and length by 3.60 percent and 11.80 percent respectively, by increasing the downstream Froude number of flow (Frd) by 0.01 while the coverage' relative wetted area (Ar) is constant. The study suggested applying coverage with a suitable area and water discharge, and protection techniques downstream of the coverage to reduce the influence of coverage and blockage on the open channel's hydraulic efficiency and the scour pattern downstream of the coverage. Also, install a trash rack upstream of the covering and remove aquatic weeds and solid wastes periodically upstream and inside the coverage.***

Keywords: ***Box coverage, Hydraulic efficiency, Blockage ratio, Scour.***

I. INTRODUCTION

Unsuitable coverage design, coverage blockage, human behavior, and a lack of maintenance all reduce the efficiency of open channels. As a consequence, the impact of box coverage area and blocking ratio on watercourse performance were studied. The researchers investigated many studies on the impact of culverts on waterways. [1] find out that the scour hole in the case of partially blocked culverts is greater than in the non-blocked culverts case, and scour parameters all significantly increased. [2] experimented with scouring downstream pipe culverts and suggested a vertical flow deflector (VFD) downstream of the culvert with different heights and positions, the results of the experiments concluded that VFD minimizes the scour dimensions, a reduction of 68 percent of the scour parameters was observed. [3] studied the influence of inclined headwalls in culverts on canal efficiency with comparing to the culverts without headwalls, the study discovered that the inclination of the headwall with an angle 15^0 within the opposite direction of the flow under the identical upstream water depth within the case of using the U.S. headwall only gives the most effective ends up in terms of efficiency. [4] studied the blocking of culverts. The study found that the scale of the culvert's clear openings is the most vital element affecting the blockage' degree, which culvert blockage is expounded to other downstream culverts. [5] proposed three baffle models to reduce water velocity and scouring downstream culverts, the experiment concluded that the increase of surface area coverage of the baffles model lead to the most effective performance. [6] conducted 117 tests in the lab to check how varied jet discharges, positions, and tailwater levels affected scour downstream of the water structure. The proposed technique reduced the scour depth by 50 to 90% and scour length by 42 to 85% when compared to cases without water jets. [7] predicted coverage and bridge blockage supported debris availability, mobility, and transportability parameters, explored coverage blockage mechanisms and their impact on flood behavior, and observed flow diversion caused by coverage blockage as compared to non-blocked coverage, Even a small blockage at the coverage entrance reduces flow and has a big impact on flood behavior. [8] changed the wing wall angle downstream of the culvert to reduce maximum scour downstream of the box culvert, the proposed technique reduced the relative depth of scouring, and the lowest value of that depth is produced by the wing wall angle of 90^0. The influence of debris obstruction on a box culvert was examined in the laboratory by [9], who found that the debris tended to align itself with the flow direction along its long axis. Since no indications of complete hydraulic blockage were observed, the data presented during this investigation allowed for the development of worst-case estimates of hydraulic blockage.

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With unrestricted conditions, a simple waterway hood improved hydraulic performance. [10] conducted 144 experimental tests for the scour downstream water structures, including cases 1, 2, and 3 as no sill, single line sill, and fully sill floor respectively and the heights and placements of the sills varied for each case. The results of the study indicated that case 3 reduced scouring parameters more than the others. Additionally, the values (height of sill/length of the sill) 0.04 and 0.013 produced smaller and higher scouring parameter values, respectively. [11] tested the parameters that influence culvert behavior and provided a whole hydraulic design consideration of the culvert as indicated within the Egyptian irrigation code employing a computer simple model. [12] examined in the laboratory the effect of pipe coverage on the hydraulic parameters of the waterway. The results show that the blockage ratio is directly proportional to the heading up, and also presented empirical equations describing the relationship between scour and flow characteristics. [13] used a physical model to investigate the velocity distribution at the pipe culvert inlet. The velocity increased rapidly in the zone within one culvert diameter of the culvert entry, and the flow has normal velocity and turbulence intensity profiles over distances greater than twice the culvert diameter. [14] used a hydraulic model set up in the lab to evaluate the influence of flow blockage at rectangular culvert inlets on the scour downstream culvert as well as the upstream water level. The study revealed that debris accumulation increases near-wall scouring, presenting a direct threat to the structure's safety and that the upstream water level increased as the blockage upstream the inlet of the culvert increased. [15] investigated experimentally the impact of debris accumulations upstream and through hydraulic structures such as culverts. The results showed that the increases in submergence ratio led to a decrease in the maximum scour depth for the same discharge rate, and also the relative energy rate loss within the non-blocked case lowers as well. Within the non-blocked case, the discharge rate was identical, and also the relative energy rate loss was similarly lower. This research investigated experimentally the impact of the presence of the blockage upstream box coverage on the scours pattern downstream the coverage in the case of sub-critical flow.

II. MATERIALS AND METHODS

Experimental settings were conducted in partially blocked and non-blocked box coverage within sub-critical flow conditions. Forty-eight runs were carried out (table 1) in an artificial canal of a trapezoidal concrete section which had a 16.22 m length, 0.6 m horizontal bed width, 0.44 m maximum depth, and 1:1 side slope (figure1). Square box section coverage of Acrylic material, side dimensions 8.80, 10.40, and 12.90 cm, and a length of 1.00 m was installed in the middle of the canal. Four blockage ratios of 0, 10, 20, and 30% at the inlet bottom of the coverage were simulated to represent the upstream vegetation, debris, and sedimentation relative to the coverage cross-section area, and four water flow rates of 2, 5, 8, and 11 L/sec passed through the canal. A sand basin of 2.00 m in length, 0.60 m in width, and 0.30 m in depth filled with bed material of D_{50} = 0.50 mm (photo 1 & figure 2) was installed directly downstream of the outlet of coverage, and the basin was divided to 10*12 cm mesh (figure 3). After many trials, the experiments observed that was no noticeable change in scour hole dimensions after 120 minutes which is selected as a set time for all runs. In each run; the sand basin surface was leveled with the bed level of the canal, the sand bed was gradually saturated to remove any air from voids and achieve uniform density, and water discharge was adjusted using the Current flow meter/uniflow universal portable flow metric, water surface levels were measured along the centerline of the canal using a point gauge fixed on a measuring carriage. Water velocities profiles were measured on two water cross sections just at water surface stability; upstream and downstream the coverage along the centerline of the artificial canal using the Vectrino 3D water velocity sensor, the velocity for the sections downstream coverage was measured at a distance of 3.5 times the height of box sections, and the upstream velocity was measured at a distance 2.5 times the height of box sections. The scour basin was surveyed, and the scour depth and length were measured using a measuring carriage (point gauge). Also, Dimensional analysis and statistical software packages, ANOVA test, and linear stepwise regression analysis] were used to establish empirical relationships between all variables. Three cases of experimental work are used according to the coverage inlet dimension, and upstream blockage of coverage with four blockage ratios of 0, 10, 20, and 30% as indicated in the table- I. The investigated data are a component of the measured data applied to the study of improving the performance efficiency, the management, and maintenance of coverage open channels which belong to the research plane of Channel Maintenance Research Institute.

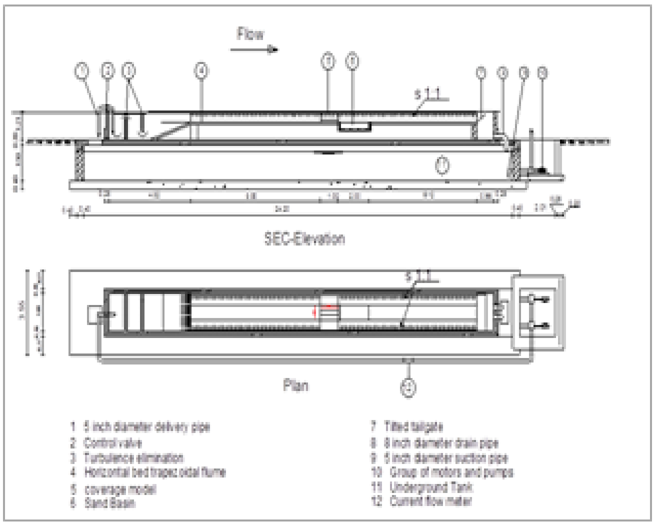

Fig. 1. Experimental flume

Table- I: Experimental Cases

Cases	No and Dimension of Cross Section	No of Discharge	No of Blockage	No of Runs
Case 1 (Box Section)	1 8.80*8.80 cm	4 2,5,8, and 11 L/s	4 0,10,20, and 30 %	16
Case 2 (Box Section)	1 10.40*10.40 cm	4 2,5,8, and 11 L/s	4 0,10,20, and 30 %	16
Case 3 (Box Section)	1 12.90*12.90 cm	4 2,5,8, and 11 L/s	4 0,10,20, and 30 %	16
Total Runs				48

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Photo 1: The artificial canal, coverage, scoured soil

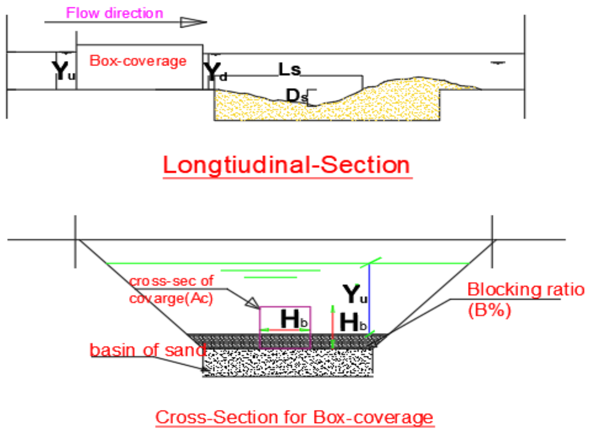


Fig. 2. The flume structure and its scoured soil basin

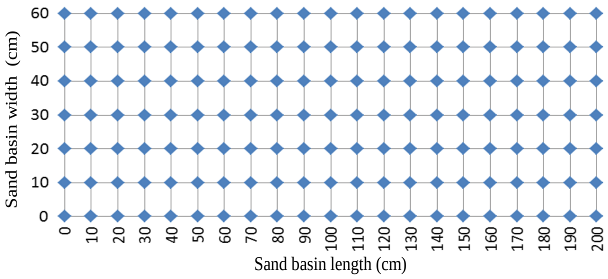


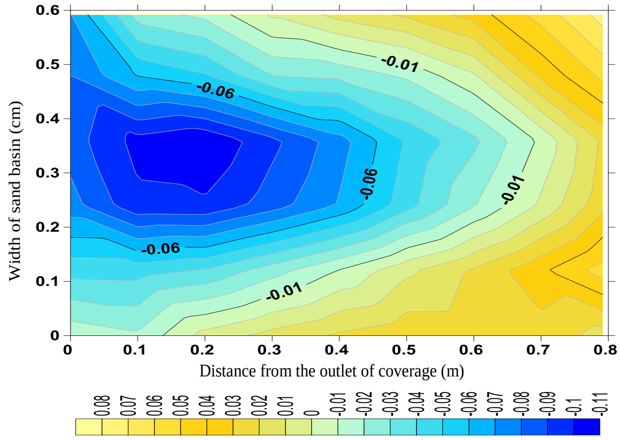
Fig. 3. Definition sketch for scouring mish downstream the coverage

III. RESULTS AND DISCUSSIONS

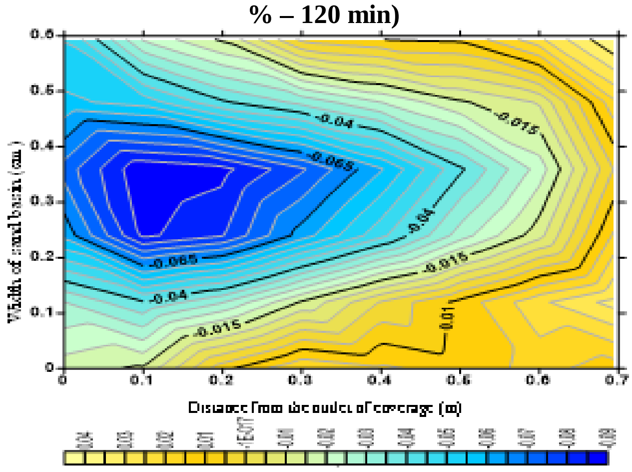
The data of the experiments were presented, and the effect of different ratios of blockages upstream coverage on the hydraulic and scour parameters was investigated. The relationships between the hydraulic and the scour parameters were developed using dimensionless analysis.

A. Scour contour map

Contour, wireframe maps, and surfer 12 programs were used to show bed deformation downstream of a box culvert at various blockages, discharges, and coverage's dimensions. The negative and positive contours represent the scour and deposition regions respectively. The different deformation in the basin downstream coverage is shown in Figure 4. In all cases, the scour hole appears symmetrical in shape, and it is deeper in partially blocked coverage than in non-blocked coverage.



a: Scour contour map for (case1-Q=8 l/s– blocking ratio 0 % – 120 min)



b: Scour contour map for (case1-Q=8 l/s– blocking ratio 20% – 120 min)

Fig. 4. Scour contour maps for sand basin downstream coverage

B. Water Velocity Profiles

The relationships between the water depth and the velocity downstream coverage were plotted for each run to describe the effect of coverage dimension and blockage ratio in the velocity and scour downstream coverage as indicated in figure 5. It was observed that the downstream velocities for three cases of coverage are not having a specific trend, the velocities were turbulent disturbance after the water exit of coverage directly, and formation of submerged hydraulic jump. The presence of coverage and increasing the blocking ratios upstream coverage in open channels led to an increment in the velocity near the channel bed and bed scouring. The maximum velocity value for cases 1, 2, and 3 were 0.085, 0.083, and 0.082 m/s respectively at 11 l/s discharge and 30% blockage, The velocity value for cases 1,2 and 3 at no-blockage (0 %) and 11 l/s discharge were 0.084, 0.082, and 0.081 m/s respectively, and the percentage of the maximum velocity of cases 2 and 3 relative to the maximum velocity of case 1 were about 97.01, and 96.67% respectively. Finally, as a result of the previous findings, increasing downward velocities produces scouring forces that form horseshoe vortices and scour deep into the bed materials.

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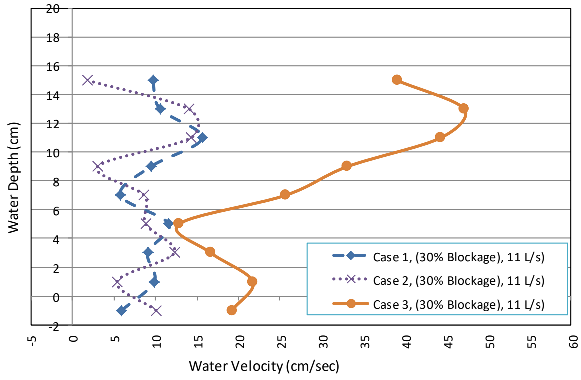
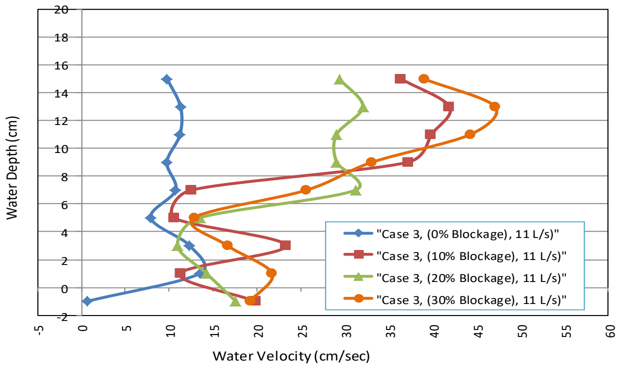
As a result, choose the suitable size of coverage and lower discharges to achieve minimum scour depths.



a: Velocity profiles downstream coverage at different areas, and the same blockage & discharge



b: Velocity profiles downstream coverage at the different blockages, and the same area & discharge

Fig. 5. Velocity profiles downstream coverage

C. Relationship between discharge, blockage Ratio, scour length, and scour depth

The relationships between the blockage percentage and depth and length of the scour downstream coverage were plotted as shown in figures (6, 7, 8, and 9) to indicate the influence of the coverage area, discharge, and blocking ratio on the scour parameters downstream coverage. The plotted figures show the following:

- The increase of the discharge and blockage upstream of the same coverage area led to an increase in the scour depth and length downstream coverage.
- The coverage area has a great effect on the scour downstream coverage, where the scour depth and length decreased within increments of the coverage area at a constant blockage ratio and constant discharge.
- The Non-blocked coverage has less scour depth than the partially blocked coverage, where for cases 1,2, and 3; the maximum scour depth for the Non-blocked coverage (0 % blockage) at discharge 11 l/s were 0.108, 0.079, 0.059 m respectively. The maximum scour depth for the partially blocked coverage at the discharge of 11 l/s and blockage ratio of 30% were 0.148, 0.109, and 0.071 m respectively, and the percentage of the maximum scour depth of the Non- blocked coverage for cases 1, 2 and 3 relatives to maximum scour depth at discharge 11 l/s and blockage ratio 30% were 73, 72, and 17 % respectively.
- The Non-blocked coverage has less scour length than the partially blocked coverage, where for cases 1, 2, and 3; the maximum scour length for the Non-blocked coverage (0 % blockage) at discharge 11 l/s were 1.100, 0.785, and 0.635 m respectively, the maximum scour length for the partially blocked coverage at discharge 11 l/s and blockage ratio 30% were 1.418, 1.015, and 0.759 m respectively. The percentage of the maximum scour length of the Non- blocked coverage for cases 1, 2, and 3 relatives to maximum scour length at discharge 11 l/s and blockage ratio 30% were 77.56, 77.34, and 83.66 % respectively.

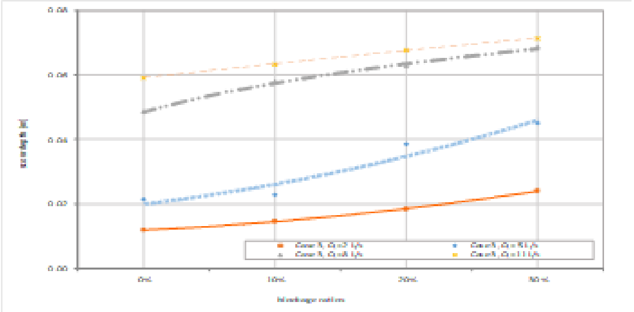


Fig. 6. Relationship between blockage ratio and maximum scour depth downstream coverage for constant coverage area (case 3) and different discharge (2, 5, 8, and 11 L/s)

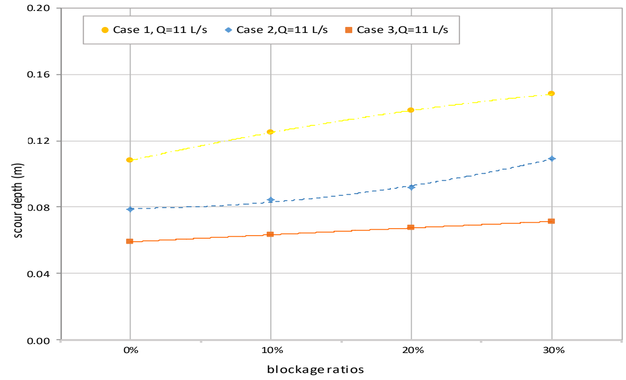


Fig. 7. Relationship between Blockage ratio and maximum scour depth downstream coverage for different coverage areas (cases 1, 2, and 3), and constant discharge (Q = 11 L/s)

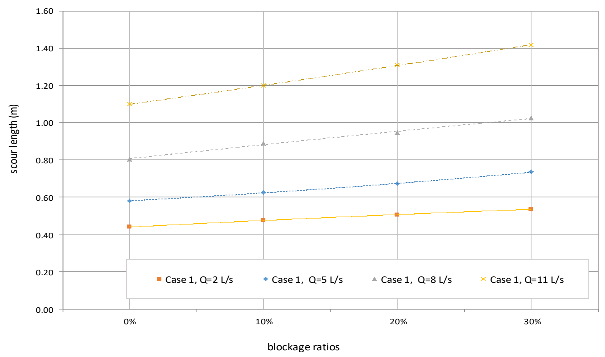


Fig. 8. Relationship between Blockage ratio and maximum scour length downstream coverage for constant coverage area (case 1) and different discharges (2, 5, 8, and 11 L /s)

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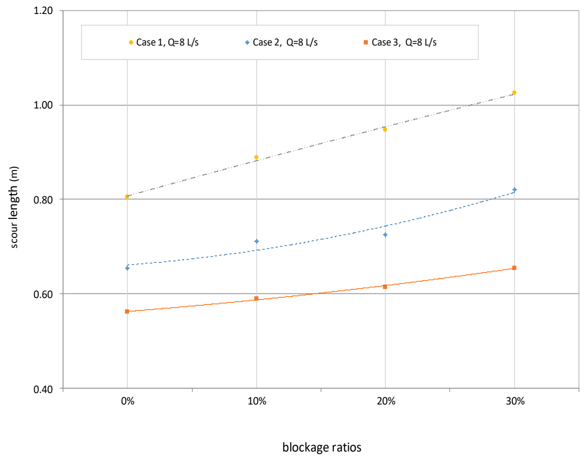

Fig. 9. Relationship between Blockage ratio and maximum scour length downstream coverage for different coverage areas (cases 1, 2, and 3), and constant discharge (Q = 8 L/s)

D. The effect of Froude number on scour depth and length downstream coverage

The ratio of the flow inertia to the external field is known as the Froude number (Fr), which is a dimensionless number.

$$Fr = \frac{V}{\sqrt{gD}} \quad \ldots\ldots\ldots\ldots\ldots Eq\ (1)$$

Where: (V) is the water velocity, (D) is the hydraulic depth, and (g) is the gravity.

After analyzing the measurements, the following was obtained:

- The Froude number upstream and downstream coverage in all the study cases was less than 1(Fr < 1), and the flow was sub-critical.
- Figures 10&11 show that the scour depth and length increased with increasing Froude number and discharge due to increasing the velocity downstream the coverage. Also, the Froude number increased with increasing blockage ratio for the same area of coverage.
- The maximum Froude number downstream coverage was 0.066 in case (1) with 11 l/s water discharge and 30 % blockage ratio, and the Froude number downstream coverage in case (1) with no-blocking (0 %) and 11 l/s discharge was 0.064 which is about 97.81 % relative to the maximum Froude number downstream blocked coverage.

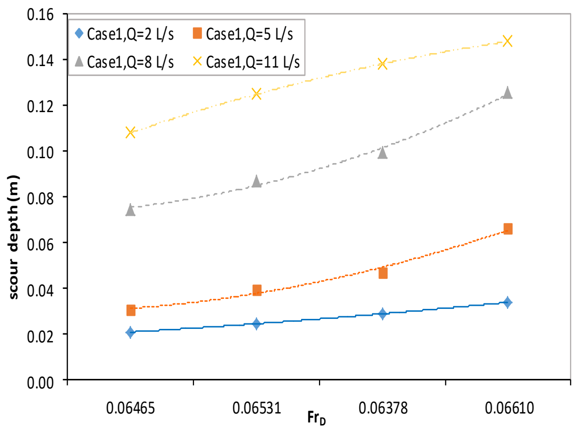

Fig. 10. Relationship between Froude number and maximum scour depth downstream coverage for constant coverage area and different discharges and blockage ratio

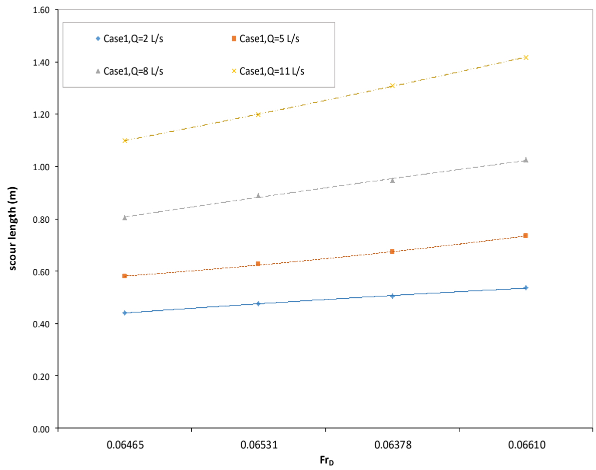

Fig. 11. Relationship between Froude number and maximum scour length downstream coverage for constant coverage area and different discharges and blockage ratio

IV. EMPIRICAL RELATIONSHIP

Dimensional analysis and statistical software packages [Data fit 9 software (Data Fit Curve Fitting and Data Plotting Software by Oakdale Engineering), Anova test, and linear stepwise regression analysis] were used to establish empirical relationships between the dependent and independent variables as in equation (2).

$$f\ (y_u, y_d, V_u, V_d, Q, L_s, D_s, V_s, A_{we}, A_p, A_c, A_b, h_u, \rho, g, \mu, \rho_s, D_{50}, \varphi, B, y_s) = 0 \ldots Eq\ (2)$$

The multiple regression analysis was performed using a 95% confidence level. Quadratic functions were found to provide the best fit data.

From dimension analysis and multiple regression analysis, the hypothetical relationships can be as follow;

$$(L_s/Y_u, h_u/Y_u, Y_s/Y_u, D_s/Y_u) = (Fr_u^2/Fr_d^2, Q/Y_u^2 * V_u, A_r, B/Y_u) \ldots\ldots\ldots\ldots\ldots\ldots Eq\ (3)$$

Where: Dimensions

- μ : dynamic water viscosity (Kg/m.s)
- g : gravitational acceleration (m/s^2)
- ρ : water density (Kg/m^3)
- ρ_s : Bed material density. (Kg/m^3)
- ϕ : Internal friction angle of bed material (°)
- Y_d: Water depth downstream coverage. (m)
- Y_u: Water depth upstream coverage. (m)
- Y_s: Water depth in case of no coverage. (m)
- H_b : Box height of coverage. (m)
- A_c : the coverage inlet area (m^2)
- A_b : the blockage area of coverage (m^2)
- A_{we} the wetted area of canal upstream coverage (m^2)
- A_p The wetted area of coverage (m^2)
- A_r :the relative wetted area of coverage (A_p/A_{we}). (Dimensionless)
- B : Blocking ratio (A_b/A_c)%. (%)
- D_s : Scour depth in case of coverage presence. (m)
- L_s : Scour length in case of coverage presence. (m)

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Q: Flow discharge. (m^3/s)
h_u : heading up upstream the coverage. (m)
V_d: Flow velocity downstream coverage. (m/s)
V_u: Flow velocity upstream coverage. (m/s)
Fr_d: Froude number downstream the coverage. (Dimensionless)
Fr_u: Froude number upstream the coverage. (Dimensionless)

The correlation matrix for the hypothetical relationships, which shows the strength of the relationship between the independent parameters and the dependent variables for Box-sec, is shown in table- II. The results of the ANOVA test for relative scour length are shown in Table- III. The relevance of the varying coefficients (a, b, and c) of the different variables in equation 4 is shown in table- IV. Also, the results of the ANOVA test for relative scour depth are shown in table- V. The relevance of the varying coefficients (a_1, b1, and c1) of the different variables in equation 5 is shown in table- VI.

$$\left(\frac{L_s}{y_u}\right) = (b\, Fr_d - c\, LN\, A_r + a) \qquad R^2 = 0.86 \qquad \text{......Eq (4)}$$

$$\left(\frac{D_s}{y_u}\right) = (b_1\, Fr_d - c_1\, LN\, A_r + a_1) \qquad R^2 = 0.83 \qquad \text{......Eq (5)}$$

The comparison of measured relative scours length and depth values, and predicted values are shown in Figures 12&13 respectively, where the followings were observed: -

- The ratio of Ls/y_u increased by 11.8% with an increasing Fr_d by 0.01 and A_r was constant.
- The ratio of D_s/y_u increased by 3.6% with an increasing Fr_d by 0.01 and A_r was constant.

Table- II: The correlation matrix for the hypothetical relationships

	A_r	LN(A_r)	Fr_d	Fr_u	hu	hu/y_u	y_u/y_s	D_s	D_s/y_u	L_s	L_s/y_u
Ar	1										
LN(Ar)	0.96	1.00									
Fr_d	-0.42	-0.46	1.00								
Fr_u	0.24	0.30	0.63	1.00							
hu	-0.74	-0.86	0.73	-0.06	1.00						
hu/y_u	-0.79	-0.870	0.800	0.07	0.97	1.00					
y_u/y_s	-0.76	-0.885	0.714	-0.07	1.00	0.98	1.00				
Ds	-0.72	-0.806	0.841	0.17	0.95	0.96	0.95	1.00			
D_s/y_u	-0.63	-0.644	0.869	0.44	0.75	0.83	0.75	0.92	1.00		
L_s	-0.76	-0.858	0.801	0.07	0.98	0.98	0.98	0.98	0.84	1.00	
L_s/y_u	-0.74	-0.732	0.841	0.38	0.77	0.84	0.77	0.89	0.94	0.87	1.00

Table- III: Results of ANOVA test for relative scour length

Regression Variable Results				
Variable	Value	Standard Error	t-ratio	Prob(t)
a	3.03	0.09	32.23	0.0
b	11.42	1.12	10.23	0.0
c	-0.27	0.04	-7.04	0.0

Table- IV: Coefficient and significance of different variables in Equation (4)

95% Confidence Intervals				
Variable	Value	95% (+/-)	Lower Limit	Upper Limit
a	3.03	0.1892	2.8385	3.2170
b	11.42	2.2476	9.1736	13.6689
c	-0.27	0.0760	-0.3418	-0.1897

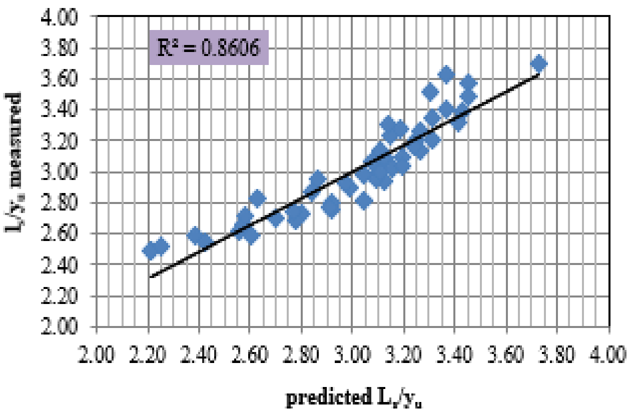

Fig. 12. Predicted L_s/y_u against the measured L_s/y_u for Box-sec

Table- V: Results of ANOVA test for relative scour depth

Regression Variable Results				
Variable	Value	Standard Error	t-ratio	Prob(t)
a_1	0.20	0.03	6.81	0
b_1	3.63	0.34	10.62	0
c_1	-0.05	0.01	-4.56	0.00004

Table- VI: Coefficient and significance of different variables in Equation (5)

95% Confidence Intervals				
Variable	Value	95% (+/-)	Lower Limit	Upper Limit
a_1	0.20	0.058	0.138	0.254
b_1	3.63	0.688	2.938	4.313
c_1	-0.05	0.023	-0.076	-0.029

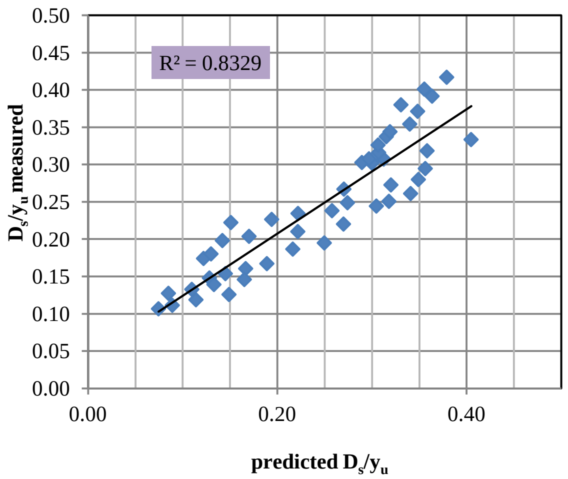

Fig. 13. Predicted D_s/y_u against the measured D_s/y_u for Box-sec

V. CONCLUSIONS AND RECOMMENDATIONS

This research investigated experimentally the impact of the presence of the blockage upstream box coverage on the scours pattern downstream the coverage in the case of sub-critical flow. To achieve the research objective, a series of conditions were tested in the hydraulic laboratory, with the following findings:

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- The increase in the coverage' blockage ratio and discharge, and reducing the inlet area of the coverage lead to an increment in the scour depth and length downstream coverage.
- Flow velocities and the relative wetted area of coverage (A_r) are the most effective variables for relative scour depth and length. The relative scours depth and length displayed an inverse relationship with A_r. The maximum velocity value for cases 1, 2, and 3 were 0.085, 0.083, and 0.082 m/s respectively at 11 l/s discharge and 30% blockage, and the velocity value for cases 1, 2, and 3 at no-blockage (0 %) and 11l/s discharge were 0.084, 0.082, and 0.081 m/s respectively, and the percentage of the maximum velocity of cases 2 and 3 relative to the maximum velocity of case 1 were about 97.01, and 96.67% respectively.
- The Non-blocked coverage has less scour depth than the partially blocked coverage, where the maximum scour depth of the non-blocked coverage for cases 1, 2, and 3 relatives to maximum scour depth of partial coverage at discharge 11 l/s and blockage ratio 30 % were 73, 72, and 17 % respectively.
- The Non-blocked coverage has less scour length than the partially blocked coverage, where the percentage of the maximum scour length of the partially blocked coverage for cases 1, 2 and 3 relatives to maximum scour length at discharge 11 l/s and blockage ratio 30% were 77.56, 77.34, and 83.66 % respectively.
- As the Froude number (Fr_d) was increased in this investigation, the scour depth and length increased (the flow is sub-critical).
- The maximum Froude number downstream coverage was 0.066 in case (1) with 11 l/s water discharge and 30 % blockage ratio, and the Froude number downstream coverage in case (1) with non-blocking (0 %) and 11 l/s discharge was 0.065 which is about 97.81% relative to the maximum Froude number downstream coverage.
- With a 0.01 increase in (Fr_d) and a fixed relative wetted area of coverage (A_r), the relative scour depth increased by about 3.60 percent.
- Increasing (Fr_d) by 0.01 while keeping A_r unchanged, increased relative scour length by 11.80 percent.

Appropriate coverage area, discharge, and protection method downstream coverage must be studied carefully during the design and implementation of the coverage to minimize the impact of coverage area and blockage on the hydraulic characteristics of the open channel and the scour pattern downstream the coverage. Also, install a trash rack upstream of the covering and remove aquatic weeds and solid wastes periodically upstream and inside the coverage.

NOTATION

The following symbols are used in this paper: -

μ : Dynamic water viscosity

g : Gravitational acceleration

ρ : Water density

ρ_s : Bed material density.

ϕ : Internal friction angle of bed material

Y_d : Water depth downstream coverage.

Y_u : Water depth upstream coverage.

Y_s : Water depth in case of no coverage.

H_b :Box height of coverage.

A_c :The coverage inlet area

A_b :The blockage area of coverage

A_{we} :The wetted area of canal upstream coverage

A_p :The wetted area of coverage

A_r :The relative wetted area of coverage

B : Blocking ratio.

D_s : Scour depth in case of coverage presence.

L_s : Scour length in case of coverage presence.

Q : Flow discharge.

h_u : Heading up upstream the coverage.

V_d: Flow velocity downstream coverage.

V_u :Flow velocity upstream coverage.

Fr_d: Froude number downstream the coverage.

Fr_u: Froude number upstream the coverage.

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