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Assessment the impact of covering a part of watercourse by pipe

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Abstract

This experimental investigates the effect of coverage a part of watercourses with varies blocking ratio and discharges. The research includes 52 test runs with three inner diameter of the circular coverage (10, 12, and 14.5) cm, four tested blocking ratio of the pipe (0, 10, 20, and 30%) and four discharges (2,5,8 and 11)Lit/sec.
The water surface profile and shape of the developed scoured holes downstream the coverage at each scenario were recorded. Based on the analysis, it could be concluded that the heading up is directly proportional, so it is recommended to carry out continuous maintenance for removing the upstream blocking. To avoid the sharp increase in the heading up (h_u), it is recommended to keep the maximum allowable inlet area of coverage per wetted area of canal upstream coverage (ratio of relative area) A_s/A_o less than 5 %. Empirical equations were developed to describe the relationships between the characteristics of scour (the length and the depth), and flow characteristics (discharge, velocity and heading up).

Key words: Coverage; Blocking ratios; Heading up; Scour.

INTRODUCTION

The irrigation sectors of the Ministry of Water Resources and Irrigation (MWRI) are implementing water coverages in some densely populated areas to overcome the problem of decreasing the hydraulic efficiency of watercourse in this area. Implementation of coverage without suitable design has caused hydraulic problems for watercourses. However, after the implementation of these coverages within the residential areas, the people continues to dump their garbage, which leads to block the entrance screen of the coverages. It was required to study examples of coverage with percentage of blockages upstream and determine its effect on the performance of the watercourse and the required methods to maintain the.coverage. It's required to evaluate the hydraulic efficiency for coverage. Many researchers have studied different type of canal coverages (culverts) and it's performance as following:

(El-Zaher, 2006), studied the main factors affect the behavior of culvert by using a computer simple model, was designed to give a detailed hydraulic design consideration of culvert as stated in (Egyptian code of irrigation, 2003). (Larry W. Mays 1999), stated in his book "Hydraulic Design Handbook" that high outlet velocities observed at the culvert outlets may result in excessive scour of the channel in the vicinity of the outlet. The flow exhibits normal velocity and turbulence intensity profiles at distances greater than 2.0 times or 2.5 times the culvert diameter (Kolerski and Wielgat, 2014) and (Day R. A., 1997). (Liriano et al., 2002) analyzed the turbulent flow structure in scour holes downstream of the pipe culvert. (Sorourian S, Keshavarz A, 2015)). They used culvert with opening is 200×200 mm and the length of the culvert barrel is 900 mm and with two sizes of plates (200×80 mm and 200×120 mm), The downstream velocity of a partially blocked culvert was about 40% more than a non-blocked culvert. (Sorourian *et al.*, 2014), used the previous steps to study the relationship between the maximum scour depth, blockage ratio of the culvert and flow characteristics. The scoured area at the blocked culverts was 20–60% more than non-blocked conditions and scouring length and width increased up to 17% in the partially blocked conditions. (Ruff, et al., 1982). developed equation (1) to determine the maximum scour characteristics under specified flow conditions. is as follow.

$$\frac{d_s}{R_c}, \frac{w_s}{R_c}, \frac{L_s}{R_c}, \frac{V_s}{{R_c}^3} = C_s C_h \left(\frac{\alpha}{\sigma^{\frac{1}{3}}}\right)\left(\frac{Q}{\sqrt{g}{R_c}^{2.5}}\right)^{\beta}\left(\frac{t}{316}\right)^{\theta}$$

In which, ds is the scour depth, ws is the scour width, Ls is the scour length, $V\ s$ is the scour volume, Rc is the culvert end's hydraulic radius, Q the discharge of flow, g is the gravitational acceleration, t is the duration of scour in minutes, $\sigma = \sqrt{D84/D16}$, D84 and D16 are sieve diameter of the material for which 84 and 16 percent is finer by weight respectively, Cs, Ch, α, β, θ are coefficients. (Mustaffa, Madzlan, and Rasool, 2013), dealing with supercritical flow in culvert by proposing three blocks in different models in downstream the culvert to disperse energy resulting from the passage of flow in the culvert. (Negm, A.M, Nassar, M.A , and Elnikhely, 2014), used a vertical flow deflector (VED) on rigid bed to dissipate the flow excess energy to minimizing of scour and deposition downstream pipe culvert. (Aly, 2017), used headwall as photo 1 with different angles to improving the efficiency of culvert. He concluded that Using a headwall in

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both sides of circular culvert, of an inclination angle of 60° in the opposite direction of the flow gives better results than that obtained with other tested inclination angles, where it decreases the head loss with an average value equals 17.5 %, and decreases the values of the inlet and the exit losses coefficient (Kin + Kex) with an average value equals 18.5% with respect to the projected culvert.

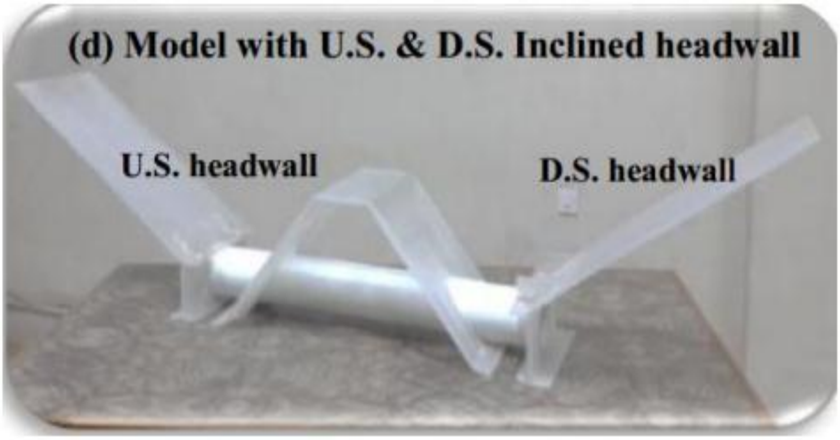

Photo 1. Experimental model. [8]

METHODOLOGY

Experimental set up.

The experiments were conducted in a reinforced concrete flume with trapezoidal cross section provided with a regulator with one vertical sluice gate as shown in Fig. 1. The flume bed was horizontal and supplied by water through re-circulating system. The flow discharges, which were adjusted via a discharge valve, were measured with a current flow meter, and a mobile point gage was used to measure the water depths to the nearest ±1 mm. A coverage length 100 cm was constructed approximately in the middle of the flume length. There are three inner diameters for the circular coverage are 10, 12 and 14.5 cm respectively. The four-tested blocking ratio upstream relative to the coverage area 0, 10%, 20%, and 30% were used. The sandy layer is of dimension 2 m length and 0.60 m width and is simulated downstream the coverage and was divided into mesh every 10*12 cm to measure the scour depth at each point of the mesh as shown in Fig. 2 and photo 2. The total number of test runs were 52 as shown in Table 1 with the measured elements included discharge, velocity, scour depth and length, four discharges and four blocking ratios were utilized.

Table 1. Experimental Runs.

Case	Discharge	No. of inner diameters	Upstream blocking ratios (B%)	No. of cases
Smooth	4Q (2,5,8,11)lit/sec	-	-	4
pipe	4Q (2,5,8,11)lit/sec	3inner diameters (10,12,14.5)cm	4 Blocking ratios (0,10,20,40)%	48
Total				52

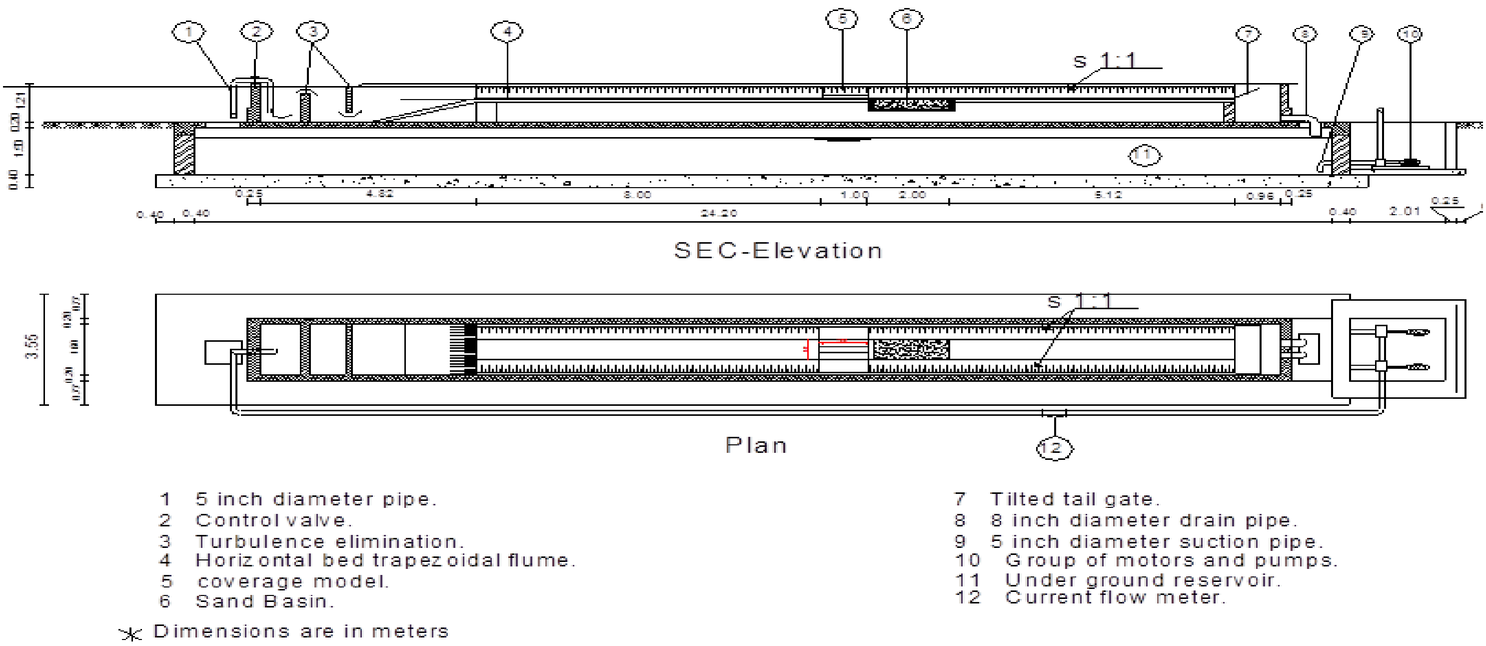

Fig. 1. Experimental flume

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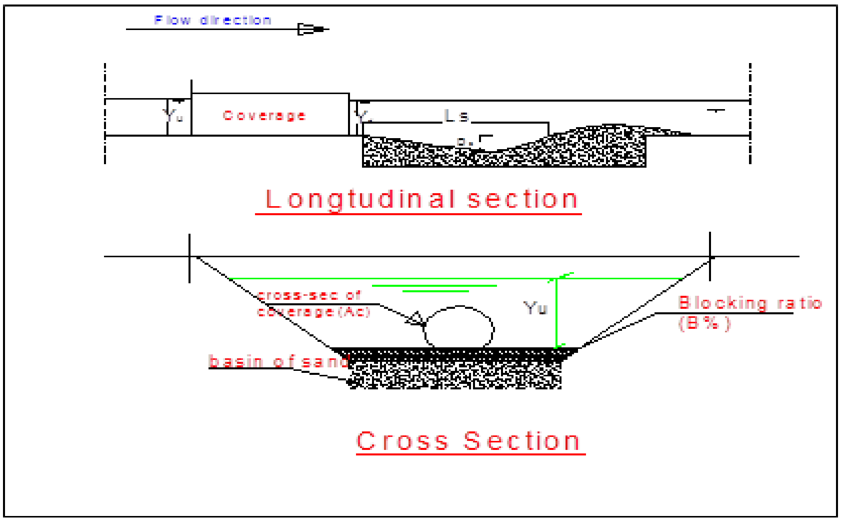

Fig. 2. The flume structure and its scoured soil basin

Photo 2. The coverage and its scoured soil basin.

Analysis of results

The experimental data is presented in table 2, the local scour downstream coverage and the effect of the presence for different ratios of blockages upstream coverage on the scour parameters is analyzed. On the basic of dimensionless analysis, the relationships between the hydraulic parameters and the scour parameters are developed.

Table 2. Experimental data.

	Pc1							Pc2							Pc3						
Q(m/s)	A_s(m^2)	A_o(m^2)	B %	L(m)	D_p(m)	D_s(m)	L_s(m)	A_s(m^2)	A_o(m^2)	B %	L(m)	D_p(m)	D_s(m)	L_s(m)	A_s(m^2)	A_o(m^2)	B %	L(m)	D_p(m)	D_s(m)	L_s(m)
0.002	0.008	0.136	0	1	0.1	0.03	0.510	0.011	0.131	0	1	0.12	0.021	0.470	0.017	0.128	0	1	0.145	0.017	0.427
0.002	0.011	0.136	10	1	0.1	0.029	0.545	0.010	0.132	10	1	0.12	0.028	0.500	0.015	0.128	10	1	0.145	0.021	0.440
0.002	0.006	0.140	20	1	0.1	0.034	0.590	0.009	0.133	20	1	0.12	0.030	0.530	0.013	0.129	20	1	0.145	0.026	0.456
0.002	0.005	0.143	30	1	0.1	0.039	0.610	0.008	0.134	30	1	0.12	0.034	0.560	0.012	0.130	30	1	0.145	0.028	0.479
0.005	0.008	0.173	0	1	0.1	0.043	0.625	0.011	0.147	1	1	0.12	0.032	0.530	0.017	0.140	0	1	0.145	0.029	0.490
0.005	0.011	0.178	10	1	0.1	0.050	0.645	0.010	0.151	10	1	0.12	0.041	0.570	0.015	0.142	10	1	0.145	0.035	0.517
0.005	0.006	0.191	20	1	0.1	0.068	0.745	0.009	0.156	20	1	0.12	0.057	0.630	0.013	0.142	20	1	0.145	0.043	0.550
0.005	0.005	0.205	30	1	0.1	0.084	0.846	0.008	0.164	30	1	0.12	0.067	0.694	0.012	0.144	30	1	0.145	0.059	0.590
0.008	0.008	0.240	0	1	0.1	0.092	0.925	0.011	0.192	0	1	0.12	0.071	0.775	0.017	0.148	0	1	0.145	0.055	0.605
0.008	0.011	0.244	10	1	0.1	0.096	0.975	0.010	0.194	10	1	0.12	0.080	0.781	0.015	0.154	10	1	0.145	0.064	0.655

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0.008	0.006	0.281	20	1	0.1	0.128	1.105	0.009	0.203	20	1	0.12	0.092	0.845	0.013	0.156	20	1	0.145	0.069	0.675
0.008	0.005	0.297	30	1	0.1	0.144	1.175	0.008	0.220	30	1	0.12	0.111	0.915	0.012	0.170	30	1	0.145	0.085	0.725
0.011	0.008	0.338	0	1	0.1	0.129	1.205	0.011	0.219	0	1	0.12	0.088	0.860	0.017	0.166	0	1	0.145	0.067	0.675
0.011	0.011	0.345	10	1	0.1	0.138	1.275	0.010	0.231	10	1	0.12	0.097	0.915	0.015	0.173	10	1	0.145	0.073	0.725
0.011	0.006	0.411	20	1	0.1	0.159	1.475	0.009	0.261	20	1	0.12	0.108	1.055	0.013	0.181	20	1	0.145	0.079	0.769
0.011	0.005	0.433	30	1	0.1	0.170	1.608	0.008	0.300	30	1	0.12	0.128	1.225	0.012	0.190	30	1	0.145	0.084	0.835

Note: Pc1,Pc2 and Pc3. The three Pipes (cicular-section of area 1, area 2 and area 3 respectively).

Effect of ratios of blockage upstream the coverage on the flow characteristics.

Water surface profiles

Fig. 3 and Fig. 4 show the relation between the water level and the longitudinal distance for the smooth case and three cases of runs. (Pc1, Pc2, Pc3) are three inner diameters for the circular coverage (10, 12 and 14.5 cm) respectively. Water surface profiles were plotted for all cases along the centerline of the flume. Samples of water surface profiles were plotted as shown in Fig.3 and Fig. 4.

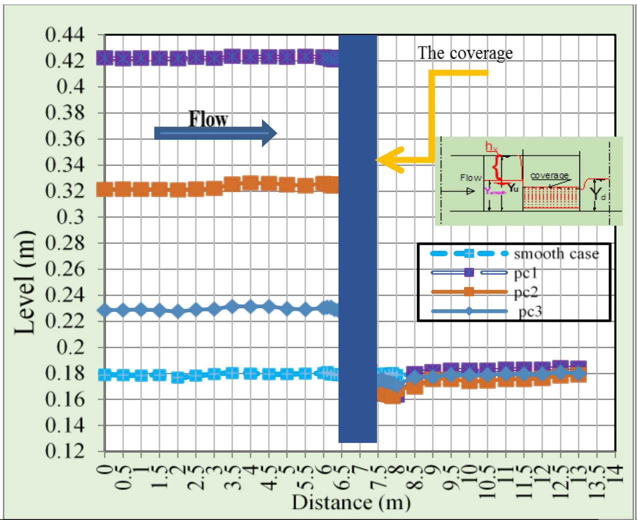

Fig. 3. Water surface profile comparison between p_{c1}, p_{c2}, p_{c3}, and smooth case at (Q=11lit/sec and blocking ratio 30%).

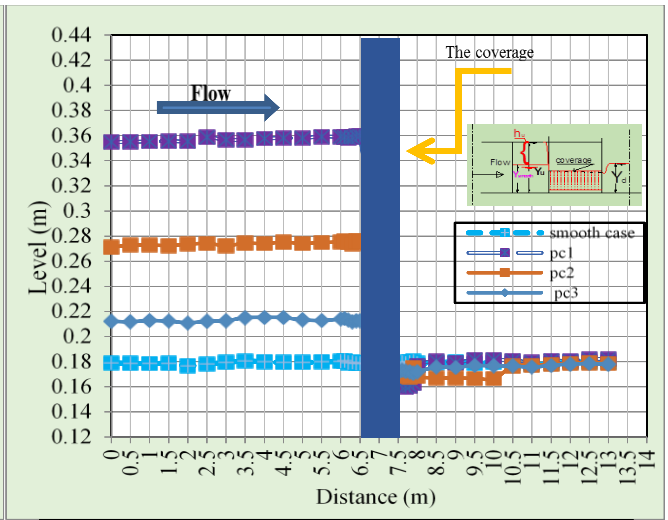

Fig. 4. Water surface profile comparison between p_{c1}, p_{c2}, p_{c3}, and smooth case at (Q=11lit/sec and blocking ratio 10%).

From Fig. 3. The maximum depth of water upstream is almost 42.4 cm at pc1. On the other side, Fig. 4. The maximum depth of water upstream is almost 35.9 cm at pc1. At constant discharge and constant cross section of coverage, hu increased by increasing the blocking ratio. After discharge reached to 5lit/sec, the heading up increased sharply for all blocking ratios.

Water velocity profiles

The velocity for the sections upstream coverage were measured at distance 2.5 times the diameter of circular sections of coverage shown in Fig. 5. The velocity for the sections downstream coverage were measured at distance 3.5 times the diameter of circular sections for coverage.

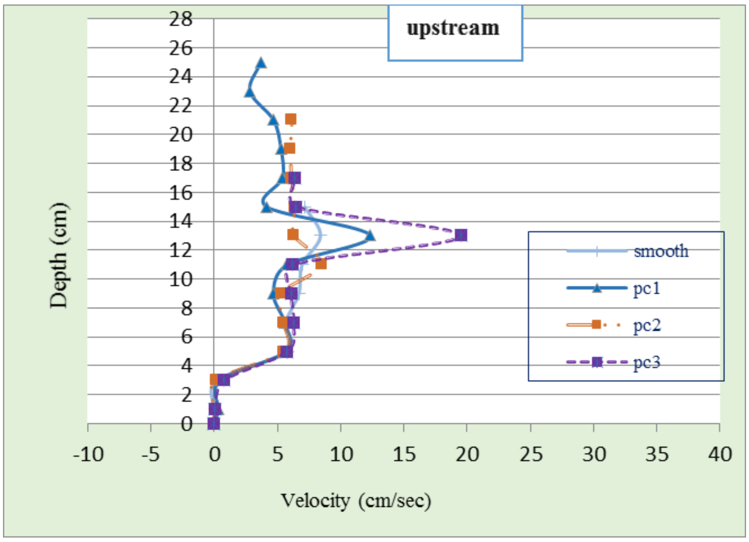

Fig. 5. Effect of presence of different circular coverages in open channels upstream velocity profile at blocking ratio 20% and (Q= 8 l/s).

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The upstream velocity distributions is shown in Fig. 5 the range of velocity for all cases is between (0-19.5) cm/sec. The large value is only at the beginning and end of the coverage vent up to 19.5cm/sec.

The downstream velocities for three cases of circular coverage is not having a specific trend. The flow was turbulent. The increasing of the downward velocities creating scouring forces that form horseshoe vortices and scour deep into bed materials.

Scour contour map

Some samples of the experiment runs are represented as contour maps as shown in Fig .6 to show the effect of different variables on local scour downstream coverage. Fig. 7. Show the effect of coverage for circle section and blocking ratio presence on local scour.

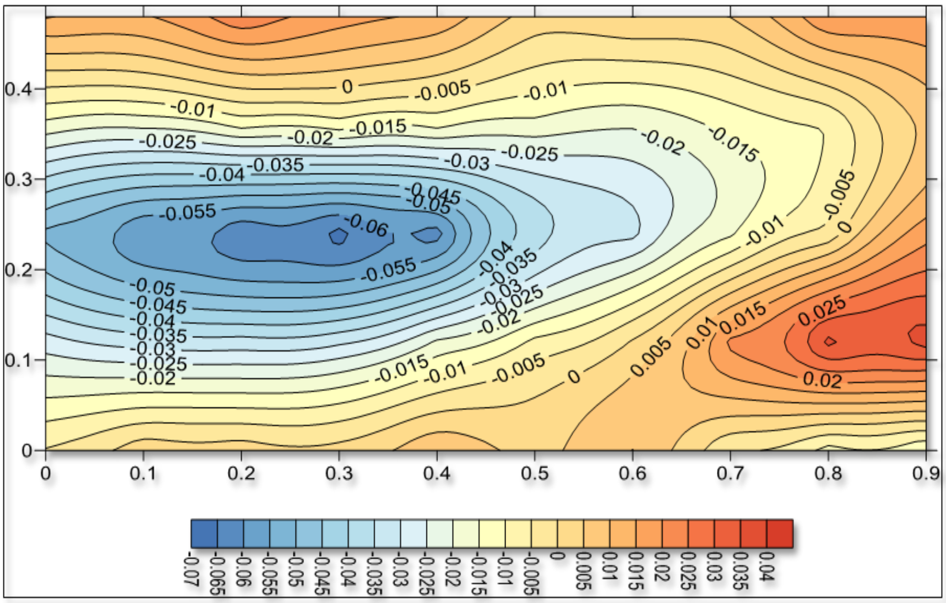

Fig. 6. Scour Contour Map for (p_{c3}-Q=8 L\s –20% blocking ratio – 30 min).

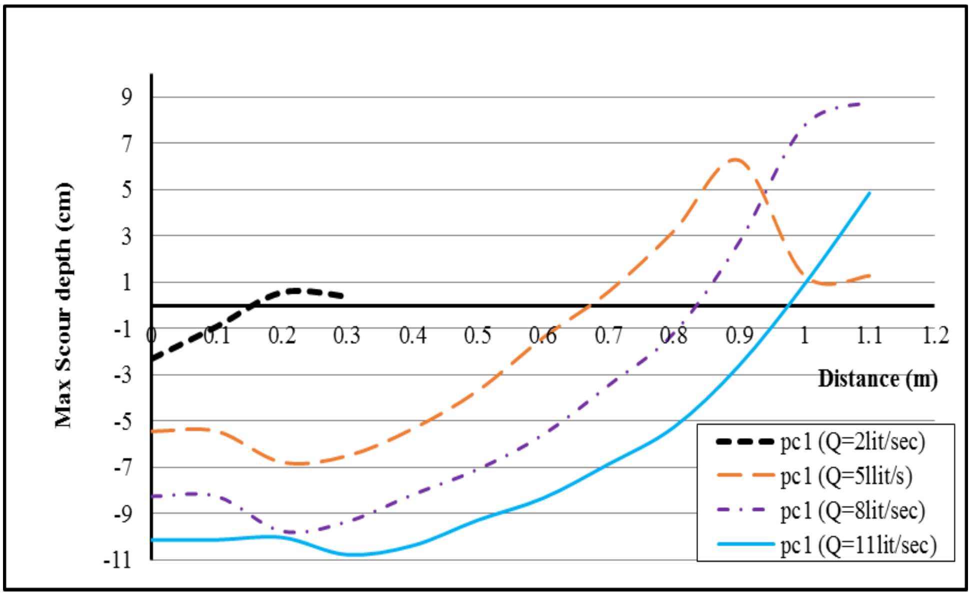

Fig. 7. Local scour maximum levels for different discharges (p_{c1}–20% blocking ratio – 30 min).

From Fig. 7 and Fig. 8. The follow can be concluded.

- The presence of coverage in open channels, leads to an increase in the downstream velocity near the channel bed, which leads to an increase in the bed scouring downstream the coverage.
- Increasing discharge, leads to increasing scour depth downstream the coverage as shown Fig. 8.
- Increasing the blocking ratio upstream coverage, leads to increasing scour depth downstream the coverage.

Empirical Relationship

Dimension analysis.

The homogenous function of variables, which affect the characteristics of the hydraulic efficiency, that cover the studied models of coverage phenomenon may be expressed in the following form:

$$f\ (Y_u, Y_d, V_u, V_d, Q, L_s, D_s, V_s, A_c, A_b, h_{loss}, G, \rho, g, \mu, \gamma_s, D_{50}) = 0$$

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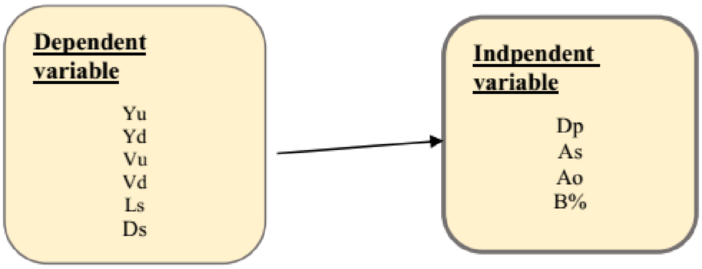
The variables used in dimensional analysis are defined and classified into three groups as follows.
a. Flow characteristics. (Dimensions)
Yu : Upstream water depth. (L)
Yd : Downstream water depth. (L)
hu : The difference between the water depth of upstream (Dimensionless) coverage and smooth case.
Vu : The velocity of flow under the gate (LT^{-1})
Vd : The velocity of flow downstream the hydraulic structure (LT^{-1})
Q : Total discharge. (L^3T^{-1})
The definition sketch of flow characteristics is shown in Fig (2).
b. Geometric characteristics. (Dimensions)
Ls : scour length in case of coverage presence. (L)
Ds : scour depth in case of coverage presence. (L)
Do : scour depth in case of no coverage presence. (L)
Vs : scour volume in case of coverage presence. (L^3)
Dp : diameter of pipe coverage (L)
Lc : length of coverage (L)
Ac : coverage area (L^2)
Ab : area blocking from coverage (L^2)
Ao : wetted area of canal upstream coverage (L^2)
As : the inlet area of coverage (L^2)
G : tail gate opening. (L)
c. Fluid characteristics (Dimensions)
g : gravitational acceleration (LT^{-2})
ρ : fluid density (ML^{-3})
μ : dynamic viscosity ($M L^{-1}T^{-1}$)
d. Soil characteristics (Dimensions)
γs specific weight of bed materials ($ML^{-2}T^{-2}$)
D50 mean diameter of sediments. (L)
By using Backingham's π -theorem the function can be written as the following.

$$\left(L_s/Y_u, D_s/Y_u, V_s/Y_u^3 \right) = \left(1/Fr_d, Q/Y_u^2 * V_u, A_b/A_c, A_b/Y_u * Y_d, h_{loss}/Y_u, G/Y_u, D_p/L_c \right)$$

Regression analysis
Multiple linear regression analysis and dimension analysis were used to establish empirical relationships between the characteristics of coverage and (independent variable) and the flow and scour characteristics (dependent variable).



The correlation matrix for the hypothetical relationships, which show the strength of the relationship between the independent parameters and the dependent variables for Circular-sec as Table 3.

Table 3: The correlation matrix for the hypothetical relationships, which show the strength of the relationship between the independent parameters and the dependent variables for Circular-sec.

	As/Ao	*Ln(As/Ao)*	*1/(As/Ao)*	*L/Dp*	*1/lnB%*	*hhu/Yd*	*Fru*	*Frd*	*ln(Q/yu²*vu)*	*lnQ/yd²*Vd*	*hhu/Yd*	*Ds*	*Ls*
(As/Ao)%	1												
Ln(As/Ao)	0.96	1											
1/(As/Ao)	-0.83	-0.95	1										
L/Dp	-0.84	-0.82	0.71	1									
1/lnB%	-0.31	-0.29	0.26	0	1								
hhu/Yd	-0.77	-0.89	0.94	0.56	0.15	1							
Fru	-0.56	-0.65	0.7	0.22	0.06	0.88	1						
Frd	-0.4	-0.45	0.46	0.02	0	0.69	0.95	1					
ln(Q/yu²*vu)	0.77	0.87	-0.89	-0.52	-0.14	-0.99	-0.92	-0.78	1				
lnQ/yd²*Vd	0.65	0.69	-0.67	-0.32	-0.09	-0.82	-0.91	-0.9	0.89	1			
Ln(As/Awe)	0.93	0.97	-0.92	-0.86	-0.08	-0.89	-0.66	-0.47	0.88	0.7			
Ds	-0.73	-0.82	0.84	0.39	0.26	0.94	0.93	0.82	-0.97	-0.9	0.94	1	
Ls	-0.77	-0.87	0.91	0.49	0.22	0.98	0.92	0.77	-0.99	-0.87	0.98	0.98	1

The highlighted number in the previous table shows the influence for each independent variable on the dependent terms.

The test runs were carried out with three inner diameter of the circular coverage (10, 12, and 14.5) cm, four tested blocking ratio of the pipe (0, 10, 20, and 30%) and four discharges (2, 5, 8, 11) Lit/sec. The next regression equations have been developed with limitations.

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	A_s/A_o	B%	L/D
Lower limit	1.268	0	6.897
upper limit	12.901	30	10

Relation between the coverage characteristics and Ls.

$$Ls = \left(-0.6\ln\frac{A_s}{A_o} + \frac{0.5}{(A_s/A_o)} - 0.18\frac{L}{D_p} - 0.05(1/\ln B\%) + 3.3 \right) \quad (m)$$

R2 =0.98 …...Eq. (2)

Relation between the coverage characteristics and Ds

$$Ds = \left(-0.1\ln\frac{A_s}{A_o} - \frac{0.01}{(A_s/A_o)} - 0.031\frac{L}{D_p} - 0.01(1/\ln B\%) + 0.6 \right)$$

R2 =0.95 …...Eq. (3)

Relation between the coverage characteristics and $^{hu}/_{yd}$

$$h_u/y_d = \left(-57.7\ln\frac{A_s}{A_o} + \frac{108.3}{(A_s/A_o)} - 16.05\frac{L}{D_p} - 6.6(1/\ln B\%) + 253.4 \right)$$

R2 =0.97 …...Eq. (4)

Additional equations help to design.

Relation between the coverage characteristics and $Q/(v_u * y^2_u)$

Governing equation

$$\ln\left(\frac{Q}{V_u * Y_u^2}\right) = \left(2.3\ \ln\frac{A_s}{A_o} + \frac{-0.4}{(A_s/A_o)} + 0.5\frac{L}{D_p} + 0.2(1/\ln\ B\%) - 3.9 \right)$$

R2 =0.970 …...Eq. (5)

Relation between the coverage characteristics and $Q/(v_d * y^2_d)$

$$\ln\left(\frac{Q}{V_d * Y_d^2}\right) = \left(0.5\ \ln\frac{A_s}{A_o} + \frac{0.5}{(A_s/A_o)} + 0.1\frac{L}{D_p} + 0.031(1/\ln\ B\%) + 3.8 \right)$$

R2 =0.824 …...Eq. (6)

Relation between the coverage characteristics and Fru

$$Fr_u = \left(-0.002\ln\frac{A_s}{A_o} + \frac{-0.0005}{(A_s/A_o)} - 0.06\frac{L}{D_p} - 0.0002(1/\ln B\%) + 0.01 \right)$$

R2 =0.89 …...Eq. (7)

Relation between the coverage characteristics and Frd

$$Fr_d = \left(-0.002\ \ln\frac{A_s}{A_o} + \frac{-0.002}{(A_s/A_o)} - 0.0005\frac{L}{D_p} - 0.0002(1/\ln B\%) + 0.01 \right)$$

R2 =0.81 …...Eq. (8)

Finally, the suitable design for section of coverage and suitable maintenance application are very important to avoid the effect of the coverage presence on the water velocity in the watercourse, which causes scour in bed downstream the coverage, especially in large discharges.

CONCLUSION

This research was carried out to clarify the effects of coverage apart of watercourses, and the effect of varies ratios of blockages upstream coverage on the scour parameters downstream the coverage. A laboratory physical model was used for simulation of different scenarios. Different scenarios of circular coverages areas with different ratios of blockages were analyzed in detail. Based on this analysis, the present research has concluded that:

- Empirical equations were developed to compute the relationships between the main characteristics of the coverage, the scour parameters (the length and the depth) and the flow characteristics (discharge, velocity and heading up). Also to help the designers of the coverages in open channels to conclude the maximum length and the maximum depth of the scour downstream the coverage as well as to rehabilitate the bed downstream coverage and protect it.
- The maximum flow velocity downstream the coverage was recorded when the relative area upstream As/Ao was less than 5.5 %. While, the velocity began to drop down gradually when the relative area increased.
- Empirical equations (Eq. (2,3)) was derived for the proposed method. This equations can be used to estimate the scour parameters (Ls,Ds) downstream coverage.
- To avoid the sharp increase in the heading up (hu), it is recommended to Keep the maximum allowable ratio of relative area As/Ao less than 5 %. Therefore, it is recommended to remove the upstream blockages before passing the maximum water requirements.
- Due to the developed heading up in using coverage the watercourses, it is recommended not to wide use to coverages except in cases of urgent necessity.
- The presence of coverages and shortage of maintenance, both affect the water parameters upstream and downstream coverages.

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