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) L/it/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 (h0), it is recommended to keep the maximum allowable inlet area of coverage per wetted area of canal upstream coverage (ratio of relative area) A/Au 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 its performance as following:

(El-Zaheer, 2006), studied the main factors effect 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.

\[ \frac{d_s}{R_c}, \frac{w_s}{R_c}, \frac{L_s}{R_c}, \frac{V_s}{R_c^3}, C_s, C_h, (\frac{\alpha}{\sigma^3}), (\frac{Q}{\sqrt{g}R_c}), 2.5, (\frac{t}{3.16})^\theta \]

In which, ds is the scour depth, ws is the scour width, Ls is the scour length, Vs 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, \( \sigma = \sqrt{D_84/D_16} \), 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 Elnikely, 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
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.

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

Fig. 1. Experimental flume
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 basis of dimensionless analysis, the relationships between the hydraulic parameters and the scour parameters are developed.

Table 2. Experimental data.

<table>
<thead>
<tr>
<th>Q(m/s)</th>
<th>A1( m²)</th>
<th>A2( m²)</th>
<th>B %</th>
<th>L( m)</th>
<th>D1( m)</th>
<th>D2( m)</th>
<th>L1( m)</th>
<th>A1( m²)</th>
<th>A2( m²)</th>
<th>B %</th>
<th>L( m)</th>
<th>D1( m)</th>
<th>D2( m)</th>
<th>L1( m)</th>
<th>A1( m³)</th>
<th>A2( m³)</th>
<th>B %</th>
<th>L( m)</th>
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<th>L1( m)</th>
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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.

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.

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

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

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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%).

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

**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:

\[
 f (Y_u, Y_d, V_u, V_d, Q, L_s, D_s, V_s, A_c, A_b, h_{loss}, G, \rho, g, \mu, \gamma_s, D_{50}) = 0
\]
The variables used in dimensional analysis are defined and classified into three groups as follows.

a. Flow characteristics. (Dimensions)
   - \( Y_u \): Upstream water depth. (L)
   - \( Y_d \): Downstream water depth. (L)
   - \( h_u \): The difference between the water depth of upstream (Dimensionless) coverage and smooth case.
   - \( V_u \): The velocity of flow under the gate \((L^2/T)\)
   - \( V_d \): The velocity of flow downstream the hydraulic structure \((L^2/T)\)
   - \( Q \): Total discharge. \((L^2/T)\)
   - \( L_c \): length of coverage (L)
   - \( A_c \): coverage area \((L^2)\)
   - \( A_o \): wetted area of canal upstream coverage \((L^2)\)
   - \( A_s \): the inlet area of coverage \((L^2)\)
   - \( G \): tail gate opening. \((L)\)
   - \( V_d \): downstream water depth. \((L)\)
   - \( V_u \): under the gate \((L/T)\)
   - \( D_{50} \): mean diameter of sediments.

b. Geometric characteristics. (Dimensions)
   - \( L_s \): scour length in case of coverage presence. \((L)\)
   - \( D_s \): scour depth in case of coverage presence. \((L)\)
   - \( D_o \): scour depth in case of no coverage presence. \((L)\)
   - \( V_s \): scour volume in case of coverage presence. \((L^3)\)
   - \( D_p \): diameter of pipe coverage \((L)\)

\[ D_{s} / Y_d, D_o / Y_s, V_s / Y_d^3 = (V / F r_u , Q / Y_u^2 * V_u, A_s / A_o, A_s / Y_u, h_u / Y_s, G / Y_u, D_p / L_c) \]

### 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).

By using Buckingham’s \( \pi \) -theorem the function can be written as the following.

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.

<table>
<thead>
<tr>
<th></th>
<th>As/Ao</th>
<th>Ln(As/Ao)</th>
<th>f/As/Ao</th>
<th>L/Dp</th>
<th>f/lnB%</th>
<th>hhu/Yd</th>
<th>Fru</th>
<th>Frd</th>
<th>ln(Q/yu^*vu)</th>
<th>ln(Q/yd^*Yd)</th>
<th>hhu/Yd</th>
<th>Ds</th>
<th>Lc</th>
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<td>-0.82</td>
<td>-0.91</td>
<td>-0.9</td>
<td>0.89</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>hhu/Yd</td>
<td>0.93</td>
<td>0.97</td>
<td>-0.92</td>
<td>-0.86</td>
<td>-0.08</td>
<td>-0.89</td>
<td>-0.66</td>
<td>-0.47</td>
<td>0.88</td>
<td>0.7</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ds</td>
<td>-0.73</td>
<td>-0.82</td>
<td>0.84</td>
<td>0.39</td>
<td>0.26</td>
<td>0.94</td>
<td>0.93</td>
<td>0.82</td>
<td>-0.97</td>
<td>-0.9</td>
<td>0.94</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>As/Ao</td>
<td>-0.77</td>
<td>-0.87</td>
<td>0.91</td>
<td>0.49</td>
<td>0.22</td>
<td>0.98</td>
<td>0.92</td>
<td>0.77</td>
<td>-0.99</td>
<td>-0.87</td>
<td>0.98</td>
<td>0.98</td>
<td>1</td>
</tr>
</tbody>
</table>

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.
**Relation between the coverage characteristics and Ls.**

\[
L_s = \left( -0.6 \ln \frac{A_s}{A_o} + \frac{0.5}{(A_s/A_o)} - 0.18 \frac{L}{D_p} - 0.05 \left( \frac{1}{\ln B\%} \right) + 3.3 \right) \text{ (m)}
\]

R² = 0.98  

**Relati...**

**Relation between the coverage characteristics and Ds**

\[
D_s = \left( -0.11 \ln \frac{A_s}{A_o} - \frac{0.01}{(A_s/A_o)} - 0.031 \frac{L}{D_p} - 0.01 \left( \frac{1}{\ln B\%} \right) + 0.6 \right)
\]

R² = 0.95  

**Relation between the coverage characteristics and h_{w/yd}**

\[
h_{w/yd} = \left( -57.7 \ln \frac{A_s}{A_o} + \frac{108.3}{(A_s/A_o)} - 16.05 \frac{L}{D_p} - 6.6 \left( \frac{1}{\ln B\%} \right) + 253.4 \right)
\]

R² = 0.97  

**Additional equations help to design.**

**Relation between the coverage characteristics and Q/ \left( \nu_w \cdot y_u^2 \right)**

**Governing equation**

\[
\ln \left( \frac{Q}{V \cdot \nu \cdot y_u^2} \right) = \left( 2.3 \ln \frac{A_s}{A_o} - \frac{0.4}{(A_s/A_o)} + 0.5 \frac{L}{D_p} + 0.2 \left( \frac{1}{\ln B\%} \right) - 3.9 \right)
\]

R² = 0.970  

**Relation between the coverage characteristics and Q/ \left( \nu_d \cdot y_d^2 \right)**

\[
\ln \left( \frac{Q}{V \cdot \nu \cdot y_d^2} \right) = \left( 0.5 \ln \frac{A_s}{A_o} + \frac{0.5}{(A_s/A_o)} + 0.1 \frac{L}{D_p} + 0.031 \left( \frac{1}{\ln B\%} \right) + 3.8 \right)
\]

R² = 0.824  

**Relation between the coverage characteristics and Fr_u**

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

R² = 0.89  

**Relation between the coverage characteristics and Fr_d**

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

R² = 0.81

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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REFERENCES