Available online at www.ejournals.uofk.edu
UofKEJ Vol. 5 Issue 1 pp. 1-9 (February 2015)

UNIVERSITY OF KHARTOUM ENGINEERING JOURNAL (UOFKEJ)

Local Scour of Highway Cross Drainage Structures

M. Akode Osman, Zeinab Mohamed Adam

Department of Civil Engineering, Faculty of Engineering, Khartoum University,
P. O. Box 321 Khartoum, Sudan (*E-mail:* mohdakode@yahoo.com)

Abstract: In this paper methods for determination of maximum local scour depth and eroded material volume downstream of highway drainage structures were developed. Severe local scour leads to undermining followed by collapsing of the drainage structure. The analysis method is based on integrating a new technique of improved drainage structure outlet geometry, jet hydraulic characteristics and soil properties. The jet velocity, induced shear stress, critical shear resistance to erosion and particle size are the main factors that control the erosion process downstream of a drainage structure. The study is of experimental and theoretical nature. The developed mathematical model was calibrated using collected field data in addition to laboratory tests. The produced scour holes were plotted for each laboratory run and the scour hole depth, width and length were measured. A semi- empirical relation has been developed for predicting the depth of local scour hole. It is based on Densimetric Froude number. It is found that the semicircular apron gives less scour depth and width when compared to the linear front apron. The comparison of the model outputs and field study is found of a good agreement. The model is recommended for engineering design of highway drainage structures located on streams of sandy bed.

Keywords: *Drainage structure; Local scour; Critical shear stress; Densimetric Froude number; Submerged jet velocity; Linear front apron; Semi-circle front apron*.

1. INTRODUCTION

A culvert is a structure constructed under a roadway to convey surface water underneath a highway, a railroad or any other embankment. Drainage structures are very important parts in road construction. These structures crossings affect the hydrological behavior and morphology of streams. They are usually constructed out of metal or concrete and have numerous cross-sectional shapes. The most commonly used shapes are box and circular type.

Drainage structures at Sudan road network suffers from many problems and scour is one of them. Local scour is the most dangerous type of scour as it occurs immediately in the vicinity of the highway drainage structures. Severe local scour leads to undermining and road collapsing. Local scour can affect the stability of structures and lead to failures if measures are not taken to combat its effects. There is also considerable cost like loss of properties, users delay cost and detours. Loss of lives is a major problem caused by failure of structures as well.

The objective of this study is to determine the characteristics of local scour hole that occurs downstream highway drainage structures (pipe culvert). This involves determination of the maximum local scour depth and eroded material volume.

Most previous studies consider scour downstream of circular culverts where the flow is three dimensional. Abida and Townsend [1] investigated local scour downstream box culvert. Ruff, Abt et al. [2] and Bohan [3] used square, arch and rectangular culvert in their experiments. Abt et al. [4] concluded that culvert shape has a significant influence on scour-hole geometry.Abt, Ruff et al. [5] noted that a sloped culvert canincrease the maximum dimensions of scour hole considerably comparing with a horizontal culvert. Doehring and Abt [6] study's showed that culvert drop height has a significant influence on the scour hole geometry. Ruff, Abt et al. [2] stated that the installation of a perpendicular headwall at culvert outlet moves only the scour hole downward and has no effect on the rate and magnitude of the scour. The scour hole geometry remains the same as for the case without the headwall.

Many investigators identified tailwater depth as an important parameter in determination of scour hole.Smith [7] and Dey and Sarkar [8], among others, defined a critical tailwater depth after which the amount of scour decreases. Aderibigbe and Rajaratnam [9] and Dey and Sarkar [8] observed that the sediment nonuniformity has a significant effect on reducing the size of the scour hole produced by the jet. Abida and Townsend [1] found that local scour was more severe for uniform sands than for well graded mixtures.

According to Abida [10], for the same hydraulic conditions the scour depth was much smaller when the downstream channel was narrow. This was because, for the narrow channels, energy eddy is destroyed through frictional resistance with the channels banks leading to an increase in energy transfer to small turbulence which then is transformed into heat.Lim [11] observed that the lateral development of scour hole was affected by the downstream channel width when it became narrow and restricted for normal diffusion of three dimensional jet flow.

Experiments conducted by Ruff, Abt et al. [2] indicated that approximately 70% of the maximum depth, width and length of scour have been attained in the initial 31 minutes. Dey and Sarkar [8] found that the time variation of scour depth has been scaled by an exponential law, which increases linearly with densimetric Froude number. Rajaratnam and Mazurek [12] observed that the maximum depth of erosion increases linearly with the logarithm of time for a large part of the erosion process but departed from this trend as the scour hole neared the asymptotic state and this was typically seen for submerged jets.

1.1 Prediction of Local Scour

The maximum local scour depth at culvert outlets is usually estimated by combining the physical models results and theoretical approaches. The resulting equations differ significantly in their form and in the magnitude of their predictions as they have been developed and controlled by specific conditions. Commonly used equations and models are based on experimental data studies. Accordingly, the see quations do not count accurately some of the variables that are encountered in fields.

Ruff, Abt et al. [2] mentioned that Jacks [13] performed an analysis studying local scour at culvert outlets. Utilizing the work of Bohan [3], Jacks [13] developed an equation to estimate the depth of scour hole as a function of the depth of flow at pipe outlet (d_o) and Froude number (Fr). According to Jacks [13], the depth of the scour hole can be given by:

$$y_s = 0.75\, d_o\left(\sqrt{40.51 - (\mathrm{Fr} - 5.66^2)} - 2.93\right) \tag{1}$$

This equation is applicable when the tailwater exceeds one half of the culvert diameter.

Valentin's [14] developed a relationship which estimates the scour depth produced by wall jets emerging from sluice gates and discharging over sand beds. Valentin's [14] expressed the depth of scour (d_s) as a function of flow depth (y), Froude number (Fr) and particle size (d_{90}). The depth of scour (d_s) can be written in the following functional form:

$$\frac{d_s}{y} = \left(exp\frac{Fr-2}{2.03}\right)\left(\frac{d_{90}}{y}\right)^{-0.55} \tag{2}$$

Abida and Townsend [1] produced a modified version of Valentin [14] equation to estimate the maximum scour depth downstream box culverts for sand bed. The investigators observed that this equation was valid only for those cases in which the culvert runs full or partly full and in which the tailwater depth is equal to the culvert flow depth. The maximum scour depth is expressed by

$$\frac{d_s}{H} = \left(exp\frac{Fr-2}{2.03} - 0.373\right)\left(\frac{d_m}{H}\right)^{-0.275} \tag{3}$$

where, d_s is depth of scour measured from the original bed elevation (m), Fr is flow Froude number, d_m is effective grain size (mm), and H is culvert height.

Corry, Thompson et al. [15] presents a method for predicting local scour at the culvert outlet based on discharge (Q), culvert shape, soil type, duration of flow and tailwater depth. Empirical equations defining the relations between culvert discharge intensity, time and depth, length, width and volume of the scour hole are presented for the maximum or extreme scour case. The general expressions determining scour geometry in a cohesionless (Equation 4) and Cohesive (Equation5) soil for circular pipe flows full are:

$$\left[\frac{h_s}{D}, \frac{W_s}{D}, \frac{L_s}{D}, \frac{V_s}{D^3}\right] = \propto \left(\frac{Q}{\sqrt{g}D^{2.5}}\right)^{\beta}\left(\frac{t}{t_0}\right)^{\theta} \tag{4}$$

$$\left[\frac{h_s}{D}, \frac{W_s}{D}, \frac{L_s}{D}, \frac{V_s}{D^3}\right] = (\propto)\left(\frac{\rho V^2}{\tau_C}\right)^{\beta}\left(\frac{t}{t_0}\right)^{\theta} \tag{5}$$

Using the outcomes ofAbt, Ruff et al. [5] and Doehring and Abt [6] studies, Thompson, Kilgore et al. (2006)[16] presented a modified method of (4) and (5) by adding slope correction coefficient C_s, and drop height influence adjustment coefficients, C_h. where;

$$\left[\frac{h_s}{R_c}, \frac{W_s}{R_c}, \frac{L_s}{R_c}, \frac{V_s}{R_c}\right] = C_s C_h\left(\frac{\propto}{\sigma^{1/3}}\right)\left(\frac{Q}{\sqrt{g}R_c^{2.5}}\right)^{\beta}\left(\frac{t}{316}\right)^{\theta} \tag{6}$$

$$\left[\frac{h_s}{D}, \frac{W_s}{D}, \frac{L_s}{D}, \frac{V_s}{D^3}\right] = C_s C_h(\propto)\left(\frac{\rho V^2}{\tau_C}\right)^{\beta}\left(\frac{t}{t_0}\right)^{\theta} \tag{7}$$

Abt, Kloberdanz et al. [17] carried out experiments to estimate the dimensions of scour in a variety of noncohesive materials at culvert outlets. The tailwater was established and maintained at 0.45D. Power equations were formulated for the prediction of the scour depth as follows:

$$\frac{d_{sm}}{D} = \frac{3.65}{\sigma^{0.4}}\left[\left(\frac{Q}{g^{0.5}D^{2.5}}\right)\left(\frac{d_{50}}{D}\right)^{0.2}\right]^{-0.57} \tag{8}$$

(Azamathulla and Haque [18] put Equation (8) in the form of Densimetric Froude number as follows:

$$\frac{d_{se}}{d_0} = -3.67(Fr_0^{0.57} d_{50}^{0.4} \sigma^{0.4}) \tag{9}$$

Chiew and Lim [19] studied local scour caused by deeply submerged circular jet in the laboratory. The investigators used wall and offset jets with uniform cohesionless sediments bed. Densimetric Froude number, Fr_o , was determined as the main characteristic. From model tests on different jets relationships have been derived between densimetric Froude number and scour hole depth as follows:

$$\frac{d_{sem}}{D} = 0.21 Fr_0 \tag{10}$$

where
d_{sem} is equilibrium scour depth (m),
D is the pipe diameter for circular outlets (m),
Fr_o is the densimetric Froude number.

Liriano [20] studied the influence of near-bed turbulent bursting structures on scour downstream of pipe culvert outlets Liriano and Day [21]and deduced the following relations

$$\frac{d_{se}}{D} = a \ln Fr_0 + b \quad (11)$$
$$a = 0.877(H/D)^{-0.37}$$
$$, b = 2\ln(H/D) - 0.24$$

where
d_{se} is the maximum depth of scour (m)
D is the pipe diameter for circular outlets and the outlet height for non-circular outlets(m)
H is the depth of water in the downstream receiving channel (tailwater depth) (m)
Equations (10) and (11) are used for verification in this study.

1.3 Reduction of Scour

Reduction of local scour hole depth downstream drainage structures is an important subject for dealing with the problems associated with scour. Since complete protection against scour may prove to be highly expensive. So reducing the depth of local scour not to expose or undermine the foundations shall be significant in improving the stability of the drainage structure.

Scour reduction measures aim to improve flow conditions at a structure to reduce the magnitude and effects of scour May, Ackers et al. [22]. Based on the theory of submerged jet diffusion and the shape of scour hole observed in the field study, an improvement of culvert outlet was adopted. A new technique of semicircular front apron was built in the lab to improve flow conditions. The semi circular front apron is a tool to redistribute the flow concentration over a longer perimeter. So scour holes produced by this kind of apron are shallower, narrower, longer and smaller than those produced by the linear front ones. A significant difference can be noted between longitudinal sections shape attained downstream the linear front and semi-circular aprons. Fig. 1 shows the comparison for longitudinal profiles attained by both linear front apron and semi circular.

2 MATERIALS AND METHODS

2.1 Site Description

Within the scope of research activities with respect to local scour occurs downstream drainage structures, intensive field investigations were carried out. For this purpose, one hundred kilometers of ElGaily - Shendi road was chosen for field study as severe local scour were observed at the downstream of several cross drainage structures in this part of the road as shown in Fig. 2, 3, 4 and 5. Field study data were used to verify and calibrate the relations obtained from the theatrical analysis and experimental study.

The road lies in the eastern terraces of the River Nile which consists of scattered rocky hills, wadis and plains forming moderate to steep terrain. In this area, the average annual rain intensity is about 200mm and most of the investigated drainage structures were designed to be aligned with the flow. But due to the steep undulated terrain, water reaches the road with relatively high velocities at these crossing structures.

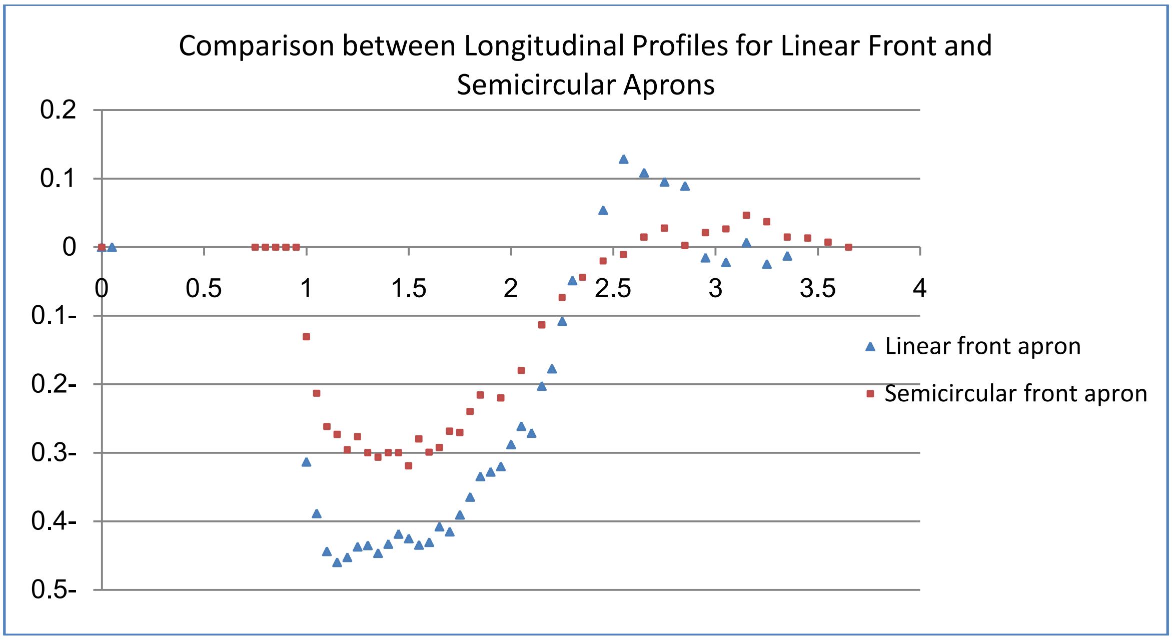

Fig. 1. Comparison between Longitudinal Profiles for Linear Front and Semicircular Aprons

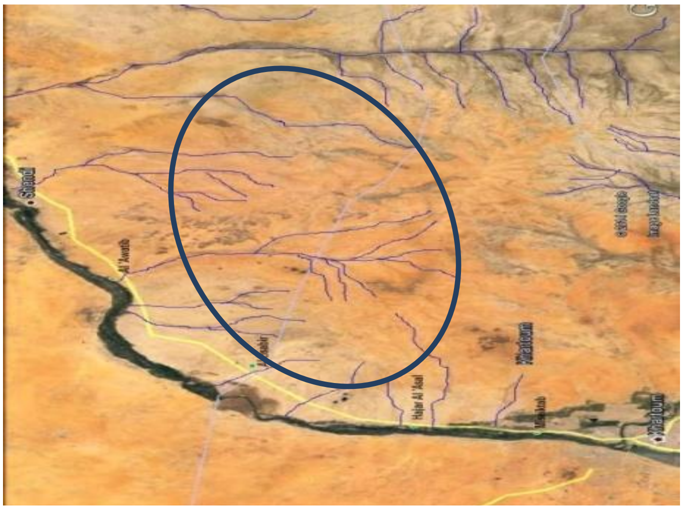

Fig. 2. Site location

Fig. 3 Scour Hole in Plan View

Fig. 4 Length of Scour Hole

Fig. 5. Post Protection by Boulders after Occurance of Local Scour

2.2 Test Facilities and Experimental Procedure

Extensive experiments were carried out at hydraulic laboratory of University of Khartoum. The entire set comprised the results of 30 tests runs. All the reported tests were performed to asymptotic conditions that can be defined as a state beyond which no significant changes occur in the scour geometry.

A series of experiments were conducted in a recirculating flume 24m long, 1.2m wide and 0.95 m deep. A PVC pipe with 0.15m internal diameter and 2.0m length was used to model the culvert. Two types of aprons were used in the study: the linear and semicircular front aprons. They were tied at the downstream end of the pipe culvert. The models were tested for two sizes of cohesionless soils obtained from the field. Fig (6.a) shows model arrangement at the laboratory.

The bed was leveled to the invert elevation at the culvert outlet. Tailwater elevation was controlled by a downstream wall to insure the submergence of the issued jet at the culvert outlet. Discharge measurements were taken over a three hours period to insure that equilibrium state is reached. Tests were carried out for flow discharges ranged from (0.005 m3/s) to (0.0221m3/s).The produced scour holes were plotted for each run and the scour hole depth, width and length were measured. Fig (6.b) shows the acting jet and resulted scour holes.

2.3 Analysis and Development of Relations

The maximum scour depth (y_s) was correlated to the Particle Densimetric Froude number, and Froude number. Three semi-empirical relations were developed for predicting the depth of local scour hole. The scour hole depth was expressed as dimensionless parameters of y_s/H and ys/D. From regression analysis of the collected data the maximum scour depth can be expressed as follows:

$$\frac{Y_s}{H} = 0.3\ln Fr_0 + 0.18 \quad (12)$$

$$\frac{Y_s}{D} = 0.58\ln Fr_0 + 0.34 \quad (13)$$

$$\frac{y_s}{D} = 9.6(Fr) - 0.34 \quad (14)$$

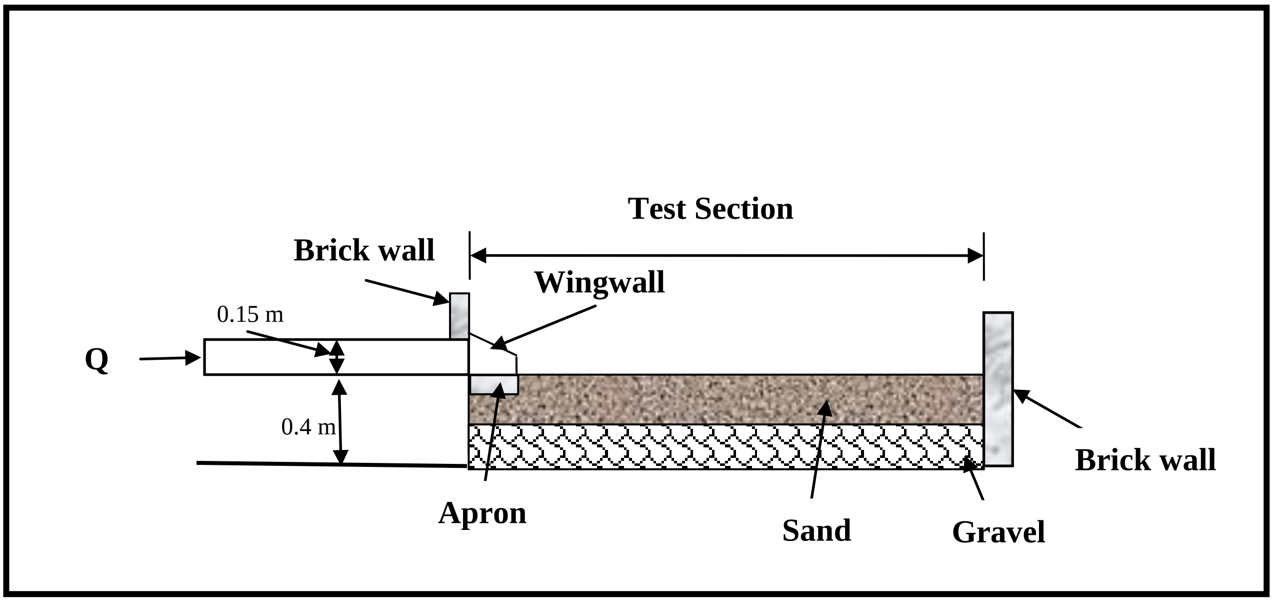

Fig. 6.a Model arrangement at the lab

Fig. 6.b Acting jet and the scour holes

where
Y_s is maximum depth of scour hole, m,
H is upstream headwater measured from the culvert centre line, m,
Fr_0 is particle Densimetric Froude number,
D is the jet diameter, m.
Fr is flow Froude number.

2.4 Verification of Semi-emprical equations

The comparison between experimental and field data is difficult due to the complexity of flow in the natural channel. Due to absence of gauging stations, the magnitude of the discharges that cause the scour hole in the field were estimated from resistance relation such as Manning's equation. The time required to reach equilibrium scour depth in the field is not the same as that required in the laboratory since the rate of scour is not similar.

In this paper, Equations correlated to Densimetric Froude number were only verified as to provide better prediction for bed materials comparing with the equation based flow Froude number. For the field study, Densimetric Froude number range was 2.17 ~ 8.0 while in the experimental study it was 0.5~ 2.17. Statistical tests, as shown in table1, were applied to validate any differences between observed data and results obtained by the developed equations. Statistical tests applied in this paper are Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Nash-Sutcliffe coefficient. Nash-Sutcliffe coefficient which is an indicator used to quantitatively describe the accuracy of model outputs. Definitions of the flow parameters measurements' in field study are shown in Fig. 7.

To evaluate the performance of equation (1), data measured at the field were plotted against results obtained from equation (1) as shown in Fig.9. A line of perfect agreement was plotted in order to check the accuracy of the developed equation and compare the data. After discarding locations with D50>1mm, equation (1) fits the observed data in the field with an accepted correlation coefficient of a value for 0.66. Nash-Sutcliffe coefficient is 0.39 which indicates that the equation predictions are moderately accepted. Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) of values of 0.19 and 0.15 are reasonable considering the uncertainty of some computed parameters in field conditions.

Table 1 Summary of the Statistical Tests

Scour Equation	Mean Absolute Error, MAE		Root Mean Square Error, RMSE		Standard dev		Pearson Correlation Coefficient		Nash-Sutcliffe coefficient (E)	
	Lab. Data	Field Data	Lab. Data	Field Data	Lab. Data	Field Data	Lab. Data	Field Data	Lab. Data	Field Data
Model 1*	-	0.15	-	0.19	-	0.23	-	0.66	-	0.39
Model 2*	-	0.39	-	0.44	-	0.46	-	0.48	-	0.12
Chiew& Lim1996	0.15	0.50	0.19	0.69	0.25	0.59	0.86	0.17	0.51	-0.64
Chiew& Lim1996*	-	0.38	-	0.45	-	0.45	-	0.46	-	-0.14
Liriano 1999	0.18	0.67	0.23	0.56	0.24	0.51	0.9	0.32	0.07	0.32
Liriano 1999*		0.38		0.45		0.48		0.60		-0.12

* Results of statistical tests using field data of streams having D_{50}<1mm

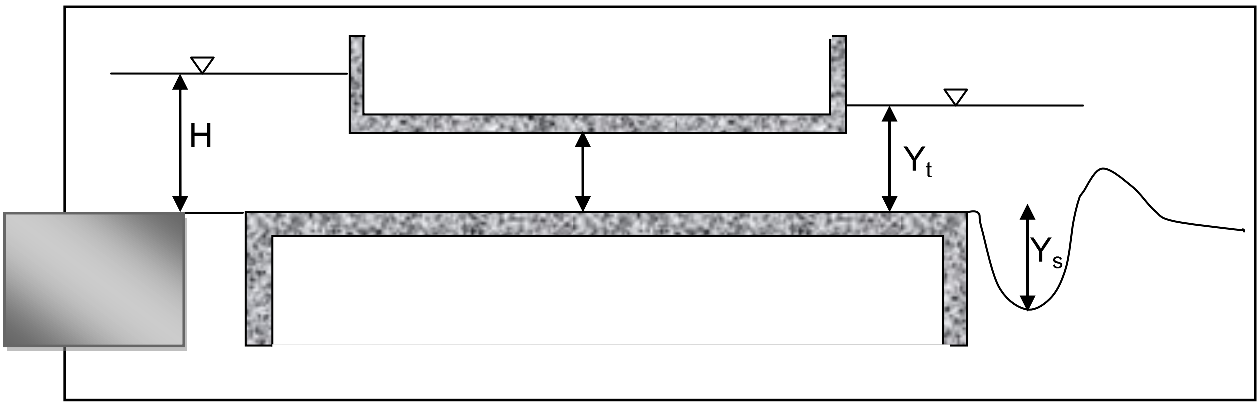

Fig. 7. Definition sketch for measurements of flow parameters in field study

Mainly field data scattered around a line of perfect agreement and there are some remote data. The data filtering results shows that the equation outcome's is more accurate for fine material. So, it is concluded that equation (1) appears reasonable and practical to give a good prediction of scour depth values for sand materials that have D_{50}<1mm.

To check the accuracy of equation (2) developed in this research study, results obtained from this equation were compared with data measured in the fieldas shown in Fig (9).Visual comparison shows that equation (2) overestimates most of the data measured during the field study as they are under the perfect agreement line. Moreover, the statistical tests show that the equation fits the field data with a poorly Pearson correlation coefficient of a value of 0.14, Nash-Sutcliffe coefficient was -0.1,the minimum RMSE of a value of 0.58 and (MAE) of value 0.56.

So equation (2) does not provide accurate prediction of scour depth values and this reflects in the poor correlation and large values of RMSE and MAE.

Existing equation developed by Chiew and Lim [19] was used to evaluate the data measured in this experimental study. It was noted that values measured in the present experimental study were larger compared with that results obtained from Chiew and Lim [19] relationshipas shown in Fig (10). This is due to the conditions in which these equations were developed. As Chiew and Lim [19] study was controlled by specific ranges of (d_{50}/D) and Densimetric Froude number. So the shift observed in trends of the present study and Chiew and Lim (1996) [19] is acceptable and consists with what has been expected.

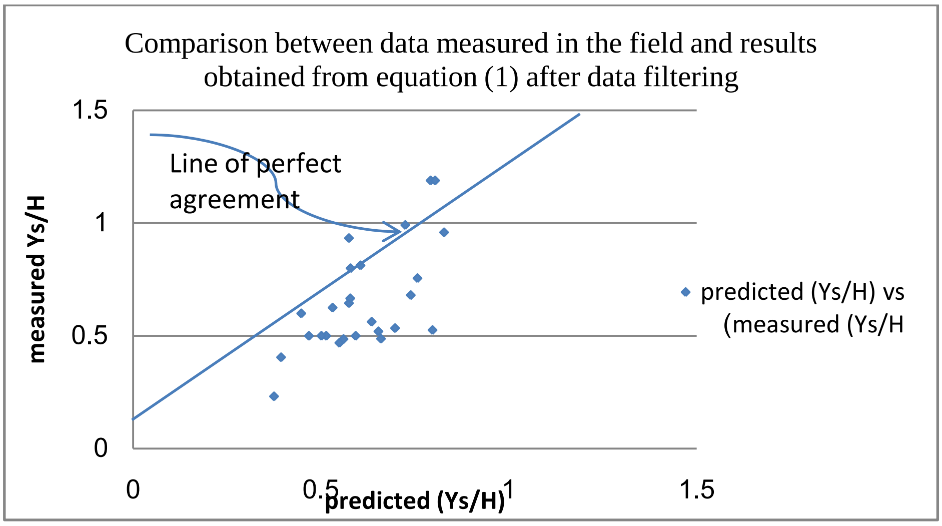

Fig. 8 Comparison between data measured in field with D50<1mm and results obtained from Equation (1)

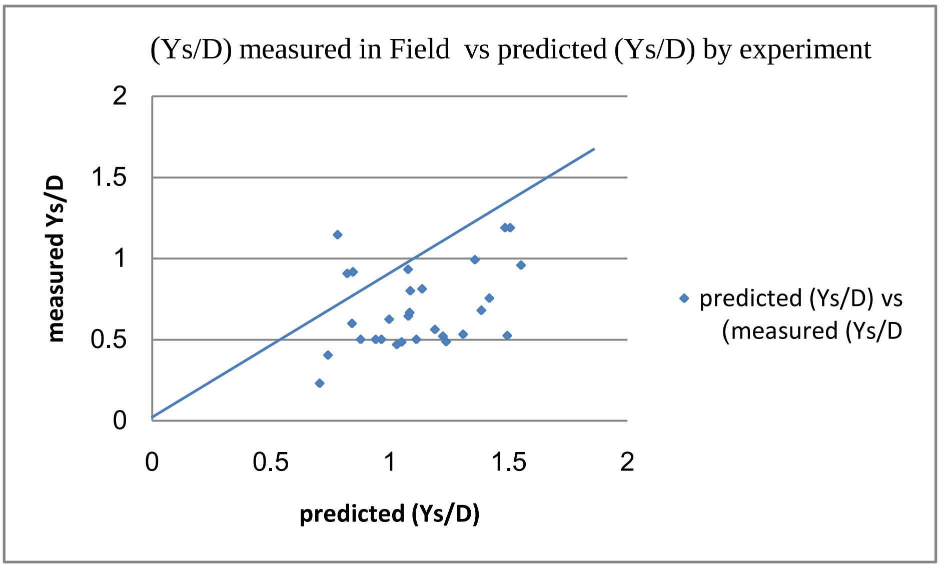

Fig. 9 Comparison between data measured in Field and results obtained from Equation (2)

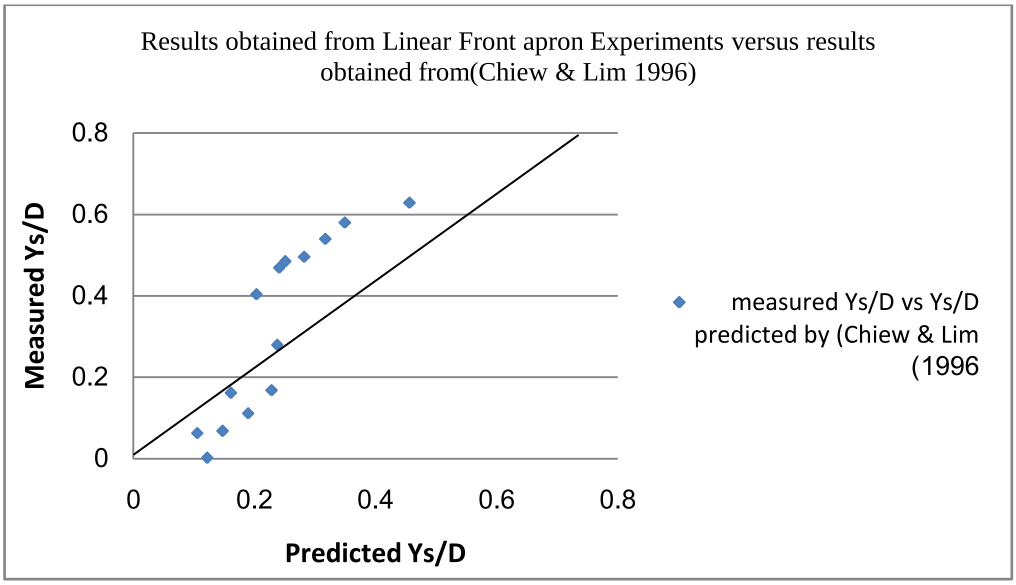

Fig. 10. Comparison of Measured Ys/D Obtained from Experiments and Ys/D obtained from (Chiew and Lim 1996) Formula

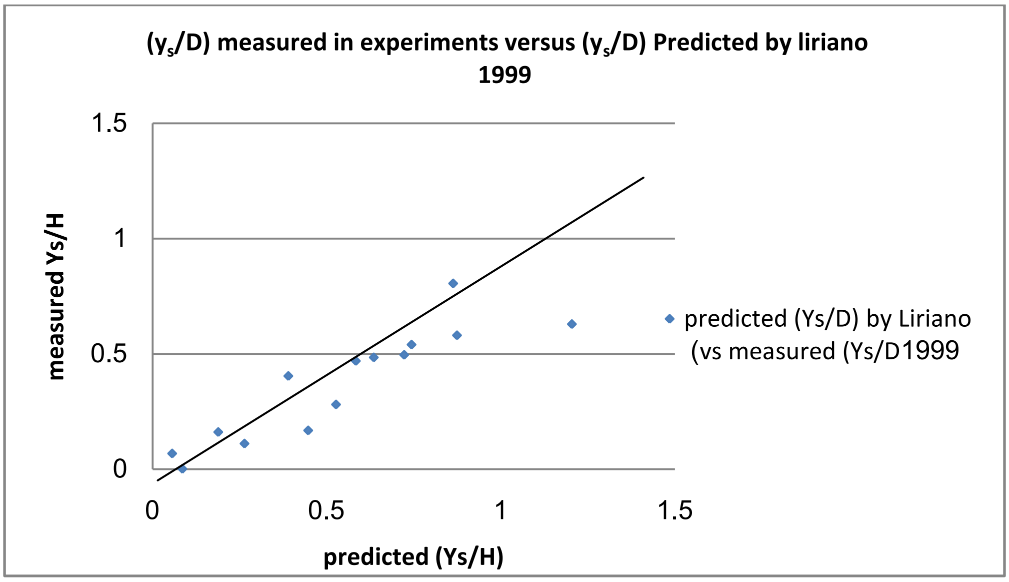

Fig. 11. Comparison of Y_s/D Measured in Experiments and Y_s/D obtained from (Liriano 1999) Formula

Equation developed by Liriano [20] was used to evaluate the data measured in this experimental study. Generally, it was observed that some of the values of Y_s/D measured in the present experimental study were smaller compared with the results obtained from Liriano [20] relationshipas shown in Fig (11). This might be due to the different in the range of outlet flow depth and Densimetric Froude number values.

4. CONCLUSIONS

In this paper, methods for estimating the maximum local scour depth and eroded material volume downstream of highway drainage structures (pipe culvert) were developed. The analysis method is based on integrating a new technique of improved drainage structure outlet geometry, jet hydraulic characteristics and soil properties.

The developed mathematical model was calibrated using collected field data in addition to laboratory tests. The produced scour holes were plotted for each laboratory run and the scour hole depth, width and length were measured. A semi- empirical relation has been developed for predicting the depth of local scour hole. It is based on Densimetric Froude number. It was noted that the equilibrium scour depth increases with the increase of Densimetric Froude number in a logarithmic manner.

For the outlet geometry, it is found that the semicircular apron gives less scour depth and scour hole width when compared to the linear front apron. Further studies are still necessary to appropriately predict the scour depth and adopt new techniques to prevent or reduce the scour in a cost effective manner in order to save the structure from the danger of failure due to local scour.
Densimetric Froude number is the major significant parameter.

A semi circular front apron is a tool to redistribute the flow concentration over a longer perimeter. So scour holes produced by this kind of apron are shallower, narrower, longer and smaller than those produced by the linear front ones.

REFERENCES

[1] Abida, H. and R. Townsend (1991). Local scour downstream of box-culvert outlets. Journal of irrigation and drainage Engineering 117: 425-440

[2] Ruff, J., S. Abt, et al. (1982). Scour at culvert outlets in mixed bed materials.

[3] Bohan, J. P. (1970). Erosion and riprap requirements at culvert and storm-drain outlets, Hyd. Laboratory Investigation, Report H-70-2, U.S. Army Waterways Experiment Station, Vicksburg, Miss.

[4] Abt, S. R., J. Ruff, et al. (1987). "Influence of culvert shape on outlet scour." Journal of Hydraulic Engineering 113: 393-400.

[5] Abt, S. R., J. F. Ruff, et al. (1985). "Culvert slope effects on outlet scour." Journal of Hydraulic Engineering 111: 1363-1367.

[6] Doehring, F. K. and S. R. Abt (1994). Drop height influence on outlet scour. Journal of Hydraulic Engineering 120: 1470-1476.

[7] Smith, G. L. (1957). Scour and Energy Dissipation below Culvert Outlet, Colorado Agricultural and Mechanical College Fort Collins, Colorado.

[8] Dey, S. and A. Sarkar (2006). "Scour downstream of an apron due to submerged horizontal jets." Journal of Hydraulic Engineering 132: 246-257.

[9] Aderibigbe, O. and N. Rajaratnam (1998). Effect of sediment gradation on erosion by plane turbulent wall jets. Journal of Hydraulic Engineering 124: 1034-1042.

[10] Abida, H. (1989). A laboratory investigation of local scour downstream of box culvert outlets and an alternative measure for its control, MSc, Thesis.University of Ottawa

[11] LIM, S. Y. (1995). "Scour below unsubmerged full-flowing culvert outlets." Proceedings of the ICE-Water Maritime and Energy 112: 136-149.

[12] Rajaratnam, N. and K. Mazurek (2003). Erosion of sand by circular impinging water jets with small tailwater. Journal of Hydraulic Engineering 129: 225-229.

[13] Jacks, W. (1976). "Scour at Culvert Outlets." Presentation at Dallas-Fort Worth Workshop on Hydraulics,

[14] Valentin, F. (1967). Considerations concerning scour in the case of flow under gates.

[15] Corry, M., P. Thompson, et al. (1983). Hydraulic design of energy dissipators for culverts and channels (HEC-14), Publication FHWA-EPD-86-110. FHWA, US Department of Transportation.

[16] Thompson, P., R. Kilgore, et al. (2006). Hydraulic design of energy dissipators for culverts and channels (HEC-14). U. D. o. T. Publication FHWA-NHI-06-086. FHWA.

[17] Abt, S. R., R. L. Kloberdanz, et al. (1984). Unified culvert scour determination. Journal of Hydraulic Engineering 110: 1475-1479.

[18] Azamathulla, H. and A. Haque (2012). Prediction of scour depth at culvert outlets using gene-expression programming. International Journal of Innovative Computing Information and Control 8(7 B): 5045-5054.

[19] Chiew, Y.-M. and S.-Y. Lim (1996). Local scour by a deeply submerged horizontal circular jet." Journal of Hydraulic Engineering 122(9): 529-532.

[20] Liriano, S. (1999). The influence of near bed turbulent bursting structures on scour downstream pipe culverts. Hatfield, U.K, PhD, Thesis, University of Hartfordshire.

[21] Liriano, S. and R. Day (2001). Prediction of scour depth at culvert outlets using neural networks." Journal of hydroinformatics 3: 231-238.

[22] May, R., J. Ackers, et al. (2002). Manual on scour at bridges and other hydraulic structures, Ciria.

NOTATION

The following symbols are used in this paper:

D	is the diameter of culvert
d_{50}	is is the particle size for which is 90% of the material is finer (mm)
d_{90}	is is the particle size for which is 90% of the material is finer (mm)
d_m	is effective grain size (mm)
d_o	is depth of flow at pipe outlet
d_s	is depth of scour measured from the original bed elevation
Fr	is flow Froude number below the sluice gate
g	is acceleration of gravity, (9.81 m/s^2)
H	is culvert height (m)
h_s,	depth of scour (m)
W_s	width of scour hole (m)
L_s	lengthof scour hole (m)
V_s	volume of scour hole (m)
Q	is discharge(m^3/s)
t	is time in minutes
t_0	is the base time in experiments in minutes
y	is flow depth below the sluice gate (m)