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Effect of Angled Submerged Vanes on Bed Morphology Downstream Sluice Gate

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Scour is a characteristic marvel caused because of the erosive activity of flowing stream on alluvial beds which expels the silt around or close structures situated in streaming water. In this paper, an experimental study was directed to foresee the impact of oriented vanes introduced on level stilling basin downstream a sluice gate on bed material planning to limit the local geometry of scour and silting. The considered shape in this exploration is easy to be utilized as an additional component to be implemented on the stilling basin of any current water structures. Two hundred and sixty runs were executed using 10 models of stilling basins considering different heights and angles of vanes under various flow conditions including the discharges and tail gate water depths. An instance of level floor without vanes was incorporated into the test program to foresee the impact of vanes establishment. The experimental outcomes were accounted for 2 distinctive bed materials. Results were analyzed and graphically introduced. Simple formulas were given to estimate the geometry of the local scour and silting.

Keywords: Vanes; morphology; stilling; basin; flume; angled; scour; silting.

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ABBREVIATIONS

B	=	Flume width	[m]
d_{50}	=	Mean particle diameter	[m]
d_s	=	Maximum scour depth	[m]
g	=	Gravitational acceleration	[m/s^2]
H_{up}	=	The upstream water head in front of the sluice gate	[m]
h_{si}	=	Maximum silting height	[m]
L_f	=	Floor length	[m]
L_s	=	Maximum scour length	[m]
L_{si}	=	Maximum silting length	[m]
Q	=	Water discharge through the flume	[m^3/s]
V	=	The mean velocity at the downstream cross section of flume	[m/s]
V_d	=	Vane distance from the sluice gate	[m]
V_h	=	Vane height	[m]
V_w	=	Vane width	[m]
y_g	=	Water depth under the sluice gate	[m]
y_t	=	Tail gate water depth	[m]
ρ	=	Water density of the flow	[kg/m^3]
ρ_s	=	Soil particle density	[kg/m^3]
μ	=	Dynamic viscosity of water	[kg/m.s]
R_e	=	Reynolds number	
F_r	=	Froude number	
S_o	=	Flume bed slope	
θ	=	Vane angle	

1. INTRODUCTION

Water releases at high flow velocity through hydraulic structures, for example, sluice gates or spillways, may cause instability issue of the riverbed downstream of the structure. Nearby scour at the region of hydraulic structures was considered as an essential phenomenon which may jeopardize the dependability of such structures. In the event that the depth of scour hole is sufficiently huge, the stability of upstream stilling basins might be in danger. For a typical scouring process, the three detectable phases of scouring are: (I) an underlying stage with fast rate of scouring; (ii) an advancement or disintegration arrange which has a moderately slower rate of scouring; (iii) a harmony organize where there are no recognizable changes in the scour depth after a long scouring time [1].

Local scour downstream, a stilling basin, was examined by numerous scientists [2-13]. Diverse procedures were created to diminish the bed morphological changes downstream of the hydraulic structure [14-22].

Both numerical and experimental models were utilized for scour expectation downstream gates related with stilling basin. Yasser [23] exhibited Gene articulation program (GEP) and artificial neural network (ANNs), to mimic nearby scour depth downstream hydraulic structures. The examination demonstrated that the stilling basin gave current redirector put at various relative positions demonstrated a decent execution in controlling the local scour depth. Mohammad et al. [24] numerically foresee the nearby scour depth downstream of sluice gates with a cover utilizing distinctive methodologies. The examination demonstrated that Model Tree (MT) approach yielded the most exact forecasts in correlation with the other proposed models and conventional equations.

Underscoring the experimental studies; Abdelazim and Yasser [25] exhibited an examination planned to explore the impact of stilling basin shape on the nearby scour downstream controller. The investigation suggested ideal shape and measurements of stilling basin to diminish the geometry of scour opening under certain flow conditions. Javad and Hossein [26] experimentally examined the local scour downstream of adverse stilling basins, the outcomes demonstrated that the scour profiles at any bed incline pursue shape similitude. Additionally, likewise the greatest depth of scour hole was diminished as the length and slope of stilling basin expanded, though the longitudinal dimensions of the hole were expanded.

Elnikhely [27] experimentally investigated the impact of utilizing cylinder blocks settled on the back incline of the spillway on the scour hole measurements downstream of spillway under various flow conditions. The examination detailed the ideal measurements for the cylindrical blocks to decrease the estimations of scour parameters. Additionally, for practical reasons it was prescribed that to utilize blocks made of precast concrete as an additional component over existing spillway structures for limiting of the scour. Mohamed et al. [28] experimentally investigated the impact of the height of corrugation components on the scour geometry downstream of submerged hydraulic jumps. The outcomes showed that as the scour holes increments as the submergence ratio expands, the corrugated beds diminish the scour hole by rate from 27% to half in contrasting and the scour hole of smooth bed.

The present examination meant to explore the impact of submerged vanes with various angles and heights installed on stilling basin on the geometry of local scour and silting downstream a sluice gate. In addition, 3 distinct discharges, 9 diverse tail gate water depths, and 2 types of bed materials were utilized for this reason. The results were contrasted with a stilling basin without any vanes to characterize the execution of vanes establishment.

2. DIMENSIONAL ANALYSIS

The local bed configurations downstream a sluice gate with a stilling basin of angled submerged vanes settled on its surface rely upon a large number of flow and sediment factors as follows:

$$\phi\left(B, H_{up}, y_t, L_f, V,\ d_{50},\ d_s,\ L_s,\ h_{si}, L_{si}, g, Q, \rho_s, \rho, \mu, S_o, V_h, V_w, V_d, \theta, y_g\right) = 0 \tag{1}$$

Where: B= flume width, H_{up}= the upstream water head in front of the sluice gate, y_t= tail gate water depth, L_f= floor length, V= the mean velocity at the downstream cross section of flume, d_{50}= mean particle diameter, d_s= maximum scour depth, L_s= maximum scour length, h_{si}= maximum silting height, L_{si}= maximum silting length, g= gravitational acceleration, Q= water discharge through the flume, ρ_s= soil particle density, ρ= water density of the flow, μ= dynamic viscosity of the water, S_o= flume bed slope, V_h= vane height, V_w= vane width, V_d= vane distance from the sluice gate, θ= vane angle, y_g= water depth under the sluice gate.

Where in this study $\frac{V}{\sqrt{g y_t}}$ = Froude number, and $\frac{\rho Q}{d\mu}$ = Reynolds number. Moreover B, H_{up}, L_f, ρ, S_o, V_w, and V_d were kept constant all through the test program; therefore they were ignored from Eq. (1). The impact of viscosity is accepted of auxiliary significance in assessing the scour parameters as the flow is principally gravitational, along these lines the impact of Reynolds number, Re, can be ignored. The time of balance for the local scour depth and silting geometries was settled for all runs; at that point, the Eq. (1) may be written in the accompanying structure:

Utilizing π- theorem and applying the properties of dimensional analysis, it yields;

$$\left(\frac{d_s}{y_t}, \frac{l_s}{y_t}, \frac{h_{si}}{y_t}, \frac{l_{si}}{y_t}, \frac{d_{50}}{y_t}, \frac{V_h}{y_t}, F_r, \theta\right) \tag{2}$$

3. MATERIALS AND METHODS

The experimental work was carried out in a flume at the Hydraulics Research Institute (HRI) of the National Water Research Center, Egypt. The flume channel was 24.5 m long, 0.74 m wide, 0.70 m depth. A centrifugal pump was utilized to supply water to the head tank from the capacity tank. The head tank has a gravel box which was utilized to give an even flow appropriation over the flume, likewise has portable downstream gate situated toward the end of the flume to adjust the downstream water level. Centrifugal pump driven by induction engine to re-circulate the flow from an underground supply to the flume. The model was a sluice gate made of steel was utilized as a heading-up structure. The gate has 0.02 m thick 0.5 m height and 0.74 m width. The stilling basin downstream the sluice gate was 1.2 m length and 0.74 m width. The first and last 0.30 m of the stilling basin was level. Anyway the middle part of 0.60 m has 15 indistinguishable submerged vanes of 0.10 m width each were settled and orchestrated symmetrically in 5 columns and 3 lines. The distance between columns were 0.15 m, however the distance between lines were 0.11 m, (Fig. 1). The scopes of the utilized variables were introduced in Table 1.

To run a regression analysis model for generation numerical equations used to explore the morphological impact of the previously mentioned variables; two distinctive bed materials of 0.25 m depth 2.0 m length filling the flume width were independently utilized. Sieve size distribution tests were done to characterize the materials properties and the results were outlined in Table 2.

Table 1. Range of variables used in the experiments

Parameter	Symbol	Value	Range		Units
			From	To	
Discharge	Q	20, 30, 40	20	40	l/s
Vane Height	V_h	6, 9, 12	6	12	cm
Vane angle of inclination	θ	45^o, 90^o, 135^o	45^o	135^o	degree
Tail gate water depth	y_t	$1.5V_h$,$2.0V_h$,$2.5V_h$	9	30	cm
Height of gate opening above bed	y_g	1.6, 2.4, 3.1	1.6	2.4	cm
Bed material	d_{50}	0.442, 3.11	0.442	3.11	mm

Table 2. Characteristics of bed materials

Bed material No.	d_{10}(mm)	d_{16}(mm)	d_{50}(mm)	d_{60}(mm)	d_{84}(mm)	C_u	γ_b (gm/cm^3)
1	0.155	0.203	0.442	0.542	0.861	3.49	1.92
2	1.92	2.54	3.11	3.75	4.52	1.95	1.61

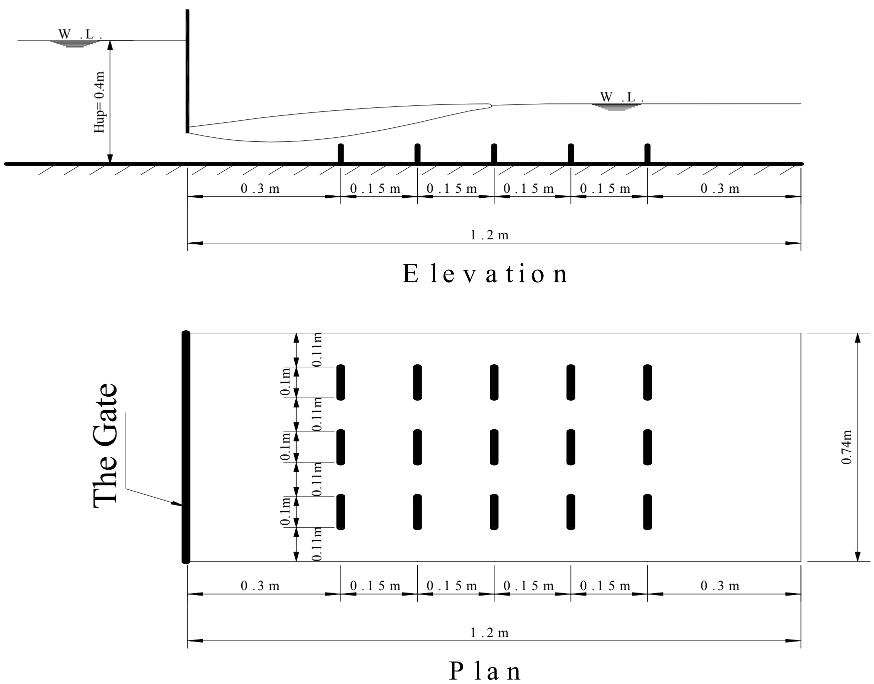

Fig. 1. Definition sketch of the used stilling basin

3.1 Justifications of Parameters Assumptions

The present investigation has some parameter presumptions as a basic examination focused on sluice gate measurements, discharge, and tail gate water depth, vanes height, and their angles of orientation. The sluice gate width was picked 0.75 m, where the flume width was 0.74 m and the rest 0.01 m was required for supporting the gate to the grooves in flume block side dividers. The thickness was 2 mm for useful motivations to replicate a sluice gate. After a few preliminary trial works, the parameters suspicions were:

- The gate height was 0.50 m to allow a satisfactory height for gate opening with no overtopping flow if there should be an occurrence of the greatest tried discharge (40 l/s).
- The vanes height under 6 cm didn't demonstrate any seen impact on bed geography explicitly on account of the smallest tried discharge 20 l/s and most

extreme downstream tail gate water depth of $2.5V_h$ (i.e.15 cm). Be that as it may, vanes height more than 12 cm prompted finish development of bed material in case of discharge and tail gate water depth of 40 l/s and $1.5V_h$ (i.e.18 cm), separately.

- For a stilling basin with vanes of orientation angle lower than 45° or higher than 135° estimated from flow heading (see Fig. 8) demonstrated inconsequential impact in the geometry of nearby scour downstream the sluice gate contrasted with the stilling basin with no vanes.
- The discharges under 20 l/s didn't demonstrate any remarkable impact on bed geography by virtue of stilling basin with 6 cm vanes height and 135° angle of orientation. However, the discharges higher than 40 l/s may provoke to overtopping flow because of the confinements of the height of flume side walls.
- At long last, the tail gate water depths, it was seen the bed material was totally removed if the tail gate water depth was lower than 9 cm on account of maximum discharge (40 l/s) goes underneath a sluice gate. Then again, no exceptionally warnings were represented tail gate water depth higher than 30 cm.

4. TEST PROCEDURE

4.1 Duration of Test Run

Toward the start of the experimental works, a few tests were executed utilizing diverse stilling basin models. The first model was totally level where no vanes were actualized. The second model has submerged vanes of 6cm height and 90° angle of orientation. To characterize the run duration; Fig. 2 was plotted for settled discharge and tail gate water depth of 40 l/s and 9 cm, individually.

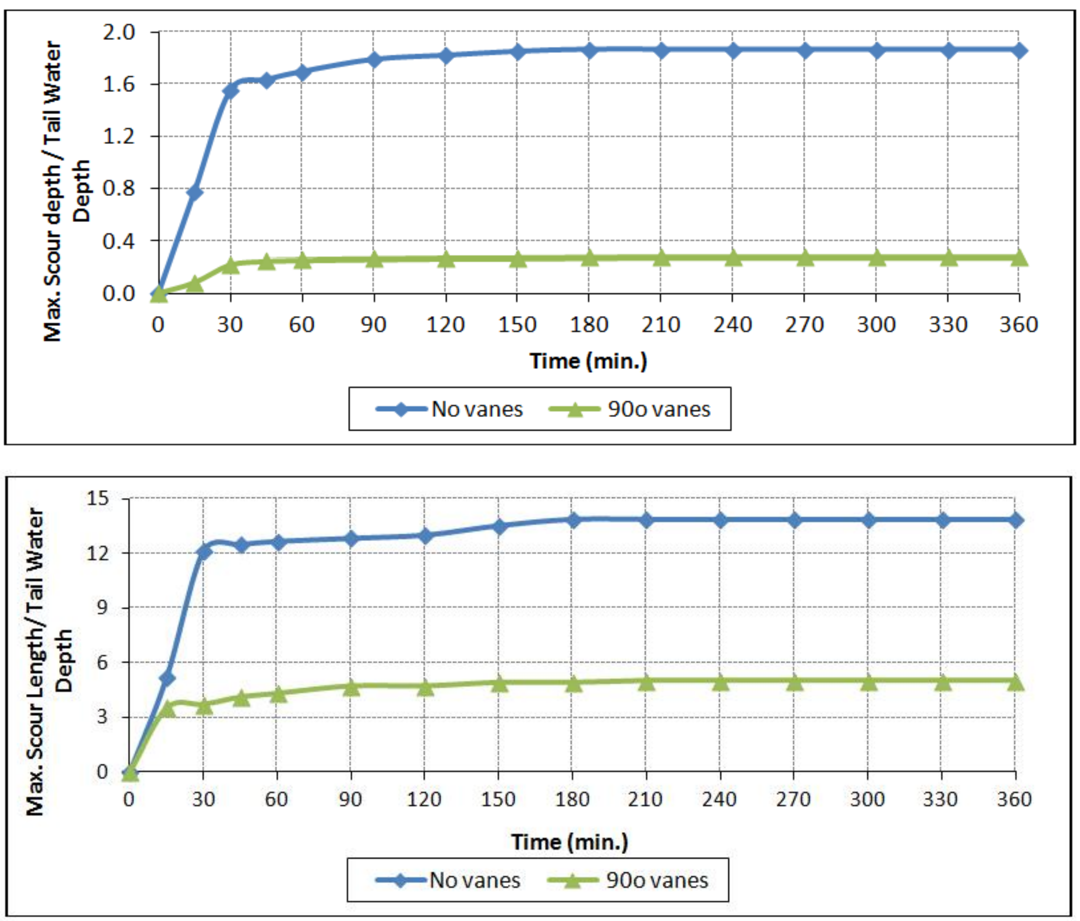

Fig. 2. Relation between time and maximum scour depth and length downstream stilling basin with and without vanes

The selected bed material in this procedure was No.1, (Fig. 2); where the bed changes were time consuming because of the fine diameters and the higher specific weight contrasted with bed material No.2, (Fig. 2) of larger diameters and lower specific weight, (Table 2).

The overall time was taken as 6 hours. The geometry of local scour exhibited as far as depth and length were recorded each 15 min in the first hour, then at regular intervals each 30 minutes for the rest test time. It was seen that following 30 minutes from beginning, the depth and length scour hole were stretched around 75-85% their greatest values settled following 3 hours from beginning. Thusly, the run duration of any test was equivalent to 5 hours to accentuate the quasi-equilibrium state were occurred as there are no calculable changes in the geometry of the local scour hole.

4.2 Procedure of Test Run

After the flume was loaded up with 0.25 m depth bed material and precisely leveled (the leveling accuracy was checked by methods for a point gauge with an accuracy of ± 0.1 mm and leveling device). The accompanying steps were done for each run: 1-The chosen stilling basin type was implemented precisely in the flume in its place, 2-The tail gate was totally shut, back water feeding was begun first until the point that its depth achieved higher than the coveted downstream water depth, 3-The control valve at the sustaining opening was bit by bit opened till keep up the required discharge, 4-The correct water discharge was estimated utilizing a ultrasonic flow-meter with an accuracy of ±1%, 5-The tail gate was screwed steadily until the point that the required downstream water depth is come to at utilizing the point gauge, 6-The running time of the test is begun, 7-After 5 hours (where there is no obvious change in bed profile), the pump was turned off, 8-The flume was exhausted from water by tail gate gradually with the end goal to don't irritate the bed configurations, 9-After the model was drained, the bed levels were recorded utilizing point gauge and normal scale through a settled lattice. Stages 1 to 9 were totally rehashed for each run.

5. MODEL RUNS

The test program comprises of 216 experimental tests utilizing 9 tail gate water levels, 3 discharges, 3 vanes heights and 3 vanes angles of inclination. 10 models of stilling basin were used and introduced in terms of vanes heights and angles of inclination. The scenarios were selected to characterize the course of action of the submerged vanes under various flow conditions to limit the local scour downstream the sluice gate in case of 2 diverse bed materials.

A designed mesh comprises of 51 measuring points masterminded in 3 lines, 0.185 m separating and 17 sections begun by the end of the stilling basin and finished after 2 m which was the total length of bed material. The separating between segments were gathered at the first 1 m; where the area of maximum local scour was expected (Fig. 3), and to describe the bed profile with high accuracy. However, at the rest locale of bed material, the separating between sections were expanded to be each 0.25 m, (Fig. 4).

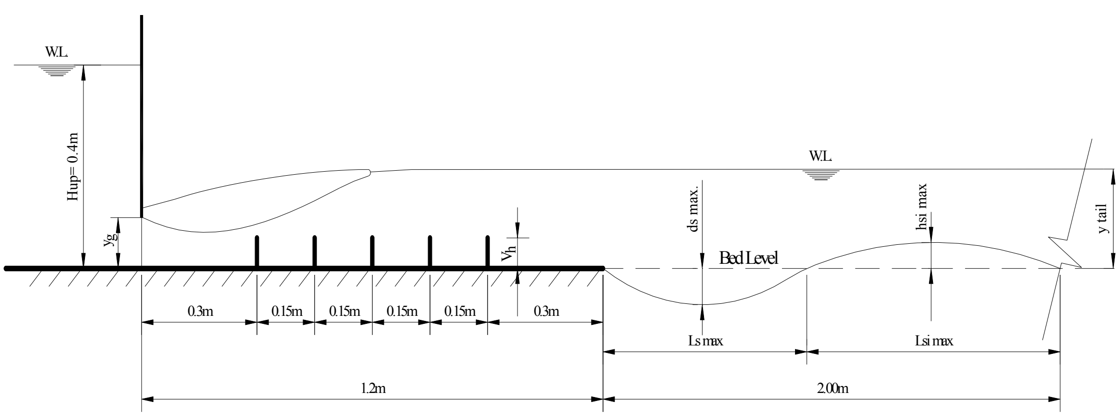

Fig. 3. Schematic diagram for the geometry of the local scour and silting

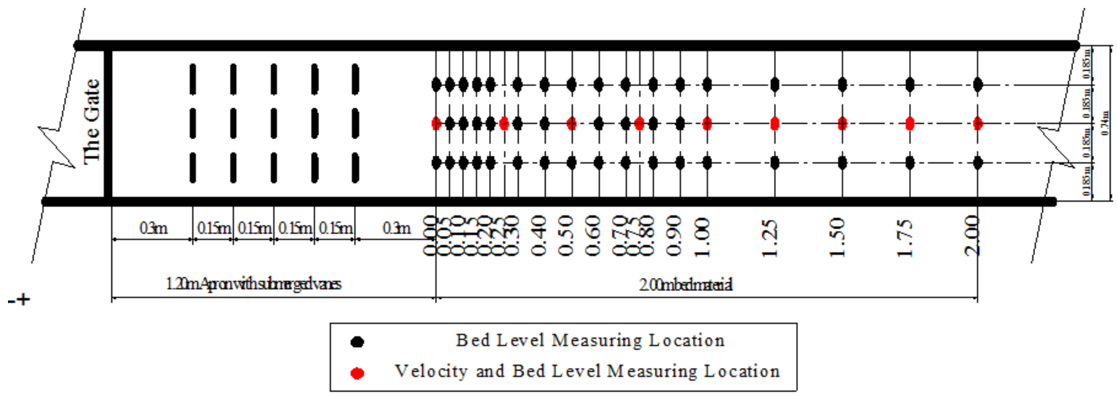

Fig. 4. Locations of bed profile and velocity measuring points

6. RESULTS AND DISCUSSION

Figs. 5 and 6 were obtained to check the ability of vanes implemented on stilling basin in abatement the bed configurations downstream the sluice gate. The figures were plotted under settled 40l/s discharge and 9 cm tail gate water depth utilizing the readings of the 51 measuring points presented in Fig. 4 to examine the morphological changes utilizing bed material No.1 on account of stilling basin without any vanes and with vanes of 6 cm height and 90° angle of orientation. Concentrate the outcomes demonstrated in Figs. 5 and 6 it was seen that the bed configurations in terms of average local scour were diminished by 65.39% in case of using a stilling basin associated with vanes differentiated to the traditional stilling basin without vanes. Focusing on the local sedimentation, the figures pronounced that no nearby depositions were unmistakably seen in case of stilling basin with vanes.

To depict the clarifications for that, Fig. 7 was plotted for the Froude No. along the tried length of bed material demonstrated in the current investigation for the two types of stilling basin. It should be indicated that the velocity measurements were begun simply downstream the stilling basin and stretched out along the total length of bed material.

9 locations were utilized for velocity measurements introduced in Fig. 4. At each point the velocity was measured at 3 depths (0.2, 0.4, and 0.6 of tail gate water depth). However, the Froude No. was determined utilizing the velocity measurements at 0.6 of tail gate water depth as the most extreme velocity values were recorded.

Investigating Fig. 7, outstanding contrasts were found in the Froude No. for the both types of stilling basin especially at the first 0.5 m of bed material. The vanes presence lessens the water turbulences downstream the stilling basin, at that point the velocity was reduced, thus subsequently the Froude No. It was seen that the vanes installation prompted saw decrement in the average Froude No. by 50.86%. That clarifies the revelations in Figs. 5 and 6 where the geometry of the local scour and silting for the stilling basin without vanes was especially observed differentiated to the stilling basin with vanes. It should be referenced that similar comments were seen if there should be an occurrence of utilizing bed material No.2 unless the geometry of scour and silting was greater.

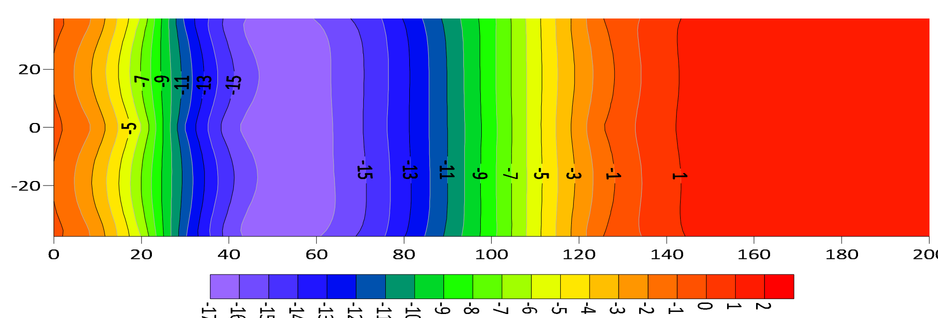

Fig. 5. Bed levels in the case of stilling basin with no vanes

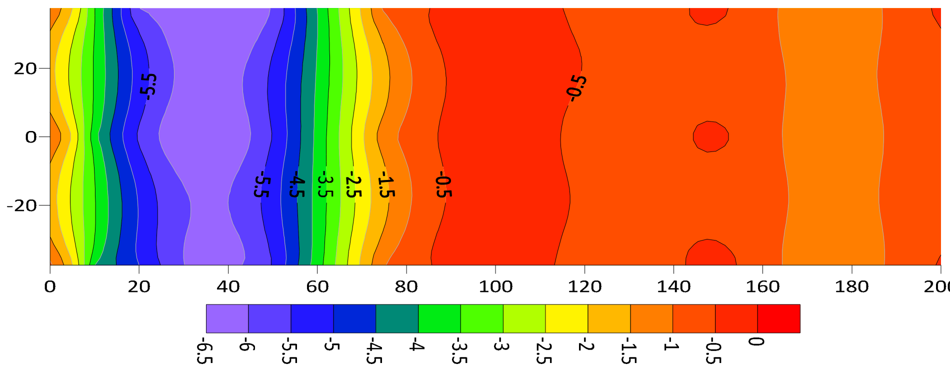

Fig. 6. Bed levels in the case of stilling basin with vanes

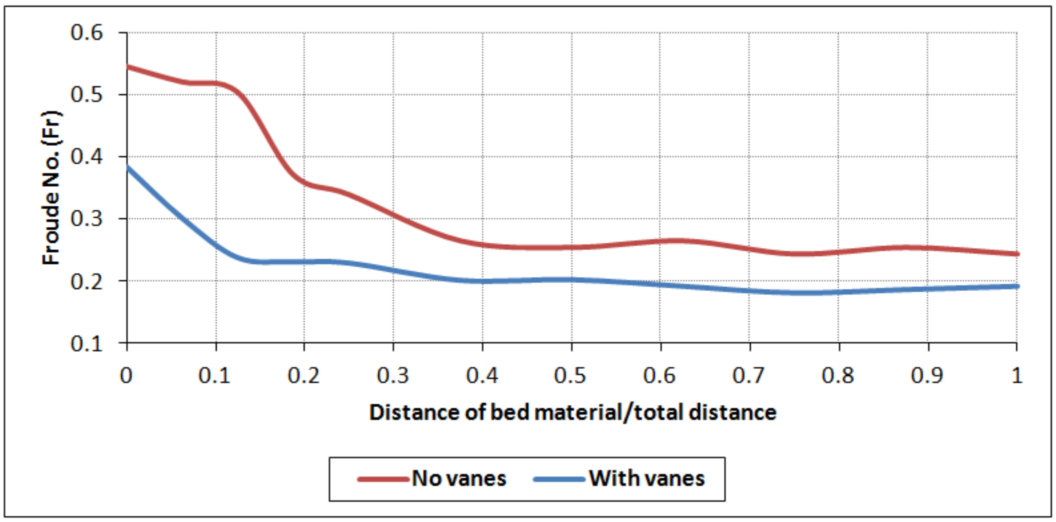

Fig. 7. Froude No. in case of stilling basin with and without vanes

6.1 Influence of Vanes Angle

Figs. 9 and 10 were plotted to investigate the impact of vanes angle on the bed morphology utilizing bed materials No.1 and 2 respectively. The figures were introduced under settled discharge, vanes height and tail gate water depth of 40 l/s, 6 cm, and 9 cm individually. It should be mentioned that all vanes fixed on the stilling basin have a similar angle. 3 vanes angles were tried 45°, 90°, and 135° estimated inverse to flow direction, Fig. 8.

Examining Figs. 9 and 10 it was denoted that the stilling basin associated with vanes anyhow their angles diminishes the downstream local scour differentiated to the stilling basin without any vanes, which concurred with the discoveries in Fig. 6. Additionally, the bed geography was impacted by the vanes angle regardless the bed material; where the geometry of the local scour was seen to be increased as the angles of vanes increased.

Table 3 summarized the findings of Figs. 9 and 10 as the most extreme decrease in the geometry of local scour was displayed in terms of depth and length was given by vane angle of 45° for the tried bed materials. That can be represented as the vanes oriented against the flow direction goes about as a repulsing obstacle which thusly diminishes the flow disturbance related to the hydraulic jump delivered due to flow underneath the sluice gate. Subsequently the water energy was scattered and the local scour was reduced.

Differentiating Figs. 9 and 10 it was seen that the delivered local scour geometry in bed material No.2 was high contrasted to bed material No.1 under settled test parameters. That was because of the light weight of bed material No.2, subsequently enables the particles to simple move even under small water current. Besides, the near bed velocities encourage the development of large particle diameters by rolling contrasted with particles of smaller diameters.

Combining the results of Figs. 9 and 10 it was denoted that the presence of vanes nevertheless their angles of orientation diminishes the bed configurations downstream the sluice gate notwithstanding the characteristics of bed material.

6.2 Influence of Vanes Height

Figs. 11 and 12 demonstrated the impact of vanes heights on the bed morphology in case of bed materials No.1 and 2 respectively. The figures were plotted under settled discharge, vanes angle and tail gate water depth of 40l/s, 90°, and 18 cm separately. Notwithstanding the bed material, a similar trend for the bed configurations was remarked; where the local scour depth was conversely corresponding to the vanes heights. Then again, the local scour length was not essentially affected by the vanes heights. Additionally, the location of the maximum scour depth was swung nearer to the stilling basin in case of vanes usage regardless vanes height contrasted with the traditional stilling basin without vanes.

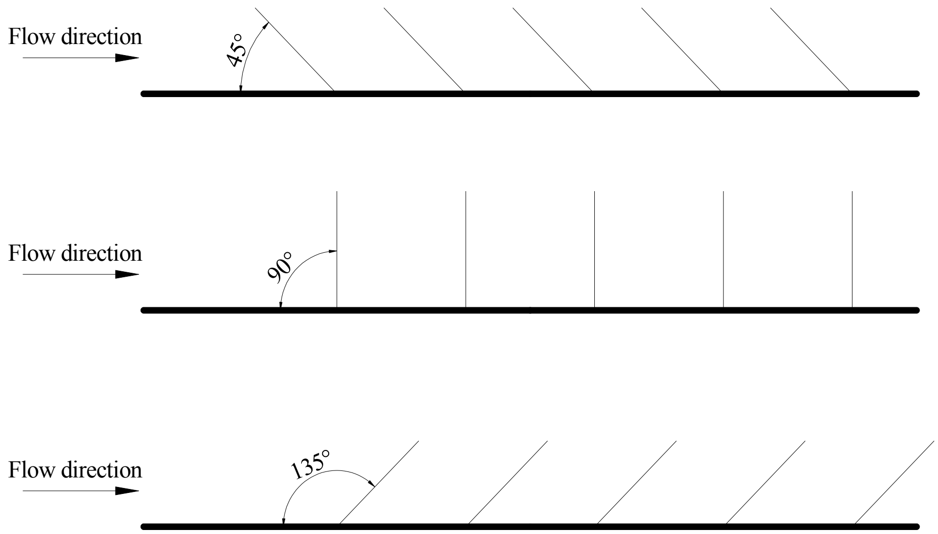

Fig. 8. Measurement of vanes angles of orientation

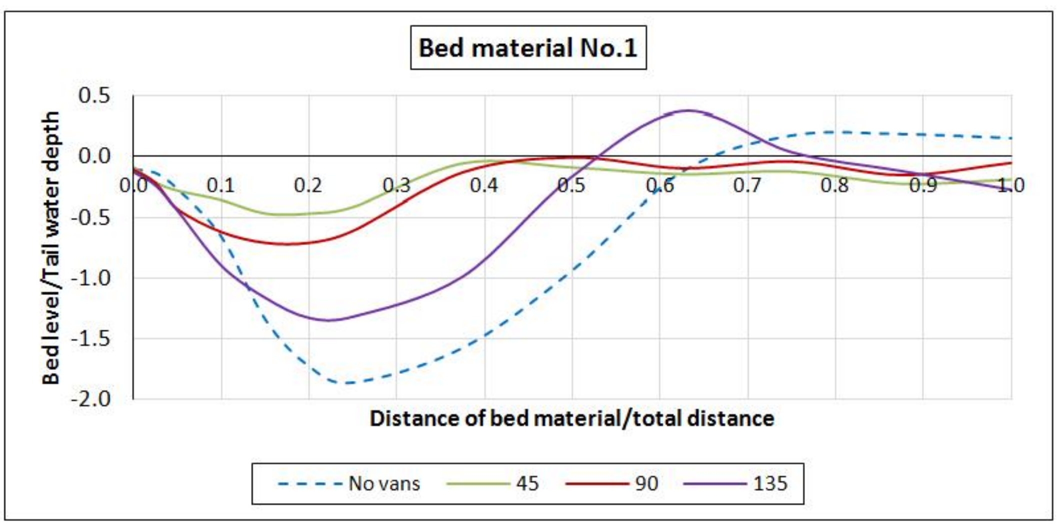

Fig. 9. Effect of vanes angle of orientation in case of bed material No.1

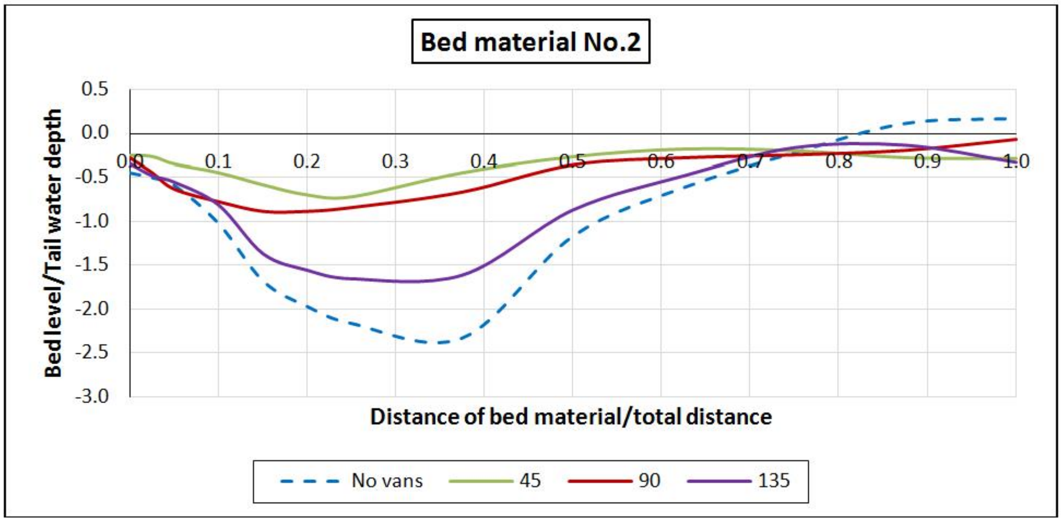

Fig. 10. Effect of vanes angle of orientation in case of bed material No.2

Table 3. Reduction in the geometry of the maximum local scour

Vanes angle	% Reduction in maximum scour for bed material No.1		% Reduction in maximum scour for bed material No.2	
	Depth	Length	Depth	Length
45°	297.87	56.82	233.61	----
90°	163.38	38.01	161.79	----
135°	40.60	23.21	37.21	----

Emphasizing the bed material No.1, Fig. 11 outlined that the maximum local scour depth was diminished by 81.25%, 75.01%, and 68.75% in case of utilizing vanes heights of 12 cm, 9 cm, and 6 cm, separately. Noticing the bed material No.2, Fig. 12 investigated that the most extreme local scour depth was diminished by 61.91%, 57.14%, and 47.62% in case of utilizing vanes heights of 12 cm, 9 cm, and 6 cm, separately.

Consolidating the findings of Figs. 11 and 12 it was presumed that the vanes usage at any height diminishes the bed morphological changes downstream the sluice gate regardless the characteristics of bed material.

6.3 Influence of Discharge

To investigate the impact of discharge on the geometry of local scour downstream stilling basin without vanes; Fig. 13 was plotted demonstrating the bed material No.1 under settled 18 cm tail gate water depth. The figure exhibited that the local scour depths and sedimentation heights were expanded as the discharge increment. In any case, under settled discharge it was seen that the local scour depth was around equivalent the silting height. Nevertheless, the local scour and silting introduced regarding lengths didn't demonstrate any perceptible effect by the discharge. Additionally, the impact of discharge on the bed topography exhibited a similar pattern which was representative at the first 38% from the tested region of bed material, and after that the discharge impact was vanished.

Introducing vanes of 12 cm height and 90° angle of orientation prompted a considerable impact on the bed morphology under 18 cm tail gate water depth. Exploring Fig. 14, it was shown that the local scour hole was shallower and more extensive differentiated to the stilling basin of no vanes. Combining the comments of Figs. 13 and 14 it was derived that the most extreme local scour depth was diminished by 66.67%, 69.23%, and 71.01% for the discharges of 20, 30, and 40 l/s, respectively. Additionally, the nearby scour length was increased by 309.9%, 354.5%, and 472.7% for the same tested discharges arrangement. Emphasizing the geometry of sedimentation, it was depicted that fixing vanes prompted discernible decrease in the maximum silting height; where was reduced by 72.72%, 86.66%, 88.88% for discharges of 20, 30, and 40 l/s, individually.

It should be referenced that similar discoveries and curves trend were accounted in the case of bed material No.2; anyway the numbers and percentages were extraordinary.

6.4 Influence of Tail Gate Water Depth

Figs. 15 and 16 were plotted to investigate the impact of tail gate water depth on the bed morphology characterized in terms of local scour and silting in case of stilling basin without vanes and with vanes of 12 cm height and 90° angle of orientation, separately. The figures were plotted under settled discharge of 40 l/s.

Investigating Fig. 15 it was devoted that the dynamic zone of bed material impacted by the flow was the primary 38% (i.e. the first 75 cm); similar discoveries were exhibited in Fig. 13. The local scour depth and silting height were increased as the tail gate water depth decrease. However, for settled tail gate water depth, the local scour depth was around equivalent the silting height. Also, the local scour length was 64.28% shorter than and silting lengths. Likewise, the local scour and silting lengths were observed to be uninfluenced by the tail gate water depth.

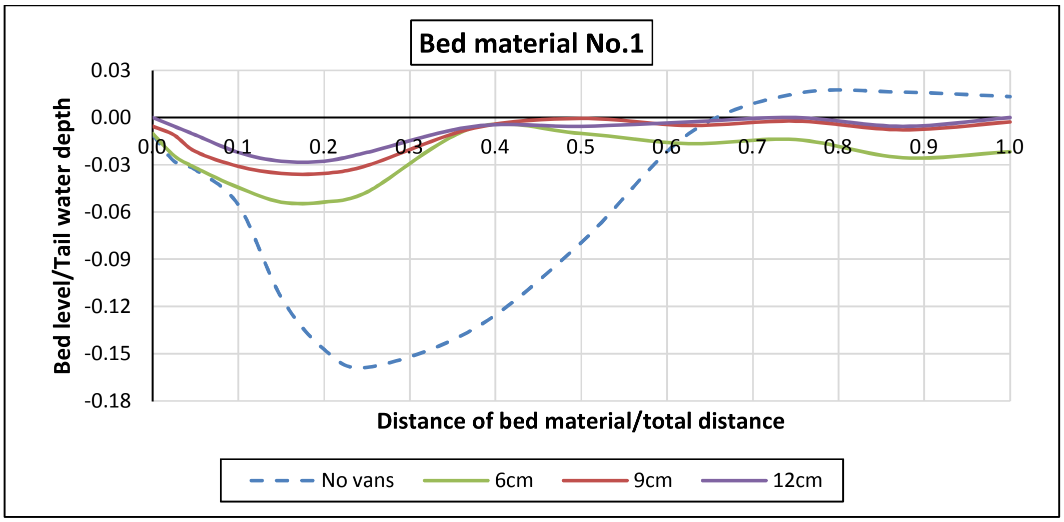

Fig. 11. Effect of vanes height in case of bed material No.1

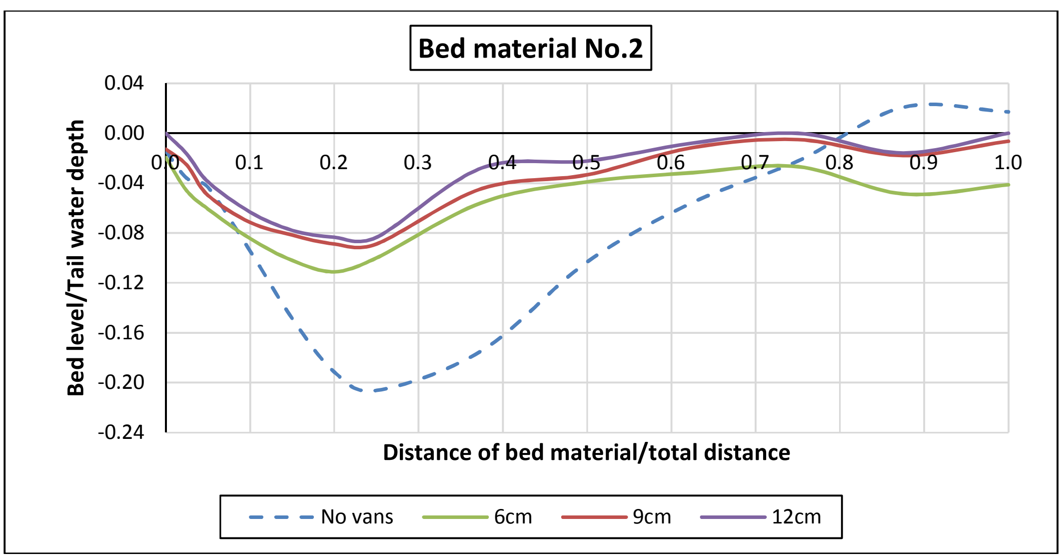

Fig. 12. Effect of vanes height in case of bed material No.2

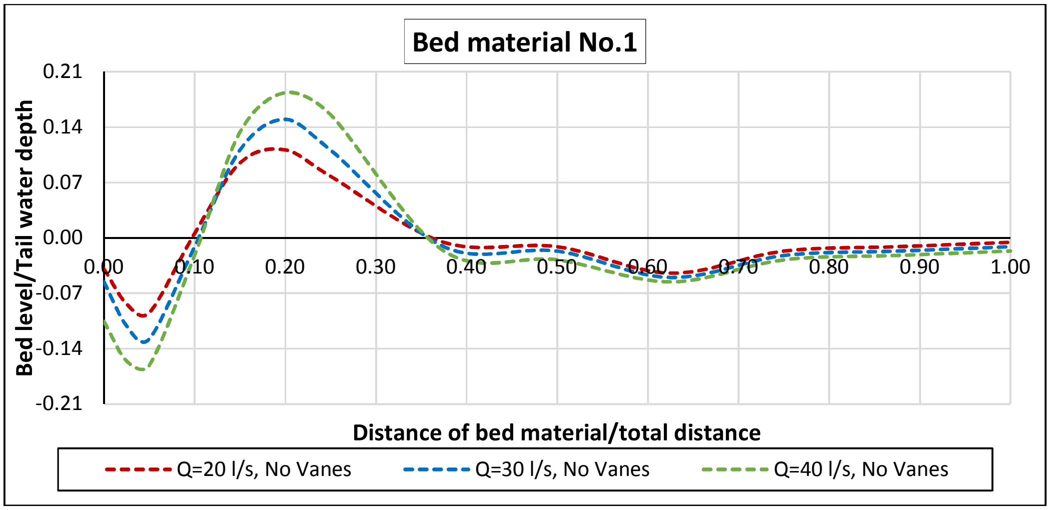

Fig. 13. Effect of discharge in case of stilling basin with no vanes

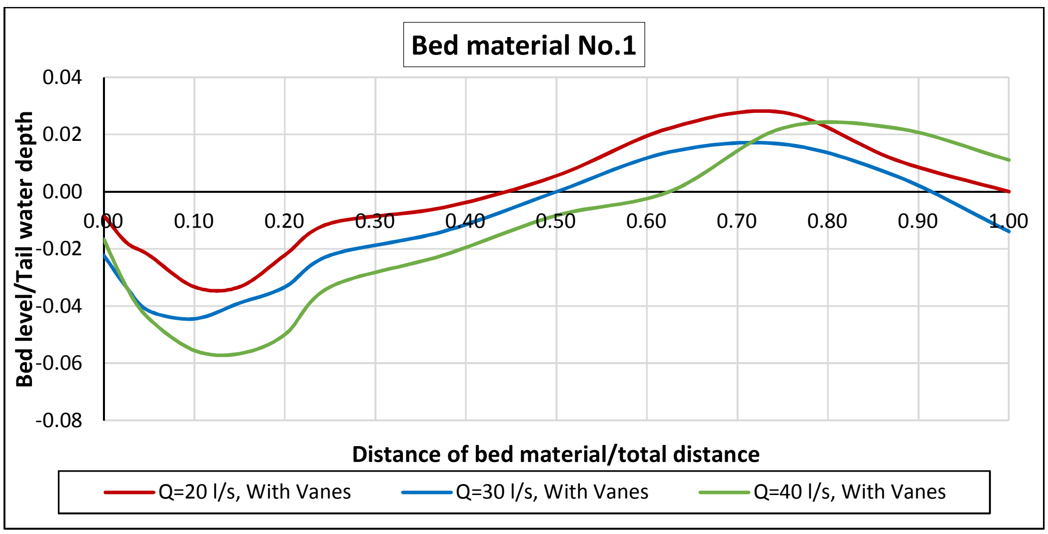

Fig. 14. Effect of discharge in case of stilling basin with vanes

Combining the aftereffects of Figs. 15 and 16 it was signified that the maximum local scour depths was decreased by 62.51%, 63.63%, and 65.01% for tail gate water depths of 18, 24, and 30 cm. Then again the maximum local silting height was diminished by 89.28%, 86.95%, and 84.61% for tail gate water depths of 18, 24, and 30 cm, respectively.

6.5 Influence Vanes on Volumes of Local Scour and Silting

Fig. 17 and Table 4 were displayed to outline the findings in the current investigation notwithstanding demonstrate the adequacy of installing vanes on a stilling basin in limiting the detached impact of the hydraulic jump downstream slice gate characterized in terms of local morphological changes. Fig. 17 exhibits the volumes of scour and silting on account of bed materials No.1 and 2 by applying flow conditions that creates maximum morphological changes. The discharge was 40l/s while the tail gate water depth was 9 cm.

Table 4 was displayed to investigate the rates of decrease in the geometry of local scour and silting because of vanes establishment differentiated to stilling basin without vanes. The outcomes were accounted in case of stilling basin without any vanes and with 6 cm vanes height under various orientation angles.

The figure demonstrated that under settled flow conditions, the local morphological changes for bed material No.2 was higher than the bed material No.1. Besides, the local scour was contrarily corresponding to the vanes angles of orientation which was concurred with the concluded in Figs. 9, 10 and sub- section 6.1.

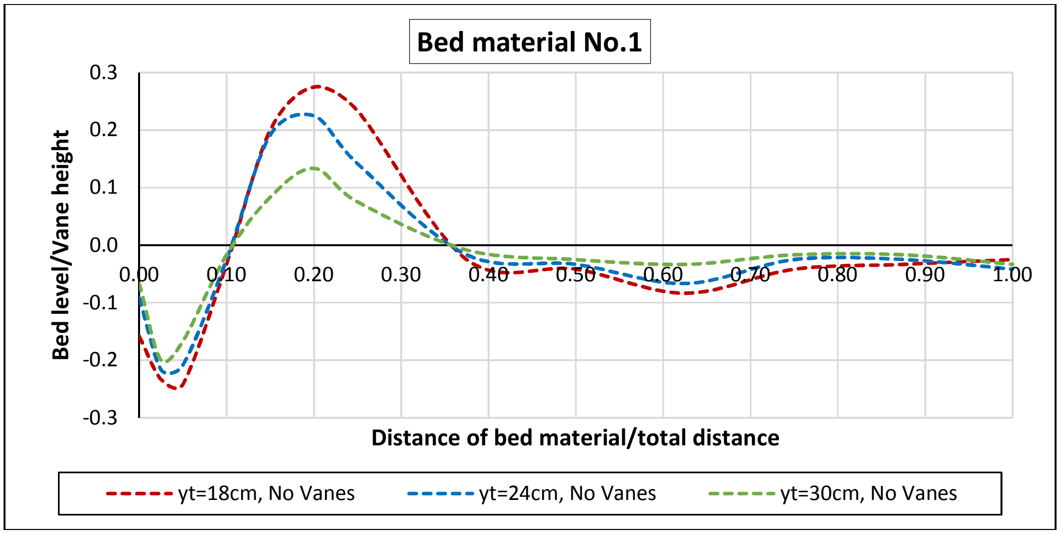

Fig. 15. Effect of tail gate water depth in case of stilling basin with no vanes

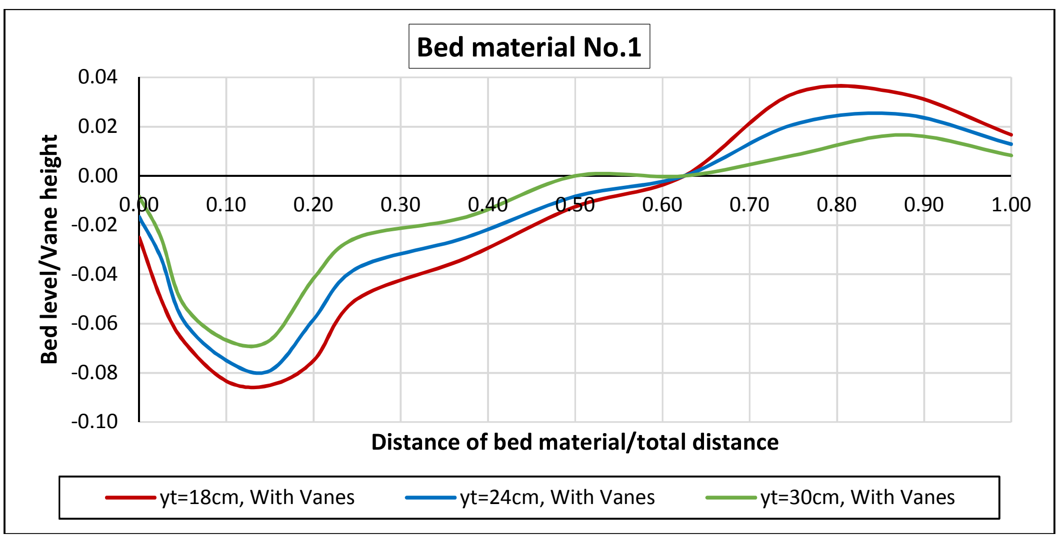

Fig. 16. Effect of tail gate water depth in case of stilling basin with vanes

Table 4. Percentages of reduction in volumes of scour and silting

Bed material	θ	% Reduction	
		Scour	Silting
1	45°	239.792	100.000
	90°	201.576	100.000
	135°	56.728	0.000
2	45°	193.740	100.000
	90°	115.599	100.000
	135°	24.164	100.000

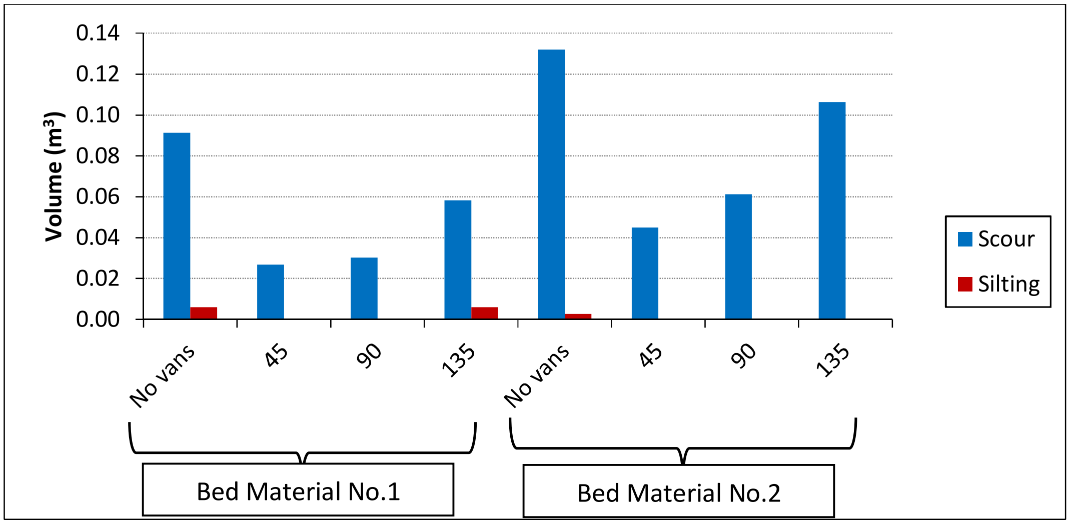

Fig. 17. Volumes of scour and silting

6.6 Developing the Scour and Deposition Parameters

The morphological changes downstream of hydraulic structures characterized regarding local scour and silting were essential factors that should be included in design. Along these lines, utilizing statistical regression analysis, many function frames were tried to foresee the distinctive geometrical parameters d_s, L_s, h_{si}, L_{si}. Out everything being equal, the best equations anticipating the maximum scour depth, and length, in addition to sedimentation height and length in case of stilling basin associated with vanes downstream sluice gate were as following:

$$\frac{d_s}{y_{tail}} = 0.422\frac{V_h}{y_{tail}} + 18.798\frac{d_{50}}{y_{tail}} + 2.453F_r - 0.002\theta - 0.478 \text{ , } (R^2 = 0.98) \quad (3)$$

$$\frac{L_s}{y_{tail}} = 10.740\frac{V_h}{y_{tail}} + 138.703\frac{d_{50}}{y_{tail}} + 2.326F_r + 0.021\theta - 3.955 \text{ , } (R^2 = 0.92) \quad (4)$$

$$\frac{h_{si}}{y_{tail}} = -0.018\frac{V_h}{y_{tail}} + 5.201\frac{d_{50}}{y_{tail}} + 0.430F_r + \theta - 0.034 \text{ , } (R^2 = 0.84) \quad (5)$$

$$\frac{L_{si}}{y_{tail}} = -0.952\frac{V_h}{y_{tail}} + 162.420\frac{d_{50}}{y_{tail}} + 14.217F_r + 0.004\theta - 0.898 \text{ , } (R^2 = 0.72) \quad (6)$$

7. CONCLUSIONS

The experimental study to investigate the impact of submerged vanes with various angles and heights fixed on stilling basin on the geometry of local scour downstream a sluice gate under differed discharges, tail gate water depths, and bed materials incited the accompanying conclusions:

- Installing vanes regardless their angles of orientation and heights fixed on a stilling basin demonstrated a decent execution in diminishing the bed morphological changes downstream a sluice gate.
- The geometry of the local scour was influenced by vanes angles than vanes heights.
- The geometry of the local scour was directly proportional to the vanes angles of orientation.
- The local scour depth was conversely corresponding to the vanes heights.
- The impact of vanes heights on the local scour length was unnoticeable.
- The bed material of smaller diameters was touchy to vanes presence than the bed material larger diameters under a similar flow conditions.
- The geometry of local scour was increased as the discharges increase regardless the vanes existence.
- Installing vanes demonstrated a noteworthy reduction in terms of local scour depth and silting height, under settled discharge.
- The impact of vanes on decrease of the local scour and silting was remarked as the discharge and tail gate water depth increment.
- The geometry of local scour and silting was contrarily corresponding to the tail

gate water depth in case of stilling basin with or without vanes.

- The tail gate water depth didn't demonstrate any significant impact on the local scour and silting lengths in case of stilling basin notwithstanding to vanes presence.

The author recommend in further investigations to utilize the detailed scenarios in the current examination under higher flow conditions. Also, use different shapes of obstacles introduced on the stilling basin (e.g. rectangular, square, tube shaped… etc.), to be used downstream different hydraulic structures rather than the sluice gate to display the influence of the obstacles geometry for the purposes of energy dissipation.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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