# Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 8 (13): 2396-2403, 2008
ISSN 1812-5654


# Experimental Investigation of the Effects of Submerged Vanes for Sediment Diversion in the Veis (Ahwaz) Pump Station

[1]S. Emamgholizadeh and [2]H. Torabi
[1]Department of Water and Soil, Agriculture College, Shahrood University, Shahrood, Iran
[2]Department of Hydraulic Structures, Lorestan University, Lorestan, Iran

**Abstract:** In order to investigate the effect of submerged vanes in the exclusion of inflow sediment into the Veis pump station, a distorted Froude scale model is used. The physical model was constructed in the Hydraulic Laboratory at the Water and Science Collage of the University of Shahid Chamran, Ahwaz, Iran. The submerged vanes were used with three different vane arrays. The result of this research indicates that the submerged vane has effectiveness role to limit the inflow bed and suspended load sediments into water intakes. Ultimately the two rows vanes which were located outside of intake entrance were most effective and they can reduce the sedimentation 63% into the water intakes.

**Key words:** Submerged vanes, intake, bed load, suspended load, sediment, Veis pump station, Karoon river

## INTRODUCTION

Large riverside intakes for power-plant cooling water, municipal and industrial water supply, irrigation, etc., are often beset by sediment deposition. This type of shoaling is particularly severe for crib houses along rivers transporting sediment that moves primarily as bed load and can disturb the entering flow to the extent that damaging pump vibration results, cause malfunctioning of traveling screens and even block the bays at low river stages. The deposition results from the curvature and the deceleration of the flow from the river into the crib house, both of which diminish the sediment transport capacity of the flow (Nakato *et al*., 1990). In recent years for control and prevent of inflow sediment to the pump intake, submerged vanes are proposed.

Submerged vanes are small-aspect ratio flow training structures installed on the streambed, usually oriented at 10 to 25 degrees to the local primary flow direction. Vane height is typically 0.2 to 0.5 times the local water depth during design flow conditions (Odgaard and Spoljaric, 1989).

The combination of vane-induced circulation and streamwise velocity causes a helical motion, or vortex, in the flow downstream from the vanes. The vortex extends downstream, gradually widening and decaying in strength due to the water viscosity (Fig. 1). The helical flow created by the vortex causes transverse shear stresses on the riverbed, resulting in sediment transport in a direction transverse to the flow direction. The transverse shear stresses causes sediment to be picked up on the vane's suction side and deposited on the pressure side. Consequently, a scour trench forms along the downstream side of the vane (Barkdoll and Odgaard, 1999). By placing vanes in rows, the scour trench can be extended to cover a comparatively wider area (Odgaard and Wang 1991a, b). This scouring action makes vanes useful as a means for minimizing bed sediment ingestion into diversions from alluvial channels. They have been used for this purpose at about a dozen lateral diversion water intakes for thermal power stations and municipal water supply facilities (Barkdoll and Odgaard, 1999).

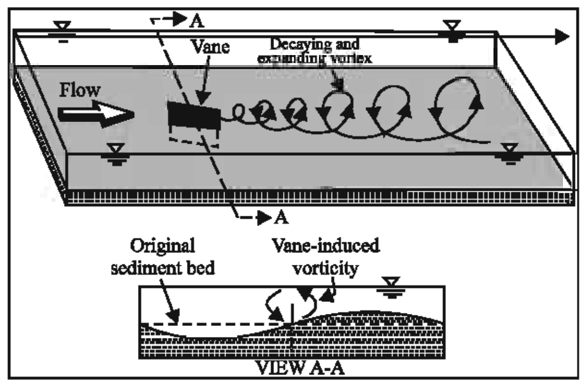


Fig. 1: Schematic showing submerged vane and vane-induced circulation

Several parameters affecting submerged vane performance, including submerged vane height H, length

**Corresponding Author:** Samad Emamgholizadeh, Department of Water and Soil, Agriculture College, Shahrood University, Shahrood, Iran

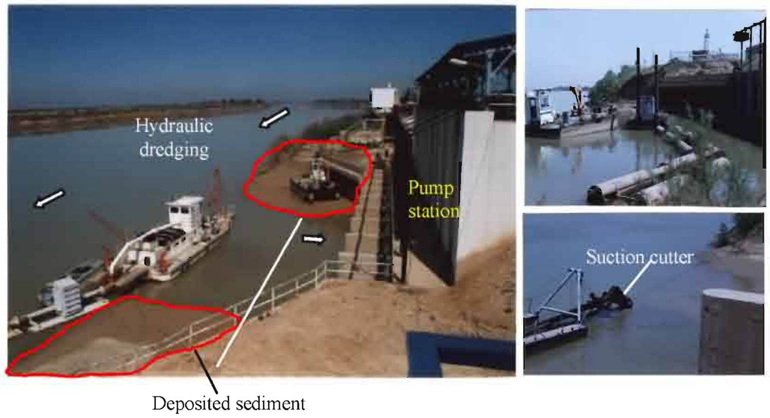


Fig. 2: The Veis pump station and deposited sediment in front of water intake and hydraulic dredging machine

L, angle to main flow direction α, vane streamwise spacing δs and vane transverse spacing from outer bank and än (Voisin and Townsend, 2002).

Submerged vanes have been shown to be effective in protecting stream banks against erosion, in maintaining navigation depth and flood-flow conveyance capacity in rivers and in controlling sediment at diversions and water intakes (Odgaard and Wang, 1991a, b; Wang *et al*., 1996). Since the area of streambed affected by a single vane is limited, for applications, usually a number of vanes are installed in parallel to widen the effective area. For these vanes to work together, the distance between the vanes can not be too large. However, if the spacing between the vanes is too small, the vanes will interact to each other. The interaction between the vanes interferes with the development of the vane-induced circulations and consequently reduces the efficiency of the vane system. It is the main purpose of this study to investigate this phenomenon of vane interaction and also its effects on the vane-induced transverse bed profile. Studies about the vane-technique can be found in Odgaard and Wang (1991a, b), Wang *et al*. (1996), Wang and Odgaard (1993), Barkdoll and Odgaard (1999), Voisin and Townsend (2002), Sinha and Marelius (2000) and Flokstra (2006).

**Problem definition:** The Veis pump station with capacity of 22 $m^3$ $sec^{-1}$ is one of the seventh large pump station which has been constructed in east of Ahwaz along the Karoon riverside. The Karoon river is one of the largest rivers in the province of Khozestan, south west of Iran. The river initiated from northern states and after passing Khozestan it enters to the Persian Golf. In the study area, river usually carries a large amount of sediments as bed and suspended load. The Veis pump station was constructed a distance of 25 km away from Ahwaz city. The river at study area site carries large amount of sand as bed load and sand, silt and clay in suspension especially during the flood season. Some sediment deposits in front of intake and some enters the pump sump and transported by flow and enters the main irrigation canal. The sediments can cause damage to the pump and even block the bays at low river stages. Also they deposit in the main irrigation channel and reduce the channel capacity.

After 3 years operation of the Vies pump station, it was counted to accumulate of sediments in front of water intake. Undesirable sedimentation in front of the intake building may obstruct the water inflow. For solving this problem the KWPA (Khozestan Water and Power Authority) decided to use hydraulic dredging machine for remove accumulated sediment near the water intake. Figure 2 shows the Veis pump station, hydraulic dredging machine and deposited sediments. Using hydraulic dredging machine has some problems such as its operation and also expensive dredging at regular intervals.

Therefore, it was decided to conduct a study to investigate the sediment deposition and the effect of submerged vanes to exclude sediment load to the pump station water intake.

**Field data:** The hydrological data such as flow discharge were obtained from a nearby hydrometric station on Karoon River (Molasani Station) which located upstream of the study area. In this station the minimum, mean and maximum flow discharge are 826, 2803 and 5370 $m^3$ $sec^{-1}$, respectively.

The suspended and bed sediment particle size distribution also are available. The minimum, mean and maximum suspended concentrations are 15, 850 and 1600 mg $L^{-1}$, respectively. A plan of the study site 700 m upstream and 300 m downstream of the pump were taken. Three cross-sections of the river upstream and one cross-section downstream of the pump station also were taken. A rating curve (discharge-elevation) was constructed at the study site by measuring the flow using flow meter.

## MATERIALS AND METHODS

**Description of the physical model:** The flow patterns in the vicinity of riverside pump station especially at the bay are strong three-dimensional, therefore it causes the sediment behavior would be very complex. Therefore, it is decided to conduct experimental model tests to examine intake sedimentation issues. Thus a distorted model from the study area was constructed in the Hydraulic Laboratory at the Water and Science Collage of the University of Shahid Chamran, Ahwaz, Iran, in 2005. With the limiting of laboratory space, the horizontal and vertical scales of the model were selected 1: 130 and 1:50, respectively.

The overall dimensions of the model were 8 m length, 2 m wide and 0.5 m height. A schematic diagram of the flume is shown in Fig. 3.

In order to construction the physical model it was required to provide cross sections from river at study area. Therefore 4 cross sections were provided by field surveying from the 1 km reach of the study area (distance of 700 and 300 m upstream and downstream of the pump station, respectively). The pump intake also modeled and installed on the river side. A sediment injector device was constructed and placed upstream where the flow enters the model. At this location turbulent flow is created for complete mixing of the sediment. Figure 3 shows the plan view of the model and sediment injector device. The model consists of three main areas:

- Flow dissipater area with 1 m length, 1.5 m depth and 2 m wide. In this region the turbulent of inflow will be dissipated and flow as uniform flow entrance to the reservoir.
- Study area with 8 m length, 0.6 m height and 2 m wide
- Settling basin area with 0.5 m length, 2 m wide and 0.80 m height. The outflow (mixed water and sediment released to this region and the sediment settle within it).

In order to regulate the water elevation in the model, a simple tailgate was considered at the downstream end of the basin. For the measurement of the outflow discharge from the model a WSC flume was placed on the rectangular channel, which placed in alongside to the main model. Water was supplied by a pump at desired steady flow by controlling the valve of the pipe. The intake structure was built geometrically similar to the prototype and attached to the model basin. The water flow through the intake structure was withdrawn

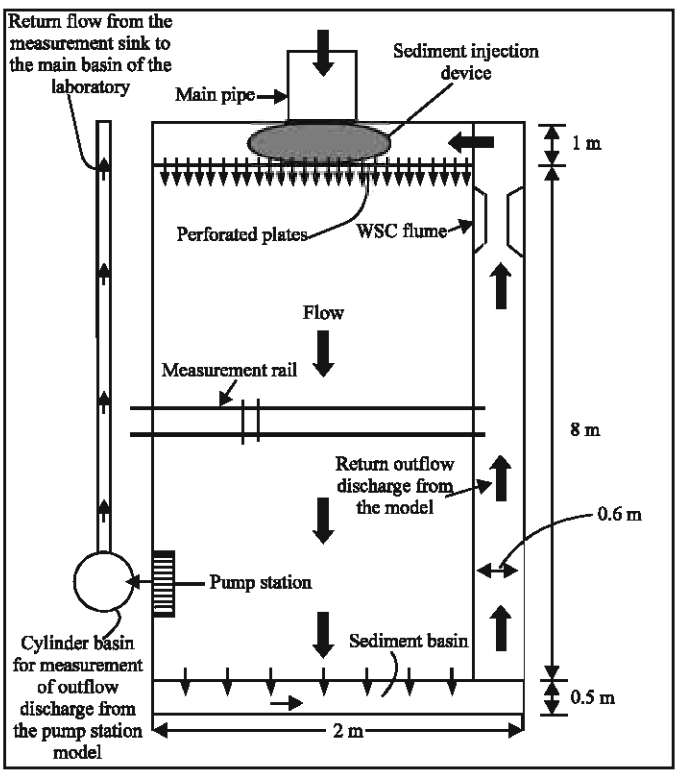


Fig. 3: The plan view of the model

separately through each pump bay using pipes attached to the back walls. Each pipe was fitted with a valve and for measuring the discharge from them a cylinder basin was used. Water withdrawn was feed back to the laboratory basin with a pipe of 3 inch in diameter.

**Model rules:** In most open channel flow problems the force of gravity is the primary force. Therefore in this study the model was built based on the Froude law. According to the Froude law the general flow conditions, such as velocity and discharge capacity can modeled as following (Novak and Gabelk, 1981).

$$V_M = \frac{V_P}{\sqrt{L_V}} \tag{1}$$

$$Q_M = \frac{Q_P}{L_V^2 . L_H} \tag{2}$$

In which V is the velocity and Q is the discharge, $L_H$ and $L_V$ are the horizontal and vertical scales, respectively. Subscripts of P and M denoted prototype and model conditions, respectively.

For sediment transport as bed load the Sheilds criterion can be applied (Novak and Gabelk 981). According to this role:

$$\left(\frac{\tau}{(\gamma_s - \gamma_W)D_s}\right)_P = \left(\frac{\tau}{(\gamma_s - \gamma_W)D_s}\right)_M \tag{3}$$

In which $\tau$ is the shear stress, $\gamma_S$ and $\gamma_W$ are specific weight of sediment and water, respectively and $D_s$ is the particle size.

From Eq. 1, using the sediment with the same specific weight, the following equation is obtained:

$$D_{SM} = \frac{D_{SP}}{(L_V)^2 / L_H} \tag{4}$$

In which $L_V$ and $L_H$ are the vertical and horizontal scales, respectively equal to 50 and 130 in this study, therefore:

$$D_{sm} = \frac{D_{sp}}{19.2} \tag{5}$$

For sediment transported in suspension the Rouse model rule is applied. According to this rule the model and prototype suspended sediment concentration distribution will be the same, if the following equation is satisfied:

$$\left(\frac{\omega}{u_*}\right)_M = \left(\frac{\omega}{u_*}\right)_P \tag{6}$$

In which $\omega$ is the particle fall velocity and u* is the shear velocity. From Eq. 4, $\omega_R = u^*_R$ in which $\omega_R$ and $u^*_R$ is the scale of fall velocity and shear velocity, respectively. Since, $u_* = \sqrt{gRS}$, in which R is the hydraulic radius and S is the slope, the $u_{*R}$ in distorted model will be equal to $\frac{L_V}{\sqrt{L_R}}$, therefore the Eq. 3 can be written in the following from:

$$\omega_R = \frac{\omega_P}{\omega_M} = \frac{L_V}{\sqrt{L_H}} \tag{7}$$

Applying Stock's formula for the fall velocity

$$\omega = \frac{D_s^2}{18\mu}(\gamma_s - \gamma_W)$$

and assuming $\mu_P = \mu_M$, and $\gamma_{sp} = \gamma_{sm}$ thus $\omega = D_{SR}^2$ and therefore, Eq. 5 can be written as:

$$D_{SR}^2 = \frac{L_V}{\sqrt{L_H}} \tag{8}$$

$$D_{SM} = \frac{D_{SP}}{L_V^{1/2} / L_H^{1/4}} \tag{9}$$

With respect to $L_H = 130$ and $L_V = 50$, it can be written as:

$$D_{sm} = \frac{D_{sp}}{2.09} \tag{10}$$

Equation 5 and 10 were used to determine the grain size distribution of the bed and suspended load sediment. Figure 4 and 5 show grain size distribution curves of bed load and suspended load of the prototype and model, respectively.

**Laboratory experiments:** The experiments were conducted in two phase as following:

- Hydraulic experiments
- Sediment Experiments with

In the first phase the experiments were conducted in order to investigate the hydraulic similarity between model and prototype and the flow pattern in front of water intake.

In the second phase two sets of experiments were conducted:

- The experiment was performed with original design without using vane structures in order to investigate sedimentation into the pump station bay.

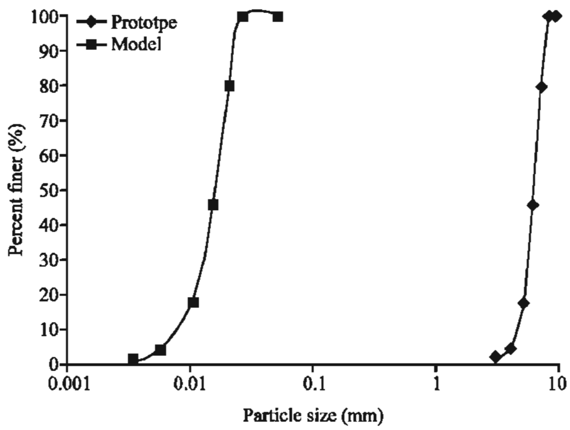


Fig. 4: Grain size distribution curves of bed load sediment of prototype and model

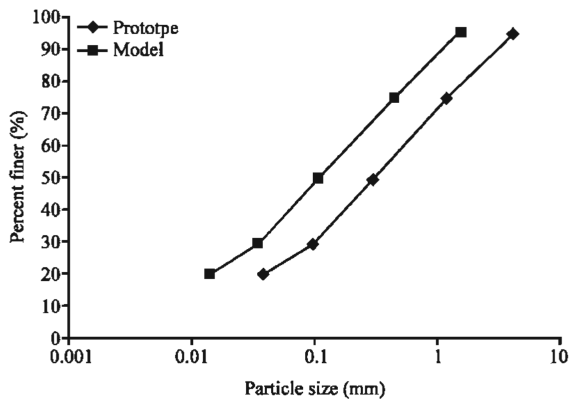


Fig. 5: Grain size distribution curves of suspended load sediment of prototype and model

- The experiments were performed with using one, two and three array vanes in order to investigate the effects of submerged vanes to exclude of sediment into the pump station bay.

**Hydraulic experiments:** In order to investigate the hydraulic similarity between model and prototype, a series of hydraulic experiments were conducted. Two motions are said to be kinematically similar if the patterns or paths of motion are geometrically similar and the ratios of the velocities of the particles involved in the two motions are equal (French, 1986).

Therefore the flow velocities in model were measured by micro Moline in three sections, A, B and C with distance of 2, 4 and 6 m from the upstream of the model, respectively. Table 1 shows the measured velocity in the prototype and model. And also the velocity in the model corresponding to the prototype velocity by Froude law is

Table 1: The comparison between the measured velocity in the prototype and model

| Cross section No. | Measured velocity in the prototype ($m\ sec^{-1}$) | Measured velocity in the model ($cm\ sec^{-1}$) | Calculated velocity in the model by Froude law ($cm\ sec^{-1}$) | Velocity error (%) |
|---|---|---|---|---|
| A | 0.530 | 7.10 | 7.500 | 5.33 |
| B | 0.560 | 7.49 | 8.033 | 6.76 |
| C | 0.525 | 7.20 | 7.420 | 2.96 |

Fig. 6: The downstream view of the model and the circulation flow pattern which formed in the front of water intake (the model run with water discharges of 43.41 L $sec^{-1}$)

calculated. The velocity error was calculated between the measured velocity and calculated velocity by Froude law.

As the result of Table 1 indicated, the calculated velocity error is very small. In other word, there is a good hydraulic similarity between prototype and model.

**Investigation of the flow pattern in the front of the water intake:** In order to investigate the flow pattern in the model, the experiment was performed with original design. Model run with water discharges of 43.41 and 17.41 L $sec^{-1}$ corresponding to 1800 and 800 $m^3\ sec^{-1}$ at the prototype condition. Flow patterns at the front of intake were observed using neutrally buoyant dye injected at various locations by means of a dye wand. The Fig. 6 shows the flow pattern in the front of pump station intake when the water discharge was 43.41 L $sec^{-1}$. As it is obvious a circulation flow pattern is produced because of upstream wing wall of the pump station in original design. The strong of circulation flow depended to the quantity of flow discharge, as at water discharges of 43.41 L $sec^{-1}$ it was very strong rather than to water discharge of 17.41 L $sec^{-1}$.

**Sediment experiments**

**Investigation of sedimentation in the pump station bay:** In order to investigate the amount of deposited sediment in pump station bay, the first test run with no vanes present. Therefore the simulated bed load sediment with medium diameter of 0.018 mm, were spread over through the model with a thickness of 5 cm. Then the model was filling with water approximately to the desired river water level. This had to be done very slowly in order not to destroy the existing bed-form pattern. Model run with water discharge of 43.41 L sec$^{-1}$. Then the simulated suspended sediment with medium diameter of 0.0033 mm injected into flow by injection device with rate of 30 g sec$^{-1}$. The experiment was run nearly 5 h. For this flow condition, the flume's sand bed was in a dune regime, with sand moved as bed load. Sediment moved and deposited in the front of water intake bay.

As these Fig. 7 and 8 show sediment moved and deposited in the front of water intake structure. At the end of the experiment, the deposited sediment in the bay was collected and weighed. It was measured 30.1 g.

**Experiments with using vanes:** The vane experiments were performed under the same conditions of flume flow and sediment movement used for the experiments without vanes. In total of the experiments, each vane was 2.5 cm wide (3.25 m in prototype dimensions) and 4 cm effective height (up to bed level) (2 m in prototype dimensions). They constructed from Plexiglas and installed at an angle of 20° to the flow. The distance between two vanes in each row was 8 m.

The performance of submerged vanes to scour bed-load sediment away from the intake was investigated with three different vane arrays:

- The array of one row vane
- The array of two rows vanes
- The array of three rows vanes

**Flow turning vanes installed in one row:** The vanes were installed in one row in four layouts (test 1, 2, 3 and 4). In four tests the distance between row and the water intake face was 1.5, 7.5, 13.5 and 19.5 m, respectively.

In the first and second test, six and seven flow turning vanes were installed in front of the intake structure. And in the third and forth test, nine vanes were installed in front of the intake structure. The exact third nine-vane layout is depicted in Fig. 9.

The using of submerged vanes indicted that the scour trench developed around the vanes and they prevented the bed-load sediment from entering into the pump bays (Fig. 9).

At the end of the experiments with four layouts, the deposited sediment in the bay was collected and weighed.

Fig. 7: Downstream view of the water intake structure before the operation

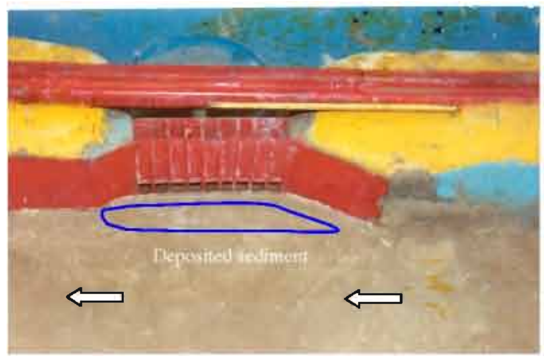


Fig. 8: Sedimentation in the front of water intake structure after 5 h of the operation (flow from right to left)

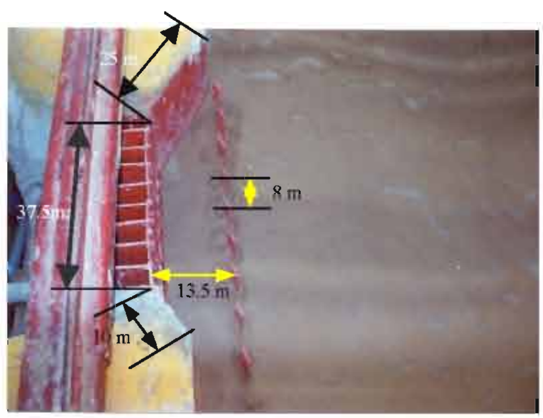


Fig. 9: The one row layout of vanes (test 3) after 5 h operation (flow from up to down and distances are in prototype dimensions)

It was achieved 28.4, 25.1, 18.3 and 20.2 g for the first, second, third and fourth vanes layouts, respectively.

**Flow turning vanes installed in two rows:** The vanes were installed in two rows in three layouts (test 5, 6 and 7). In

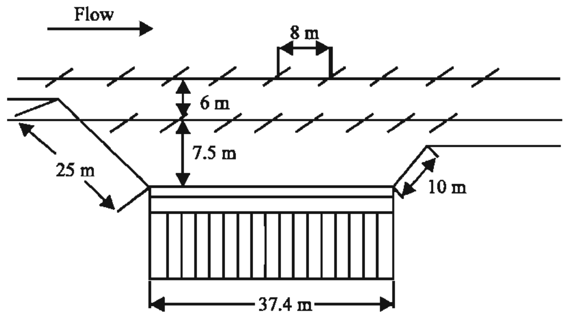


Fig. 10: The two rows layout of the vanes (test 6) in the front of intake (internal layout)

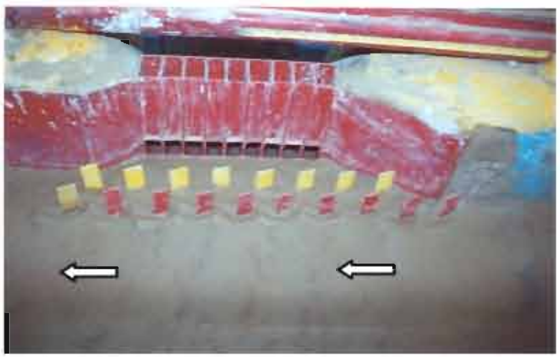

Fig. 11: The two rows layout of vanes (test 6) after 5 h operation (internal layout)

the first layout (test 5), one row being 1.5 m (with 5 vans) and second 7.5 m (with nine vans) from the intake face. In the second layout (test 6) one row being 7.5 m (with eight vans) and second 13.5 m (with nine vans) from the intake face. In the third layout (test 7), one row being 13.5 m and sec 19.5 m from the intake face. In the last layout in each row, nine flow turning vanes were installed in front of the intake structure. The exact second layout of nine-vane is depicted in Fig. 10.

Figure 11 shows the submerged vanes (test 6) and the developed scour trench around the vanes.

At the end of the experiments with three layouts, the deposited sediment in the bay was collected and weighed. It was achieved 24.2, 18.3 and 14.2 g for the first, second and third vanes layouts, respectively.

As the measurement of deposited sediment indicted, in the third layout (Fig. 12) the amount of deposited sediment into the pump bays was minimum. Therefore this layout was modified and run again (test 8). Figure 13 shows the new arrangement of vanes. The deposited sediment in the bay was measured 11.1 g.

**Flow turning vanes installed in three rows:** The vanes were installed in three rows in two layouts (test 9 and 10).

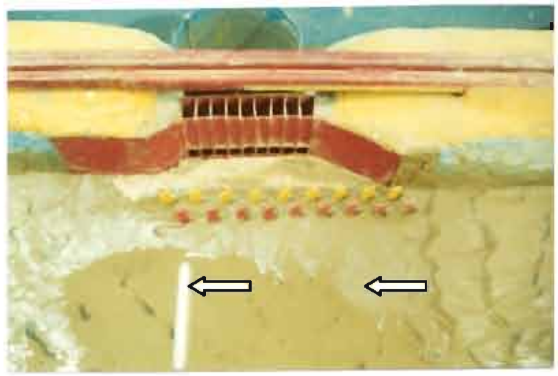

Fig. 12: The two rows layout of vanes (test 7) after 5 h operation (external layout)

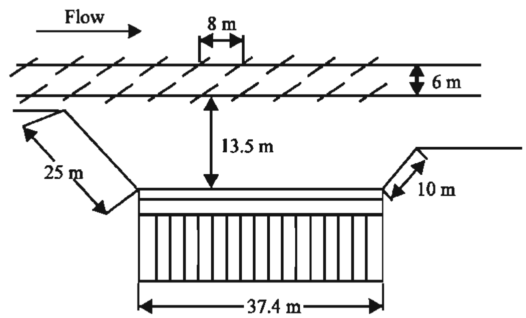


Fig. 13: The two rows layout of vanes (test 8) (external layout)

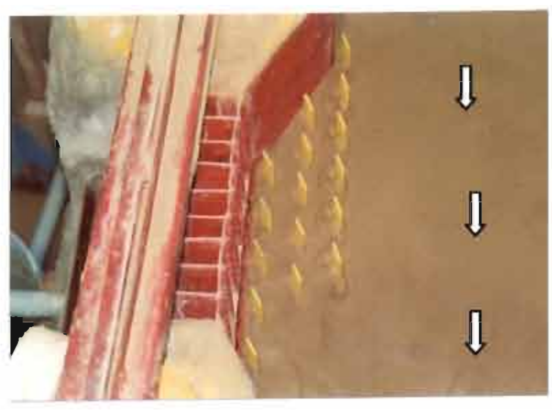

Fig. 14: The three rows layout of vanes (test 9) after 5 h operation (internal layout)

In the first layout the distance of first, second and third rows of vanes from the intake face were 1.5, 7.5 and 13.5 m, respectively. And in the second layout the distance of first, second and third rows of vanes from the intake face were 7.5, 13.5 and 9.5 m, respectively. In the first layout in the first, second and third rows, 5, 5 and 7 flow turning vanes were installed.

Table 2: The comparison for the effect of different array vanes in the decreasing of sedimentation into the water intake bay

| Vanes array | No. of test | Type of layout | Distance between row vanes and the intake face (in the prototype dimension, m) | Weight of deposited sediment in the front of water intake bay (g) | Effect of vanes in the decreasing of sedimentation (%) |
|---|---|---|---|---|---|
| Without vane | - | - | - | 30.1 | - |
| One array | Test-1 | Internal layout | 1.5 | 28.4 | 5.65 |
| | Test-2 | Internal layout | 7.5 | 25.1 | 16.61 |
| | Test-3 | Internal layout | 13.5 | 18.3 | 39.20 |
| | Test-4 | External layout | 19.5 | 20.2 | 32.89 |
| Two array | Test-5 | Internal layout | 1.5, 7.5 | 24.2 | 19.60 |
| | Test-6 | Internal layout | 7.5, 13.5 | 18.3 | 39.20 |
| | Test-7 | External layout | 13.5, 19.5 | 14.2 | 52.82 |
| | Test-8 | External layout | 13.5, 19.5 | 11.1 | 63.12 |
| Three array | Test-9 | Internal layout | 1.5, 7.5, 13.5 | 17.4 | 42.19 |
| | Test-10 | External layout | 7.5, 13.5, 19.5 | 13.8 | 54.15 |

Figure 14 shows the submerged vanes in the first layout and the developed scour trench around the vanes.

In the second layout (test 9), seven, nine and nine flow turning vanes were installed in the first, second and third rows, respectively.

The model was run with aforementioned two layouts of vanes. The amount of deposited sediment in the bay were measured 17.4 and 13.8 g, for the first and second layout, respectively.

## CONCLUSIONS AND RECOMMENDATIONS

This study presents sample results of a physical model testing program of Vies Pump station structure which investigated flow pattern in the front of water intake and submerged vane performance to prevent sediment from flowing into the water supply intake structure. The following conclusions and recommendations were derived from the present 1:130 horizontal and 1:50 vertical scaled distorted moveable bed model.

The hydraulic experiments show a circulation flow was formed in the water intake bay. Therefore it causes the sediment deposited in the front of water intake. Also the results of this study show the applying of different array can exclude the sediment into the water intake bay. To determine of this issue which array is more efficient, a comparison was made between the achieved results with different array vanes (Table 2).

As the comparison in the Table 2 is indicated, the two rows array (test-8) reduced the sedimentation 63.12% rather than to issue which non vanes were used in the front of intake. Therefore, it is recommended that two rows of scour-promoting, flow-turning vanes with concentration of vanes at upstream of the intake structure be installed. Each rows consisting of nine vanes at a distance of 13.5 and 19.5 m from the intake face (Fig. 14). These array vanes can act as a sediment barrier wall, thereby avoiding bed-load sediment entraining the pump bays. Suspended sediment entering the pump bays can never be stopped completely. However, the lower bed elevation at the stop log due to the scour trench should reduce the suspended-sediment concentration because this concentration is usually highest at the riverbed and lower towards the free surface.

Also the result of this study show the inclined vanes which installed just outside the water intake bay was very effective, in other word the external layout was effective rather than internal layout.

## REFERENCES


Barkdoll, B.D. and J.A. Odgaard, 1999. Sediment control at lateral diversions: Limits and enhancements to vane use. J. Hydraulic Eng. ASCE., 125 (8): 682-870.

Flokstra, C., 2006. Modelling of submerged vanes. J. Hydraulic Res., 44 (5): 591-602.

French, H.R., 1986. Open Channel Hydraulics. McGraw Hill, New York.

Nakato, T., J.F. Kennedy and D. Bauerly, 1990. Pump-Station intake-shoalling control with submerged vanes. J. Hydraulic Eng. ASCE., 116 (1): 119-128.

Novak, P. and J. Gabelk, 1981. Models in hydraulic engineering. Pitman Publishing London, UK., pp: 459.

Odgaard, J.A. and A. Spoljaric, 1989. Sediment Control by Sub-Merged Vanes: Design Basis. In: River Meandering, Ikeda, S. and G. Parker (Eds.). American Geophysical Union, Washington, DC., pp: 127-151.

Odgaard, A.J. and Y. Wang, 1991a. Sediment management with submerged vanes. I: Theory. J. Hydraulic Eng. ASCE., 117 (3): 267-283.

Odgaard, A.J. and Y. Wang, 1991b. Sediment management with submerged vanes. II: Applications. J. Hydraulic Eng. ASCE., 117 (3): 284-302.

Sinha, S.K. and F. Marelius, 2000. Analysis of flow past submerged vanes. J. Hydraulic Res. IAHR., 38 (1): 65-71.

Voisin, A. and R.D. Townsend, 2002. Model testing of submerged vanes in strongly curved narrow channel bends. Can. J. Civ. Eng., 29: 37-49.

Wang, Y. and A.J. Odgaard, 1993. Flow control with vorticity. J. Hydraulic Res. IAHR., 31 (4): 549-562.

Wang, Y., A.J. Odgaard, B.W. Melville and S.C. Jain, 1996. Sediment control at water intakes. J. Hydraulic Eng. ASCE., 122 (6): 353-356.