UTILIZING SEDIMENTATION DEFLECTOR SYSTEM FOR REDUCING SEDIMENTATION AT EL-KURIMAT POWER STATION INTAKE, EGYPT

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ABSTRACT

This paper presents the findings of undistorted movable hydraulic scale model 1:30 experiments conducted to investigate the efficiency of using the sediment deflector system in front of El-Kurimat Power station intake. The sediment deflector system consists of sediment barrier and submerged bottom vanes which used in preventing excessive bed sediment entry into riverside water intakes of El-Kurimat power Station. The hydraulic model simulates 2.5 km of the Nile River including the existing intake and the proposed two additional intakes for future extension. The model is running with different river flow conditions; minimum, dominant and the maximum discharges. Different alternatives for the sediment deflector system and two upstream flow deflectors were tested in order to increase the flow percentage in front of the existing intake and enhance the efficiency of the sediment deflector system. The model showed that the two upstream flow deflector was effective in increasing the flow in front of the existing and the proposed additional intakes. Also, the model showed that using the sediment deflector system with a certain length, height, angle and arrangement preventing the sediment entering the intakes of the power station.

INTRODUCTION

Rivers are dynamic in the sense that they have continuous morphological changes. Morphological changes are primarily manifested in the form of changes in bed-level, width and slope resulting from scour and deposition processes. Due to differential gradients normally existing in the transport of water and sediment in the river channel, scour and deposition of the bed and banks are more likely to occur.

Most of the Nile sediment load has been depositing in Lake Naser upstream High Aswan Dam (HAD) that had been in operation for about 39 years. This gives the impression that the almost silt free Nile River downstream the dam had reached equilibrium conditions as the water and small sediment flows are nearly constants in time. However, local scour and deposition in the Nile River have been observed at many places. Several sources of sediments exist such as sediment from wind-blown sands, from bank failure, dredging operations, flash floods and the Nile bed itself. The

Hydraulic Research Institute (HRI) has been involved extensively in solving the local scour and deposition problems in the Nile and its pioneering works are too many in this respect.

The Nile River reach at El Kurimat power plant is one example of the dynamic river changes where riverbed levels rise and severe sedimentation problems have been observed (HRI 1996, HRI 2000). El Kurimat power plant is located on the eastern bank side on the Nile. It has an intake of 40 m^3/s and a downstream outlet discharge unit about 500 m from the intake units. The power plant is located just downstream El Kurimat-island in a reach with several small islands or sand bars. This indicates that there is an intensive local sediment transport and deposition in this region. The year 2000 river survey revealed that the bed level of the river reached from 18.5m+MSL to 19.5m+MSL at the vicinity of the intake structure whereas the minimum water level at El Kurimat gauging station is about 20.46m+MSL. Clearly this situation constitutes a major problem to the operation of the pump unites withdrawing water from the intake structure. A second issue is that extension of the current power plant by adding new two additional intakes for two combined cycle units of 750 MW. The discharge that required is $13.6m^3/s$ for each unit. The locations of the two additional intakes were proposed upstream the existing intake. It is required to test the optimum location of the new units and to make sure that no sedimentation problems exist for both the current and future units. Figure 1 shows the surveyed reach which represents 9 km of the Nile River at El Kurimat area.

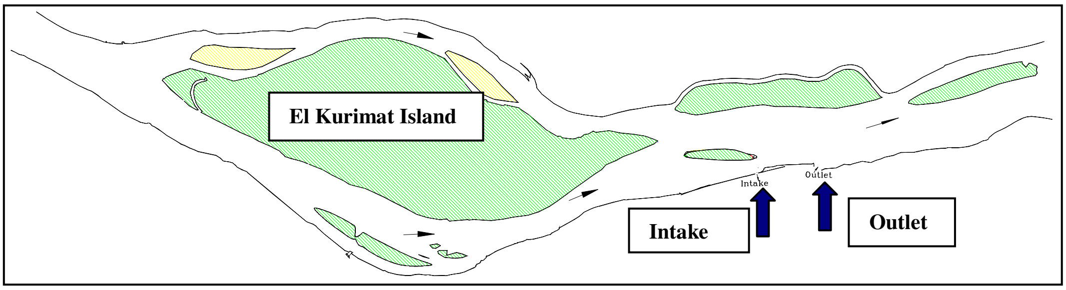

Figure 1 General layout of the Surveyed Reach

OBJECTIVES OF THE STUDY

The main objectives of constructing the physical model are as follow:

- Testing the proposed alternatives, which are suggested by the numerical model.
- Optimizing the selected alternative in order to get the final dimension of the selected alternative.
- Testing the effective length of the emerged groin and the dredging level of the area between the right bank and the small Island.

THE MOVABLE BED MODEL

Based on the available data and the site visit during 2003, a potential solution for the sedimentation problem in the exiting intake of units 1 and 2 will include the construction of an intake sill and /or sediment deflector barrier outside the intakes with or without an array of submerged vanes. The hydraulic model is used for determining the design parameters (length, height, and alignment) of such structures, which would be suggested by a numerical model and to provide a detailed mapping of the approach flow velocity distribution at the intakes. The proposed hydraulic model is an undistorted movable bed model which is considered to be a useful tool to simulate the erosion and sedimentation. The process takes place at the eastern branch of the river.

It should be noted that part of the model will be as fixed bed and at the problem area a special material is used. The discharge in the eastern branch of El Kurimat Island was determined as 52% of the discharge (1700 m^3/s) in the river, which is based on the data from the field.

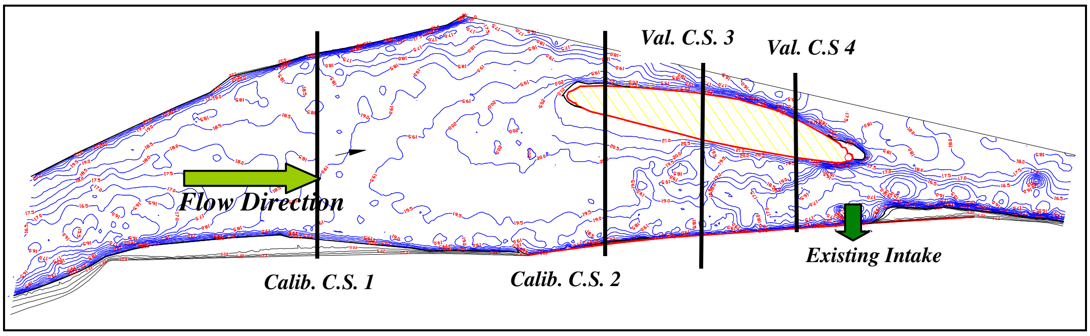

Figure 2 The Modeled Reach

For model verification the data from numerical model is used, the velocity distribution at different location in the eastern branch and the bed configuration. It should be noted that the bed material that is used in the model was made of PVC, which was chosen to simulate the bed material in prototype and the sediment in the river. The concentration of the bed material is obtained through a tap connected to the circulation pipeline.

MODEL SIMILARITY REQUIREMENTSError! Bookmark not defined.

For correct reproduction of the important hydraulic phenomena in a hydraulic model, a number of requirements must be fulfilled when determining the model scales.

Geometrical Similarity

Geometrical similarity of a model is achieved if all geometric dimensions (length, width, and depth) in nature, exhibit a constant ratio to the corresponding dimensions in the model.

Length ratio = n_l
Area ratio = $(n_l)^2$
Volume ratio = $(n_l)^3$

For the current case and for simplifying the modelling and analysis processes an undistorted model scale was chosen.

Kinematic Similarity

Kinematic similarity requires that time-dependent events proceeded in the model in such away, that corresponding time intervals in nature and the model would show a constant ratio:

$n_t = n_l / n_v$

Dynamic Similarity

Dynamic similarity implies that corresponding forces in nature and in model must show a constant ratio. These ratios can be derived from the relations between the acting forces in the flow field. The relevant forces in case of free surface flow with density difference are inertia, gravitation, buoyancy, and viscous forces. The force ratios are:

Froude Number

$$Fr = \frac{V}{\sqrt{gh}}$$

Reynolds Number

$$Re = \frac{Vh}{\nu}$$

From the condition that the scale of the Froude Number in both nature and model should be equal, the velocity scale ratio can be determined from which the other scale ratios can be derived:

Velocity scale ratio = $n_v = (n_h)^{0.5}$

Discharge scale ratio = $n_q = (n_h)^{2.5}$

Time scale ratio = $n_t = n_l / n_v = n_l / (n_h)^{0.5}$

Since generally the kinematic viscosity in the model and prototype is the same, the condition that Reynolds Number is equal for both prototype and model in combination with the velocity scale determined as above can not be fulfilled. However in practice the nature of the turbulent transport does not depend upon the Reynolds Number as long as it exceeds a certain critical value. For river models this value is

$$Re_c = V\, h / \nu \geq 2000$$

Additional Scale Requirements for Movable Bed

The similarity criteria, for morphological parameters governing mobile bed models, are quite complex, because both water movement and sediment movement have to be respected. Sometimes the model results, for the above reasons, appear to be not very precise. It is mainly the respect of sediment transport conditions that increases the complexity of the problem, especially if the prototype morphological conditions should be exactly known.

MODEL SCALE

The model was designed as movable bed model with scale 1:30, and the density of the prototype bed material is 2650 kg/m^3 and has a particle diameter D_{50} of 0.30mm. The model bed material has density of 1010 and particle diameter D_{50} of 1.6mm. Such material should not present any secondary phenomena of electrostatic nature. In addition, it should be chemically inert so that does not react with eventual actions present in the water. The details of scale parameters are given in Table 1.

Table 1 Summery of Model Scale Parameters

Parameters	**Prototype**	**(Prototype/model) Ratio**	**Model**
Length scale ratio n_h		30	
Velocity scale ratio $n_v = (n_h)^{0.5}$		5.48	
Time scale $n_t = (n_h)^{0.5}$		5.48	
Discharge scale ratio $n_Q = (n_h)^{2.5}$		4929.5	
Bed material diameter scale ratio $n_D = (n_h)^{-0.5}$		0.18257	
Density scale ratio $n_\Delta = (n_h)^{1.5}$		164.317	
Similarity Results			
Simulated prototype length (m)	2100m	30	70 m
Averaged prototype width (m)	550m	30	18.5 m
Discharge (m^3/s)	1700/2 m^3/s	4929.5	172.4 lit./s
Bed material diameter D_{50}	0.3 mm	0.18257	1.6mm
Bed material density	2650 kg/m^3	164.317	1010kg/m^3

The model was constructed in the northern experimental hall of HRI. Photo 1 presents the layout of the modelled reach. The modelled reach simulates the eastern branch of the Nile River, which is bordered by the right bank of the River and El Kurimat Island. In the model, the small island in front of the power plant intake structure is presented in detail. Part of the River width to the west of the small island is represented.

Photo 1 General View of El Kurimat Movable Bed Model

MODEL CALIBRATION AND VALIDATION

The model was calibrated at two cross sections with fixed bed as shown in Figure 2. The total discharge of 496 m^3/s and the water level of 21.35m +MSL from the eastern channel of El Kurimat Island. The first cross section was located at the entrance of the model to adjust the flow at the entrance. The second cross section located between the small island and the right bank. The velocity was measured in prototype at 60% of water depth at seven points along the cross section. The results of the calibration after several trails were successfully carrying out at both cross sections as shown in Figure 3.

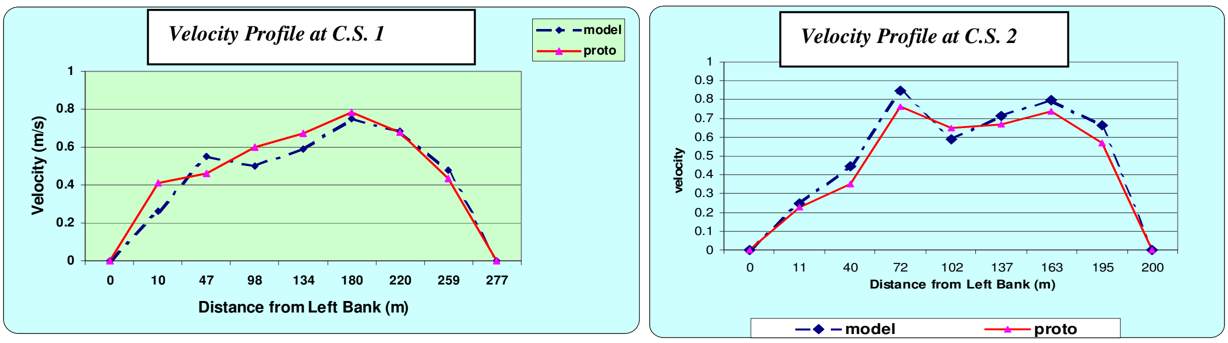

Figure 3 Model Calibration at Cross Section 1 and 2

Another discharge and water level from numerical model were used for model validation. The discharge was 626 m^3/s and water level was 22.84m +MSL at the Power Plant. There were two cross sections used in the model validation and located between the small island and existing intake as shown in Figure 2. The velocity was measured at mid depth at 10 points along the cross section. The results of the model validation were shown in Figure 4.

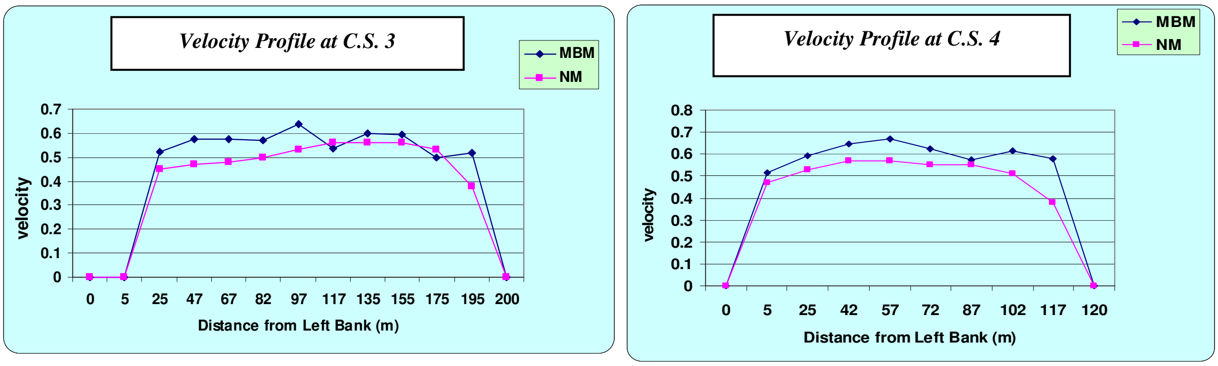

Figure 4 Model Validation at Cross Section 3 and 4

THE TEST PROGRAMME

The model test programme covered both the sediment enclosure devices and the River Training Structures. The sediment enclosure devices were implemented to eliminate the sediment ingress towards the existing intake structure. While, trimming the top end of the sandbar and several combination of dredging activities and groin construction constitutes the main River Training alternatives.

Table 2 presents the test programme that was carried out to find the most efficient method to ensure the safe operation of the existing cooling system and to allow for the construction of new power plants.

The tests were carried out according to the Nile River hydrograph. The followed up hydrograph was defined according to the available five years records of the water levels and discharges as defined in Table 3.

Table 2 Model Test Programme

Alt. No.	**River Disch.**	**Water Level M+ MSL**	**Groins Dimensions KI**			**Groins Dimensions SI**	**Dredging Level m+ MSL**	**Small Island Cond.**	**Bottom Vanes Crest Level m+ MSL**	**Sub. Sill Crest Level m+ MSL**	**Existing Intake**	**New two Intakes**
			100 m	**125 m**	**150 m**	**50 m**						
2	Max. Dom. Min.	23.52 21.79 20.46	**X**	**X**	**X**	**X**	18.00	Cutting	18.50	18.50	□	**X**
3	Max. Dom. Min.	23.52 21.79 20.46	□	**X**	**X**	**X**	18.00	Cutting	18.50	18.50	□	**X**
5	Max. Dom. Min.	23.52 21.79 19.95	□	**X**	**X**	**X**	18.00	Original	18.50	18.50	□	**X**
6	Max. Dom. Min.	23.52 21.79 19.95	□	**X**	**X**	□	18.00	Original	18.85	18.85	□	□
7	Max. Dom. Min.	23.52 21.79 -	**X**	□	**X**	□	18.00	Original	18.85	18.85	□	□
8	Dom.	21.79	**X**	**X**	□	□	18.00	Original	18.85	18.85	□	□
9a	Max. Dom. Min.	23.52 21.79 19.95	□	**X**	**X**	□	18.00	Original	18.85	18.85	□	□
10	Max. Dom. Min.	23.52 21.79 19.95	□	**X**	**X**	□	18.00	Original	18.85	18.85	□	□

Table 3 River Hydrograph Conditions

River Flow Condition	**Water Level M+MSL**	**Discharge m^3/s**	**Period Month**
Minimum Flow	20.46	733	1.5
Dominant Flow	21.79	1038	4
Maximum Flow	23.52	2098	2
Dominant Flow	21.79	1038	4
Absolute Minimum Flow (Winter Closure)	19.95	463	0.5

THE MEASUREMENTS

The flow velocity was measured at five cross sections as shown in Figure 5. The Cross sections numbers 1, 2 and 3 were located upstream the existing intake. Cross section Number 4 at the center line of the existing intake and the cross section number 5 was located downstream the existing intake. The velocity was measured at the mid depth. The calibration velocity cross sections were measured at some cases to get the percentage discharge which passes through the eastern channel. These five cross sections were measured with the maximum, dominant and Minimum River flow. For each alternative the following measurements were carried out:

- Five cross-sections velocity profiles.
- Bed configuration after each alternative at the five cross-sections.
- Video recording for changing the bed with each alternative.
- Digital camera for bed change during and after each alternative.

The two proposed intakes, combined cycle units were tested with Alternatives 3 to 10.

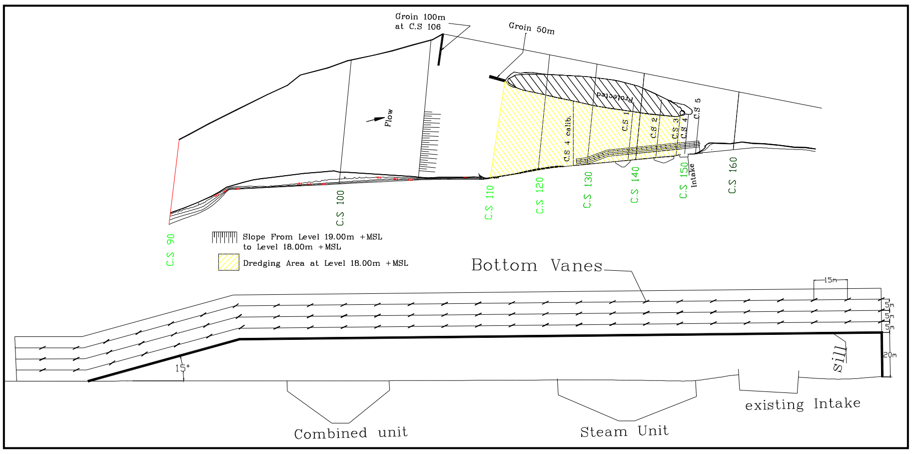

Figure 5 The Arrangement of the Submerged Sill and Bottom Vanes and the Proposed Groins at El Kurimat Area

RESULTS AND ANALYSIS

The main aim of the investigation was to provide a solution to the sediment ingress problem towards the existing intake and to allow for the construction of the new power plants by increasing the flow passing to the east of the small island. The results of all simulation indicated that the submerged vanes managed to direct the bed sediment load away from the existing intake while the submerged sill prevented sediment from entering the existing intake.

Table 4 presents the percentage discharge passing to the east of the small island with all alternatives based on the velocity profile at cross-section 1 of the five velocity cross-sections.

Table 4 The Percentage Discharge at the Eastern Channel with Different Alternatives

Alt. No.	River Discharge.	Bed Level m+MSL	Cross Sec. Area m^2	Average Velocity m/sec	Q Passing in Eastern Channel m^3/sec	Percentage Discharge %Q
2	Maximum	18.07	1007.00	0.692	697.00	33.20
	Dominant	18.04	694.00	0.420	291.50	28.10
	Minimum	17.80	492.00	0.375	184.40	25.17
3	Maximum	18.07	1007.00	0.797	802.60	38.25
	Dominant	18.04	694.00	0.528	366.40	35.30
	Minimum	17.80	492.00	0.427	210.10	28.66
5	Maximum	17.81	858.00	0.820	703.60	33.53
	Dominant	18.13	560.00	0.637	356.70	34.37
	Minimum	18.05	308.00	0.573	176.50	38.12
6	Maximum	17.73	864.00	0.853	737.00	35.13
	Dominant	17.80	598.00	0.640	382.70	36.87
	Minimum	17.76	326.00	0.570	185.80	40.13
7	Maximum	17.68	873.00	0.857	748.20	35.66
	Dominant	17.73	607.00	0.672	407.90	39.30
8	Dominant	17.67	588.00	0.668	393.00	37.84
9a	Maximum	17.64	880.00	0.810	712.80	34.00
	Dominant	17.72	608.00	0.638	387.90	37.37
	Minimum	17.70	334.00	0.495	165.30	35.71
9b	Observation only					
10	Maximum	17.45	909.34	0.876	796.60	38.00
	Dominant	17.52	639.20	0.666	425.70	41.00
	Minimum	17.52	374.40	0.416	155.64	33.64

Trimming the small island was not effective as indicated from the comparison between the results of alternatives 2 and 3. The results show that the discharge through the eastern channel has hardly changed due to small island reshape. The civil work associated with the island reshape will be very expensive baring in mind the minor increase in flow percentage. It was found that groins could help effectively to obtain the required increase in flow through the River branch to the east of the sandbar.

An emerged groin with length of 50m upstream the small island was needed together with another one of 100m length at the north of the El Kurimat Island in order to increase the percentage discharge at the eastern channel.

The two proposed intakes of the planned combined and steam units were also tested. Also, the crest level of the sill and the bottom vanes were fixed at level of 18.85m +MSL. With alternative 4 the percentage discharge at the eastern channel was increased to be 35.13, 36.87 and 40.13% with the maximum, dominant and minimum River flows respectively.

The Groin Length at Kurimat Island

The groin length was tested with alternatives 5 and 6 in order to get the optimum length. Groin with lengths of 125m and 150m were tested in alternatives 5 and 6 respectively. The percentage discharge during alternative 5 was found to be 35.66 and 39.3% with maximum and dominant River flow respectively. Also, during alternative 6 the percentage discharge was found to be 37.84% with the dominant River flow. As a result it was decided to limit the length of the groin to 100m.

The Location of the Groin With Respect to the Kurimat Island

Alternative 7 was implemented to test the effect of location of the emerged groin. A new location was tested. The new location of the groin was 125m south of the Main Island Northern tip. The percentage discharge was found to be 34, 37.37 and 35.71% with maximum, dominant and minimum River flows, respectively. By comparing the results of alternative 4 and 7 from the percentage discharge point view, it was found that no major change was achieved. But the location of the groin in alternative 7 is more acceptable from the construction and site characteristics point of view.

The Effect of Minimum Flow

During testing alternatives 4, 5, 7, 8 and 9 with the minimum River flow especially after installing the emerged groin at the tip of the Kurimat Main Island, it was observed that flow passes through two narrow streams, one closed to the right bank and the second is closed to the small Island. The area in the middle of the eastern channel and closed to the sandbar has a level ranges between 18.00 to 20.50 m MSL while the water level with the minimum river flow was 19.95m +MSL. Therefore, most of cross section area was blocked; consequently high velocity closed to the right bank was created. This high velocity moved the bed material towards the intakes. The need for dredging is then essential to allow for better flow velocity distributions.

During testing alternative 7, it was observed that there was scouring and sedimentation at the right bank. The eroded area of the right bank was the source of depositing material that reached the bottom vanes near the intake structure. Also, during testing alternative 9, it was observed that there was scouring and deposition at the right bank. The eroded material was moved and deposited at the bottom vanes vicinity.

Dredging the area between the right bank and the small island to a level 18.00m +MSL will improve the flow condition and the percentage discharge through the eastern channel. Also, it was observed that there was no scouring and deposition at the right bank with alternative 8 especially during the minimum River flow.

The submerged sill

The total length of the submerged sill is 355.5m with crest level of 18.85m+MSL. The length of the submerged sill divided into two parts; the first has a length of 287m and parallel to the sheet piles on the right bank, the second part has a length of 68.5m and has an angle of 15 degrees with the sheet piles on the right bank. The distance between the sill and the sheet piles is 20m. Photo 2 shows the arrangement of the sill and the bottom vanes

The submerged bottom vanes

The bottom vanes are distributed along the length of the submerged sill in three rows. The crest level of the submerged bottom vanes is 18.85m+MSL and has a length of 3m. Also, it has an angle of 25 degrees with the line parallel to the sheet piles on the right bank. The distance between the submerged sill and the first row of the bottom vanes is 5m. The distance between the centerline of the bottom vanes parallel to the sheet piles is 5m. The distance between each three vanes is 15m. The bottom vanes on the inclined part have an angle of 20 degrees with the line parallel to the inclined line. The total number of the bottom vanes is 78. Photo 2 shows the detail arrangement of the bottom vanes, which tested in the model.

Photo 2 The arrangement of the Tested Submerged Sill and Bottom Vanes in the Model

CONCLUSIONS AND RECOMMENDATIONS

A hydraulic movable bed model with scale 1:30 was constructed as the study tool to investigate the proposed alternative to eliminate sediment ingress to the existing intake structure of the El Kurimat Thermal Power Station. The study aims also to find the most suitable yet economical River Training Activity to increase the flow percent passing to the east of the existing sandbar in front of the power plant.

The following are the main conclusions of the movable bed model:

- The sediment barrier "submerged sill" and submerged bottom vanes with crest level 18.85m +MSL have a very good effect in preventing the accumulation of bed load in front of the intake.
- Trimming of the small Island has minimum effect on increasing the discharge through the eastern channel, if compared with its cost.
- Dredging the area between the small island and the right bank of the eastern channel to level of 18.00m+MSL has a better effect for the percentage discharge through the eastern channel, as well as sediment accumulation at the sill vicinity.
- Groin of 100m at cross-section 106 in alternative No.6 "at the tip of EL-Kurimat Island" in addition to groin of 50m at upstream the small island increase the discharge of eastern channel to reach 35% of total river flow.
- Groins of 125m and 150m increase this percentage to 37% of total river flow.
- Groin of 100m at cross-section 103 in alternative No.9a in addition to groin of 50m at upstream of small Island gives a percentage discharge at the eastern channel similar to that one with alternative No.6, but improving the sediment accumulation at the sill vicinity. It also far from the gas pipe line of Petrojet Co.
- There was no series effect of the operation of the combined cycle intake on the existing intake.
- Velocities at the right bank in front of the groin with length 100 on Kurimat Island reached 1.2 m/s during the minimum flow condition. Therefore, rip rap protection is needed.
- The Nile River training activities have a great impact on the flow condition. Due to the hydraulic conditions of the area under consideration, a regular monitoring programme is required to identify the progress of the solution and provide insight to the river morphological condition.

Based on the results of the model, it is recommended to construct the alternative No.10. This alternative included the following:

- Construct a deflector (groin) of 100 m length located far from the most down stream end of the Kurimat Island with a distance of 125 m to the upstream direction. The deflector is located in the eastern branch of the Kurimat Island and is perpendicular to the flow direction.

- Construct a deflector (groin) of 50 m length located at the most upstream end of the small island. Its direction parallel to the flow direction.
- Dredging the area between the small Island and the sheet pile should be following the bed configuration as indicated in Alternative No.10.
- Bank protection was needed for the right bank with a length of 350m upstream the existing sheet piles.
- Carry out a bathymetric survey each year after the flood period for the studied area to provide the recommendations if any maintenance is required.
- Carry out an inspection on the pipeline area after each draught period to maintain the safety of the pipeline.
- The length of El Kurimat Island groin might be increased to 120m if needed based on the results of the monitoring programme.

LIST OF ABBREVIATIONS

V or v	Avarage flow velocity	(m/s)
g	Gravitational acceleration	(m/s^2)
h	Mean flow depth	(m)
ρ	Density of the fluid	(kg/m^3)
ν	Kinamatic viscosity	(m^2/s)
D	Mean flow depth	(m)
Fr	Froude number	(-)
Re	Reynolds number	(-)
n_h or n_l	Length scale ratio	(-)
n_t	Time scale ratio	(-)
n_v	Velocity scale ratio	(-)

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