Original Article

The use of baffle columns to mitigate undesired hydraulic conditions at river intake structures

Abdel Hamed Khater *, Muhammad Ashraf

National Water Research Center (NWRC), Hydraulics Research Institute (HRI), Delta Barrage 13621, Egypt

Abstract

In practice, the location of riverside water intakes is chosen based on land-property considerations rather than strict design criteria. For power plants intakes, abstraction efficiency is directly affected by the uniformity of flow distribution within the intake structure. The intake structure of South Helwan Power Plant (SHPP) is located downstream a Groin Like Formation (GLF) at the right bank of the Nile River, South Cairo, Egypt. This GLF disrupted the uniformity of flow approaching the intake. In this study, an arrangement of baffle-columns at the upstream and the offshore sides of the intake structure was investigated as a mitigation measure for flow non-uniformity at the intake. A scaled physical model was constructed, and three different configurations of the proposed structure were tested and compared to the base case without the installment of the baffle columns. During these scenarios, the changes in transverse and longitudinal flow velocities were observed. Results demonstrated the effectiveness of the baffle-columns in achieving uniform flow conditions. The baffle-columns technique may present a viable solution to resolve non-uniform flow problems at numerous riverside water intakes.

© 2017 Production and hosting by Elsevier B.V. on behalf of Cairo University. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

Thermal power plants are equipped with cooling systems to mitigate the excess heat associated with the plant operation. These plants use once-through cooling systems to cool down the con-
densers. In these systems, cold water is withdrawn from a water body through an intake structure, and then circulated through the plant. The effluent warm water is eventually discharged back to the water body. As a result, these water bodies are adversely impacted by the operation of the cooling system [1]. The locations of Power plants are mostly selected based on the proximity of natural water-body that can be used in the cooling systems [2]. For example, Iowa’s Council Bluffs power station is located along the left concave bank of the Missouri river near Council Bluffs, Iowa [3]. Similarly, many power plants in Egypt are constructed at the banks of the Nile, e.g., Banha Power Plant. This plant’s capacity is 750 MW and abstracts its cooling water from El-Rayah El-Tawfiki through its intake and water is discharged back through the plant outfall [4]. Tebbin Power Plant was constructed at the right bank of the Nile River, about 30 km upstream of the Delta Barrage, and is equipped with a direct once-through cooling system [5]. Talkha power plant generates electricity using two different methods by steam turbines and gas turbines. It is located in Talkha City, Dakahlia Governorate, at the West Bank of the Nile River, Damietta Branch [2]. El Kurimat power plant is located on the eastern bank side on the Nile and abstracts 40 m$^3$/s for the plant operation [6]. The above mentioned plants are located along the Nile River to use its water during plant operation and cooling. Many other plants were built along the Nile River and future plants are planned to be built as well.

The expansion in the construction of power plants in Egypt is led by the increasing demand on electricity. Consequently, the Ministry of Water Resources and Irrigation (MWRI) has set rules and regulations in order to preserve the environmental conditions and the stability of the Nile River and other channels. These rules and regulations are included in the Ministry of Environment Law No. 9, 1994. This law imposes restrictions on the discharge of heated water to open channels by limiting the increase in water temperature to 3 °C above the ambient water temperature with a maximum water temperature of 35 °C. To study the efficiency of cooling systems and their impacts on the environment, hydraulic models are considered as a robust and efficient tool for providing a clear insight into the flow distribution in the vicinity of the intake structure.

**Study area**

The South Helwan Power Plant (SHPP) includes a direct once-through cooling system that uses water abstracted from the Nile River. The plant’s capacity is 3 × 650 MW, which is generated using natural gas, residual (Mazout) oil, or a combination of both. SHPP is located in Helwan Governorate, which is 100 km south of Cairo and 23 km north of Bani Suef, as shown in Fig. 1. The area of land allocated to the plant is about 480 m wide and 750 m long (29.218°N 31.212°E, 29.219°N 31.219°E). It is located at the east bank of the Nile River, 7.5 km upstream of El-Kureimat power plant and 0.75 km upstream of El-Kureimat island.

The intake structure of the SHPP is located downstream of an elevated natural-land located, as shown in Fig. 2. This part of the bank which can be called “Groin Like Formation (GLF)” is functioning from the hydraulic point of view as an artificial groin, where the approaching flow is subjected to a high degree of non-uniformity, a creation of an area of separation, and reverse flow. These non-uniform hydraulic conditions of the approaching flow towards the intake location negatively affect the desired flow pattern inside the intake structure.

**Problem identification**

The uniformity of flow approaching the intake structure is of great importance to the efficiency and performance of the pumps. Consequently, this uniformity represents a basic requirement for the design of the intake structure. The alignment of the intake structure, the bathymetry of the waterway bed and banks, and the river-flow conditions approaching the intake structure are significant factors that may affect the flow uniformity and induce unfavorable flow conditions. For example the existence of GLF in a waterway divides the flow in its vicinity into two regions, the
Groins decrease the effective width of channels causing flow to accelerate in the region between the groin tip and the opposite channel bank. Moreover, two zones of eddies and recirculation are formed directly at the upstream and downstream of the groin. The recirculation zone at the downstream of the groin starts from the tip of the groin and stretches with the same width towards the downstream direction, and then its width starts to decrease until the main flow region eventually spans the entire width of the waterway. These hydraulic conditions may not only affect the abstraction efficiency of the intake, but also disturb the natural flow regime of the river.

**Fig. 2.** General alignment of the intake and outfall structures of South Helwan Power Plant (SHPP).

**Fig. 3.** A view of South Helwan Power Plant (SHPP) modeling facility from upstream direction.

**Fig. 4.** A view of South Helwan Power Plant (SHPP) modeling facility from downstream direction.

**Fig. 5.** The modeled intake structure with baffle columns of South Helwan Power Plant (SHPP).
uniformity of flow passing through vents of the intake structure is essential to the efficiency of the intake’s performance and the safety of the suction pump units [9].

Objectives

The effect of such unfavorable hydraulic conditions, due to the existence of GLF, on the performance and the efficiency of intake structures has not been investigated by many researchers. Detailed assessment of the hydraulic conditions at the SHPP intake and evaluation of the effectiveness of using mitigation measures to enhance flow uniformity in its vicinity is the main objectives of this study, regardless of the conditions at or impact on the pump units themselves.

Methodology

An innovative technique using baffle columns was employed in this study to overcome the non-uniform flow problem. Different configurations of the baffle columns were used to achieve this objective. Physical modeling was chosen as an effective tool to study the effect of these baffles columns on the flow uniformity.

Physical model

A physical model was constructed at the Hydraulics Research Institute experimental hall, National Water Research Center (NWRC), Delta Barrage, Egypt to study the flow hydrodynamics in the study area, Figs. 3 and 4.

The model represents part of the Nile River and the intake structure. The physical model was scaled according to the Froude Similarity Laws with an undistorted geometrical scale of 1:38. The value of the Reynolds number was in the range of 4000, which satisfies the requirement for simulation. The model was successfully calibrated as it reproduced the measured velocity distribution at four

Table 1
Different configurations for the baffle columns allocations.

| Configuration | Upstream baffle columns | Off-shore baffle columns |
|---------------|-------------------------|--------------------------|
| Base case     | No                      | No                       |
| 1             | Yes                     | No                       |
| 2             | No                      | Yes                      |
| 3             | Yes                     | Yes                      |

Fig. 6. The chosen grid in front of the intake structure of South Helwan Power Plant (SHPP) for velocity measurements.

Fig. 7. Base case and tested three configurations of the baffle columns of South Helwan Power Plant (SHPP) downstream of Groin Like Formation (GLF).

Fig. 8. Non uniform flow in the intake structure of South Helwan Power Plant (SHPP).
Fig. 9. Velocity vectors indicating the presence of flow nonuniformity in the basin.

Fig. 10. (a) Flow velocities inside the vents of the intake structure for base case, (b) longitudinal flow velocities at the selected grid points, (c) transverse flow velocities at the selected grid points.
cross-sections in the prototype. The inflow discharge into the model was 252.2 L/s, which represents the maximum seasonal discharge of the Nile River (2245 m³/s). The intake was constructed according to the design drawings including the piers and sediment basin (Fig. 5). The pump intake was designed to uniformly withdraw 75 m³/s through the twenty vents with an average velocity of 0.2 m/s.

Modeled scenarios

Three different configurations of baffle columns were introduced to the model to be tested as shown in Table 1 and Fig. 6. The effect of each configuration on the flow velocities downstream GLF and inside the intake vents were observed and recorded. Seventeen longitudinal sections (1:17) and eight transverse sections (A:H) were used to cover the simulated area of this study, as shown in Fig. 7.

Two dimensional velocity components were measured by electromagnetic velocity meter. The measurements were taken at approximately 60% of water depth, representing the depth averaged velocity. Wooden parts were used to simulate the baffle columns and to determine the performance of each configuration.

Simulation results

Base case

The base case represents the model without installing the baffle columns. During the base case, fine plastic-tracers were used to track the paths of flow as shown in Figs. 8 and 9. In this case, negative flow was observed at the first six vents as shown in Fig. 10a. Flow velocities reached up to 0.63 m/s at vent number 19. These high velocities occurred as a consequence of the negative velocities
occurring at the first few vents. Longitudinal velocity-sections showed positive flow velocities outside and inside the offshore edge of the basin as shown in Fig. 10b. Then, flow velocities decreased gradually towards the intake vents until negative flow velocities were observed. The natural flow-distribution is expected to decrease gradually towards the vents without reversing direction (to negative flow) as shown in Fig. 10b, Sec 1:4. The observed negative velocities reveal the significant impact of the GLF on the flow in the vicinity of the intake. Negative flow velocities occurred and extended longitudinally from C.S. 6 until C.S. 13, and transversely from C.S. A to the middle of the basin, as shown in Fig. 10c. The effect of the GLF diminished at C.Ss. 15:17 and the river reverted to its natural regime.

Configuration 1

In this case, velocities improved at the first few vents and negative flow velocities diminished compared to the base case. However, negative flows occurred at vents 1 and 2 and velocities at the last few vents decreased to 0.35 m/s. Generally, flow uniformity at the intake vents was not attained, as shown in Fig. 11a. Fig. 11b showed that the observed negative longitudinal velocities during the base case (inside the basin) were minimized, as an impact of the modification in configuration 1. Additionally, Fig. 11c showed that reverse transverse velocities inside the basin diminished compared to the base case. Transverse velocities showed positive values flowing inwards to the

Fig. 12. (a) Flow velocities inside the vents of the intake structure for configuration 2, (b) longitudinal flow velocities at the selected grid points, (c) transverse flow velocities at the selected grid points.
intake vents at C.S. A:H at most of the basin area except for C.S. 7 at A:D.

Configuration 2

For configuration 2, the velocities entering the intake at the last few vents decreased (compared to the previous cases), as shown in Fig. 12a, and the highest flow velocities were observed at the middle vents. Although negative flow was observed at fewer vents compared to the base case, higher negative velocities were observed with a maximum value of 0.4 m/s, as shown in Fig. 12a and b. The highest longitudinal and transverse velocities were observed near to the offshore edge of the basin at sections 6–7 (The first vents from the upstream direction), and the peak velocities migrated inwards in the basin until the middle vents. Moreover, negative longitudinal and transverse velocities were observed at the first vents, which is an indication of flow circulation taking place in this region.

Configuration 3

The distribution of flow entering the vents (Fig. 13a) presented the combined effect of configurations 1 and 2. Reverse flow was minimized and occurred only at vents 1 and 2 as an effect of configuration 1. Also, the concentration of the flow appeared at the middle vents due to the effect of configuration 2. This configuration showed improved flow distribution compared to previous configurations. Fig. 13b showed that velocities inside the basin were very low compared to that outside of the basin. It can be concluded that the baffle columns minimized the negative velocities inside the basin. The average variation of measured velocities was ±0.03 m/s (prototype units), which is shown as error bars in graphs (a) of

Fig. 13. (a) Flow velocities inside the vents of the intake structure for configuration 3, (b) longitudinal flow velocities at the selected grid points, (c) transverse flow velocities at the selected grid points.
Conclusions and recommendations

This paper presents the positive impact of baffle-columns on minimizing the non-uniform flow distribution and reverse flow velocities approaching the intake structure. Different configurations of the baffle columns were investigated using a scaled physical model.

Base case (without baffle columns) showed non-uniform flow distribution inside the vents of the intake structure. Reverse flow occurred at the first six vents from upstream side. Configuration 1 of the baffle columns managed to minimize the negative flow (which occurred only in the first two vents in this case) and decreased the high velocities at the last few vents. Configuration 2 redistributed the flow to be concentrated at the middle part of the vents, and high negative velocities as still observed in the first few vents. On the other hand, Configuration 3 combined the positive effect of the configurations 1 and 2 and provided the best velocity distribution approaching the intake vents. The flow uniformity was significantly improved by this arrangement of the baffle columns. However, a completely uniform-distribution is still not obtained. Possible means of overcoming the aforementioned disadvantages might be accomplished by varying the baffle-columns spacing or adjusting their orientation angle.

As a conclusion, this newly developed approach of using baffle columns improved the hydraulic conditions at the inlet, and had a significant effect in mitigating the undesired flow patterns approaching and entering the intake structure. Therefore, this technique is highly recommended for enhancing the intake withdrawal-efficiency, through eliminating undesired non-uniform flow conditions approaching the intake.

Conflict of interest

The authors have declared no conflict of interest.

Compliance with Ethics Requirements

This article does not contain any studies with human or animal subjects.

Acknowledgments

The experimental work reported in this study was carried out at the Hydraulics Research Institute (HRI) experimental lab, National Water Research Center (NWRC), Ministry of Water Resources and Irrigation (MWRI). The author gratefully acknowledges the collaboration and effort done by the staff members of the Institute during the experimental work.

References

[1] Ali J, Fieldhouse J, Talbot C, Mishra R. The diffusion of thermal discharge into water. International conference on flow dynamics, Sendai, Miagai, Japan; 2009.
[2] Rady RA. Modeling the hydrothermal impact of the capacity extension of talkha power plant. J Appl Sci Res 2011;7(12):2506–16.
[3] Nakato T, Kennedy JF, Bauerly D. Pump-station intake-shoaling control with submerged vanes. J Hydraul Eng 1990;116(1):119–28.
[4] Shawky Y, Nada AM, Abdelhaleem FS. Environmental and hydraulic design of thermal power plants outfalls case study: banha thermal power plant, Egypt. Ain Shams Eng J 2013;4(3):333–42.
[5] Mahgoub SE. Investigating the velocity distribution in the vicinity of power plant intake structure (Case Study The Tebbin New Power Plant Intake Structure). Int J Appl Sci Eng Res 2013;2(4).
[6] Ali AM, El-Balasy A, Soliman M. Utilizing sedimentation deflector system for reducing sedimentation at El-Kurimat power station intake, Egypt. In: Eleventh international water technology conference, IWTC11 2007 Sharm El Sheik, Egypt; 2007.
[7] Chen FY, Sieda S. Horizontal separation flows in shallow open channels with spur dikes. J Hydrosi Hydraul Eng, JHHE 1997;15(2):15–30.
[8] Yossef YF. The effects of groynes on rivers. (Literature Review), Delft Cluster Report No. DC1-334-4, Delft University, The Netherlands; 2002.
[9] Nakato T. A hydraulic model study of Korea electric power corporation's ulchin nuclear units 3 and 4 circulating water and essential service water intake structures. Iowa Institute of Hydraulic Research, the University of Iowa, Iowa City, Iowa; 1994.