Physical Model Investigation of Pump Station Basins

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Abstract

Experimental tests were carried out to improve the flow patterns and vortices formation in a pump station basin. An undistorted physical model, of scale 1:30, was constructed in the Hydraulics Research Institute (HRI) Laboratory hall. Different alternatives were proposed and simulated. These alternatives consists of the original design with side slope of 2:1, another alternative with side slope of 1.25:1 and a third with different basin shape entrance. The model was then modified by adding a bridge at its end. All possible pump operation conditions were simulated and measurements (i.e. velocity distributions along three cross sections at several layers in the approach flow for each operation condition, the vortices created in the front of the intakes, eddies and separation zones in the basin) were undertaken. The results of the measurements were analyzed and discussed.

It was found that the vortex formation decreased when a curtain wall was added. It was also noticed that the flow separation occurs at the beginning of the side slope. It was thus recommended to operate the pump symmetrically at low water level. This would help to avoid vortex formation, which might reduce total pumping capacity. Evaluation of the tendency to vortex formation preferred to be made with the results from intake model**.**

Keywords: Undistorted model**,** pump basin**,** velocity distribution, vortices**,** separation zones**,** approach flow and intake model.

1. INTRODUCTION

Flow patterns and vortices formation induce big problems in pump stations basins such as reduce pump discharge and loss of efficiency, vibration and causes the load on the impeller to fluctuate, which can lead to noise, vibration and bearing problems. In order to improve this, a physical model of Mubarak pump station was employed. This pump station basin (Mubarak pump station) is located on the western bank of Nasser Lake at about 230 km upstream Aswan Dam, figure 1. The discharge is conveyed from the lake to the basin by canal with a bottom width of 10 m and a level of 134 m ASL which is the same pump station bed level.

Experimental tests were carried out in a pump station basin. The pump station consists of 24 units with a double row of pumps grouped parallel to the conveyance canal axis, which coincides with the axis of the pump station. The basin has a bed level of 134 m ASL and is connected to a lake which has minimum water level of 147 m ASL.

The water level in the basin is almost identical to the level of the lake. The pump station has a length of 138.85 m and a width of 44.80 m. The design discharge per unit of the pump station is 16.7m^3/s.

Figure 1: Satellite images show the location of Mubarak pump station on the western bank of Nasser Lake

2. STUDY OBJECTIVES AND METHODOLOGY

The aim of the study is to investigate the flow characteristics in the pump basin and pump intake area at different configurations of the basin shape and pump operations. These flow investigations include the flow velocity at different layers, the flow separations and the formed vortices. An undistorted physical model of scale 1:30 of the pump basin and a part of the conveyance canal was built.

3. THE PROPOSED ALTERNATIVES

The original design has a circular shape entrance, (the connection of the suction basin and the conveyance canal). The side slope in both the basin and the conveyed canal is 2: 1. In order to achieve the above objectives, four alternatives were proposed. Also the original design was taken into consideration. The alternatives are described below:

- The first alternative is similar to the original design with a variation of the shape of basin entrance.
- The second alternative is similar to the original design with a side slope of 1.25: 1.
- The third alternative is similar to the original one with all gates provided by a curtain wall.
- The forth alternative is similar to the original one provided by a bridge at the end of the basin with a bed and bottom slab levels of 132.5 and 141.5 m ASL, respectively. It is also provided by a gate which can prevent the water flow to pass to the other side of the basin.

Figures 2, 3 and 4 are sketches to the forth alternative, cross sections A and C, respectively.

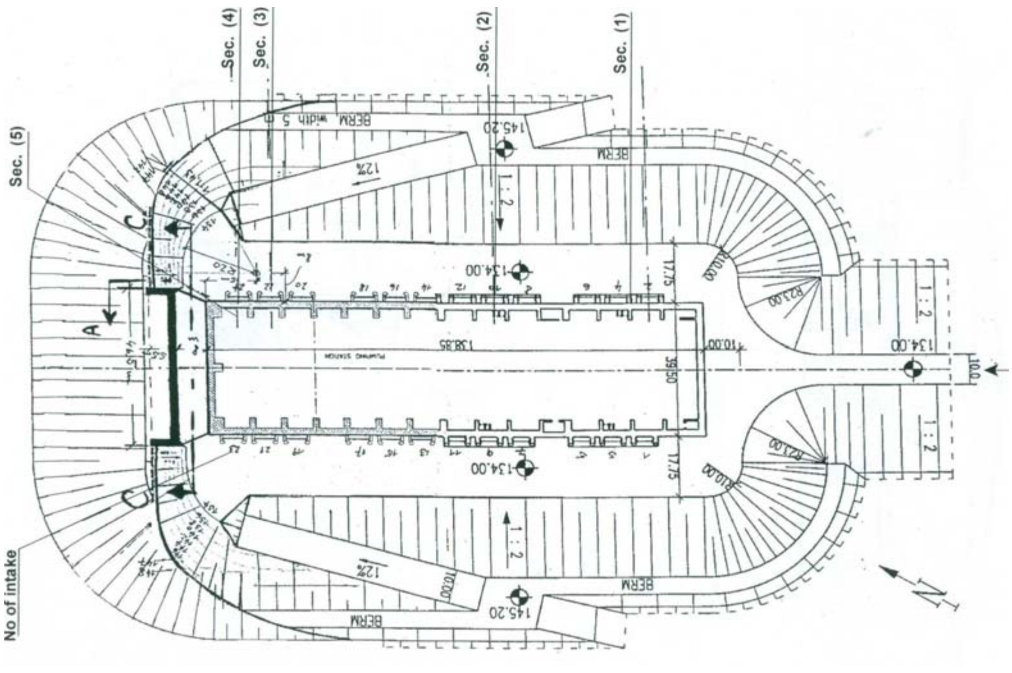

Figure 2: Sketch of alternative four

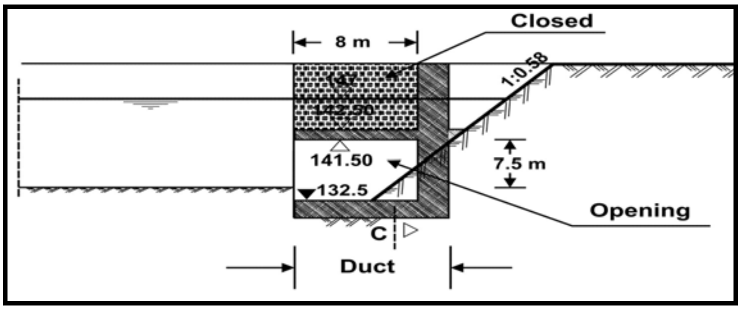

Figure 3: Section A-A

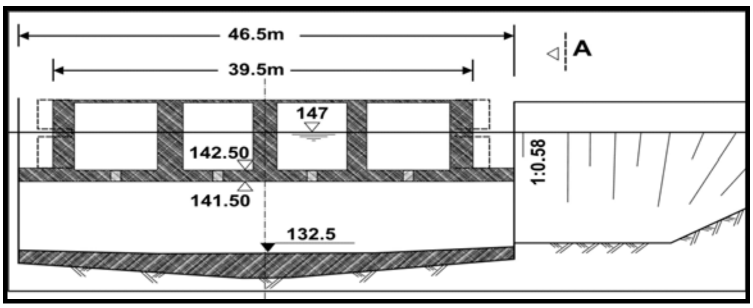

Figure 4: Section C-C

4. MODEL CONSTRUCTION AND DESCRIPTION

The model includes a part of the conveyance canal, the intake structure and the pumping units. It forms the center of a suction basin with pool elevations almost identical to the levels of the lake. The basin is 15.1m wide and its bed level is at 134 m ASL. The area of the model is 23 x8 m. The simulated lengths of the basin and a part of the conveyance canal are 261 and 239 m, respectively. The bed and banks of the basin and conveyance canal are made of sand-cement mortar. The pump station sidewalls are made of bricks and wood. The pump intake is modeled in details (i.e. including the pump intake column and bell mouth that were made of wood and steel sheets). The intake water flow is withdrawn by the pump through a suction pipe of 0.08 m diameter, to a manifold collector pipe of 0.25 m diameter. Discharges through the individual pump lines are regulated using butterfly valves.

The water is recycled from the manifold collector using a pump with a capacity of 170 l/sc. The flow is fed into the upstream end of the channel through 0.25 m diameter pipes and controlled using a butterfly valve. The flow rate in this pipe is measured by an Electromagnetic flow meter. The water levels are measured by using two gages located in the conveyance canal and the basin respectively. Photos 1 and 2 show the general view and the pump station intakes of the model, respectively. For more model description details, refer to Ibrahim (2000).

Photo 1: General view of the model including the basin and part of the canal

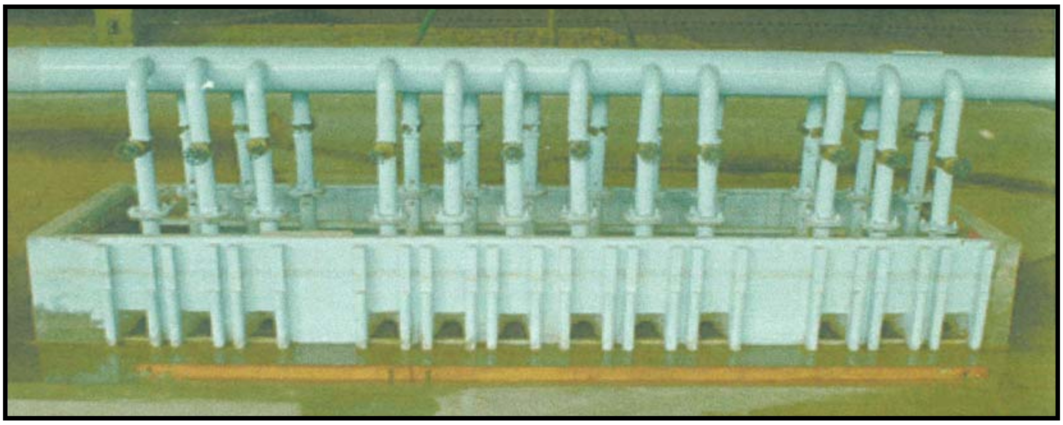

Photo 2: View of the pump station intakes

4.1 Model Similitude

The model was designed using an undistorted geometric similarity in order to simulate the kinematics and dynamics of the fluid flow field, based on the Froude similarity law. The Froude number "F_r" must be the same in both the model and prototype. The Froude ratio "F_r" is given by:

$$F_r = F_m / F_p \tag{1}$$

$$\left[\left(V_m / \sqrt{gL_m} \right) / \left(V_p / \sqrt{gL_p} \right) \right] = 1 \tag{2}$$

where:
V is the velocity
L is the characteristic length

g is the acceleration due to gravity Subscripts m, p represent the model and the prototype, respectively. If the length scale (L_r) is given by $L_r = L_m / L_p$, , where L_m and L_p are the length in the model and prototype, respectively, then the velocity scale v_r and discharge scale Q_r can be expressed as follows:

$$V_r = V_m \; / \; V_p \quad = L_r^{0.5} \tag{3}$$

$$Q_r = Q_m \; / \; Q_p \quad = L_r^{2.5} \tag{4}$$

where:
Q_m and Q_p are the discharge in the model and prototype, respectively

4.2 Model Scale

The length scale ratio l_r was selected to be 1:30 to have acceptable Froude number and Weber number in the model. Scale range up to 1:42 can represent the behavior of swirling flow in an adequate way, as suggested by Odgaard (1986). Using that length scale, the model scales are as the following: velocity scale V_r = 1: 5.477 and discharge scale Q_r = 1: 4929.503

4.3 Check for Other Similarity Laws Effect

According to the prototype dimensions, the following model dimensions can be obtained:

Flow rate/pump (Q_m)	= 3.388	l/s
Suction pipe internal diameter (d_m)	= 0.08	m
Available submergence (h_m)	= 0.433	m

To achieve similar velocity profiles inside the pump column in the model as in the prototype, a high enough turbulence level in the model suction pipe should be produced. This can be assured if the value of the Reynolds' number inside the suction pipe (Re)s is greater than $3x10^4$ according to Wijdieks (1985). In this model (Re)s is equal to $5.4 \text{ x}10^4$

To predict whether air-entraining vortices will occur in the real pumping station, Froude number F, Reynolds number R_e and Weber number W_e should have the same values in model and prototype. This can only be reached if the length scale l_r = 1. The influence of the surface tension on scale effects can be estimated by the Weber number. The Weber number should exceed 11 for a vortex formation, unaffected by surface tension, according to Jain et al. (1978). In the present model $W_e(_m)$ equals to 22.48. Therefore, the Reynolds Number and the Weber Number are sufficient in the scale model for the minimum lake water level.

A common technique to overcome the possible scale effects in vortices modeling is to exaggerate the flow discharge in the model while maintaining the Froude scaled parameters. Therefore, the exaggerated discharges applied in the model to test the vortex formation were limited to 1.5 times the normal discharge.

4.4 Model Tests

Model tests were executed and measurements were undertaken. The test measurements, for all alternatives, were as follows:

- The formation of vortices in the vicinity of the bell mouth for the pump columns.
- The formation of vortices in the vicinity of the bell mouth for the pump columns.

The carried out tests were with the following pump station operating conditions:

- Twenty four pumps with double row (12+12).
- Twelve pumps on the right hand side (12+0).
- Twelve on the right hand side and six pumps on the other side (12+6).
- Twelve on the right hand side and eight pumps on the other side (12+8).
- Nine pumps in each row (9+9).
- Six pumps in one row (6+0).

5. MODEL TEST RESULTS

After undertaking the measurements, the results were analyzed and are represented here, as follows:

5.1 Vortex Formation Results

The tendency of the vortex formation was observed by eye and documented. The observation was compared with the classification of vortex phenomena as recommended by Weinerth et al. (2003), figure 5. As a criterion for the vortex phenomenon, only types 1 and 2 are allowed to occur since types 3 and 4 will affect the pump performance. The model sump velocity was increased 1.5 times, because of the low model Weber number. Vortex formation was studied with normal and exaggerated velocity. The results indicated that vortex types 2, 3 and 4 disappeared during the normal velocity operation, for all alternatives. Few vortices type 1 and 2 appeared in front of some intakes during the exaggerated velocity operation in the first and second alternatives.
Vortex type 3 appeared in front of intake number 6 at (12+6) and (12+0) pump runs during the exaggerated velocity operation in the second alternative. Also Vortex type 3 appeared in front of intake number 14 at (12+0) pump run during the exaggerated velocity operation in the second alternative. The intakes numbers are given in figure 2.

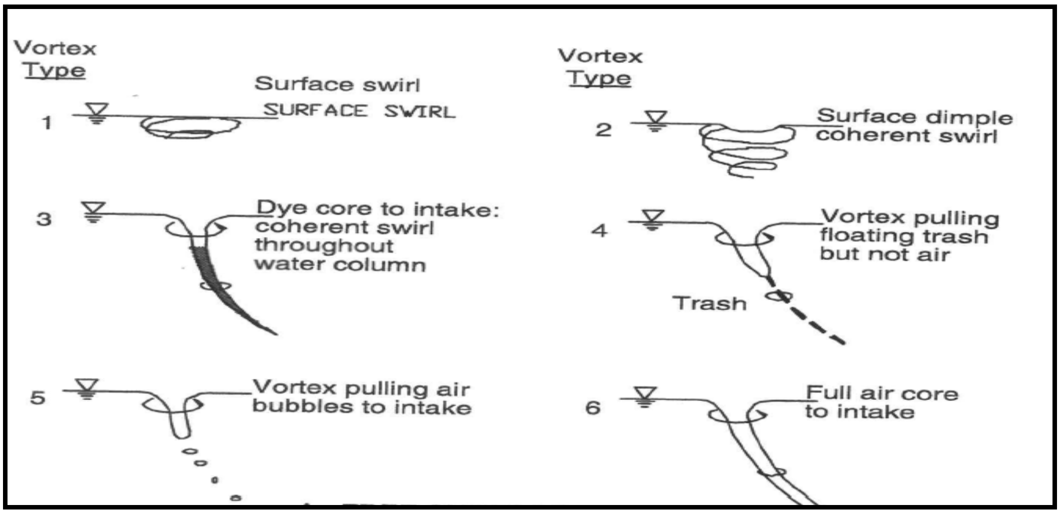

Figure 5: Sketch shows a free surface vortex types, Weinerth et al. (2003)

Vortex formation tests were carried out after constructing curtain walls on all gates. The curtain wall begins from the top edge of the intake to the free surface flow level with the same intake width, figure 6. It was found that no vortex was formed in the case of normal operation. Vortex type 1 was formed in front of some intakes.

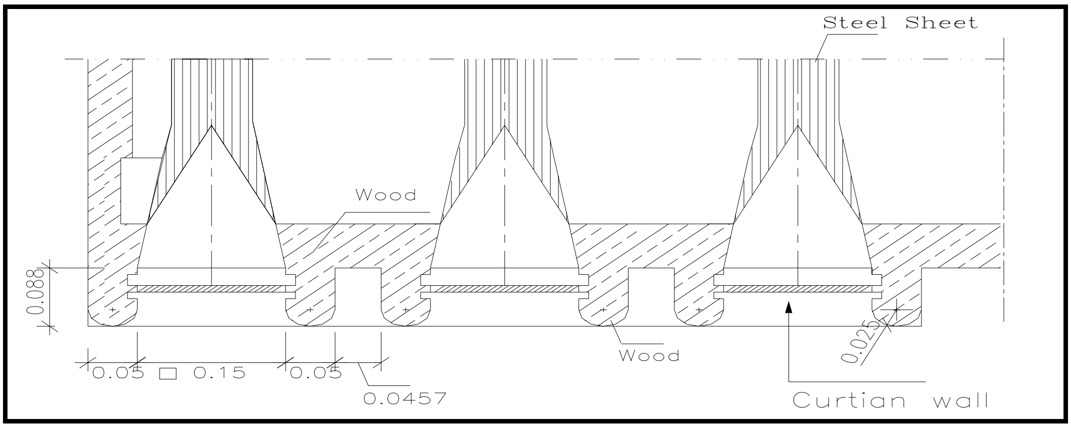

Figure 6: Plane of three intakes shows the curtain wall locations

From the results the following was evaluated:

- For symmetrical operation pumps (12+12), (9+9) and (6+6) without curtain wall the vortex intensity is reduced proportional to the reduction of the discharge.
- For asymmetrical operation pumps (12+6), (12+0) and without curtain wall the intensity of the vortex formation increases.
- With the curtain wall, vortex formation is reduces by about 70% compared with the case without curtain wall. The reduction appeared to be due to the reduced space between the piers by curtain wall. Vortex formation could probably be eliminated if the intakes would start from a straight intake front without the intersection by the piers. This is structurally not possible.

5.2 Evaluating the Velocity Measurements

The velocity distribution within the basin and in the approach area from the intake canal into the basin may affect the velocities in the vicinity of individual pump intakes. From the inlet canal to the end of the pump station structure, the approach velocity will decrease passing pump by pump, so that the first units adjacent to the inlet canal will be subject to higher stream velocities than the last units. Under some conditions (i.e. the number of operating units on each side of the station being significantly different), currents could occur around the end of the station.

For each of original, first and second alternatives, velocity measurements were conducted at three cross sections (1, 2 and 3) located on the basin in front of intakes numbers 2, 10 and 22, respectively. The locations of these three sections are given in figure 2. The orientation of the measured velocity component is:
+ x in direction of the intake canal approach flow and - x in reverse flow
+ y perpendicular to the pump station axis, directed towards the intakes and - y in reverse flow

The results of the velocity distribution in the basin were analyzed and discussed as the following:

- The results of original, first and second alternative are grouped and analyzed together in order to demonstrate the flow behavior in case of different basin shapes (geometry).
- The velocity distribution results of original alternative with all gates have curtain wall which means different conditions of the intakes are analyzed separately. This case illustrates the effect of actual modification in the pump intake entrances on the velocity distribution in the basin.
- The velocity distribution results in the basin are discussed in case of apart submerged bridge at the end of the basin providing by a gate. This case represented another flow scheme in the basin.

5.2.1 Results of original, first and second alternatives

The velocity was measured in x direction at different water depths on the points located on each cross section, figure 7. The measured velocity profiles in x direction along cross sections 1, 2 and 3 at $z/d = 0.82$, 0.35 and 0.12 for the three alternatives in case of all pumps (24 pump) are in operation as shown in figures 8 to 10, where d is the water depth and z is the height of the point velocity measurement from the bed.

The measured velocities in x direction started by low value in the area closed to the intakes 2, 10 and 22 (intake effected area) and gradually increased until the beginning of the side slope. The current velocity decreased again due to the separation resulting from the side slope.

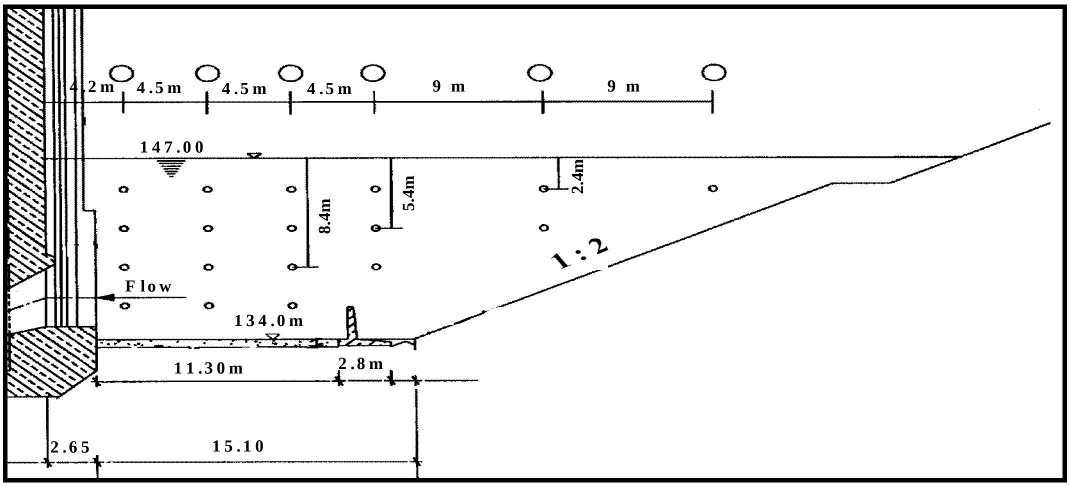

Figure 7: Velocity measurement point locations

From the results, the following can be concluded:

- The flow velocity field in x direction is observed at two characteristic zones. One of them in the vicinity of the pump station is affected by the pump suction. The other zone is not affected by the pump suction.
- The maximum x velocity component in x direction, in the vicinity of the pump station, are found of Vx=0.87, 0.51, 0.39 m/s at sections 1, 2 and 3, respectively.
- In cross section 1, there is a significant component of reverse flow -Vx resulting from flow separation at the edge of the intake structure. However; rounding the edge of the structure does not reduce the bulk turbulence, induced near the surface, and does not cause major improvement of the velocity field.
- The longitudinal velocities are significantly lower in the zone far from the structure. Reverse flow occurred in the lower range of the measured velocities as part of circulations which form near the entrance and in the central zone of the basin.
- The different tested basin configurations revealed that the basin shapes or slopes affect the zones far from the structure, but there are no noticeable effects on the longitudinal velocities in the vicinity of the structure.

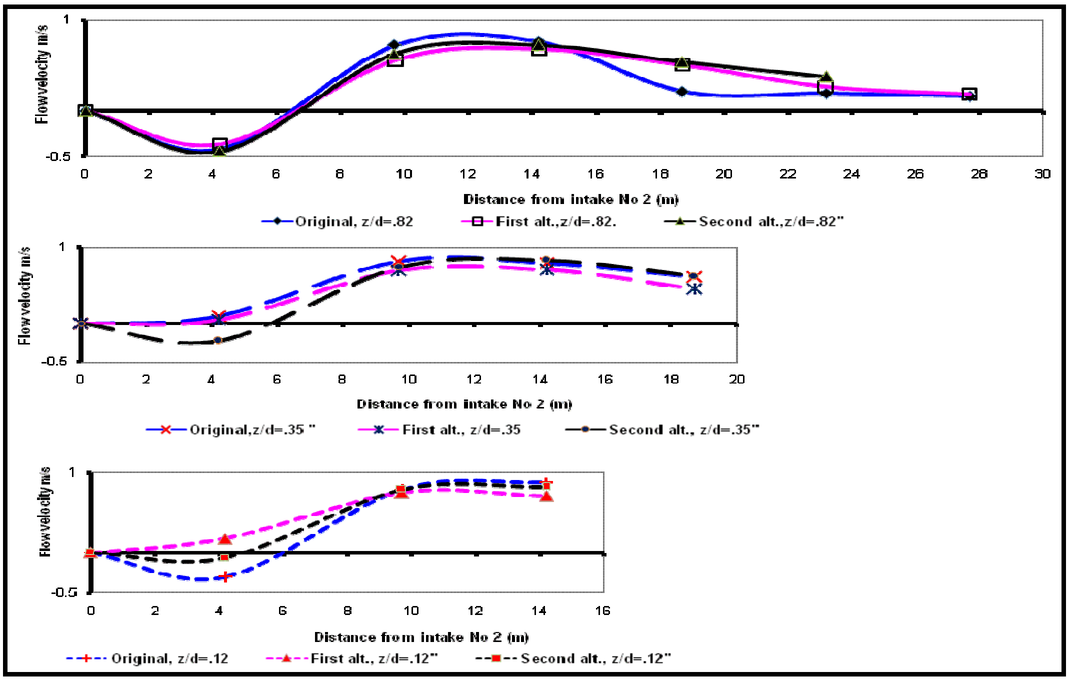

Figure 8: Velocity profile in x direction at c.s.1, (12+12) pumps in operation

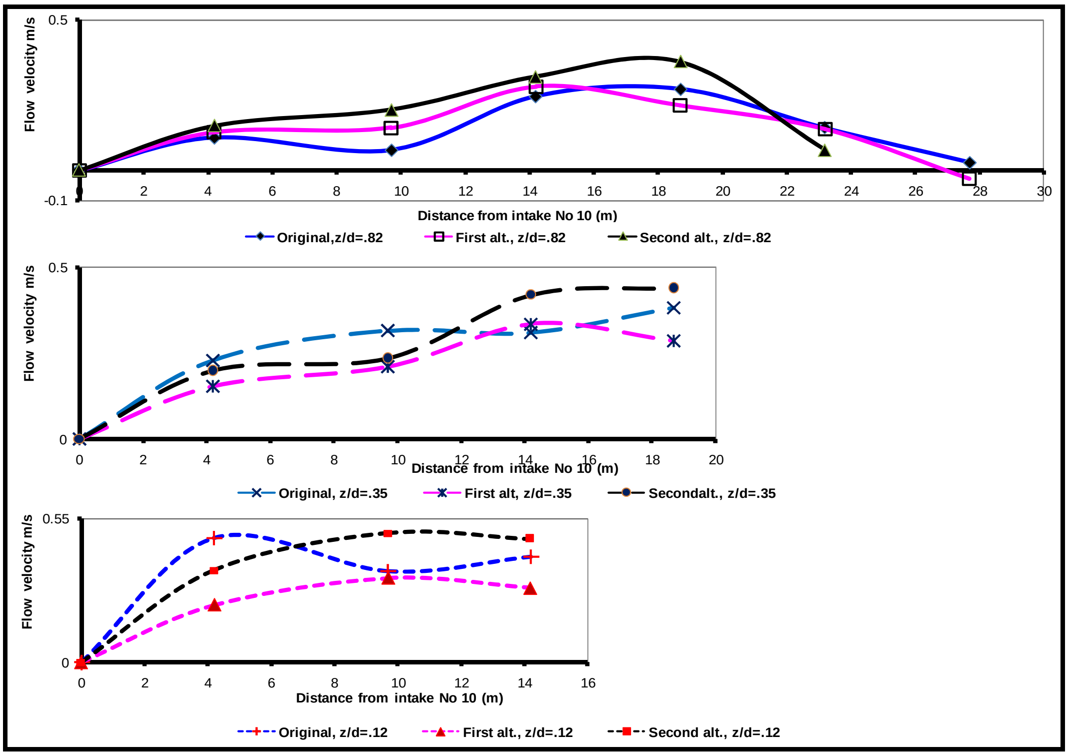

Figure 9: Velocity profile in x direction at c.s.2, (12+12) pumps in operation

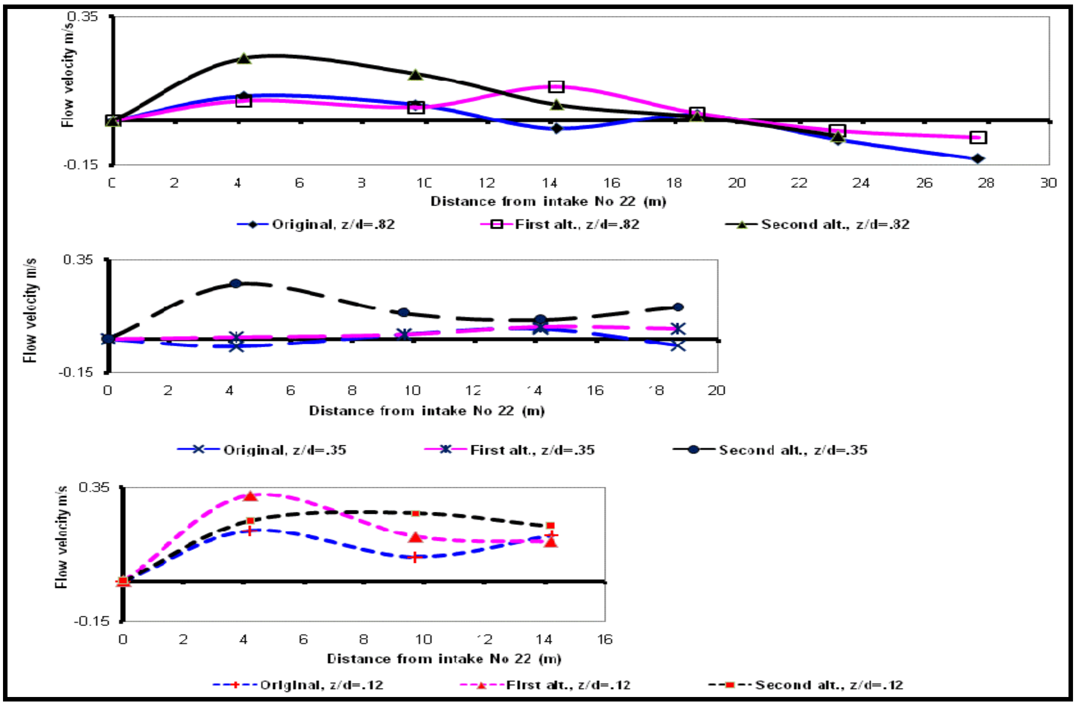

Figure 10: Velocity profile in x direction at c.s.3, (12+12) pumps in operation

5.2.2 Results of the original alternative (all gates with curtain wall)

All tests were repeated with all gates with curtain walls. The pump configurations during the operation were as follows: (12+8), (12+6), (12+0) pumps in two rows. Figures 11 and 12 show the measured velocity profiles in x direction at each point along cross sections 1 and 3 at z/d =0.82, 0.35 and 0.12 for the above mentioned configurations. The results show that the velocity components in x direction at each point along cross sections 1 and 3 at z/d =0.82, 0.35 and 0.12 are reduced when the passing discharge in the basin is reduced until reached to –Vx at cross section 3. The velocity components in x direction at cross section 1 (intake No 2) do not cause –Vx because of its location at the beginning of the basin while –Vx are exist at cross section 3 (intake No 22) because of its location at the end of the basin (the water moves from the left to the right side of the basin).

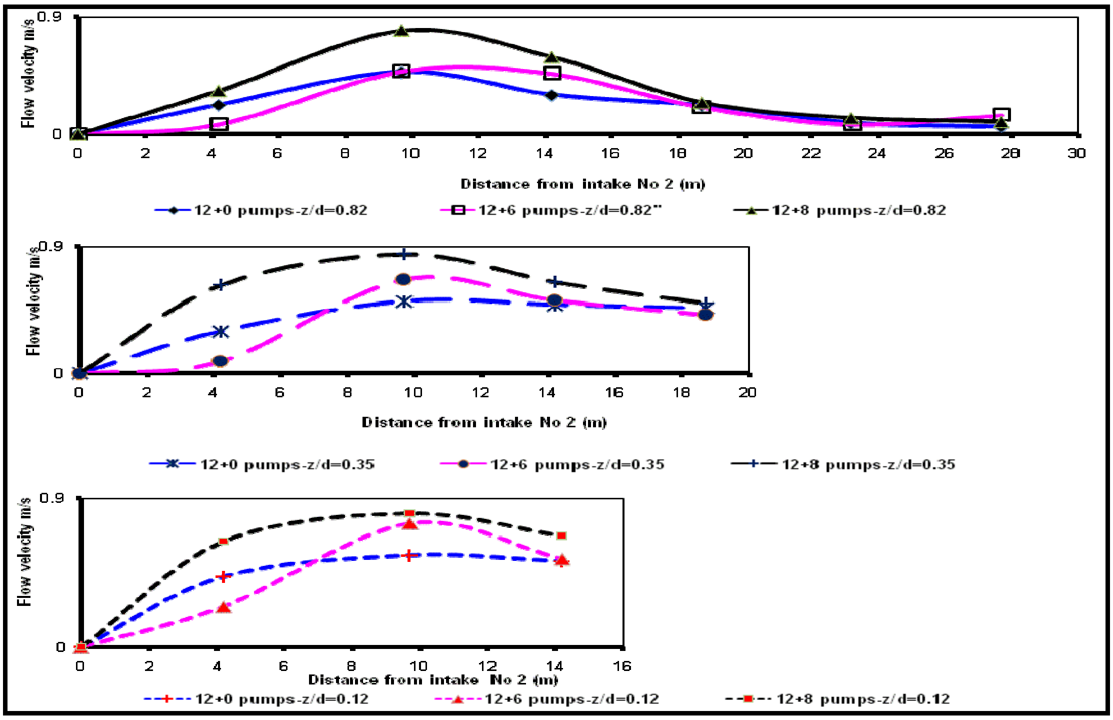

Figure 11: Velocity profile in x direction for c.s.1, original alternative with curtain wall

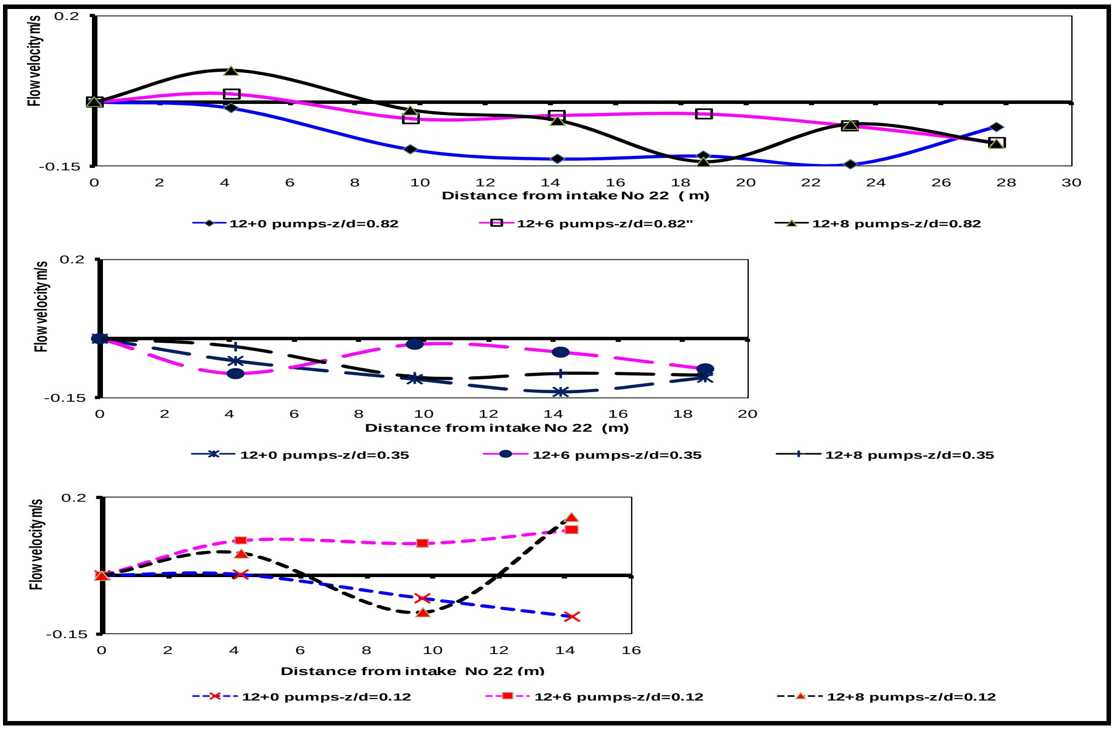

Figure 12: Velocity profile in x direction for c.s.3, original alternative with curtain wall

5.2.3 Test results with part submerged bridge at the basin end

The third alternative is similar to the original one provided with a bridge at the end of the basin with a bed and bottom slab levels of 132.5 and 141.5 m ASL, respectively. This means that 5.5m of the bridge body are submerged in the water in case of minimum water level (147m ASL). The back side of the model was reconstructed with new slopes and dimensions, figures 2 to 4. The flow was controlled by two wood gates located on the two sides of the gate opening.

Figures 13 to 15 show the velocity profile results in x direction for cross section 3 (intake 22), 12+0 , 12+6 and 12+8 pumps in operation in a comparison with the corresponding conditions of original, open and closed end. They also show that most of Vx at that section in case of the above mentioned pump operations are reverse flow. At the conditions of original, open and closed end, the following is noticed that in case of z/d =.82 , 12+0 , 12+6 and 12+8 pumps in operation, reverse velocities in x directions along the section were existed except little zone located on the side slope in cases of open and closed end. This causes flow separation. Irregular Vx was appeared in case of open end. A significant stream, around the station, occurs at the end of the pump station structure when the pumps are operated asymmetrically. This also results flow separation and vortices.

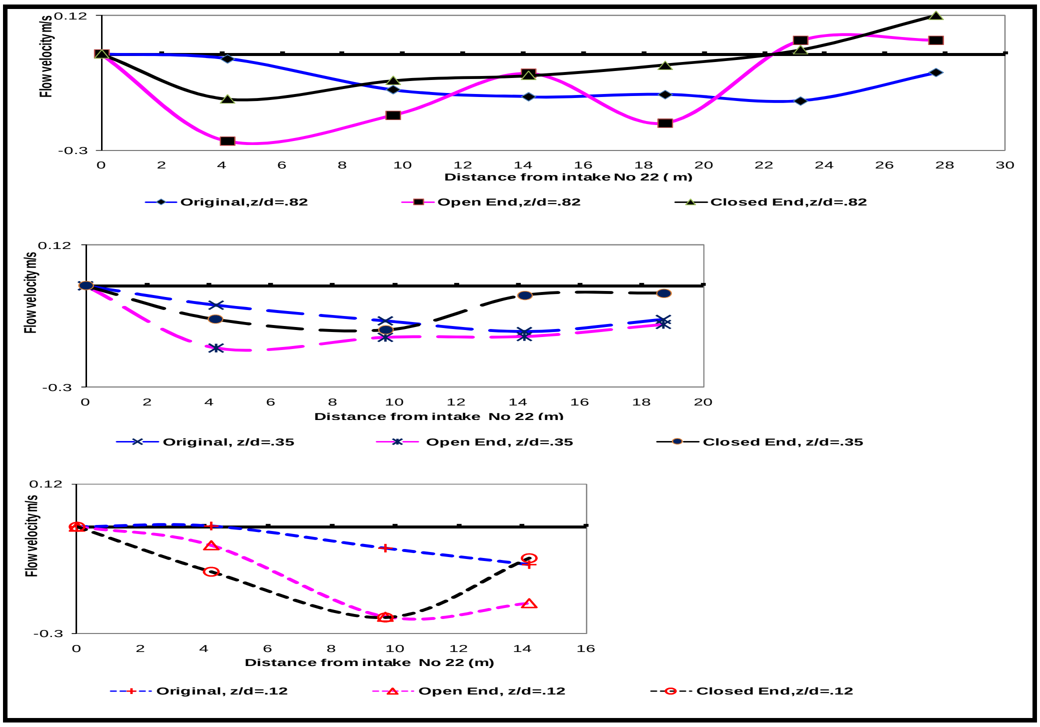

Figure 13: Velocity profile in x direction for c.s.3, (12+0) pumps in operation

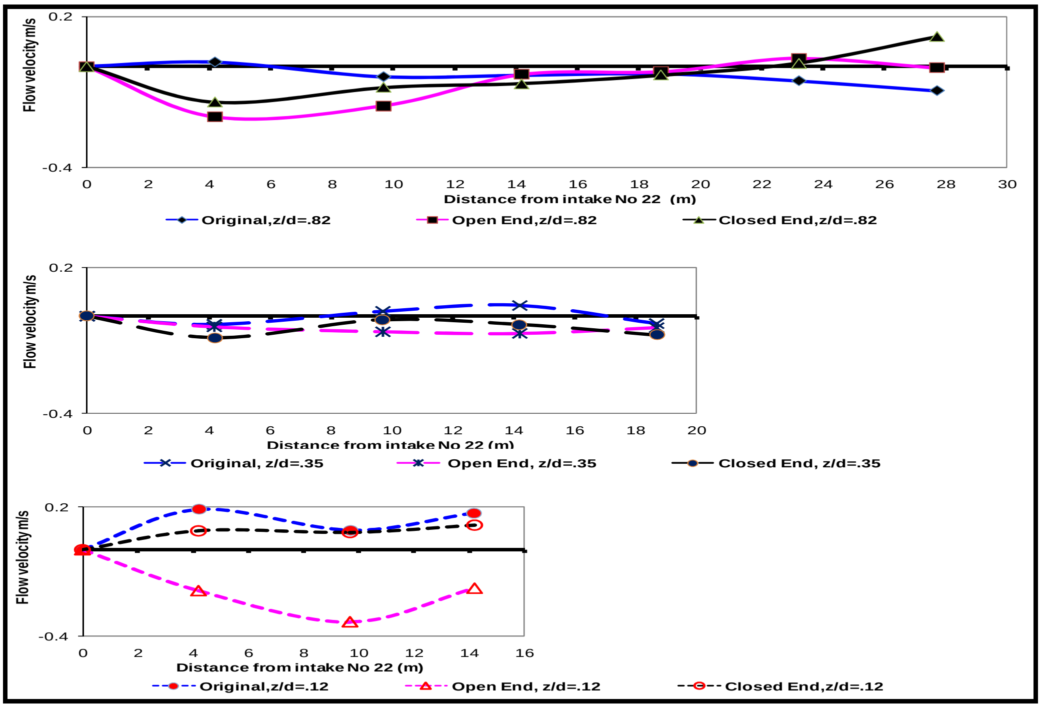

Figure 14: Velocity profile in x direction for c.s.3, (12+6) pumps in operation

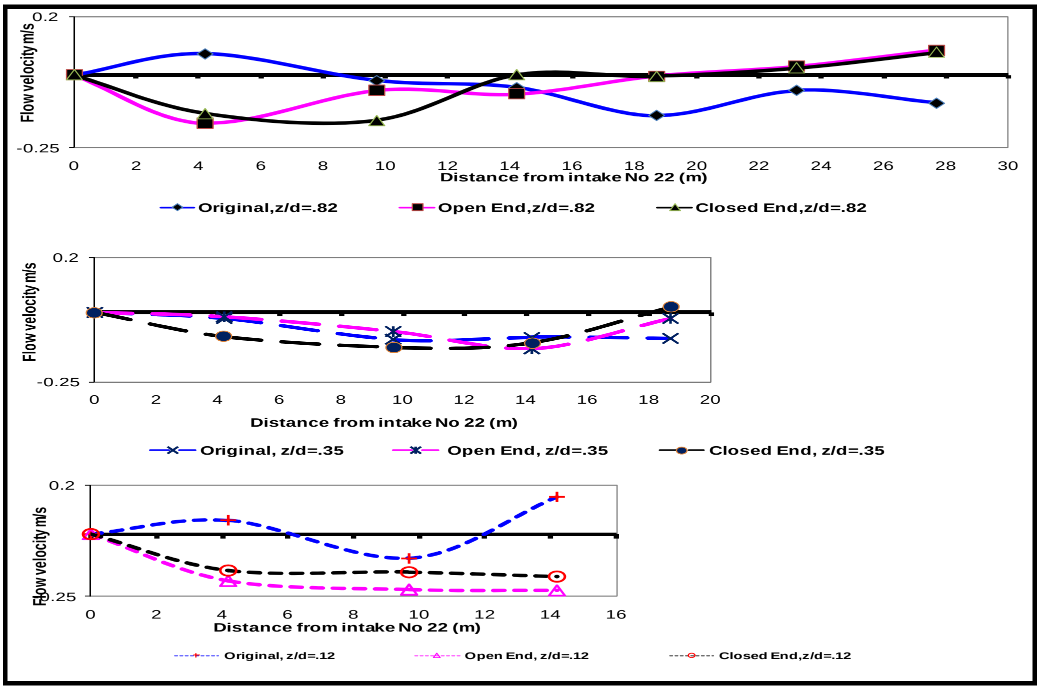

Figure 15: Velocity profile in x direction for c.s.3 (12+8) pumps in operation

6 CONCLUSIONS

The following conclusions are derived from the experimental investigations:

- Changes of the shaping of the canal entrance to the basin and of the basin slopes (1.25:1 instead of 2:1) do not induce noticeable improvement in the approach flow condition.
- The flow separation occurs at the beginning of the bank slope.

- A significant stream, around the station, occurs at the end of the pump station structure when the pumps are operated asymmetrically. This stream results in flow separation and supports the formation of vortices at the last group of units.
- It is recommended that the flow section at the backside of the station is totally closed or so far partially closed that the approach stream around the backside is significantly reduced.
- The vortices forming at the intakes at the water level 147m ASL and with a discharge increased by a factor of 1.5, correspond mostly to type 1, less to type 2 and only exceptionally to type 3. The curtain wall reduces the vortex formation by about 70%.
- When operating the pump station at the low water level, symmetrical operation of pumps is recommended, this would help to avoid vortex formation, which might reduce total pumping capacity.
- Evaluation of the tendency to vortex formation can only be made with the results from intake model**.**

7 ACKNOWLEDGMENTS

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