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Forced circulation used in maintaining sea quality in closed basins

1. Introduction

Construction or use of natural closed basins for specific industrial, traffic or touristic purposes is nowadays quite common, particularly at the sea shores. In this case, the basin of marina communicates dynamically with the surrounding sea only through a narrow passage which in itself is not sufficient for preventing negative modifications in the ecosystem of sea in the basin.

The influence of tidal changes, currents and waves on the frequency of change of the water masses is greatly reduced and the harmful changes occur to a certain extent even without additional human influences (waste water discharge, economic activities etc.). Although the initial quality of the surrounding sea and the sea in the enclosed basin might be the same, the biological processes that will develop in both cases will differ to a great extent. Thus, degradation of water quality, rapid growth of flora, local pollution of the sea surface and increase of biological activities occur in the closed basin which influences considerably the ecological system of both basin and the surrounding sea.

In order to maintain the ecosystem of the basin in the state similar to that of the surrounding sea, it is necessary to obtain sufficient water circulation.

The experts in ecology recommend, for the conditions prevailing at the Adriatic sea, that at least 95% of water be changed in the period of 5 days. It is however important that no local areas be left out as that would enhance development of adverse processes.

Hydraulic solution of controlled frequency of water change is possible only by forced recirculation i.e. by bringing in adequate quantity of fresh water from the surrounding

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sea. This provokes the process of turbulent mixing and forcing out part of the sea water from the basin through the existing passage. In this case, two solutions are possible: application of the system of full mixing or bringing in water practically without mixing by using the plut flow system of water change.

2. Theoretical basis of the investigation

The problem of water circulation through the closed basin can be described by the conservation of kinetic energy:

$$\int_{\forall} \frac{d}{dt} \frac{(\rho v^2)}{2} d\forall = \sum_{i=1}^{n} F_i S_i \tag{1}$$

where the left side of the equation corresponds to the total derivation of kinetic energy in a specified time period and the right side is the work of external forces, all in specified control volume $\forall$.

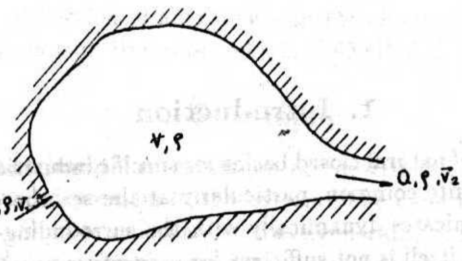

Fig. 1. Scheme of closed basin during the process of forced circulation

If ρ = const, and the flow is stationary and if influence of internal forces of friction is dominant, then the equation (1) is reduced as follows:

$$\frac{\rho Q}{2}(v_2^2 - v_1^2) = -W_T \tag{2}$$

where W_T represents work of internal forces of friction in a specified unit of time (turbulent mixing).

If the speed v_2, which is relatively small in comparison with v_1, is neglected, we obtain:

$$W_T = \rho \, Q \, v_1^2 \tag{3}$$

which is, after introducing $Q = v_1 A_1$ (where A_1 – cross section of incoming jet), transformed to:

$$W_T = \rho \, A_1 \, v_1^3 \tag{4}$$

It can therefore be concluded that the turbulent mixing increases with the third power of the incoming jet velocity but linearly with the increase of cross section which clearly indicates the way of solving this problem.

The increase of speed is related to the technical solution of jet nozzle while the increase of inlet area implies the use of the plug flow system. Behaviour of the incoming jet can be described by Albertson's equation (1):

$$V_{x,r} = 6.2\frac{V_o D_o}{x} \exp\left(-76.21\frac{r^2}{x^2}\right) \tag{5}$$

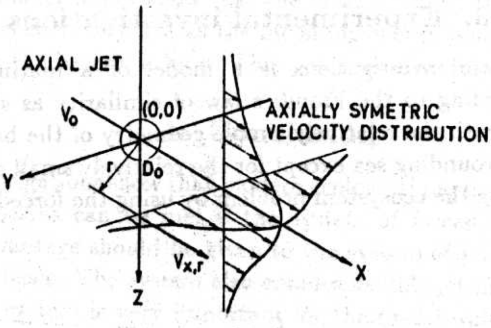

Fig. 2. Velocity distribution described by Albertson's equation

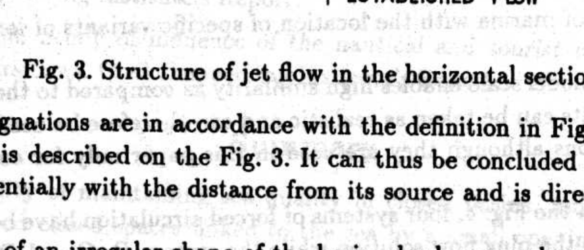

Fig. 3. Structure of jet flow in the horizontal section

where the designations are in accordance with the definition in Fig. 2. The structure of the jet flow is described on the Fig. 3. It can thus be concluded that the jet speed reduces exponentially with the distance from its source and is directly dependent on the inflow.

In the case of an irregular shape of the basin, dead zones where no mixing occurs will appear if plug flow is applied. The size of such zones increases with the irregularity of the basin's shape. It should be noted that this system must be located on the side contrary to the exit as the greatest effect is then obtained.

The factor of mixing must also be introduced in order to enable comparison of results of model investigations.

$$K_M = \frac{V_A}{V_i} \tag{6}$$

V_A – volume of sea contained in the basin

V_i – total volume of the jet inflow needed for obtaining satisfactory ecological conditions

If the necessary circulation is 100%, theoretically the biggest value is $K_M = 1$. As the K_M value is reduced the efficacy of the circulation system is equally reduced.

3. Experimental investigations

The base for these investigations is a model of a marina to the scale of 1 : 90 designed according to the Froude's law of similarity as shown on the Fig. 4. This model is made with the relatively simple geometry of the basin, it is completely closed toward the surrounding sea except for the relatively small entrance. It is a typical example for solving the ecosystem problem by using the forced circulation method.

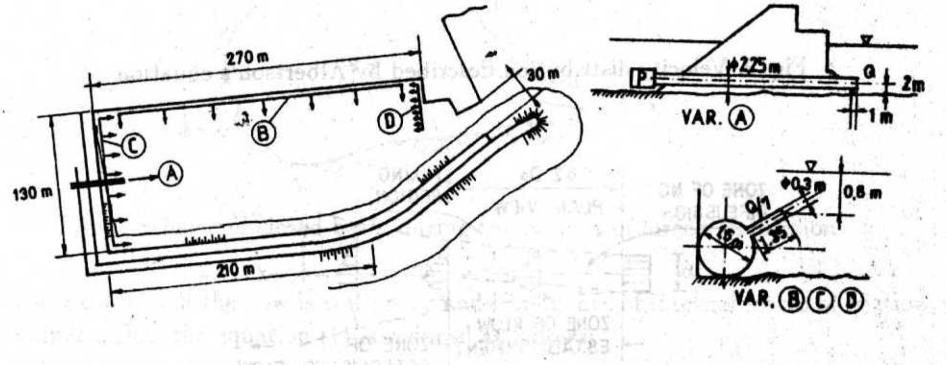

Fig. 4. Plan view of marina with the location of specific variants of forced circulation

The choice of model scale enables high similarity as compared to the natural conditions and the results can be taken as realistic and can therefore be used for forecasting in the real situations although they are used in this paper only for comparative purposes.

As indicated on the Fig. 4, four systems of forced circulation have been tested. The system A concerns the plug flow solution while the system B, C and D are variants of the jet nozzle system. For all systems the discharge capacity is 2 m^3/s.

The testing technique in coloring the marina basin with the 0.5% solution of KM_nO_4 and the time criterion for cleaning was attained when the color concentration was reduced for 95% (practically invisible to the eye). The K_M coefficient is calculated so as to indicate the quality of each system. This coefficient amounts to:

Variant	V_A [m^3]	V_i [m^3]	K_M
A	235.000	1.008.000	0.23
B	235.000	806.400	0.29
C	235.000	651.600	0.35
D	235.000	939.600	0.25

If the ecological criterion of 5 days cleaning time is accepted then the $K_M = 0.27$ and therefore the variants *B* and *C* are satisfactory. The tests made on the same system but with smaller inflow show that the flow, at which the basin cleaning is not sufficient, can be reached very fast as the incoming energy is inadequate for turbulent mixing throughout the basin's volume. This point requires further investigations.

4. Conclusion

The above investigations show that modern ecological requirements related to water quality in closed basins can be met if the system of forced circulation is used. In most cases, the advantage should be given to the system of jet nozzles which induces high turbulence in basin. The system also enables flexible jet nozzle distribution. The distribution of the system is very important for the final result. The best results are obtained when a row of jet nozzles is located on the side contrary to the entrance of the basin and they must be oriented so as to provoke turbulence in the whole basin and to act partly as the plug flow system. The introduced coefficient of mixing gives an adequate view of the each system's quality.

References

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Summary

The possibility of maintaining sea quality in closed basins, most often by using artificially shaped closed spaces linked to the sea by a small opening, is discussed in this paper.

By introducing a jet of fresh sea water into the basin, the water is mixed and partially forced out of the confined space thus reducing the concentration of harmful components.

Water movement in basin is preliminary discussed by the way of energetic equation. The influence of jet speed to the mixing process is also presented.

A possibility of cleaning basin by a big propeller device and by adequate jet nozzle system is examined on a hydraulic physical model of a simple geometry marina.

This study is completed by modification of jet nozzle distribution in the basin.