INTERNATIONAL ASSOCIATION FOR HYDRAULIC RESERACH

AN EXAMPLE OF A COMBINED DISCHARGE-CONTROL AND AERATION STRUCTURE

(Seminar 3)

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SYNOPSIS

The design of a hydraulic structure in a cooling water circuit is described which serves the dual purpose of controlling the water levels in the system upstream and of providing a maximum oxygen uptake without discharging large amounts of air into the subsequent pressure duct in order to avoid blow-out problems.

INTRODUCTION

For thermal power plants located at rivers, the cooling water system usually has to be designed in such a way that it can operate independently of the varying river stages. This requires a hydraulic control structure at the downstream end of the condensor, which controls the flow conditions in the system. Such structures are weirs or drop structures, in which the drop height can vary greatly with varying water levels in the river.

An example of such a structure is described for a power plant with cooling water discharges up to 21.5 m^3/s and drop heights up to about four meters. For water quality purposes, the discharge cooling water has to be oxygenated. On the oter hand, there follows a pressure duct of about two hundred meters in length to convey the water across the flood plain to the main river channel. This duct should possibly not be discharging large amounts of air, since this may lead to coalescence, air pockets, and unstable flow conditions with blow-out effects which are to be avoided because of navigation.

The task, therefore, was to design a structure which provides a maximum air entrainment in the drop section, optimal flow conditions for the air-water mixture for oxygen uptake, and a detrainment section for removing the major part of the air before entering the pressure duct. Under the constraints of given space limitations, such a structure was designed by an electric power utility and its engineering consultants. The design was tested and optimized by a model investigation at the authors' institute.

HYDRAULIC DESIGN CONSIDERATIONS

The structure conceived for these purposes is given in Fig. 1. As a component in the system, the elevation of the structure is determined by the condition that no backwater effects across the structure are allowed except for flood stages. The structure consists of a control section(weir and grid), an aeration chamber and a deaeration chamber. For the dimensions of the structure, the following hydraulic design considerations, along with structural constraints, were of importance:

- The control section has to provide a stable flow control without fluctuations over the entire range of discharges. This could be achieved by the combination of a weir sill and a subsequent grid or array of slots.
- In order to achieve favorable flow conditions in the aeration and deaeration chambers, the horizontal momentum flux of the inflow should be minimal. A simple overflow weir proved to be unsatisfactory for this reason. An array of horizontal slots is therefore more suitable for the given spatial restrictions.
- The amount of air entrainment per unit time depends primarily on the vertical momentum flux of the impinging jet, which is determined by the discharge and the height of fall.
- For a given momentum flux, air entrainment increases with the circumference of the impinging jets; therefore, an arrangement of several slot jets is preferable.
- It is desirable to achieve a stable hydrodynamic pressure on the grid bars without fluctuations and an even distribution of the discharge per unit length along all slots. This aim could be better achieved by arranging the slots lengthwise than by an arrangement perpendicular to the approach flow.
- Optimal conditions are reached when the two-phase jets (bubbles) reach the floor of the plunge pool. The larger the number of slots, the smaller will be the bubble penetration depth.
- Plunge pool depth and number of slots have to be chosen such that sufficient contact time for oxygen transfer is provided. In highly turbulent flows, oxygen transfer occurs very rapidly and requires essentially only a few seconds.
- The buoyancy of the entrained air (as determined by the air discharge) has a pronounced effect on the resulting flow field in the aeration and deaeration chambers; these effects are primarily of importance for the dimensions necessary for an efficient deaeration chamber.
- At the entrance to the subsequent pressure duct, care has to be taken in order to avoid a reentrainment of air by vortices from the free surface of the deaeration chamber.

MODEL TESTS

1. Model . The performance of the structure was investigated in an undistorted model at scale 1 : 10. Since the flow processes are primarily affected by inertial and gravitational forces, the flow was modelled according to Froude's law. This allows appropriate modelling of the approach flow conditions, water levels and slot jet characteristics. Also, the rate of air entrainment of the impinging jets is approx. similar in the model. It can hence be assumed

that the bulk bubble-stream buoyancy, which depends primarily on the rate of air entrainment, is also approximately similar and hence the resulting interaction between air and water flow field can be taken at least as a reasonable indication of the prototype behaviour, although, of course, individual bubble sizes and paths are not modelled correctly.

2. Hydraulic performance. In Fig. 2, observed flow patterns are sketched for three different downstream water levels (river stages). A comparison shows that at the lower water level the air entrainment and hence the effect of the bubble swarm upon the flow field is most pronounced. The rising bubbles induce an upward flow in the deaeration chamber which gives rise to a recirculation zone near the floor. With increasing water levels, air entrainment is less and hence these buoyancy-induced effects are less pronounced, until finally at maximum water levels there is comparatively little air entrainment and buoyancy effects virtually vanish; in this case, the flow pattern changes completely (Fig. 2).

For discharges over a weir, the horizontal momentum flux of the impinging jet is so strong that it overrides the buoyancy-induced flow and hence leads to a direct jet flow towards the pressure duct conveying large amounts of air into this duct, which is highly undesirable.

3. Air entrainment and detrainment. Measured air entrainment rates are shown in Fig. 3 for various downstream water levels and hence plunge depths. With increasing fall height, the relative air entrainment increases. An arrangement with six slots entrains more air than one with four slots, due to the larger length of the impinging jet circumference. On the other hand, the bubble jet penetrates deeper with the four slot array than with six slots, which enhances the oxygen transfer.

The major part of the entrained air is removed in the deaeration chamber. Only very small bubbles (below 1 mm) and few larger bubbles are carried into the pressure duct, so that the measured air flow rates in the duct are in all instances well below 0.1 percent of the water flow rate. This indicates that the arrangement of the deaeration chamber serves its purpose well, and that no severe disturbances of the water flow in the pressure duct are to be expected.

4. Oxygen uptake. The oxygen transfer depends, apart from hydraulic conditions, upon the saturation concentration c_s and hence the temperature, pressure, salt content, etc. of the water, and upon the initial oxygen deficiency of the approach flow. These effects are encompassed in the reaeration coefficient r, usually definded as

$$r \equiv \frac{c_s - c_{upstream}}{c_s - c_{downstream}}$$

For water of constant temperature and constant quality, this coefficient depends upon the geometric and hydraulic conditions such as the air entrainment rate, the turbulent mixing and surface renewal in the air-water mixture, and the residence time of the bubbles, which in turn depends upon their path in the flow field.

Theoretical calculations indicate that the major part of the oxygen transfer to the water under turbulent conditions is completed for typical bubble sizes within less than a few seconds (1). Typical contact times of the bubbles are near ten seconds in the model and considerably more in the prototype. The theoretical approach illustrates that the initial phase of contact between air bubbles and water is very important for the oxygenation process. Therefore, the hydraulic design should be concentrated on a high air entrainment rate and a high enough penetration of bubbles into the tailwater.

For oxygenation tests, the laboratory water was deoxygenated to a 50 percent deficit, and concentration measurements were made in the approach channel, at various locations in the aeration and deaeration chambers and in the outlet at the end of the pressure duct. In all cases, well mixed conditions were established and essentially homogeneous oxygen concentrations in the water body including the recirculating zone were measured.

Oxygenation tests were performed at the given discharge for various tailwater elevations, for grids with two to eight slots of various geometries (nine different configurations) and for a simple weir structure. Fig. 4 summarizes the results of these measurements. At a given tailwater elevation (Δh = const), the weir structure shows a poorer performance that the slot grids. However, the variation among the various slot arrangements is surprisingly small. This is mainly due to the fact that there is a jet interaction for the multiple slot arrangement which results in a reentrainment of air at the plunging point. The rate of reentrainment of air bubbles as well as the smaller penetration length of the bubbles, of course, reduce the efficiency of the oxygenation. Therefore, the increase in air entrainment is to a considerable extent counteracted by a decrease of the efficiency of the oxygen uptake.

The results given in Fig. 4 allow a comparative assessment of the influence of flow geometry upon the oxygenation process. Howver, it has to be kept in mind that the model does neither reproduce the turbulence properties nor the bubble properties correctly and hence cannot be directly related to prototype conditions. Apart from the pronounced effects of temperature and water quality the oxygen uptake in the prototype structure will be more efficient and can be extrapolated by some theoretical considerations and literature data (2, 3).

CONCLUSION

Hydraulic considerations for the design of a structure combining discharge control, oxygenation of the water and subsequent deaeration have been described, and the results of model tests have been presented. However, there remains a number of open questions concerning the hydraulic similitude of the air-water flow in the scale model and in the prototype. In particular, predictions about the oxygenation performance are not possible because water quality and temperature effects are unknown in addition to the hydraulic scale effects. The structure is presently being built, and prototype measurements are envisaged which should help to answer some of the open questions and provide some insight into the nature and size of these scale effects.

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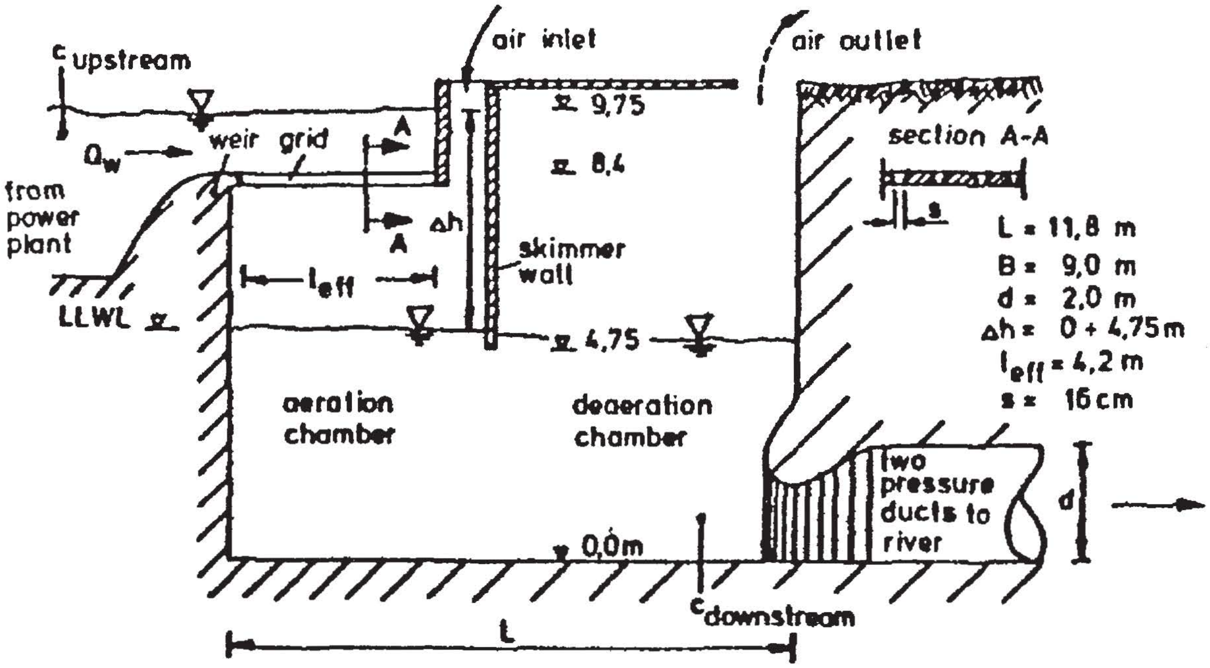

Fig. 1: Definition sketch

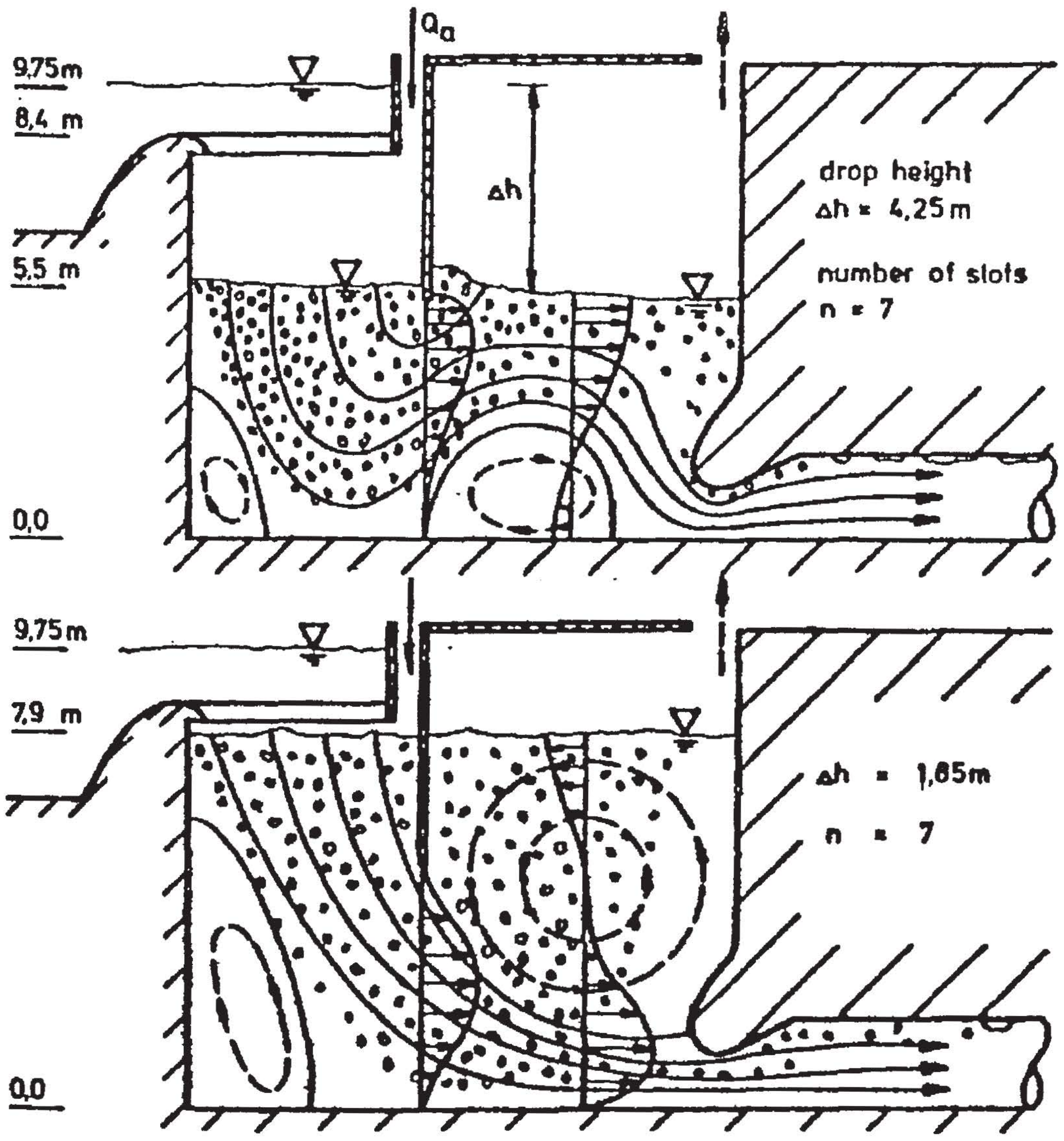

Fig. 2: Flow pattern for different tailwater elevations

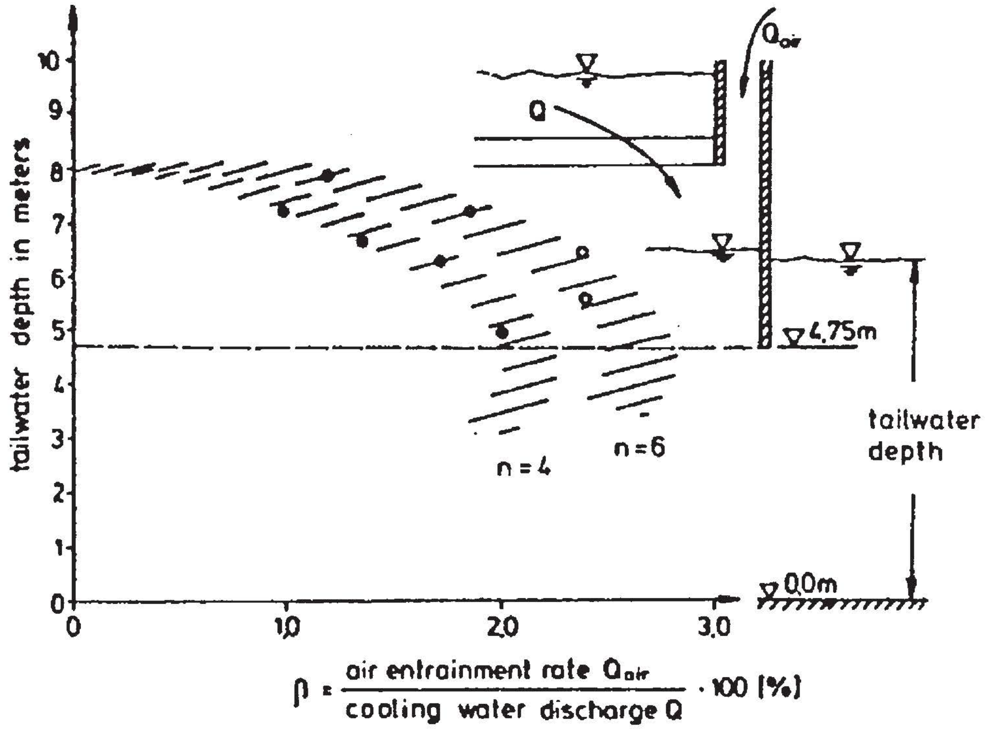

Fig. 3: Air entrainment rate for streamwise slot arrangements

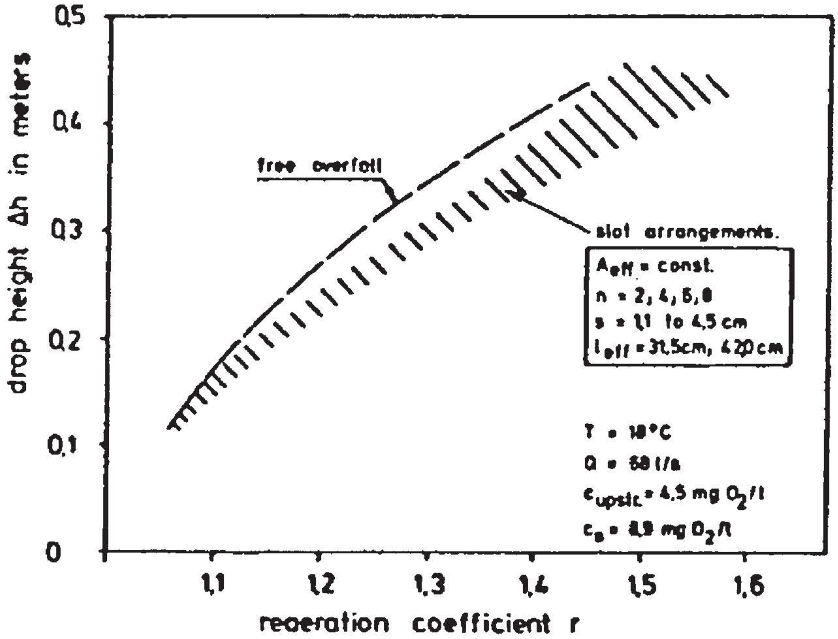

Fig. 4: Reaeration coefficient for all tested arrangements