MODEL TEST ON THE COLD-WATER CANAL OF A NUCLEAR POWER PLANT

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Introduction

Hungarian energy consumption is redoubling about every eight years, hence impossible to be met in the long run by conventional energy carriers. Therefore in the *Paks* region, construction of a nuclear power plant has started, to be realized in three stages.

Cold water for cooling the power plant condensers will be conveyed by a canal about 1.2 km in length — branching off the Danube right bank — to the intake works. Here the water undergoes rough filtering, then it is forwarded by a pumping plant through pressure mains to the condensers, and after being heated by about 8 °C, returned to the Danube through an overfall regulating water level, and a hot-water canal (Fig. 1).

Steam precipitation in condensers is optimum in case of cooling water at +2 °C. In winter, with Danube water at 0 °C, the recycling of a given volume of warm water markedly increases the power plant efficiency. Then part of the heated cooling water is fed back through a closed-section r.c. canal and an overfall to the cold water canal, in order to raise water temperature.

The first two intake works will include a canal and mixing plant A, and the third one a second canal and mixing plant B. Model tests were aimed at finding the optimum location of these mixing plants, in order to achieve uniform water distribution between the intake works, and at examining the flow conditions in the bay.

1. Model test fundamentals

1.1 Basic data

Withdrawal through the intake works (iw):

Intake 1: 54 cu·m/s; intake 2: 54 cu·m/s; intake 3: 108 cu·m/s.

Hot water added through mixing plants amounts to 2×25 cu·m/s. Investigation referred to LLW and MW (lowest and medium river stages) at the Danube section concerned, on a model built first according to construction stage 2, then to stage 3. The canal formation corresponding to construction stage 1, plotted in dash-and-dot line in Fig. 2 had not been examined, namely it is obvious that for any possible position of mixing plant A, in stage 1, the entire hot water goes to intake 1. A position had to be found for structure A, likely to provide in stage 2 (dashed line in Fig. 2) for a possibly uniform distribution of hot water between intakes 1 and 2. Structure B will be constructed in stage 3, to forward in an optimum case all its hot water to intake 3.

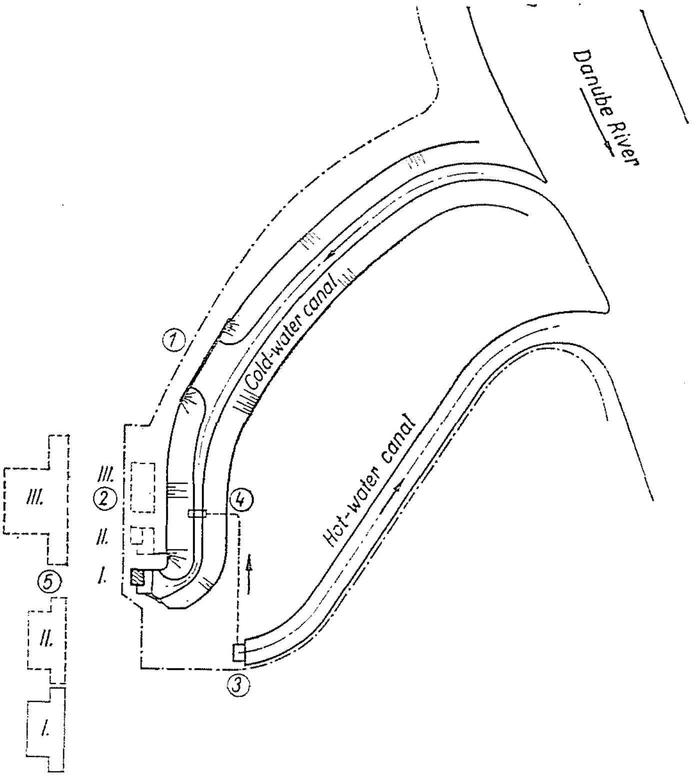

Fig. 1. 1. Harbour; 2. water intake works; 3. overfall for hot water level regulation; 4. hot water recirculation; 5. power stations; — · — service road for flood control

With a view on available space and pump capacity in our Hydraulic Laboratory, as well as on the turbulence criterion, a scale $\lambda = 75$ was chosen for the undistorted scale model. Forces of inertia and of gravity being predominant, the Froude model law has been applied.

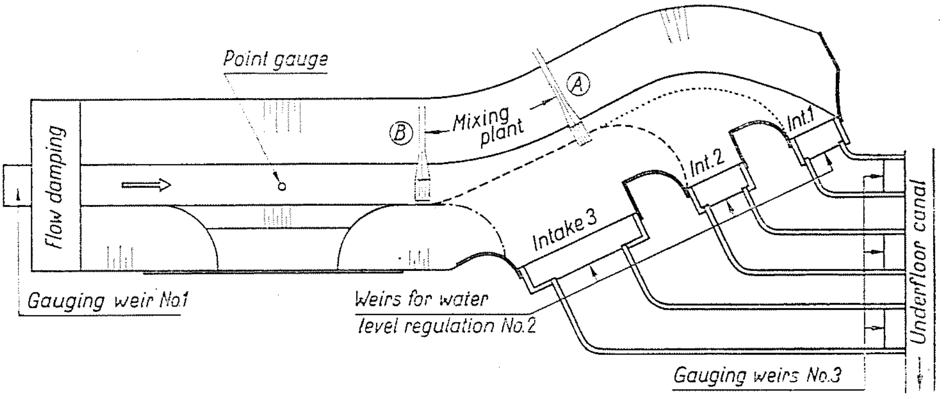

Fig. 2. ....building stage 1; ------ building stage 2; -·-·-·- building stage 3

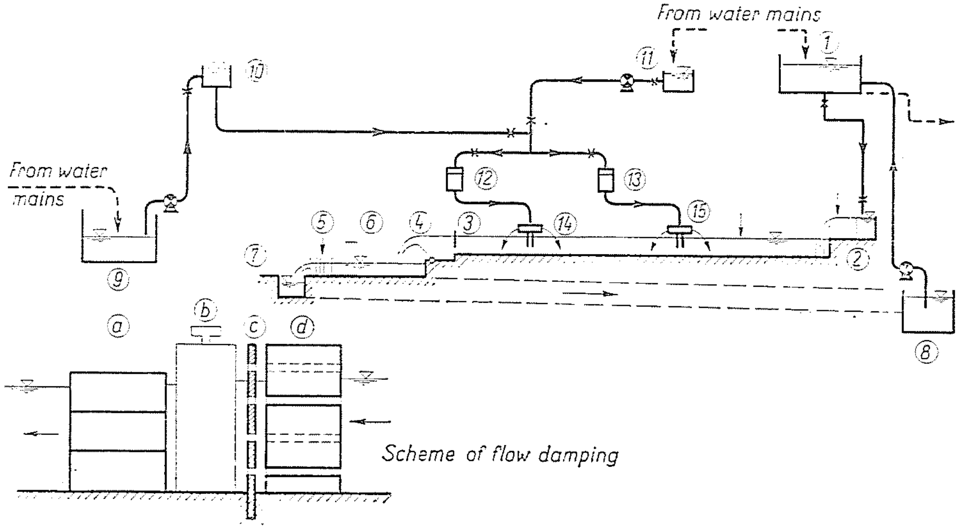

Fig. 3. 1. overhead tank; 2. gauge overfall 1; 3. skimming wall; 4. weir No. 2; 5. gauging weir No. 3; 6. intake canal; 7. underfloor canal; 8. suction shaft; 9. suction shaft; 10. overhead tank; 11. concentrated salt solution; 12. calibration tank **a**; 13. calibration tank **b**; 14. mixing plant **A**; 15. mixing plant **B**; *a)* horsehair blanket; *b)* baffle plates; *c)* perforated steel plate; *d)* hollow brick; pump; —×— gate valve; ↓ point gauge

1.2 Description of the scale model

Figures 2 and 3 present the lay-out and the flow diagram of the model, respectively.

The water flowed in a closed circulatory system, recirculated hot water was taken from outside.

In reality, the discharge withdrawn from the Danube has been metered by the V-notch weir No. 1. Water intake works have been replaced by skimming walls with adequate holes, with sharp-edged overfalls behind (overfalls No. 2) allowing for a very accurate adjustment. These had the double function to help adjustment of specified water levels in the model itself, and to control or to bring about discharges through each intake work by means of a slight relative displacement. From each intake work, water was conducted by a separate canal ending in built-in overfalls No. 3, metering the flow to each unit.

Relatively slight discharges (0,513 l/s) through mixing plants have been metered by so-called "Danaides" (small calibration tanks) permitting precision adjustment. Water was fed through rubber hoses to the mixing plants. Thereby these were easy to transfer in the frequent cases of examining alternatives.

1.3 Methods of measurement

Simulating return water raised great many design problems. Realistic tests using hot water would have involved costly equipment and time loss. Therefore simulation by dilute salt solution, simple and cheap to implement, has been chosen.

This method has the inconvenience of untrue density conditions. While hot water of lower density floats on the surface, salt solution subsides. This is only valid, however, in lack of heat transfer between the two systems.

In our case the design itself of intake structures provided for perfect mixing, as ascertained by visual observation, and by sampling water from the bottom and the surface. Near mixing plants A and B, there is an intensive turbulence so that a stratified flow in the model is unlikely.

In our tests, the substitution of hot water by salt solution proved to be adequate, namely it was only attempted to distribute the hot water flow according to given proportions. Remind, however, that in reality, on its way from the mixing plant to the intake work, hot water undergoes a quality change — it cools down during a shorter or longer storage in the bay — a variation not occurring with salt solution.

We shall come back later to this problem.

Simulation by salt solution is based on the following mathematical considerations:

Salt quantities entering and leaving the system must be equal. Quantities q_a and q_b entering through mixing plants are distributed between intakes according to a certain proportion (Fig. 4).

We have to know these quantities q_I, q_{II} and q_{III} with regard to hot water distribution.

For instance, in stage 3:

$$q_I + q_{II} + q_{III} = q_a + q_b \cdot \tag{1}$$

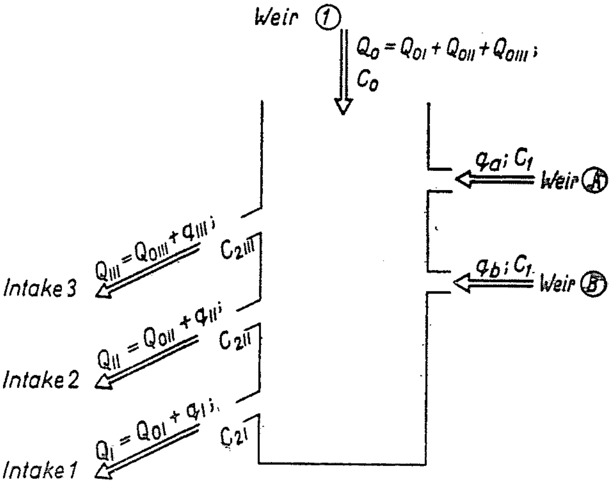

Fig. 4

Hence, the entire water volume leaving through an intake is composed of two parts, a hot part q_x and a cold part Q_{0x} coming from the Danube to that particular intake.

Hence:

$$Q_0 = Q_{0\mathrm{I}} + Q_{0\mathrm{II}} + Q_{0\mathrm{III}} \tag{2}$$

$$Q_\mathrm{I} = q_\mathrm{I} + Q_{0\mathrm{I}} \tag{3}$$

$$Q_\mathrm{II} = q_\mathrm{II} + Q_{0\mathrm{II}} \tag{4}$$

$$Q_\mathrm{III} = q_\mathrm{III} + Q_{0\mathrm{III}} \tag{5}$$

Now, the salt balance for intake 1 will be:

$$Q_\mathrm{I} \cdot C_{21} = q_\mathrm{I} \cdot C_1 + Q_{0\mathrm{I}} \cdot C_0 . \tag{6}$$

After substituting and rearranging one has:

$$q_\mathrm{I} = Q_\mathrm{I} \cdot \frac{C_{21} - C_0}{C_1 - C_0} . \tag{7}$$

The same relationships are to be derived for intake works 2 and 3:

$$q_\mathrm{II} = Q_\mathrm{II} \cdot \frac{C_{2\mathrm{II}} - C_0}{C_1 - C_0} \tag{8}$$

and

$$q_\mathrm{III} = Q_\mathrm{III} \cdot \frac{C_{2\mathrm{III}} - C_0}{C_1 - C_0} . \tag{9}$$

Concentrations C_{2x} may be observed during the period where increasing concentration is followed by a quasi-steady state. Other symbols are interpreted according to Fig. 4. In relationships (7), (8) and (9), the Q_x values are known, concentrations C_0, C_1 and C_{2x} can be determined by measurements.

A good opportunity for checking the accuracy of our measurements was offered by Eq. (1). Maximum difference between "hot water" inflow and outflow was below 5%.

2. Measurement results

The scale model test involved a total of 52 measurements in two measurement series (construction stages 2 and 3), for different mixing plant positions.

The entity of model tests permitted to conclude on the impossibility of siting mixing plants so as to uniformly distribute hot water if the bay before the intake works was constructed according to the original design.

Although in the position corresponding to stage 2, an optimum site has been found for mixing plant A — likely to distribute hot water in a 1 : 1 ratio between intakes 1 and 2 — values shifted by about 10% to the benefit of intake 2 for lower water levels.

In construction stage 3, the developing flow conditions and the operation of mixing plant B fundamentally changed the situation. Intake 1 received too much, intake 2 again not enough of hot water. At higher river stages, the situation improved somewhat but even then important discrepancies appeared between hot-water proportions arriving to the various units.

This was due to the fact that main flow tending from the harbour to the intakes, — occupying a rather narrow band compared to the dimensions of the whole section — almost barred hot water of mixing plant A from intake 2. About 70% of the bay participated but indirectly in the water conveyance, flow was extremely slow, even reversed along the left bank, giving rise to eddies. In addition to the risks of silting up and winter freezing, the bay put to stake the main goal — to optimalize cooling water temperature.

Model tests showed the bay to affect adversely the process of hot-water distribution. Previously, it has been mentioned that part of the potassium permanganate solution introduced through mixing plant A flowed into the quoted dead area whence it leaved but slowly. Similar was the phenomenon in continuous salt addition where the concentration *vs.* time curve needed 20 to 30 min to attain the peak, while tracers in the main stream appeared at the intake works already a few minutes later. This can be attributed to the time needed for the salt content in the bay to increase so as to provide equality between salt flowing into, and leaving this space. Once this condition has set in, salt concentration at intake works did not grow any more, equilibrium being restored.

Thus, salt solution attained the intakes with a certain lag but eventually it has not suffered quantitative or qualitative changes. In fact, however, hot water stored for a long time is susceptible to important heat losses (great free surface, eddy currents, low riverside depths etc.) responsible for quality (more correctly, temperature) differences between slow inflow into the system, and its outflow. Obviously, it cannot have an effect comparable to that of hot water arriving with the main stream.

As a conclusion, optimum hot water distribution called for the modification of the bay design, by way of making another test series.

3. Suggestion for the bay design

Certain stipulations imposed to consider the greatest part of the right bank of the cold water canal as given, only the left bank of the bay before the intake works allowed certain modifications. After having performed a rough flow-pattern examination of several alternatives, solution shown in Fig. 5 has been chosen. Improvement of flow conditions attempted to achieve a nearly constant mean velocity of the flow passing before the intake works. A flow pattern active from the aspect of the suction orifices was required, really carrying water and at the same time providing a stable onflow and hot water distribution in a wider range of water levels than before.

The suggested channel reach offers a solution that consists in reducing the area of water-conveying section in proportion to the discharge in the bay before the intake works, and carrying water faster to the suction openings.

It was interesting to see the main peculiarity of the flow pattern of the original channel (slow rotation of the countercurrent water mass) to vanish only in the immediate vicinity of the bank development following the given layout.

The bay has been transformed by taking the state corresponding to full operation of the power plant into consideration. Obviously, it is not justified to undertake fundamental alterations for the sake of a rather short period preceding full operation; design is expected to look further ahead. Therefore the bay has been constructed for the needs of completion (stage 3), taking also stages 1 and 2 into consideration.

In the transformed cold water canal, three positions each of both mixing plants have been tested. Measurements were up to expectations, in the best case, the respective shares of intake works in hot water differed as little as by 1 to 3 per cent from the optimum value within the tested range of river stages.

The evaluation of scale model test results showed the modified cold water canal to meet requirements of continuous, undisturbed operation.

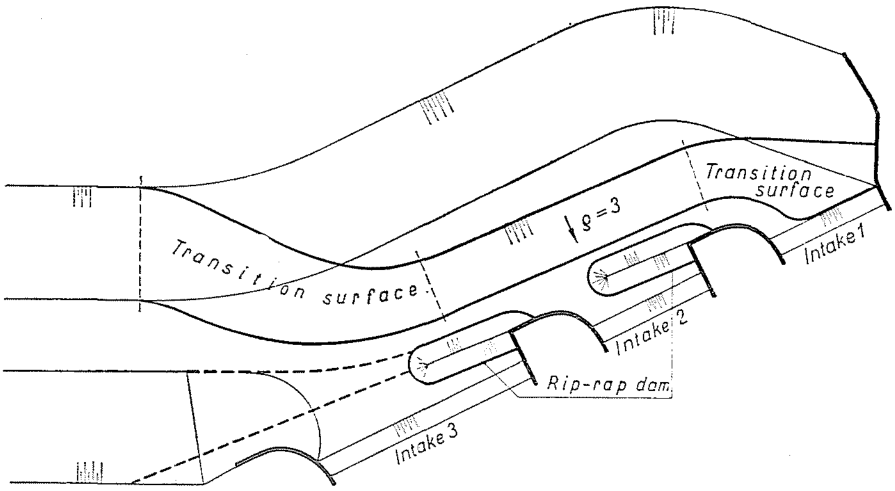

Fig. 5

	Discharge	Salt concentration
Water arriving from weir 1 — (simulating the Danube)	Q_1	C_0
Salt solution fed by mixing plant A into the system	q_a	C_1
Salt solution fed by mixing plant B into the system	q_b	C_1
Water discharged through intake 1	Q_{I}	C_{21}
Water discharged through intake 2	Q_{II}	$C_{2\mathrm{II}}$
Water discharged through intake 3	Q_{III}	$C_{2\mathrm{III}}$

$Q_{0\mathrm{I}}$ — discharge of cold water to intake 1,
$Q_{0\mathrm{II}}$ — discharge of cold water to intake 2,
$Q_{0\mathrm{III}}$ — discharge of cold water to intake 3,
q_{I} — discharge of hot water to intake 1,
q_{II} — discharge of hot water to intake 2,
q_{III} — discharge of hot water to intake 3

Gradual acceleration of water approaching the intakes not only reduces — or even offsets — the silting-up of the bay but also increases the mixing efficiency between water layers of different temperatures, achieved through increased turbulence caused by higher mean velocity. Thereby not only the introduced hot water but also heat stored in water near the bottom, warmer in winter, are better utilized, likely to promote substantially a favourable temperature development.

Although, eddies were not to be eliminated in the forebays of suction orifices still they seemed stable during tests and are thus expected to cause only deposits unlike to affect directly the intake operation. At the same time, the stability of eddies permits to specify regular maintenance dredgings for relatively constant areas.

Acknowledgements

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Summary

Scale model tests on the cold water canal reach before the intake works of the Paks Nuclear Power Station, now under construction, have been analyzed. Measurements and observations permitted to locate optimally hot water mixing plants and to suggest a hydraulically better design of forebays before the intake works.

Measurement method based on dilute salt solution has been presented in particulars, pointing out, however, that simulation of hot water by salt solution is an approximation admissible in special cases alone, since it is unfit to simulate thermodynamic processes in all their aspects.

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