CHAPTER 177

HORIZONTAL DIFFUSION IN TIDAL MODELS AND SCALING CRITEREA FOR THERMAL-HYDRAULIC MODEL TESTS

by

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INTRODUCTION

Near Brokdorf at the lower Elbe river (West Germany) a nuclear power plant is projected. The electric energy output shall be 1300 MWe; therefore the waste heat output will be about 2600 MWe. The maximum allowed temperature rise in the condenser amounts to 10 K. Accordingly the cooling water discharge is about 61 m^3/s in case of the provided once through cooling.

For the purpose of the mixing and spreading of the discharged cooling water by

mean tidal conditions and storm-tide conditions

model tests have been carried out at the Franzius-Institut of the Technical University of Hannover.

SCALING CRITEREA FOR THERMAL-HYDRAULIC MODEL TESTS

With regard to the environmental impact and ecological aspekts the temperature distribution has to be determined.

Therefore the whole far-field region is reproduced in the distorted model with a vertical scale of 1:100 and a horizontal scale of 1:300.

The scales of the far-field model were selected with regard to the reproduction of the turbulent diffusion and with re-

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gard to the heat exchange at the water surface due to the following scaling criterea for the heat exchange

$$k_r = \frac{K_N}{K_M} = \frac{\lambda_V^{1.5}}{\lambda_H} \quad \text{(as outlined in reference (3))}$$

where K is the heat exchange coefficient in $W/m^2 \cdot K$ and λ_V the vertical scale and λ_H the horizontal scale.

In the laboratory without wind effects) heat exchange coefficient K_M of about 15 $W/m^2 \cdot K$ were measured. For the German estuarine areas one assumes significant mean low heat exchange coefficients of about 50 $W/m^2 \cdot K$, hence the value of k_r in the above mentioned model study is 3.33.

In regard to the reproduction of the turbulent diffusion in the model the Reynolds number should be large enough to satisfy that the turbulence is sufficiently well developed.

The scale of the Reynolds number r is given by this relationship

$$r = \frac{Re_N}{Re_M} = \lambda_V^{1.5}$$

where λ_V is the vertical scale, index N indicates prototyp dimension and index M model dimension.

A special near-field model was built for the purpose of cooling water discharge currents, the waste heat recirculation, the dilution and dispersion influenced by the outlet design.

In the near-field region physical effects such as buoyancy, density currents, stratified flows, jet-diffusion and the advective and diffusive heat transport processes are predominant. Therefore a scale of 1:50 and no distortion were selected for the near-field model.

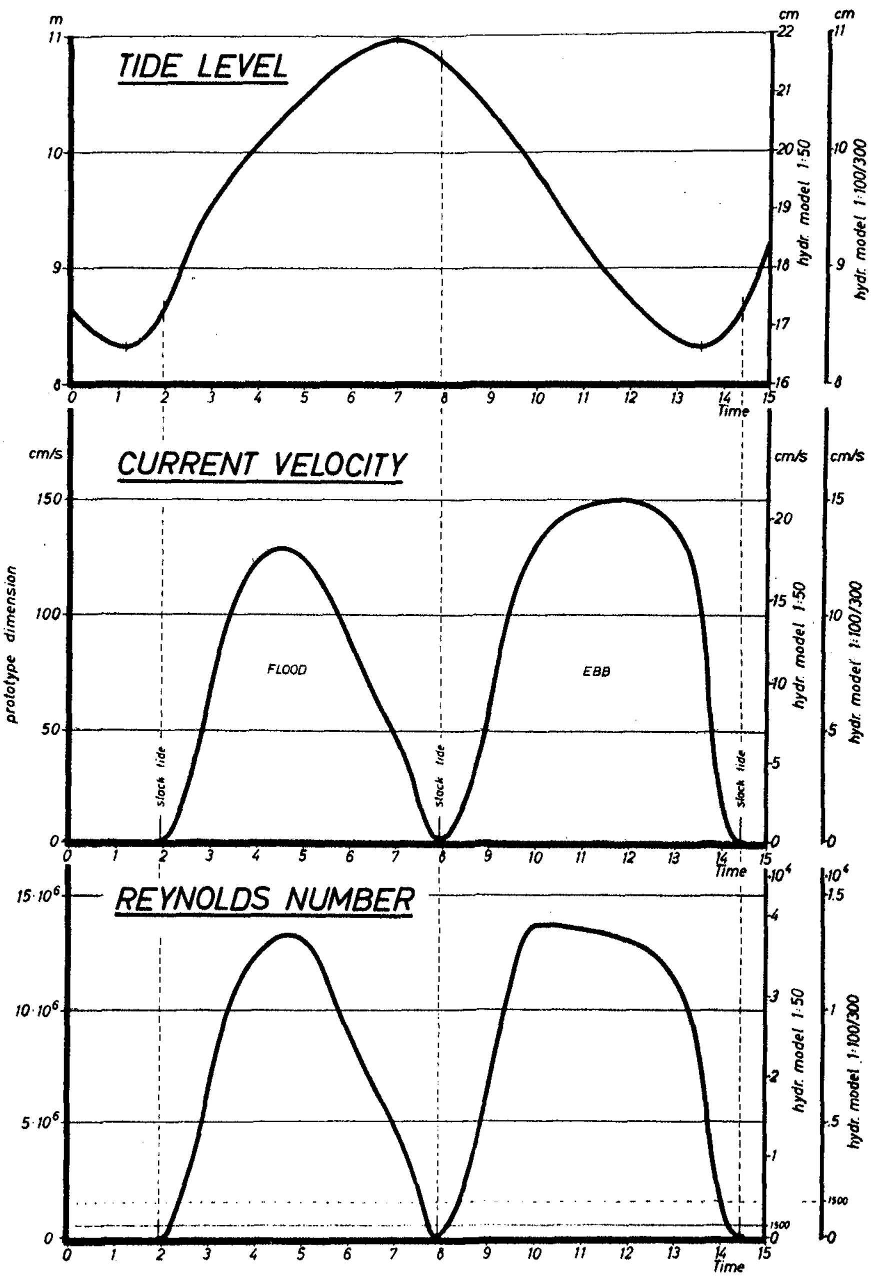

TIDE LEVEL
CURRENT VELOCITY
REYNOLDS NUMBER
FLOOD
EBB
slack tide
prototype dimension
hydr. model 1:50
hydr. model 1:100/300
Time
m
cm
cm/s
1500

Figure 1

Figure 1 shows the characteristic values for the water depth (tidal level), the current velocity and the reynolds number as a function of time. On the left hand the prototype dimension and on the right side the values for the undistorted near-field model with a scale of 1:50 and the three times distorted far-field model are represented.

The diagram shows that only during a short time before and after slack tide the Reynolds number of onethousendfivehundred is not satisfied. The dotted line belongs to the far-field model.

DIFFUSION AND TURBULENCE PHENOMENA IN TIDAL MODELS

The model tests showed a characteristic behavior of the horizontal diffusion coefficient D_Z during the tidal cycle (Fig. 2).

During the well developed tidal current the horicontal diffusion coefficient is nearly constant. But a short time before and a short time after slack tide the horizontal diffusion coefficient becomes a maximum.

This result leads to the question: What kind of physical effects induces this behavior of the horizontal diffusion?

Theoretical considerations lead to the following statement:

The turbulence is mainly generated through large eddies, the energy of which is a function of the mean flow velocity. The large eddies transfer their energy to smaller eddies until the eddies become so small that they are dissipated by viscosity effects (1).

In turbulence theory distinction is made between:

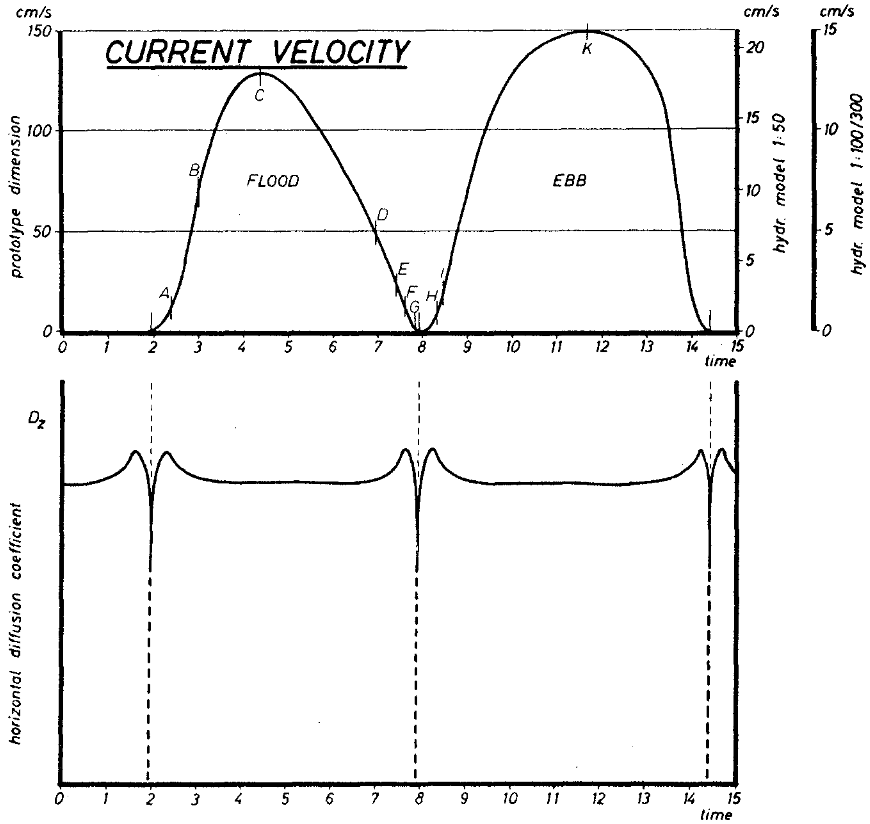

CURRENT VELOCITY
cm/s
150
100
50
0
prototype dimension
cm/s
20
15
10
5
0
hydr. model 1:50
cm/s
15
10
5
0
hydr. model 1:100/300
A
B
C
D
E
F
G
H
I
K
FLOOD
EBB
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
time
D_z
horizontal diffusion coefficient
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
time

Figure 2

integral scale Λ (a macro scale) $\Lambda :: L$ (1)

Taylor scale Λ (a micro scale) $\Lambda :: \nu \frac{\sqrt{u'^2}}{\varepsilon}$ (2)

Kolmogoroff scale η (a micro scale) $\eta :: (\frac{\nu^3}{\varepsilon})^{1/4}$ (3)

where L: characteristic dimension of length (for example: water depth)

ε: energy dissipation per unit mass and unit time

ν: coefficient of cinematic viscosity

u': turbulent velocity fluctuation

The turbulent energy induced by the bottom shear in the fluid motion per unit mass amounts to:

$$E :: \frac{\tau_b \cdot L^2 \; u}{\rho \; L^3} :: \frac{f_b \cdot u^3}{L} \qquad (4)$$

where τ_b = bottom shear stress ($\tau_b = \frac{1}{8} f_b \cdot \rho \cdot u^2$)

f_b = bottom shear coefficient

Assuming that a state of equilibrium exists between induced turbulent energy and energy dissipation.

$$E = \varepsilon \qquad (5)$$

From this condition, we derive (Abraham (2)) the following relationship between the Reynolds number and the scales of turbulence:

$$\frac{\eta}{L} :: Re^{-3/4} \qquad (6)$$

$$\frac{\lambda}{L} :: Re^{-1/2} \qquad (7)$$

where the Reynolds number is defined as follows:

$$Re = \frac{\bar{u}L}{\nu}$$

Equation 6 and 7 lead to the following conclusion:

With decreasing Reynolds numbers the size of the eddies which are dissipated by viscosity (Kolmogoroff scale, Eq. 6) increases. The size of eddies of which only a small fraction is dissipated by viscosity (Taylor scale, Eq. 7) increases also with decreasing Reynolds numbers.

These theoretical arguments lead to the statement, that - a short time before and a short time after slack tide, when the horizontal diffusion coefficient D_Z increases, the turbulence spectrum of the flow contains mainly large eddies.

Therefore the next step of research was to investigate the behavior of the turbulence spectrum during the tidal cycle - in both models.

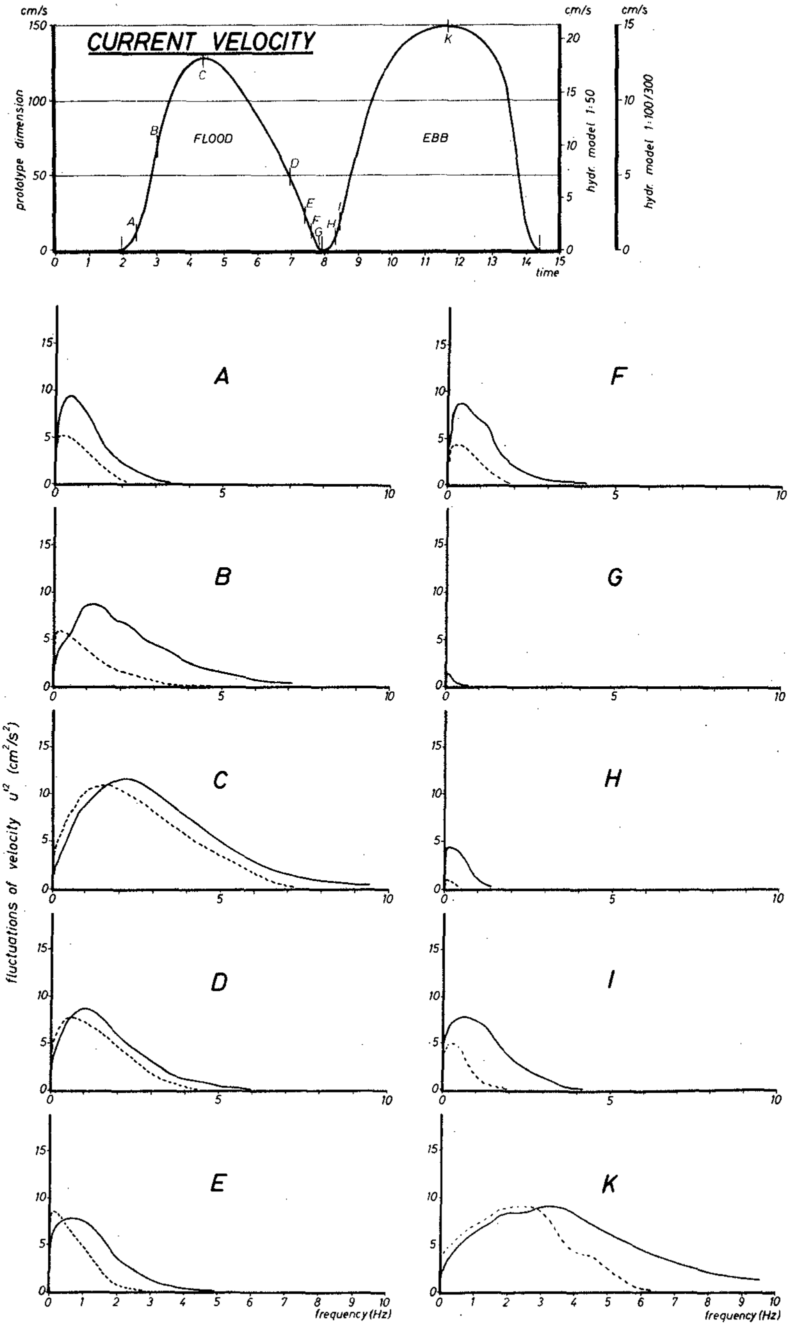
Figure 3 shows in the upper diagram the characteristic current velocity as a function of the tidal process and the turbulence spectra at the marked points of time in the upper diagram. The full-line represents the results of the undistorted model, scaled 1:50, and the dotted line represents the results of the distorted model, scaled 1:100/1:300.

The ordinate indicates the velocity fluctuation.

Diagram A points out, that a short time after low water slack the turbulence is not fully developed - in both models. The frequency is smaller than two Hertz, that means only large eddies exist.

At time B the turbulence spectrum in the near-field model is more developed.

That means the turbulence spectrum contains also small eddies. The predominant eddy size is indicated by the maximum of the



CURRENT VELOCITY
cm/s
prototype dimension
hydr. model 1:50
hydr. model 1:100/300
FLOOD
EBB
A
B
C
D
E
F
G
H
I
K
time
fluctuations of velocity u'^2 (cm^2/s^2)
frequency (Hz)

Figure 3

curve. The dotted line shows that - at the same tidal point - in the distorted model the turbulence is not well developed. Only a small fraction of small eddies represented by the higher frequency exists.

At C the turbulence is fully developed. In both models the spectrum has nearly the same shape. In comparison to B the fraction of large eddies decreases; but the fraction of small eddies increases. The total of turbulence intensity - with other words the integral of the curve - becomes a maximum.

At D the turbulence intensity decreases. Mainly the small eddies are filtered out by viscosity effects - or with other words the range of higher frequencies is dissipated. The range of low frequencies has not changed importantly.

At E and F the intensity of turbulence decreases more and more. One can observe that the smaller eddies, that means the range of the higher frequencies of the spectrum, in this case from four to two Hertz, are filtered out. With other words the size of the existing eddies becomes more and more uniform.

At G that means at slack tide there is no turbulence in the far-field model (1:100/300). In the near-field model only a very small fraction with low intensity of turbulence exists.

At H the development of the turbulence has started again. But at this time only a small intensity of turbulence exists. Only large eddies - indicated by low frequencies - are generated.

At I one can confirm a further development of the turbulence spectrum. The spectrum contains mainly large eddies with frequencies to about two Hertz.

At K a fully developed turbulence sprectrum exists. In comparison to G, H, I one can confirm that at first the larger eddies are generated and with increasing intensity more and more smaller eddies are produced until the turbulence is fully developed - as shown in diagram K.

CONCLUSION

The statement, that the maximum of the horizontal diffusion coefficient D_Z a short time before and a short time after slack tide is caused by the effects of turbulence - that means the turbulence spectrum becomes more and more uniform containing only large eddies - seems to be verified by the investigations in both models.

As well known the turbulence is of a statistically manner.

Thereforethe transportation proces is also a statistically process - and one can imagine, that the efficiency of the transport process is also influenced by the rate of uniformity of the eddy size.

And in regard to the mentioned behavior of the horizontal diffusion coefficient, it seems that the increase of the eddy size and the uniformity of the eddies after my opinion cause this phenomen. But to get sure information about this effect and about the magnitudeof this effect for prototype conditions field investigations about the variation of the turbulence spectrum during the whole tidal cycly will be done as soon as possible.

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