Minimizing Transverse Flow Effects on Passing Ships at Inland Waterways

Tobias Linke (1) and Claus Zimmermann (2)

(1) Associate Member; Franzius-Insitute for Hydraulic, Waterways and Coastal Engineering, University of Hannover (Germany), Nienburger Strasse 4, 30167 Hannover, Germany; PH +49 (0) 511 762 8942; FAX +49 (0) 511 762 4002; email: tl@fi.uni-hannover.de
(2) Fellow; Franzius-Insitute for Hydraulic, Waterways and Coastal Engineering, University of Hannover (Germany), Nienburger Strasse 4, 30167 Hannover, Germany; PH +49 (0) 511 762 5481; FAX +49 (0) 511 762 4002; email: zi@fi.uni-hannover.de

Abstract

Transverse flows from lateral water discharges, e. g. from cooling water outlets at power stations or storm water outfalls, into inland waterways (rivers and canals) may affect passing ships. To provide operational traffic safety such transverse flow effects on ships from outfall structures are to be restricted with suitable cross-flow velocities and cross-flow distributions.

Inland canals in Germany allow operation of ships with lengths up to 185 m and widths up to 11.4 m, were dimensions are restricted by locks. Allowing a traffic lane width of 16 m in each direction, there is a safety clearance of 2 m between the lanes. Ship speeds may not exceed 12 km/h for low draft ships and 8 km/h for deep draft ships. Ships approaching locks reduce speed and thus loose manoeuverability. Drifts on ships passing outfall structures depend on ship parameters, parameters of fairway, and parameters of lateral water discharge.

For a storm water outfall in the City of Bamberg (Germany) with strong topographic restrictions at the Main-Danube-Canal in the approach to a lock, drifts on ships passing the lateral discharge location shall not to exceed a safety clearence of 2 m between the traffic lanes for extremely low ship speeds of 3 km/h. Following a prelimilary empirical approach extensive physical model tests, scale 1:25, with prototype ships passing the outfall structure have been performed and compared with 3-D numerical simulations using Computational Fluid Dynamics (CFD) Technique. With a uniform flow distribution obtained with an overflow weir and a submerged wall, ship drifts were acceptable for varying discharges.

Introduction

Discharge of flows into a waterway, e.g. from industrial and power plants or storm water collectors, may affect passing ships depending on the induced transverse momentum acting on a ship in front of an outfall structure. Effects could be a complete lateral drift of the ship which, according to prototype tests on the River Rhine, may reach two times the ships's width or more (DVWK, 1984) and/or a rotation in the vertical ship axis, Figure 1.

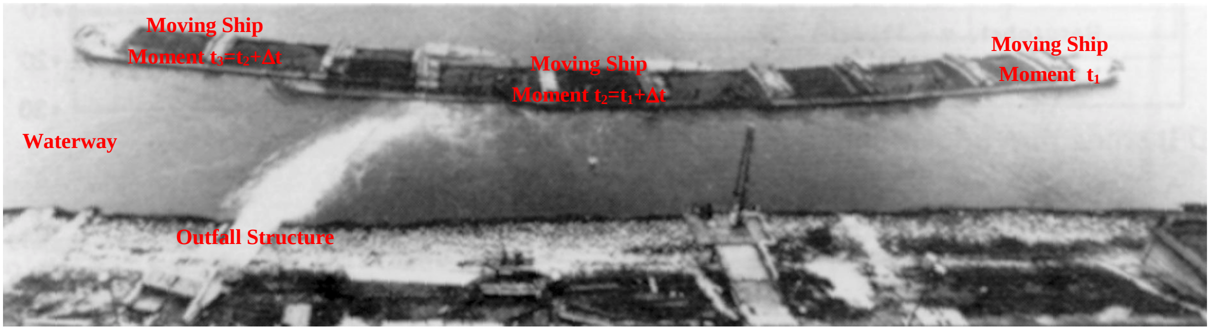


Figure 1. Deviation of a Ship Passing an Outfall Structure (DVWK, 1984).

Both effects may cause collision hazards to other passing or oncoming ships. Lateral ship drifts and rotations depend on the ship parameters mass, width, length, draught and speed. Parameters of the fairway are depth and width, while parameters of the lateral water discharge are distance to ship, width and magnitude and distribution of outfall velocities.

So far, no analytical concept or model exists to predict the effects of parameter variations on ship drifts in order to avoid collision hazards. Reasons are their number and variability, but mainly the interactions and unsteadiness of the flow field in front of the outfall structure due to the moving ship.

In previous years the Waterways Administration in Germany allowed cross-flow velocities not to exceed 0.3 m/s along a defined boundary in the fairway with the navigation canal based on some experiences with ships of very low speeds. For German Waterways hydraulic model tests with free running model ships had and still have to demonstrate that outfall conditions do not exceed a defined drift, depending on the local nautical and navigational conditions and hazards to be expected.

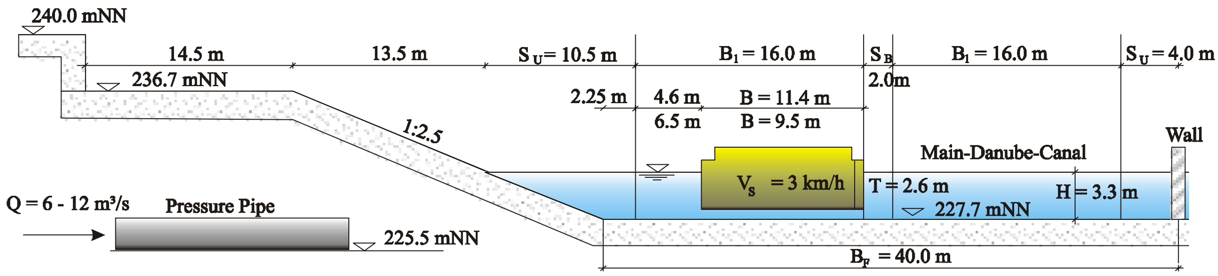
For a storm water outfall in the City of Bamberg (Germany) discharges between 6 m^3/s and 12 m^3/s into the recently finished Main-Danube-Canal, which connects the River Rhine with the River Danube in the center of Germany, it had to be shown that the lateral drift of a passing ship will not exceed 2 m. Navigation conditions are restricted due to a nearby lock approach with reduced water depth and therefore ships operate at low speeds affecting strongly their manoeuverability.

3-D numerical simulations were performed to find the optimum outfall structure with minimum and uniform cross-flow velocities based on a semi-empirical approach of Pulina (1993) for a preliminary layout. The results were tested in a hydraulic model in the shallow water towing tank of the Franzius-Institute for Hydraulic, Waterways and Coastal Engineering since numerical modelling of the transverse flow fields and their highly unsteady interactions with a passing ship is not possible so far.

Boundary Conditions

Waterway and Navigation

The Main-Danube-Canal traversing the City of Bamberg in the southern part of Germany has a fairway width of 40.0 m and a reduced water depth of 3.3 m, compared to the design water depth of 4.0 m, Figure 2.



v_S = Speed of Ship;
m_{Schiff} = Mass of Ship;
B = Width of Ship;
B_F = Width of Fairway;
B_1 = Width of Traffic Lane;
H = Water Depth;
L = Length of Ship;
Q = Discharge;
s_B = Safety Clearence between the Lanes;
s_U = Safety Clearence to Bank;
T = Draught of Ship.

Figure 2. Cross-Section of Main-Danube-Canal Traversing the City of Bamberg (Germany).

Canal dimensions allow two-lane traffic with standard ships of 185 m length and 11.4 m width (push tows) or 80 m length and 9.5 m width (self propelled single ships). Maximum allowed draught is 2.6 m for which a maximum speed of 8 km/h is allowed, while low draught ships are allowed up to 12 km/h.

Since the canal reach under consideration is within the approach to the first lock of the Main-Danube-Canal, ships operate at very reduced speeds of 3 km/h. Due to the reduced manoeuverability, cross-flows may result in a lateral ship drift. For safety reasons the Waterways Administration does not allow a lateral drift of a passing ship to exceed 2 m. Therefore, any discharge into the canal has to be controlled by structuring the cross-flow velocities accordingly (Linke & Zimmermann, 2000).

Discharges into the Canal

From the storm water drainage system of the City of Bamberg between 6 m³/s and 12 m³/s shall be discharged into the Main-Danube-Canal, depending on the connected area of precipitation. The topography of the city allows only a pressurized collection system with a pressure pipe of 2.2 m in diameter arriving beneath canal bottom, Figure 2.

Preliminary Outfall Structure Design

A preliminary estimate of the structural dimensions for the outfall was obtained, applying continuity considerations with the maximum cross-flow velocity from the semi-empirical approach of Pulina (1993). From previous experience (Zimmermann, 1990) it was known that uniform flow distributions can be obtained only with a combination of overfall weir and submerged wall in front or within the outfall structure, Figure 3.

To simulate the flows within and in front of the outfall structure, 3-D numerical simulations were performed for various alternatives. Interactions between cross flow fields and passing ships were tested in a hydraulic model.

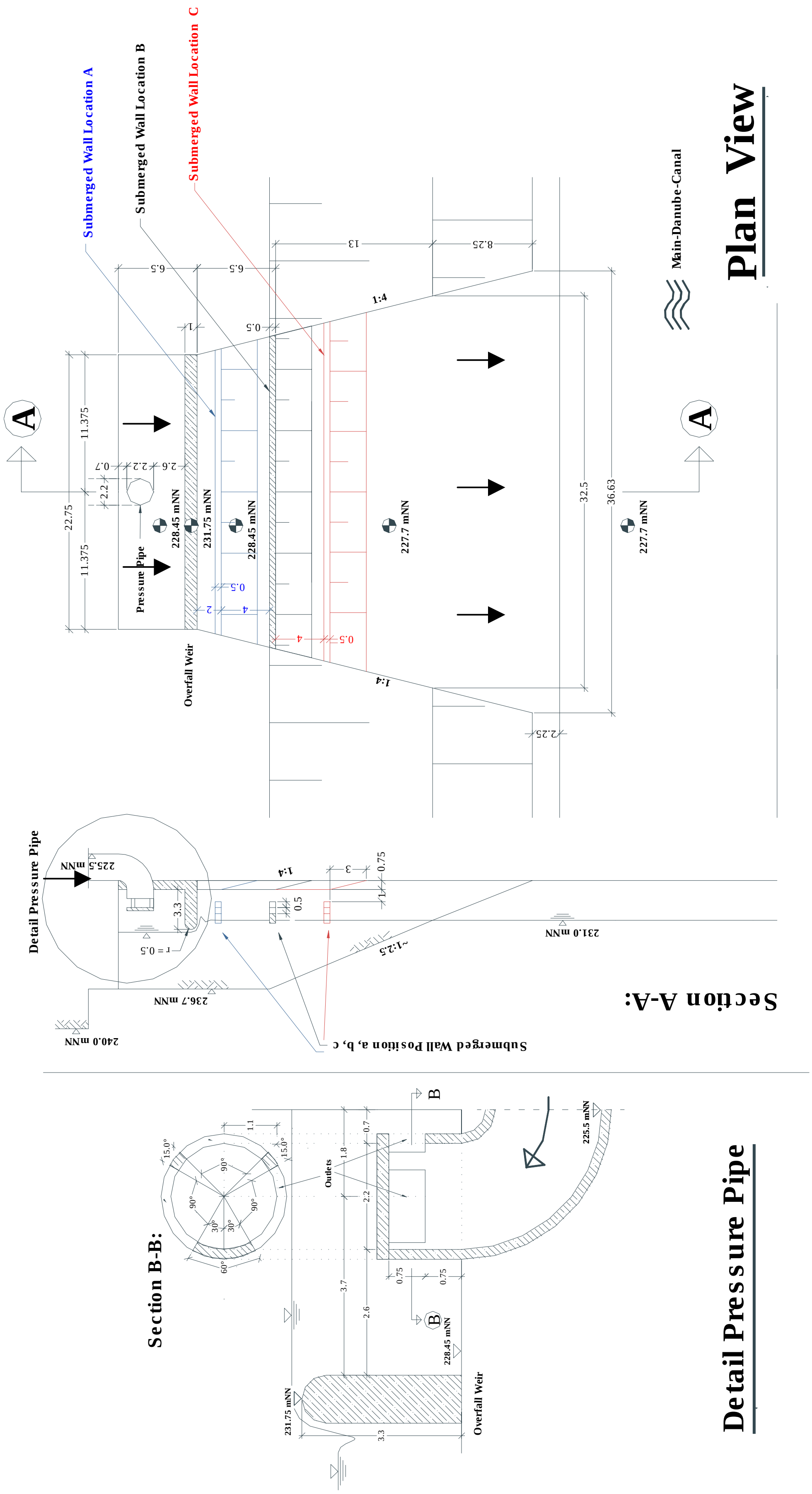
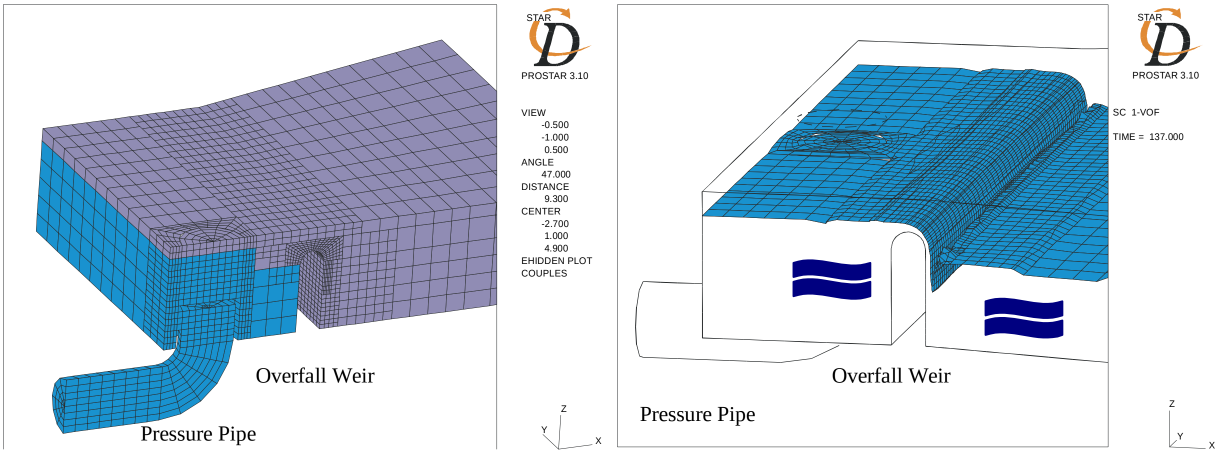


Figure 3. Preliminary Design of Outfall Structure.

3-D Numerical Simulations

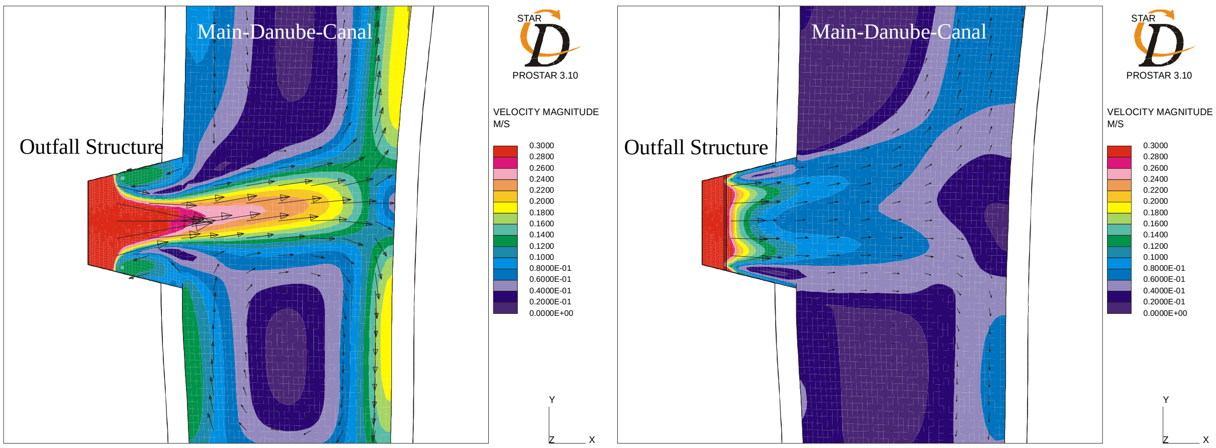
Distribution of flows from the pressurized pipe into the outfall structure required a specific structural set-up, Figure 3. Thus, the overfall weir and the effects of a submerged wall were simulated using Computational Fluid Dynamics (CFD) Technique (Wendt, 1991) from STAR-CD (Computational Dynamics Limited, 1999) with a variable grid within the structure and 400 m of the upstream and downstream canal reaches, Figure 4.



(a) (b)

Figure 4. (a) Part of Computational Grid within Outfall Structure; (b) Simulated Water Surface within Outfall Structure (Discharge: 8 m^3/s).

Examples of the simulated flow fields are shown on Figure 5. Without a submerged wall in front of the overfall weir the flow coming from the central pressure pipe behind the overfall weir still retains a jet-like distribution. The combination of the overfall weir with the submerged wall at the position obtained from various trails turned out to give a rather uniform flow distribution within the outfall structure and in front.

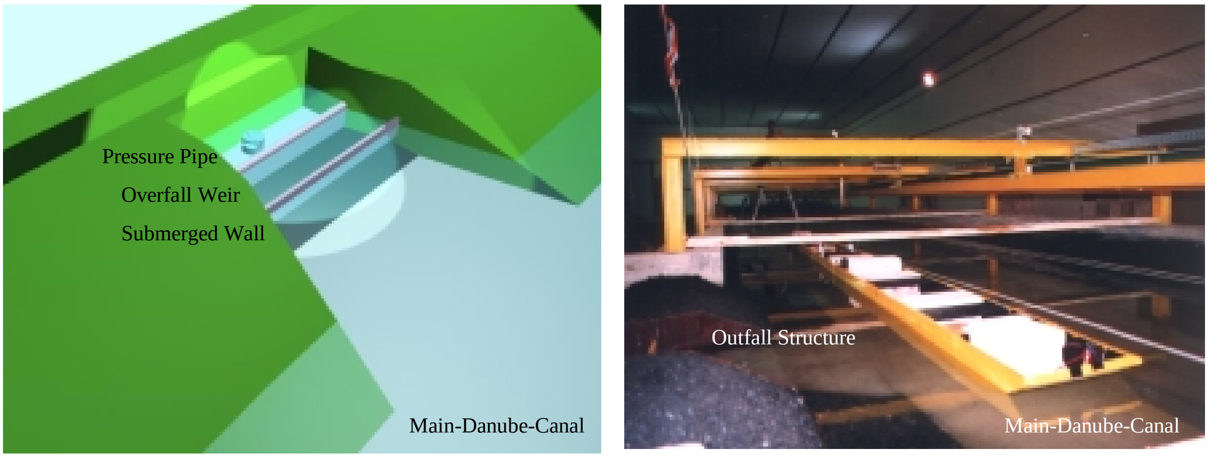


(a) (b)

Figure 5. Simulated Flow Distributions within and in Front of Outfall Structure at Mid Water Depth (Discharge: 8 m^3/s): (a) Without Submerged Wall; (b) With Submerged Wall in Front of Overfall Weir.

Hydraulic Model Tests

Flows within and in front of the outfall structure and their interactions with passing ships were tested in a hydraulic model scaled 1:25, Figure 6.

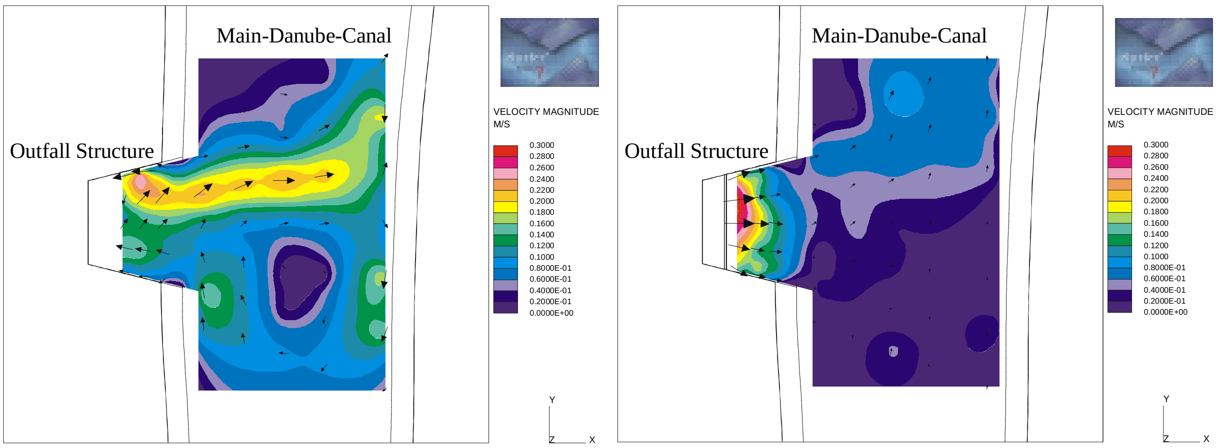


(a) (b)

Figure 6. (a) Hydraulic Model of Outfall Structure; (b) Main-Danube-Canal with Ship Model (Push Tow).

Velocity distributions were obtained using an Acoustic Doppler Velocimeter (ADV) in 10 vertical sections within outfall structure and in the Main-Danube-Canal containing about 15 points each. The equalizing flow effect from the submerged wall in front of the overfall weir is demonstrated also in the hydraulic model, Figure 7.

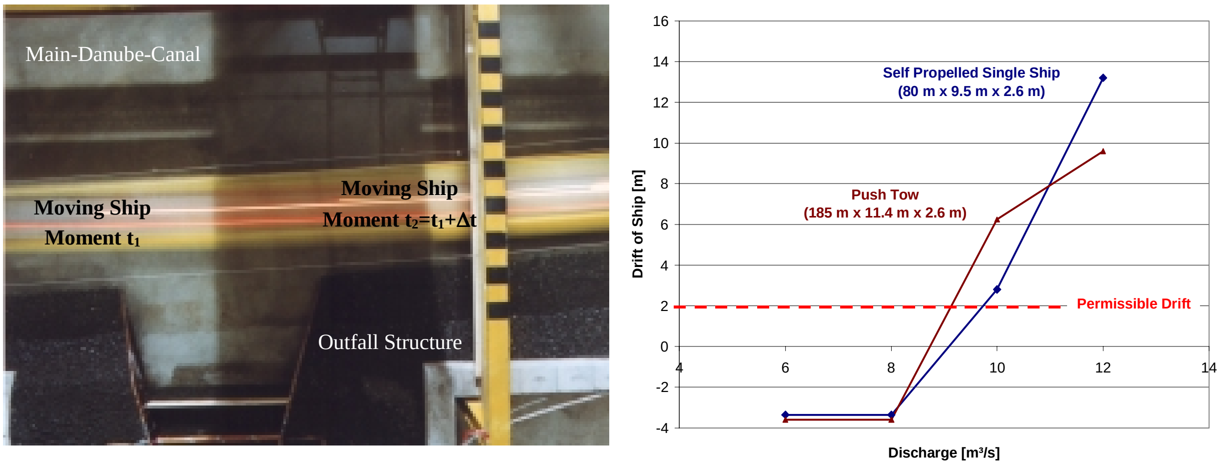
However, the limitations from the measurements in a scaled hydraulic model have to be realized, compared with the results from the 3-D numerical simulations. Due to the probe dimensions, flow velocities only at mid water depth could be measured. Verification with numerical results appears to be acceptable.



(a) (b)

Figure 7. Flow Distributions within and in Front of Outfall Structure at Mid Water Depth Obtained from Hydraulic Model Tests (Discharge: 8 m^3/s): (a) Without Submerged Wall; (b)With Submerged Wall in Front of Overfall Weir.

Simulations of cross-flow effects from the outfall structure on ship drift were made using free running self propelled model ships. The results showed a dramatically increasing drift with outfall discharges above 8 m³/s for the selected structural dimensions, Figure 8. Extension of the structure width would allow higher discharges with acceptable drifts.



(a) (b)

Figure 8. (a) Self Propelled Model Ship (Push Tow) Passing Outfall Structure (Discharge: 8 m^3/s); (b) Ship Drifts as Function of Discharge for Selected Outfall Structure.

Since the local situation did not allow for the extension of the outfall structure, the recommendation was to limit the discharges to 8 m³/s, accepting the minor risk of a larger drift once within 5 years due to such extreme weather conditions. Risks are even less, since the effects of rudder during ship's passage was not considered in the hydraulic model tests.

Concluding Remarks

The comparison of results from simulations of flow fields with a 3-D numerical model and a hydraulic model showed the reliability, even the superiority, of the numerical model.

However, interactions with a moving boundary like the passing ship still exceed the possibility of 3-D numerical modelling. Research is underway to close this gap.

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