FEDERAL INSTITUE OF HYDROLOGY
Koblenz

FEDERAL WATERWAYS ENGINEERING AND RE-SEARCH INSTITUTE
Karlsruhe

Examinations of Technical-Biological Bank Protections on Inland Waterways

<u>Information Sheet:</u>

Ship-Induced Waves – Phenomenon, Influence Quantities and Measurement

R & D – Project
(BAW – BfG)

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Content

1. Phenomenon

The purpose of the first chapter is providing a general understanding of hydraulic phenomena that are linked with ship passages in waterbodies. Local and temporary changes of the water surface and flows around the vessel occur during ship passages due to mutual hydraulic interactions between ship and waterbody. These changes cause the creation of waves and ship-induced flows that have an impact in the form of hydraulic charges on banks of the waterbody.

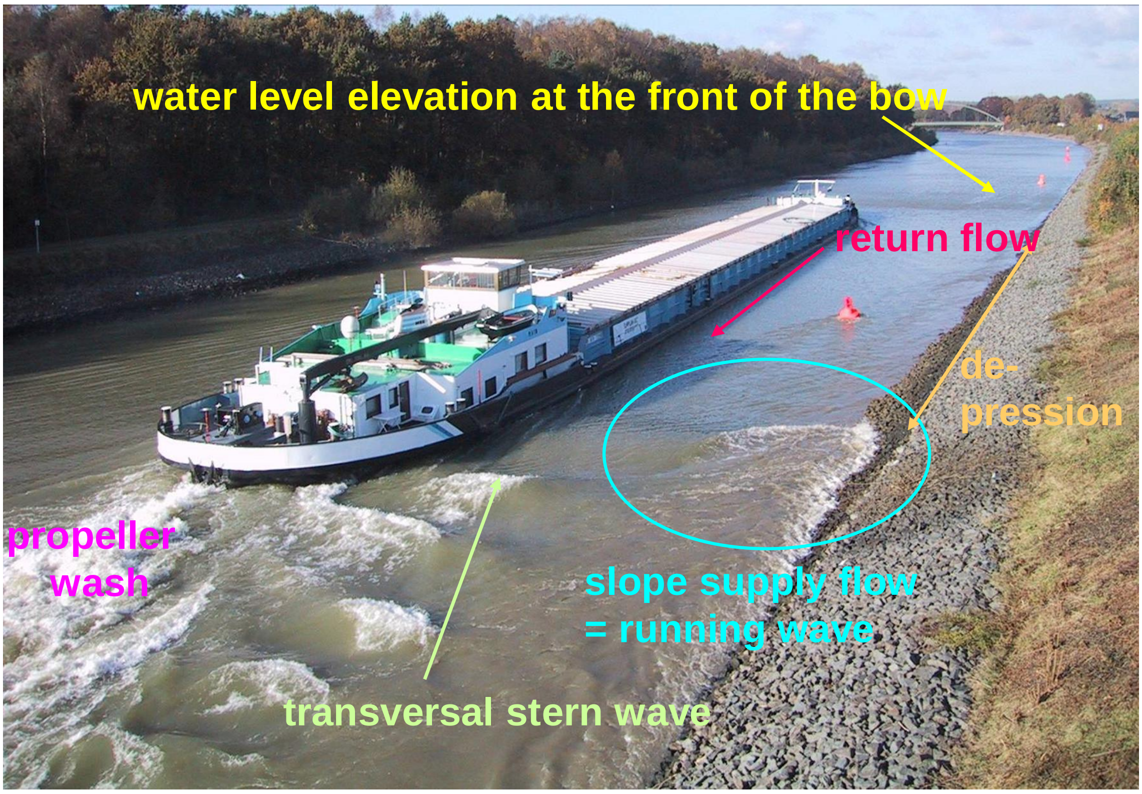

Figure 1 Ship-induced waves and flows at the Wesel-Datteln Canal during a field campaign in October 2002; the image shows a near-bank passage of the *MS Main* with maximal draught at a critical vessel speed

In the most distinct manner, the phenomenon of the interaction between ship and waterway occurs in narrow canals. A water surface elevation of a few centimetres on a length of roughly one vessel-length can be observed in front of the ship (cf. figure 1). This is the so called piston-effect. A swell, called **bow wave**, is generated directly in front of the bow and pushed ahead permanently. From this position on, flow-conditions change remarkably. The so far undisturbed waterbody cross section decreases by the size of the vessel cross section. In this reduced cross section, the moving ship triggers a displacement-flow towards the stern. Alongside the prismatic hull, this accelerated flow is called the return flow, which decreases only when its distance to the vessel is increasing; thus, the return flow is an important load intensity for the banks in the narrow canal. With a distance of one half of the vessel-length to both parts of the watercraft (which corresponds with a **depression** of the length of the ship's diameter), no significant flow return will appear anymore.

The acceleration of the flow again causes a water level drawdown next to the ship – called **drawdown**/ **depression**. The physical cause of the water level drawdown owing to ship-induced flows lies within the energy balance. The entire energy consists of the potential as well as of the kinetic energy. The potential energy is largely determined by the water level. The kinetic energy in this particular case is increasing due to the return flow. As the total energy has to be constant in the first approximation, the result is a reduction of the potential energy and thus a water level drawdown. In this depression, the vessel is sinking constantly, which is described as **squat** or as **dynamic sinking**. Squat and drawdown are equal in the first approximation

A compensation of the flow conditions, which is linked with a water level elevation – the **transversal stern wave** – and a **slope supply flow** in the form of a **running wave**, occurs at the stern of the ship. The higher the speed of the ship, the more stringent the restrictions of fairway conditions (width, depth) and the smaller the distance to the banks, to higher the increase of all ship-induced charges mentioned above; increasing ship dimensions (width, draught) have the same influence at constant watercourse cross sections (decreasing n-value). The entire sequence comprising the bow wave, depression and stern wave alongside the ship occurs in the shape of a wave and is described as **primary wave,** whose wave length corresponds with the ship-length.

Simultaneously, regular, short-period waves – described as **secondary waves** –, which appear as elementary waves due to differences in shape, occur at the bow and stern of the ship:

– at the bow section of the ship where the hull is widening from the tip of the bow to the prismatic and fully-shaped ship's cross section as well as
– at the stern section where the prismatic and fully-shaped ship's cross section is narrowing towards the stern.

On the one hand, these secondary waves are diverging waves propagating in a particular angle to the ship's axle. On the other hand, secondary waves are transversal waves that are oriented nearly perpendicularly to the ship's axle (cf. figure 2). The superposition of both systems creates an interference line that shows a characteristic angle to the ship's axle depending on the ship's velocity. At common velocities, this angle amounts to 19.3°. The angle amounts to a maximum of 45° with an approximation to the critical velocity. Secondary waves, in contrast to primary waves, can reach banks that are more distant from the ship as secondary waves are characterised as free-surface waves, whose height is diminishing only slightly compared to the covered distance. In the first approximation, their wave height raises proportional to the square of the vessel velocity $v_{S.}$

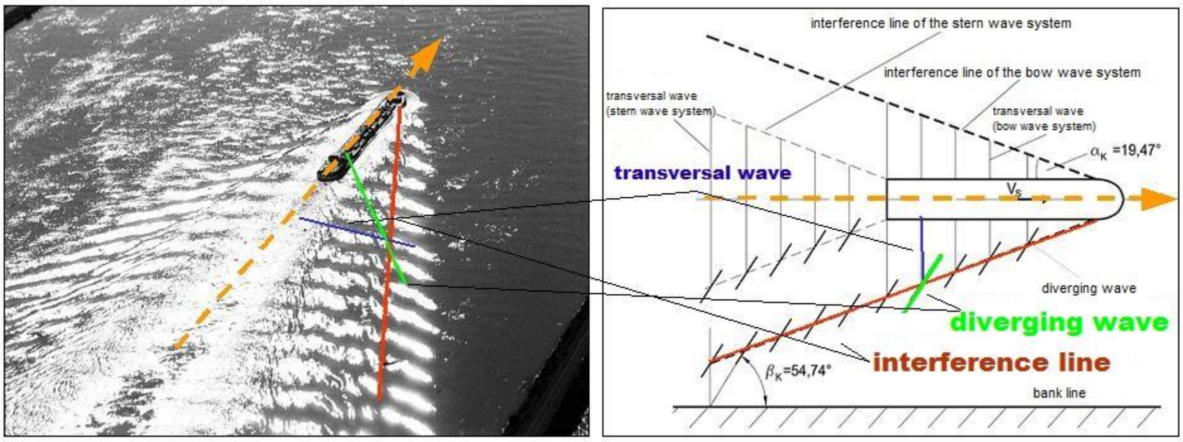

Figure 2 Aerial image of a secondary wave system caused by an inland vessel on the river Rhine; the image also shows the propeller wash area

As a last relevant hydraulic load, the propulsion and steering units with the respective **propeller jet** additionally influence the wave system at the water surface (cf. figure 2):

- at the bow with the bow thruster, which is more often becoming a part of modern ship equipment nowadays as well as
- at the stern and at the wake, e.g. propeller and jet propulsion

Due to its high speed and turbulences, the propeller unit can cause remarkable loads, especially during manoeuvres.

The process explained above is illustrated in a highly simplified draft (figure 3) showing a ship's passage through a trapezoidal canal. The moving ship causes a drawdown below the water level that was undisturbed prior to the passage. Consequently, the cross section is diminishing which leads to a return flow from the bow to the stern, parallel to the ship's hull. The ship causes waves that are propagating to the banks. The propulsion current can be seen at the stern of the ship (bow thruster is not illustrated).

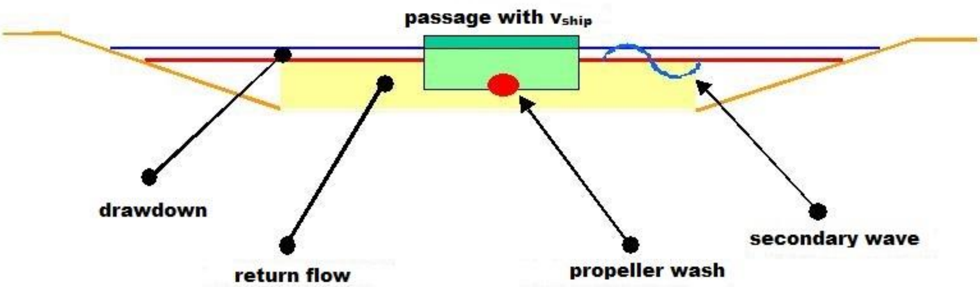

Figure 3 Highly simplified draft of hydrodynamic processes occurring around a moving inland vessel passing through a trapezoidal cross section

The following effects are caused by this process:

- The drawdown at the bank causes underground pore water pressure changes, which have to be considered during the geotechnical dimensioning of the bank protections. The rapid water level drawdown at the bow in particular can trigger excess pore water pressure, which can lead to failure by sliding depending on the permeability of the ground.
- Drawdown-induced flows out of connected backwaters or protected shallow water zones may cause in- and output of bed load.
- Depending on the specific water body topography, drawdown can trigger temporary drainage with desiccation of bank areas causing danger to the existing juvenile fish fauna.
- Waves induce short-periodic water level changes and charges at the bank that have to be considered during freeboard determination and wave run-up as well as according to the influence on flora and fauna at the banks.
- The return flow induces bottom shear stress at the bed and at the bank, which plays a significant role in erosion stability of bed load and bank revetments.
- The propeller wash at the bed as well as the bow thruster wash at the bank and the bed lead to temporary bottom shear stress and can thereby induce the development of scour.

2. Influence Quantities

Geometrical and hydraulic parameters of the **waterway**, **ship** dimensions and velocity as well as figures consisting of combinations of these parameters and results from theoretical derivations about the interaction between **ship** and **waterway** are important influence quantities for the description of the interaction between ship and waterway. The following influence quantities have to be mentioned for the respective topics (cf. GBB 2004 (BAW, 2004) and/or GBB 2010 (BAW, 2011)):

2.1 Waterway

Waterbody cross section A, water level width b_{wsp}, bed-width b_s, fairway cross section A_F, mean water depth h_m, flow velocity v_{fl}, slope inclination m, bed and bank roughness, curve radius if necessary.

2.2 Ship

Ship width B, immerged ship cross section A_M, ship length L, actual ship velocity through the water v_{SdW}, draught T, shape of the ship's hull, propeller and bow thruster parameters, drift angle if necessary.

2.3 Ship/Waterway

Cross section ratio n ($\triangleq A_M/A$), critical ship velocity v_{krit}, relative ship velocity above ground $v_{SüG}$, remaining cross section next to the ship during passage A_{netto}, eccentricity between course and canal axle (eccentricity) y

3. Wave Measurement

Important insights about the interaction between ship and waterway can only be gained from field measurements and/or traffic observations, either with the aid of data acquisition from ongoing navigation or through measuring during test runs under defined conditions. On the one hand it is possible to determine the location of the ship using the GPS measurement procedure which then enables the determination of the ship's position in the waterbody, of its drought and velocity. Another way to determine the above mentioned parameters is the usage of a radar system, especially if the observation of ship traffic should be unaffected in its original navigation behaviour. On the other hand, the registration of water level changes at the bank prior to, during and after the ship's passage enables an evaluation of primary and secondary waves as well as drawdown and drawdown velocity. A typical registration is depicted on figure 4. The design wave height according to the difference between the trough at the stern and the highest water level straight behind the ship is regarded as the highest hydraulic load on banks, for the purpose of dimensioning the weight of a single stone within the rip rap according to GBB 2010 (BAW, 2011) for instance.

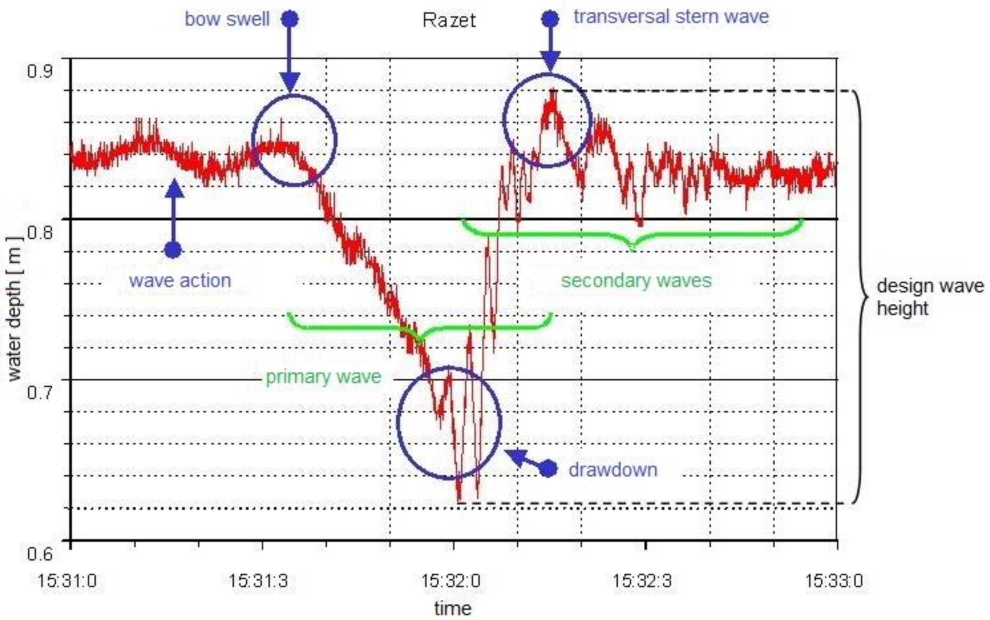

Figure 4 Passage of the powered cargo vessel *Razet* (l/w/d = 105m, 9.50m, 1.20m ≙ empty) on the Neckar – kilometre 78.900 with a velocity above ground of 3.4 m/s = 12.24 km/h, according to the measurement by (Leissler, 2000)

The information leaflet „ Ship-Induced Waves and Flow around the Ship Hull – Measurement and Analysis" contains further information on the topic of wave measurement.

4. Results: Hydraulic Loads

The following hydraulic loads are the result of the interaction between a moving ship and the waterway:

Mean maximal water level drawdown (discharge cross section) Δh, mean maximal return flow velocity $v_{rück}$, slope supply flow u; wave height at the toe of slope H_{BF} during the passage in the centre of the fairway, water level drawdown at the toe of slope z_a, wave height during eccentric passage H_a, secondary wave height H_{sek}.

From a geotechnical perspective, the interaction between ship and waterway is characterised by the temporary change in pore water pressure in the bank.

5. Literature

(BAW, 2004) Bundesanstalt für Wasserbau
Grundlagen zur Bemessung von Böschungs- und Sohlsicherungen an Binnenwasserstraßen (GBB 2004)
BAW-Mitteilung Nr. 87
Eigenverlag, Karlsruhe 2004

(BAW, 2011) Bundesanstalt für Wasserbau
Grundlagen zur Bemessung von Böschungs- und Sohlsicherungen an Binnenwasserstraßen (GBB 2010)
BAW-Merkblatt, Ausgabe 2010
Eigenverlag, Karlsruhe März 2011

(Leissler, 2000) Leissler, A.
Bestimmung von Größe und Auflaufhöhe schiffserzeugter Wellen an einer Uferböschung am Neckar in der Stauhaltung Guttenbach (Neckar-km 78,9000 – 79,000)
Diplomarbeit
Karlsruhe 2000
unveröffentlicht