AN AFFECTING ON THE PORT BOTTOM
BY SHIP'S WATER JET DURING BERTHING MANOEUVRE

Wiesław Galor

Maritime University of Szczecin, Faculty of Navigation
Wały Chrobrego Street 1/2, 70-500 Szczecin, Poland
tel.: +48 91 4891 514, fax: +48 91 4809 539
e-mail: w.galor@am.szczecin.pl

Abstract

In port engineering in the vicinity of quays, the action of the ship's propulsion is a prime eroding element. This may cause scouring of the bottom of port water area and erosion so great that it could lead to quay damage by change of its stability. Thus, the speed of ship's water jet is important criterion of navigational safety assessment. Scouring of an unprotected bottom depends on the type of manoeuvres (ship's settings and their duration), area depth and type of bottom. As the number of cruise ships, irregularly calling at ports, has increased recently, there is often a need to accept such ships for berthing along quays with an unprotected bottom. Bottom protection is a costly investment, far from profitable when callings are not frequent. The situation when a ship gives up its own propulsion during berthing and unberthing and has to use tugs is not profitable for ship operators. As a result, ships may resign from calling at such ports. For this reason it is purposeful to make a navigational analysis [1] of ship manoeuvring near the quay and to assess the effect of water jet on the bottom. This paper examines large ships manoeuvres during berthing. The study focuses on analytical methods for assessing ship's affect on the port bottom. The paper presents some problems on possible manoeuvres of cruise ships with own propulsion along the Bulwar Chrobrego Quay in the port of Szczecin.

Keywords: ship's water jet, safety of navigation, scoring of port bottom

1. Introduction

The action of ship's propeller water jet (propeller stream) in the vicinity of port structures is an important score factor. As a results of affecting on the port bottom near quay, it can be violated the stability of structure. In port engineering in the vicinity of quays, the action of the ship's propulsion is a prime eroding element. This contrasts with the current speeds of natural river or drift currents, which is a few times lower. The revolving propeller of a ship or its thruster's propeller create in the surrounding water a jet of substantial speed. This phenomenon applies to manoeuvring ships using the main propulsion. These are cruise ships, passenger ships, ferries, ro-ro vessels and container ships. Ships of other types (mainly bulk carriers and tankers) manoeuvre to berth pulled and pushed by tugs, so they do not create water jet. The requirement of safety ship's manoeuvre is following:

$$Vmax(\Delta t) \leq Vadm\ (\Delta t),\qquad\qquad(1)$$

where:
$V_{max}(\Delta t)$ - speed of ship's water jet near port structure (bottom, scarp of canal, quay etc.) in time period Δt,
$V_{adm}(\Delta t)$ - admissible speed of water near port structure in time period Δt.

It should be marked that overdoing of given period time Δt the admissible speed water jet leads to destroy of structure.

Scouring of an unprotected bottom depends on the type of manoeuvres (ship's settings and their duration), area depth and type of bottom. As the number of cruise ships, irregularly calling at ports, has increased recently, there is often a need to accept such ships for berthing along quays

with an unprotected bottom. Bottom protection is a costly investment, far from profitable when callings are not frequent. On the other hand, the situation when a ship gives up its own propulsion during berthing and unberthing and has to use tugs is not profitable for ship operators. As a result, ships may resign from calling at such ports. Thus the determination of ships water jet affecting is needed in cases when the protective layer mainly is not applied. Then the port structures are secure by calculation the theoretical foundation port bottom at a depth which takes account of corresponding scour surcharge. For this reason it is purposeful to make a navigational analysis [1] of ship manoeuvring near the quay and to assess the effect of water jet on the bottom. Ferries and cruise ships equipped with two propellers and a few thrusters feature very high manoeuvrability. Thanks to very good manoeuvring characteristics, such ships can do without tugs while approaching the port and berthing or unberthing. Various tactics can be used while berthing. If there is river water current in the, it's speed should be accounted for by the proper initial positioning of the ship in relation to the quay. The thrusters should be set to push her to the quay, while the propellers can additionally work so that the propeller closer to the quay is running ahead, the other is running astern. During a faster berthing manoeuvre the rudders are put to the side further from the quay [2]. The unberthing operations require reverse settings. For slower unberthing thrusters are set for pushing away from the quay. What we should bear in mind that in the process of unberthing there occur large suction forces produced by the operation of thrusters when the tunnel outlet is near the quay. However, passenger ships have forward and aft outlets at some distance from the quay due to the shape and breadth of the underwater part of the hull, which is significantly smaller that the hull is elsewhere. As such ships manoeuvre being parallel to the quay, distance of thrusters outlets from the quay wall are not smaller than 0.4 ship's breadth.

2. The influence of water jets on the area bottom

The revolving propeller or thrusters creates a stream of water called water jet or propeller stream. In order to determine the effect of the water jet, its speed at the bottom and area of action have to be identified. The water speed V_o right next to the propeller plane propeller can be defined as [2]:

$$Vo = Cp(Pd/\rho w\ D2)1/3, \tag{2}$$

where:

V_o - speed of water at the propeller plane [m/s],
D - propeller diameter[m],
P_d - engine power [kW],
ρ_w - water density[t/m^3],
C_p - 1.17 for a propeller in a tunnel,
C_p - 1.48 for a propeller (non-tunnelled).

In most cases ferries and cruise ships employ controllable pitch propellers. When the speed is changed from 'full ahead' or 'full astern' the propeller pitch is altered. Therefore, the jet speed in its close vicinity will also decrease in proportion to the propeller pitch.

The highest speed of water V_{max} at the bottom generated by the water jet:

$$Vmax = E(hp/D)aVo\ [m/s], \tag{3}$$

where:

E = 0.52 for twin-propeller ships with rudders placed behind the propellers,
a = -0.28 for twin-propeller ships,
h_p - distance between the propeller axis and the bottom.

If one propeller runs ahead, and the other does not rotate, or rotates astern, then for the propeller working ahead, then:
E = 0.71,
a = -1.0.

When working astern, the maximum speed of water jet at the bottom reaches about 70% of the stream generated when the propeller runs ahead.

If the rudder is set to port or starboard, then the water jet speed is determined from one of the following relations:

$$Vmax = Vo \ A \ (x/2.8D)\text{-}b \ [m/s], \tag{4}$$

where:

$$A = 1/(1+5.2 \ 10\text{-}6 \ \delta 3,25), \tag{5}$$

where:

δ - rudder angle [^{0}],

b = 1.1 for ships with one rudder,

b = 0.6 for ships with two rudders.

The rudder deflection will cause the speed of water jet at the bottom to decrease by as much as 40%.

The bottom area affected by water jet with its maximum speed is defined by the distances from the propeller plane to the place where the beginning and centre of the water jet contact the bottom.

$$xp = 2.1445 \ hp \ [m], \tag{6}$$

$$xs = 3.7321 \ hp \ [m], \tag{7}$$

where:

x_p - distance from the propeller plane to the place the jet beginning contacts the bottom,

x_s - distance from the propeller plane to the place the jet centre contacts the bottom.

For thruster water jet speed to be determined we can apply the following equation:

$$VB = 1.04 \ (PB/\rho w \ DB2)1/3 \ [m/s], \tag{8}$$

where:

V_B - jet speed at the tunnel outlet of the thruster [m/s],

P_B - power of the thruster [kW],

D_B - inside diameter of the thruster tunnel,

ρ_w - water density [t/m^3].

The water jet speed decreases as the distance from the tunnel outlet increases and equals:

$$VBmax = 2.0 \ (L/DB) \ VB, \tag{9}$$

where:

V_{Bmax} - jet speed at a distance L from the tunnel outlet [m/s],

L   - distance from the tunnel outlet [m].

It has been assumed that the jet speed by the quay at a distance L after spilling out , has the same value at the bottom [5].

For this reason it is purposeful to make a navigational analysis [1] of ship manoeuvring near the quay and to assess the effect of water jet on the bottom. This paper will examine berthing manoeuvres of a passenger vessel coming alongside the Bulwar Chrobrego Quay in Szczecin (Fig. 1).

Fig. 1. The view on Wały Chrobrego Quay alongside Odra River

3. Location and parameters of the quay

The Bulwar Chrobrego Quay makes up a section of the western bank of the River Odra and is situated between the Maritime University (southern side) and the Pasażerskie Quay (northern side) in way of Wały Chrobrego (Chrobry Embankments), a major sightseeing place of the city of Szczecin (Fig. 2).

To reach the quay from seaside vessels have to proceed along the Świnoujscie–Szczecin fairway about 67 km long. The Bulwar Chrobrego Quay, 277 m in length, consists of two sections of different construction [4]. The southern section, rebuilt in 1987, is a 99 m long concrete area mounted on a steel watertight wall consisting of Larssen IIIn profiles, while from the land side the quay rests on ferroconcrete piles. The horizontal quay slabs are six metres wide. The northern section, 178 m in length, consists of a ferroconcrete slab, whose width varies from 8.4 m to 6.9 m in the remaining sections. The structure of the former quay makes the support on the land side. The quay is equipped with double mooring bollards, of Gdyński ZL-G-40 type. In May 2005 the quay was fitted with fenders: Trellex Fender MX 400. The depths range from 6.5 m to 7.5 m. Locally, depths are lower, i.e. 5-6 m, or greater than that range. The maximum depth at the quay wall is 7.0 m. The ordinate of the quay crown is +2.0 m above the sea level. In the light of available archival documentation, divers' surveys done during the mounting of fenders and external surveys of the quay walls and surface, it can be said that the technical condition of the quay structure is good. The bottom along the quay is mainly sandy with sand granularity of approx. 1 mm.

Taking into consideration:
- port regulations defining the maximum size of ships that are allowed to call at the port of Szczecin,
- depths at the Bulwar Chrobrego Quay,
- minimum under-keel clearance,
- size of ships calling at ports in the region of the Baltic Sea,

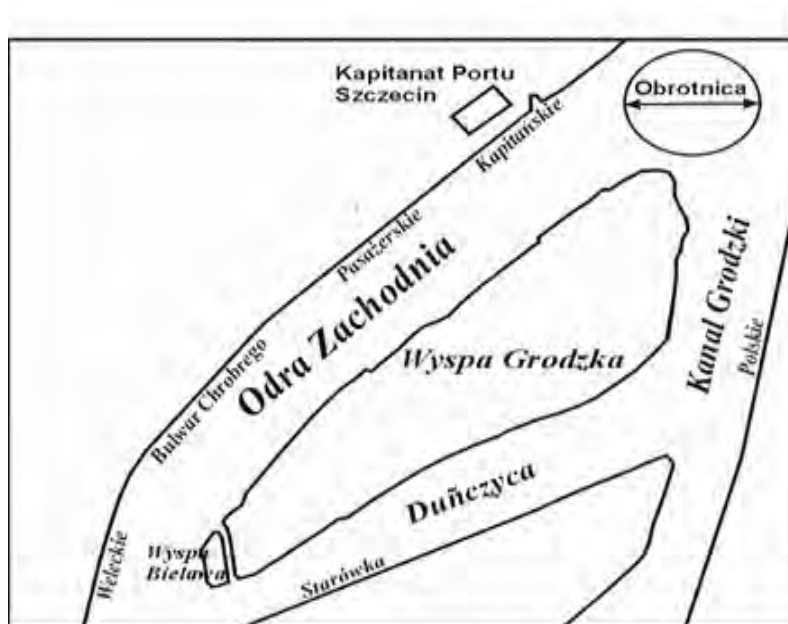we can define maximum parameters of those characteristic ships that will come alongside the Bulwar Chrobrego Quay.

Fig. 2. The location of Bulwar Chrobrego Quay in Szczecin

Length overall	up to 215 m,
Beam	up to 30 m,
Draft	up to 6.0 m,

Engine power   up to 22000 kW,
Propeller diameter   4.30 m,
Propeller spacing   14.0 m,
Thrusters   up to three bow and stern,
Power of one thrusters   2000 kW,
Thrusters tunnel diameter   2.5 m.

For such assumptions, the calculation (2,3) of water jet speed for propeller's water jet at bottom was made (Tab. 1). The results are presented for 1 to 5 setting of main propulsion (all range up to 10).

Tab. 1. Water jet speed of the propellers at the port bottom

Water jet speed for ahead manoeuvre [m/s]			Water jet speed for astern manoeuvre [m/s]			
Setting	Ship's draft [m]		Setting	Ship's draft [m]		
	6.0	5.0	4.0		6.0	5.0	46.0
1	0.67	0.62	0.58	-1	0.43	0.40	0.38
2	1.33	1.23	1.16	-2	0.87	0.80	0.75
3	2.00	1.86	1.74	-3	1.30	1.20	1.13
4	2.67	2.47	2.32	-4	1.73	1.61	1.51
5	3.33	3.10	2.90	-5	2.16	2.02	1.89

The thrusters water jet speed as a function of tunnel outlet distance for settings 1-4 are presented on Fig. 3. They are calculated according formulas 8 and 9.
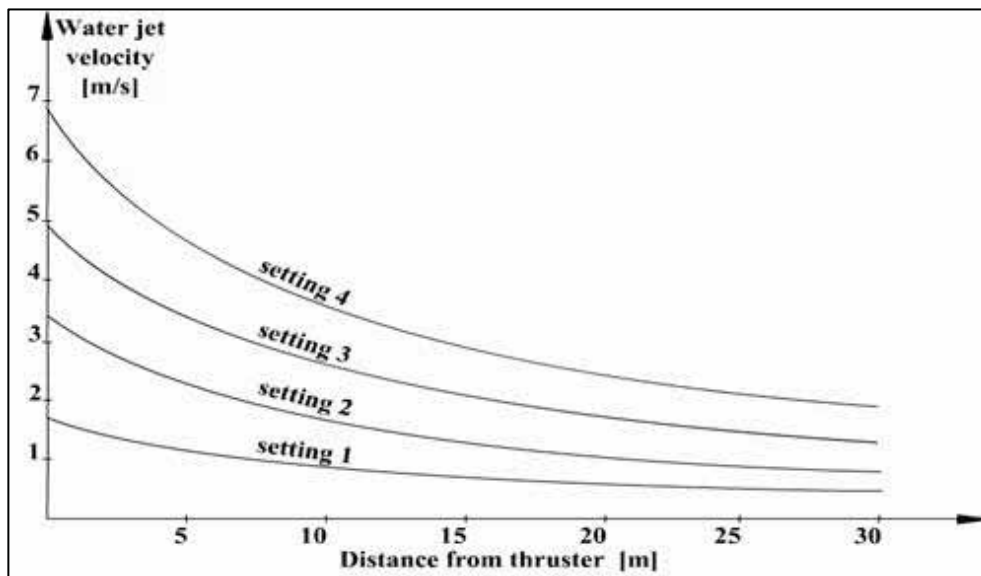

Fig. 3. The thrusters water jet speed as a function of tunnel outlet distance

4. The affect of water jets on the water area bottom

The magnitude of underwater hull resistance at very small speeds occur when a ship is berthing or unberthing can be defined from relationships that give approximated values practically sufficient for manoeuvring. When a ship moves sideways, i.e. at a right angle to its centre line, the

underwater hull resistance is equal to [3]:

$$Rc = 454.2 \; v2 \; Fp \; [N],$$ (10)

where:

R_c - underwater hull resistance,

v - ship's speed [m/s],

F_p - area of longitudinal cross-section of underwater hull [m²].

For characteristic ships (L_C = 215 m, T = 6.0 m) the underwater hull resistance equals R_c = 13.2 kN) for a speed of 0.15 m/s and R_c = 146.4 kN for a speed of 0.50 m/s. The propulsion power needed to overcome the resistance created at a given ship's speed results from the work being the product of force used and distance covered in a specific time.

The power needed during berthing or unberthing manoeuvres of a characteristic ship that comes alongside the Bulwar Chrobrego Quay can be defined from the following relationship:

$$PM = (Rc \; L)/tm,$$ (11)

where:

P_M - propulsion power needed for sideways movement of a ship approaching or moving away from the quay [W],

R_c - underwater hull resistance [N],

L - distance from the berth [m],

t_m - duration of the manoeuvre [s].

Figure 4 presents required propulsion power for various speeds of a characteristic ship approaching the berth, with two different times of the manoeuvre: 300 and 600 s (5 and 10 minutes).
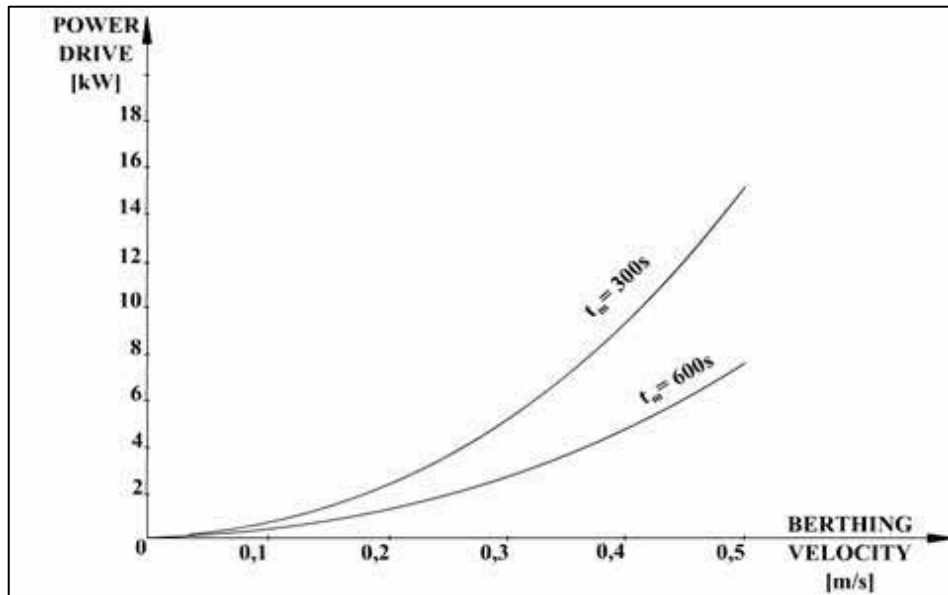

Fig. 4. Propulsion power needed for various speeds of a ship during its berthing

There are maximum water jet speeds V_{max} allowed at the bottom so that the bottom material will not be moved. The values of V_{max} depend on the kind of bottom and can be determined as follows:

$$V_{max} \leq (d_m \; B^2 \; g \; \rho(\rho_s-\rho_w)/\rho_w)^{1/2} \; [m/s],$$ (12)

where:

B = 1.25 for ships with the rudder not deflected,

g = 9.81 [m/s²],

ρ_s - density of bottom material [kg/m³],

ρ_w - density of water [kg/m³].

For the ground along the Bulwar Chrobrego Quay, (sand with grains of about 1 mm diameter, the maximum jet speed which no caused scoring is $V_{max} \leq 0.5$ [m/s].

5. Conclusions

- The water jet of a ship manoeuvring at a slow speed in an area of restricted depth can cause the erosion of port bottom. The water jet of a ship manoeuvring close to the quay may cause bottom scour, which will threat the structure stability.
- Scouring of an unprotected bottom depends on the type of manoeuvres (ship's settings and their duration), area depth and type of bottom.
- There is purposeful to make a navigational analysis of ship manoeuvring near the quay and to assess the effect of water jet on the bottom.
- For unprotected bottom (something like Bulwar Chrobrego Quay in Szczecin) with mean diameter of grain of sand (about 1 mm) maximum water jet speed is less than 0.5 m/s.
- In such case the manoeuvring ships close to the berth should be used low propulsion power and proper tactics.
- On unprotective bottom it is possible the manoeuvring of ships by its own propulsions without assistance of tugs, but the area should be checked continuously by sounding so that it is possible to react at once to exceeding of admissible scour.

References

[1] Galor, W., *Bezpieczeństwo żeglugi na akwenach ograniczonych budowlami hydrotechnicznymi,* Wyd. FRWSM Szczecin 2002.
[2] Mazurkiewicz, B. *Morskie budowle hydrotechniczne. Zalecenia do projektowania i wykonywania Z1-Z45, Wydanie V.* Wyd. FPPOiG, Gdańsk 2008.
[3] Nowicki, A., *Wiedza o manewrowaniu statkami morskimi. Podstawy teorii i praktyki.* Wyd. Trademar, Gdynia 1999.
[4] *Opinia dotycząca możliwości cumowania statków o długości do 215 m przy nabrzeżu Bulwar Chrobrego w Szczecinie.* Sprawozdanie z badań, Consultant, Szczecin 2005.
[5] *Recommendations of the Committee for Waterfront Structures Harbours and Waterways EAU 2004,* Ernst & Sohn, Berlin 2006.