

# Depth Optimization of Designed New Ferry Berth

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**ABSTRACT:** Increasing sea ferries traffic on Baltic Sea has in the recent years motivated the design of larger ferries. Currently the lengths of the most ferries, which call at port of Świnoujście, do not exceed the limit of 170 meters. The new projected ferry berth will be adopted for ferries with LOA equal 220 and even 230 meters. It is obvious that propeller of that sea ferries will produce a propeller stream with greater velocity and initial diameter as well, particularly that they will maneuver without any tugs. That water jet can much easier cause bottom erosion especially at mooring berth. This article is a presentation of depth optimization process at berth No 1 of Sea Ferries Terminal (SFT) in port of Świnoujście.

## 1 INTRODUCTION

The paper presents the simulation method of determination the propeller jet stream's velocity at the bottom and depth optimization method for berths, which take advantage of jet streams' velocity at the bottom for different value of depth. The presented method was used to determine the depth of berth no 1, at Świnoujście Sea Ferries Terminal (SFT).

The ships model that was used in simulations was worked out in Institute of Marine Traffic Engineering at Maritime University of Szczecin.

The simulations of mooring maneuvers were conducted for maximum allowed Ro-Pax ferry's at new building berth no 1 in Świnoujście SFT.

The safety of navigation is determined by vessel's size and her maneuvering characteristics. Those parameters define a maximum vessel, which is the biggest vessel which may safety maneuver at given area, at given navigational conditions. Vessel may be consider maximum if only one of her dimensions is maximum (e.g.: draft, beam, length, speed).

After ferry market analysis and navigational analysis of port of Świnoujście were done, the maximum ferry was determined. It turned out, that maximum Ro-Pax ferry for Świnoujście is 220 m long and her main engines power is 14000 kW.

## 2 SIMULATION METHOD OF DETERMINATION THE PROPELLER WATER-JET VELOCITY AT THE BOTTOM

Presented method of determination the propeller jetstream, takes advantage of simulation trials. The series of trials are done for given vessel and given conditions. During trials vessel movement's parameters are recorded as a text files. After trials are done, the jest stream's velocity is calculated for every single vessel's position recorded (fig. 1). Jet stream's velocities at the bottom are determined for the whole area, due to adopted level of discretisation. The jest stream's velocity is a function of following variables:

$$V_{x,y} = f(x, y, h, x_s, y_s, KR, N, R) \quad (1)$$

where  $V_{x,y}$  = stream velocity at  $(x, y)$  point of the bottom,  $h$  = depth,  $(x_s, y_s)$  = vessel's coordinates, KR = vessel's heading, N = current main engine command, R = rudder deflection.

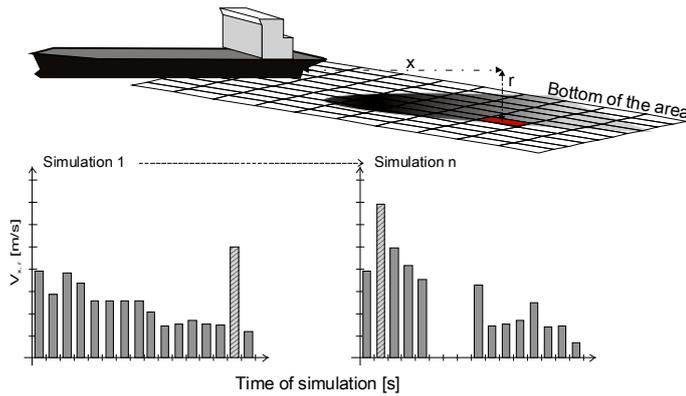


Fig. 1. Determination of maximum stream velocity, in the  $(x, y)$  point of bottom area, for each simulation

The following vessel's parameters, which are of static nature, play also a vital role:

- length over all,
- vessel's draught,
- power delivered on propeller,
- propeller coordinates' shifting from recorded vessel's position (usually center of gravity's position is recorded),
- distance between the horizontal axis of propeller and the bottom.

Existence of any harbor's structure is also taking into account. The velocity of water jet stream is consider zero, if any part of hydrotechnical structure is located in discrete area or obscure it (fig. 2).

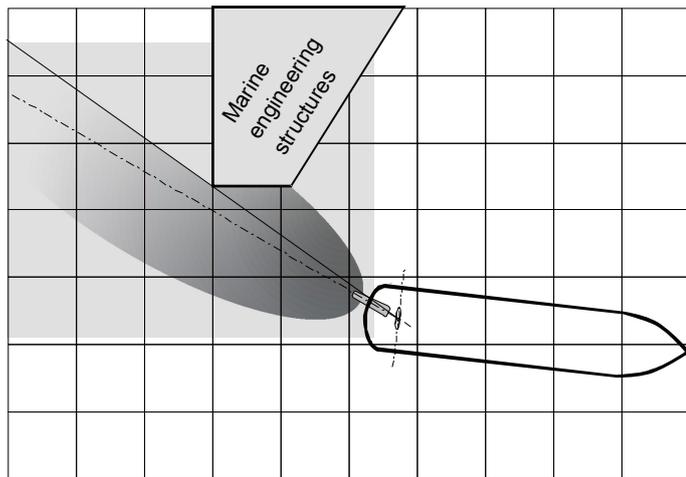


Fig. 2. Propeller stream obscured by harbor's structures.

The algorithm to determine the jet stream velocities at the bottom is as follows:

- 1 Calculate a speed of inducted water jet near the propeller:

$$V_0 = K_d \cdot \left( \frac{k \cdot P_d}{d_s^2 \cdot \zeta_w} \right)^{\frac{1}{3}} \quad (2)$$

where  $V_0$  = stream velocity nearby propeller,  $K_d$  = empirical coefficient equal 1.48 for free propeller,  $k$  = power utilization coefficient,  $P_d$  = a power delivered on propeller,  $d_s$  = propeller diameter,  $\zeta_w$  = water density.

- 2 Choose centre point of the discrete area  $(x_d, y_d)$  according to discretisation level;
- 3 Check following items:

- is centre point of discrete area located on water area?
- is it not covered by other quay structures?

- 4 Calculate the distance  $s$ , between the propeller plane and projection of the point  $(x, y)$  onto a propeller's horizontal axis;
- 5 Calculate the speed  $V_{x \max}$ , in calculated distance  $s$  rom the propeller (rudder angle is 0);

$$V_{s \max} = V_0 \cdot 1.88 \cdot e^{0.161 \left( \frac{h_p}{d_s} \right)} \cdot \left( \frac{s}{d_s} \right)^{-a} \quad (3)$$

where  $V_{x, \max}$  = the distance from the propeller plane,  $h_p$  = distance between bottom and propeller horizontal axis,  $s$  = the distance from the propeller's plane and projection of point  $(x, y)$ .

At given rudder angle:

$$V_{s \max} = V_0 \frac{1}{1 + 5.2 \cdot 10^{-6} \cdot (\delta)^{3.25}} \cdot \left( \frac{s}{2.8 \cdot d_s} \right)^{-b_1} \quad (4)$$

where  $\delta$  = rudder angle.

- 6 Calculate the distance  $r$  between propeller's horizontal axis and the centre of the discrete area  $(x, y)$ ,
- 7 Calculate the velocity of the propeller jet stream at the bottom, in a middle of discrete area;

$$V_{s,r} = V_{s \max} \cdot e^{\left[ -m \left( \frac{r}{s} \right)^2 \right]} \quad (5)$$

where  $V_{s,r}$  = the stream velocity in distance  $s$  from the propeller plane and distance  $r$  from the propeller axis,  $r$  = the distance from the propeller axis (a radius).

- 8 Record, as a text file, the maximum value of screw jet stream velocity at the bottom for given coordinate  $(x, y)$ .

### 3 PROPELLER JET STREAM DETERMINATION FOR FERRY BERTH DESIGN

The design vessel's parameters, for berth no 1 at Świnoujście SFT, is as follow:

- LOA 220 [m],
- Beam 32 [m],
- Draft 7.0 [m],
- Nominal power of ME 2 x 14000 [kW],
- Diameter of propeller 4.0 [m],
- Two pitch adjustable, left handed propellers.

Several conditions were chosen for simulations' trials. Number of single trials within given conditions was at least 15.

The following conditions were considered the hardest:

- unmooring and swinging by port side, wind W 15 m/s, inbound current 1.5 kn,
- mooring with port side, wind E 15m/s, inbound current 1.5 kn,
- unmooring and swinging by starboard side, wind W 15 m/s, outbound current 1.3 kn,

Two series were done, for zero-state conditions – no wind, no current:

- mooring with port side,
- unmooring and swinging by any side.

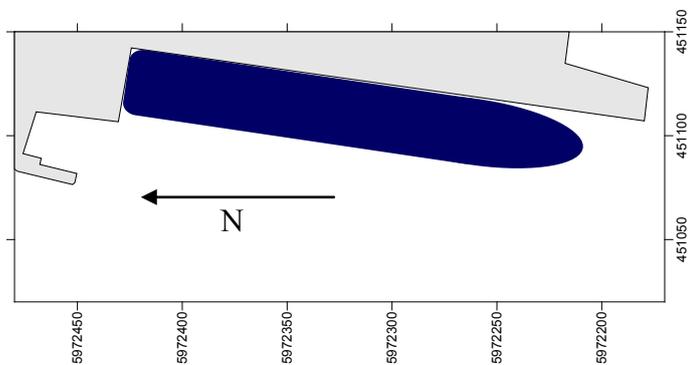


Fig. 3. Berth no 1 layout with a ferry moored at

Maximum propeller jet stream's velocity was calculated for the depth shown in table 1.

Table 1. Depths and distances to a bottom [m]

Available depth	Depth for calculation	Under keel clearance	Distance from propeller's axis to bottom
9	8	1	3.4
12	11	4	6.4

Mean sea level in port of Świnoujście, which has been recorded for many years, is 4.90m. Minimal mean sea level, calculated for the last 10 years is 1 meter less than mean sea level. Therefore, an appropriate depth allowance was considered.

Bottom at berth no 1 was loaded with jet streams the most during maneuvers with the inbound current. The mooring maneuvers were done with the pushing away eastern wind, whilst unmooring maneuvers were conducted with pushing western wind. In both cases, vessel was to stand up the great wind force, which produced significant lateral pressure. That pressure forced captain to use top command on main engine telegraph.

The distribution of maximum jet streams' velocity is shown on fig. 4. The depth of considered area is 8 meters. The distributions differ in that areas heavily loaded with jet streams are shifted. For mooring operations that area is moved to the middle of investigated area, whilst for unmooring manoeuvres the area is smaller and is close to berth's wall. It is worth to emphasize, that jet stream's velocities were higher for unmooring manoeuvres. The maximum velocity of jet streams whilst mooring was 8.9 m/s, and whilst unmooring it exceeded 9.5 m/s. However the area affected by streams with velocity more than 8.5 m/s was not extensive. Taking that into consideration, as well as 1 meter depth allowance for area depth 9 m, it was assumed that bottom affecting velocity of jet streams is 7.5 m/s.

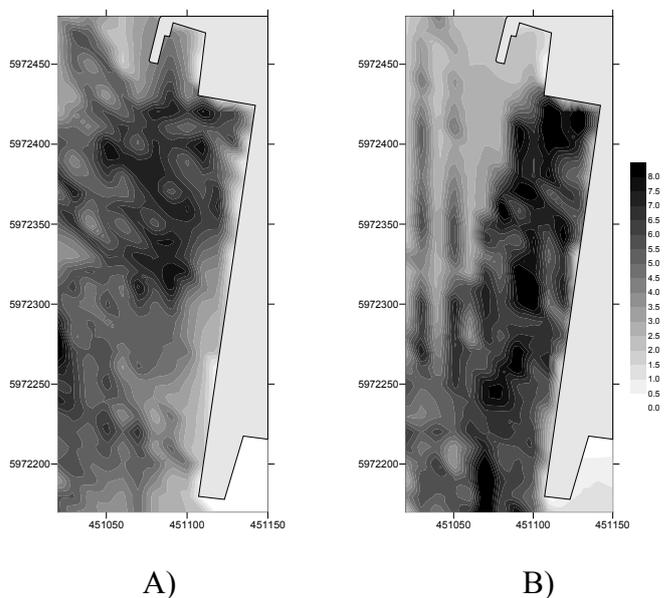


Fig. 4. Distribution of maximum water jet velocity at a bottom, depth 8m. A) mooring port side, wind E 15 m/s, current inbound average max (1.5 kn); B) unmooring and swing by port side, wind W 15 m/s, inbound current average max (1.5 kn)

Distributions of maximum velocities at berth no 1, for mooring and unmooring maneuvers are shown on fig.5. The available depth is 12 meters. The

maximum velocity for mooring is 5.7 m/s and for unmooring is 6.1 m/s. Taking that into consideration, as well as 1 meter depth allowance, it was assumed that bottom affecting velocity of jet streams is 4.5 m/s.

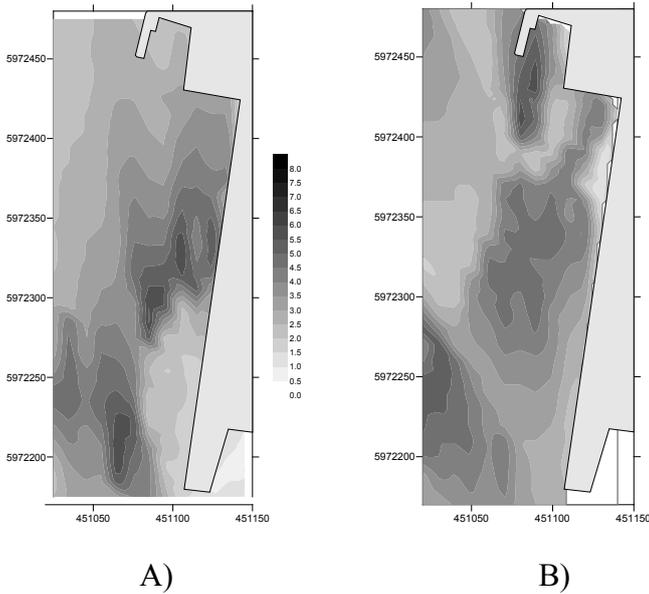


Fig. 5. Distribution of maximum water jet velocity at a bottom, depth 11m. A) mooring port side, wind E 15 m/s, current inbound average max (1.5 kn); B) unmooring and turn by port side, wind W 15 m/s, inbound current average max (1.5 kn)

The picture below presents decreasing of jet streams' velocity at the bottom as a result of depth increase up to 12 meters.

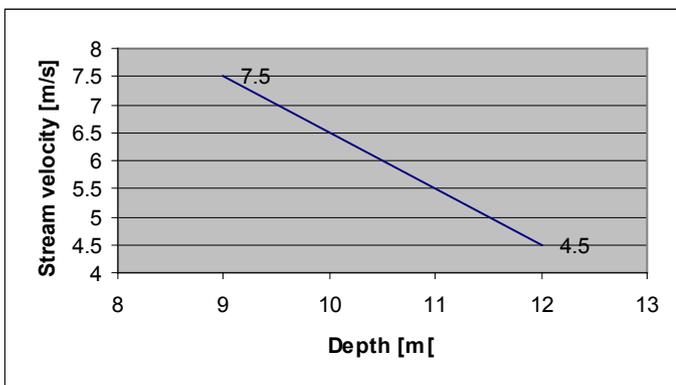


Fig. 6. Distribution of maximum water jet velocity at a bottom, depth 11 m

Increase of available depth considerably reduced jet streams' velocities at the bottom. But there is one question, concerning economical aspect of new-building berth. Either more profitable is to dredge the considered area or apply proper bed protection?

#### 4 BERTH NO 1 OF ŚWINOUJŚCIE SFT AS AN EXAMPLE OF BED PROTECTION PARAMETERS' OPTIMIZATION

Evaluating the optimizing function of berth depths' optimize as a cost of berth building and bed reinforce, following assumptions were adopted:

- investigated vessel maneuvers on restricted area, her position is defined on Cartesian axes,
- investigated area is a set of elements  $x \in X$ ,  $y \in Y$ ,
- coordinates that define the set are Cartesian's product,
- on investigated area, only vessels that are included within set  $i \in I$ , are allowed to maneuver. It concerns either vessel's size (LOA, beam, draft) or engine power and type,
- vessel maneuvering on the area, may perform one of the maneuvers, that are within set  $j \in J$ . It is the set of all available maneuvers on given area,
- investigated vessels may maneuver in conditions that are within set  $k \in K$ . It concerns either hydro meteorological (wind, current, sea, ice) conditions or navigational and traffic conditions.

The safety of navigation and harbor's structures, evaluated by means of berth depths' optimizing model, is determined by following items:

- under keel clearance,
- jet streams velocity at the bottom.

Adopting above assumptions, optimizing function may be presented as a following formula:

$$Z = a \cdot l \cdot b \cdot h + q \cdot l \cdot b + c \cdot l \rightarrow \min \quad (6)$$

where  $l = f_1(D)$ ,  $b = f_2(D)$ ,  $q = f_3(V_{x,y})$ ,  $c = f_4(h)$ , with following constraints:

$$1. \quad d_{ijk} \subset D$$

where

$$i \in I, j \in J, k \in K$$

$$2. \quad \bigwedge_{p(x,y) \in D} h_{xy} \geq T_i + \Delta_{ijk}$$

$$3. \quad \bigwedge_{p(x,y) \in D} V_{xyijk} > V_{xydna}$$

$$4. \quad \bigwedge_{p(x,y) \in D} V_{xyijk} \leq V_{dxy}$$

where:

- $Z$  – costs of building new berth, dredging maneuvering area, bed protection;
- $a$  – cost of dredging of 1m<sup>3</sup>;
- $l$  – berth length;
- $b$  – bed protection width;

- $h$  – depth of area at designer berth;
- $q$  – cost of protection of 1m<sup>3</sup> of bed;
- $c$  – cost of 1m of berth;
- $d_{ijk}$  – maneuvering area, for  $i$ th vessel,  $j$ t type of maneuvers,  $k$ t navigational conditions, where  $V_{xy} > V_{xydna}$ ;
- D** – maneuvering area, that meet requirement  $V_{xy} > V_{xydna}$ , for investigated set of vessel I, maneuvers J, and navigational conditions K.
- $T_i$  – maximum draft of  $i$ th vessel,
- $\Delta_{ijk}$  – under keel clearance, for  $i$ th vessel,  $j$ t type of maneuvers,  $k$ t navigational conditions,
- $V_{xyijk}$  – maximum jet streams velocity at the bottom in certain position  $(x, y)$  for  $i$ th vessel,  $j$ t type of maneuvers,  $k$ t navigational conditions,
- $V_{xydna}$  – available velocity of water at the bottom, for position  $(x, y)$  for existing bed type,
- $V_{xyd}$  – available velocity of water at the bottom, for position  $(x, y)$  for bed after protection.

Based on simulations' results, existing bathymetrical and hydro meteorological conditions and above detailed costs of designed berth No 1 at Świnoujście SFT, the safety depth at berth was set to 12,5 m. During the whole optimization project, the depth of waterways near berth and southern swinging area depth were considered as well.

## 5 CONCLUSION

The paper presents depth optimizing models at ferry terminals, which take advantage of propeller jet velocities at the bottom, determined by means of original simulation method.

The method was used to determine the depth at the new building berth no 1 at Świnoujście Sea Ferries Terminal.

The method is all purpose. After adaptation, it may be used to optimize the depths at any berth, for any type of vessels.

## REFERENCES

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