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Original scientific paper

Solutions to Minimize Sediment Resuspension in Ports*

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Abstract: Sediment resuspension has, among other things, negative consequences for marine flora and fauna. A solution to this problem could lie in alternative ship manoeuvres, automated mooring systems and bottom protection techniques. The paper deals with the methodology for determining sediment resuspension, which consists of real-time kinematic measurements and in-situ measurements with (PNS-RTK) sensors. Real-time data from the manoeuvring vessel is used to determine the critical vessel rate per minute (RPM) or propeller jet velocity on the seabed and to identify the most common critical vessel manoeuvres on approach to port and departure. The Full Mission Bridge Simulator (FMBS) can be an excellent simulation tool for the analysis of real-time and on-site measurements, which is proposed for further research.

Keywords: Sediment Resuspension, Real Time In-Situ Measurements, Alternative Ship Manoeuvres, Full Mission Bridge Simulator.

1. Introduction

Sediment resuspension has become a major concern for marine biologists and port authorities. Marine biologists are concerned about the marine ecosystem and port authorities are concerned about the impact of resuspended material on the seabed caused by the rotation of ship propellers [1] [2]. The solution lies in the implementation of structural measures and new procedures for manoeuvring ships. The latter solution is based on analytical criteria for determining sediment resuspension (SR), which are applied to most ships that have the greatest impact on SR in the port of Koper, taking into account the frequency of their calls. The ships and their manoeuvres are analysed to find the least interaction between ship and seabed. Each port is specific from a global point of view in terms of its geographical location, type of operating costs and available manoeuvring space, type of seabed and ba-

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thymetry, prevailing weather conditions, waves, winds and currents. Nevertheless, some of these manoeuvring procedures are applicable to similar ports.

2. Methods and tools for determining sediment resuspension

The real-time data of the manoeuvring vessel is obtained from the following sources: Automatic Identification System (AIS), Pilot Navigation System (PNS) in conjunction with Real Time Kinematic (RTK) GNSS receivers and records of vessel course, heading, speed, telegraph status, rates per minute (RPM) recorded on board. An assessment of the real ship is made: type, size, draft, propeller type and diameter. All the above parameters are used to determine the critical ship RPM or propeller jet speed on the seabed. Previous research methods for calculating propeller jet velocity are being investigated to find the most suitable method. The Full Mission Bridge Simulator (FMBS) is used to replicate a real ship manoeuvre. A similar type of ship is selected for the FMBS. The chosen propeller jet speed method is used to compare the real and simulated ship manoeuvres and determine the agreement of the results and any discrepancies. The next step is to perform optimal ship manoeuvres with experienced local pilots and tugs on the FMBS. The aim is to use less engine power, give telegraphic commands, use the tugs optimally and adjust their positioning to the vessel's requirements. The test manoeuvres are repeated to achieve satisfactory results, depending on how the jet speed affects the seabed.

2.1. Tools

The AIS is a widely used tool for monitoring ship movements while underway and manoeuvring. It provides information such as: course, direction, speed, position, vessel type and vessel track. This data is important to identify the most common critical ship manoeuvres when approaching and leaving port. The PNS is normally used when the vessel enters port. As it presets the desired personal settings, it simultaneously enables the recording of all dynamic data on the ship's manoeuvres. Researchers and pilots can also set up RTK sensors that provide more accurate information about the vessel's position, movement and acceleration.

Collaboration between master, pilot and researcher can lead to safer harbour manoeuvres and reduced sediment stir-up by sharing best practises and records of vessel speed, course, heading and Under Keel Clearance (UKC). The FMBS is a useful tool to recreate a real ship manoeuvre and obtain all desired dynamic parameters for ship movement. Alternative Ship Manoeuvres (ASM) are performed to obtain the least sediment stir-up due to propeller rotation. The ship motion parameters are processed with a suitable method to determine the velocity of the jet on the seabed.

An important tool for determining the interaction between the ship's propeller and the seabed is also the bathymetry map of the port of Koper. It should be inserted into FMBS as an overlay to obtain realistic ship motion data.

2.2. Methods

The methods for calculating the volume of sediment resuspension are based on theoretical equations with hypotheses that are not reliable and on experimental studies with scaled propeller systems in test basins. The jet outflow velocity (V_0) is the most important parameter for the analysis of sediment resuspension, as all theoretical equations developed so far use it as a dependent variable. Fig. 1 shows the propagation of the propeller jet in axial (x) and radial (r) directions.

The outflow velocity (V_0) is the maximum velocity at the front of the propeller [3] which is shown in (1).

$$V_0 = 1.59 n D_p \sqrt{C_T} \tag{1}$$

In equation (1) n is the rotational speed of the propeller in revolutions per second, D_p is the propeller diameter in metres and C_T is the thrust coefficient of the propeller. This equation does not take into account the propeller geometry [3].

Other researchers introduce equations with the propeller geometry; one of them is Hashmi [4] who proposed (2) and (3).

$$V_0 = E_0 n D_p \sqrt{C_T} \tag{2}$$

$$E_0 = \left(\frac{D_p}{D_h}\right)^{-0.403} C_t^{-1.79} \beta^{0.744} \tag{3}$$

He improved this equation by not dimensioning the propeller diameter (D_p) but dividing it by the hub diameter (D_h) with value 14.92 mm; the blade area ratio (β) is the projected area of the blades relative to the propeller disc area.

In many cases, there are no parameters derived from the area of the propeller disc and the number of revolutions per second. The authors [6] solved this problem by establishing the following equation (4).

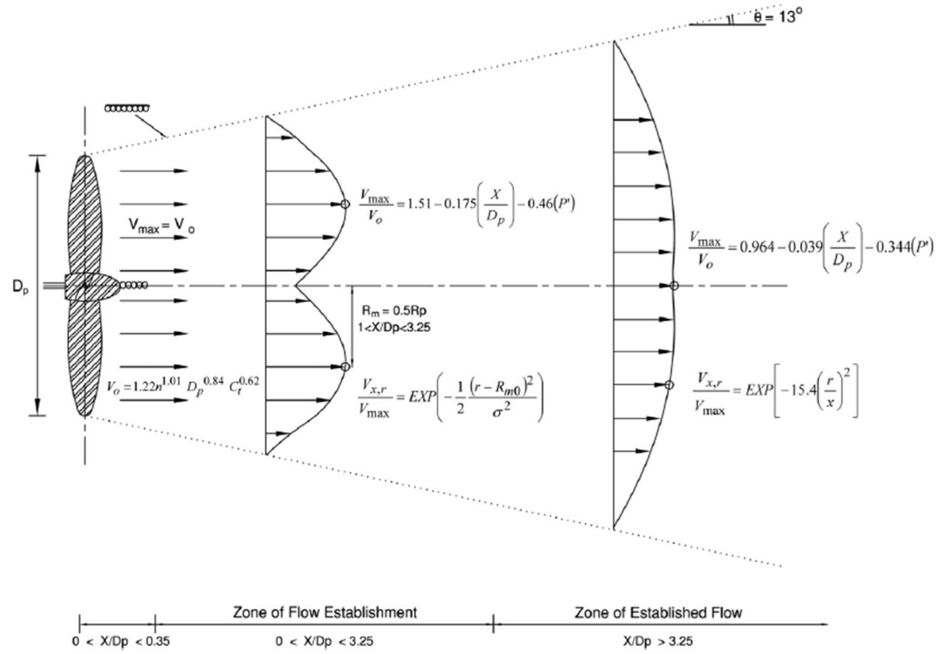


Fig.1 - *Definitions for jet of the main propulsion system (without rudder) [6].*

$$V_0 = C_2\left(\frac{f_p P_{Max}}{\rho_W D_p^2}\right)^{\frac{1}{3}} \tag{4}$$

Here, the coefficient C_2 has a value of 1.17 for propellers with air ducts and of 1.48 for propellers without air ducts; f_p is the expected average engine power (which can be 0.15 or 0.4 according to [7]) due to arrival and departure manoeuvres; P_{Max} is the maximum installed engine power; and ρ_w is the media density in which the ship is sailing.

The next step is to calculate the jet speed along the centreline of the propeller (x-axis). The German method with equation (5) is presented.

$$V_{ax} = AV_O\left(\frac{D_p}{x}\right)^a \tag{5}$$

This equation can be used for range from x/Dp>2.6. Value A is presented below (6), (7), (8).

$$A = 1.88 \times exp\left(-0.092 \times \left(\frac{h_t}{D_p}\right)\right) propeller\ without\ rudder,$$

$$0.9 \leq \frac{h_t}{D_p} \leq 9 \tag{6}$$

$$A = 1.88 \times exp\left(-0.0161 \times \left(\frac{h_t}{D_p}\right)\right)\ propeller\ with\ rudder\ on\ centerline,$$

$$0.9 \leq \frac{h_t}{D_p} \leq 9 \tag{7}$$

$$A = 0.92 - 0.018 \times exp\left(\frac{h_t}{D_p}\right)\ for\ ships\ with\ two\ propellers,$$

$$0.9 \leq \frac{h_t}{D_p} \leq 9 \tag{8}$$

where:

A = 0.9 twin screw

a = 0.6 influence of bottom and water surface only

a = 0.3 extra influence for lateral quay wall (A is not applicable then, but the equation below should be used with r=0).

$$h_t = C + \frac{D_p}{2} \tag{9}$$

Here the parameter h_t is the distance between the propeller axis and the seabed and the parameter C is the distance between the propeller tip and the seabed.

The following is a simplified equation (10) for determining the velocity of the propeller jet at a certain distance (x) and radius (r) from the propeller plane.

$$V_{(x,r)} = V_{ax} exp\left[-22.2\left(\frac{r}{x}\right)^2\right] \tag{10}$$

Equation (11) predicts maximal bottom velocity produced by propeller jet.

$$V_{b,max} = EV_0\left(\frac{D_p}{h_t}\right)^b \tag{11}$$

Where E = 0.71, b = 1.0 for seagoing ships with rudder; E = 0.42, b = 0.275 for sea-going ships without rudder; E = 0.52, b = 0.275 for sea-going ships with twin propeller and double rudder [6].

3. Recommended solutions to minimise sediment resuspension

The most important solution for further research is alternative ship manoeuvres [8] and manoeuvers using tugs [9]. Another solution is active docking fenders. Various techniques are used in ports around the world to overlap the harbour floor to prevent re-suspension, which have advantages and disadvantages [10].

3.1. Alternative ship manoeuvres

The most important principle for minimising sediment resuspension is to use a lower propulsive power or speed per minute (RPM). Reducing the propulsive power results in a lower speed of the propeller jet hitting the harbour bottom. The use of propulsive power on board a vessel depends not only on the pilot/captain and tug master, but also on the experience, personalities and communication between them. The type of manoeuvre (departure, arrival) also has a major influence. The departure manoeuvre requires more power to get the vessel moving. Environmental conditions such as: visibility, wind and current direction, water density, traffic in the port and its approach, approach and composition of berths. The above factors play an important role in the difficulty of the manoeuvre and indicate that more force is required to perform a safe manoeuvre.

The arrival manoeuvre starts with a predefined entry speed and a position course towards a conspicuous object at the berth. The speed and course will vary depending on weather conditions. The involvement of the tugs in the manoeuvring process must be carefully planned. Up to what point in the approach channel should the tugs be connected to the vessel and where will they be too fast in relation to the vessel. There must be close cooperation between the ship's master/port pilot and the tug master regarding the manoeuvrability of the ship (ship's master/port pilot) and the desired angle and tow of the connected tugs (pilot/tug master). Tugs also stir up sediments, but they disturb less due to their shallower draught. The tug's pull/push is also used in determining alternative vessel manoeuvres in terms of "optimal tug deployment".

The outbound manoeuvre is again influenced by all the parameters from the previous paragraph. Statistically, it leads to more sediment stirring, comparable to the arrival manoeuvre, while more propulsive power is needed to get the vessel moving. The solution lies in the "optimal use of tugs" and the non-aggressive kick-ahead mode (gradual increase of RPM).

3.2. Automated mooring system

The Automated Mooring System (AMS) was developed with efficiency, economy and environmental friendliness in mind. The system comprises an extendable hydraulic arm with vacuum cushion, controlled via monitoring and control interfaces. The system was primarily developed to speed up the berthing process, resulting in a faster turnaround time in port and consequently having a positive impact on reducing sediment stir-up. Less propulsion power and tug assistance is required to align the vessel at berth. The hydraulic extension arm is able to push the vessel between 600 and 2500 mm away from the pier (depending on the AMS model), resulting in a moment of inertia of the vessel and requiring less propulsion power and tug assistance.

Source: https://tekointerface.com.ua/wp-content/uploads/2019/12/112.pdf, Available 23.11.2021.

Fig. 2 - *Automated mooring system (QuaySailor 40)*

3.3. Techniques to prevent scouring of the harbour bottom

There are various scour protection techniques (SPT) to reduce the sediment stirring up from the propeller jet. The type of scour protection depends on: the sediment size, the bathymetry of the harbour bottom, the economic perspective and the time needed to set up this system (interference with shipping traffic and economic losses due to construction works).

The most common types of scour protection are: Riprap (basalt, granite, syenite, quartzite, limestone); riprap impregnated with asphalt primer; riprap impregnated with underwater concrete; cabled concrete block mats; concrete slabs; concrete-filled fabric mattresses; stone-filled fibre-reinforced bitumen mattresses; geosynthetic bags, mattresses, tubes and containers filled with sand, gravel or a combination thereof [10].

The rock size for the riprap system is determined according to the German method (12).

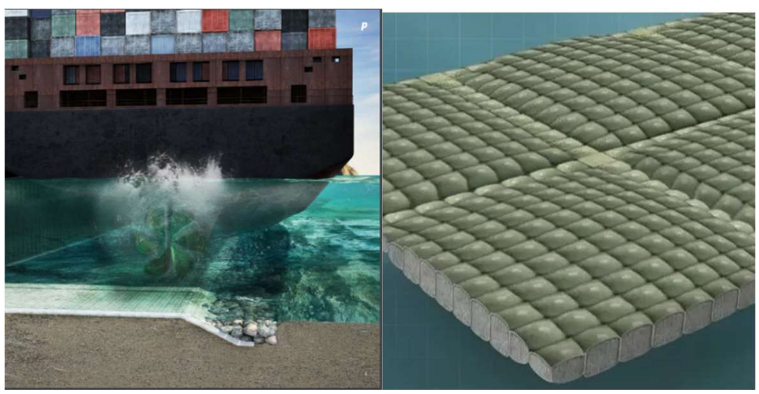
$$V_{b,max} = B_{cr}\sqrt{D_{50} g \Delta} \tag{12}$$

$$\Delta = \frac{\rho_s - \rho_w}{\rho_w}$$

Coefficient B_{cr} is ranging from 0.9 to 1.25, D_{50} indicates the sediment size such that 50 % of the sediment particles are smaller than this size; g is the acceleration due to gravity, Δ is the relative density, ρ_s is the density of the sediment and ρ_w is the water density. The thickness of the mattresses or concrete slabs is determined with (13).

$$D > \frac{C_L V_{b,max}^2}{2g\Delta} \tag{13}$$

Coefficient C_L is ranging from 0.50 to 0.75 [9]. Figure 3 shows concrete-filled fabric mattresses lay-up and structure design.



Source: https://proserveltd.co.uk/. Avaliable 23.11.2021.

Fig. 3 - *Concrete-filled fabric mattresses on harbour bottom.*

Scouring of the harbour bottom also has a negative impact on the environment (on flora and fauna). Future dredging (global trends in shipping indicate a continuous increase in ship size and thus deeper draught) will require the removal of the concrete-filled fabric mattress prior to dredging.

4. Conclusion

The paper reviews the existing literature on tools and methods for assessing the impact of ship scour caused by propeller jets and presents existing techniques that use the new ASM approach to avoid sediment resuspension. The main ship manoeuvres are analysed (collection of voyage data recorders, PNS movement data from pilots and records from AIS). The data will be used to determine the velocities of the propeller jets and their impact on the harbour bottom. A similar type of vessel will be used on the FMBS to accurately track the manoeuvring of vessels in real time. The real-time and FMBS manoeuvres will be compared and the data variance will be evaluated to determine possible and expected deviations. The following technique will also show whether FMBS is a suitable tool for reconstructing "real" ship manoeuvres. When performing ASM, the deviations of time/location and FMBS manoeuvres are taken into account. Several ship manoeuvres will be tested with FMBS to find guidelines and recommendations to reduce ship scour.

Automated mooring systems may also help to reduce ship scour, but are not expected to significantly improve ship scour. Techniques to protect the harbour bottom from scour are already in use and are very effective. Their negative impact on the environment and future dredging is highlighted.

Further research should consider a holistic approach to a truly sustainable system of global maritime trade, because the costs and environmental damage caused by global maritime transport are primarily caused by profit-driven large shipping companies in collusion with construction companies that profit from port expansion contracts. At some point there will either come a time when actual sustainability is achieved, which would only be possible with a far more egalitarian economic system, or current trends will carry an abused environment beyond a point of no return.

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