

The Increase in Container Capacity at Slovenia's Port of Koper

M. Perkovic, E. Twrdy & M. Batista

University of Ljubljana, Faculty of Maritime studies and Transport, Slovenia

S. Jankowski & L. Gucma

Maritime University of Szczecin, Poland

ABSTRACT: The ports of the northern Adriatic are ranged in three countries, Koper's being the only one in Slovenia and therefore of distinctive import to the country, which with its limited coastal space has no other options for expanding maritime trade than increasing the capacity of this one extant port. The state of Slovenia is the largest shareholder and the future development of the port depends on decisions made by the Ministry of Infrastructure. The increase in container throughput in the Port of Koper requires a reconstruction and extension of the current container terminal as an absolute priority. Regarding economic sustainability the extension must be in line with the estimated growth of traffic as well as with the exploitation of present and future terminal capacities. The occasional expansion projects must fulfil environmental and safety requirements. For large container vessels (LOA more than 330 m) calling at the Port of Koper the safety of the berthing and departure conditions have to be simulated under various metocean conditions. At the same time manoeuvres should not be intrusive – expected propeller wash or bottom wash phenomena must be analysed. When large powerful container vessels are manoeuvring in shallow water bottom wash is expected and because sediments at the port are quite contaminated with mercury some negative environmental influence is expected. The most important expected investment in the container terminal is therefore extending (enlarging) and deepening the berth. The paper will present statistics and methods supporting container terminal enlargement and a safety and environmental assessment derived from the use of a ship handling simulator.

1 INTRODUCTION

The Adriatic Sea penetrates deep into the middle of the European continent, providing the cheapest maritime route from the Far East, via the Suez Canal, to much of Europe. Large commercial and industrial hubs like Vienna, Munich and Milan are just a few hours' drive away. In the last twenty years the total container traffic in the northern Adriatic ports has increased almost exponentially, on average 7% per year, though the rate has varied among ports (Fig. 1), (NAPA). The fastest growth of container traffic was recorded at the Port of Koper, at an average of 14% per year, in Venice the growth was constant, while at

Ravenna the traffic barely increased at all. The minimum throughput was and remains at the Port of Rijeka, which lost a great deal of traffic due to the state of war in Croatia; since about 2003 the increase in Rijeka's container throughput has been more in line with that of Koper, Trieste, and Venice.

2008 and 2009 – the worst years of the global economic and financial crisis – offer some interesting results. In Venice during this period, throughput kept steadily increasing by 5% per year; the other four ports experienced a decrease averaging 15%. The largest drop in traffic was recorded in Trieste, a decrease of more than 58,000 TEUs (17.5%), though by

percentage Rijeka fared worse, declining at the rate of 22.5% (38,000 TEUs less). We performed the shift-share analysis proposed by Notteboom (2007). In this analysis we include absolute growth of container traffic ABSGR and the share effect among ports. The calculation is based on the following formulas

$$ABSGR_k = TEU_{k1} - TEU_{k0} \quad (1)$$

$$SHARE_k = \left(\frac{\sum_i TEU_{i1}}{\sum_i TEU_{i0}} \right) \quad (2)$$

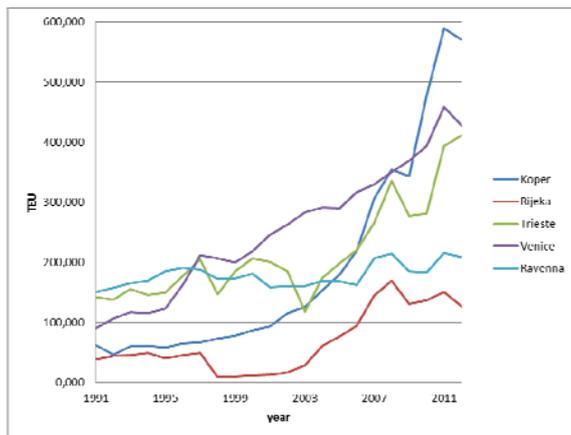


Figure 1. Container throughput in NAPA ports during 1991-2012 (1000 TEUs), (NAPA)

Table 1. Absolute growth of container throughput and total shift of containers for NA ports (1991-2011)

| Period | Koper | Rijeka | Trieste | Venezia | Ravenna |
|----------------------|----------------|----------------|----------------|----------------|-----------------|
| Absolute growth TEU | | | | | |
| 1991 1995 | -3,758 | 2,000 | 8,200 | 32,300 | 34,600 |
| 1995 1999 | 19,821 | -29,866 | 35,163 | 76,703 | -11,595 |
| 1999 2003 | 48,033 | 18,164 | -66,765 | 83,864 | -13,045 |
| 2003 2007 | 179,411 | 116,742 | 147,465 | 45,845 | 46,220 |
| 2007 2011 | 283,666 | 5,637 | 127,323 | 128,851 | 8,756 |
| 1991 2011 | 527,173 | 112,677 | 251,386 | 367,563 | 64,936 |
| Containers shift TEU | | | | | |
| 1991 1995 | -11,851 | -4,065 | -12,307 | 16,801 | 11,422 |
| 1995 1999 | 10,121 | -34,235 | 10,592 | 51,003 | -37,481 |
| 1999 2003 | 38,067 | 16,572 | -84,646 | 59,706 | -29,698 |
| 2003 2007 | 68,289 | 71,020 | 37,144 | -124,752 | -51,700 |
| 2007 2011 | 125,743 | -50,263 | 8,739 | -16,309 | -67,910 |
| 1991 2011 | 263,476 | 13,175 | -62,571 | -7,743 | -206,337 |

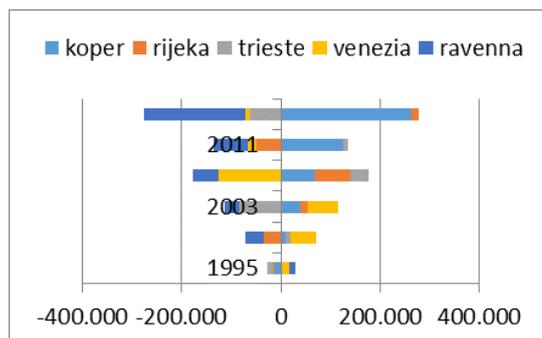


Figure 2. The evaluation of the shift shares in NAPA ports (1991-2011)

Results of the calculation are displayed in Table 1, and Figure 2, which shows that the port of Koper has by far experienced the largest absolute growth and shift in the region.

All other ports have oscillations. The most unpleasant situation is at the port of Ravenna.

Although the total container traffic in the northern Adriatic ports increased in recent years it still represents a negligible proportion in total throughput of the European ports. The data indicate (Table 2) that container traffic in northern Adriatic ports in the European Common throughput shows a slight increase – in 2008 it was 1.6 percent and it amounted to almost 2 percent in 2011. In the proportion - the throughput of all North Adriatic ports present just 15.2 percent of the throughput, which has created Europe's largest port Port of Rotterdam in 2011.

Table 2. Container throughput (in TEUs in 1000). Comparison of the three largest European ports and North Adriatic (NA) ports

| | 2008 10 ³ TEU | 2009 10 ³ TEU | 2010 10 ³ TEU | 2011 10 ³ TEU |
|-----------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Rotterdam | 10784 | 9743 | 11147 | 11877 |
| | 11.9 % | 12.5 % | 13.0 % | 12.9 % |
| Hamburg | 8664 | 7310 | 8468 | 9014 |
| | 9.6 % | 9.4 % | 9.8 % | 9.8 % |
| Antwerp | 9737 | 7008 | 7896 | 8664 |
| | 10.7 % | 9.0 % | 9.2 % | 9.4 % |
| NA ports | 1423 | 1305 | 1471 | 1806 |
| | 1.6 % | 1.7 % | 1.7 % | 2.0 % |
| EU | 90710 | 78011 | 86014 | 92164 |

2 INCREASING CONTAINER CAPACITY IN THE PORT OF KOPER

Container vessels are becoming larger, necessitating the expansion of the infrastructure at the Port of Koper's container terminal. Thus far investment toward the extension of the container shore, expansion of storage space and the purchase of specialized transport equipment has proven to be decisive in combating the financial crisis in part through maritime trade. The quantity of transported containers has reaching enviable numbers. This very success, though, has at the same time created a problem. The growth of container throughput in the Port of Koper is at the limit of the capacity for the existing container terminal. Therefore, it is necessary to start construction on a new container terminal and reconstruction and extension of the current container terminal. The extension is in line with the estimated growth of traffic as well as with the exploitation of present and future terminal capacities.

New projects and potential investments are important steps for the development of the Port of Koper, enhancing its performance and increasing its market share. The figure below (Fig. 3) shows the enlargement plan of the Port of Koper. A new pier, 3, is foreseen as an additional container terminal, while the existing container terminal shall be extended to accommodate one more berth (berth 7D). At present a large container vessel can call at the container terminal (berth 7C) with a limited draft of 11.6 m.

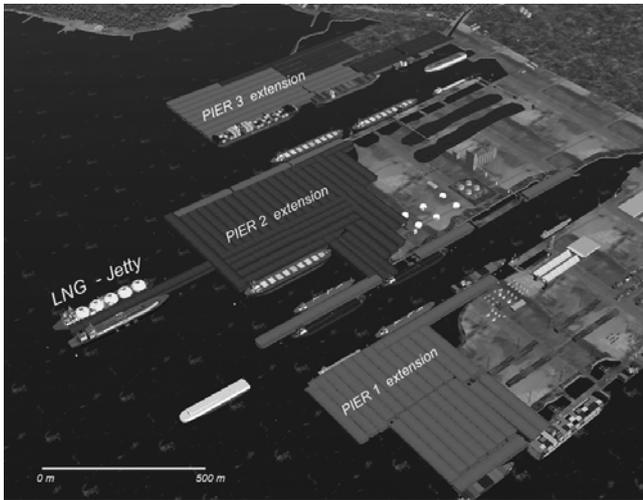


Figure 3. Existing and extended piers (Perkovic et al. 2012b)

To extend the pier and to determine the appropriate channel depth, deterministic and semi-probabilistic methods for designing a channel were applied. The minimum width and shape of the channel must be appropriate for safe calling and departure of characteristic container vessels presented at wind conditions up to 5 knots. As a result of the extension of pier 1 the entrance into basin 1 will narrow, which can affect the safety of approach for the largest cruisers (LOA up to 347m, draft 14.0m) calling at berths 1 and 2.

The extended plan with a fully loaded berth is presented in figure 4. The initial step was to analyse aspects relative to safety of an approaching cruiser while the extended container terminal is occupied by a large container vessel – figure 5a, shows the approaching trajectory and measurement lines of safe margins.

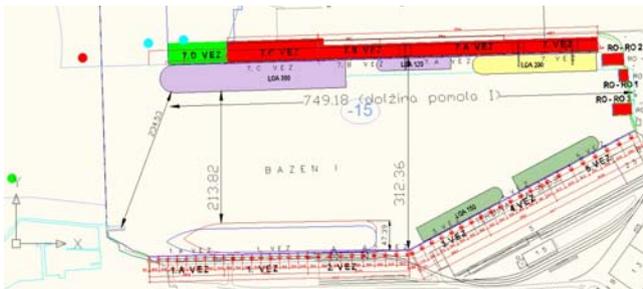


Figure 4. Basin 1 - fully loaded berths; at top extended container terminal (berth 7D)

Figure 5b shows the results of the first attempt at designing an entrance to a channel dredged to -15 m and the trajectory of a large container vessel entering basin 1. The designer hoped to make the channel as short as possible to minimise dredging costs, which is why the designed entrance was steep and narrow. Such an approach was also chosen because of limited amount of landfill capacities. Even brief simulation using a full mission ship handling simulator (Transas NTPro 5000, version 5.25) (Transas 2012) running with previously chosen container vessel model - clearly shows that such a channel is not an adequately safe approach for large container vessels. Based on those initial simulations further research work was ordered (Perkovic et al. 2013).

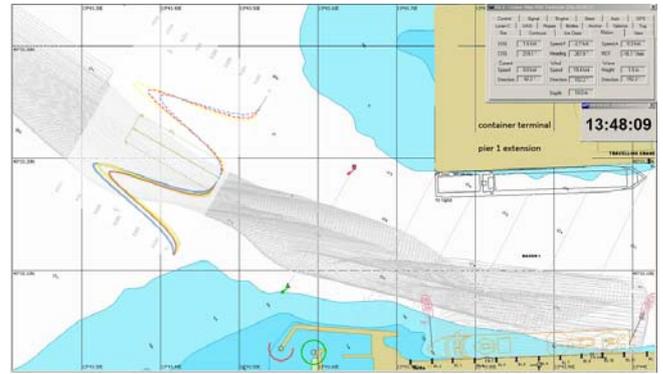


Figure 5a. Basin 1 – approaching trajectories of cruising vessel

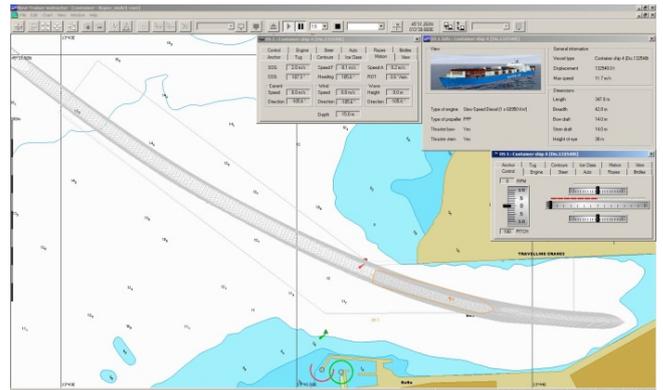


Figure 5b. Basin 1 – approaching trajectories of container vessel (initial test)

2.1 Determining nominal channel width by the determinist method

The fundamental criterion for defining and dimensioning elements forming a navigation channel or a harbour basin is safety in manoeuvring and operations carried out within them (Puertos del Estado 2007). The criteria for the geometric layout definition of the following navigation channels and harbour basins: fairways, harbour entrances, manoeuvring areas, anchorages, mooring areas, buoy systems, basins and quays is based on knowing the spaces occupied by vessels, which depends on: a) the vessel and the factors affecting its movements, b) the water level and factors affecting its variability. The main references for defining those factors are ROM 3.1 “The Recommendations for the Design of the Maritime Configuration of Ports, Approach Channels and Harbour Basins” (Puertos del Estado, 2007) and PIANC “Permanent International Association of Navigation Congresses” (PIANC 1997). The key parameters in approach channel design according to PIANC and ROM are alignment, traffic flow, depth, and width. They are all interrelated to a certain extent, especially depth and width. Factors included in determination of the channel width include: vessel manoeuvrability (oo), ship speed (a), prevailing cross wind (b), prevailing cross current (c), prevailing longitudinal current (d), significant wave height (e), aids to navigation (f), bottom surface (g), depth of waterway (h), cargo hazard level (i), width for bank clearance (j). The minimum channel width designed for the analyzed container vessel turned out to be 162.64 meters for wind conditions 4-6 according to the Beaufort scale (Table 3). As a particular (gusty)

katabatic wind is present in that area - manoeuvres should not be allowed at wind stronger than 5 according to the Beaufort scale. That limit was confirmed by the simulation (semi-probabilistic) method described in the next paragraph. The effectiveness of such simulations depends on the simulator capabilities to properly represent maneuvering characteristics and factors influencing ship behavior (Kobylnski 2011).

Table 3. PIANC approach – factors determining minimum channel width

| Basic manoeuvring lane width and additional widths | | Factors for multiplying vessel beam (B=42.8) | |
|--|--|--|-------------|
| 00 | vessel manoeuvrability (poor) | 1.8 | |
| Additional Widths for Straight Channel Sections | | wind <4°Bf | wind 4-6°Bf |
| a | ship speed (slow, less than 5 knots) | 0.0 | 0.0 |
| b | prevailing cross wind | 0.1 | 0.5 |
| c | prevailing cross current (low, 0.2 – 0.5 knots) | 0.1 | 0.2 |
| d | prevailing longitudinal current (low) | 0.0 | 0.1 |
| e | significant wave height | 0.0 | 0.1 |
| f | aids to navigation (moderate with poor visibility) | 0.3 | 0.3 |
| g | bottom surface (smooth and soft, < 1.5T) | 0.1 | 0.1 |
| h | depth of waterway (h/T) 1.25–1.5 | 0.4 | 0.4 |
| i | cargo hazard level (low to medium) | 0.2 | 0.2 |
| j | width for bank clearance | 0.1 | 0.1 |
| Sum | | 3.1 | 3.8 |
| The bottom width of the waterway (channel) | | 132.68 m | 162.64m |

2.2 Determining nominal channel width through the semi-probabilistic method

Channel geometric design in this procedure is mainly based on statistically analysing the areas swept by vessels in the different manoeuvres considered, which, should a sufficient number of manoeuvre repetitions be available, will enable the resulting design to be associated to the risk present in each case (Brigsa et al. 2003, Solari et al. 2010). This method was applied on the basis of real simulator studies. The simulations were performed in different meteorological conditions. Under every type of condition adequate numbers of trials were executed by human navigators. After the simulations, each trial was processed statistically in order to obtain the probability density function of ships' maximum distances from the centre of the waterway and the accident probability calculation in the given conditions. Finally, a safe water area was plotted with consideration of previously set up admissible risk level.

The navigational risk R is defined as:

$$R = P \cdot C \quad (3)$$

where: P - probability of accident, C – consequences. The risk is expressed usually in monetary values over a given period of time (one year in this kind of analysis). The vessel can safely navigate only in such an area where each point satisfies the depth requirement. If such case exists, the area is referred to

as the safe navigable area. The vessel carrying out a manoeuvre in a navigable area sweeps a certain area determined by the subsequent positions of the vessel. The parameters of that area have a random character and depend on a number of factors. Therefore, for fairways and harbour entrances the navigational safety condition can be transformed to this form (Gucma 2013).

$$D_m(t) \geq d_{ijkm}^s \quad (4)$$

where:

$D_m(t)$ – breadth of the navigable area at the m -th point of the fairway at the moment t , for which the safe depth condition is satisfied: $h(x, y, t) - T(x, y, t) + (x, y, t)$;

d_{ijkm}^s – breadth of the safe manoeuvring area at the m -th point of the fairway for the i -th vessel, performing the j -th manoeuvre in k -th navigational conditions.

$h(x, y, t)$ – area depth at a point with the coordinates (x, y) at the moment t ,

$T(x, y, t)$ – vessel's draft at a point with the coordinates (x, y) at the moment t ,

$\Delta(x, y, t)$ – under-keel clearance at a point with the coordinates (x, y) at the moment t .

$$d_{ijkm}^s = f(d_{ijkm}) \quad (5)$$

where:

d_{ijkm} – swept path of the i -th vessel performing the j -th manoeuvre in k -th navigational conditions for the m -th point of the waterway.

The layout of a swept path is presented in figure 6

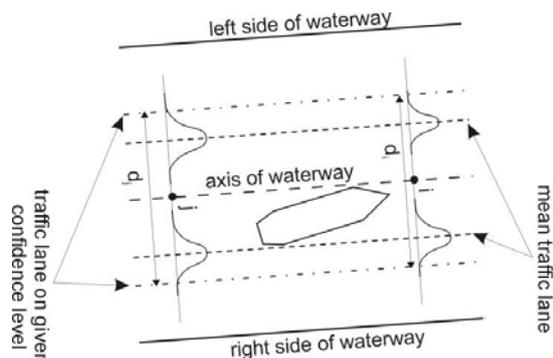


Figure 6. The breadth of a swept path at a specific confidence level at points (i) and (i+1) of the fairway.

2.3 Simulations and results

First, it was necessary to build the planned, enlarged port area based on precise bathymetry. The sailing area was created using Transas application Model Wizard (Transas 2011). Highly precise bathymetry (Figure 7) (spatial resolution 1m x 1m) was inserted and the projected manoeuvring area was quickly created. Figure 8 is a screenshot from the ship handling simulator NTPro5000 (Transas 2012).

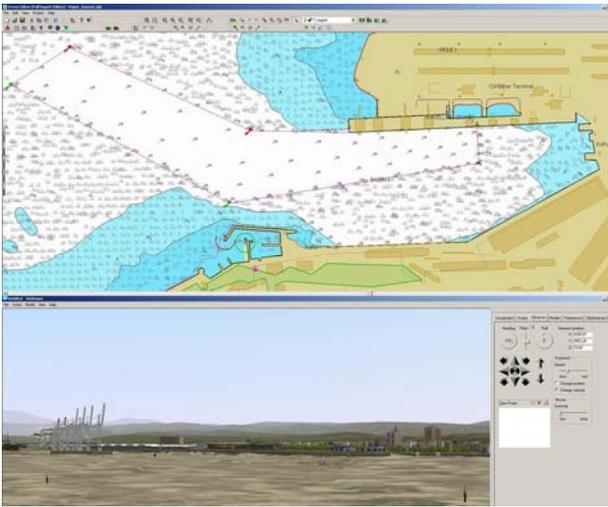


Figure 7. Modified channel - created with Model Wizard sw.



Figure 8. Fully loaded container vessel (111626 DWT) approaching terminal with assistance provided by pilot and two tugs – wind 5 knots from 060°



Figure 9. Final layout – the green sector shows the minimum required width based on statistical analyses and a 95% confidence level at various metocean conditions.

44 simulations were executed in various metocean conditions. Manoeuvres were processed according to the model previously described. The resulting safe waterway area at a 0.95% confidence level is presented with figure 9 (green colour). Such a confidence level is used most frequently for the design of the waterways.

In more critical solutions the level 99% could be considered. In port basins, however, the ship's speed is slow enough to significantly reduce the consequences of accidents, which explains the tolerance of 0.95% as a starting point for more serious considerations and risk analyses.

3 BOTTOM WASH

Among the many environmental issues concerning transport, one that seems to be largely overlooked is that of re-sedimentation, the effect of maritime vessels on the sea bottom - particularly, of course, in and near ports. The Gulf of Trieste is a semi-enclosed gulf in the north-eastern part of the Adriatic Sea, a shallow water area with an average depth of 16 m and a maximum depth of 25 m. This shallow area is subject to special pollution consideration related to bottom wash phenomena. There is a high mercury concentration (*In the town of Idrija, Slovenia, the world's second largest mercury mine was active for 500 years and an estimated 37,000 tons of mercury has in consequence dispersed throughout the environment*) in the subaquatic sediment which rises into the sea column while ships are manoeuvring. This sediment cloud (smaller particles) is then moved by currents for several hours before re-sedimenting, which has a nefarious effect on the aquatic food chain. The process of bottom wash is basically a function of the size, type and speed of propeller, vessel speed, sub-propeller clearance and sediment conditions (Gucma & Jankowski 2007). It is obvious that the process is dynamic; continuously changing vessel position results in variable bathymetry and vessel/tug propulsion. This process can be simulated and compared with actual manoeuvring results where telegraph recording data is collected together with vessel dynamics.



Figure 10. Intrusive manoeuvre "full astern" resulting in extensive propeller wash

An example of an intrusive manoeuvre is visible in figure 5. The pilot ordering full astern, which equaled -72 RPM, while the ship was at rest, resulted in maximum slip and thrust creating extensive propeller wash.

Figure 11 shows the departure procedure, but simulated, where the full mission simulator was used together with two virtual bridges; the first tug was the Voith Schneider propulsion type and the second was the tractor propulsion type.

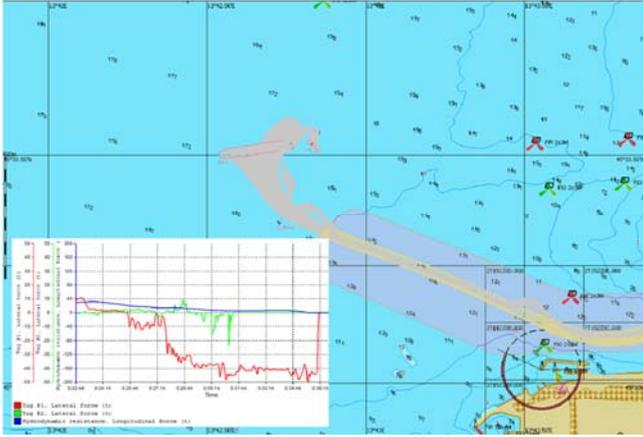


Figure 11. Simulated based Container departure, ship resistance and tugs forces

3.1 Model and some results

As a vessel moves, the propeller produces an underwater jet of water. This turbulent jet is known as propeller wash, or bottom wash (or propwash). If this jet reaches the bottom, it can contribute to re-suspension or movement of bottom particles. Velocity distribution behind the propeller is, for fully developed turbulent flow, given by (Albertson et al. 1950):

$$\frac{v_x}{v_0} = \frac{1}{2\xi} \exp\left(1 - \frac{\rho^2}{2\xi^2}\right) \quad \left(\xi > \frac{1}{2}\right) \quad (6)$$

where

$$\xi \equiv \frac{C_1 X}{D_0} \quad \rho \equiv \frac{r}{D_0} \quad (r^2 = z^2 + y^2) \quad (7)$$

and v_0 is initial velocity, D_0 propeller diameter, C_1 empirical constant and x, y, z are coordinates. The maximal velocity at a given ρ is obtained from the condition

$$\frac{d}{d\xi} \left(\frac{v_x}{v_0} \right) = -\frac{\xi^2 - \rho^2}{2\xi^2} \exp\left(-\frac{\rho^2}{2\xi^2}\right) = 0 \quad (8)$$

so

$$\xi = \rho$$

and maximal velocity is

$$\frac{v_{x,max}}{v_0} = \frac{1}{2\rho} \exp\left(-\frac{1}{2}\right) \quad (9)$$

At the bottom we have $\rho = \frac{h}{D_0}$ therefore

$$\frac{v_{b,max}}{v_0} = \frac{e^{-1/2}}{2h/D_0} \approx \frac{0.303}{h/D_0} \quad (10)$$

In Propeller Wash Study (Moffatt & Nichol, 2005) the maximal bottom velocity is given by

$$\frac{v_{b,max}}{v_0} = \frac{\alpha}{h/D_0} \quad (11)$$

where α is 0.22 for open propellers and 0.3 for ducted propellers.

The simulated manoeuvring procedure described in figure 7 and 11 was this time analysed for the purpose of bottom wash calculation. Ship position, dynamics and tug forces were recorded with a time resolution of one second (1 Hz). Data were stored and used for the bottom wash model where velocity streams are calculated for the sea bottom level.

Figure 12 shows propeller jet streams at the sea bottom for the approaching manoeuvre of the analysed container vessel. Wherever bottom velocity streams exceed 0.5 m/s some re-sedimentation is expected.

Figure 13 shows propeller jet streams at the sea bottom for the departure maneuver of a post panamx bulk vessel in ballast condition. Figure 14 corresponds to streams associated to two tugs assisting the bulk carrier. Figure 15 is the cumulative composition for a departing bulk carrier and tugs together.

Even though the Container Carrier installed engine is much greater, the applied power during berthing is much less compared to the bulk carrier departure condition.

Further modelling must be done to calculate the total amount of sediment transport divided further into bed-load, suspended-load and wash load, analysed separately for approaching and departure manoeuvres.

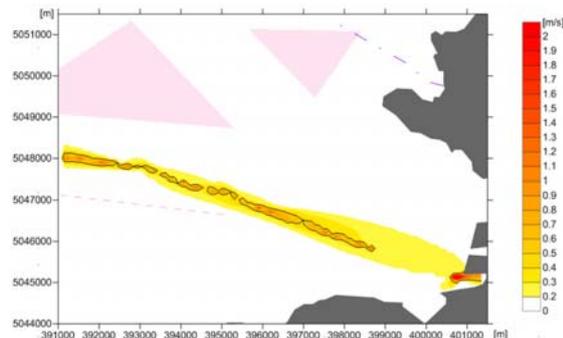


Figure 12. Bottom velocity streams for approaching Container carrier

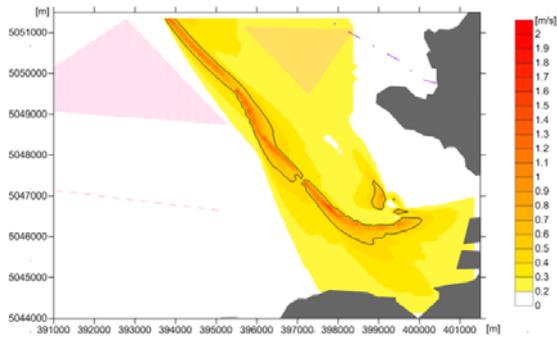


Figure 13. Bottom velocity streams for BC

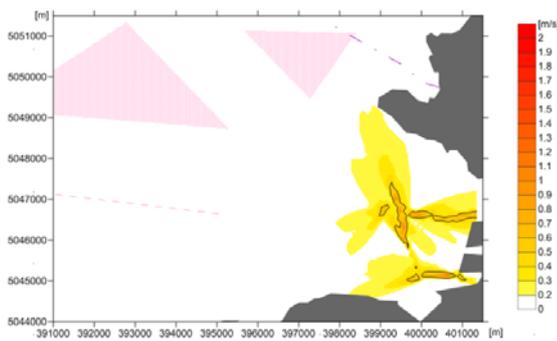


Figure 14. Bottom velocity streams for TUG's

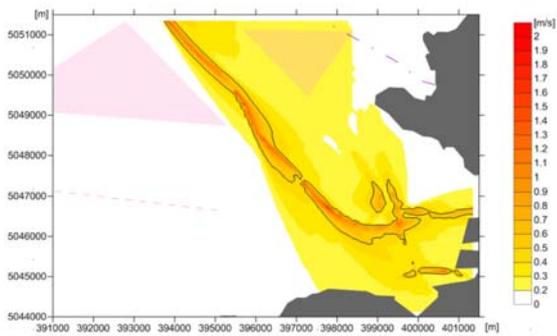


Figure 15. Departure; Total bottom velocity streams (Balk Carrier + TUG's)

At any rate the next two figures demonstrate that there will be no major increase of re-sedimentation for large container vessels calling at the Port of Koper. Installation power of main engine will increase by 10%, but when analysing bottom wash at zero speed (when the vessel is on stop and start to accelerate, maximum wash is expected) with telegraph command ordered to "Slow Ahead" propulsion power is equal 2.803 kW for larger container carrier compared with 2.545 kW for existing vessel. The main hull and propulsion particulars are:

Figure 16 shows the axial and vertical velocity streams, where the left edge of the image represents the water surface, while the right edge is the sea bottom margin. The image shows the velocity streams of the studied vessel where the shaft line is -9.9 m under the sea surface and 11.4 m above the sea bottom while the existing vessel has 2.4 meters smaller draft (limited vessel draft of 11.6 m comparing to 14 m draft after the dredging). The studied sea depth is 21.3 m. Figure 17a and 17b show the bottom velocity streams in the axial direction. The main difference in bottom velocity streams between existing (Fig 17b) and larger container carriers (Fig 17a) is mostly due to the increase of the vessel draft.

Again such increase is minor; maximum speed at bottom will increase only by approximately 0.2 m/s.

| Studied Container ship | Existing Container ship |
|--------------------------|----------------------------|
| Displacement = 132.540 t | 120.000 t (estimated) |
| Engine power = 60.950 kW | 54.853 kW |
| Service speed = 22.8 knt | 25.0 knt |
| Length o.a. = 346.98 m | 318.20 m |
| Breadth m. = 42.80 m | 42.80 m |
| Draft = 14.00 m | 14.00 m (limited to 11,6m) |

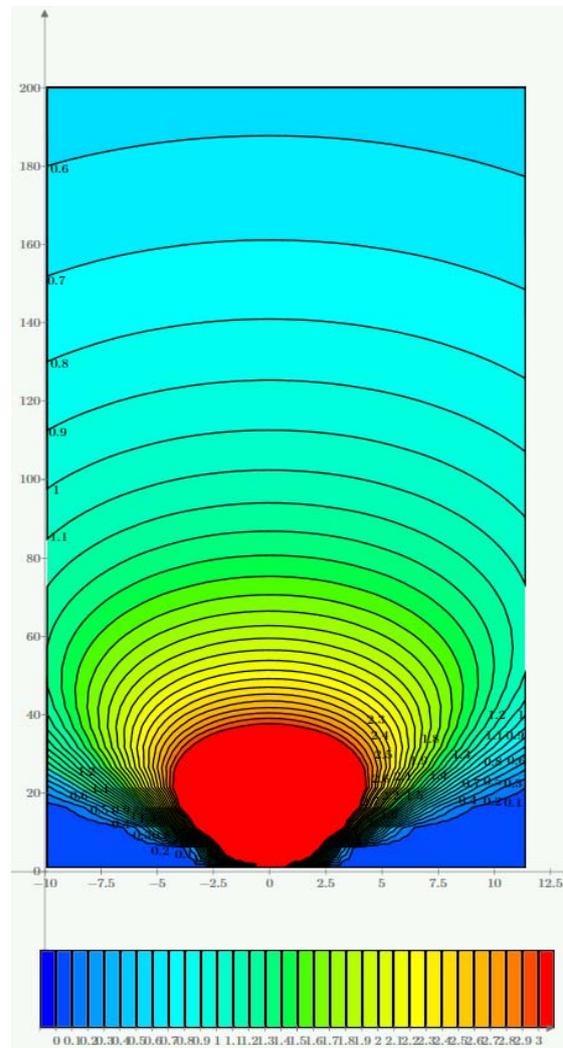


Figure 16. Velocity streams for planned container carriers

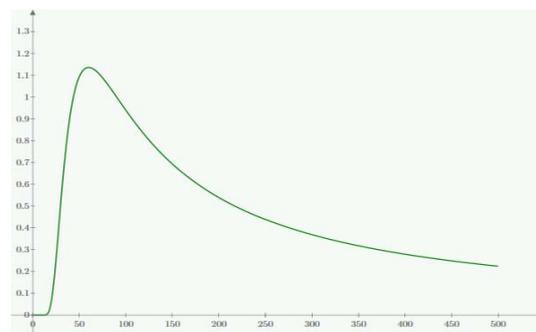


Figure 17a. Bottom velocity streams for planned container carriers

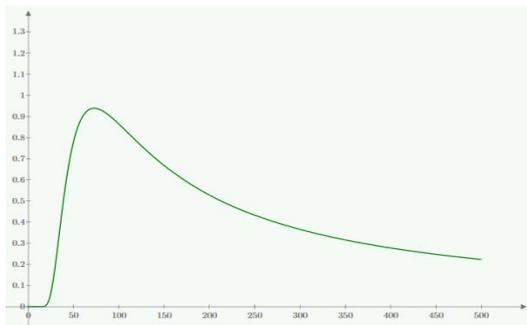


Figure 17b. Bottom velocity streams for existing container carriers

4 CONCLUSION

The future will bring ever larger and more container vessels, Ro-Ro traffic will remain heavy and likely increase, and passenger vessels seem likely to grow in size as well. The Port of Koper estimates that it will have to increase cargo operations from the current 16-18 million tons to 30-40 million tons in five to ten years, doubling the cargo capacity and nearly doubling the number of vessels calling.

For each alteration at the precise point where the land meets the sea at a port, a number of considerations are likely to arise. The two concerns discussed here are safety and potential environmental harm. Not for the first time, we demonstrated that ship handling simulators can help reconstruct real domain thrust conditions in a variety of circumstances. A number of careful simulations were necessary to determine the best, that is, safest and most cost-efficient, means for expanding a berth and channel, the extent of dredging required, and the best approach for large vessels.

The environmental factor covered here is one that does not seem to attract much research as of yet – the effect of vessel manoeuvres in and near ports in regard to bottom wash and re-sedimentation. The effects of current shipping trends on the sea bed must be understood with a long term view to eliminating environmental damage, in this case particularly as it may affect cross-border sedimentation.

It is thus far unclear whether the maritime transport business will reach a period of something like stasis, when ships are of optimal size for each type of cargo, when ports have reached optimal or maximal capacity, and, perhaps most important of all, when all negative effects on the environment have been eliminated. Until then, perhaps every change must attract careful scientific scrutiny, so that the potential harmful effects of growth in wealth are mitigated.

NOTE

Part of the paper is the result of work performed with national ARRS project titled "Influence of circulation and maritime traffic on sediment transport in wide open bays" number L2-4147 (D)

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