Operationally Forecasting Required Tug Resources for Vessel Turning

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Summary
Swinging large container vessels with large windage areas require several tugs with large bollard pull. A method for operationally forecasting the required tugs and bollard pulls for swinging large vessels has been developed. The method gives clear instructions for port authorities on the required tugs to be ordered up to 7 days ahead using forecasted wind and currents in the swing basin.

Keywords: Port Operations, Tug Resources, Operational System, Port Planning, Vessel Turning

Introduction

Traditionally the required towage resources for vessel swings are set out in Harbour Master guidelines for each port using static guidelines of vessel size, wind speeds and tide or calculated by the pilots before a swing.
The static method is often overly conservative for most vessels to ensure that even the largest vessel covered under each section can safely be turned in the swinging basin. This means that for most vessel movements more tugs than required are assigned to the vessel, this increases cost, environmental impact but also reduces the total number of vessel movements possible as there is only a finite number of tugs in each port.
Whereas the calculations often overly simplify the changing environmental forces during the swing and can be quite time consuming.
SeaportOPX has as part of the NCOS Online Safe Transit program developed an operational system for forecasting the required bollard pulls and required number of tugs up to 7 days ahead using accurate models of wind and currents inside the swinging basin. This has the potential to reduce the number of required tugs or increase windows where vessels can be moved safely.

Vessel Turning

To swing a vessel the combination of tugs and thrusters must be larger than these three forces mentioned:

- The environmental forces from wind and currents;
- Turning moment from the vessel itself;
- Turning moment from the added (virtual) mass of the vessel.

Environmental Forces

In NCOS Online the environmental forces from wind and currents are calculated using drag coefficients for the vessel type and loading, the wind/current speed and relative direction to the vessel. This follows the methodology outlined by OCIMF [1].
The environmental forces in the x- and y-direction as well as the yawing moment are calculated, this calculation is done for every 10 degrees during the vessel swing. The calculations are done using both spatially and temporally varying environmental conditions.

Figure 1 shows the definition of the forces and moment on the vessel from only environmental conditions.

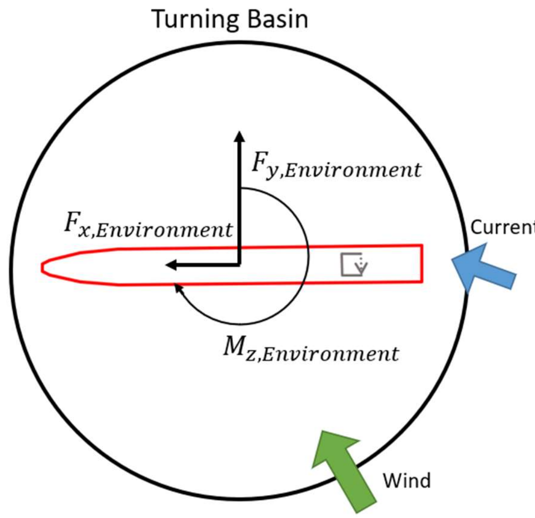

Figure 1 Environmental forces on a vessel. Showing the wind and current directions, as well as the forces on the vessel in the x- and y-direction as well as the rotational moment generated.

Vessel Mass

The moment of inertia in yaw to rotate the vessels mass is given by [2]:

$$A_{66} = \nabla \cdot \rho_w \cdot \left(\frac{L_{pp}}{4}\right)^2 \qquad (1)$$

Where ∇ = vessel displacement in m^3; ρ_w = density of the water; and L_{pp} = Length between perpendiculars. The last term represents the gyration radius squared.
There is also an additional mass that must be overcome, this is the added or virtual mass of the vessel, this represents the volume of water that must additionally be moved when rotating the vessel, this can if assuming very large water depth be approximated as [2]:

$$A'_{66,\infty} = \frac{1}{120}\pi \cdot \rho_w \cdot L_{pp} \cdot B \cdot T\,(L_{pp}^2 + B^2) \qquad (2)$$

Where $A'_{66,\infty}$ = the yaw added moment of inertia at infinite depth; B=vessel beam; and T = vessel draft. This added mass is only valid at very large depth to draft ratios.

Shallow Water Effects

For most vessels and ports, the depth is often much less than twice the draft, therefore shallow water effects should be included. These effects come from the water around the vessel being much harder to move during the rotation if the depth is shallow, as the water must be moved under the keel, where there is limited space. This effect is included by [3]. Which gives an increase in the added mass for shallower depths as:

$$\frac{A'_{66}}{A'_{66,\infty}} = \begin{cases} 1 + \frac{0.413+0.0192\left(\frac{B}{T}\right)+0.00554*\left(\frac{B}{T}\right)^2}{\left(\frac{h}{T}-1\right)^{0.82}}, & C_B \leq 0.75 \\ 1 + \frac{-0.5418- \ .7927\left(\frac{B}{T}\right)+0.147\left(\frac{B}{T}\right)^2+1.4864\,C_B+0.042\left(\frac{Lpp}{T}\right)}{\left(\frac{h}{T}-1\right)^{0.7157}}, & C_B > 0.75 \end{cases} \quad 3)$$

Where h = depth and C_B= block coefficient.

Turning Moment

The turning moment (yaw moment) to accelerate the vessels mass and added mass through the water can now be calculated as

$$M_{z,Mass} = (A_{66} + A'_{66}) \cdot \alpha \quad (4)$$

Where α = the rotational acceleration of the vessel, which can be changed on a port by port or vessel class/size basis, and A'_{66} = the added moment of inertia including shallow water effects.

Force Balance

Using the calculated forces and turning moments from wind, current and the vessel acceleration a force balance is made to calculate the required bollard pull at the fore and aft of the vessel at the tug attachment points. Figure 2 shows the definition of the forces from a tug at fore and aft used for the calculations.

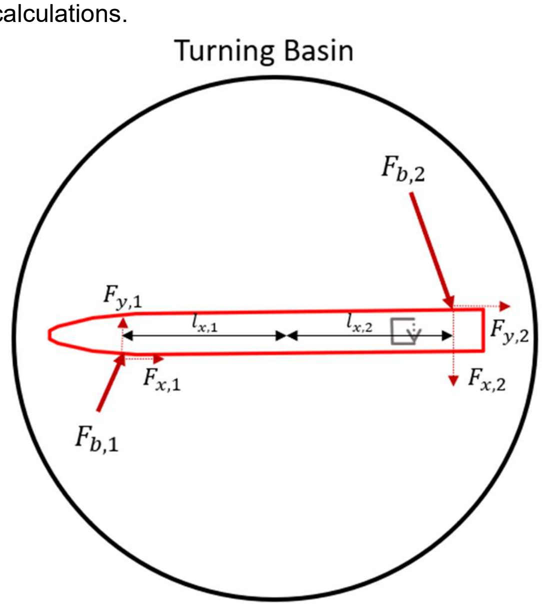

Figure 2 Image showing the definition of the forces on a vessel from tugs at the fore and aft of the vessel. Showing distance to tug attachment points and the forces.

The forces at the tug attachment points in the x-direction can be calculated as:

$$F_{x,1} = F_{x,2} = -\frac{1}{2} F_{x,Env} \quad (5)$$

In the y-direction it can be calculated as:

$$F_{y,1} + F_{y,2} = -F_{y,Env} \quad (6)$$

And for the moment in yaw:

$$F_{y,1} \cdot l_{x,1} + F_{y,2} \cdot l_{x,2} = -M_{z,Tot} \quad (7)$$

Where l_x= the distance from center of vessel to the tug attachment point.

Substituting and reducing we can now calculate the force in the y-direction as:

$$F_{y,1} = \frac{-M_{z,Tot}+F_{y,Env} \cdot l_{x,2}}{l_{x,1}-l_{x,2}} \quad (8)$$

Where $M_{z,Tot}$=$M_{z,Mass} + M_{z,Env}$. Using the above equations, the forces and moments on the vessel are now balanced, and we have satisfied equation 9.

$$\sum F_x = \sum F_y = \sum M_z = 0 \quad (9)$$

The required bollard pull at each end can now be calculated using equation 10.

$$F_b = \sqrt{F_x^2 + F_y^2} \quad (10)$$

Vessel Swing

A whole swing is modelled using NCOS Online and in each timestep all the above calculations are made. The highest required bollard pull in each direction and at each end are found. The required number of tugs and the required bollard pulls are shown in a report.

The effect of both bow and stern thrusters have also been implemented into NCOS Online Safe Transit, where they are included as an additional external force acting only in the y-direction.

The model assumes that the vessel swing is made at vessel speeds below 0.5knots.

The model also includes checks for requiring additional tugs if the force direction changes rapidly during the swing at either end, which will require an additional tug to ensure that the shift from pull/push can be done safely.

Conclusion

A method has been developed for combining all forcings on a vessel during swing operations in ports. This method has been implemented into NCOS Online as part of the Safe Transit module, where it gives recommendations in forecast to port operators on the required tug resources for all swing operations. This helps optimize required tugs and highlight periods where the tug resources are not adequate to safely swing the vessel.

References

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