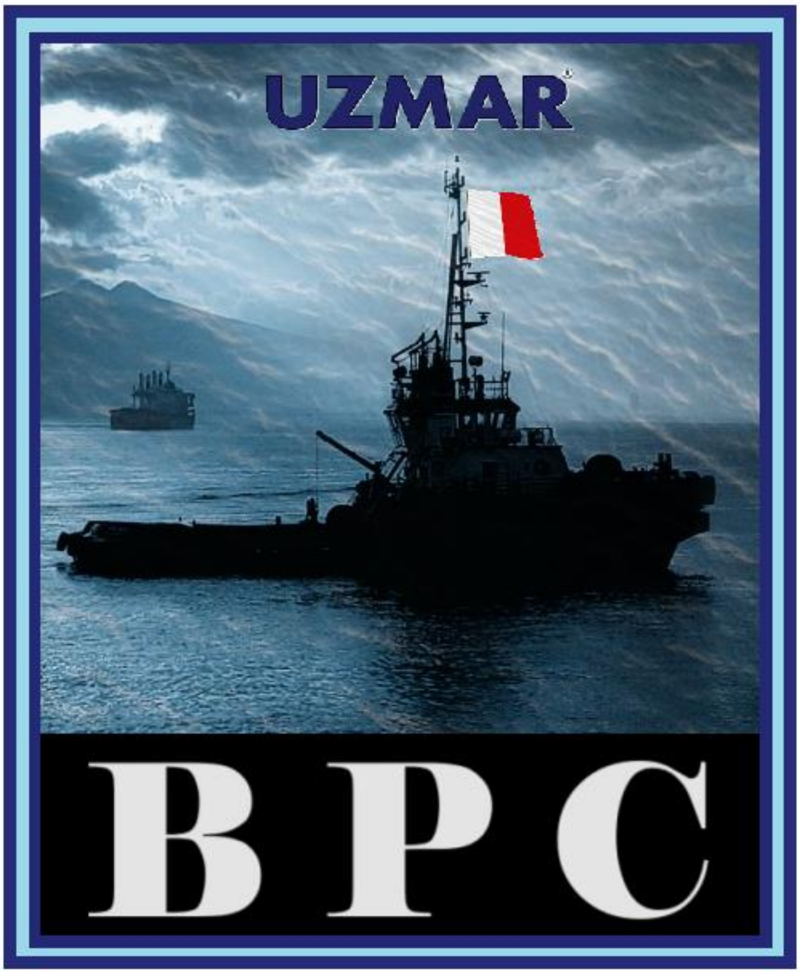


PILOT's TUG ASSIST TOOL - PTAT

BOLLARD PULL CALCULATION FOR MARINE PILOTS

1.0 Introduction

Pilots rely on their extensive professional expertise and the prevailing ship conditions to determine the requisite additional tugboat power and quantity amidst varying weather dynamics. Despite their expertise, pilots face time constraints that hinder accurate real-time decision-making. Compounded by adverse weather, the scope for error amplifies during assessments, risking reduced tugboat efficacy in challenging operational environments. While legally designated as advisors, pilots bear full accountability for precise calculations and subsequent decisions devoid of time constraints or operational pressures. In the event of mishaps, judicial entities and legal representatives promptly scrutinize the situation with proper tools and adequate time allocation to ascertain the authentic tug power and tugboat quantity requisites.

The "**Bollard Pull Calculator**" stands as a valuable and user-friendly tool for estimating the total tug power essential for navigating ships through diverse wind and current scenarios swiftly, aiming to streamline the determination of optimal tug power and quantity efficiently. Developed based on methodologies outlined in Capt. Henk **HENSEN**'s "**TUG USE IN PORT**" Chapter 5, seminal works such as **BS 6349-1, OCIMF** Mooring Equipment Guidelines (MEG4) 4th Edition 2018, **SIGTO**'s Prediction of Wind Loads on Large Liquefied Gas Carriers (2007), Post-Panamax Full Loaded Cond. Jare, Andersen I.M.V. (2003), Parameter identification of wind loads on ships, Werner **BLENDERMANN** (1993) and other significant references, this program digitizes and adapts linear and non-linear regression formulas derived from scholarly research for mobile application deployment. Insightful elucidations on calculations are accessible via the program's "ⓘ" symbol, guiding users through intricacies. Further program elucidations are intricately detailed in subsequent sections for comprehensive understanding.

2.0 The Various Sections

A. BPC SECTION

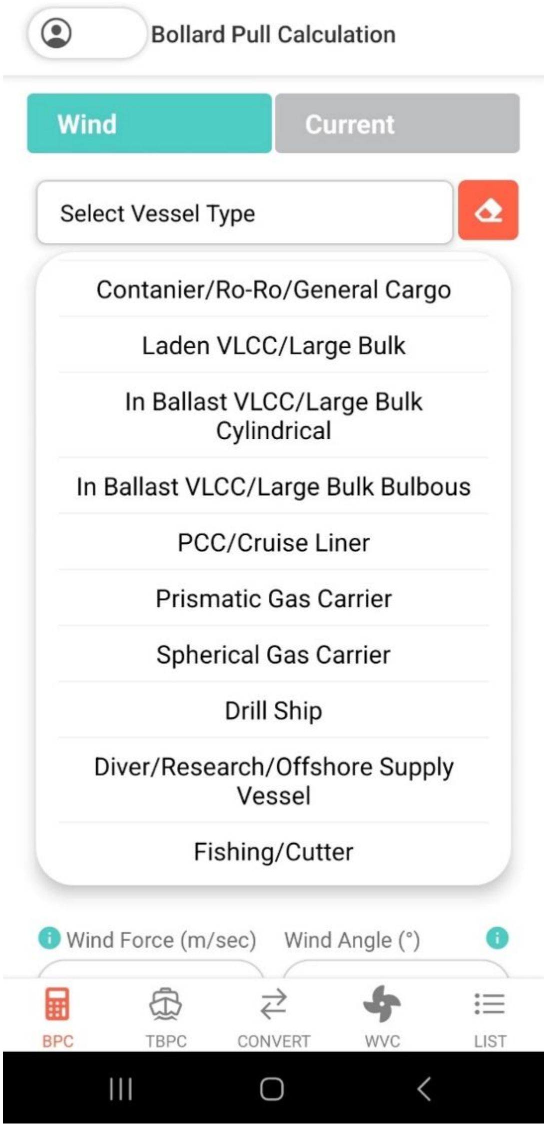


Fig.1 BPC Section

i. Calculations for required tug power in case of winds

In this section, first the ship type is selected and other data entries are made. Ship types are classified as shown in *(Figure 1)*. Among the values to be entered afterwards, the data entries determined as "***Longitudinal Height***" and "***Frontal Height***" are very critical as they are based on user calculation and observation. *(Figure 2)*

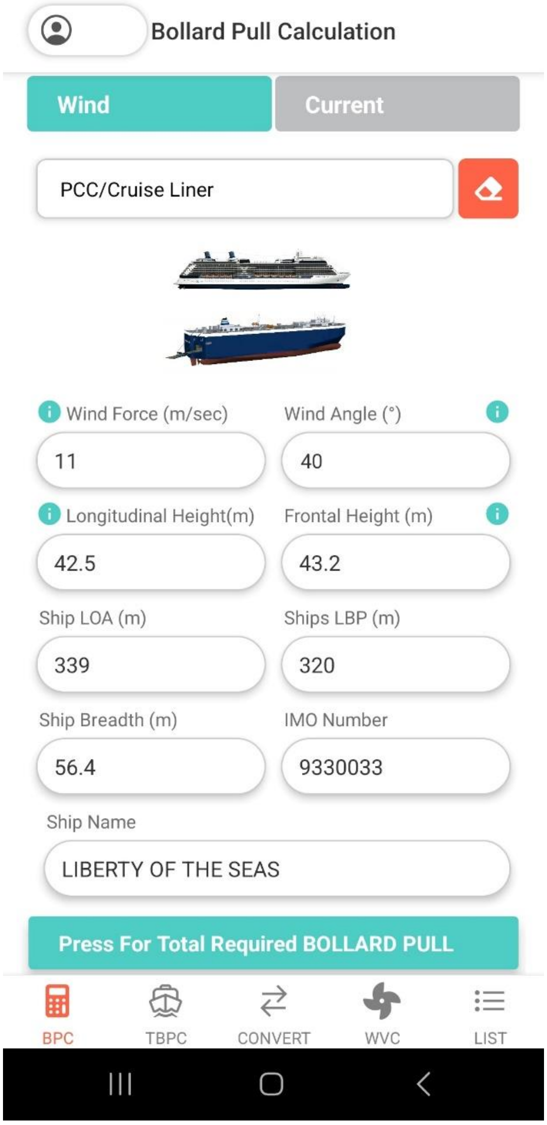


Fig. 2 Wind Data Input Section

Longitudinal Height*:* The value to be written in this box is critical.

It is the height from sea level to the average maximum height of the vessel, or in case of deck the average maximum height of cargo loaded on deck, including deckhouse.

It can be difficult to assess the sideways wind area. With container vessels it is rather easy.
When you keep in mind that the height of one container is about **2.60m,** then it is easy to calculate the total height of the containers on deck. Between the lowest container and the main deck is also about 2 meters space. Height of container can furthermore be used to assess other heights as well, such as the height of main deck above water.

Frontal Height: Average height of the superstructure.
It is the height from sea level to the average maximum height of the superstructure. (The Monkey Island Deck or The Funnel Top)

Wind force*:* Another important box in the same section. *(Figure 2)*

As wind does not blow at constant speed, the highest wind speeds are important.

Therefore, it is recommended to use the estimated wind force in gusts.

Wind speeds given in Beaufort scale are average wind speeds during a 10 minutes period and therefore too low and not suitable for calculation of required bollard pull.

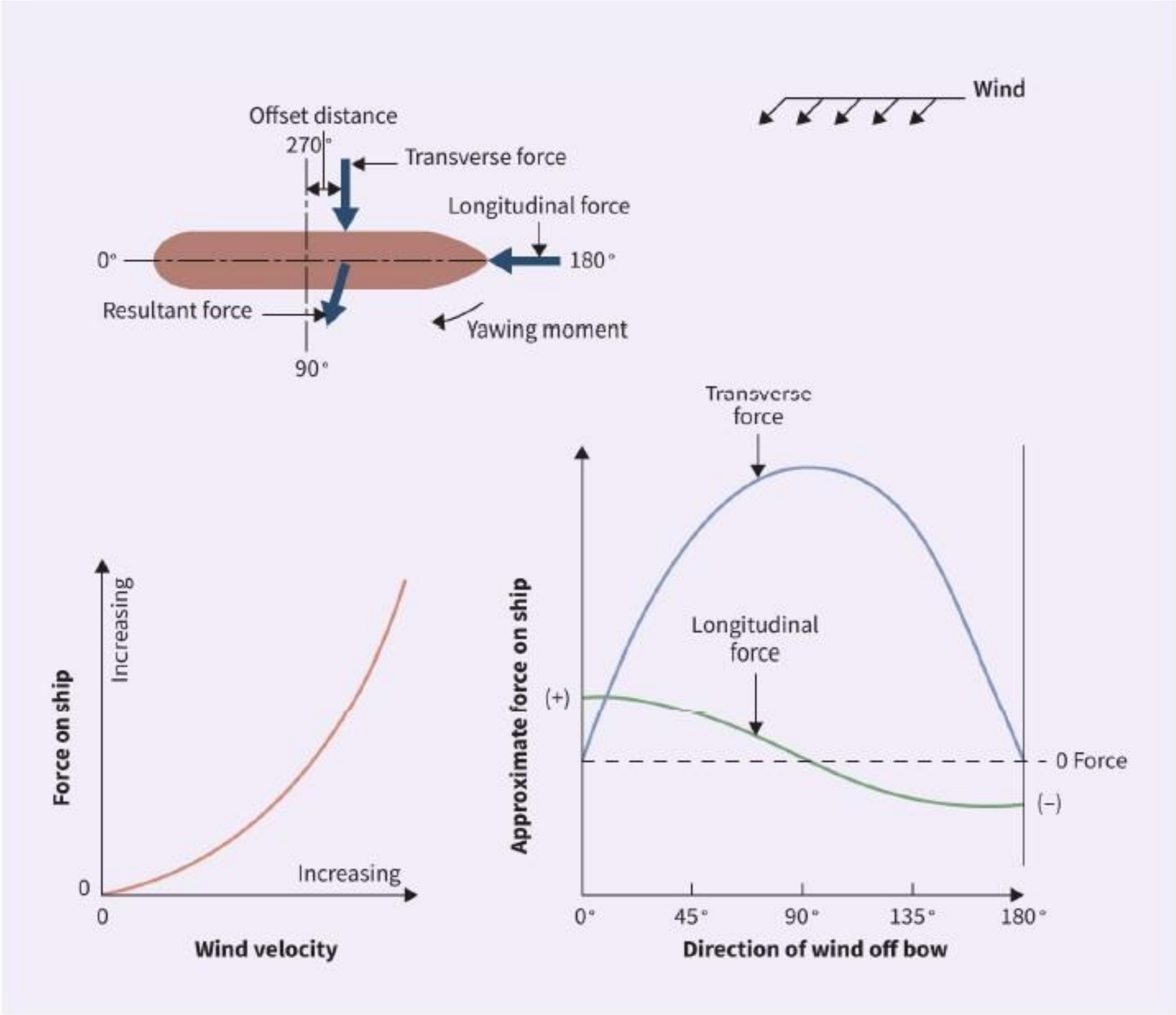
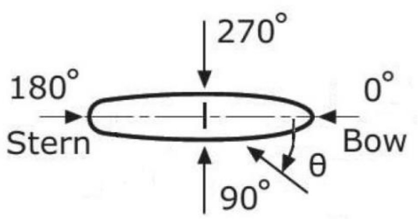


Fig.3-a Wind forces on a ship (OCIMF –MEG4)

Another data entry to be made in this section is the ***"Wind Angle (°)".***

Relative wind angle of attack : 0° at the bow-on to 180° stern. The coefficients are equally applicable to winds from 181° to 359° with the appropriate changes in the signs of the coefficients.



Wind is commonly treated as steady-state static force and this force is calculated using the well-known drag force equation:

F = 0,5*C(y_w)* ρ*V^2*A(l) *Newton*
V   = Wind velocity in m/sec
C(y_w)   = Lateral wind force coefficient

The wind force coefficients can be determined in wind tunnel tests and from computations. For several ship types the wind coefficients are known for all angles of attack and certain loading conditions. *(Fig. 3-b)*

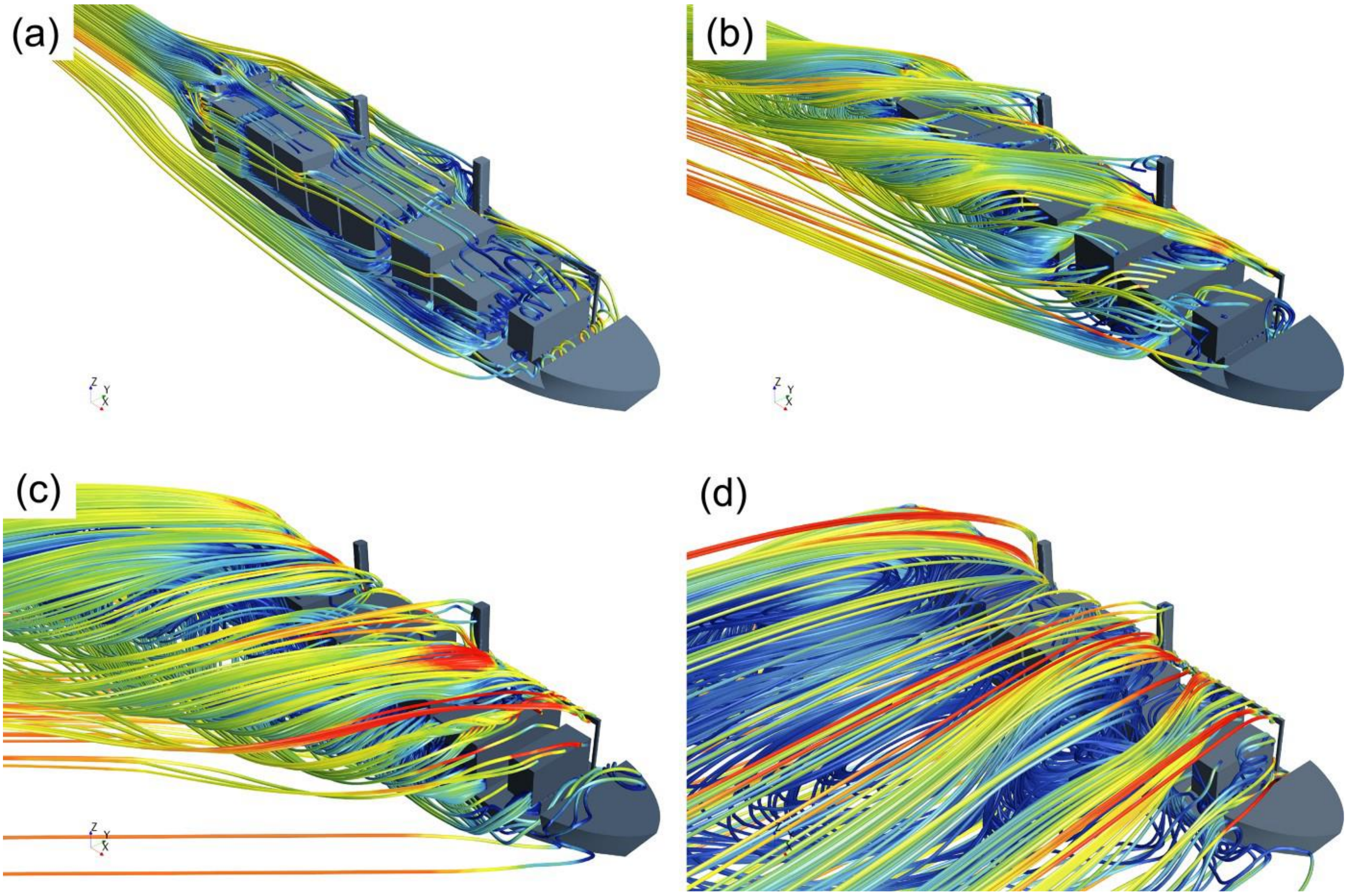


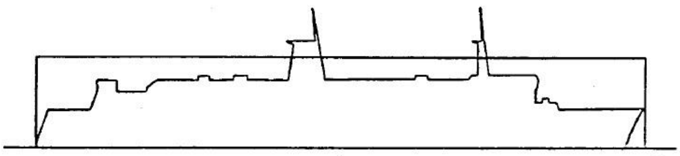
Fig. 3-b Numerical streamlines for 1900TEU container ship set at different wind angles
(a) θ = 0˚; (b) θ = 20˚; (c) θ =50˚; (d) θ = 90˚.
(https://doi.org/10.1371/journal.pone.0221453.g010)

For tankers and gas carriers they can be found in for instance, OCIMF publications. Lateral forces are largest and most important for calculating bollard pull required. C(y_w)varies between approximately 0,8 and 1,0 for beam winds, depending on ship's type and loading condition, but lies mostly between 0,9 and 1,0.

This coefficient (C(y_w)) is get from reference at non-lineer regressions & CFD calculations datas as below;

OCIMF Mooring Equipment Guidelines (MEG4) 4th Edition 2018
OCIMF Recommendations for ship´s fittings for use with tugs [2002]
SIGTO’s Prediction of Wind Loads on Large Liquefied Gas Carriers (2007)
Post-Panamax Full Loaded Cond. Jare, Andersen I.M.V. (2003)
Parameter identification of wind loads on ships, Werner BLENDERMANN (1993)
Die Windkrafte am Schiff, Werner BLENDERMANN (1986)
Schiffsform und Windlast-Korrelations- und Regressionsanalyse von Windkanalmessungen am Modell Werner BLENDERMANN (1993)

$A(l)$ = Longitudinal (broadside) wind area in m²



Longitudinal (Broadside) area of the vessel has calculated as shape of cuboid. This calculation is to make a margin of safety.

ρ =Density of air in kg/m³

Note: The formula above is based on a density of air of 1.28kg/m^3 which applies to dry air of 0^0 Celsius and 1 atmosphere (1000kPa) air pressure.
If for an actual situation a more accurate outcome is needed, density of air should be calculated based on the actual atmospheric air pressure (if needed taking into account height), temperature and humidity. Density of air increases with air pressure and for the same air pressure decreases with higher temperatures and humidity. It means that with a high pressure the required bollard pull calculated with the mentioned formula is somewhat too low, particular with low temperatures and dry air.

Another vector wind field is the calculation of the forces acting on the stern/bow line of the ship, called "longitudinal". This is calculated by following the same method and by reaching the resultant force, the direction and intensity of the resultant wind acting on the ship is calculated.

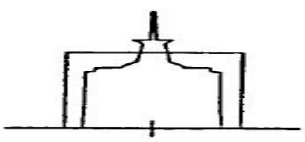
$F = 0,5 * C(x_w) * \rho * V^2 * A(t)$ Newton

V = Wind velocity in m/sec

$C(x_w)$= Longitudinal wind force coefficient

ρ =Density of air in kg/m³

$A(t)$ = Longitudinal (transverse/ head-on) wind area. (m²)



Transverse (Frontal/Head on) area of the vessel has calculated as shape of cuboid. This calculation is to make a margin of safety.

Details of the calculations mentioned above could be viewed after pressing the "***Press For Total Required BOLLARD PULL***" button. (*Figure 4*)

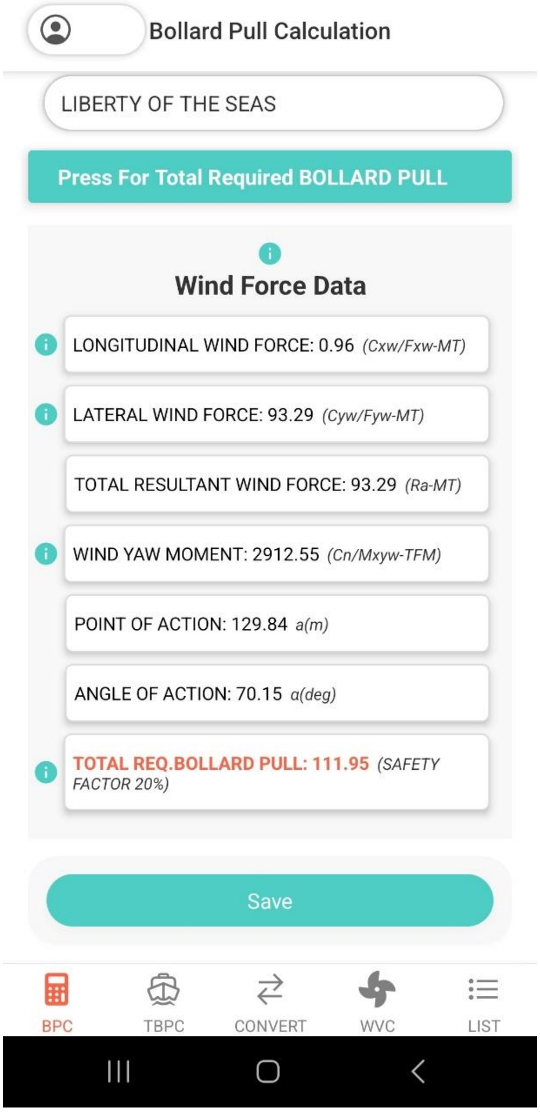
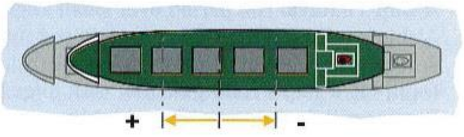
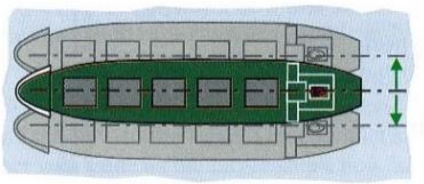


Fig.4 BPC wind force data detail info section

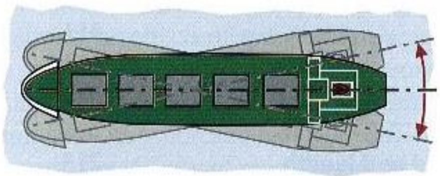
This information consists of:



longitudinal wind force (surge motion),

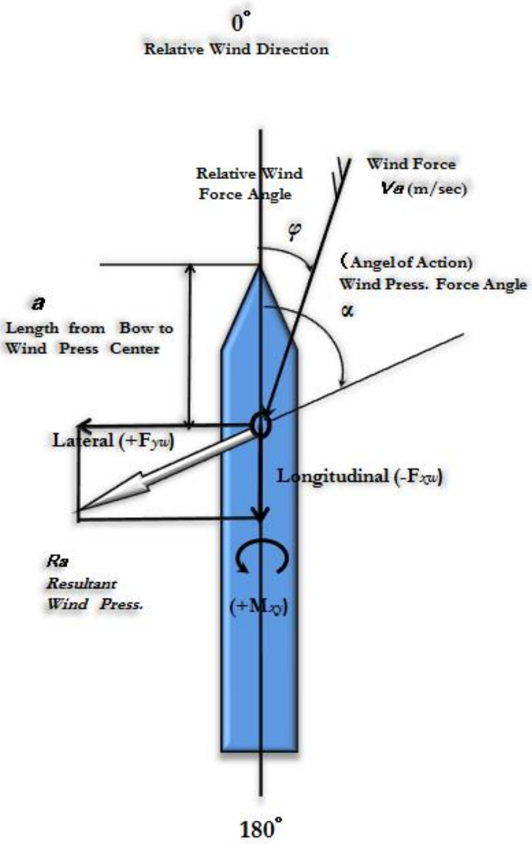


Lateral wind force (sway motion),



Wind yaw moment,

The resultant wind force, its direction and impact point and finally the total bollard pull requirement can be seen.



A safety margin of 20% is included. Therefore 20% has been added to the outcome of previous formula. *(The reasons why a safety margin is needed are explained in the "ⓘ" sign of "**total req.bollard pull**" line.)*

ii. Calculations for required tug power in case of currents

Current force considerations are similar to those of wind force. The magnitude of current forces on a ship depends on the velocity of the current, the hull form and area exposed to the current and the under keel clearance (UKC) of the vessel. Again lateral current forces experienced e.g. during berthing are most important.

The current forces acting on a ship can be calculated in the same way as the wind forces.

Formula for lateral current force:

$F = 0,5 * C(y_c) * \rho * V^2 * LBP * T$ Newton

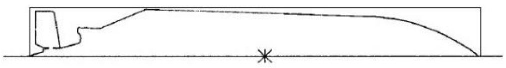
V = Current velocity in m/sec

ρ = Density of water in kg/m³

The average salinity of all oceans in the world is approximately 3.5%. This ratio indicates the content of approximately 35 grams of dissolved salt (mostly sodium chloride ions Na+ and Cl-) in each kilogram (or liter) of seawater. The average density of sea water is 1.025 g/ml (1025 kg/m³) on the water surface. The program referenced the density of average seawater as 1025 kg/m3.

An important point here is that;
For fresh water (1000kg/m³), the Calculated ***<u>Resultant current force</u>*** for currents is just 2.5% too high. (*For detailed information, press the "ⓘ" sign in the "Resultant Current Force" line in Figure-6*.)

LBP =Length between perpendiculars in m.
T = Draft in m.
C(y_c) = Lateral current force coefficient



Another vectorial flow field is the calculation of the forces acting on the stern/bow line of the ship, called "longitudinal". This is calculated by following the same method and by reaching the resultant force, the direction and intensity of the resultant current acting on the ship is calculated.

Formula for longitudinal current force:

F = 0,5* C(x_c) * ρ *V²* LBP*T Newton

What is different in this formula is C(x_c) = Longitudinal (frontal) current power coefficient. The mentioned coefficient values are taken from non-linear regression diagrams obtained from SIGTO's Prediction of Wind Loads on Large Liquefied Gas Carriers (2007) and **OCIMF** Mooring Equipment Guidelines (MEG4) 4th Edition 2018 model test results.
When the UKC decreases, the forces due to currents increase. The magnitude of current force can be three times as great on vessels with very small UKC as for vessels in deepwater.*(Fig.3)*

Current force increases, as with wind, with the square of the velocity. If the current velocity doubles, the current force is four times larger. If the velocity triples, the force is nine times larger.

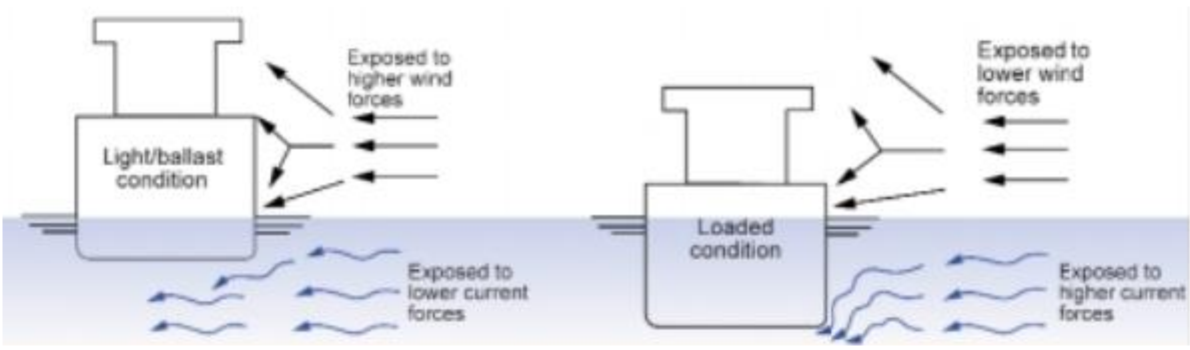


Fig.5 Effect of wind/current forces

The program interpolates the ratio draft-depth for the correct lateral current force coefficient.

In addition, The velocity at a known water depth should be adjusted by the factors provided to obtain the equivalent average velocity over the draught of the ship. Vertical velocity gradient was assumed to vary according to 1/7 Power Law (*Figure 7*). The data entry for this calculation should be entered in the section titled "**Vessel %**" (*Figure 6*).

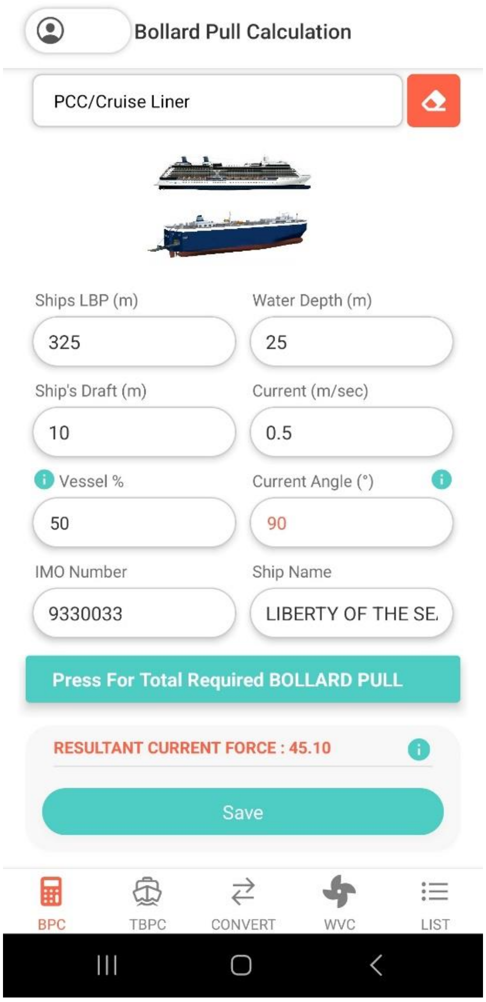


Fig.6 BPC current data input section

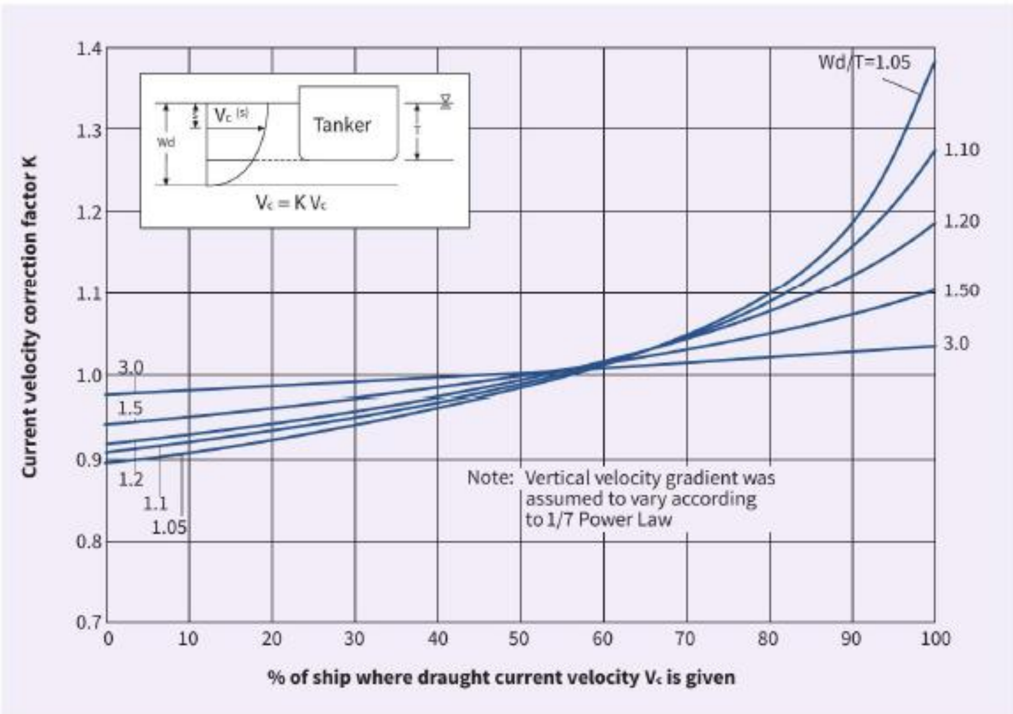
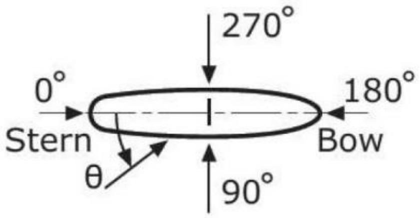


Fig. 7

In this section, after the user enters the ship's length between perpendicular ***"LBP"***, ***"Water depth"*** in the maneuvering area, ***"Ship's Draft"*** and ***"Current"*** data entry; The current direction should be selected as ***"Current angle".***

The point to be considered here is that the current direction starting point (0˚) should be at the stern of the ship.



Details of the calculations mentioned above can be viewed after pressing the "**Press For Total Required BOLLARD PULL**" button. (*Figure 8*)

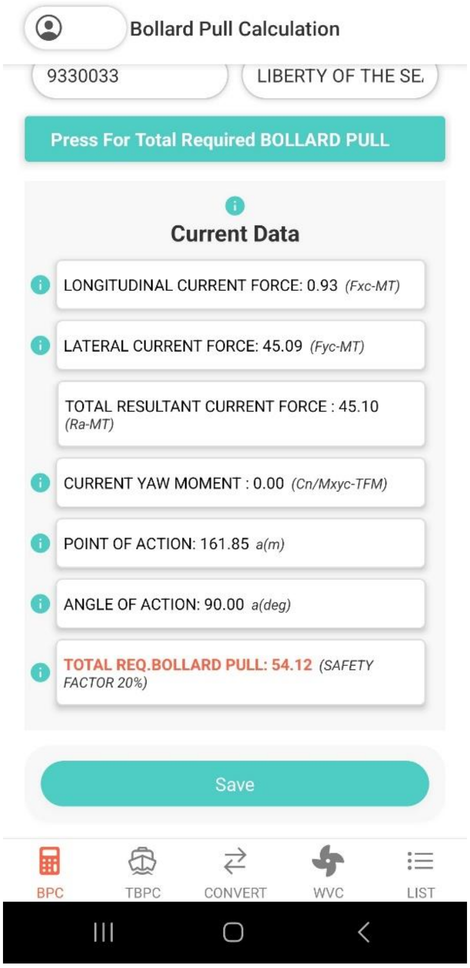
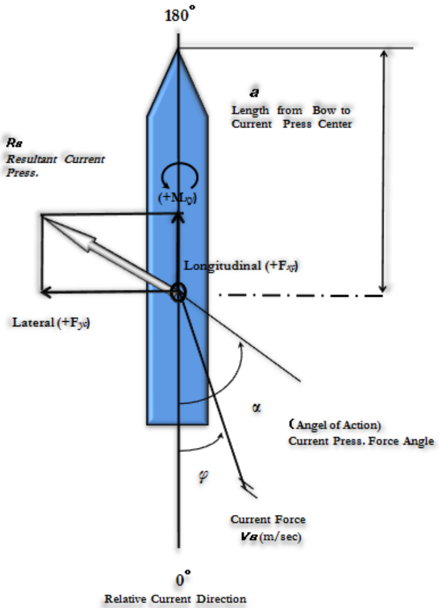


Fig.8 Current data detail info section

Within this detailed information , longitudinal current force (surge motion), Lateral current force (sway motion), Current yaw moment (rotation moment and direction), resultant current force, direction and impact point and finally total bollard pull requirement could be seen.



A safety margin of 20% is included. Therefore 20% has been added to the outcome of previous formula.
*(The reasons why a safety margin is needed are explained in the "ⓘ" sign of "**total req.bollard pull**" line.)*
Note:
It should be well understood that when pulling on a short towline, for instance at a distance of one tug length between tug and ship, there can be a large loss in pulling effectiveness of even up to 60% of the bollard pull of the tug, depending on direction of tug propeller wash and UKC of the ship. The shorter the distance the larger the loss. The negative effect of a pulling Voith tug will be less. As situations of distance and UKC varies, this loss can not be included in the program.

B. CONVERTER

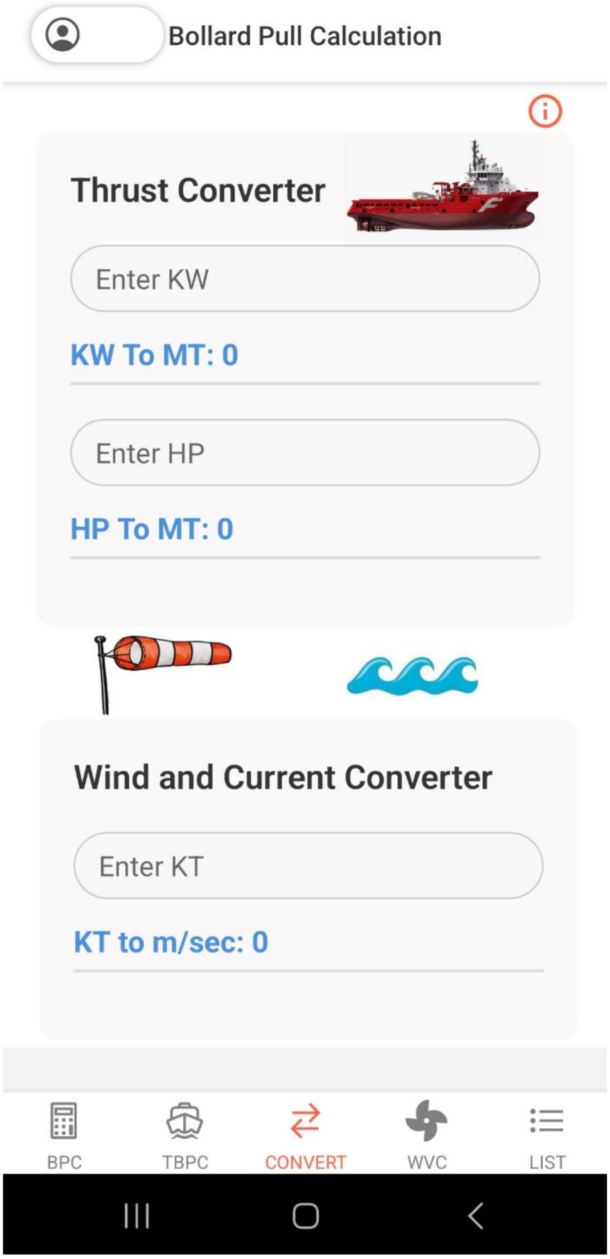


Fig.9 CONVERT section

It is possible to convert in the **"CONVERT"** section:

kW and HP to metric tons thrust for bow and stern thruster, and knots to m/sec for wind.

C. STOPPING SIDEWAYS MOVEMENT

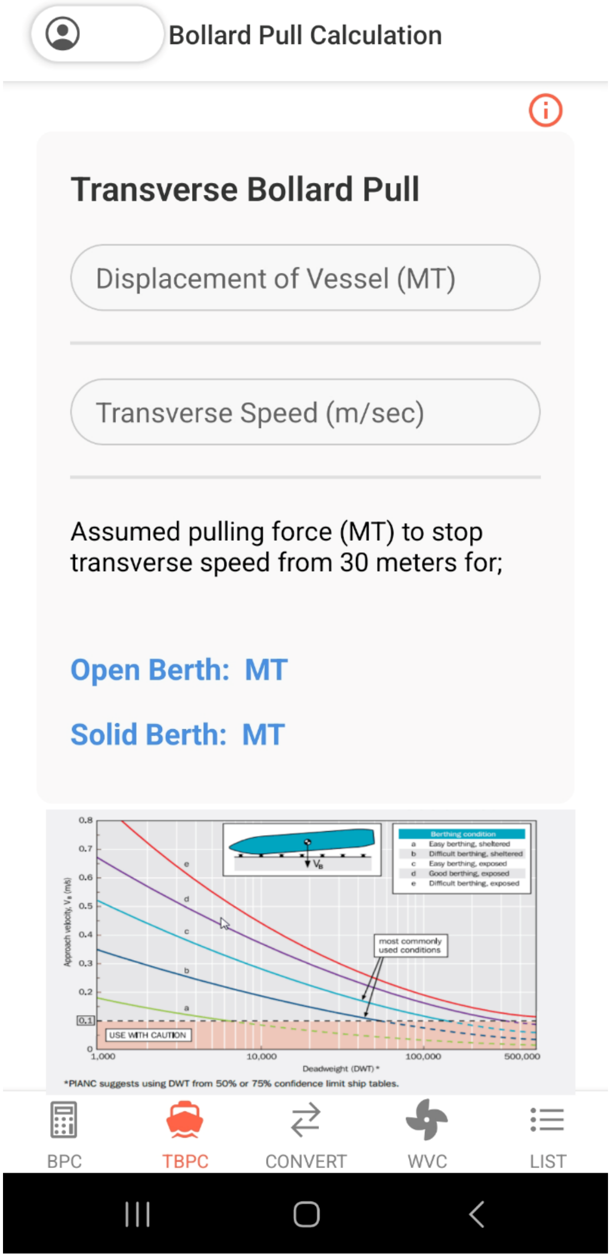


Fig.10 TBPC section

In this section the user can calculate the required tug power to stop a sideways moving ship which has at 30m distance from the berth a certain transverse speed. This could be helpful for certain ships, such as those loaded with dangerous or hazardous cargo. Calculations can be performed for open as well as for solid berths.

Calculations apply to approximately 10% UKC.

D. WIND VELOCITY CALCULATION

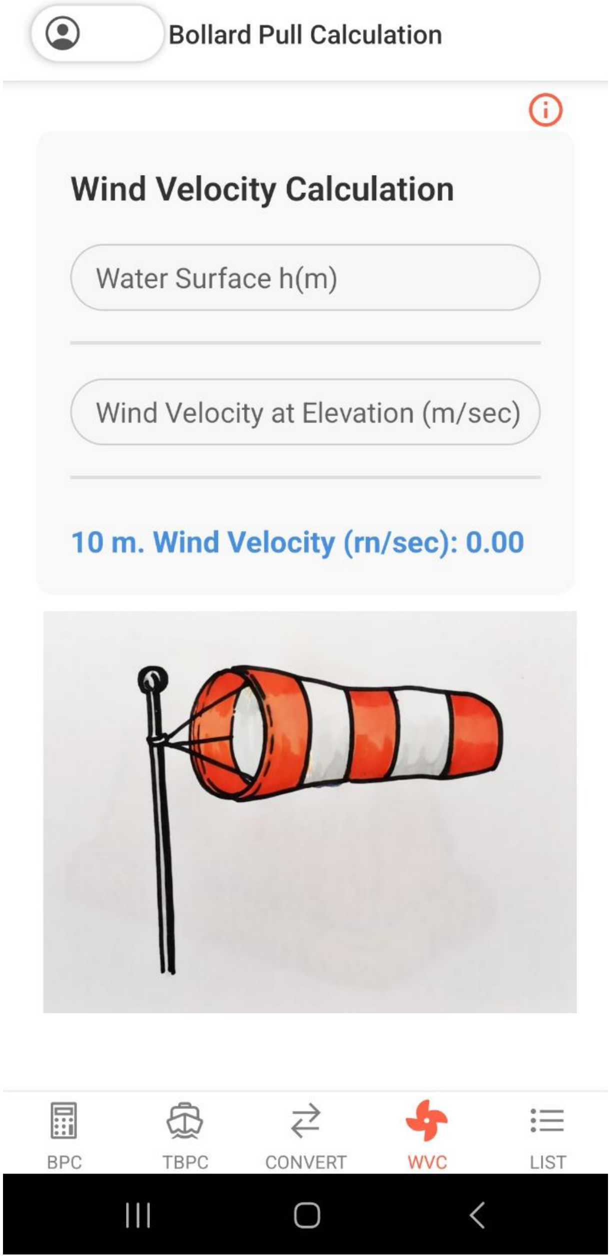


Fig.11 WVC section

For calculating wind force in the equations, basically its velocity at 10 meters height should be used.
For wind velocities obtained at a different elevation, adjustments to the equivalent 10 metre velocity can be made with this section.
On the other hand, wind indications given by a wind meter on top of a ship's mast give safe approximations for evaluation of the lateral wind force and bollard pull required.

3.0 Finally

I hope that all will use the app and that it may help you to bring ships alongside in a safe way particularly during adverse weather conditions, but preferable during good days and calm seas. Any suggestion for improvement of the app is welcome. (baykpost@uzmar.net / baykpost@gmail.com)

Furthermore:
I would like to thank **UZMAR**® Group of Companies for unlimited support, Capt. Henk **HENSEN** for his advice and consultancy on the system, which has been invaluable. Also, I would like to thank who contributed to the transformation of the program into an application and its use and accessibility by the world maritime industry, as the names as below;
UZMAR® IT and Solution Sys. Inc. General Manager, Mr. İbrahim **ÖZDEMİR**, Software Developer Manager, Mr. Aydın **ÖZTÜRK**, Software Developer Eng. Mss. Zeynep Sena **ÖZDEMİR**.

Web link to free download the mobile application "**Bollard Pull Calculator**";

https://play.google.com/store/apps/details?id=com.semerp.bollardpullcalculator

https://apps.apple.com/tr/app/bollard-pull-calculator/id6502411796?l=tr

Uzmar Uzmanlar Denizcilik Inc.

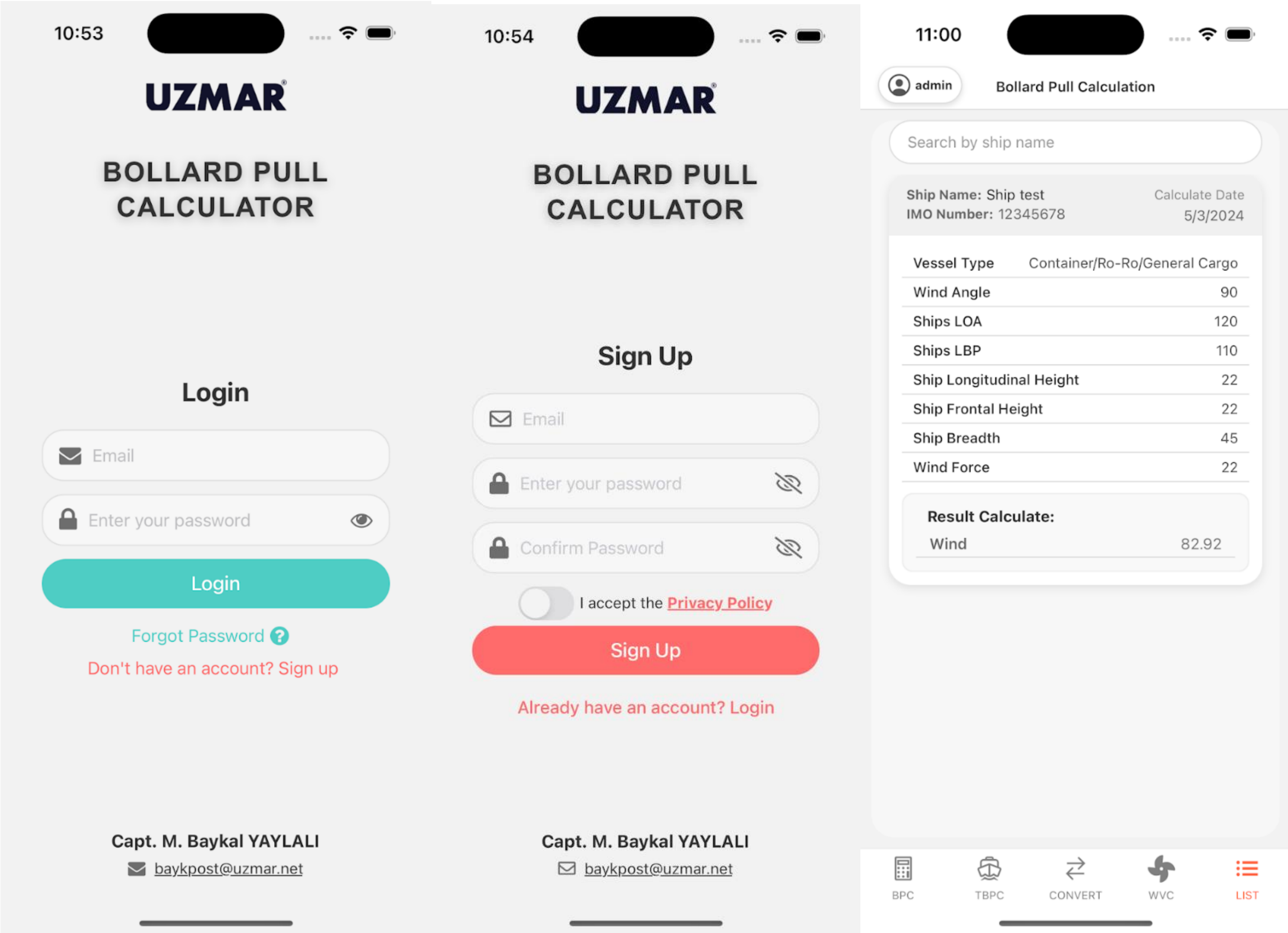
İzmir Nemrut Bay/**TURKEY**

Capt. M.Baykal **YAYLALI**

Important note: *Please note that data provided by the application are based on theoretical calculations. The calculations give an indication of the required bollard pull and should always be handled with care.*

This tool has been developed for informational use only and cannot be used as a direct reference when performing ship manoeuvres.

Screenshots from the program:



Assumptions Values & Coefficients for Wind Calculation

** Density of air in kg/m³ is assumed as* ***1,28***

** The wind drag coefficients assumed the trim is zero in the fully loaded condition and* ***0.8*** *degrees in the ballast condition.*

** Wind drag coefficients (nonlinear diagrams) of* ***VLCC*** *(laden or in ballast)/Prismatic & Sypherical Gas Carrieers*

in determined by wind tunnel tests are taken from ***OCIMF MEG4.*** *(The wind coefficients are based on data obtained from wind tunnel tests conducted at the University of Michigan in the* ***1960****s.)*

The wind coefficient values are based on a comprehensive set of wind tunnel tests conducted on prismatic and spherical gas carriers for ***SIGTTO****'s Prediction of Wind Loads on Large Liquefied Gas Carriers (2007). Model tests covered the following sizes: Spherical 125,000, 135,000 and 150,000m³ / Prismatic 75,000,135,000 to 155,000, 210,000 and 260,000m³*

** Wind drag coefficients (nonlinear diagrams) of "General cargo/Container" in determined by wind tunnel tests (Post-Panamax Full loaded cond.)are taken from* ***Andersen I.M.V. 2003***

** Wind drag coefficients (nonlinear diagrams) of "PCC/CRUISE LINER" are taken from* ***W.Blendermann,1994/2014***

** Wind drag coefficients (nonlinear diagrams) of "DRILL SHIP", "FISHING/CUTTER", "DIVER/RESEARCH/OFFSHORE SUPPLY VESSEL"*

Assumptions Values & Coefficients for Current Calculation

** Density of sea water in kg/ m³ is assumed as* ***1025***

** The trim is assumed to be zero for all the current drag data and the effects of trim on current coefficients were not investigated.*
(However, the effect of trim will be most pronounced for the yaw current coefficients for ballasted tankers in shallow water.)

** Current drag coefficients (nonlinear diagrams) of* ***VLCC*** *(laden or in ballast)/Prismatic & Sypherical Gas Carrieers are taken from* ***OCIMF MEG4.****The current coefficients are the result of Computational Fluid Dynamics (****CFD****) modelling, performed by Lloyd's Register on behalf of* ***OCIMF****, and have been extracted from a* ***2017*** *report on that work.*
(Full scale ***CFD*** *modelling run on ships of 50,000,150,000 and 300,000 DWT.)*

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Schiffsform und Windlast-Korrelations- und Regressionsanalyse von Windkanalmessungen am Modell Werner BLENDERMANN (1993)
CFD simulations of wind loads on a container ship: Validation and impact of geometrical simplifications, W.D. Janssen, B. Blocken, H.J. van Wijhe (2017)
Experimental–numerical analysis of added resistance to container ships under presence of wind–wave loads.(2019) W.Wang , T. Wu, D. Zhao, C. Guo, W. Luo,Y. Pang