ΕΡΓΟΔΟΤΗΣ

Αρχή Λιμένων Κύπρου

ΕΡΓΟ

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20 Δεκεμβρίου 2023

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ΣΥΝΟΠΤΙΚΗ ΠΕΡΙΓΡΑΦΗ

Η Αρχή Λιμένων Κύπρου προγραμματίζει την επέκταση του λιμένα Λεμεσού – Τερματικό 2 (Βασιλικό) προς τα ανατολικά.

Το παρόν τεύχος περιγράφει μία από τις υποστηρικτικές μελέτες της επικαιροποιημένης Μελέτης Εκτίμησης Επιπτώσεων στο Περιβάλλον (ΜΕΕΠ) για την επέκταση του Λιμένα Λεμεσού – Τερματικό 2 (Βασιλικό), και συγκεκριμένα τη Μελέτη Πλοήγησης.

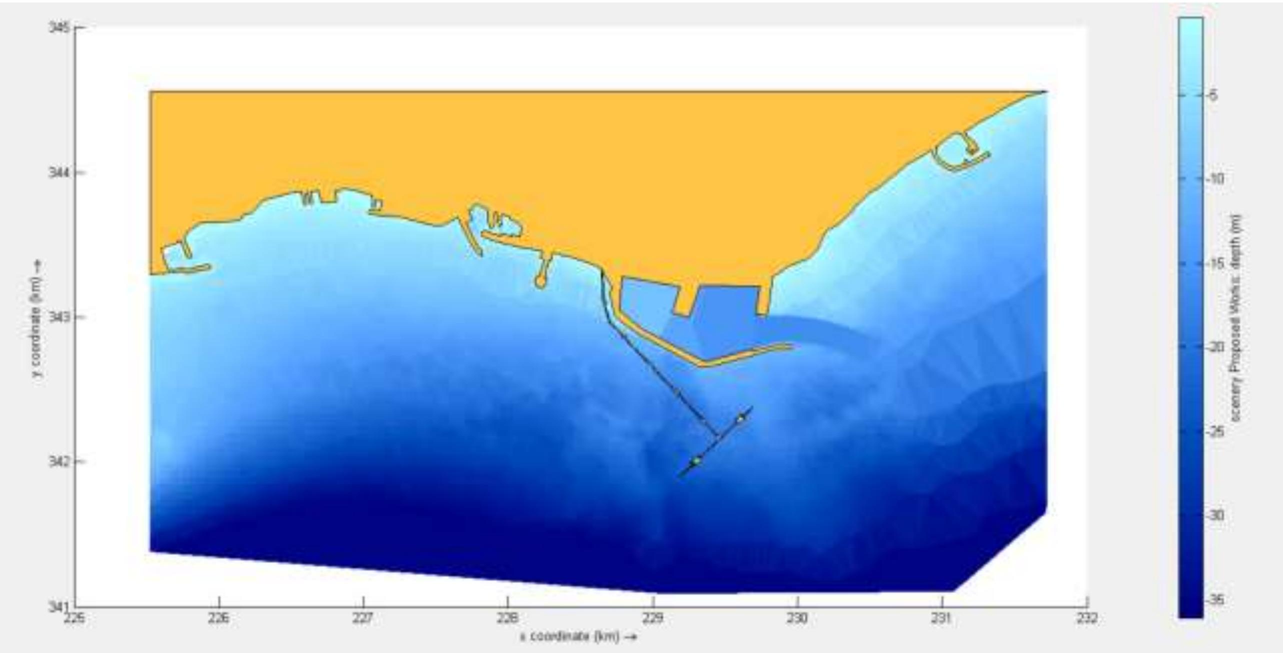
Σκοπός της παρούσας Μελέτης Προσομοίωσης Πλοήγησης είναι η διερεύνηση της καταλληλότητας των προτεινόμενων έργων, όπως περιγράφονται στη σχετική ΜΕΕΠ, σχετικά με την ασφαλή προσέγγιση και ελλιμενισμό του πλοίου σχεδιασμού εντός της νέας λιμενολεκάνης υπό την δράση έντονων περιβαλλοντικών φορτίσεων (ανέμων, κύματος και ρεύματος).

Για την εκπόνηση της παρούσας Μελέτης έγινε χρήση του λογισμικού SHIPMA7, αναγνωρισμένου διεθνώς για εφαρμογές σχεδίασης λιμενικών έργων, το οποίο βασίζεται σε υπολογιστικό μοντέλο ισορροπίας δυνάμεων επί του κινούμενου πλοίου εντός του εκάστοτε διαύλου ή της εκάστοτε λιμενολεκάνης υπό διερεύνηση.

Ως δεδομένα εισόδου στο μοντέλο για την περιγραφή της περιοχής μελέτης δίνονται τα ακόλουθα:

- λεπτομερής βαθυμετρία (κάναβος 10μ x 10μ.) περί των 3 χλμ. Ανατολικά και Δυτικά των υφιστάμενων λιμενικών εγκαταστάσεων του Λιμένα Λεμεσού – Τερματικού 2,
- οι υφιστάμενες γειτονικές λιμενικές εγκαταστάσεις (π.χ. προβλήτας VTTV),
- τα όρια των νέων προτεινόμενων έργων επέκτασης του Λιμένα Λεμεσού – Τερματικό 2 (Βασιλικό),
- η διαμόρφωση του πυθμένα για τον σχηματισμό του προτεινόμενου διαύλου προσέγγισης με ωφέλιμο βάθος 16,5μ. από Κατώτατη Ρηχία (ΚΡ).

Απεικόνιση της περιοχής μελέτης, όπως εξάγεται από το λογισμικό, δίνεται παρακάτω:



Σχήμα 0-1 Περιοχή μελέτης

Τα κλιματικά δεδομένα (κύματα, άνεμοι, ρεύματα) που λήφθηκαν ως παράμετροι εισόδου στην προσομοίωση πλοήγησης παρουσιάζονται στον παρακάτω πίνακα:

Πίνακας 0-1 Κλιματικά δεδομένα

Cases	Direction	Wind speed (kn)	Wave Height (m)	Wave Period (s)	Current Speed (kn)
1	S (180^o N)	29	3.75	7.74	0.41
2	SW (225^o N)	33	2.5	6.63	0.41
3	NE (45^o N)	29	~ 0	~ 0	0.8745

Σημειώνεται ότι ο παραπάνω συνδυασμός καιρικών συνθηκών σε κάθε περίπτωση, όπου ο άνεμος, τα κύματα και τα ρεύματα κατευθύνονται προς την ίδια ακριβώς κατεύθυνση, θεωρείται συντηρητική προσέγγιση. Επίσης, τα παραπάνω φαινόμενα ανέμου και κύματος θεωρούνται ως ακραίες τιμές, στις οποίες το πλοίο σχεδιασμού θα μπορούσε να καταφέρει να εισέλθει στο λιμάνι, και δεν συσχετίζονται μεταξύ τους ως ένα καθεστώς κύματος που προκαλείται από τον άνεμο στην ανοικτή θάλασσα.

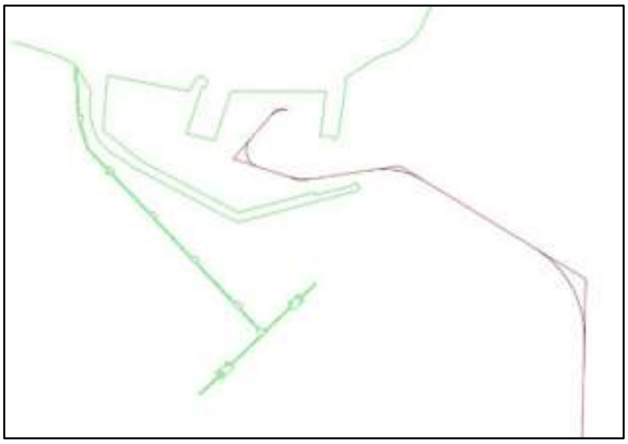
Το υπό διερεύνηση πλοίο, για την απόδοση της πλοήγησής του με προσέγγιση εντός του λιμένα και ελλιμενισμό του στο τερματικό 2, είναι ένα πλοίο μεταφοράς ξηρού χύδην φορτίου (Bulk Carrier) μήκους τάξεως 250 m. Τα βασικά του χαρακτηριστικά του μοντέλου του αντίστοιχου πλοίου που υπάρχει διαθέσιμο στις βιβλιοθήκες του λογισμικού και χρησιμοποιήθηκε για τις προσομοιώσεις που περιγράφονται στον ακόλουθο πίνακα. Πλήρη στοιχεία των χαρακτηριστικών του πλοίου δίνονται στο Παράρτημα.

Πίνακας 0-2 Βασικά Χαρακτηριστικά μοντέλου πλοίου

Ολικό μήκος (L_{OA})	245.3 m
Πλάτος (B)	32.2 m
Βύθισμα (T)	13 m
Μέγιστη Ταχύτητα ελιγμών	11.663 kn
Μέγιστη γωνία πηδαλίου	35^o
Επιτάχυνση προπέλας	0.045 1/s^2
Μέγιστος ρυθμός στροφής πηδαλίου	3 ^{o}/s
Μετωπική επιφάνεια	740 m^2
Πλευρική επιφάνεια	2,389 m^2

Οι ελιγμοί προσέγγισης περιλαμβάνουν ένα αρχικό στάδιο γραμμής πλεύσης κατεύθυνσης από Νότο προς Βορρά, κατόπιν ένα στάδιο στροφής του πλοίου με μεγάλη ακτίνα ώστε να προσανατολιστεί σε θέση εισόδου στον δίαυλο Πλοήγησης του λιμένα, την διάσχιση του διαύλου μέχρι να λάβει θέση ενώπιον της λιμενολεκάνης του τερματικού και το τελευταίο στάδιο της ρυμούλκησης αυτού εντός της λιμενολεκάνης προς τη θέση ελλιμενισμού του με περιστροφικές κινήσεις που εξασκούν στο πλοίο τα ρυμουλκά.

Η χάραξη του διαύλου προσέγγισης επιλέχθηκε να σχηματίζει μικρή καμπυλότητα, έναντι ευθύγραμμης χάραξης στην είσοδο του λιμένα και ως την ισοβαθή του βάθους σχεδιασμού του διαύλου. Ο σχεδιασμός αυτός επιλέχθηκε ως βέλτιστη οικονομοτεχνική και περιβαλλοντική λύση για την αποφυγή εκτεταμένης βυθοκόρησης και εξασφάλιση της μικρότερης δυνατής επίπτωσης σε λιβάδια Ποσειδωνίας που συναντώνται στην περιοχή. Για την αποφυγή απόκλισης της πορείας του πλοίου από τον δίαυλο προσέγγισης προτείνεται η εγκατάσταση κατάλληλης σηματοδότησης στα όρια αυτού.



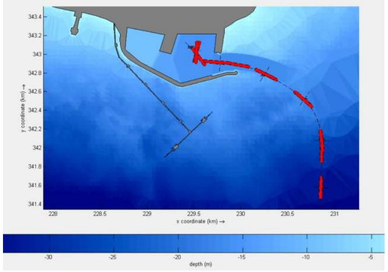
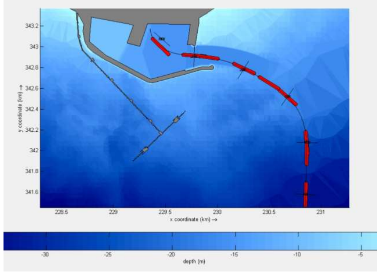
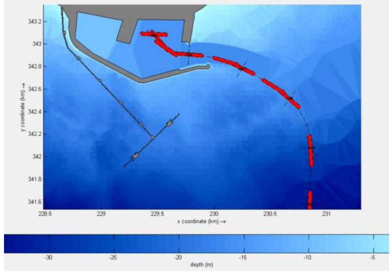
Πίνακας 0-3 Όρια δίαυλου προσέγγισης

X	Y	Radius (m)
230838.699	341077.917	0.0
230869.158	342399.457	461.35
230059.436	342891.816	378.75
229333.051	342922.958	75.0
229520.711	343137.838	89.41
229600.928	343137.838	0.0

Τα αποτελέσματα της προσομοίωσης αναδεικνύουν την επάρκεια των προτεινόμενων τροποποιήσεων του Λιμένα Βασιλικού για ασφαλείς προσεγγίσεις και ελιγμούς εντός της λιμενολεκάνης για πλοία μεταφοράς χύδην φορτίου του επιθυμητού μεγέθους, σε δυσμενείς συνθήκες λειτουργίας του λιμένα, ήτοι σε ανέμους έως 33 κόμβους. Σε κάθε περίπτωση, στο λιμάνι δραστηριοποιούνται ρυμουλκά με τεχνογνωσία να φέρουν εις πέρας τον ελλιμενισμό μεγάλων πλοίων με προκαθορισμένη ελκτική ικανότητα. Οι παρούσες προσομοιώσεις συμπεριέλαβαν τη δράση τέτοιων λέμβων ρυμούλκησης στο τελευταίο στάδιο που έλαβε χώρα εντός της εξωτερικής λιμενολεκάνης του Λιμένα και παρατηρήθηκε ότι υπάρχει, με τα προτεινόμενα έργα, η απαιτούμενη επάρκεια χώρου εντός αυτής για τον τελικό ελλιμενισμό του πλοίου σχεδιασμού. Συγκεκριμένα λήφθηκε η παραδοχή ότι ασκούνται δυνάμεις ρυμούλκησης τάξεως 300kN πρώρα και 300kN πρύμνα που είναι εύλογες τιμές για ανάλογα πλοία και σχετικούς ελιγμούς. Η μελέτη, ωστόσο, δεν βασίστηκε στα πραγματικά δεδομένα ελκτικών ικανοτήτων και διαστάσεων των ρυμουλκών και των εξοπλισμών αυτών που ήδη λειτουργούν στον Λιμένα Βασιλικού και δύναται να συμπληρωθεί στο μέλλον σχετικά.

Απεικονίσεις των αποτελεσμάτων για τις δυσμενέστερες περιβαλλοντικές συνθήκες που αναμένεται να προσεγγίσει πλοίο στον Λιμένα παρουσιάζονται παρακάτω:

Πίνακας 0-4 Δυσμενέστερες Περιβαλλοντικές Συνθήκες

		
Άνεμοι: 29kn **Νότιοι** Κύματα: **Ύψος 3.75 m, Περίοδος 7.74 s Νότια**	Άνεμοι: 33kn **Νότιο-Δυτικοί** Κύματα: **Ύψος 2.5 m, Περίοδος 6.63 s Νότιο-Δυτικά**	Άνεμοι: 29kn **Βόρειο-Ανατολικοί** Κύματα: **Αμελητέα**

<u>Συμπεράσματα</u>

- Η παρούσα ανάλυση πλοήγησης και ελιγμών πλοίου μεταφοράς χύδην φορτίου περιλαμβάνει ένα στάδιο προσέγγισης στο δίαυλο του λιμένα Βασιλικού από την ανοικτή θάλασσα με αυτοπρόωση, την δια του διαύλου είσοδο στη λιμενολεκάνη του τερματικού 2 (όπως διαμορφώνεται αυτή με τις προτάσεις της παρούσας μελέτης) επίσης, με αυτοπρόωση, καθώς και τις τελικές ελκτικές κινήσεις με την επενέργεια ρυμουλκών.
- Όλη η διαδικασία αυτοπρόωσης για το εξεταζόμενο πλοίο σχεδιασμού έως το στάδιο εισόδου στη λιμενολεκάνη είναι ασφαλής έως ανέμους 33 κόμβων στις διάφορες διευθύνσεις, με βάση τη διάταξη των προτεινόμενων έργων και δεν παρουσιάζονται αποκλίσεις στην πορεία του εκτός της προδιαγεγραμμένης.
- Ήδη με τις παρούσες αναλύσεις δεν παρουσιάζονται φαινόμενα παράσυρσης και απώλειας της συγκράτησης του πλοίου εκτός των προδιαγεγραμμένων σημείων της υποστηριζόμενης από ρυμουλκά τελικής πορείας του εντός της λιμενολεκάνης, και παραμένει η ασφάλεια του νέου σχεδιασμού. Αυτό που παρουσιάζεται είναι, πριν την οριστική περιστροφή στην τελική θέση ελλιμενισμού, δυσκολία στην ώθηση του πλοίου από τα ρυμουλκά, σε έντονους αντίθετους ανέμους, με συνήθεις διατάξεις έλκουσας λέμβου 300kN πρώρα και ωθούσας λέμβου 300kN πρύμνα. Το ζήτημα, όμως, αντιμετωπίζεται με ταυτόχρονη λειτουργία προπέλας-πηδαλίου σε χαμηλές στροφές, και οπωσδήποτε μπορεί να διευθετηθεί πλήρως με κατανόηση των πραγματικών δυνάμεων που ασκούνται από τις σχετικές υφιστάμενες υποδομές του λιμένα. Εφόσον, επομένως, κρίνεται απαραίτητο, θα πρέπει να διενεργηθούν στο μέλλον εκτενείς αναλύσεις στα τελευταία στάδια ρυμούλκησης με λέμβους προς τη θέση ελλιμενισμού, για συνθήκες ανέμων 33 κόμβων και για την περίπτωση αντιθέτων στην κίνηση των ρυμουλκών ΒΑ ανέμων από 29 κόμβους.
- Σε κάθε περίπτωση άλλα εμπορικά πλοία που ενδεχομένως χρησιμοποιήσουν το Terminal 2 στο μέλλον (πχ γενικού φορτίου ή και ορισμένα σύγχρονα ή μετασκευασμένα χύδην φορτίου) τα οποία διαθέτουν thrusters δεν αναμένεται να αντιμετωπίσουν πρόβλημα ελιγμού και τελικού ελλιμενισμού.
- Λαμβάνοντας υπόψιν όλα τα σενάρια ισχυρών καιρικών φαινομένων και την άριστη ανταπόκριση της προσέγγισης και εισόδου του πλοίου σχεδιασμού στη λιμενολεκάνη χωρίς αποκλίσεις από τα

επιθυμητά όρια του διαύλου προσέγγισης, κρίνεται κατάλληλη η προτεινόμενη επέκταση των λιμενικών έργων για λειτουργία εμπορικού τερματικού στην υποδεδειγμένη θέση και υπό τις προτάσεις επεκτάσεων της παρούσας μελέτης.

1. INTRODUCTION

The Cyprus Ports Authority is planning to extend the Limassol Port - Terminal 2 (Vassilikos) to the east.

The present analyses aim at the evaluation of safety of the selected proposed works, through mathematical simulations of navigational and manoeuvring scenarios through severe weather, which include arrivals - dockings - departures of ships from/to terminal 2. The ship examined corresponds with a Bulk Carrier model which will be one of the principally operating types, for this terminal.

Vassilikos Port is located at the eastern side of Vassiliko Bay. It is currently operated by Vassiliko Cement Works under a concession agreement with the Cyprus Ports Authority for a period of 50 years (until 2033). The port is capable to handle dry and liquid bulk cargoes.

To achieve the present goal, one of the most sophisticated commercial navigation and manoeuvring simulations tools, for both, the marine engineering / operation and coastal design perspectives, has been employed: the software SHIPMA7 developed by MARIN NL/DELTARES [1]. The particular one is chosen due to its large number of specified ship models included, as well as due to its flexibility to analyse the ship's routes through any cruising channel and under complex conditions due to obstacles and environmental loads, simultaneously. Overall, its -internationally celebrated- performance for development of port infrastructures and sea transport strategies lead us towards the employment of this robust solution.

Figure 1-1 Study Area – Satellite view of current situation at Limassol Port – Terminal 2 (Vassilikos)

1.1 Team of Consultants

The team of Engineering Consultants from ROGAN ASSOCIATES S.A. is formed by

Dr. S. Katifeoglou, Naval Engineer (SK)

A. Stamatiadis, Port & Coastal Engineer (AS)

Dr. C. Solomonidis, Port & Coastal Engineer (CS)

1.2 Brief Description of Software Used

Software SHIPMA7 [1] is employed internationally for the design of ports and cruising channels, due to its capability for dynamic simulations of ship courses and manoeuvring through narrow waters with simultaneous robust determination of environmental loading conditions (wind, waves, currents) as well as other natural obstacles. The PIANC [2] regulations, nevertheless, require the employment of mathematical simulations ship navigation and manoeuvring for port design studies when careful approximations of cruising channels are demanded with respect to marine and near-shore traffic conditions and environmental parameters. SHIPMA7 is such a proved simulation tool, however its coupled coastal engineering mathematics/ ship hydrodynamics modeling is more dedicated to mathematical approximations of loads and responses of ships and must not be confused with that of a Bridge Simulator system which is dedicated to general navigation aspects. More analytically, SHIPMA7's capabilities include all parameters that must be taken into consideration for ship-to-port and cruising channel design, as:

- Treatment of each vessel-type's motion restrictions (according to proper hydrostatic-stability-hydrodynamic parameterization).
- Robust determination of shore/coastal infrastructures' outline, including also offshore elements (buoys, jetties, island riffs, anchorages etc.) as well as of the bathymetric information.
- Proper mathematical modelling of environmental loads affecting the vessel's motion.
- Proper approximation of internal forces produced by the ships propulsion/maneuvering system (rudder, propeller, thruster).
- Contribution of forces produced by tugs to the maneuvering of large vessels through cruising channels, etc.

The expected outcome of such simulations can be

- The track & direction of the ship
- Deviations and distances from the desired track
- Timeseries of rudder angles and propeller revolutions (rpm)
- Wind & wave loads, directions, heights applied on the moving ship
- Depth at the center of gravity of the ship
- Current velocities acting on the ship
- Bank suction forces when ship approaches docking
- Tug forces

The aforementioned quantities can provide insights both to the ship's performance and produced work during handling, navigation and manoeuvring as well as to the existing infrastructure's capability to host any particular ship or to any need for further modifications. Furthermore, the combination of ship routes scenarios under the scope of safety and operability for the local marine traffic situation, can be also derived through the particular simulation methodology and, also, reveal any further need of improvisation of the existing infrastructures.

The determination of vessel motion and track from the simulator is based on an Autopilot assumption, which corresponds with the most severe case of navigation in narrow channels with several obstacles, thus, engineering-wise, it can properly serve the present scope, among all port design analysis aspects.

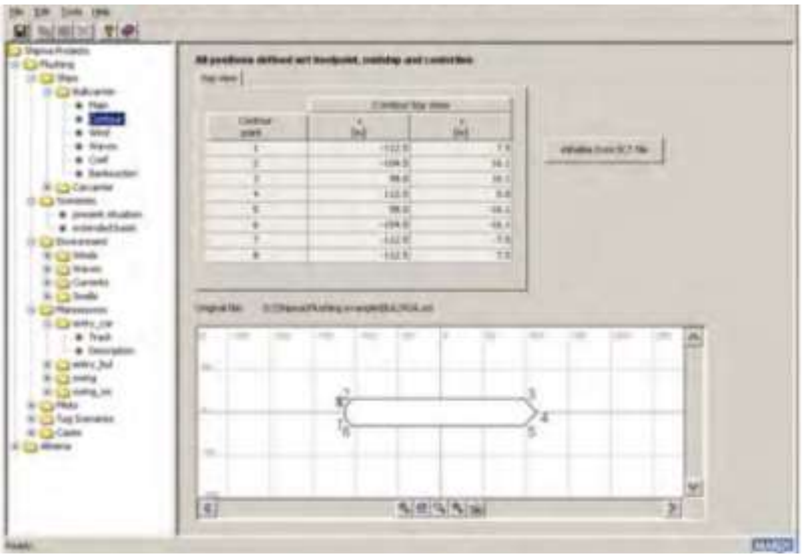


Figure 1-2 Structure of SHIPMA7 software's modules and assignment of input values

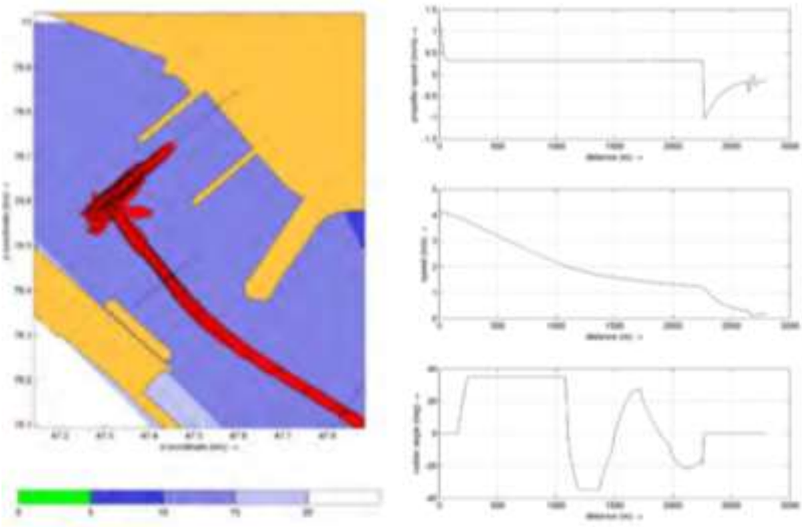


Figure 1-3 GUI including map view of simulation field/track plot and data plot

2. SIMULATION SETUP

2.1 MATHEMATICAL BACKGROUND OF VESSEL NAVIGATION SIMULATION

In brief, SHIPMA software employs the 4DOF forces-moments equilibrium equations according to the Abkowitz model [3]:

$$m[\dot{u} - rv - x_g r^2] = X$$
$$m[\dot{v} - ru - x_g \dot{r}] = Y$$
$$I_x \dot{p} = K$$
$$I_z \dot{r} + m x_g(\dot{v} + ru) = N$$

Where,

- Linear velocity: U=(u,v,w),
- Angular velocity: Ω=(p,q,r)
- p: Inclination from the horizontal axis (trim), r: rotation around the vertical axis
- m: ship’s mass,
- Ix, Iz 2nd moments of inertia with respect to axes Ox, Oz
- X, Y elements corresponding with directions x, y of the body-centric coordinate system of the ship, and represent the total inertial, hydrodynamic and external forces as vector elements
- K, N corresponding vector elements for the moments with respect to the same body-centric system x, y.

The internal forces-moments of hydrodynamic damping and inertia, for the velocity and acceleration, respectively are given with the following vectors:

$$F = F_i[X_i(\dot{u},\dot{v},\dot{r},\dot{p}), Y_i(\dot{u},\dot{v},\dot{r},\dot{p})] + F_0[X_0(\dot{u},\dot{v},\dot{r},\dot{p}), Y_0(\dot{u},\dot{v},\dot{r},\dot{p})],$$
$$M = M_i[K_i(\dot{u},\dot{v},\dot{r},\dot{p}), N_i(\dot{u},\dot{v},\dot{r},\dot{p})] + M_0[K_0(\dot{u},\dot{v},\dot{r},\dot{p}), N_0(\dot{u},\dot{v},\dot{r},\dot{p})],$$

$$F_0 = F_{OH} + F_{OR} + F_{OP} + F_{OT} + F_{OA} + F_{OW} + F_{OC} + F_{int},$$

$$M_0 = M_{OH} + M_{OR} + M_{OP} + M_{OT} + M_{OA} + M_{OW} + M_{OC} + M_{int},$$

Where indicator for the hull: H, of steer-rudder: R, of propeller: P, of Thruster: T, of wind: A, of Wave: w, of current: C and of interaction of the afore: int.

The hydrodynamic coefficients for the ship are introduced as constant factors and have been derived, for each ship model, by previous, experimental wave tank campaigns and CFD simulations.

The loads acting on ship, according to the afore formulation, are listed as:

- Propeller/Thruster forces
- Moment and Thrust coefficients for several models
- Hydro propulsion
- Steer/Rudder Forces
- Tug forces

- Wind loads
- Current loads
- Wave loads through spectra
    - Pierson-Moskowitz
    - JONSWAP

2.2 Determination of Simulation Domain

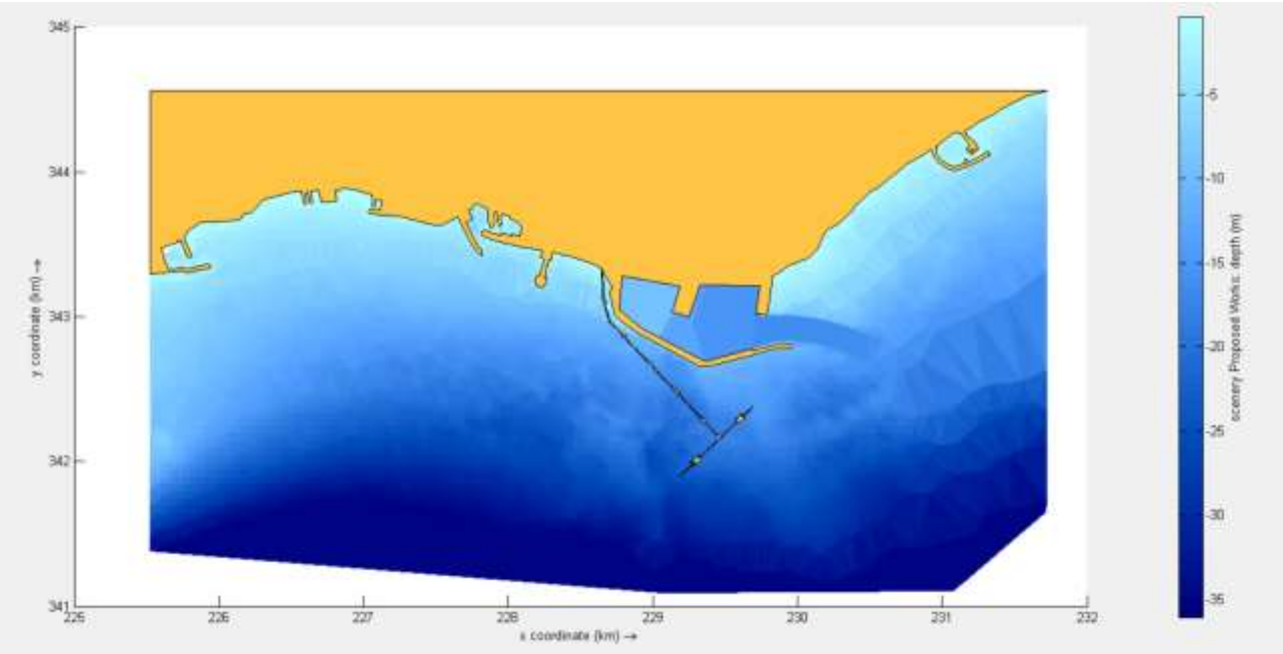


Figure 2-1 Contours of bathymetry and outline of coastal infrastructure of Vassilikos Port including the present study's proposed works

In the above figure the detailed bathymetry contours are depicted, as introduced in the software's computational domain with nodal values on a 10m X 10m grid. The whole domain extent is approximately 3km East and 3 km West of the existing port infrastructure of Terminal 2. However, the outline of coastal facilities also includes the nearby installations (i.e. VTTV Jetty) as well as the outlines of the proposed, with the present, works for expansion of Vassilikos Terminal 2, taking also into account the sea bottom reformation for the proposed, with the present, navigation (approach) channel of depth overall 16.5 m, as measured from the lower low water according to local tidal measurements.

2.3 Determination of Environmental Conditions: Wind, Waves, Currents

2.3.1 Wind data

Observed wind data from the study area were not available for this study. A comprehensive approach to enable describing a representative wind climate, as an input for the navigation simulation, has been followed.

A modelled wind climate for the area of Zygi is available from the meteoblue database, which gives insight for mean annual wind speeds and directions, based on 30-years of hourly weather model simulations. Figure 2-2 shows the days per month of wind speed distribution in the Beaufort scale.

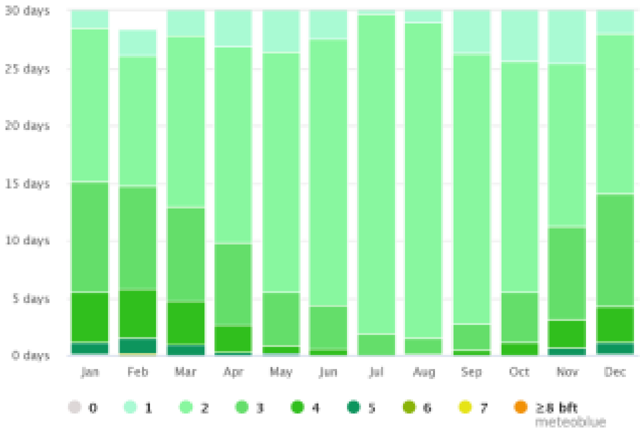


Figure 2-2 Wind speeds per month at Zygi (modelled)

The respective wind rose for the wind climate of the area of Zygi is shown in Figure 2-3.

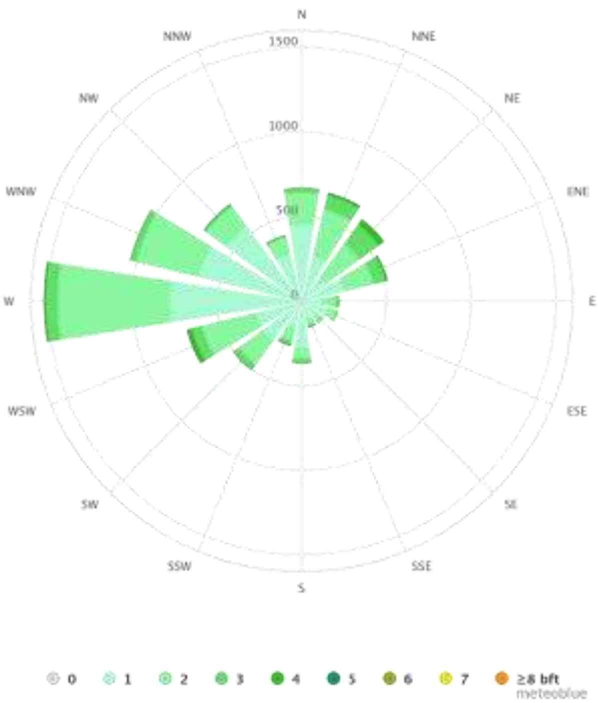


Figure 2-3 Annual wind rose at Zygi (modelled)

In order to validate the modelled wind climate derived from the meteoblue model, wind data collected at Larnaca Airport was used. Table 2-1 presents the annual wind frequency at Larnaca Airport for the time period between 1996 and 2012. In the aforementioned table, wind speed is classified in bins of 2.5 m/s and wind direction in sections of 22.5 degrees.

Table 2-1 Annual wind frequency at Larnaca Airport (1996 – 2012)

	Total	**3.2**	**3.3**	**3.1**	**2.0**	**3.6**	**2.6**	**1.9**	**3.5**	**10.2**	**15.3**	**6.5**	**3.3**	**5.5**	**12.9**	**14.6**	**9.1**	**100**
Wind Speed (m/s)	>17.5																	
	15.0 - 17.5										0.02							**0.02**
	12.5 - 15.0			0.01						0.02	0.2	0.06	0.01					**0.3**
	10.0 - 12.5	0.04	0.08	0.06		0.01				0.12	1.26	0.24	0.04		0.02	0.03	0.6	**2.5**
	7.5 - 10.0	0.2	0.36	0.31	0.08	0.1	0.02	0.01	0.05	0.8	3.8	0.66	0.11	0.04	0.11	0.17	0.25	**7.07**
	5.0 - 75	0.89	1.08	0.97	0.36	0.51	0.28	0.32	0.95	4.92	4.73	1.48	0.29	0.21	0.45	1.03	1.3	**19.77**
	2.5 - 5.0	1.42	1.29	1.25	0.93	1.84	1.79	1.24	2.01	3.23	3.76	2.54	1.2	1.93	7.55	8.39	4.66	**45.03**
	0 - 2.5	0.63	0.46	0.52	0.66	1.11	0.49	0.37	0.45	1.07	1.51	1.56	1.61	3.33	4.73	4.98	2.25	**25.73**
Direction (°)		0 - 22.5	22.5 - 45	45 - 67.5	67.5 -90	90 -112.5	112.5 - 135	135 -157.5	157.5 -180	180 - 202.5	202.5 -225	225 - 247.5	247.5 -270	270 - 292.5	292.5 - 315	315 - 337.5	337.5 - 360	**Total**

Furthermore, the data above have been statistically analyzed to generate a weighted arithmetic mean and a max wind speed value correlated to the eight (8) main directions. The results are shown in Table 2-2.

Table 2-2 Statistical analysis on the annual wind frequency at Larnaca Airport

	Angle (°N)	Weighted Mean m/s	Max m/s
N	0	5.67	12.5
NE	45	6.12	15
E	90	4.76	12.5
SE	135	4.89	10
S	180	6.18	15
SW	225	7.02	17.5
W	270	3.86	15
NW	315	4.31	12.5

2.3.2 Wave data

Taking into account the orientation of Vassilikos Port, the waves affecting the new facility have the following incident directions:

- Southwest
- South
- Northeast
- East

In order to determine the wave conditions of the study area, the available wave data from the study "Coastal Zone Management for Cyprus: Nearshore Wave Climate Analysis by Xenia Loizidou and John Dekker (Delft Hydraulics), March 1994" were used. The table below shows the annual probabilities of wave occurrence for specific ranges of wave heights and specific directions in the -20m depth contour.

Observed Wave Height (m)	Wave Direction (deg.N)												
	-15.: 15.	15.: 45.	45.: 75.	75.: 105.	105.: 135.	135.: 165.	165.: 195.	195.: 225.	225.: 255.	255.: 285.	285.: 315.	315.: 345.	Total
< .25	3.19	2.30	2.97	2.78	.88	.60	1.11	2.09	9.65	8.30	6.78	5.99	46.65
.25: .75	.29	.51	2.25	3.75	1.08	1.05	1.00	3.49	15.03	5.97	2.32	.58	37.32
.75: 1.25	.	.	.18	1.86	.61	.69	.76	1.95	5.15	.28	.06	.	11.54
1.25: 1.75	.	.	.02	.48	.27	.21	.12	.80	1.13	.	.	.	3.03
1.75: 2.25	.	.	.	.17	.10	.03	.11	.31	.27	.	.	.	.99
2.25: 2.75	.	.	.	.04	.03	.04	.03	.15	.06	.	.	.	.36
2.75: 3.25	.	.	.	.01	.	.	.01	.04	.01	.	.	.	.08
3.25: 3.75	.	.	.	.	.	.	.01	.	.	.	.	.	.02
3.75: 4.25	.	.	.	.	.	.	.	.01	.	.	.	.	.01
4.25: 4.75	.	.	.	.	.	.	.	.01	.	.	.	.	.01
4.75: 5.75	.	.	.	.	.	.	.	.01	.	.	.	.	.01
5.75: 6.75	.	.	.	.	.	.	.	.	.	.	.	.	.
6.75: 7.75	.	.	.	.	.	.	.	.	.	.	.	.	.
7.75: 8.75	.	.	.	.	.	.	.	.	.	.	.	.	.
8.75: 9.75	.	.	.	.	.	.	.	.	.	.	.	.	.
9.75:10.75	.	.	.	.	.	.	.	.	.	.	.	.	.
10.75:12.75	.	.	.	.	.	.	.	.	.	.	.	.	.
12.75:14.75	.	.	.	.	.	.	.	.	.	.	.	.	.
> 14.75	.	.	.	.	.	.	.	.	.	.	.	.	.
Total	3.48	2.81	5.41	9.09	2.96	2.62	3.16	8.87	31.32	14.56	9.16	6.58	100.00

Figure 2-4 Annual wave frequency for offshore waves at Vassilikos Bay

Taking into account the above data and the directions that can cause disturbance within the port, the table below presents the wave characteristics given as input to the numerical simulation model. It is noted here that a conservative approach is applied for the selection of wave heights as the upper limit is selected each time from the ranges of heights categorised by the occurring waves (e.g. from the range 4.75-5.75, a wave height of 1.75m is selected for simulation).

Table 2-3. Extreme wave events from predominant directions

	Hs (m)	Tp (sec)	Dir (°)
1	3.25	7.21	90
2	2.75	6.63	135
3	3.75	7.74	180
4	5.75	9.59	210
5	2.75	6.63	210
6	3.25	7.21	240

2.3.3 Sea currents data

Tidal activity in the coastal ports and in Vassilikos Bay is generally limited. The maximum peak range is from 0.3 to 0.4 m. The shoreline can be described as microtidal, with very few tides having a range greater than 0.5 m. The coastal currents in Vassilikos Bay are roughly parallel to the coast. During winter, the main direction of the pathway varies between east and west, with the strongest currents arriving from the east with a maximum speed of 0.45 m/s, while during summer the currents travel mainly from west to east and reach speeds of 0.21 m/s (Figure 2-5).

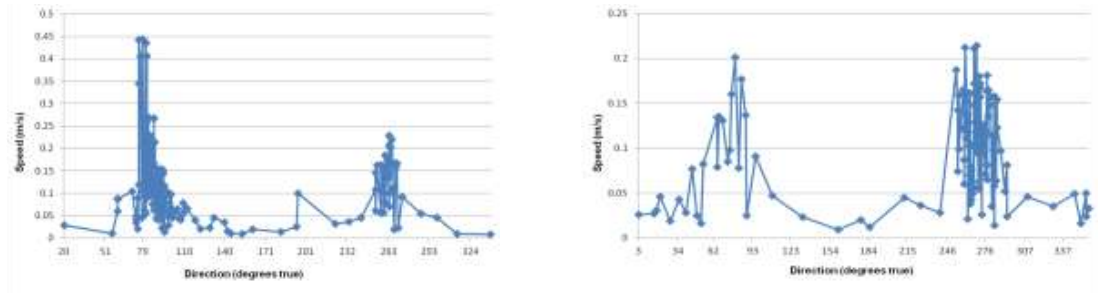


Figure 2-5 Current speed and direction during (a) winter season (Dec 2010 – January 2011), (b) summer season (Jube 2010) at Vassiliko Bay

2.3.4 Simulation environmental cases

Based on the above analysis and for the purpose of this navigation study the following cases have been specified for the simulations:

Table 2-4 Simulation environmental cases

Cases	Direction	Wind speed (kn)	Wave Height (m)	Wave Period (s)	Current Speed (kn)
1	**S** (180° N)	29	3.75	7.74	0.41
2	**SW** (225° N)	33	2.5	6.63	0.41
3	**NE** (45° N)	29	~ 0	~ 0	0.8745

It is noted that the above combination of weather conditions in each case, where wind, waves and currents are heading towards the exact same direction is considered a conservative approach. Also, the above wind and wave events are assumed to be extreme values, at which the design vessel could succeed in entering the port, and are not correlated to each other as an open sea wind induced wave regime.

2.4 Characteristics of Ship Model

The ship investigated for arrival-docking to the terminal 2 is a Bulk Carrier type of approx. 250m Loa and has the following characteristics:

Table 2-5 Ship Characteristics

Geometry & Propulsion Parameters			
L_{OA}	245.3 m	**Max. velocity changing RPM**	10.924 kn
Beam	32.2 m	**Max propeller acceleration**	0.045 $1/s^2$
Draft	13 m	**Max rudder rate**	3 $^{o}/s$
Mass	$8x10^7$ kg	**Rudder/propeller distance From COG**	-116.8 m
Dist. Mom of inertia & COG	0	**Frontal windage**	740 m^2
Max manoeuvering speed	11.663kn	**Lateral windage**	2389 m^2
Max rudder angle	35^o		
Max. revolutions ahead	88.02 rpm		
Max. revolutions astern	-88.02 rpm		

Full details of the ship's characteristics are given in the Appendix.

2.5 Vessel Track

The approach maneuvers include an initial stage with a line of sailing heading from South to North (i.e. from the open sea to the port), then a stage of changing course - turning the ship with a large radius in order to orientate it to an entry position in the navigation channel of the port, the crossing of the channel until it is positioned in front of the port basin of terminal 2 and the final stage of towing the ship within the basin to its berthing position by means of rotational movements imposed on the ship by the tugs, as shown below.

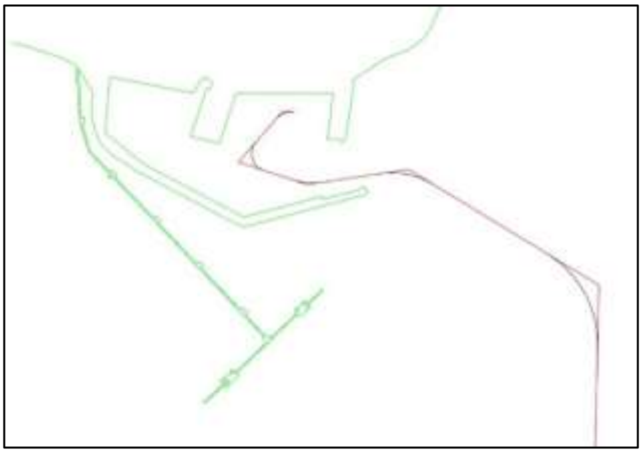


Figure 2-6 Design vessel track

X	Y	Radius (m)
230838.699	341077.917	0.0
230869.158	342399.457	461.35
230059.436	342891.816	378.75
229333.051	342922.958	75.0
229520.711	343137.838	89.41
229600.928	343137.838	0.0

Figure 2-7 Track Description

The layout of the approach channel was chosen to form a slight curvature, compared to a straight-line layout at the entrance of the port and towards the seabed level of the channel design depth. This design was chosen as the optimum technical, economic and environmental solution to avoid extensive dredging and ensure the least possible impact on Neptune meadows (Posidonia oceanica) found in the area. In order to avoid deviation of the ship's course from the approach channel, it is recommended that appropriate signaling is installed at its boundaries.

As the ship approaches terminal 2, its axial and transverse speed components should be in full control so that the forces exerted by the environment (winds - waves - currents) are counterbalanced by the action of the forces exerted by the maneuvering means (either devices, e.g. thrusters or towing boats). Under this basic principle the different navigation and maneuvering simulation scenarios were parameterized.

The details of the maneuver sections that were implemented for each case are shown at the respective tables below:

Table 2-6 Vessel maneuver description for Case 1

Start (m)	Offset (deg)	V (kn)	Pilot
0.0	0.0	6.5	voyage
800.0	0.0	5.0	voyage
1100.0	0.0	4.0	voyage
1321.89	0.0	2.0	voyage
1600.0	0.0	2.0	maneuvers in port
2100.0	0.0	1.0	maneuvers in port
2296.55	0.0	0.9	maneuvers in port
2400.0	0.0	0.8	maneuvers in port
2650.0	0.0	0.6	maneuvers in port
2700.0	0.0	0.5	maneuvers in port
2734.08	0.0	0.4	maneuvers in port
2870.0	10.0	0.3	tug only
2900.0	25.0	0.25	tug only
2930.0	45.0	0.25	tug only
2969.0	60.0	0.2	tug only
2990.0	90.0	0.2	tug only
3010.0	120.0	0.2	tug only
3030.0	165.0	0.2	tug only
3050.0	170.0	0.2	tug only

3080.0	180.0	0.2	tug only

Table 2-7 Vessel maneuver description for Case 2

Start (m)	Offset (deg)	V (kn)	Pilot
0.0	0.0	6.5	voyage
800.0	0.0	5.0	voyage
1100.0	0.0	4.0	voyage
1321.89	0.0	2.0	voyage
1600.0	0.0	2.0	maneuvers in port
2100.0	0.0	1.0	maneuvers in port
2296.55	0.0	0.9	maneuvers in port
2400.0	0.0	0.8	maneuvers in port
2650.0	0.0	0.6	maneuvers in port
2700.0	0.0	0.5	maneuvers in port
2734.08	25.0	0.4	maneuvers in port
2868.0	50.0	0.3	tug only
2978.0	90.0	0.2	tug only
3028.0	120.0	0.1	tug only
3128.0	150.0	0.2	tug only

Table 2-8 Vessel maneuver description for Case 3

Start (m)	Offset (deg)	V (kn)	Pilot
0.0	0.0	6.5	voyage
800.0	0.0	5.0	voyage
1100.0	0.0	4.0	voyage
1321.89	0.0	2.0	voyage
1600.0	0.0	2.0	maneuvers in port
2100.0	0.0	1.0	maneuvers in port
2296.55	0.0	0.9	maneuvers in port
2400.0	0.0	0.8	maneuvers in port
2650.0	0.0	0.6	maneuvers in port
2700.0	0.0	0.5	maneuvers in port
2734.08	25.0	0.4	tug only
2868.0	50.0	0.4	tug only
2978.0	90.0	0.4	tug only
3028.0	120	0.4	tug only

3078.0	135.0	0.4	tug only
3128.0	150.0	0.4	tug only

3. SIMULATION OF NAVIGATION & MANEUVERING INSIDE PORT BASIN

3.1 Principal Considerations for Examined Scenarios

The main principal through which the several reported herein scenarios of navigation simulations, was the capability for safe approach – channel entry and maneuvers-to-docking for the design Bulk Carrier vessel model towards Limassol Port and, in particular through the Port Basin of the proposed expansion of Vassilikos Port, under the action of the most severe meteorological conditions of the territory, as the latter ones were derived from the previous Metocean Analysis.

Frequently, when marine vessels experience difficulties on their self-propulsion & maneuvering systems' performance (thrusters/propellers/rudders) or they are of older builds/or for any other technical or economical reason, that they do not include modern-sophisticated standalone maneuvering devices, through narrow fairways like the one of Vassilikos, the assistance of a small tug fleet is required for the particular maneuvers.

In Vassilikos Port there is presence of such tugboats of the required operational capability for assistance of large vessels to dock. Thus, with SHIPMA software it was possible to develop simulation models which were close to reality, regarding the examined vessel's course, with a first stage of self-propulsion along the approach track, the passage through the navigation channel and the entry in the Terminal 2 basin and a second-final stage of tug-assisted maneuvers within the basin through application of pushing-pulling forces along the vessel, which would represent the tug action.

3.2 RESULTS

In the following figures, one can view the several stages of the aforementioned navigation and maneuvering scenarios according to the solution of SHIPMA7 software. Below each figure, some important remarks are highlighted.

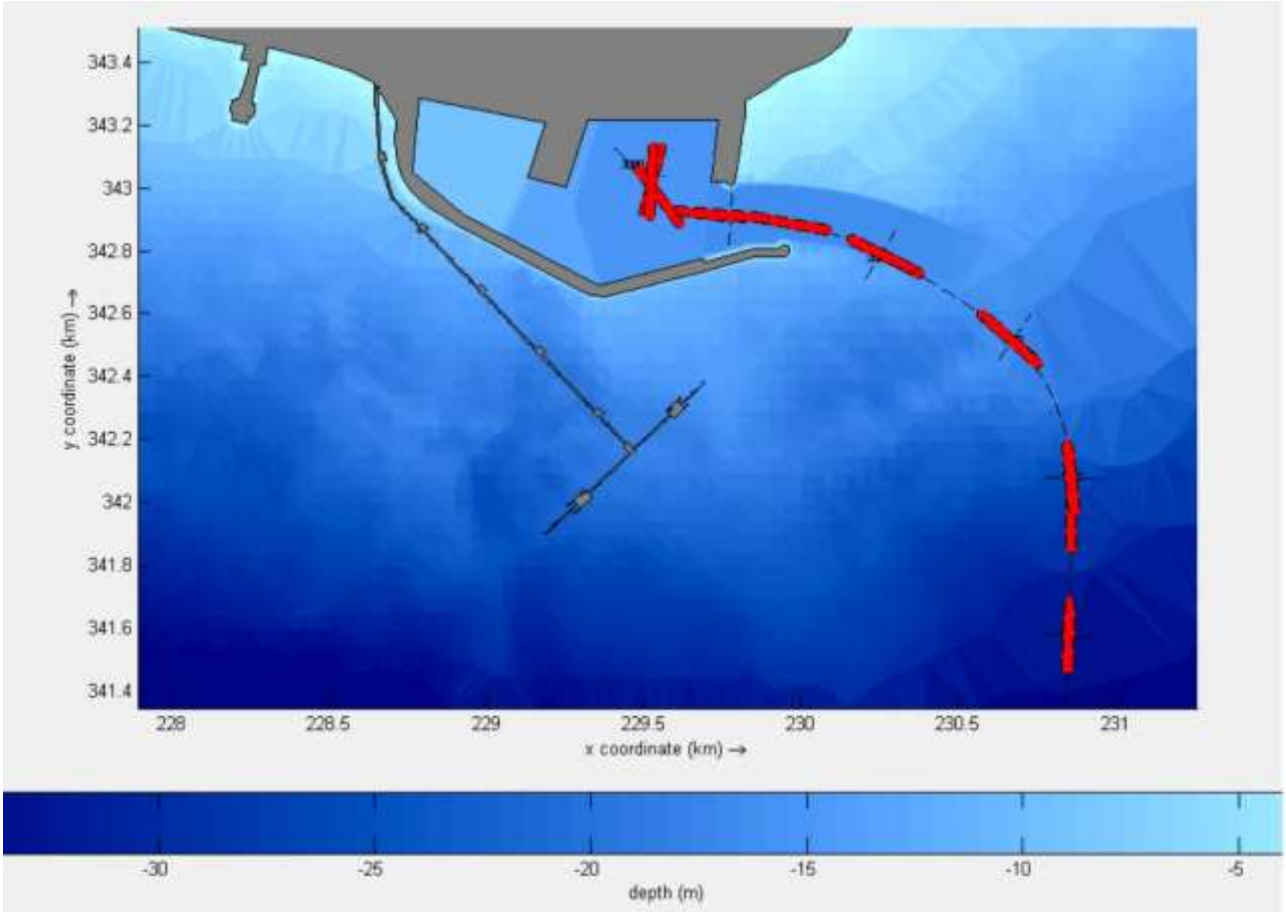


Figure 3-1 Self-navigation for approach – entry and passage through the channel and final, tug-assisted maneuvers upon docking

Wind: 29kn S (180^o N)

Waves: H = 3.75 m, T = 7.74, S (180^o N)

Remark: Coincidence of desired with realized track

Comment: Successful arrival and docking under 29 knots S winds weather.

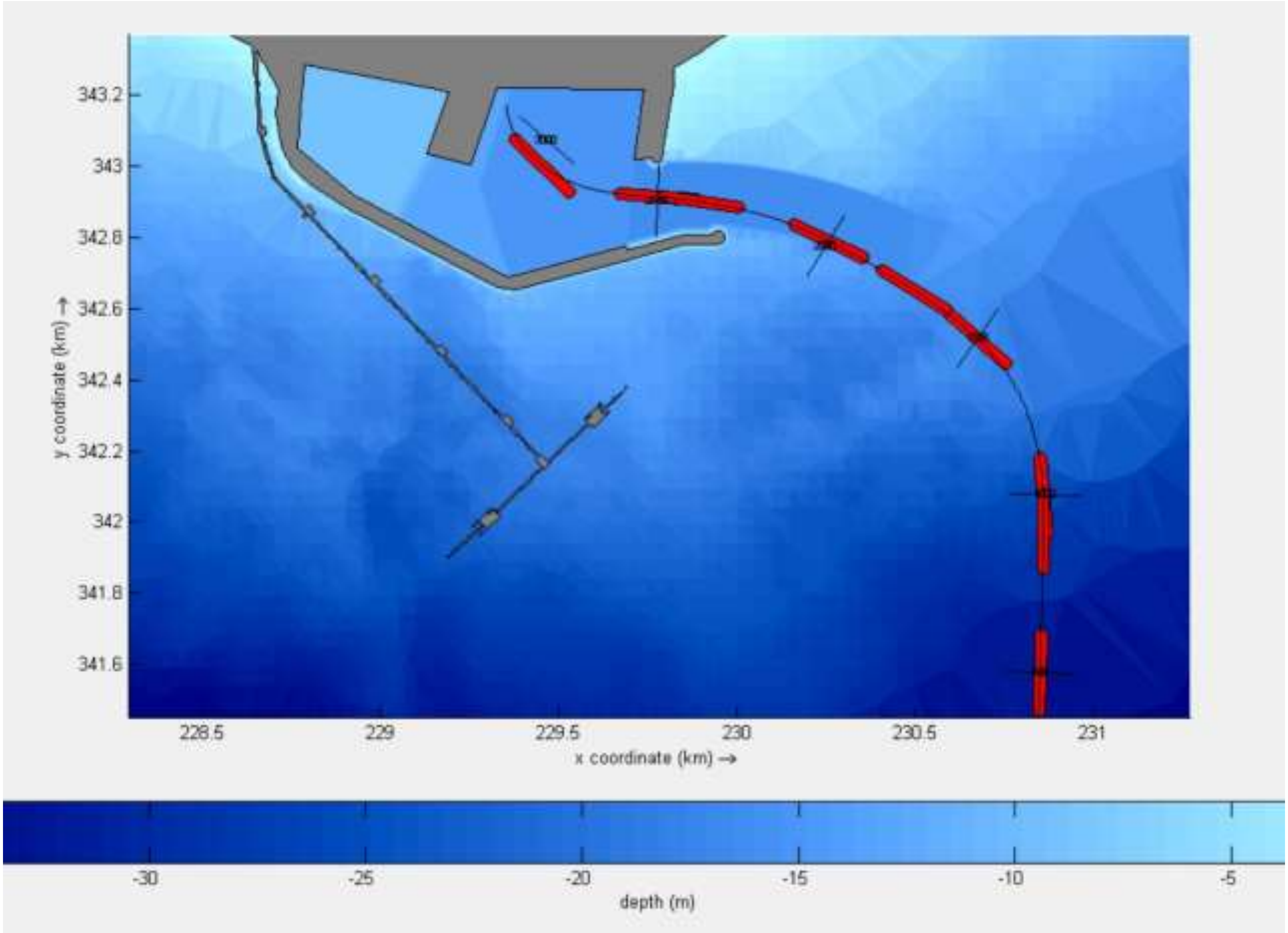


Figure 3-2 Self-navigation for approach – entry and passage through the channel and final, tug-assisted maneuvers upon docking

Wind: 33kn SW (225^o N)

Waves: H = 2.5 m, T = 6.63 s, SW (225^o N)

Remark: Coincidence of desired with realized track

Comment: Successful arrival in the basin even under SW 33 knots winds, however, final docking stage with the assistance of tugs presents larger displacement due to stronger winds, and can be achieved under special treatment. The analysis can be repeated with application of the real operating tug bollard pull loads, which are already operating in the port. In any case, no severe track inclination has been reported and the safe approach and the spatial capacity of the proposed basin to host the design vessel, are obvious.

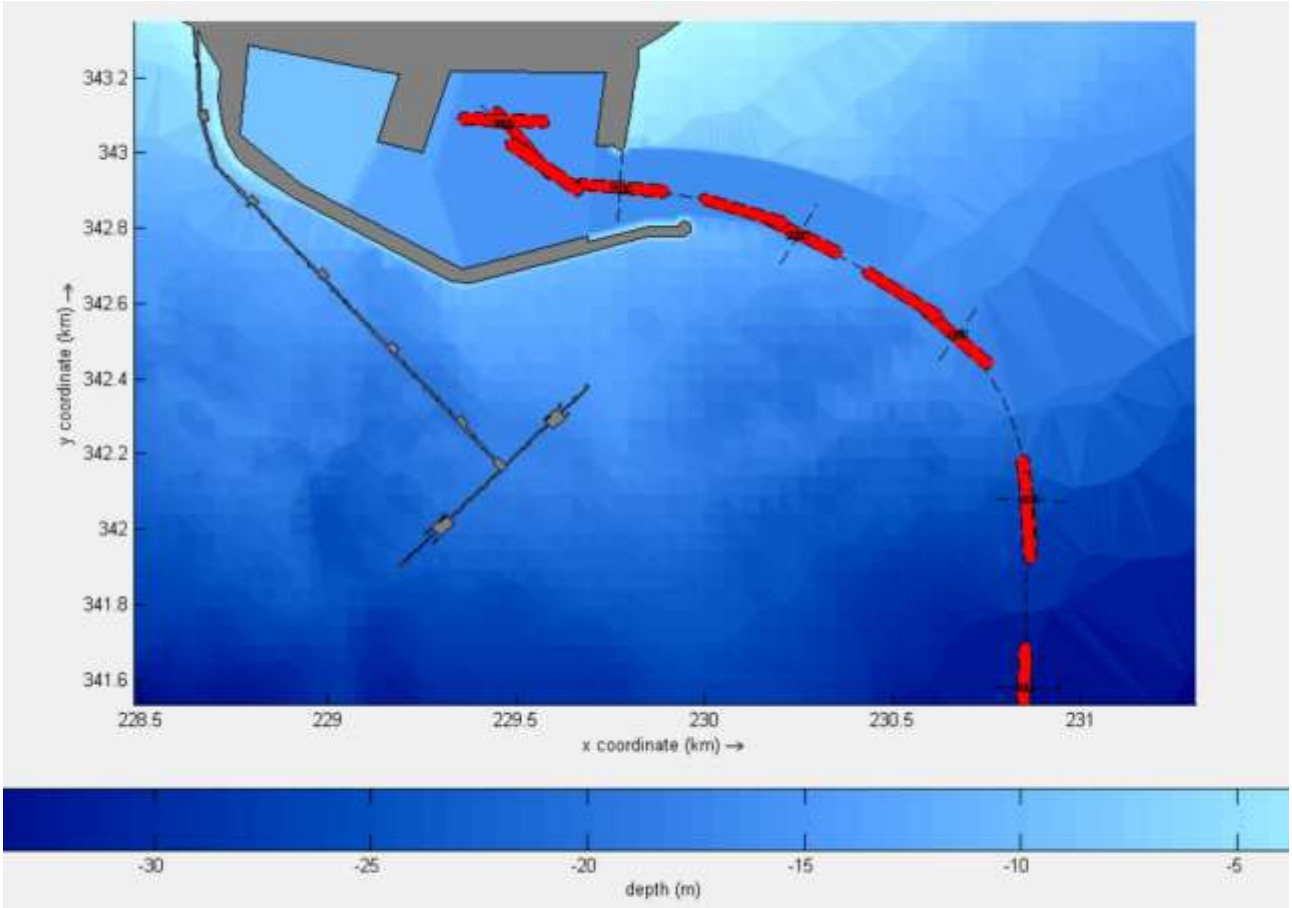


Figure 3-3 Self-navigation for approach – entry and passage through the channel and final, tug-assisted maneuvers upon docking

Winds: 29kn NE (45^o N)

Waves: Negligible wave loads due to small fetch length.

Remark: Coincidence of desired with realized track.

Comment: Successful arrival in the basin even under 29 knots NE winds, however alike **Figure 3-2**, *the final tug-assisted docking maneuver, also receives strong wind resistance, as opposed to the tugboat's efforts. Similarly, the analysis can be repeated with application of the actual, present bollard pull capacities, when submitted to the consultants. Still, the safe approach and entry into the basin of the self-navigated ship, without any collision with the rest infrastructure and within track limits, are obvious, even through opposite weather conditions. The analysis for the particular weather scenario is repeated once more, for hybrid tug-rudder/propeller maneuver with the following result.*

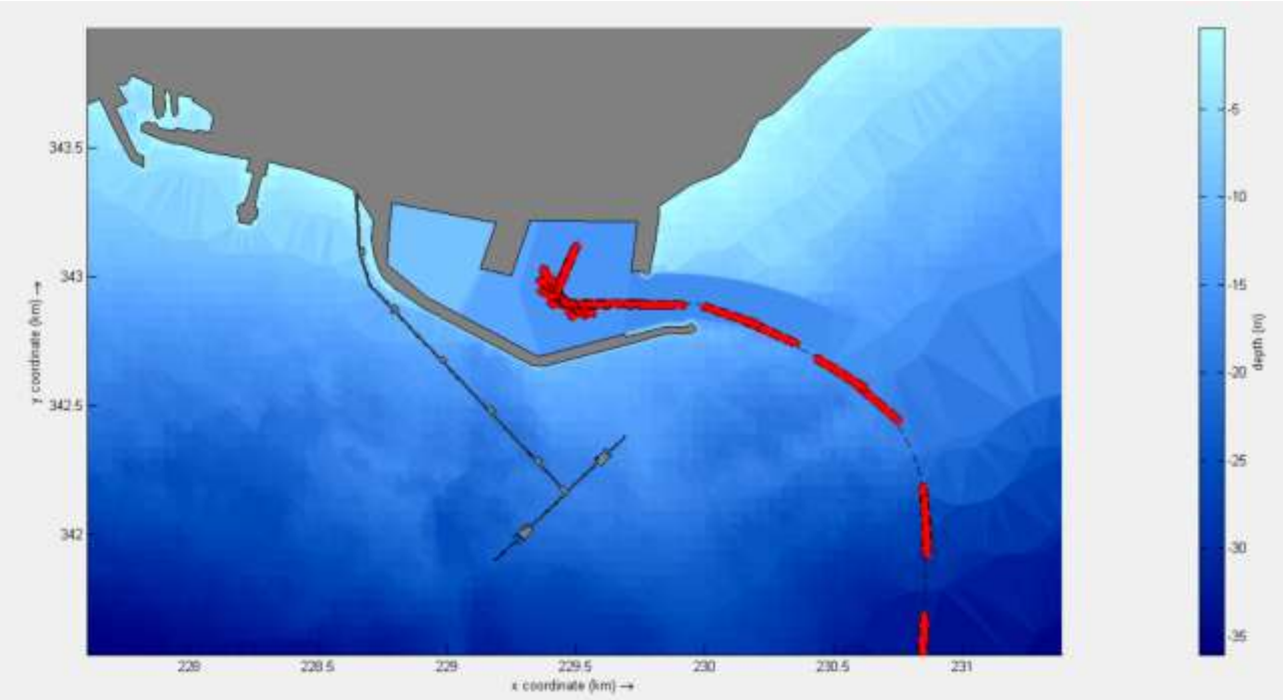


Figure 3-4 Self-navigation for approach – entry and passage through the channel and final, coupled tug & ship rudder-assisted maneuvers upon docking

Winds: 29kn NE (45^o N)

Waves: Negligible wave loads due to small fetch length

Remark: Coincidence of desired with realized track

Comment: Successful arrival in the basin under 29 knots NE winds, and, contrary to **Figure 3-2** *&* **Figure 3-3***, the final tug-assisted docking maneuver, which in the present simulation was assisted also with careful propeller/rudder piloting, eliminates the strong wind resistance and performs better maneuver upon docking.*

The above results highlight the efficacy of the proposed modifications of Vassilikos terminal 2 for safe vessel approaches and maneuvers within the terminal's basin of the desired Bulk Carrier sizes under normal operation conditions, implying Sea states up to 33 knots. In any case, the port already operates a tugboat fleet with the required bollard pull capacities to take hold of the docking maneuvers of large vessels of confined maneuverability. The present simulations included modeling of the action of tugboats at the final-upon-docking stages of the overall vessel's tracks, by introducing hypothetical tug forces from similar facilities and operations, while the actual specifications were not known to the consultants. It was observed that, with the proposed works, the required space for approach and maneuvers-to-dock is ensured.

In particular, it was assumed that towing forces of 300kN fore and 300kN aft are applied, which are reasonable values for similar ships and relative maneuvers. The study, however, was not based on the actual data of towing capacities and dimensions of the tugs and their equipment already operating in Vassilikos Port and may be supplemented in the future in this respect.

In the following figures one can view quantities representing the performance of the ship's propulsion system, which can be very useful for the real ship's decision taking – say, if limit states were to be reached – as well as for the port designer's decision taking (for improving the design of channels which may require more excessive ship performances) as well as of tug loads, during the complete simulation (voyage) time. Such evidence can be useful for further-extended analyses for detailed navigation/maneuvering/tug-assistance plans for all port operations parts.

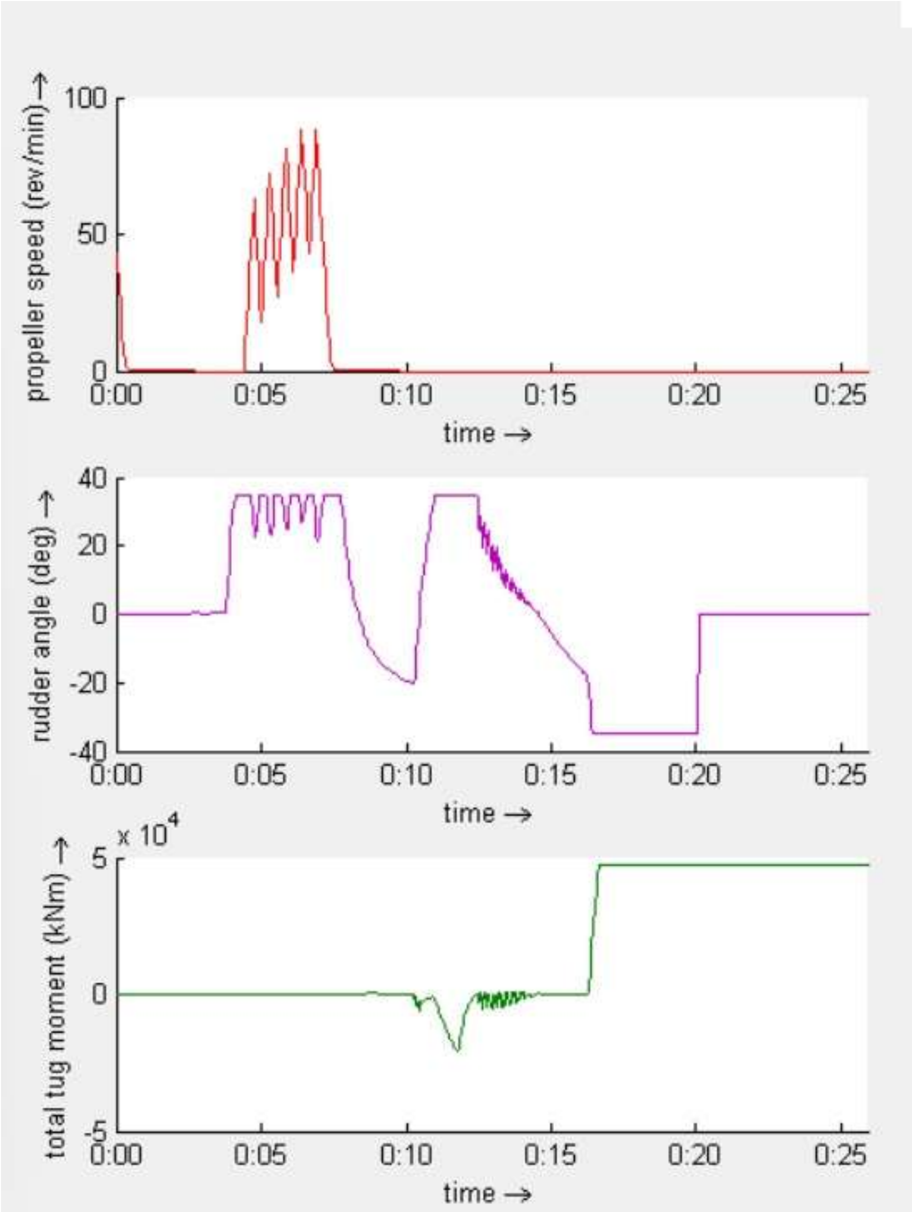


Figure 3-5 Self-propulsion values and tug loads-upon-docking

Wind: 29kn S (180^o N)

Waves: H = 3.75 m, T = 7.74 s, (180^o N)

Remark: Propeller revolutions and rudder angles are within specified safety limits and the vessel decelerates smoothly upon docking. The applied tug load upon docking is steady.

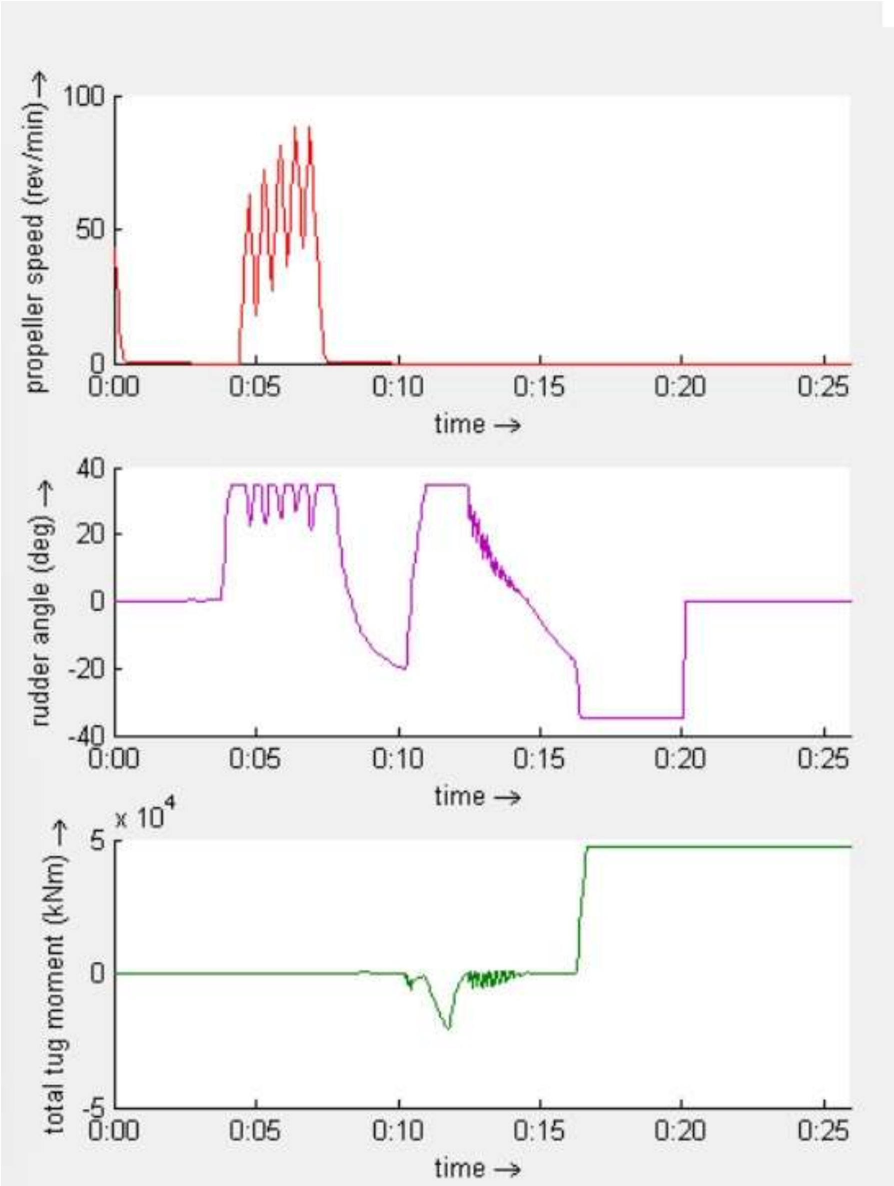


Figure 3-6 Self-propulsion values and tug loads-upon-docking

Winds: 33kn SW (225^o N)

Waves: H = 2.5 m, T = 6.63 s, SW (225^o N)

Remark: Propeller revolutions and rudder angles are within specified safety limits and the vessel decelerates smoothly upon docking. The applied tug load upon docking is steady.

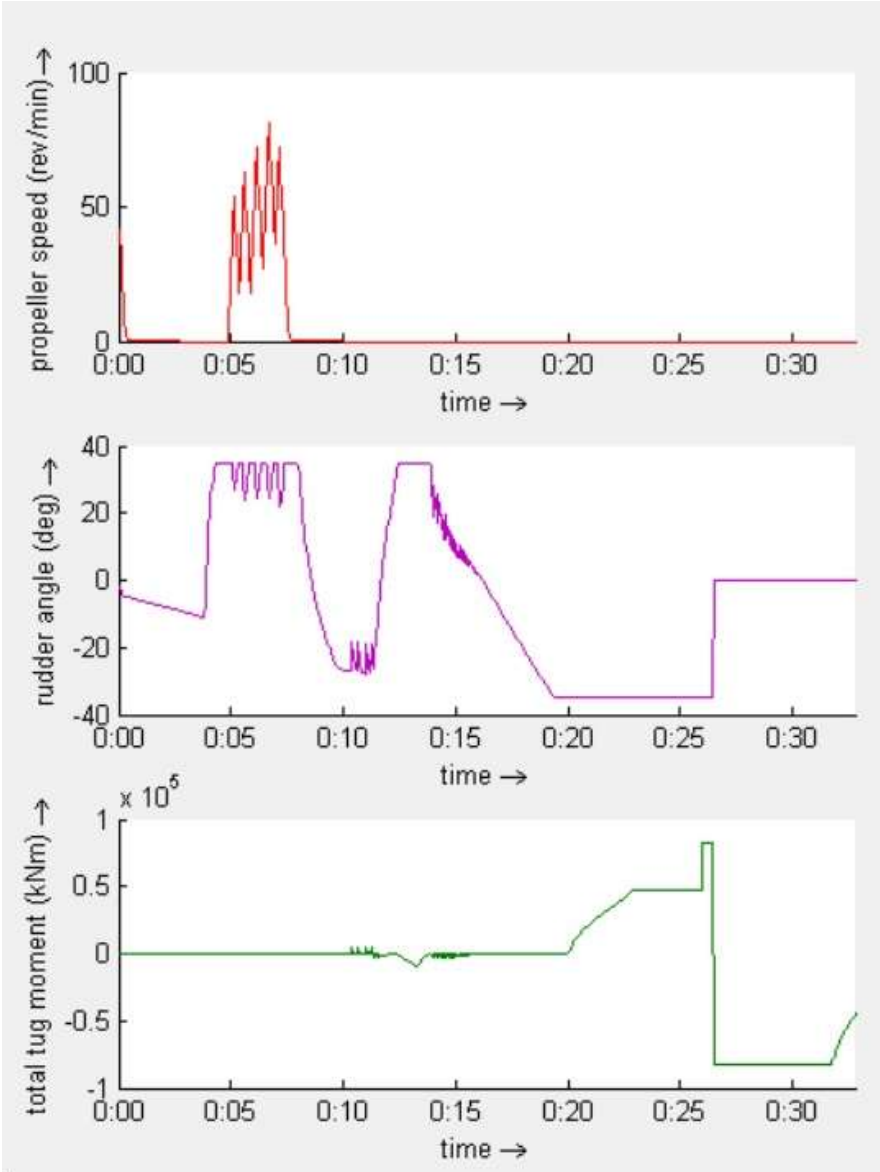


Figure 3-7 Self-propulsion values and tug loads-upon-docking

Winds: 29kn NE (45^o N)

Waves: Negligible.

Remark: Propeller revolutions and rudder angles are within specified safety limits and the vessel decelerates smoothly upon docking. The applied tug load upon docking, however, presents fluctuation and demands higher values, contrary to the previous cases, due to opposed winds simultaneous to the ship's rotation.

4. CONCLUSIONS

- The present navigation and maneuvering simulations for the design bulk carrier includes a self-propulsion entry, from offshore - to and through the port channel - to the port basin and the final tug-assisted maneuvers of the ship upon docking.
- The whole self-propulsion passage of the ship until entry in the protected Port's basin has been proved to be safe and always confronting with the desired course, up to 33 knots winds acting on site and associated sea states (according to any direction/duration event), with regard to the general arrangement of the proposed port expansion works.
- Within the context of the previous point, the present analyses also do not produce significant ship drifting motions and collision within shallow waters beyond the proposed bathymetry reformation and the design ship always remains on track.
- The tug-assisted, final maneuvers upon docking, under current hypothetical contributions of bollard-pull loads and directions, have in general revealed the spatial and weather capability of the proposed port expansion. However, the tug-assisted maneuvering analyses are highly nonlinear-extensive simulations and require real values and maneuverability parameters of the available tugboats operating in real life, which can be utilized in future detailed studies, if required by the Client.
- In some cases, before the final turn to the final berthing position, the only-tug-assisted maneuvering solutions depicted some difficulty to perform the rotational (yaw) motion in strong headwinds. The issue, however, is addressed with simultaneous low-rpm propeller-rudder operation and tug pull, and can certainly be fully resolved with an understanding of the actual forces exerted by the relevant existing port infrastructure. Therefore, if deemed necessary, extensive analyses, exclusively for the tug scenarios, could be carried out in the future (on the final stages of towing and for wind conditions of 33 knots and for the case of NE winds of 29 knots opposing the movement of the tugs).
- Taking into account the good performance through all intense weather scenarios -which are conservative assumptions that do not correspond with regular operations on terminal 2- of the present and throughout the whole ship's cruise - towards the basin of terminal-, the present navigation simulation campaign has highlighted the efficacy of the proposed herein port expansion.

REFERENCES

[1] **https://www.marin.nl/en/facilities-and-tools/software/shipma**

[2] PIANC-IAPH Working Group II-30, APPROACH CHANNELS; “A Guide for Design”

[3] Abkowitz, M.A. Lectures on ship hydrodynamics, steering and manoeuvrability Hydro- och Aerodynamisk Lab. Lyngby, Rep. no. HY-5, Copenhagen, Denmark, 1964.

[4] Coastal Engineering Manual, 2006

APPENDIX: MODEL SHIP DESCRIPTION

Ship's description: bul040a1

Contents

A. GENERAL DATA bul040a1

1. Ship's dimensions and data

Ship's type	-	Bulk carrier
Length over all	[m]	245.30
Length between perpendiculars	[m]	233.60
Beam	[m]	32.20
Depth	[m]	19.00
Draught amid ship's	[m]	13.00
Draught forward	[m]	13.00
Draught after	[m]	13.00
Displacement	[tons]	80000
Dead weight tonnage (fully loaded)	[tons]	65000
Maximum draught (fully loaded)	[m]	13.00
Engine type	[-]	Diesel
Power	[kW]	12300
Number of revolutions	[rpm]	88
Service speed	[kn]	15.6
Number of propellers	[-]	1
Diameter of propellers	[m]	6.50
Pitch ratio	[-]	1
Number of rudders	[-]	1
Frontal wind area	[m2]	740
Lateral wind area	[m2]	2389
Bow Thruster	[kW]	-
Stern Thruster	[kW]	-

2. WindCoefficients

** Hoeken : WALFA(20)
** Aantal in te lezen getallen: NWALF
**

0	10	20	30	40	50	60	70
80	90	100	110	120	130	140	150
160	170	180					

**
** X-coefficient : CXW(20)
** Aantal in te lezen getallen: NWALF
**

0.750	0.770	0.740	0.650	0.510	0.390	0.290	0.210
0.140	0.040	-0.070	-0.190	-0.330	-0.480	-0.610	-0.730
-0.830	-0.910	-0.960					

**
** Y-coefficient : CYW(20)
** Aantal in te lezen getallen: NWALF
**

0.000	0.120	0.280	0.430	0.550	0.630	0.680	0.710
0.720	0.720	0.710	0.680	0.630	0.550	0.420	0.300
0.180	0.090	0.000					

**
** N-coefficient : CNW(20)
** Aantal in te lezen getallen: NWALF
**

0.000	-0.050	-0.105	-0.145	-0.162	-0.167	-0.163	-0.147
-0.125	-0.113	-0.103	-0.093	-0.080	-0.065	-0.050	-0.033
-0.017	-0.007	0.000					

3. Wave Coefficients

The wave coefficients have been calculated with the MARIN program DBSHIP.
All computations have been made assuming a JONSWAP wave spectrum and a water depth of 20 m.

	Tp = 7.0s, Tmean =4.95 s			Tp = 10.0s, Tmean =7.07 s		
Alfa [deg]	X-Force [N]	Y-Force [N]	Moment [Nm]	X-Force [N]	Y-Force [N]	Moment [Nm]
0	6.100E+03	0.000E+00	0.000E+00	8.900E+03	0.000E+00	0.000E+00
10	6.300E+03	6.400E+03	-5.940E+04	9.500E+03	7.800E+03	-2.187E+05
20	6.600E+03	1.550E+04	-1.188E+05	1.010E+04	2.040E+04	-3.612E+05
30	6.900E+03	2.790E+04	-1.659E+05	1.020E+04	4.020E+04	-3.059E+05
40	7.400E+03	4.210E+04	-2.295E+05	1.090E+04	6.170E+04	-3.365E+05
50	9.000E+03	5.880E+04	-3.673E+05	1.470E+04	8.150E+04	-7.988E+05
60	1.050E+04	7.530E+04	-5.235E+05	1.910E+04	9.830E+04	-1.478E+06
70	1.060E+04	8.980E+04	-6.219E+05	2.070E+04	1.150E+05	-1.958E+06
80	5.900E+03	9.760E+04	-4.725E+05	9.700E+03	1.394E+05	-1.288E+06
90	-2.000E+02	1.003E+05	-2.372E+05	-3.300E+03	1.547E+05	-2.991E+05
100	-5.800E+03	9.690E+04	3.000E+04	-1.120E+04	1.399E+05	6.617E+05
110	-9.900E+03	8.850E+04	2.415E+05	-1.590E+04	1.158E+05	1.322E+06
120	-1.000E+04	7.420E+04	2.199E+05	-1.490E+04	9.840E+04	9.333E+05
130	-8.900E+03	5.810E+04	1.421E+05	-1.260E+04	8.100E+04	3.683E+05
140	-7.700E+03	4.190E+04	7.530E+04	-1.070E+04	6.110E+04	1.830E+04
150	-7.300E+03	2.820E+04	6.590E+04	-1.050E+04	4.020E+04	7.490E+04
160	-6.900E+03	1.600E+04	6.250E+04	-1.070E+04	2.090E+04	2.106E+05
170	-6.700E+03	6.800E+03	3.640E+04	-1.000E+04	8.200E+03	1.457E+05
180	-6.500E+03	0.000E+00	0.000E+00	-9.100E+03	0.000E+00	0.000E+00

Tp = 12.0s, Tmean =8.49 s

Alfa [deg]	X-Force [N]	Y-Force [N]	Moment [Nm]
0	8.9000E+03	0.0000E+00	0.0000E+00
10	9.6000E+03	8.5000E+03	-2.6160E+05
20	1.0600E+04	2.0000E+04	-4.5980E+05
30	1.1800E+04	3.6400E+04	-4.8450E+05
40	1.3500E+04	5.3600E+04	-5.9250E+05
50	1.7600E+04	6.8100E+04	-1.1544E+06
60	2.1400E+04	8.1100E+04	-1.8890E+06
70	2.1900E+04	9.6400E+04	-2.3318E+06
80	9.9000E+03	1.2850E+05	-1.3589E+06
90	-4.1000E+03	1.5110E+05	5.1000E+03
100	-1.2900E+04	1.3400E+05	1.3188E+06
110	-1.8100E+04	1.0550E+05	2.2162E+06
120	-1.7100E+04	8.6900E+04	1.7236E+06
130	-1.4500E+04	6.9600E+04	9.5770E+05
140	-1.2300E+04	5.2300E+04	3.8950E+05
150	-1.1900E+04	3.5400E+04	3.0270E+05
160	-1.1800E+04	2.0100E+04	3.2120E+05
170	-1.1100E+04	8.6000E+03	1.8280E+05
180	-1.0000E+04	0.0000E+00	0.0000E+00

4.1 Ship information Sheet

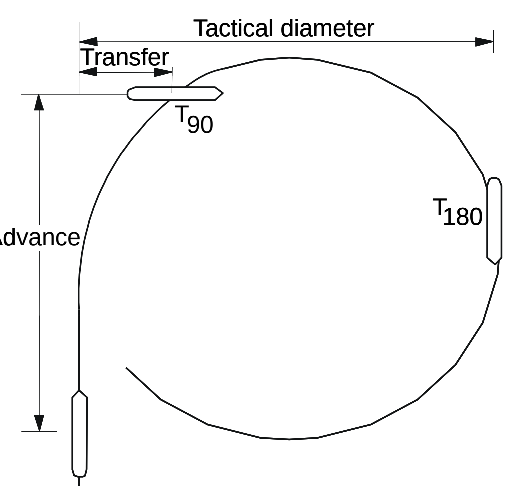
Principal dimensions			Engine		
Length over all	245.30	m	Type:	Diesel	
Beam	32.20	m	Power:	12300	kW
Draft fully laden	13.00	m	Max. revs:	88	rpm
Displacement fully laden	80000	tons	Bow Thruster:	-	kW
Dead weight tonnage	65000	tons	Stern Thruster:	-	kW

Telegraph Setting	RPM	Speed	Crash Stop Full Ahead/ Full Asterm		
			Distance	Stopping Time	
		[kn]	[mile]	[min]	[sec]
SEA FULL	88	15.6	0.53	5	57
HARBOUR FULL	66	11.7			
HALF	57	10.1			
SLOW	44	7.8			
DEAD SLOW	35	6.2			

Telegraph	Rudder	Advance	Transfer	T90		Tac. Diam.
		[mile]	[mile]	[min]	[sec]	[mile]
SEA FULL	P	0.51	0.27	2	55	0.53
	SB	0.52	0.27	3	1	0.54
HALF	P	0.50	0.27	4	29	0.53
	SB	0.51	0.27	4	37	0.54

WARNING:
The response of this ship may be different from that listed above if any of the following conditions upon which the manoeuvring information is based are varied:

1. Calm weather - wind 8 knots or less, calm sea.
2. No current.
3. Water depth twice vessels draft or greater.
4. Clean hull.
5. Load condition FULL LOAD



1.1 Turning circle test

Waterdepth 1 = 15.6 m

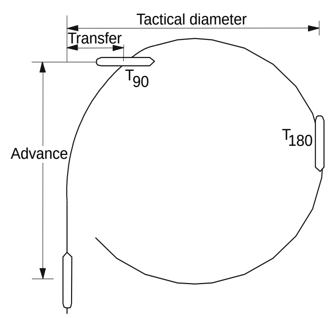
INPUT:

Initial speed	[m/s]	4.62
Number of revolutions	[1/s]	0.95
Rudder angle	[deg]	20

RESULTS:

		Starboard	Port
Advance	[m]	1321	-
Transfer	[m]	1060	-
Tactical diameter	[m]	2169	-
Final diameter	[m]	2113	-
T90	[s]	458	-
T180	[s]	890	-
T270	[s]	1323	-
T360	[s]	1755	-
uf	[m/s]	3.84	3.84
vf	[m/s]	-0.164	0.164
rf	deg/s]	0.208	-0.208

See also Figure 1.1



1.2 Turning circle test

Waterdepth 1 = 15.6 m

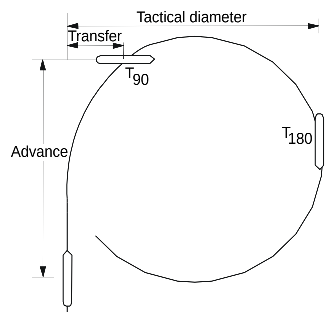
INPUT:

Initial speed	[m/s]	4.62
Number of revolutions	[1/s]	0.95
Rudder angle	[deg]	35

RESULTS:

		Starboard	Port
Advance	[m]	870	-
Transfer	[m]	594	-
Tactical diameter	[m]	1185	-
Final diameter	[m]	1000	-
T90	[s]	319	-
T180	[s]	618	-
T270	[s]	917	-
T360	[s]	1216	-
uf	[m/s]	2.6	2.6
vf	[m/s]	-0.244	0.244
rf	deg/s]	0.301	-0.301

See also Figure 1.2



1.3 Zig/zag test

Waterdepth 1 = 15.6 m

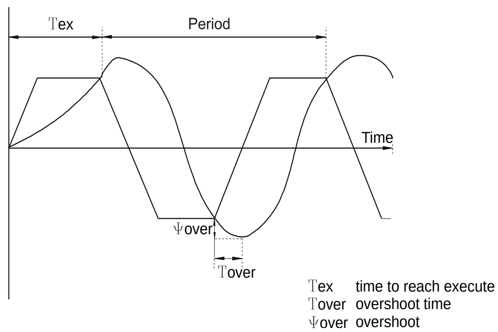
INPUT:

Initial speed	[m/s]	4.62
Number of revolutions	[1/s]	0.95
Rudder angle	[deg]	20/20

RESULTS:

Tex	[s]	123.5
Tovershoot	[s]	30.9
Overshoot angle	[deg]	3.5
Period	[s]	532.1

See also Figure 1.3 and 1.4



1.4 Stopping manoeuvre

Waterdepth 1 = 15.6 m

INPUT:

Initial speed	[m/s]	4.62
Number of revolutions ahead	[1/s]	0.95
Number of revolutions astern	[1/s]	-0.95

RESULTS:

Stopping time	[s]	291
Stopping distance	[m]	671.2
Heading after stopping	[deg]	24.8
Deviation of track	[m]	39.9

See also Figure 1.5 and 1.6

1.5 Acceleration manoeuvre

Waterdepth 1 = 15.6 m

INPUT:

Initial speed	[m/s]	0
Number of revolutions ahead	[1/s]	0.95

RESULTS:

Final speed	[m/s]	4.57
Time to reach this speed	[s]	900
Distance to reach this speed	[m]	3175

See also Figure 1.7

1.6 Spiral test

Waterdepth 1 = 15.6 m

INPUT:

Initial speed	[m/s]	4.62
Number of revolutions ahead	[1/s]	0.95
Rate of turn	[deg/s]	-0.301 - 0.301

See also Figure 1.8

2.1 Turning circle test

Waterdepth 2 = 26.0 m

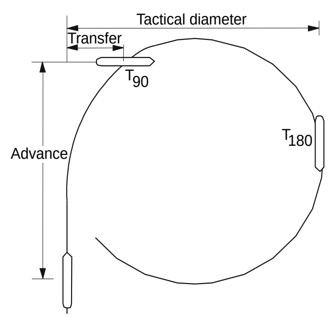
INPUT:

Initial speed	[m/s]	5.2
Number of revolutions	[1/s]	0.95
Rudder angle	[deg]	20

RESULTS:

		Starboard	Port
Advance	[m]	1259	-
Transfer	[m]	770	-
Tactical diameter	[m]	1564	-
Final diameter	[m]	1330	-
T90	[s]	353	-
T180	[s]	641	-
T270	[s]	931	-
T360	[s]	1221	-
uf	[m/s]	3.56	3.56
vf	[m/s]	-0.411	0.411
rf	deg/s]	0.3103	-0.3103

See also Figure 2.1



2.2 Turning circle test

Waterdepth 2 = 26.0 m

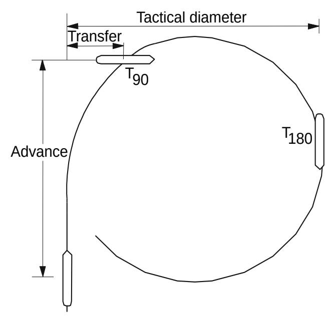
INPUT:

Initial speed	[m/s]	5.2
Number of revolutions	[1/s]	0.95
Rudder angle	[deg]	35

RESULTS:

		Starboard	Port
Advance	[m]	942	-
Transfer	[m]	501	-
Tactical diameter	[m]	989	-
Final diameter	[m]	584	-
T90	[s]	274	-
T180	[s]	496	-
T270	[s]	718	-
T360	[s]	938	-
uf	[m/s]	1.86	1.86
vf	[m/s]	-0.532	0.532
rf	deg/s]	0.4088	-0.4088

See also Figure 2.2



2.3 Zig/zag test

Waterdepth 2 = 26.0 m

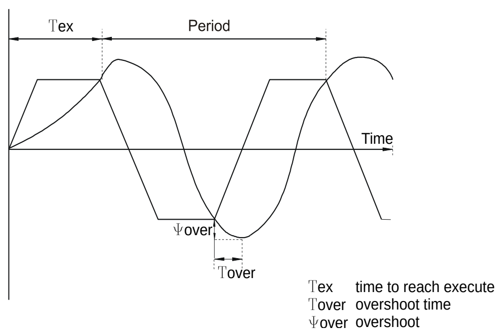
INPUT:

Initial speed	[m/s]	5.2
Number of revolutions	[1/s]	0.95
Rudder angle	[deg]	20/20

RESULTS:

Tex	[s]	122.1
Tovershoot	[s]	81.3
Overshoot angle	[deg]	11.5
Period	[s]	614.8

See also Figure 2.3 and 2.4



2.4 Stopping manoeuvre

Waterdepth 2 = 26.0 m

INPUT:

Initial speed	[m/s]	5.2
Number of revolutions ahead	[1/s]	0.95
Number of revolutions astern	[1/s]	-0.95

RESULTS:

Stopping time	[s]	374
Stopping distance	[m]	975
Heading after stopping	[deg]	27.1
Deviation of track	[m]	55.6

See also Figure 2.5 and 2.6

2.5 Acceleration manoeuvre

Waterdepth 2 = 26.0 m

INPUT:

Initial speed	[m/s]	0.01
Number of revolutions ahead	[1/s]	0.95

RESULTS:

Final speed	[m/s]	5.06
Time to reach this speed	[s]	900
Distance to reach this speed	[m]	3294

See also Figure 2.7

2.6 Spiral test

Waterdepth 2 = 26 m

INPUT:

Initial speed	[m/s]	5.20
Number of revolutions ahead	[1/s]	0.95
Rate of turn	[deg/s]	-0.4088 - 0.4088

See also Figure 2.8