

Simulation Tests of Determining Under Keel Clearance for LNG Carrier at Anchorage

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ABSTRACT: The article presents issues related to the determination of under keel clearance for LNG carrier at anchorage. The processes related to the acquisition and analysis of data affecting the safety of anchoring operations have been presented. The collected data made it possible to achieve the research goal, which was to assess the variability of under keel clearance in simulated scenarios for various hydro-meteorological conditions observed in the area of the anchorage. The result of the simulation tests is to identify the risks that may occur during anchoring of the LNG carrier and the presented issues may be helpful in safe planning of the anchorage for LNG ships.

1 INTRODUCTION

Technological development causes a significant demand for energy. The data from recent decades have indicated an increased demand for energy fuels. The costs of transporting liquid fuels resulted in changes in the means of transport, namely LNG tankers. A significant change is primarily the increase in the dimensions of the vessels. The increase in linear parameters of LNG tankers, and above all their draft, means that a significant problem to be solved is the safe under keel clearance, both during navigation and at anchorage. The need to analyze and determine the safe under keel clearance, for a given area at different times of the year is very important. When approaching a port, a ship is often stopped at an anchorage to wait for her berth or to wait out bad weather conditions. Each port has an area designated by the Maritime Administration of the Coastal State meant for anchoring ships. The simulation studies presented the problem of determining under keel clearance for tankers in areas with restricted depth. The Baltic Sea itself and approaches to many ports are

areas of relatively shallow depth, while tankers have a deep draft and it means the necessity to accurately determine safe under keel clearance both during the approach and at the anchorage.

2 REVIEW OF THE SUBJECT LITERATURE

The construction and commissioning of the LNG Terminal in Świnoujście, as well as regular calls of Q-max LNG carriers evoke the need to acquire knowledge and to assess the possibility of anchoring of this type of vessels in the area of the Pomeranian Bay.

Literature available in Poland on the calls of LNG carriers at the port of Świnoujście mainly covers issues related to safe passage through the Baltic Sea, approach to the port and risk assessment for the transport of this type of cargo which is presented below.

These are studies prepared, among others, by the team of the Institute of Marine Traffic Engineering and the Maritime University of Szczecin, e.g. „Analiza nawigacyjna budowy stanowiska rozładunkowego LNG w porcie zewnętrznym w Świnoujściu”, „Ilościowa analiza ryzyka morskiej części lokalizacji Terminalu LNG w Świnoujściu”, „Minimalne wymagane parametry podejściowych torów wodnych do Portu Świnoujście” S. Gucma, „Inżynieria Morska i Geotechnika”, nr 2/2011 r. autorstwa S. Gucma, „Ilościowa analiza ryzyka morskiej części lokalizacji terminalu LNG w Świnoujściu”, Szczecin 2010 r. (S. Gucma), Rutkowski G., „Modelowanie domeny statku w procesie manewrowania w ograniczonych akwenach”, Politechnika Warszawska Wydział Transportu, Prace Naukowe Warsaw University of Technology, Faculty of Transport, Research „T”, Warszawa 2001 r., Rutkowski G., „Ocena głębokości północnego toru podejściowego do portu Świnoujście od pozycji gazociągu NordStream do terminal LNG w aspekcie obsługi jednostek o maksymalnych gabarytach – metody uproszczone” Faculty of navigation, Gdynia Maritime University. Rutkowski G., „Zastosowanie modelu domeny do oceny bezpieczeństwa nawigacyjnego statków poruszających się w akwenach ograniczonych”, Politechnika Warszawska Wydział Transportu, Prace Naukowe „T”, Warszawa 2001 r. Warsaw University of Technology, Faculty of Transport, Scientific Works "T", Warsaw 2001 Rutkowski G., Królikowski A., „Ocena głębokości toru podejściowego na południe od Ławicy Słupskiej w aspekcie obsługi jednostek o maksymalnych gabarytach – metoda rozbudowana”. Publikacja w Zeszytach Naukowych AMW Publication in AMW Scientific Journals, ISSN 0860-889X, Zeszyt Nr 1 (180), Str.81-96, Gdynia 2010 r.

The following publications, inter alia, can be listed in foreign literature, the content of which was taken into account during the simulation process:

A Guide and in Port Approaches, 3rd Ed, ICS, 1999 r., A Guide to Contingency Planning for the Gas Carrier Alongside and Within Port Limits, 2nd Ed, ICS, 1999 r., A Guide to good practice on port Marine Operation- prepared in conjunction with the Port Marine Safety Code, 2009 r., Admiralty List of Radio Signals, Volume 6(2), NP286 (2), edycja 2009/2010 r., Admiralty Sailing Directions, Baltic Pilot, Volume I, NP18, edycja 15/2010 r., Aids to Navigation Manual Administration, Comdtinst M16500.7A, 2 Mar 2005 r., Bridge Procedures Guide, 1998, ICS, Coastal Engineering Manual – Part 5, August 2008, publ. nr EM1110-2-1100, Code for existing ships carrying - Liquefied Gases in Bulk- IMO, Code for the construction and equipment of ship carrying liquefied gases in bulk, 1983 Edition Code for the construction and equipment of ship carrying liquefied gases in bulk, IGC ; Code 1993 Edition, COLREG, 1977 with amendments IMO, Critical Incident Management Guidelines, Volpe National Transportation Systems Center, 17 April 1998 r., Critical parameters for LNG Marine Terminal Site Selection (OTC 19658 Offshore Technology Conference, Houston 2008 r.)

The analysis of literature shows that few scientists and authors of articles have become interested in the

problem of UKC of LNG ships at anchor in shallow waters. The proposed scope of simulation studies covers exactly this area of knowledge where little has been presented so far to deal with the problem of UKC of a vessel at anchor.

3 SIMULATION RESEARCH

The area of the Pomeranian Bay, No.3 anchorage was selected for the simulation tests. All tests were carried out at the Faculty of Navigation of the Gdynia Maritime University using the NaviTrainer 5000 Professional navigation and maneuvering simulator, ECDIS Navi-Sailor 4000 systems, the electronic chart simulator and Model Wizard application (v. 5.0). The ship model used for the research was LNG carrier (Figure 1), loaded condition with the following: parameters $L = 315\text{m}$, $B = 50\text{m}$, $T = 12\text{m}$, without trim. Ship model particulars are presented in Fig. 2 and Fig. 3.



Figure 1 Model of LNG carrier used for simulation

Due to lack of precise and up-to-date data on waves and sea currents occurring in the area covered by simulation, wave parameters have been calculated. It should be pointed out that the results of wave tests available in literature in the considered water area are characterized by significant differences in the obtained values of height and direction of wind wave as a function of wind speed vector.

In the initial simulation tests a comparative analysis of wave spectrum was carried out for two models, i.e. ITTC and JONSWAP respectively. The JONSWAP model was adopted for wind wave spectrum. The wave height adopted in the settings of initial parameters should be understood as the height of significant wave expressed in meters. Significant wave height distribution was generally prepared for eight wind directions (N, NE, E, SE, S, SW, W, NW).

In simulation tests the value of 6 m/s was adopted as the greatest lower bound of wind speed.

The average parameters of the generated waves were determined for winds (without squalls) of speed of $6, 9, 12, 15$ and $15.1-18.0\text{ m/s}$ every 0.1 m/s and for $6, 9, 12, 12.2-15.0\text{ m/s}$ every 0.2 m/s and $15.1-18.0$ every 0.1 m/s .

Kryłów and Titov method was taken into account while determining the wave parameters for

simulation purposes, in particular the height of the wind wave in relation to the wind speed,

The latter, taking into account its purely theoretical assumptions, computationally generates values of significant wave height obtained in the JONSWAP model for maximum values of wind wave parameters and for the value of fetch limited case of wind speed necessary for their formation.

In the coastal zone waves are transformed due to shallower bathymetry. The calculated wavelength parameters were transformed, by means of the above methods, assuming an estimated set of wave height values for a given wind speed in advance, due to the occurring phenomenon of refraction associated with the curvature of the wave crest lines and consequently the change in phase velocity, and thus the wavelength,

The model was adopted for regular undulations of a given direction of wave propagation, of certain height and period of the wave. The results of calculations of wave parameters were compared to the obtained results of research and observations in the southern part of the Pomeranian Bay, taking into account refraction and additionally compared to the analysis of observations of the wave field in the Baltic Sea used in the expansion and modernization of the ports in Gdańsk and Władysławowo. The local bathymetry system affects changes in the direction of wave radii.

Statistical analysis of data on behavior of LNG carrier model at anchor was carried out on the basis of simulations performed and discussed below and the StatGraphics program.

PILOT CARD					
Ship name	LNG 3 (Dis.142272t) TRANASAS	2.31.3.0 *	Date	23.10.2010	
IMO Number	N/A	Call Sign	N/A	Year built	N/A
Load Condition	Full load				
Displacement	142272 tonnes	Draft forward	12 m / 39 ft 5 in		
Deadweight	100800 tonnes	Draft forward extreme	12 m / 39 ft 5 in		
Capacity		Draft after	12 m / 39 ft 5 in		
Air draft	72.35 m / 237 ft 11 in	Draft after extreme	12 m / 39 ft 5 in		

Ship's Particulars			
Length overall	315 m	Type of bow	Bulbous
Breadth	50 m	Type of stern	Transom
Anchor Chain(Port)	10 shackles		
Anchor Chain(Starboard)	15 shackles		
Anchor Chain(Stern)	N/A shackles	(1 shackle = 27.5 m / 15 fathoms)	

Steering characteristics			
Steering device(s) (Type/No.)	Semisuspended / 2	Number of bow thrusters	N/A
Maximum angle	35	Power	N/A
Rudder angle for neutral effect	0 degrees	Number of stern thrusters	N/A
Hard over to over(2 pumps)	22.8 seconds	Power	N/A
Flanking Rudder(s)	0		

Stopping		Turning circle		
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAH to FAS	521.6 s	11.09 cbis	Advance	4.64 cbis
HAH to HAS	804.6 s	12.14 cbis	Transfer	2.27 cbis
SAH to SAS	865.6 s	10.28 cbis	Tactical diameter	5.48 cbis

Main Engine(s)			
Type of Main Engine	Slow speed diesel	Number of propellers	2
Number of Main Engine(s)	2	Propeller rotation	Inward
Maximum power per shaft	2 x 14560 kW	Propeller type	FPP
Astern power	51 % ahead	Min. RPM	25
Time limit astern	N/A	Emergency FAH to FAS	29.2 seconds

Engine Telegraph Table				
Engine order	Speed, knots	Engine power, kW	RPM	Pitch ratio
Full Sea Ahead	19.5	13800	85	1
Full Ahead	13.8	4786	60	1
Half Ahead	11	3297	48	1
Slow Ahead	8.5	1143	37	1
Dead Slow Ahead	6	402	26	1
Dead Slow Astern	-2.8	571	-25	1
Slow Astern	-4.1	1993	-36	1
Half Astern	-4.8	2753	-42	1
Full Astern	-6.7	7038	-63	1

Figure 2. Pilot Card

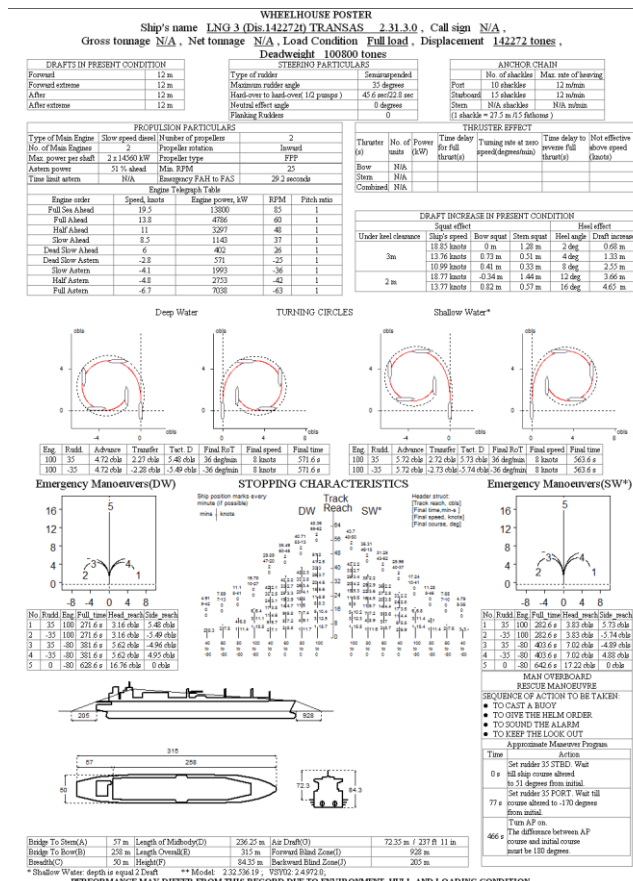


Figure 3. Wheelhouse poster

4 SIMULATION TESTS- NO. 3 ANCHORAGE, EXTERNAL PORT IN ŚWINOUJŚCIE.

Parameters of No.3 anchorage of the external port in Świnoujście were used in simulation scenario of the behaviour of a model of LNG carrier at anchor.

In the simulation series, a 15.5 m lowest depth was assumed in the entire area of the anchorage. The ship lies at anchor, port anchor with the length of the anchor cable of 7 shackles. The simulation begins after the initial positioning of the model at anchor in relation to the operating disturbances (wind, undulations). A continuous time tape with a nominal length of 03:00:00 [hh: mm: ss] was built, in which for the given wave spectrum the wind speed and the wave height are continuous non-decreasing functions. In the simulation, the wind speed domain was limited to the value of 6 m / s. The parameters of the generated waves were determined and the results of simulation tests were obtained for winds (without squalls) of the speed of 6, 9, 12, 1 m / s and 15.1 - 18.0 m / s every 0.1 m / s. The moment of complete loss of under keel clearance (hull contact with the bottom) was assumed as the end of the simulation. An example of a screenshot from electronic navigation chart with positions (contour) of LNG ship model at anchor is shown in Fig. 4.

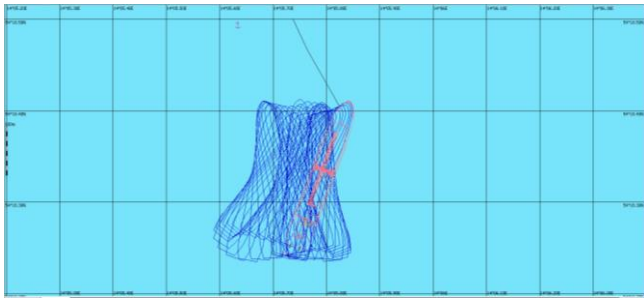


Figure 4. An example of a screenshot from electronic navigation chart with the positions (contour) of LNG ship model at anchor.

The simulation, in particular, examined the course of the variability of under keel clearance (UKC) with the set disturbance parameters (hydro-meteorological conditions). The wind speed/velocity (v_w) and the change of under keel clearance in the bow and stern parts obtained from measurements based on sensors located in the symmetry line of the bottom of the LNG carrier model are presented in the attached graphs below as a function of time.

In connection with the implementation of the task consisting in determining the boundary conditions, the attached drawings (Fig. 5-Fig. 13) present the results of tests, covering the period of the last 5 minutes of the simulation. The positive value of under-keel clearance, read each time, at the end of the simulation, is related to the hull contact with the bottom at the occurrence of the ship's rolling. Simulations were also carried out, taking into account additional influence of squalls (No.134, 134a, 136 simulations) and swell (No.129-133 and 136 simulations). The parameters of the simulations have been presented in Tab. 1.

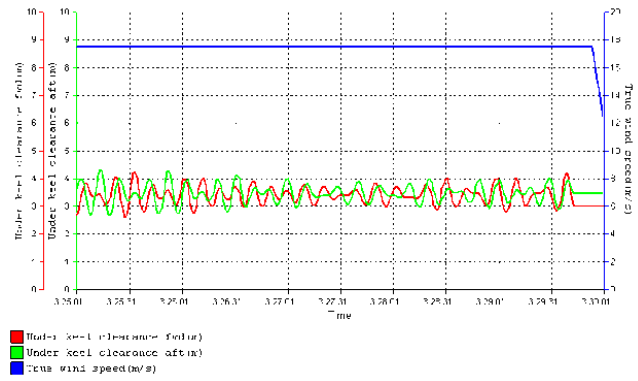


Figure 6. Graph of UKC changes and V_w (No. 134a simulation)

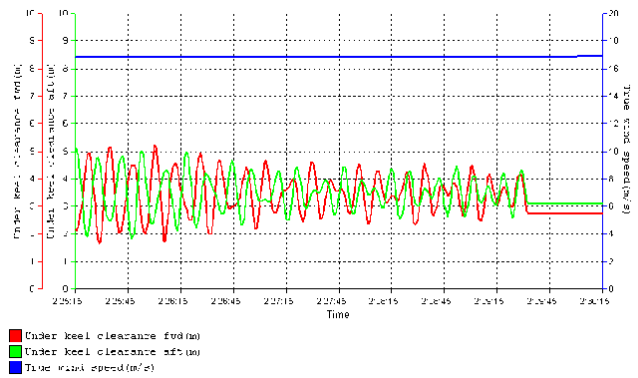


Figure 7. Graph of UKC changes and V_w (No. 129 simulation)

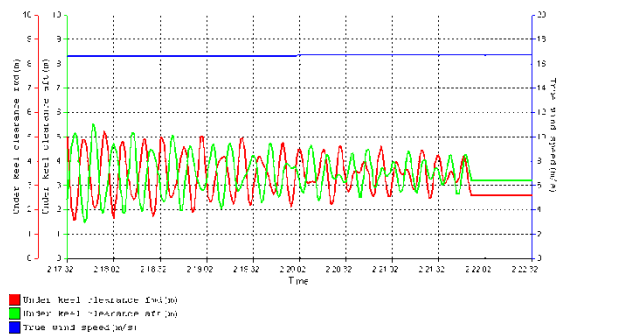


Figure 8. Graph of UKC changes and V_w (No. 130 simulation)

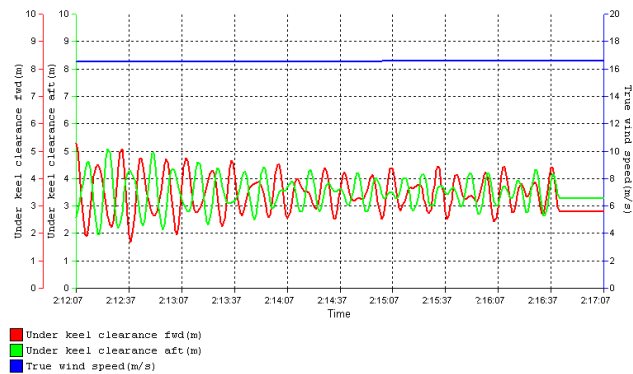


Figure 5. Graph of UKC changes and V_w (No. 109 simulation)

Table 1. Simulation parameters of the model of LNG carrier at anchor.

No. of simulations	True wind direction [°]	Wind Direction [°]	Swell Hdg [°]	Squalls	Dragging anchor	Contact with the bottom Wind speed/velocity V_w [m/s]
109	000	000	-	No	No	16,6
134	000	000	-	Yes	Yes	-
134a	000	000	-	Yes	No	17,5
136	000	000	045	Yes	No	17,1
129	000	000	000	No	No	16,8
130	000	000	045	No	No	16,7
131	000	000	090	No	No	16,9
132	000	000	135	No	No	17,3
133	000	000	180	No	No	16,6

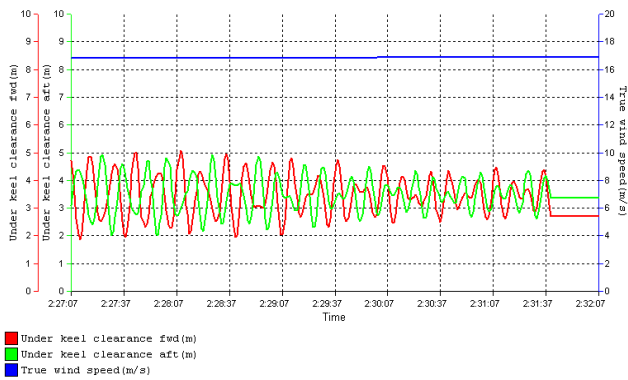


Figure 9. Graph of UKC changes and V_w (No. 131 simulation)

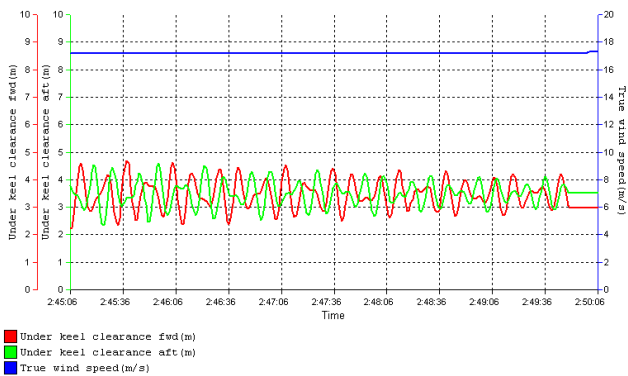


Figure 10. Graph of UKC changes and V_w (No. 132 simulation)

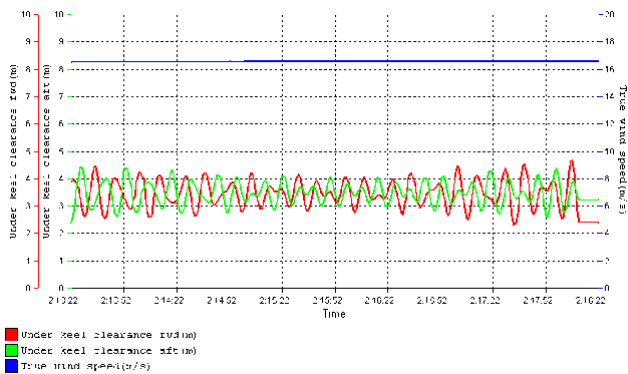


Figure 11. Graph of UKC changes and V_w (No. 133 simulation)

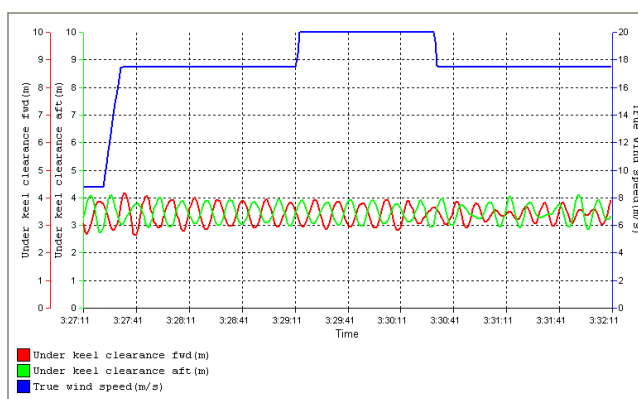


Figure 12. Graph of UKC changes and V_w (No. 134 simulation)

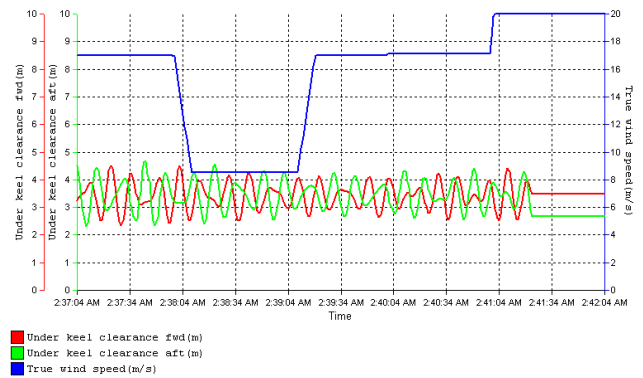


Figure 13 Graph of UKC changes and V_w (No. 136 simulation)

The developed theoretical model examines the under keel clearance of LNG ship at anchor and the boundary conditions of the ship's contact with the bottom. Based on the carried out simulation studies and the need for high accuracy and precision of the measurements of the UKC for LNG carrier, new measurements of hydro-meteorological conditions must be carried out in order to collect current and accurate data, in particular the observed wave and current parameters in the Pomeranian Bay area, with particular emphasis on the expected trajectory of LNG carriers calling at the port of Świnoujście (including the approach channel and anchorages). The observations of the maritime administration services responsible for the measurements in the Pomeranian Bay area indicate that the pressure change itself associated with the transition of the barometric systems induces a significant change in the water level in the approach channel, which is expressed in the differences in the depth reading. The knowledge of at least an estimate of frequent changes in depth caused by a change in specific hydro-meteorological conditions is of significant importance in determining the expected under keel clearance for master of LNG vessel that is fully loaded and the shore side services (Captain's Office, VTS, pilot station) co-responsible for safe passage of the ship to the LNG terminal in Świnoujście. Changes in the water level significantly affect the actual depth. The accuracy of the depth determination by hydrographic institutions is strictly defined by relevant IMO regulations, in particular, of a water depth of 10.0-20.0 m, the measurement accuracy is 0.20 m.

The greatest hazard in shallow water, which has been the cause of many contacts of a hull with seabed, is the undulations and related movements of a ship, which obviously reduce the distance between the hull and the bottom. Table 2 shows examples of reduction in under keel clearance for tankers of various dimensions caused by undulations/ wind wave.

Table 2. Reduction in UKC caused by the waves[1]

Ship's particulars	Wave		WAVE DIRECTION											
	Hight [m]	Period [s]	000°			090°			045° or 135°					
			Pitching [m]	Heave [m]	Sum [m]	Rolling [m]	Heave [m]	Sum [m]	Pitching [m]	Rolling [m]	Heave [m]	Sum Fwd or Aft [m]	Midship [m]	Fwd or Aft [m]
Deadweight =17049 t L= 149,00 m B= 21,60 m T= 9,14 m	4,57	10	2,80	0,15	2,96	2,93	2,13	5,06	2,50	2,35	0,76	3,26	3,11	3,93
	1,83	10	1,07	0,06	1,13	1,13	0,91	2,04	0,97	0,91	0,30	1,28	1,22	1,52
	4,57	10	2,80	0,30	3,11	3,78	1,52	5,30	2,50	3,05	0,53	3,05	3,58	4,42
Deadweight =37594t L= 203,00 m B= 28,00 m T= 10,97 m	1,83	10	1,07	0,12	1,14	1,46	0,61	2,07	0,97	1,16	0,21	1,19	1,37	1,68
	4,57	10	2,74	0,24	2,99	4,02	1,07	5,09	2,47	3,20	0,37	2,83	3,57	4,39
	1,83	10	0,91	0,09	1,00	1,55	0,49	2,04	0,82	1,25	0,15	0,97	1,40	1,68
Deadweight =60963t L= 236,00 m B= 32,90 m T= 12,44 m	4,57	10	2,47	0,15	2,62	4,45	0,82	5,27	2,22	3,57	0,29	2,53	3,87	4,60
	1,83	10	0,82	0,08	0,91	1,74	0,33	2,07	0,73	1,37	0,11	0,85	1,49	1,74
	4,57	10	2,20	0,12	2,38	4,88	0,61	5,49	1,98	3,90	0,21	2,19	4,11	4,75
Deadweight =81284t L= 257,00 m B= 36,30 m T= 14,02 m	1,83	10	0,97	0,00	0,97	1,89	0,24	2,13	0,88	1,52	0,08	0,97	1,61	1,92

Calculation of UKC at anchorage on the basis of simulation tests was determined on the basis of the following formulas:

$$UKC(symulator) = \min(Under\ Keel\ Clearance\ fwd(m), Under\ Keel\ Clearance\ aft(m))$$

$$UKC = UKC(symulator) - 25 \cdot \left| \sin \left(\frac{Roll\ angle(^{\circ}) \cdot \pi}{180^{\circ}} \right) \right|$$

where:

under keel clearance fwd(m)– UKC on the FWD [m],

under keel clearance aft(m) – UKC at AFT [m],

roll angle – rolling.

5 STATISTICAL ANALYSIS OF SIMULATION RESULTS FOR A MODEL OF LNG CARRIER AT ANCHOR.

The basic statistical parameters of the data obtained from simulations for LNG carrier at anchor have been presented in Tab. 3 and Fig. 14.

Table 3. Statistical parameters

Simulation	Avarage	Standard deviation	Coefficient of variation	Standard error
109	3,27415	0,375892	11,4806%	0,00414447
129	3,14816	0,503874	16,0054%	0,00530718
130	3,15613	0,452964	14,3519%	0,00489842
131	2,95505	0,592045	20,035%	0,00618968
132	2,89295	0,579977	20,0479%	0,00574122
133	3,10199	0,455714	14,691%	0,0049907
134a	2,91225	0,677372	23,2594%	0,00603451
134	2,92489	0,66794	22,8364%	0,00592026
136	2,94684	0,717248	24,3396%	0,00754747
Sum	3,0197	0,59489	19,7003%	0,00200716

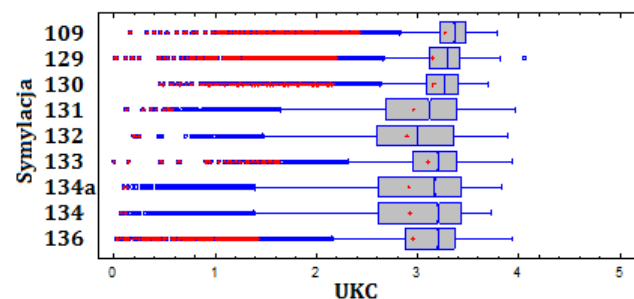


Figure 14. Box plot for UKC for a model of LNG tanker at anchor

For the data obtained from the simulation, the Kruskal-Wallisai test was performed. The rank test for mean medians is shown in Table 4, Table 5 and Table 6.

Table 4. Kruskal-Wallis test.

Simulation	Sample Size	Average Rank
109	8226	57605,1
129	9014	49593,0
130	8551	48131,0
131	9149	39556,2
132	10205	36338,5
133	8338	44090,2
134a	12600	41192,8
134U	12729	41913,6
136	9031	41288,4

Test statistic = 4588,9 P-Value = 0,0

Method: 95,0 percent LSD

Table 5. Multiple rank test,

Simulation	Count	Mean	Homogeneous Groups
132	10205	2,89295	X
134a	12600	2,91225	X
134	12729	2,92489	X
136	9031	2,94684	X
131	9149	2,95505	X
133	8338	3,10199	X
129	9014	3,14816	X
130	8551	3,15613	X
109	8226	3,27415	X

Both the rank test for mean and the Kruskal-Wallis test for medians indicate a statistically significant differentiation of the samples, i.e. the influence of the wind direction and swell on under keel clearance.

Tab. 7 and Tab. 8. show classes of under keel clearance obtained from the simulation.

Probability of UKC not exceeding 1.2 m (10% reserve), 1.8 m (15% reserve) and 2.4 m (20% reserve) thresholds and not exceeding the 2.4 m threshold for a draft of 12 m and individual test variants are presented in Table 9.

Table 7. Classification into classes for UKC.

T Range [m]	109		129		130		131		132	
	Relative frequent	Cumulative relative frequent	Relative frequent	Cumulative relative frequent	Relative frequent	Cumulative relative frequent	Relative frequent	Cumulative relative frequent	Relative frequent	Cumulative relative frequent
(0;0,6]	0,38%	0,38%	0,62%	0,62%	0,51%	0,51%	0,70%	0,70%	0,24%	0,24%
(0,6;1,2]	0,26%	0,63%	0,59%	1,21%	0,49%	1,01%	0,86%	1,56%	0,82%	1,07%
(1,2;1,8]	0,90%	1,53%	2,25%	3,46%	1,34%	2,35%	3,08%	4,65%	4,51%	5,58%
(1,8;2,4]	1,60%	3,14%	4,27%	7,73%	2,60%	4,95%	9,12%	13,76%	12,30%	17,87%
(2,4;3]	4,25%	7,39%	9,29%	17,02%	13,25%	18,20%	27,82%	41,58%	32,37%	50,24%
(3;3,6]	92,57%	99,96%	82,85%	99,87%	81,25%	99,45%	55,77%	97,34%	46,14%	96,38%
≥3,6	0,04%	100,00%	0,13%	100,00%	0,55%	100,00%	2,66%	100,00%	3,62%	100,00%

Table 8. Classification into classes for UKC.

T Range [m]	133		134a		134		136	
	Relative frequent	Cumulative relative frequent	Relative frequent	Cumulative relative frequent	Relative frequent	Cumulative relative frequent	Relative frequent	Cumulative relative frequent
(0;0,6]	0,62%	0,62%	0,52%	0,52%	0,43%	0,43%	1,72%	1,72%
(0,6;1,2]	0,19%	0,82%	2,42%	2,94%	2,26%	2,69%	2,10%	3,82%
(1,2;1,8]	0,65%	1,46%	6,37%	9,31%	6,06%	8,75%	4,55%	8,37%
(1,8;2,4]	3,63%	5,10%	10,87%	20,17%	11,53%	20,28%	6,44%	14,82%
(2,4;3]	23,81%	28,90%	16,28%	36,45%	15,40%	35,68%	15,48%	30,30%
(3;3,6]	69,61%	98,51%	63,29%	99,75%	64,21%	99,89%	68,84%	99,14%
≥3,6	1,49%	100,00%	0,25%	100,00%	0,11%	100,00%	0,86%	100,00%

Table 6. Test for simulation pairs

pairs	Sig.	difference	+/- limits
109 – 129	*	0,12599	0,0173725
109 – 130	*	0,118016	0,0175955
109 – 131	*	0,319097	0,0173113
109 – 132	*	0,381193	0,0168819
109 – 133	*	0,172152	0,0177054
109 – 134a	*	0,361896	0,01615
109 – 134	*	0,349255	0,0161176
109 – 136	*	0,327309	0,0173647
129 – 130	*	-0,0079734	0,0171991
129 – 131	*	0,193107	0,0169082
129 – 132	*	0,255203	0,0164683
129 – 133	*	0,0461625	0,0173114
129 – 134a	*	0,235907	0,0157171
129 – 134	*	0,223265	0,0156838
129 – 136	*	0,20132	0,0169629
130 – 131	*	0,20108	0,0171372
130 – 132	*	0,263176	0,0167033
130 – 133	*	0,0541359	0,0175352
130 – 134a	*	0,24388	0,0159632
130 – 134	*	0,231239	0,0159305
130 – 136	*	0,209293	0,0171912
131 – 132	*	0,0620961	0,0164036
131 – 133	*	-0,146944	0,01725
131 – 134	*	0,0427997	0,0156493
131 – 134	*	0,0301584	0,0156159
131 – 136	*	0,0082126	0,0169001
132 – 133	*	-0,209041	0,016819
132 – 134a	*	-0,0192964	0,015173
132 – 134	*	-0,0319377	0,0151385
132 – 136	*	-0,0538835	0,01646
133 – 134a	*	0,189744	0,0160842
133 – 134	*	0,177103	0,0160517
133 – 136	*	0,155157	0,0173036
134a – 134	*	-0,0126413	0,0143177
134a – 136	*	-0,0345871	0,0157084
134 – 136	*	-0,0219458	0,0156752

* means a statistically significant difference

The analysis of the impact of wind speed on UKC variable is presented in Table 10 and in Fig. 15

Table 9. Probability of occurrence of under keel clearance (UKC)

Probability	109	129	130	131	132	133	134a	134	136
UKC≤1,2	0,63%	1,21%	1,01%	1,56%	1,07%	0,82%	2,94%	2,69%	3,82%
UKC≤1,8	1,53%	3,46%	2,35%	4,65%	5,58%	1,46%	9,31%	8,75%	8,37%
UKC≤2,4	3,14%	7,73%	4,95%	13,76%	17,87%	5,10%	20,17%	20,28%	14,82%
UKC>2,4	96,86%	92,27%	95,05%	86,24%	82,13%	94,90%	79,83%	79,72%	85,18%

Table 10. Statistical Parameters

Wind speed	UKC average	Standard deviation	Coefficient of variation	Qantile quarter	Quantile six
up to 10 m/s	3,28688	0,417243	12,6942%	3,30235	3,14154
up to 12 m/s	3,28151	0,421774	12,853%	3,29012	3,12717
up to 14 m/s	3,29642	0,383915	11,6464%	3,30065	3,15747
up to 16 m/s	3,2585	0,312357	9,58591%	3,16783	3,0837
up to 18 m/s	3,06272	0,579803	18,931%	2,99711	2,72243
up to 20 m/s	3,06384	0,579493	18,9139%	2,9987	2,72492
up to 20 m/s	2,80615	0,73121	26,0574%	2,5247	2,16831
10-12 m/s	3,02875	0,540676	17,8514%	2,89459	2,56924
12-14m/s	3,33355	0,263622	7,90815%	3,31599	3,21929
14-16m/s	3,22122	0,213972	6,64257%	3,12269	3,06042
16-18m/s	2,61657	0,770409	29,4435%	2,14196	1,84353
18-20m/s	3,24475	0,495649	15,2754%	3,2171	3,10972

Table 11. Probabilities for UKC variable for different wind speed.

Vw	up to 10m/s		up to 12m/s		up to 14m/s		up to 16m/s		up to 18m/s		up to 20m/s	
	UKC_10		UKC_12		UKC_14		UKC_16		UKC_18		UKC_20	
Range	Relative	Cumulative	Relative	Cumulative	Relative	Cumulative	Relative	Cumulative	Relative	Cumulative	Relative	Cumulative
UKC [m]	frequent	relative frequent	frequent	relative frequent	frequent	relative frequent	frequent	relative frequent	frequent	relative frequent	frequent	relative frequent
[0; 0,1]	0,00%	0,00%	0,00%	0,00%	0,01%	0,01%	0,01%	0,01%	0,31%	0,31%	0,31%	0,31%
[0,1;0,3]	0,01%	0,01%	0,01%	0,01%	0,01%	0,02%	0,00%	0,01%	0,05%	0,36%	0,05%	0,36%
[0,3;0,5]	0,02%	0,03%	0,03%	0,04%	0,02%	0,04%	0,01%	0,02%	0,12%	0,48%	0,13%	0,49%
[0,5;0,7]	0,06%	0,10%	0,06%	0,10%	0,05%	0,09%	0,02%	0,05%	0,16%	0,64%	0,16%	0,65%
[0,7;0,9]	0,16%	0,26%	0,16%	0,26%	0,13%	0,21%	0,07%	0,12%	0,35%	1,00%	0,35%	1,00%
[0,9;1,1]	0,23%	0,49%	0,25%	0,51%	0,19%	0,40%	0,10%	0,21%	0,54%	1,53%	0,53%	1,53%
[1,1;1,3]	0,36%	0,85%	0,35%	0,86%	0,27%	0,67%	0,15%	0,36%	0,76%	2,29%	0,76%	2,29%
[1,3;1,5]	0,43%	1,28%	0,44%	1,30%	0,32%	0,99%	0,17%	0,53%	1,01%	3,30%	1,00%	3,29%
[1,5;1,7]	0,55%	1,83%	0,58%	1,88%	0,43%	1,41%	0,22%	0,75%	1,27%	4,58%	1,27%	4,56%
[1,7;1,9]	0,71%	2,55%	0,74%	2,61%	0,57%	1,98%	0,32%	1,07%	1,70%	6,27%	1,69%	6,26%
[1,9;2,1]	0,78%	3,33%	0,82%	3,43%	0,65%	2,63%	0,39%	1,45%	1,98%	8,26%	1,98%	8,23%
[2,1;2,3]	0,83%	4,16%	0,88%	4,31%	0,72%	3,35%	0,47%	1,92%	2,19%	10,45%	2,18%	10,41%
[2,3;2,5]	1,66%	5,82%	1,70%	6,01%	1,52%	4,88%	0,97%	2,89%	2,66%	13,11%	2,65%	13,07%
[2,5;2,7]	2,32%	8,14%	2,39%	8,40%	2,01%	6,89%	1,57%	4,46%	3,10%	16,21%	3,10%	16,16%
[2,7;2,9]	2,75%	10,89%	2,79%	11,19%	2,91%	9,80%	3,36%	7,82%	4,82%	21,03%	4,81%	20,97%
[2,9;3,1]	4,28%	15,17%	4,48%	15,67%	4,54%	14,34%	10,13%	17,95%	10,79%	31,83%	10,76%	31,73%
[3,1;3,3]	9,72%	24,88%	9,98%	25,65%	10,62%	24,96%	25,79%	43,74%	24,17%	56,00%	24,11%	55,84%
(3,3;3,5]	70,78%	95,66%	70,04%	95,69%	70,70%	95,66%	52,10%	95,84%	40,49%	96,48%	40,65%	96,49%
(3,5;3,7]	4,33%	99,99%	4,30%	99,99%	4,30%	99,96%	4,08%	99,92%	3,43%	99,92%	3,43%	99,92%
(3,7;3,9]	0,01%	100,00%	0,01%	100,00%	0,04%	100,00%	0,08%	100,00%	0,08%	100,00%	0,08%	100,00%

Table 12. Probabilities for UKC variable for different wind speed.

Vw	from 20m/s		10m/s - 12m/s		12m/s - 14m/s		14m/s - 16m/s		16m/s - 18m/s		18m/s - 20m/s	
	UKC_from 20		UKC10_12		UKC12_14		UKC14_16		UKC16_18		UKC18_20	
Range	Relative	Cumulative	Relative	Cumulative	Relative	Cumulative	Relative	Cumulative	Relative	Cumulative	Relative	Cumulative
UKC [m]	frequent	relative frequent	frequent	relative frequent	frequent	relative frequent	frequent	relative frequent	frequent	relative frequent	frequent	relative frequent
[0; 0,1]	1,44%	1,44%	0,00%	0,00%	0,03%	0,03%	0,01%	0,01%	0,99%	0,99%	0,53%	0,53%
(0,1;0,3]	0,07%	1,52%	0,00%	0,00%	0,00%	0,03%	0,00%	0,01%	0,16%	1,15%	0,00%	0,53%
(0,3;0,5]	0,17%	1,69%	0,32%	0,32%	0,00%	0,03%	0,00%	0,01%	0,38%	1,53%	0,53%	1,06%
(0,5;0,7]	0,30%	1,99%	0,00%	0,32%	0,02%	0,05%	0,00%	0,01%	0,48%	2,01%	0,00%	1,06%
(0,7;0,9]	0,65%	2,64%	0,00%	0,32%	0,05%	0,10%	0,01%	0,02%	1,00%	3,00%	0,00%	1,06%
(0,9;1,1]	0,67%	3,31%	0,96%	1,28%	0,03%	0,13%	0,01%	0,03%	1,54%	4,55%	0,00%	1,06%
(1,1;1,3]	1,19%	4,50%	0,00%	1,28%	0,07%	0,20%	0,03%	0,06%	2,16%	6,70%	0,00%	1,06%
(1,3;1,5]	1,49%	5,99%	0,64%	1,92%	0,02%	0,22%	0,02%	0,07%	2,92%	9,63%	0,53%	1,58%
(1,5;1,7]	1,89%	7,88%	1,92%	3,83%	0,05%	0,27%	0,02%	0,10%	3,66%	13,29%	1,06%	2,64%
(1,7;1,9]	3,31%	11,19%	1,92%	5,75%	0,15%	0,41%	0,07%	0,16%	4,85%	18,14%	0,79%	3,43%
(1,9;2,1]	3,85%	15,05%	2,56%	8,31%	0,22%	0,63%	0,14%	0,30%	5,62%	23,76%	0,53%	3,96%
(2,1;2,3]	3,90%	18,95%	3,19%	11,50%	0,33%	0,96%	0,22%	0,52%	6,11%	29,87%	1,06%	5,01%
(2,3;2,5]	5,32%	24,27%	3,51%	15,02%	1,09%	2,06%	0,42%	0,94%	6,53%	36,40%	1,06%	6,07%
(2,5;2,7]	5,22%	29,50%	5,43%	20,45%	1,08%	3,13%	1,13%	2,07%	6,60%	43,00%	2,11%	8,18%
(2,7;2,9]	7,63%	37,13%	5,11%	25,56%	3,22%	6,35%	3,79%	5,86%	8,15%	51,15%	2,64%	10,82%
(2,9;3,1]	15,24%	52,38%	13,74%	39,30%	4,69%	11,04%	15,64%	21,50%	12,30%	63,44%	5,28%	16,09%

(3,1;3,3]	25,02%	77,39%	2,36%	61,66%	12,21%	23,25%	40,70%	62,19%	20,50%	83,94%	13,46%	29,55%
(3,3;3,5]	20,69%	98,09%	35,46%	97,12%	72,34%	95,59%	33,82%	96,01%	14,01%	97,96%	67,28%	96,83%
(3,5;3,7]	1,91%	100,00%	2,88%	100,00%	4,29%	99,88%	3,86%	99,88%	1,96%	99,92%	2,90%	99,74%
(3,7;3,9]	0,00%		0,00%		0,12%	100,00%	0,12%	100,00%	0,08%	99,99%	0,00%	99,74%
(3,9;4,1]									0,01%	100,00%	0,26%	100,00%

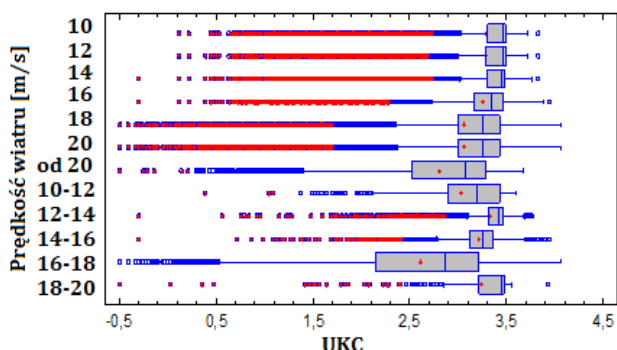


Figure 15. Box plot for UKC for a model of LNG vessel at anchor with different wind speed limits.

The simulation conclusions are included in Tab. 11 and Table 12, which contain the event probabilities that UKC variable [m] takes values from a given range for different wind speed ranges.

6 CONCLUSIONS

Designating safe anchorages for LNG carriers is one of the main tasks for safe operation of a terminal handling liquid fuels, especially LNG.

Important issue is the influence of hydro-meteorological conditions in determining the anchorage areas for LNG carriers.

The aim of the simulations was to indicate the conditions that should be taken into account when determining the anchorage, so that under keel clearance was proper during the entire period of the ship's stay at anchor in various weather conditions.

The simulations and analysis (Tab. 2.1 and Tab. 2.2) have shown that the probability of a change in under keel clearance to the limit values ranging from 0.0 m to 0.1 m may occur with a probability frequency of 0.01% at wind speed 16 m / s (31kts).

The increase in wind speed above 16 m / s (31 kts) results in the increase in frequency of UKC occurrence by 0.0m to 0.1m with a probability of

0.99%. On the basis of the above values, it can be assumed that the UKC for No. 3 anchorage area, has safe values (for this type of LNG carrier) up to wind speed of 16 m / s (31 kts). The ship model was at anchor/brought up all the time of simulation. Dragging of the anchor only occurred in the event of disturbances caused by squall. Simulation tests and their analysis have indicated that a vessel can lie at anchor at No. 3 anchorage safely with wind speed up to 16m / s (31 kts). With expected wind speed above 16 m / s (31 knots), recommendation for the vessel is to heave up anchor and move for deeper open water.

The used methodology of simulation tests can be used to determine the conditions of safe anchoring for this type and size of ships taking into account their under keel clearance in various weather conditions.

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