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Moored Ship Motions due to Tropical Cyclone Linda

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Abstract: Severe wind-wave due to tropical cyclone Linda can cause port downtime which affects port operations such as berthing, mooring and (un)loading of the ship. The ship motions are criteria for limiting the port operations, human safety and preventing the damage of port equipment and furniture. Therefore, this study discusses moored ship motions due to severe wind-wave during the tropical cyclone Linda which entered the Gulf of Thailand in November 1997. The ship motions are represented in the moored ship analysis at SRH (Sriracha Harbour Port) and BLCP (BLCP Coal-Fired Power Plant Port), and are subject to the static environmental load on the ship in accordance with Spanish Standard (ROM 0.2-1990) [1]. The environment in numerical model is derived from the wave model and hydrodynamics model using the application of Delft3D-WAVE and Delft3D-FLOW. The model location includes Ao Udom Bay and Rayong Sea. The model results represent the environment at Rayong Sea which is more severe than Ao Udom Bay. The ship motions at BLCP are mostly larger than SRH.

Key words: Moored ship motion, storm surge, tropical cyclone Linda, berth operability, port downtime.

1. Introduction

The study on port downtime is significant to estimate the berth operability. The mooring analysis is a tool for the detailed study of port downtime within the limiting motions of a moored ship at port. The port downtime is the disruption caused by the ship motions from the combination of the environment forces (wind, wave and current) on the exposed moored ship. The majority of severe environmental conditions are due to a tropical cyclone. In order to determine the ship motions in a storm event, it is necessary to obtain the water level change and strong wind-wave generated by tropical cyclone for the estimation of the environmental forces on the moored ship. Therefore, the ship motions in event storm will be set up in the wave model and hydrodynamics model in order to estimate the wave propagation from the offshore to port, tidal current and extreme current at a port.

The wave model and hydrodynamics model is set up using the applications "Delft3D-WAVE" and "Delft3D-FLOW" (this study did not couple FLOW-WAVE in the model). This is set-up separately for estimating significant wave height and current speed at the port, with the wind speed obtained from the observed data.

The ship motion limitations are in accordance to the PIANC 1995 [2] criteria for the limited ship motions due to a tropical cyclone. The ship motions are analyzed using MATLAB computer program which was written by the modified mooring equation solution of Natarajan and Ganapathy [3] which is applicable to ship motions analysis at SRH (Sriracha Harbour Port) and BLCP (BLCP Coal-Fired Power Plant Port) in Upper Gulf of Thailand.

2. Observed Data

The numerical model simulated the wave, seawater level and current due to tropical cyclone Linda which entered the Gulf of Thailand in November 1997. The observed data are used to set up the model and model validation with two sources of data such as observed sea water level and met-ocean.

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2.1 Tides

The tides in the region are predominantly semi-diurnal in nature with typically two high and two low tides each day (usually one tide has a larger amplitude than the other). Tidal levels have been based on a number of sources, including the Thai Hydrographic Chart and the Ao Udom Tide Station, Banleam Tide Station, Rayong Tide Station, Pranburi Tide Station and Leam Ngob Tide Station from the Marine Department (Hydrology Section, Engineering Bureau). Some station locations are shown in Fig. 1.

2.2 Met-Ocean

The met-ocean data were collected by manually digitizing from oceanographic buoy reports, because the met-ocean database was absent from the ASCII files, and it exists as time series data plotted as a graph in linear scale illustrate in GISTDA report [4]. The time series data were started on 1st November 1997 and continued to 6th November 1997 covering the time tropical cyclone enter the Gulf of Thailand. The buoys locations are KS (Ko Si Chang), RY (Rayong), HH (Hua Hin) and KC (Ko Chang) Buoy as shown in Fig. 1.

3. Wave Model

3.1 Wave Model Set-up

Tropical cyclone wave generation and propagation in the upper Gulf and between the islands offshore of the site have been modeled using a numerical wave model. The waves undergo wave refraction and diffraction around the offshore islands as well as shoaling and breaking over the complex nearshore bathymetry. The numerical model has been developed to estimate the growth of wind-waves and transform the waves to the nearshore.

The Delft3D-WAVE is the new version of SWAN (simulating wave nearshore) with graphical user interface. This is a third generation wave model developed at the Delft Technical University used to hindcast and transform waves towards the shore. Delft3D-WAVE or SWAN is a spectral model that includes wind-wave generation, propagation, refraction, breaking, whitecapping and interaction with currents,

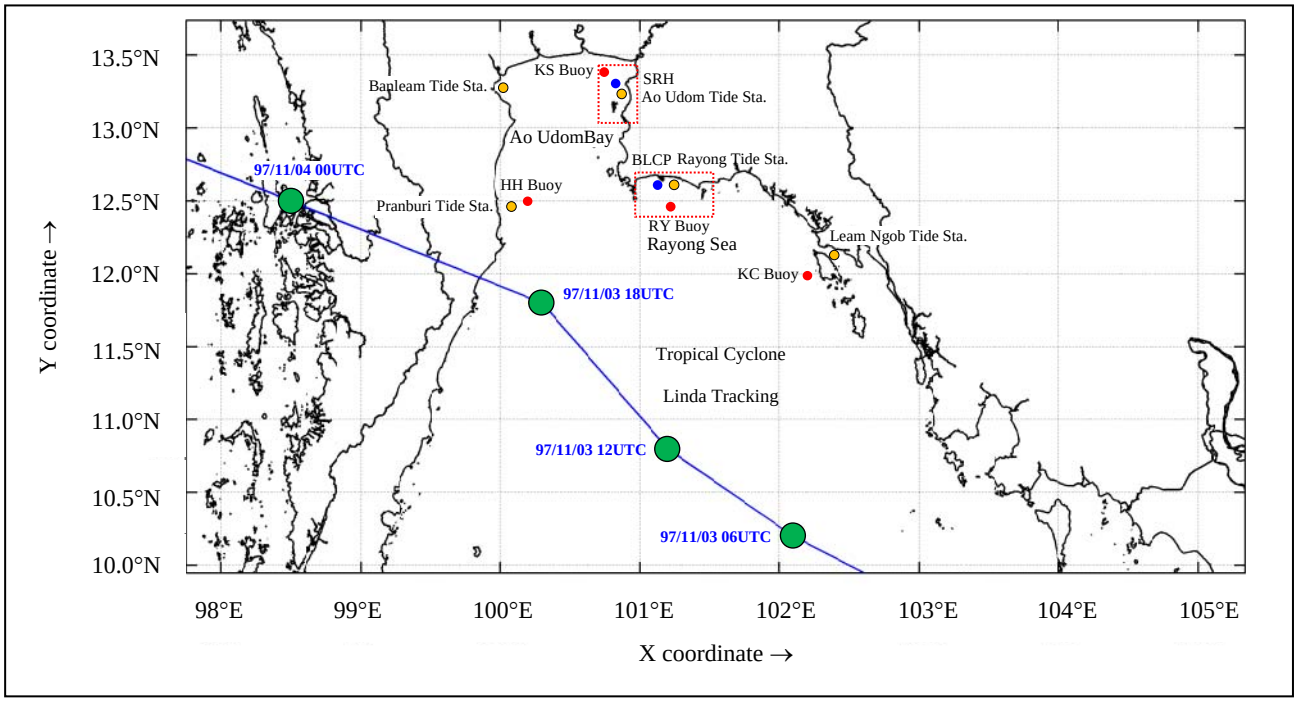


Fig. 1 Study area.

wave-wave interactions (decaying, spreading), partial transmission and reflection over structures. It handles curvilinear grids and nesting and non-stationary conditions, which allows its use in most coastal locations.

The wave model bathymetry based on THAI nautical charts and the General Bathymetric Chart of the Oceans [5] dataset of bathymetry as shown in Figs. 1-3. The nautical charts are surveyed by Hydrographic Department, Royal Thai Navy, and the charts consist of THA-142 and THA-164 for modeled wave model 1 at Ao Udom Bay and THA-142, THA-157 and THA-170 used for modeled wave model 2 at Rayong Sea respectively.

A number of model grids have been used. The first coarse grid is too large to grow waves within the Gulf of Thailand. Two nested calculation grids have been developed in addition to this coarse grid, to gradually increase the accuracy of the model at the site, and thus to obtain a better estimation of the wave characteristics at the port. Table 1 summarizes the grid characteristics.

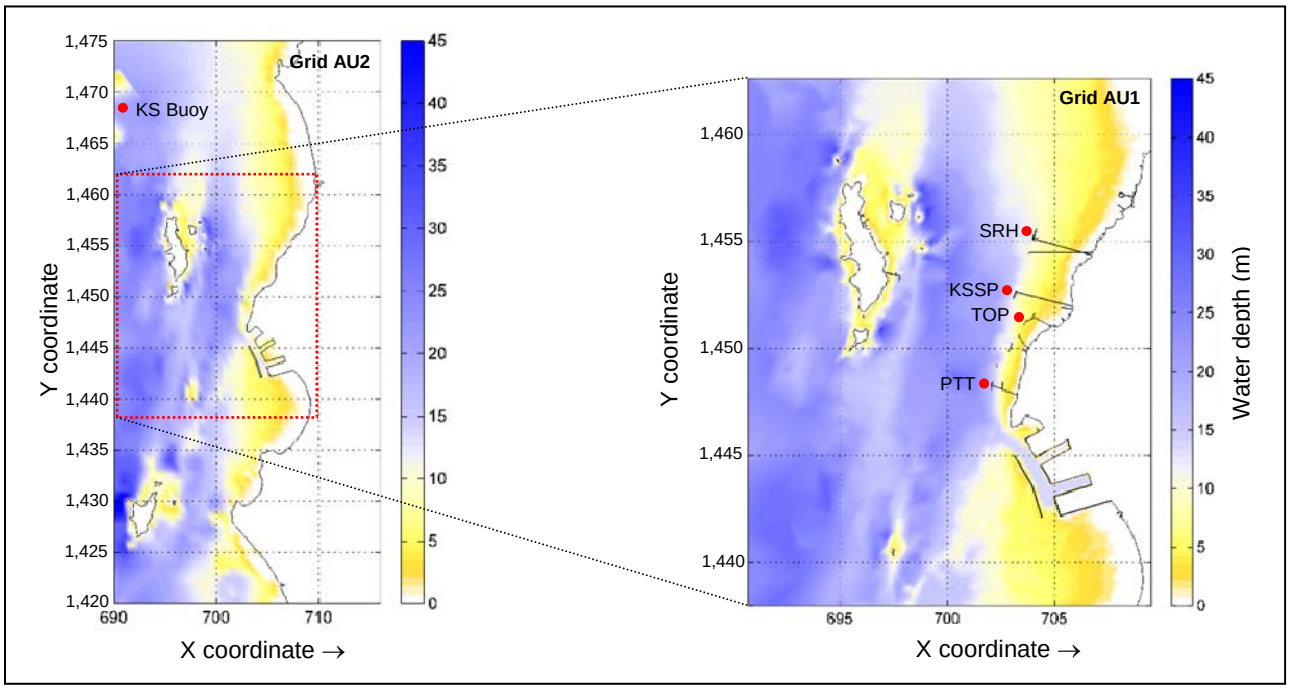


Fig. 2 Computational grid AU1 and grid AU2.

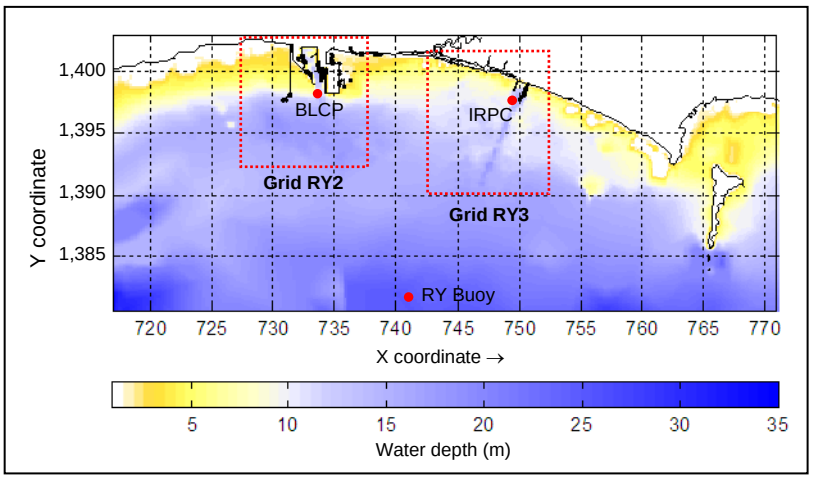


Fig. 3 Computational grid RY1, nesting grid RY2 and nesting grid RY3.

Table 1 Wave computational grid details.

Grid	Grid size	Cell size	Cell number X-direction	Cell number Y-direction	Origin *x*, *y* (m) WGS84	Rotation (Deg)
Wave model 1: Ao Udom Bay						
Grid AU1	26 km × 55 km	880 m × 680 m	109	55	689,811.94, 1,419,546.00	0
Grid AU2	18.8 km × 24.6 km	330 m × 480 m	163	163	690,671.63, 1,437,774.00	0
Wave model 2: Rayong Sea						
Grid RY1	54 km × 22.5 km	203 m × 195 m	325	167	716,938.81, 1,380,070.00	0
Grid RY2	8.9 km × 11 km	67 m × 68 m	136	190	729,906.63, 1,392,941.50	0
Grid RY3	8.9 km × 10.9 km	149 m × 136 m	82	82	744,447.19, 1,390,309.40	0

3.2 Wave Model Results

The model results have selected the point of locations at SRH and BLCP, which obtained the significant wave height, wave period and wave direction as necessary to assign the input parameters for ship mooring analysis. The model results show the significant wave height at Ao Udom Bay is smaller than the wave height at Rayong Sea. Additionally, the model results include the significant wave height at KSSP (Kerry Siam Seaport), TOP (Thai Oil Jetty), PTT (PTT Jetty) and IRPC (IRPC Port) for representing the wave height at the port in Ao Udom Bay and Rayong Sea.

3.3 Wave Model Validation

The wave model validation is a comparison between the observed significant wave height and wave model results at KS and RY buoy with time series. The differential of wave height can be represented in R-square. The R-square is equal to 1.0, meaning the model results of significant wave height are in agreement. The comparison of wave height and wave period at KS and RY buoy is in agreement as shown in Figs. 4-9, and R-square is 0.96 of wave height at KS buoy, and 0.92 of wave height at RY buoy.

4. Hydrodynamics Model

A Delft3D-FLOW model of the Upper Gulf of Thailand has been developed to estimate stormwater level, current speed and storm surges generated by tropical cyclone Linda. Delft3D-FLOW is a 2D/3D modeling system used to investigate hydrodynamics, sediment transport and morphology and water quality for fluvial, estuarine and coastal environments. The computer software is continuously improved and developed with innovative advanced modeling techniques as a consequence of the research work of

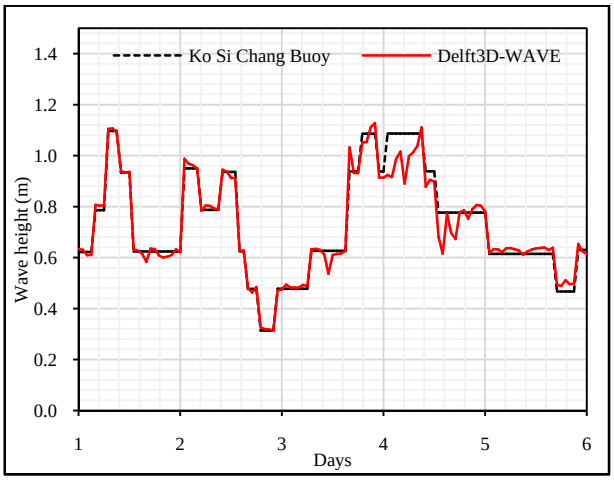


Fig. 4 Observed significant wave height and wave model result at KS Buoy.

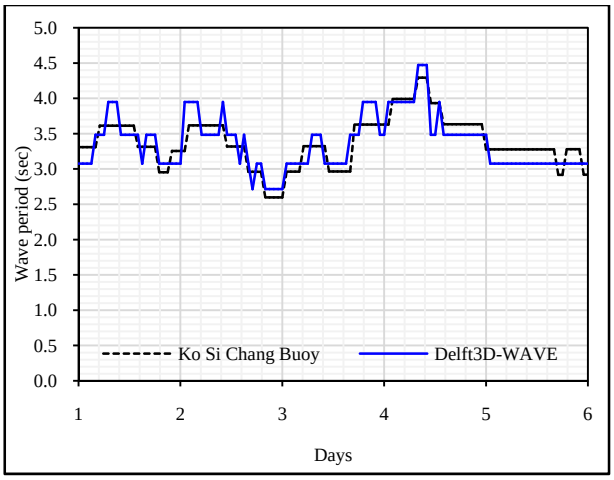


Fig. 5 Observed wave period and wave model result at KS Buoy.

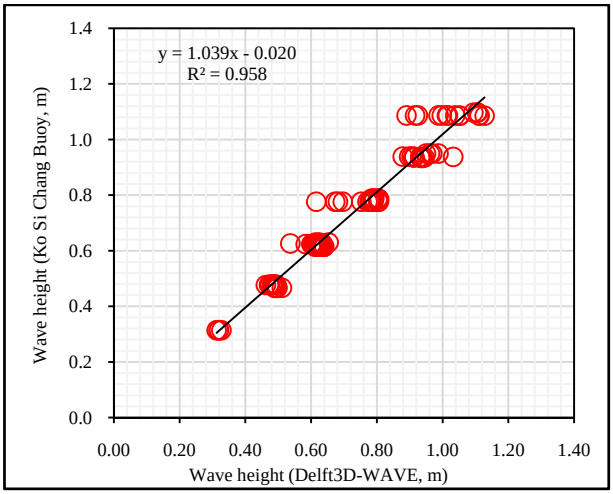


Fig. 6 Significant wave height comparison at KS Buoy.

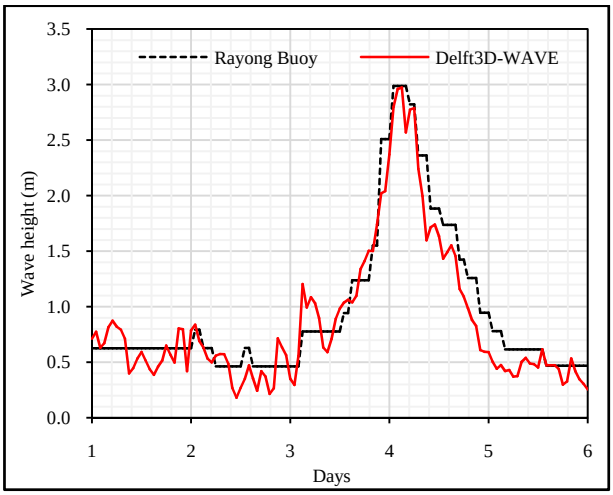


Fig. 7 Observed significant wave height and wave model result at RY Buoy.

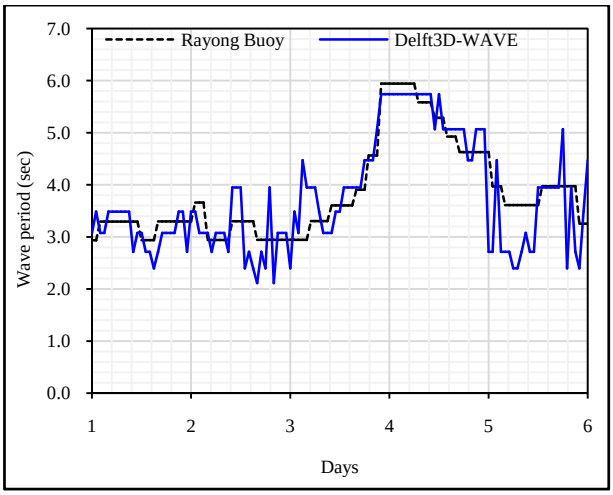


Fig. 8 Observed wave period and wave model result at RY Buoy.

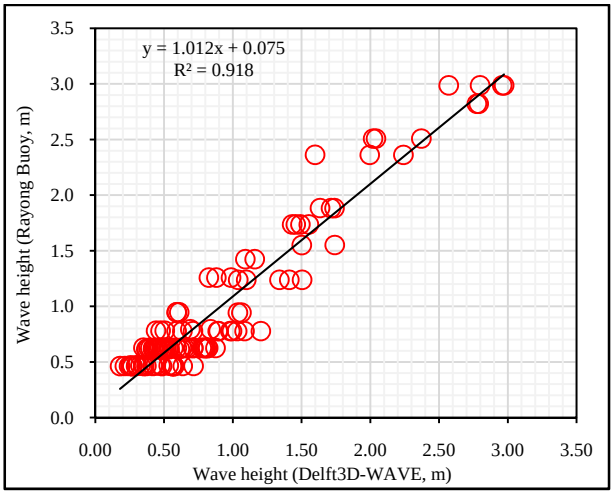


Fig. 9 Significant wave height comparison at RY Buoy.

Deltares. The wind set-up develops across the Upper Gulf of Thailand during tropical cyclone Linda, as a result of shear between the wind and the sea surface. This set-up, or surge, is inversely proportional to water depth, proportional to the fetch, and proportional to the square of the wind speed. A pressure set-up (known as the inverse barometer effect) also raises the water level. The storm surge is the combination of the wind and barometric set-up.

4.1 Hydrodynamics Model Set-Up

The data of wind speed and low pressure of tropical cyclone Linda can be collected from the JTWC (Joint Typhoon Warning Centre) [6], JMA (Japanese Meteorological Agency) [7] and Hong Kong Observatory [8]. The best tracks of three sources are different in time and the position of the typhoon center. This study selected the best track and database given by the JMA [7], the center of typhoon position and part as illustrated in Fig. 10. Storm surge is likely to be significant in event of a typhoon, but in the Gulf of Thailand hazard from storm surge is studied less. Fig. 11 showed the Delft3D-FLOW model computational grid for normal condition (tidal forcing) flow model and extreme model (storm surge).

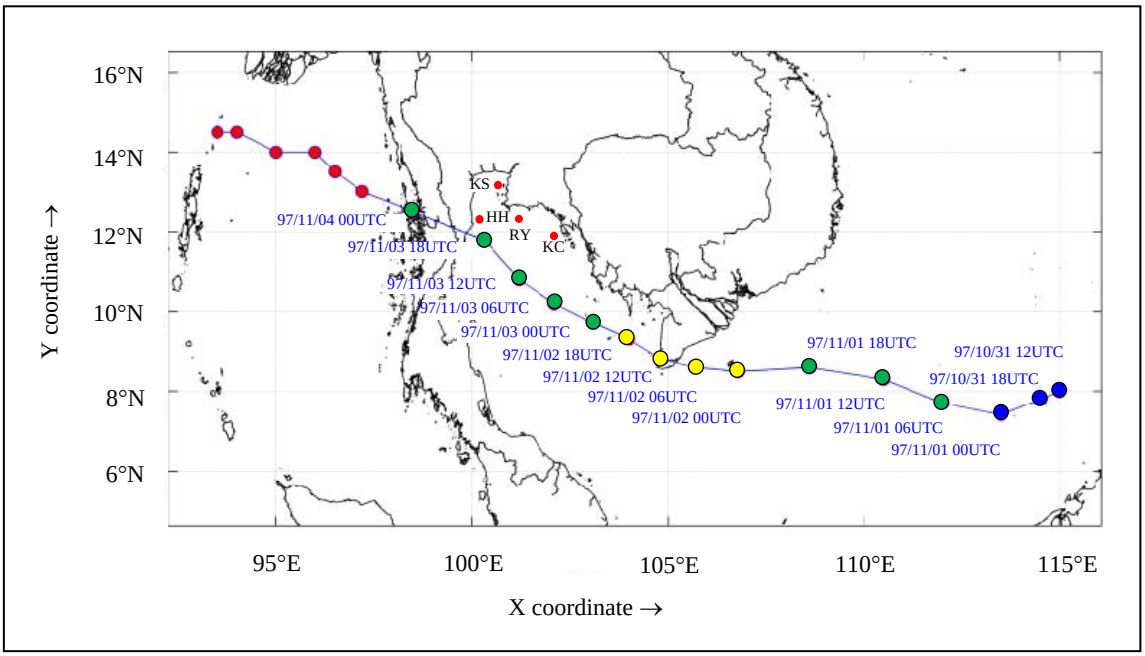


Fig. 10 Tropical cyclone Linda tracking.

4.2 Open Boundary

The Delft3D-FLOW model has been forced by both tidal harmonics and typhoon wind fields and pressure fields. The boundaries used are the water level at open boundaries which are the tidal constituents applied to the open boundary at South and East of the computational grid. The open boundary extended to the Malaysia and Vietnam coastline, given that the center of typhoon inside the computation grid during the events has low air pressure and strong wind speed. The open boundary is shown in Fig. 11. The tidal constituents are derived from tide analysis using the observed data at tide station for water level prediction and the tidal constituents at the open boundary are obtained from the Global Ocean Tides [9] and Global Tidal Solution (TPXO-8.0) [11].

4.3 Wind Model and Pressure Model

The wind model and pressures model [12] are used for defining the maximum wind speed and air pressure [13]. The radius of maximum wind speed is assumed to be 30 km as applied in the model and the radius is obtained by trial and error by comparsing the model results and observed data.

4.4 Hydrodynamics Model Results

The model results included the water level, tidal current in normal condition (tidal forcing) and extreme condition, also the storm tide level and surge height. Fig. 12 showed the water level in normal condition of low tide and high tide on 3rd November

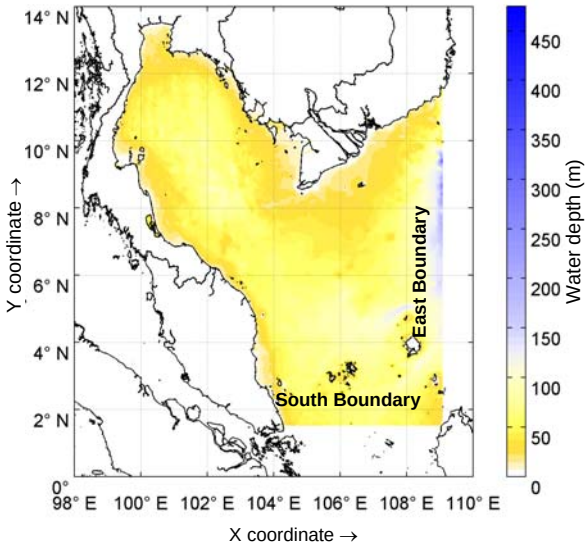
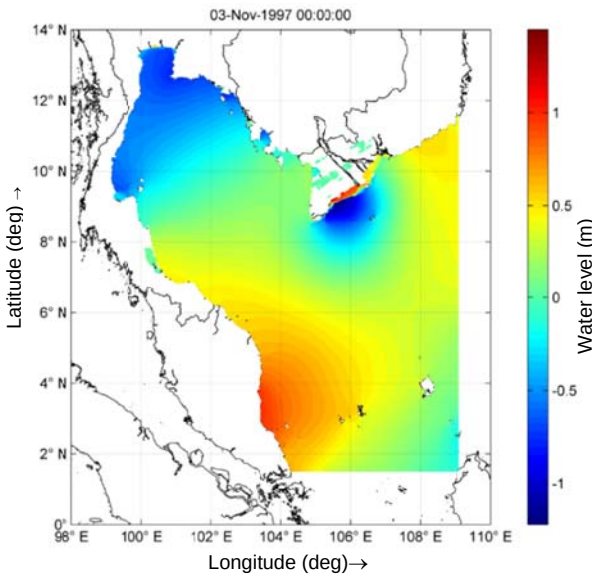
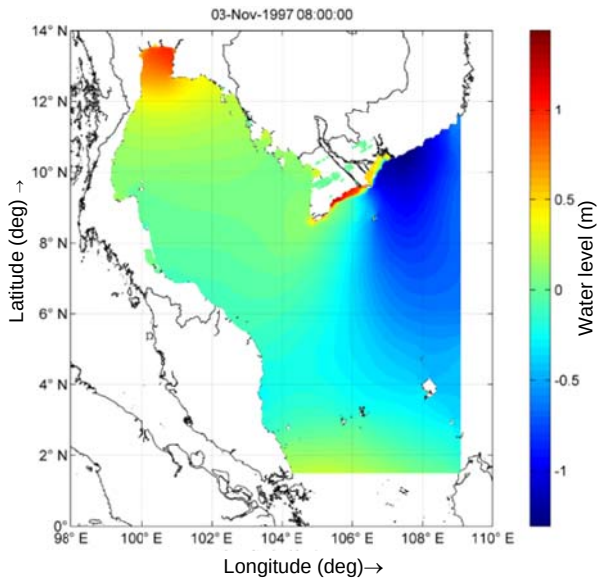


Fig. 11 Delft3D-FLOW model computational grid.



(a) Low tide at port



(b) High tide at port

Fig. 12 Water level snapshot in normal condition (MSL).

1997, the high water level becomes low tide when typhoon enters to the Gulf, these phenomena are a negative surge of the water level.

4.5 Hydrodynamics Model Validation

Validation of the hydrodynamics model has been undertaken for tidal conditions, to ensure the model can reproduce actual conditions with confidence. A comparison of tide levels at Pranburi Tide Station, Banleam Tide Station, Rayong Tide Station and Leam Ngob Tide Station was undertaken with water levels forced by tidal harmonics at the model boundary compared in order to the predict water levels at Tide Station. This is then compared to the simulations, prediction, and observation of tide and current. The comparison showed good agreement, showing that the hydrodynamics model accurately represents tidal sloshing in the Upper Gulf of Thailand. In the extreme condition, the validation is a comparison between simulated wind speed, air pressure and current by observed met-ocean data at RY, HH and KC Buoy. The comparison shows good agreement as shown in Figs. 13-16.

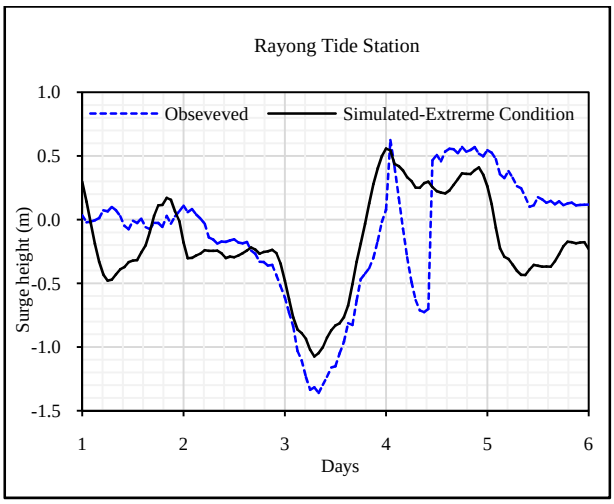


Fig. 13 Surge height at Rayong tide station (+7:00 UTC).

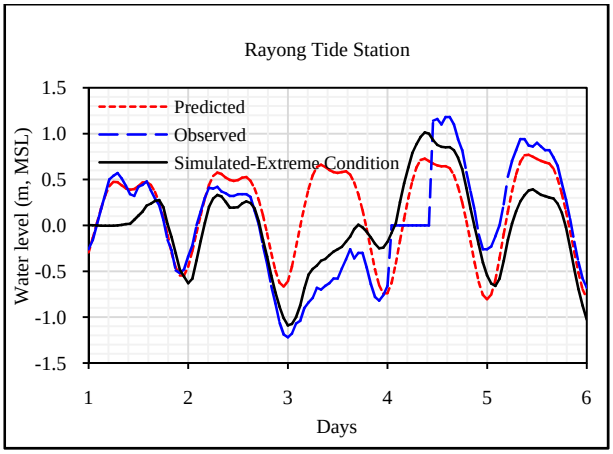


Fig. 14 Water level at Rayong tide station since 1st November to 6th November 1997 (+7:00 UTC).

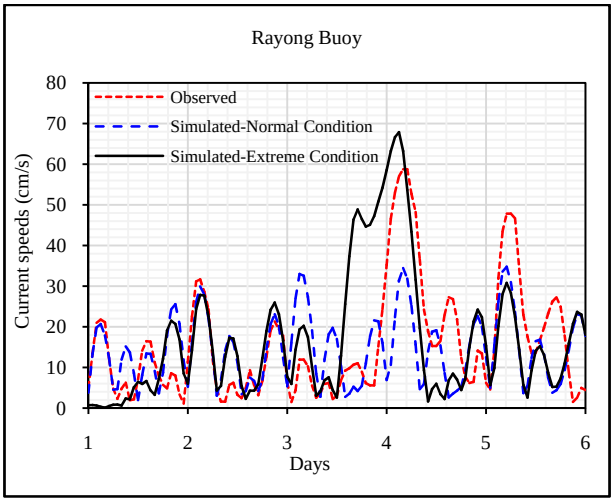


Fig. 15 Current speed at Rayong Buoy since 1st November to 6th November 1997 (+7:00 UTC).

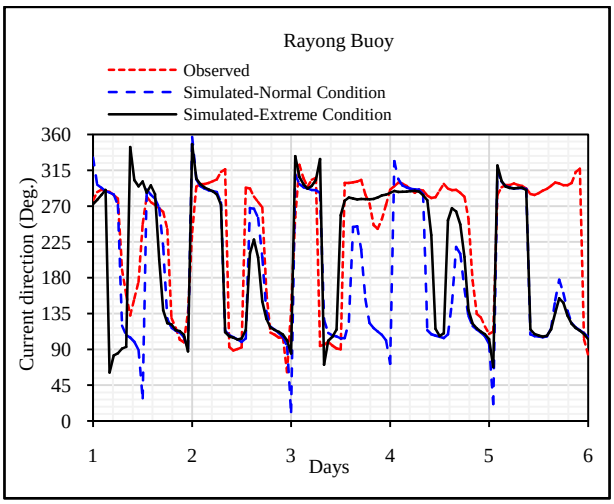


Fig. 16 Current direction at Rayong Buoy since 1st November to 6th November 1997 (+7:00 UTC).

5. Static Moored Ship Motions

5.1 Mooring Equations

The formulation of mooring problem follows the study of Natarajan and Ganapathy [3], which uses the direct stiffness method of mooring rope formed in stiffness matrix and the equilibrium of internal and external forces. The mooring pattern usually consists of head lines, breast lines, spring line and stern lines that have different angular orientation according to the international design standard such as Spanish Standard (ROM 0.2-1990) [1], British Standard BS6349 [15] and Oil Companies International Marine Forum (OCIMF) [16] guidelines as shown in Fig. 17 [3]. The numbers of mooring lines depend on the external forces subject to the wind, wave current and tide considering the operation conditions at the fully loaded and ballasted condition. The behavior of mooring poses is complicated in a nonlinear problem, in which the mooring lines hang in the air as non-coplanar catenaries [3], the assumption of the formulation assumed to straight mooring lines non-hanging in the air, and the constant stiffness of mooring line. The mooring equation is carried out using the stiffness matrix of mooring line, translation and rotation vector and static forces vector in a six-degrees-of-freedom system as shown in Fig. 18 [3]. The elastic stiffness of the mooring lines on its principal direction is represented by

$$k = \left[\frac{EA}{L} \right] \tag{1}$$

where, k is the stiffness of the mooring line along its own axis (kN/m^2), E is Young's modulus of the mooring line (kN/m^2), A is cross-sectional area of the mooring line (m^2), and L is length of mooring line

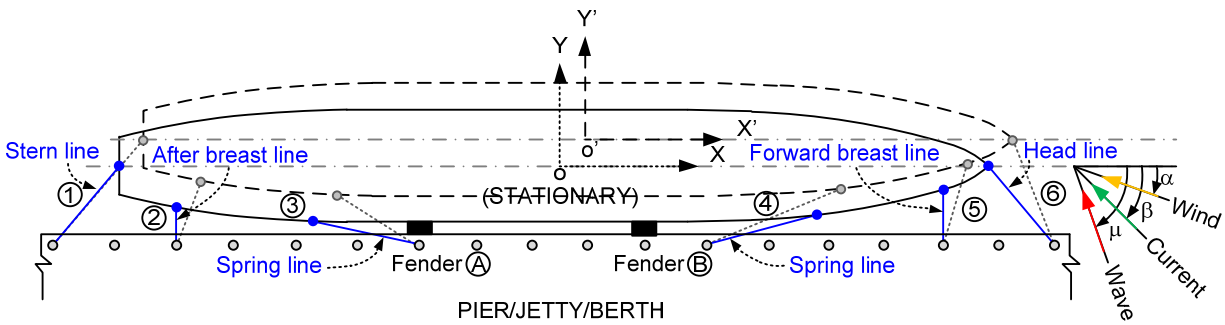


Fig. 17 Mooring arrangements.

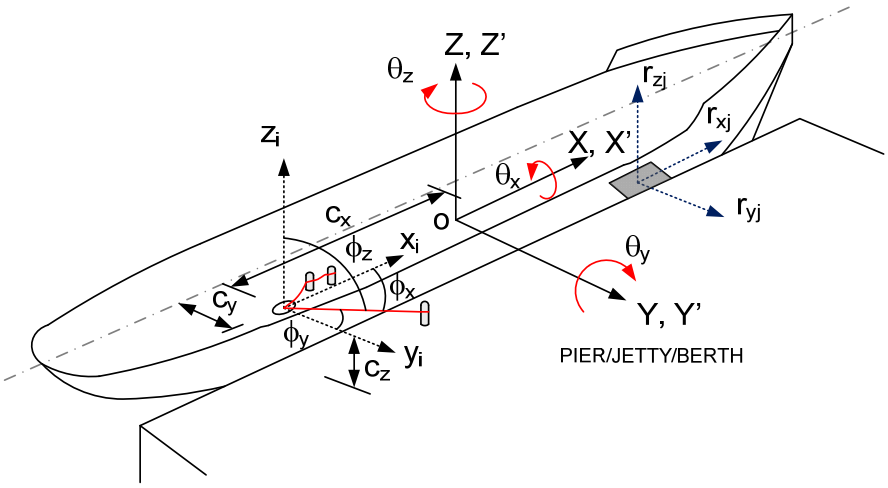


Fig. 18 Mooring coordinates.

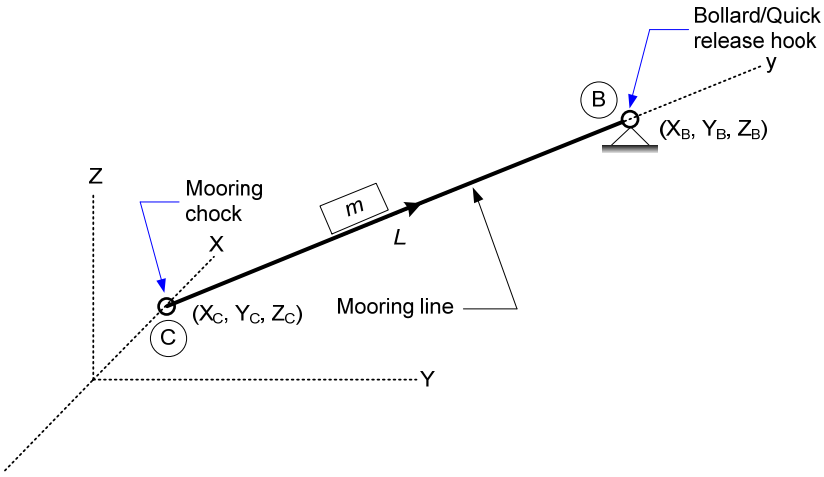


Fig. 19 Space mooring line coordinate transformations.

from the mooring bitt to the bollard (m). The coordinate transformations are considered an arbitrary member *m* of a space mooring lines as shown in Fig. 19, and let X_C, Y_C, Z_C and X_B, Y_B, Z_B be the global coordinate of the joints to which the member end C and B respectively. Then, the cosines of the member can be expressed in terms of the global coordinate by the following relationships:

$$L = \sqrt{(X_C - X_B)^2 + (Y_C - Y_B)^2 + (Z_C - Z_B)^2} \quad (2a)$$

$$\cos\phi_x = \frac{X_C - X_B}{L} \quad (2b)$$

$$\cos\phi_z = \frac{Z_C - Z_B}{L} \quad (2c)$$

$$\cos\phi_y = \frac{Y_C - Y_B}{L} \quad (2d)$$

The global stiffness matrix of ith mooring line can be expressed as

$$[K]_i = \frac{EA}{L}\begin{bmatrix} \cos^2\phi_x & \cos\phi_x\cos\phi_y & \cos\phi_x\cos\phi_z \\ \cos\phi_x\cos\phi_y & \cos^2\phi_y & \cos\phi_y\cos\phi_z \\ \cos\phi_x\cos\phi_z & \cos\phi_y\cos\phi_z & \cos^2\phi_z \end{bmatrix}_i \quad (3a)$$

Hence

$$[K]_i = \begin{bmatrix} K_{xx} & K_{xy} & K_{xz} \\ K_{xy} & K_{yy} & K_{yz} \\ K_{xz} & K_{yz} & K_{zz} \end{bmatrix}_i \quad (3b)$$

The solution of mooring equations solves the global stiffness matrix of mooring line as expressed in Eq. (3) including the reactive forces and external forces as in equilibrium equations. The plane ship motions assume the vertical translation (U_z), the angular displacement of the ship due to heel (θ_x) and angular displacement of the ship due to trim (θ_y) equal to zero. Then, the mooring equations for plan-moored ship can be expressed as

$$\left[\begin{bmatrix} K_{xx} & K_{xy} & A_{13} \\ K_{xy} & K_{yy} & A_{23} \\ A_{31}^{*} & A_{32}^{*} & B_{33} \end{bmatrix}_{i=1} + \ldots + \begin{bmatrix} K_{xx} & K_{xy} & A_{13} \\ K_{xy} & K_{yy} & A_{23} \\ A_{31}^{*} & A_{32}^{*} & B_{33} \end{bmatrix}_{i=n}\right] \cdot \begin{Bmatrix} U_x \\ U_y \\ \theta_z \end{Bmatrix} = \begin{Bmatrix} F_x wind + F_x current + F_x wave \\ F_y wind + F_y current + F_y wave \\ M_z wind + M_z current + M_z wave \end{Bmatrix} \tag{4a}$$

$$A_{13} = K_{xy}C_x - K_{xx}C_y \tag{4b}$$

$$A_{23} = K_{yy}C_x - K_{xy}C_y \tag{4c}$$

$$A_{31}^{*} = K_{xy}C_x - K_{xx}C_y \tag{4d}$$

$$A_{32}^{*} = K_{yy}C_x - K_{xy}C_y \tag{4e}$$

$$B_{33} = K_{xx}C_y^2 + K_{yy}C_x^2 - 2K_{xy}C_xC_y \tag{4f}$$

where C_x, C_y and C_z are point coordinates of the ith mooring chock from the center of the ship as shown in Fig. 19. MATLAB computer program is an application written for the mooring equation as in the matrix and solved using the equation of motion for obtaining the moored ship motions in the two-dimensional plan.

5.2 Extreme Force on Moored Ship

The extreme forces on moored ship are the equivalent static forces in the longitudinal and transverse direction. The method of obtained static force follows the maritime design standard and design guidelines such as Spanish Standard (ROM 0.2-1990) [1], British Standard (BS6349) [15] and OCIMF (Oil Companies International Marine Forum) [16], the design standard was expressed the horizontal forces and moments but OCIMF and BS6349 are not applicable to the calculation of wave force as tabulated in Table 2. In this study, the equivalent static forces are calculated according to the Spanish Standard (ROM 0.2-1990) [1] for completely the environmental forces on the moored ship with included static wind force, static current force, static current drag force and static wave force.

5.3 Validation

The validation of static moored ship analysis is a comparison between of analysis results of computer program using MATLAB computer program and the analysis results of Natarajan and Ganapathy [3], they studied the behavior of moored ship at port using computer programming called “SHIP MOOR” with 6 DOFs. The degrees of freedom include ship translation and rotation; such as swaying, surging, yawing, heaving, pitching and rolling. The studies include the comparison between the results of model experiments and results of a computer program using

Table 2 Static forces comparison of design standards.

OCIMF	ROM 0.2	BS 6349
Wind force	*Wind force*	*Wind force*
- Longitudinal static wind force	- Longitudinal static wind force	- Longitudinal static wind force
- Transverse static wind force	- Transverse static wind force	- Transverse static wind force
- Static wind moment	- Static wind moment	
Current force	*Current force*	*Current force*
- Longitudinal static current force	- Longitudinal static current force	- Longitudinal static current force
- Transverse static current force	- Transverse static current force	- Transverse static current force
- Static current moment	- Static current moment	
Wave force	*Wave force*	*Wave force*
Not applicable	- Longitudinal static wave force	Not applicable
	- Transverse static wave force	

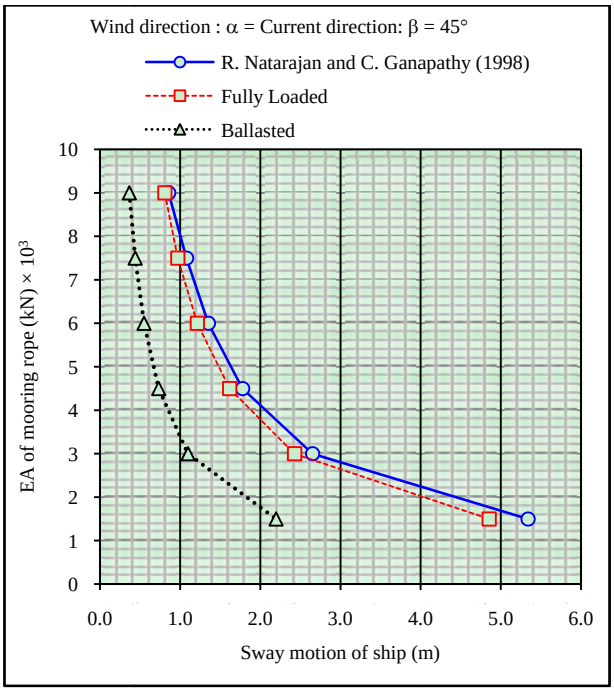


Fig. 20 Comparison of sway motion of ship.

SHIP MOOR.

The comparison satisfactorily agrees when compared with the results between SHIP MOOR program and MATLAB Computer Program in the fully loaded condition as shown in Fig. 20. The error is an result of the ship size data and the information of the water level because these two parameters are assumed in the static forces calculation.

6. Static Moored Ship Motions Analysis

The mooring analysis can be evaluated by the effects of environmental conditions such as the wind, wave and current on the moored ship at port. Also, it can provide the mooring force for berth/port structural design and is used to obtain the results in the analysis in the selection of mooring hooks and bollards. In addition, it can provide the preliminary assessment of the adequacy of the mooring arrangements and fendering at berth/port and wharf and, by comparing the mooring line tension forces, ship movements while moored, and fender breasting forces within the allowable limits. The allowable limitations are referenced in the maritime international design standard. In this study PIANC 1995 [2] limiting the ship motions at the port will be used.

The mooring analysis is evaluated in two-dimensional motions subjected to the severe wind, wave and current event tropical cyclone Linda at SRH and BLCP. The analysis ignored the impact of passing ships on the moored ship at berth/port.

6.1 Ship Data

Two ship sizes are evaluated in the analysis, the bulk carrier 50,000 DWT and 5,000 DWT with assumed to represent the maximum ship size and minimum ship size at port/berth. The list of ship data is shown in Table 3 referenced from Ship Tables in PIANC 2002 [17] at 75% confidence limits.

6.2 Mooring Rope Properties

The rope characteristics are assumed to be constant and the elastic modulus of mooring rope varies from 1,527,887.45 kN/m^2 to 4,583,662.36 kN/m^2 for a 50 mm rope diameter.

6.3 Mooring Arrangements

The bulk carrier 50,000 DWT and 5,000 DWT ships are proposed to be moored with a typical six lines mooring arrangement consisting of head line, forward breast line, forward spring line, after spring, after breast line and stern line. Two fenders were in full contact with the vessel's flatside, as shown in Figs. 21-24 at SRH and BLCP, respectively.

6.4 Environmental Conditions

The environmental conditions are the results of extreme wave model and hydrodynamics model as represented above. The mooring analysis will start at 16:00 (+7.00UTC) on 3rd November and continue to 07:00 (+7.00UTC) on 4th November 1997, in every hour as tabulated in Tables 4 and 5.

The tide level for the mooring analysis is a reference to the center of the ship at LLW (lowest low water) level of the top of the platform as shown in

Figs. 21-24. The tidal information sourced from the Thailand's Marine Department for adjusting the storm tide level (reference to MSL) to LLW level, at Ao Udom Tide Station for SRH and Rayong Tide Station for BLCP. The storm tide level is a reference to LLW as tabulated in Tables 4 and 5.

Table 3 Ship parameters.

Parameters	Max. ship	Min. ship
Ship type	Bulk carrier	Bulk carrier
Deadweight tonnage, DWT (ton)	50,000	5,000
Displacement, M_{75} (ton)	59,600	6,920
Length overall, LOA (m)	204	109
Length Bet. Perp., LBP (m)	194	101
Beam (m)	32.3	15.50
Freeboard (m)	4.8	2.40
Draft (m)	12	6.20
Lateral wind area (m^2): Full load	1,640	689
Lateral wind area (m^2): Ballast	2,870	910
Front wind area (m^2): Full load	479	221
Front wind area (m^2): Ballast	682	245

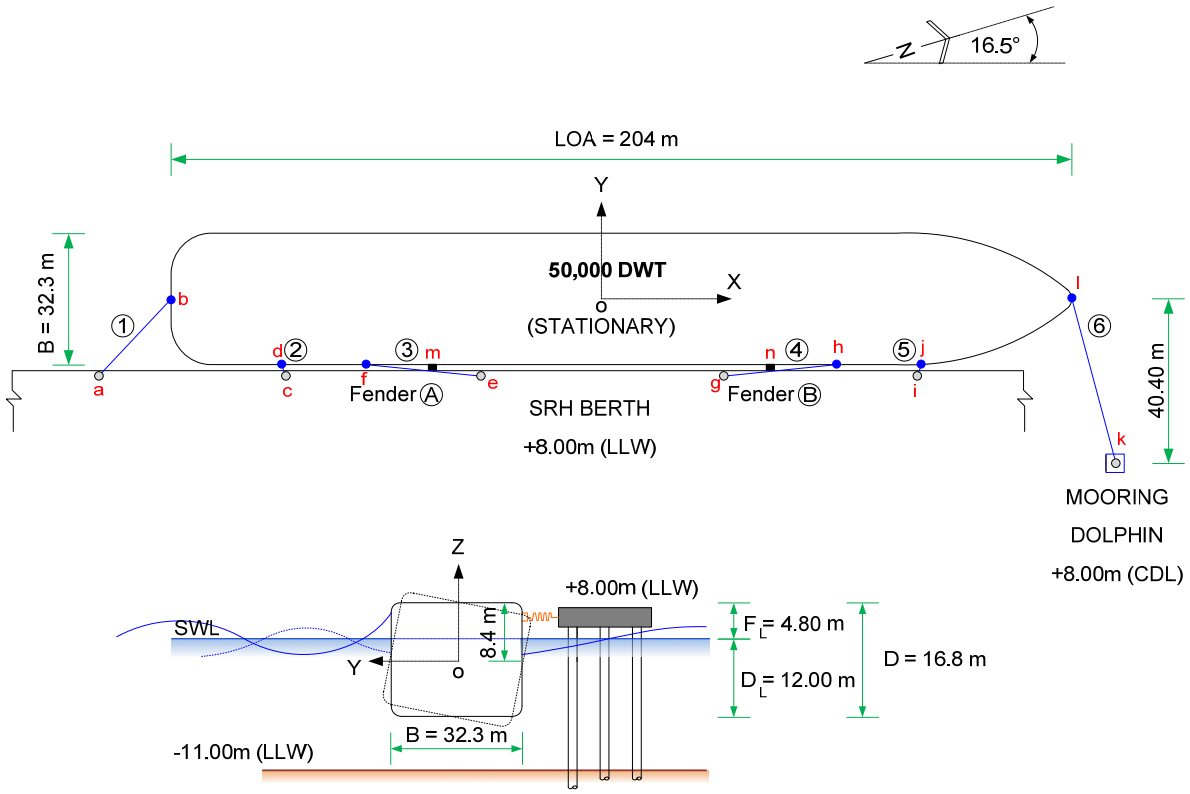


Fig. 21 Mooring arrangement at SRH port for 50,000 DWT ship.

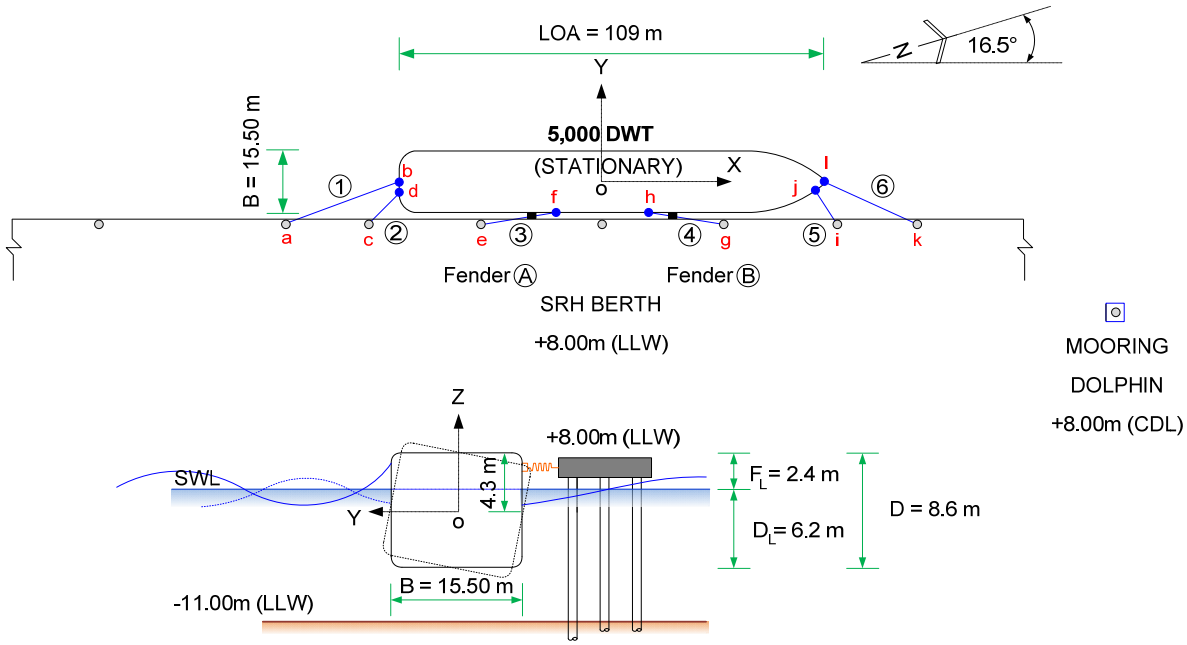


Fig. 22 Mooring arrangement at SRH port for 5,000 DWT ship.

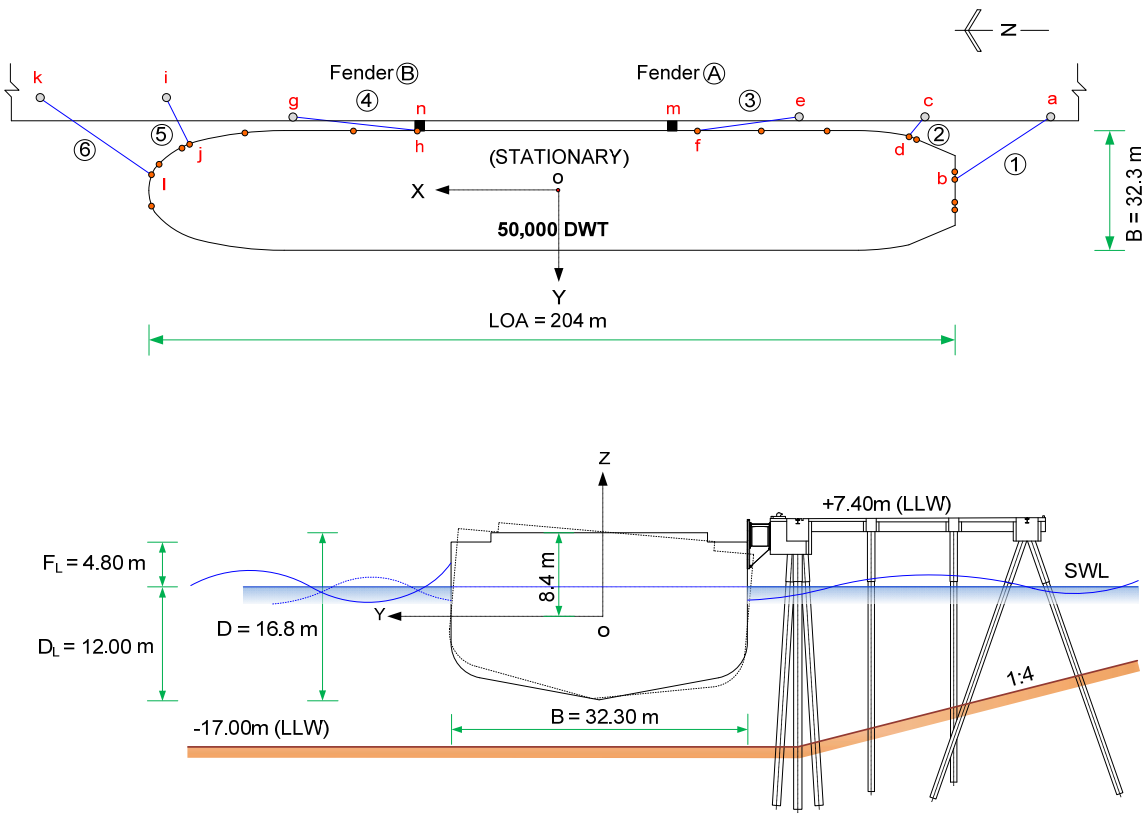


Fig. 23 Mooring arrangement at BLCP port for 50,000 DWT ship.

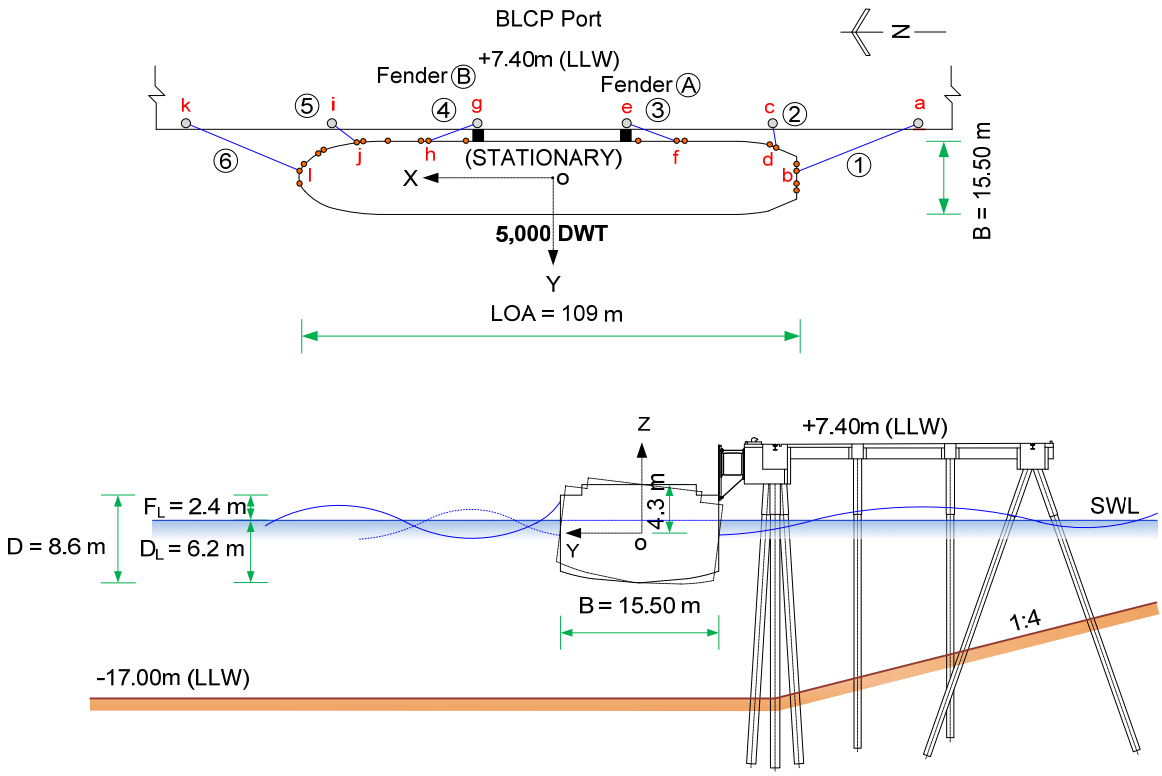


Fig. 24 Mooring arrangement at BLCP port for 5,000 DWT ship.

Table 4 Environmental conditions for static moored ship motions analysis at SRH port.

No.	Time	Water level (m, MSL)	Water level (m, LLW)	Wind		Wave			Current	
				Speed (m/s)	Dir. (Deg.)	*Hs* (m)	T_p (s)	Dir. (Deg.)	Speed (m/s)	Dir. (Deg.)
1	97/11/03 16:00	-0.35	2.12	9.37	314.66	0.93	3.95	318.39	0.04	193.85
2	97/11/03 17:00	-0.19	2.28	10.04	337.86	1.01	3.95	331.44	0.03	0.59
3	97/11/03 18:00	-0.02	2.45	10.04	338.83	1.01	3.95	332.06	0.08	5.58
4	97/11/03 19:00	0.07	2.54	11.56	8.54	1.09	3.95	348.98	0.11	8.43
5	97/11/03 20:00	0.00	2.47	11.59	8.46	1.09	3.95	349.16	0.09	6.26
6	97/11/03 21:00	-0.15	2.32	11.45	49.67	0.78	3.48	19.11	0.04	340.46
7	97/11/03 22:00	-0.35	2.12	11.55	33.90	0.91	3.95	5.57	0.05	216.67
8	97/11/03 23:00	-0.53	1.94	10.54	11.23	0.92	3.95	351.17	0.10	203.87
9	97/11/04 00:00	-0.57	1.90	10.56	11.13	0.92	3.95	350.94	0.10	204.81
10	97/11/04 01:00	-0.49	1.98	10.23	134.54	0.57	3.95	177.02	0.03	213.66
11	97/11/04 02:00	-0.32	2.15	10.06	138.08	0.58	3.95	182.53	0.10	4.63
12	97/11/04 03:00	0.00	2.47	11.16	116.82	0.47	2.11	125.53	0.25	7.01
13	97/11/04 04:00	0.44	2.91	11.39	106.74	0.45	2.11	100.64	0.35	8.62
14	97/11/04 05:00	0.88	3.35	6.59	185.09	0.60	3.95	211.28	0.42	10.38
15	97/11/04 06:00	1.29	3.76	5.39	202.75	0.57	4.47	218.49	0.47	11.00
16	97/11/04 07:00	1.62	4.09	8.08	190.67	0.76	4.47	210.84	0.43	9.48

Table 5 Environmental conditions for quasi-static moored ship motions analysis at BLCP port.

No.	Time	Water level (m, MSL)	Water level (m, LLW)	Wind		Wave		Current		
				Speed (m/s)	Dir. (Deg.)	*Hs* (m)	T_p (s)	Dir. (Deg.)	Speed (m/s)	Dir. (Deg.)
1	97/11/03 16:00	-0.04	1.54	12.66	10.79	0.37	2.40	346.94	0.50	273.87
2	97/11/03 17:00	0.01	1.59	13.79	19.55	0.40	2.40	2.48	0.45	273.88
3	97/11/03 18:00	-0.02	1.56	14.31	20.68	0.42	2.40	6.01	0.41	273.60
4	97/11/03 19:00	-0.07	1.51	14.55	33.35	0.47	3.95	62.30	0.41	273.14
5	97/11/03 20:00	-0.13	1.45	14.01	46.19	0.55	4.47	110.85	0.44	273.34
6	97/11/03 21:00	-0.20	1.38	15.47	42.03	0.62	4.47	99.14	0.47	273.67
7	97/11/03 22:00	-0.25	1.33	14.59	43.42	0.75	6.50	129.91	0.50	274.25
8	97/11/03 23:00	-0.24	1.34	12.53	68.92	1.06	5.74	150.74	0.48	274.40
9	97/11/04 00:00	-0.18	1.40	12.42	91.99	1.39	6.50	159.76	0.46	274.75
10	97/11/04 01:00	-0.08	1.50	13.04	131.54	1.89	6.50	174.34	0.46	274.90
11	97/11/04 02:00	0.02	1.60	9.81	132.58	2.05	6.50	181.21	0.46	274.67
12	97/11/04 03:00	0.25	1.83	9.95	124.78	2.00	6.50	177.09	0.44	274.71
13	97/11/04 04:00	0.46	2.04	10.02	95.48	1.49	6.50	164.39	0.40	274.41
14	97/11/04 05:00	0.63	2.21	10.60	122.71	1.92	6.50	173.38	0.31	274.26
15	97/11/04 06:00	0.79	2.37	11.93	133.65	2.04	6.50	176.00	0.24	274.30
16	97/11/04 07:00	0.88	2.46	10.23	131.22	1.58	5.74	171.75	0.15	273.50

6.5 Results

SRH and BLCP are using the crane for cargo handling along with PIANC 1995 [2] given the limitations of ship motions for allowing the port operation are 2 m of the surge, 1 m of sway and 2 degrees of yaw. These limitations are used to compare the mooring analysis results in terms of ship motions. The ship motions are analyzed in the case of variation of the stiffness of mooring rope, ship size and the operation conditions including fully loaded and ballasted as shown in Figs. 25 and 36. The ship motions at SRH Port are large in the ballasted condition, but the ship motions at BLCP Port are large in the fully loaded condition when tropical cyclone Linda entered the Gulf of Thailand. This is because of the low current speed at SRH Port compared to wind speed and therefore becoming the critical effect as in ballasted condition.

In the case of weak mooring rope stiffness, the ship motions are above the limitation, which is the maximum of a surge of 2.73 m, sway of 3.06 m and yaw motion of 3.68 degrees in the fully loaded condition at BLCP port.

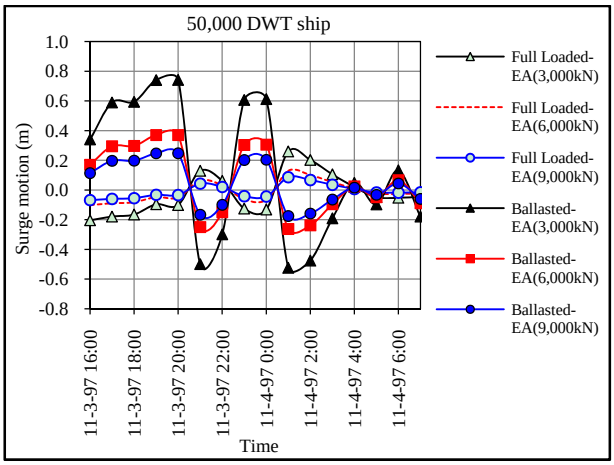


Fig. 25 Surge motion of 50,000 DWT at SRH port.

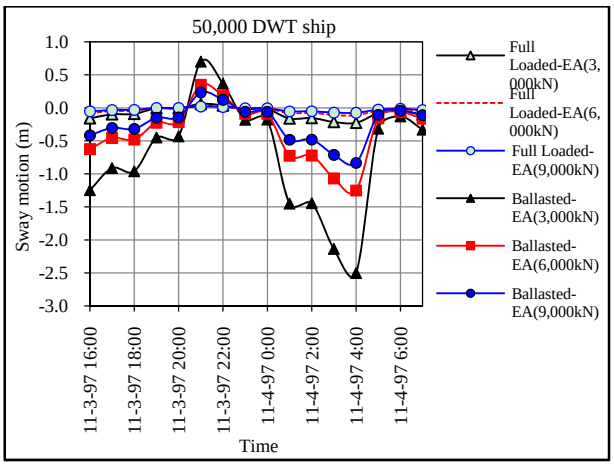


Fig. 26 Sway motion of 50,000 DWT at SRH port.

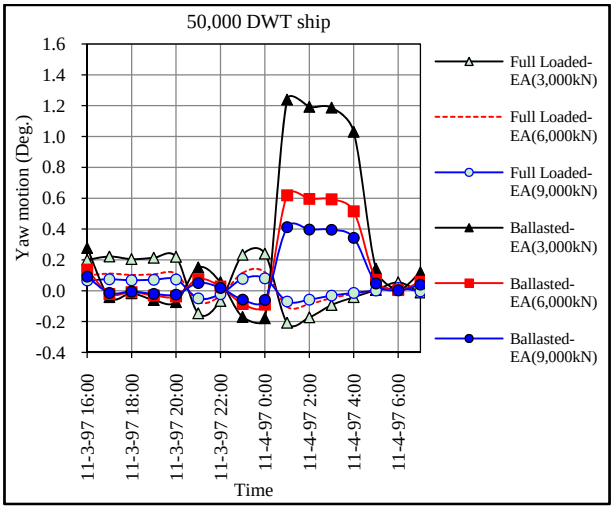


Fig. 27 Yaw motion of 50,000 DWT at SRH port.

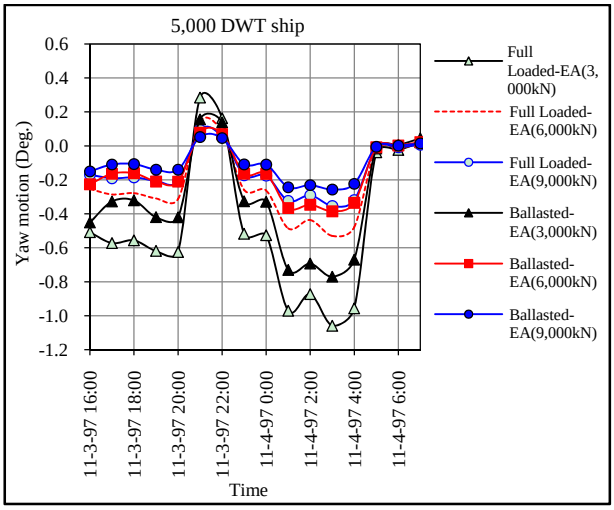


Fig. 30 Yaw motion of 5,000 DWT at SRH port.

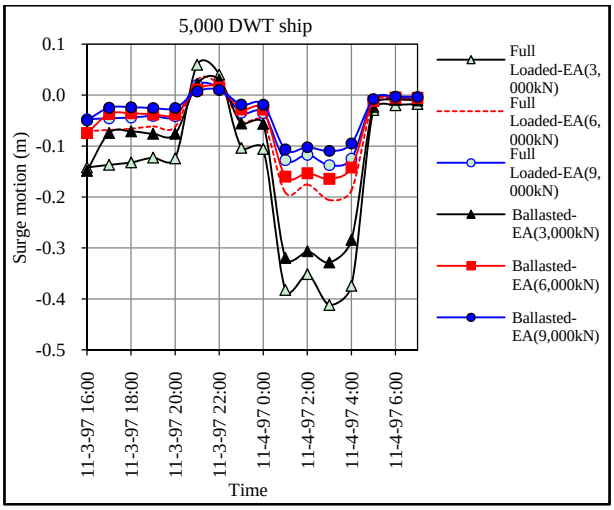


Fig. 28 Surge motion of 5,000 DWT at SRH port.

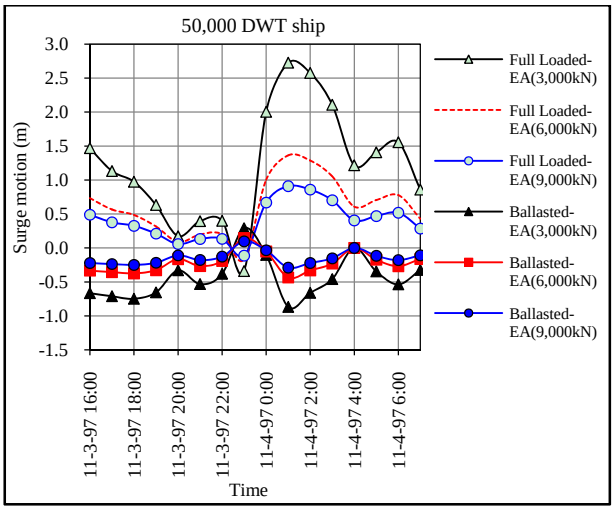


Fig. 31 Surge motion of 50,000 DWT at BLCP port.

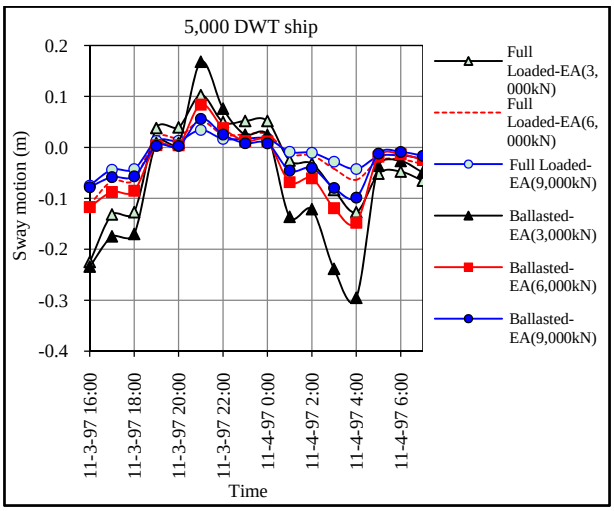


Fig. 29 Sway motion of 5,000 DWT at SRH port.

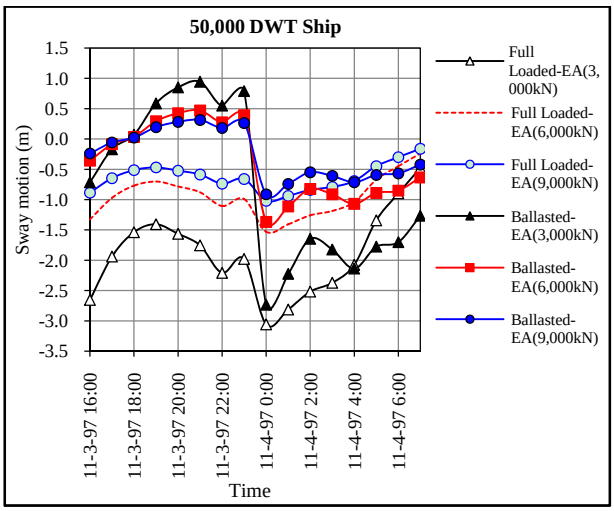


Fig. 32 Sway motion of 50,000 DWT at BLCP port.

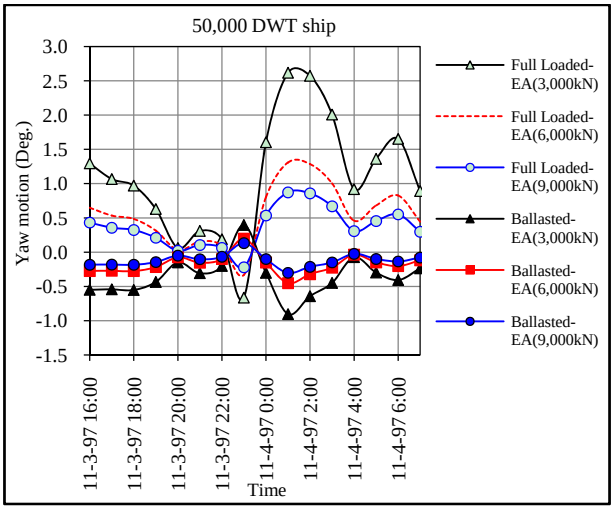


Fig. 33 Yaw motion of 50,000 DWT at BLCP port.

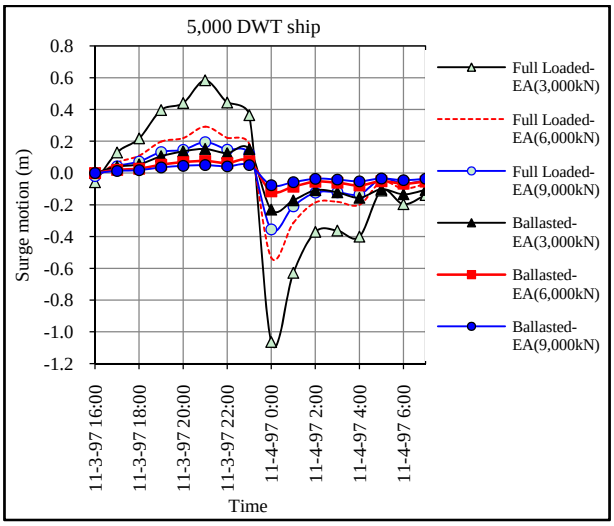


Fig. 34 Surge motion of 5,000 DWT at BLCP port.

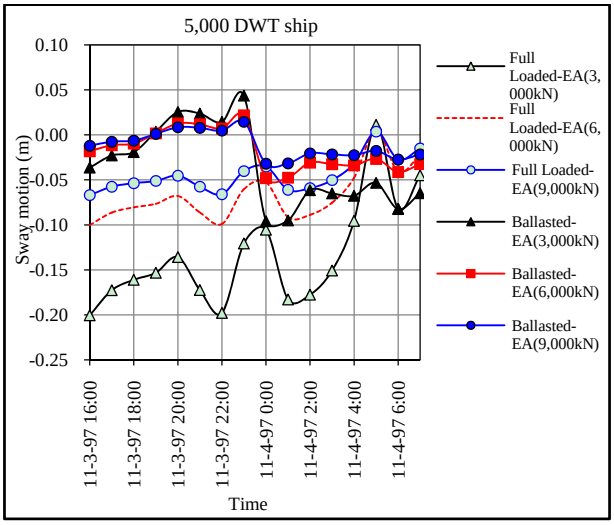


Fig. 35 Sway motion of 5,000 DWT at BLCP port.

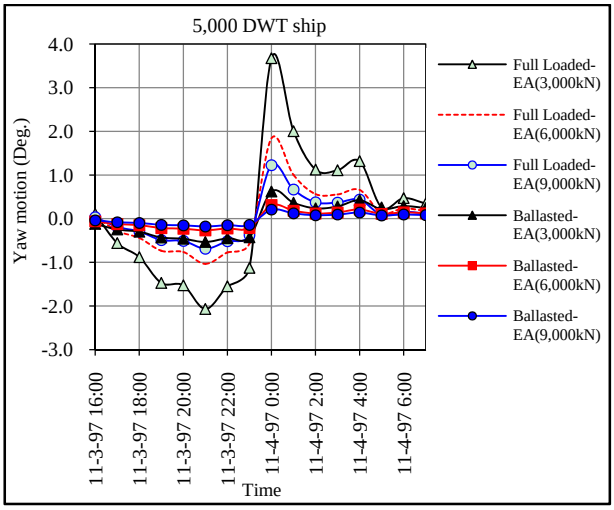


Fig. 36 Yaw motion of 5,000 DWT at BLCP port.

7. Conclusions

The significant wave height at port is the result of wave model in time series, and the maximum significant wave height due to tropical cyclone Linda at KSSP Port, PTT Port, SRH Port, TOP Port, BLCP Port and IRPC Port is a level of 1.12 m, 1.09 m, 1.09 m, 1.05 m, 2.05 m and 1.94 m, respectively. The significant wave height at Rayong Sea is more severe than Ao Udom Bay when tropical cyclone Linda entered the Gulf of Thailand. The storm surge due to tropical cyclone Linda, influences the negative surge and positive surge occurrence. The positive surge is a range from 0.5 to 1.3 m and negative surge 1.1 to 2 m.

The static mooring analysis is suitable for application of evaluating the effects of the environmental conditions where the significant wave height is not severe. The port in Upper Gulf of Thailand can use this method for calculating the mooring forces for the preliminary assessment of mooring arrangements.

The severe wind-wave due to tropical cyclone Linda affected the port operability and caused port downtime at SRH Port and BLCP Port. The sway motion is too large for the weak stiffness of mooring rope. However, in the case of the strong stiffness in to mooring rope, the ship motions are above the limitation as recommend by PIANC [2], because the

wind and wave direction are close to the direction of sway motions. The ship motions at BLCP Port are larger than SRH Port, because the location of BLCP Port is near to the center of the tropical cyclone where even strong wind and low air pressure occur. The ship motions can be reduced by increasing the stiffness of mooring rope using synthetic material. However, the mooring forces are not allowed more than 50% of minimum breaking strength.

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