

Study on Berth Operability due to Met-Ocean Data in Upper Gulf of Thailand

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*This dissertation is dedicated to
My Father, my Mother and my Family*

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Abstract

The study on berth operability is provided safe mooring and safe berthing of the ship at port and unhindered transfers of cargo between ship and land facility, and also berth operability is important for efficient berth operation that inference from an environmental condition such as the wind, wave and tidal current. There are no standard requirements for the environmental action for the operations of ports. The criteria for operations are based on the acceptable level of moored ship movement under the environmental loading, and coarse estimation by using the limitation of wind speed, significant wave height and current velocity at the port as provided in PIANC 1995 and PIANC 2014.

The berth operability is studied at the port in Eastern Thailand, which includes the area of study in Ao Udom Bay and Rayong Sea. The wave transformation is calculated by numerical wave model using Delft3D-WAVE (Open Source) for estimating the significant wave height transformation from the oceanographic buoys to port, and the hydrodynamics model will be set-up by using the application Delft3D-FLOW (Open Source) for estimation the tidal current at a port. The oceanographic buoys are operated by Geo-Informatics and Space Technology Development Agency (Public Organization: GISTDA) from 1991 to 2006. Nevertheless, this study is manually digitized time series data in GISTDA reports from 1991 to 2002 of three oceanographic buoys such as Ko Si Chang (KS), Rayong (RY) and Hua Hin (HH) buoys in the Gulf of Thailand. The met-ocean data was analyzed in short-term statistics that indicated the wind, wave and current intensity in each direction with 16 sectors by represented in the rose diagram and selected the data in dominant direction for applied as an input open boundary parameters in wave model.

The wave characteristic in East Coast of Thailand has studied the wave transformation from buoy to the port in Ao Udom Bay of observed the maximum significant wave height at Ko Si Chang (KS) buoy. The wind-wave uniform boundary is used the observed data and calculated by JONSWAP spectrum. The wave model results represent the maximum wave height at the front of Laem Chabang Port breakwater (LCP) of 2.17 m, PTT Jetty (PTT) of 2.19 m, Thai Oil Jetty (TOP) of 1.97 m, Kerry Siam Seaport (KSSP) of 2.26 m and Sriracha Harbour (SRH) of 2.35 m.

The coarse study of berth operability estimate by using the limitation of wind speed (20 to 22m/s), significant wave height (0.8 to 1 m) and current speed (0.7 m/s) at Bulk Carriers (SRH, KSSP and BLCP) and Oil Tankers (TOP, PTT and IRPC) port. The wind speed and current speed at port assumed to the equivalent observed met-ocean data at Ko Si Chang (KS) and Rayong (RY) buoy, and the significant wave height is a result of wave model. The wind speed is not severe within a range 4.89 to 10 m/s, and the wind speed is exceeding of 20 m/s that occur less than 1% of the time in monsoon season. The significant wave height is larger than 0.8 m at Bulk Carriers port, that occur 14.68%, 16.51% and 40.98% of SRH, KSSP, and BLCP respectively, and the significant wave height is larger than 1 m of Oil Tankers port, that occur 5.50%, 10.09% and 22.13% at TOP, PTT, and IRPC respectively. The current speed is under the limitation of criteria provided in PIANC 2014. Wave

disruption is a significant issue of berth operability, while the wind and current are a lesser issue of the port in Ao Udom Bay and Rayong Sea.

The details study of berth operability is the limitation of moored ship motions at the port, the ship motions analyzed by using the elastic equations of direct stiffness method as the equilibrium of internal forces and external forces. The static forces on moored ship are calculated by following the Spanish Standard (ROM 0.2-1990), which includes the wind, wave, and current forces, and the ship motions are two-dimensional motions (three-degrees-of-freedom system) such as surge, sway, and yaw motions. In this study, the moored ship motions are extreme conditions due to tropical cyclone Linda, which entered to the Gulf of Thailand in November 1997. The environmental condition is the results of wave model and hydrodynamics model at the port, which derived the significant wave height, water level, storm surge and tidal current. The model results represent the maximum significant wave height at KSSP of 1.12 m, PTT of 1.09 m, SRH of 1.09 m, TOP of 1.05 m, BLCP of 2.05 and IRPC of 1.94 m. Therefore, the significant wave height at Rayong Sea are larger than Ao Udom Bay, and the storm surge is phenomena of the negative surge and a positive surge in East coast of Thailand, which is a positive surge in a range of 0.5 to 1.3 m and the negative surge of 1.1 to 2 m.

The static mooring analysis is the method for calculation of the moored ship motions when the study area without the severe wave, therefore the port in Upper Gulf of Thailand can be used this method for calculation of the mooring forces and preliminary assessment of the mooring arrangements. The assumption of mooring arrangement includes six mooring lines, and the stiffness of mooring lines is constant. The analysis results represent the ship motions of 50,000 DWT and 5,000 DWT ship as fully loaded and ballasted condition with varied the stiffness of mooring lines ($EA = 3,000 \text{ kN}$ to $9,000 \text{ kN}$) at Sriracha Harbour Port (SRH) and BLCP Coal-Fired Power Plant Port (BLCP). These two ports is the bulk cargo port with using the cargo handling by crane, the ship are large motions as the ballasted condition at SRH, whereas the ship are large motions as the fully loaded condition at BLCP, and also the ship motions is higher than the limitation of the ship motions as provided in PIANC 1995. The ship motions can be reduced by increase the stiffness of mooring lines by using the synthetic material, and controls the mooring forces of each the mooring lines must be less than 50% of minimum breaking strength.

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Chapter 1

Introduction

1.1 GENERAL DESCRIPTION

The Kingdom of Thailand is located in the Southeast Asia, between 5° 37'N - 20° 28'N and 97° 21'E - 105° 37'E, its land bordered by Myanmar in the North and West, Laos in the North and North-East, Cambodia in the east, and Malaysia in the south. It is maritime bordered by Vietnam in the Gulf of Thailand and Indonesia, India on the Andaman Sea, the total coastline is 3,219 km of the boundary land and the sea, that significant to port development, and coastal management, the port development is mostly developed in the upper Gulf of Thailand by the government and private company. The port includes the offshore port and the harbor, the harbor is the sheltered port from the severe environments by using the breakwater for increase the berth operability for the safety of all marine operations and reduced the port downtime, while the offshore port is effected from the severe environments because there without the breakwater. Therefore, this study is studied the berth operability of offshore port in the Upper Gulf of Thailand.

The berth operability is the safe operation time and the safety of all marine operation that provide safely moored ship without the hazards cause by the severe environments and smooth (un)loading the cargoes between ship and onshore facility. The port downtime is operation stop time which a risk from the natural hazard when event the tropical storm that may cause the damage to petrochemical loading arms, petrochemical hoses, container-handling equipment, overload of mooring lines and damage to fender systems.

1.2 TROPICAL CYCLONES

The climate of Thailand is under the influence of monsoon winds of seasonal character of southwest monsoon and northeast monsoon. The southwest monsoon season starts mid-May to mid-October, it brings a stream of warm moist air from the Indian Ocean towards Thailand causing abundant rain over the country, especially the windward side of the mountains. The northeast monsoon season starts mid-October to mid-February, it brings the cold and dry air from the anticyclone in China mainland over major parts of Thailand, especially the Northern and Northeastern parts, which is higher latitude areas. In the Southern Part, this monsoon causes mild weather and abundant rain along the eastern coast of the part. (Meteorological Department of Thailand, 2015)

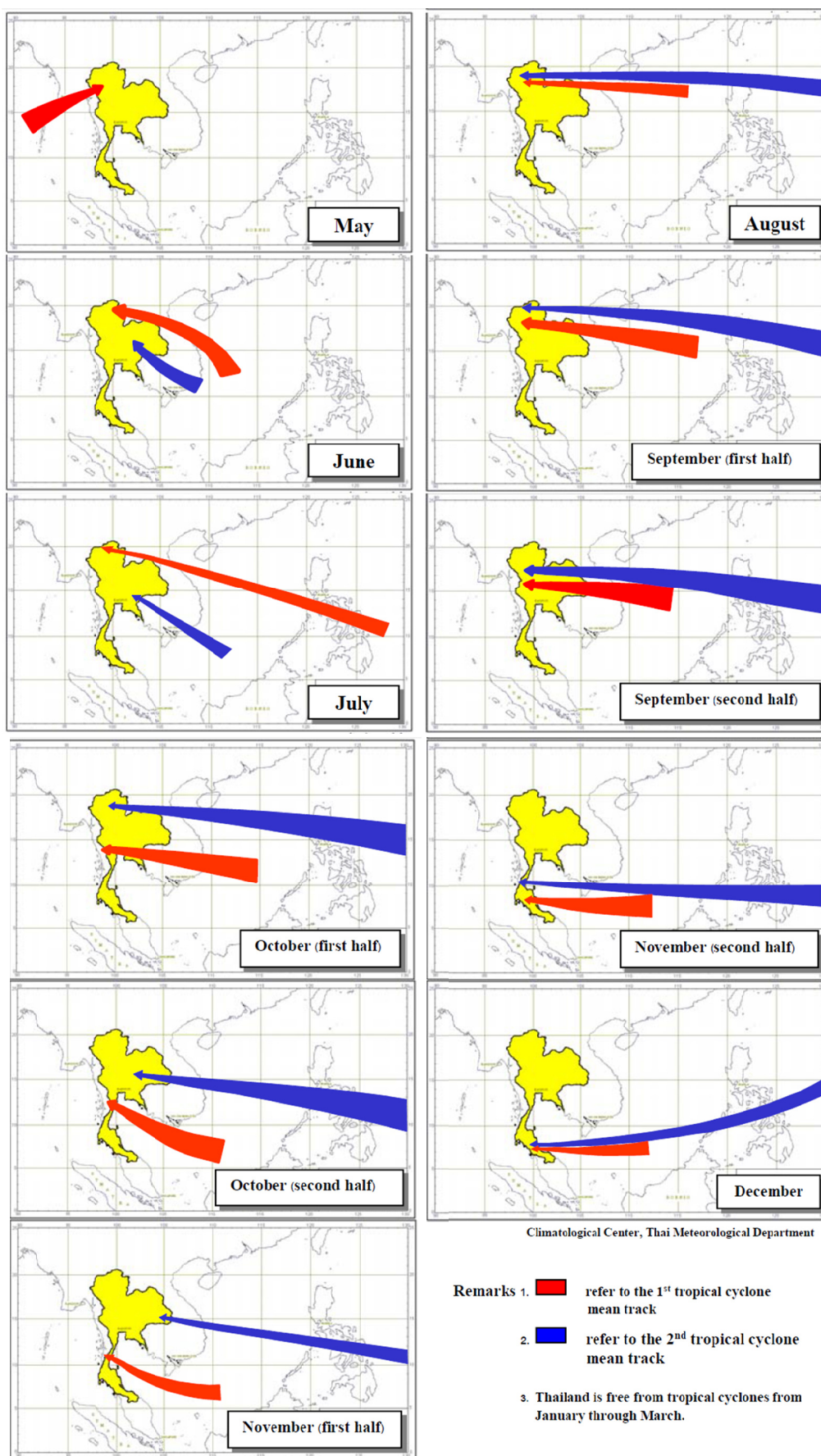


Fig. 1.1 Tropical Cyclone Mean Track (Meteorological Department of Thailand)

Tropical cyclones are affecting Thailand as events like the tropical depression, tropical storm and typhoon. The tropical cyclones are directly coming into Thailand or moving pass neighborhood country to Thailand. Moreover, it can cause damage in Thailand by strong winds, strong wave and storm surge. The tropical cyclone usually moves from the Western North Pacific Ocean or the South China Sea. Considering its strength, it may be characterized by wind speed as follows:

Tropical Depression:	the maximum sustained winds less than 34 knots (63 kilometers per hour)
Tropical Storm:	the maximum sustained winds up to 34 and less than 64 knots (63 and less than 118 kilometers per hour)
Typhoon:	the maximum sustained winds 64 knots and above (118 kilometers per hour and above)

The Sothern Part of Thailand has a high risk of tropical storms and typhoon, the history historical tropical storms include tropical storm "HARRIET" hitting Nakhon Si Thammarat Province in October 1962 and the typhoon "GAY" hitting Chumphon Province in November 1989 and the latest one was the typhoon "LINDA" which hit Prachuap Khiri Khan Province in November 1997. The annual mean of tropical cyclones are usually moving across into Thailand 3 to 4 times in a year, and Thailand never influences effects of tropical cyclones during January to March. The historical tropical cyclone database is represented, April is the first month that tropical cyclone moves across into Thailand and higher frequencies in May, particularly September and October. The tropical cyclone usually pass through the Northern and Northeastern in early southwest monsoon season and move across the southern Thailand from October to December as shown in Fig. 1.1 and Table 1.1 (Meteorological Department of Thailand, 2015)

Table 1.1 Frequencies of Tropical Cyclones during 65 Years (1951 - 2015) (Meteorological Department of Thailand, 2015)

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
North	-	-	-	-	5	2	10	17	25	11	1	-	71
Northeast	-	-	-	-	1	6	4	18	33	25	4	-	91
Central	-	-	-	-	2	1	1	-	7	9	2	-	22
East	-	-	-	-	1	1	1	-	3	13	2	-	31
South	-	-	-	1	1	-	-	-	3	15	24	9	53

1.3 OCEANOGRAPHIC BUOYS

Geo-Informatics and Space Technology Development Agency (Public Organization: GISTDA) was the operator of a marine environmental monitoring system that integrates data collection using buoy network and data analysis with an advanced computerized system for distribution of marine information to interested operators and authorities. The SEAWATCH project was started since 1991 to 2006 that separate as two-phase of 11 buoys, which is 9 buoys in Gulf of Thailand and 2 buoys in the Andaman Sea. The buoys are located 20 to 50 m in deep-sea water as shown in Fig. 1.2, and the approximate locations are tabulated in Table 1.2. The buoy systems are called SEAWATCH buoys and TOBIS buoys in Phase I, and BLUE buoys in Phase II. The data acquisition is a real time data for measurement of meteorological parameters (wind speed, wind direction, air temperature, and air pressure) and oceanographic parameters (oxygen content, light attenuation, wave (wave height/period for SEAWATCH buoys, and wave direction for BLUE buoy), currents, temperature, salinity profile and radioactivity). The buoys have also their own data logging equipment, onboard processing (data analysis and quality control), and a transmission system. (GISTDA 2010)

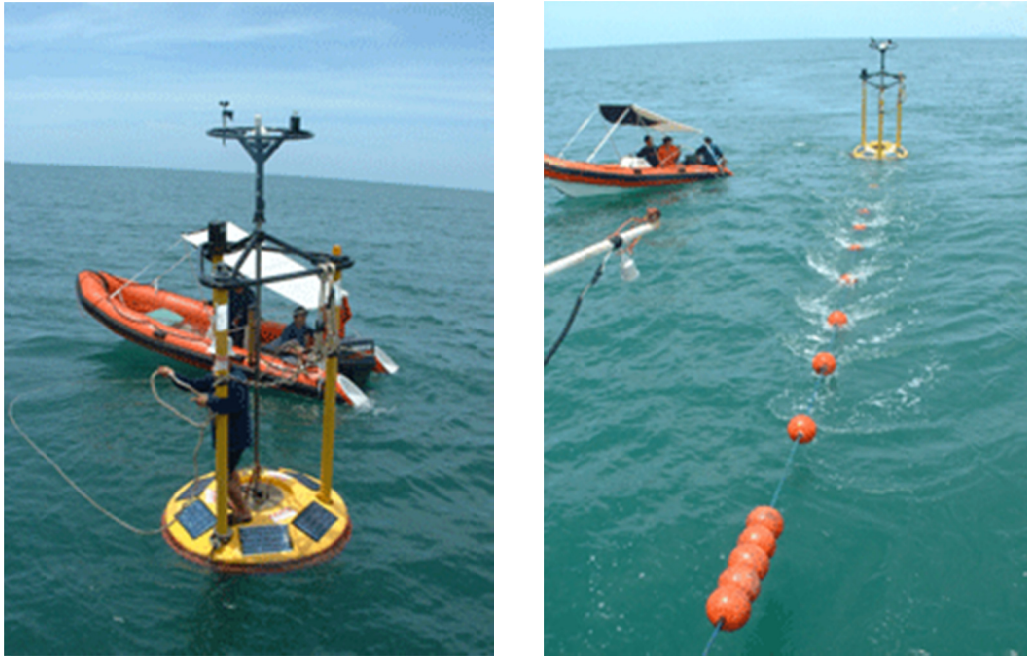


Fig. 1.2 SEAWATCH Buoys (GISTDA 2010)

1.4 MET-OCEAN DATA

The met-ocean data observed in Upper Gulf of Thailand by oceanographic buoys systems, which includes Ko Sichang (KS), Rayong (RY) and Hua Hin (HH) buoy. The data was collected by manually digitizing from oceanographic buoy reports because of the met-ocean database absent from the ASCII files. The time series started since 1991 to 2002 and using the short-term statistical analysis for class the distribution of the wind, wave and current, which the results represent the percentage of occurrence and dominant direction of the environment of each buoy as shown in Appendix A.

Table 1.2 Buoy Locations (GISTDA 2010)

No.	Code Name	Station Name	Latitude (N)	Longitude (E)
<i>Gulf of Thailand</i>				
1	KS	Ko Si Chang	13° 15' 00"	100° 45' 00"
2	RY	Rayong	12° 30' 00"	101° 13' 12"
3	KC	Ko Chang	12° 00' 00"	102° 12' 00"
4	KT	Ko Tao	10° 33' 00"	99° 49' 48"
5	SK	Songkhla	7° 30' 00"	101° 13' 12"
6	HH	Hua Hin	12° 30' 00"	100° 10' 12"
7	PCB	Petchaburi	13° 03' 00"	100° 19' 48"
8	NKST	Nakhon Si Thammarat	8° 45' 00"	100° 13' 12"
9	PT	Plathong	9° 42' 00"	101° 25' 48"
<i>Andaman Sea</i>				
10	KR	Ko Rawe	6° 34' 12"	99° 07' 12"
11	KP	Ko Phuket	8° 00' 00"	98° 00' 00"

1.5 SHIP CHARACTERISTICS

1.5.1 Ship Dimensions

A ship dimensions and mode of cargo transfer are informants for mooring analysis, port arrangement design and port structure design, the ship type such as tankers, bulk carriers, container, and ferries are different the typical dimensions and effects to the mooring arrangement. The definition of vessel dimension is depicted in Fig. 1.3, the length between perpendiculars (LBP) is the length of a vessel along the water surface from the main bow perpendicular member to the main stern perpendicular member and LBP typically represents the cargo box length of the vessel. Load waterline length (LWL) is the length of a vessel along the water surface on which it sits, length overall (LOA) is horizontal distance from the most forward part of the bow to the farthest aft end of the stern, beam (LPM) is the width of the vessel at its widest point. Freeboard (FB) is the height of the vessel's deck above the waterline, and draft (T) is the maximum vertical distance between the waterline and the vessel's keel. (John W. Gaythwaite, 2014)

1.5.2 Ship Size

The ship can be classified by size based on their cargo carrying capacity. The size of the ship is normally expressed as deadweight tonnage (DWT), which includes total weight of cargo, fuel, fresh water, etc. The lightweight tonnage (LWT) is essentially the weight of the hull structure and outfit, and the sum of the LWT and DWT is the displacement tonnage (DT). (John W. Gaythwaite, 2014)

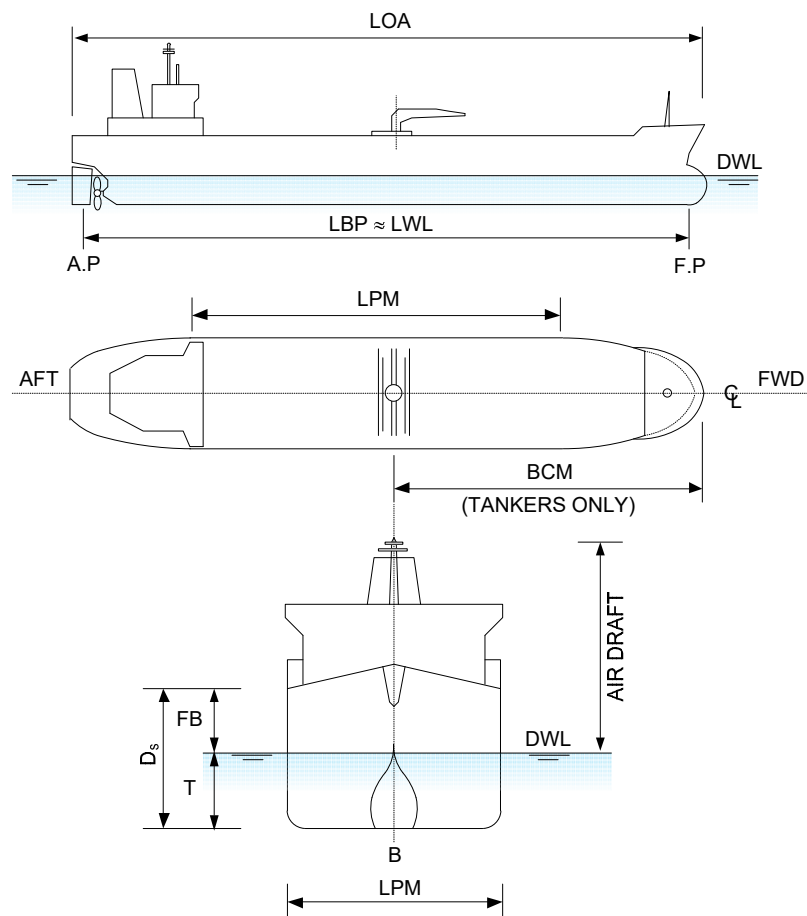


Fig. 1.3 Ship Dimensions (John W. Gaythwaite, 2014)

1.6 SCOPE OF STUDY

This dissertation is a studied on berth operability of port in the Gulf of Thailand, that includes the port at Ao Udom Bay and Rayong Sea, these areas are called “Eastern Seaboard of Thailand”, it is an economic region that plays a key role in Thailand's economy and the center for export-oriented industries. The ports are service for export high-value goods that includes the petrochemical, Japanese-branded automobiles and agricultural product. The berth operability is to provide smooth (un)loading with a safe mooring, therefore the study will be divided into two part such as coarse berth operability by limiting the environmental condition at port and detail berth operability by limiting the ship motions due to tropical cyclone Linda. The environmental condition is collect from the oceanographic buoy and numerical model by using the application Delft3D-WAVE and Delft3D-FLOW, these data are using for estimate the coarse berth operability and calculate the static force on moored ship subjected to the wind, wave and tidal current for determining the static ship motions analysis.

1.7 OBJECTIVE OF STUDY

The research objective has been a list as below

- a. Study on the background of port development in Thailand for made understanding the perspective of the maritime development.
- b. Met-ocean data collection in Upper Gulf of Thailand and analyzed the data in the short-term statistical analysis for classified the data distribution of Ko Si Chang (KS), Rayong (RY) and Hua Hin (HH) buoy. The results are useful for guiding the preliminary port arrangement and offshore structures design and can be used for hazard analysis due to environmental in the Upper Gulf of Thailand.
- c. The wave characteristics are significant for port operability and preliminary port assessment in hazard analysis from the significant wave height, then the dissertation includes the study on wave characteristics in East Coast of Thailand, which is an area of a key role in Thailand's economy.
- d. The berth operability is significant for estimation the port occupancy, port performance and port downtime, which represents the operation time and non-operation time. If the port downtime havens the high percentage per year, which represents that port is a low performance for services and high effects to the economy. Then, the dissertation will be studied on coarse berth operability and port downtime by limiting the environmental condition and details study which using the limitation of moored ship motions at the port due to a tropical cyclone. The limitation of moored are useful for hazard analysis for protection the damage of petrochemical (un)loading arm, petrochemical hoses, containers or container-handling equipment and prevent overload of mooring lines or mooring points and damage of fendering systems at the port.

1.8 DISSERTATION OUTLINE

This dissertation concerns the numerical investigation of the environment at the port in the Upper Gulf of Thailand as well as consider the effects to berth operability and port downtime by limiting the environmental conditions and moored ship motions in extreme condition due to a tropical cyclone.

This dissertation contains 7 chapters, from the introduction in Chapter 1 through conclusion in Chapter 7 as described below:

- Chapter 1 briefly presents the background of the study.

- Chapter 2 presents the background of offshore project characteristic in Thailand on the maritime development such as offshore ports and coastal structures.
- Chapter 3 presents the wave characteristics in Eastern Coast of Thailand at Ao Udom Bay, which is the maximum significant at the port that includes Laem Chabang Port breakwater (LCP), PTT Jetty (PTT), Thai Oil Jetty (TOP), Kerry Siam Seaport (KSSP) and Sriracha Harbour (SRH).
- Chapter 4 presents the coarse berth operability and operation downtime at the port in Eastern Coast of Thailand by limiting the environmental condition of the met-ocean data and the wave model result in Ao Udom Bay and Rayong Sea.
- Chapter 5 presents the wave model and hydrodynamics model for estimating the significant wave height, tidal current, storm water level and storm surge during the tropical cyclone Linda enters to the Gulf of Thailand.
- Chapter 6 presents the formulation and evaluation of the stiffness matrix of mooring equations for application to solve the mooring problem of the moored ship motions at the port due to tropical cyclone Linda.
- Chapter 7 summarizes the conclusion based on the present study.

Chapter 2

Background: Offshore Project in Thailand

2.1 INTRODUCTION

The government developer in Thailand has divided into two divisions such as Maritime Department and Port Authority of Thailand (PAT), Port Authority of Thailand is a government regulatory agency with responsibility port management and port business marketing of the government port project after accomplishment by Maritime Department. The project objective is development according to national economic and social development with the southern land bridge of two international ports as shown in Fig. 2.1 and Fig. 2.2. The land bridge connects between Andaman Sea Port and Gulf of Thailand Port by land-based transportation such as roadway and railway for transfer the container and general cargo. The land bridge project is land transportation for connection of two offshore ports by truck and rail for short sailing route and lower transportation cost from the Middle East to Leam Chabang Port and Bangkok Port. The container can be transferred to China, Korea, and Japan from Gulf of Thailand Port with short transport time and lower cost when compared with the Malacca sailing route. The private developer has been developing the liquid cargo terminal project in an offshore area for the export product to domestic market and international market. It also imports crude oil by subsea pipeline with single buoy mooring (SBM) at deep sea area to the petrochemical plant and onshore tank farm as shown in Fig. 2.3 and Fig. 2.4.

2.2 DESIGN REQUIREMENTS

2.2.1 Design Standards

The offshore and marine structures are designed in accordance with the international standards, international guidelines and local standards such as British Standards (BS), Petroleum Institute (API), Oil Companies International Marine Forum (OCIMF), World Association for Waterborne Transport Infrastructure (PIANC) and Australia Standards (AS). There is applicable to analysis and design of the reinforcement concrete structures, steel structures, approach channel and mooring arrangement by mooring analysis.

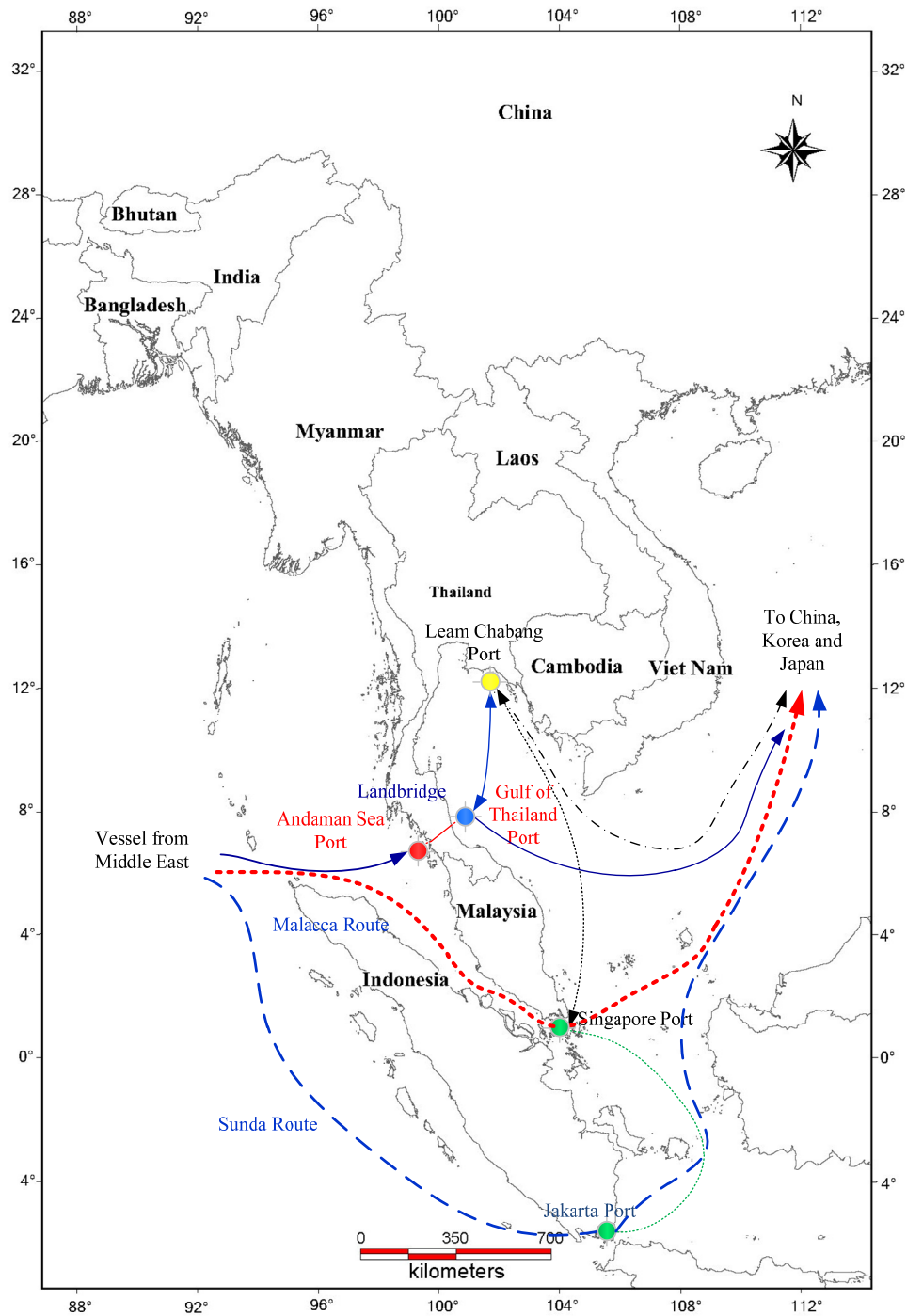


Fig. 2.1 Vessel Transportation Route and Land Bridge Location (Marine Department, 2014)

The mooring analyses are evaluating the effects of environmental conditions with wind wave, swell waves and current on the moored vessels at the wharf and platform. The mooring analysis is a preliminary assessment of the adequacy of the mooring arrangements and fendering at the wharf by comparing the calculated mooring line tension loads, vessel movements while moored, and fender breasting forces with allowable limits. The analysis results provide input for the selection of quick release hook and marine bollards, the results include mooring line load with the percentage of mooring lines breaking strength.



Fig. 2.2 Container Terminal at Laem Chabang Port in the Gulf of Thailand

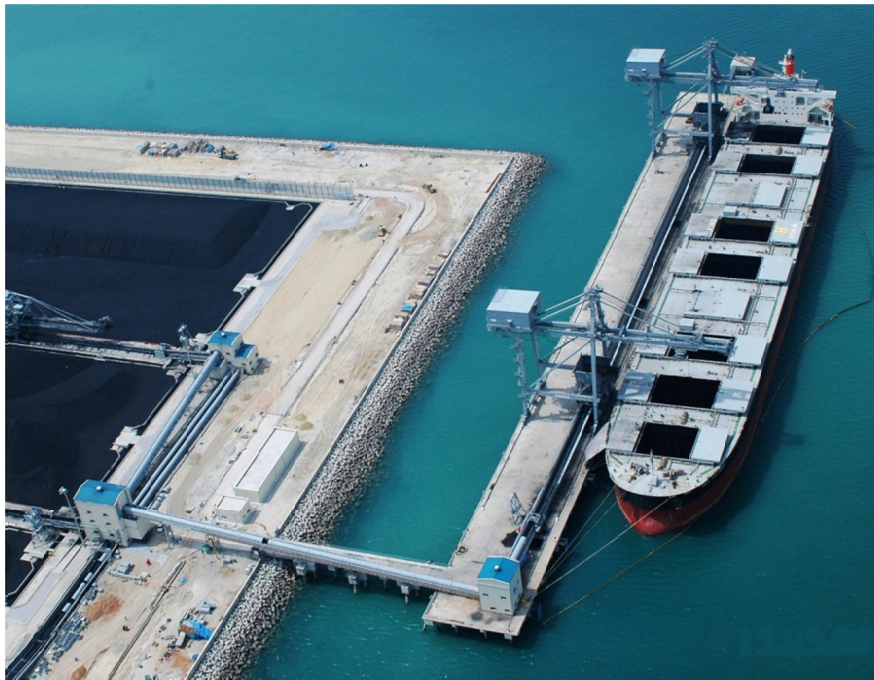


Fig. 2.3 Coal Terminal at Map Ta Phut Port in the Gulf of Thailand



Fig. 2.4 Liquid Cargo Terminal at Map Ta Phut Port in the Gulf of Thailand

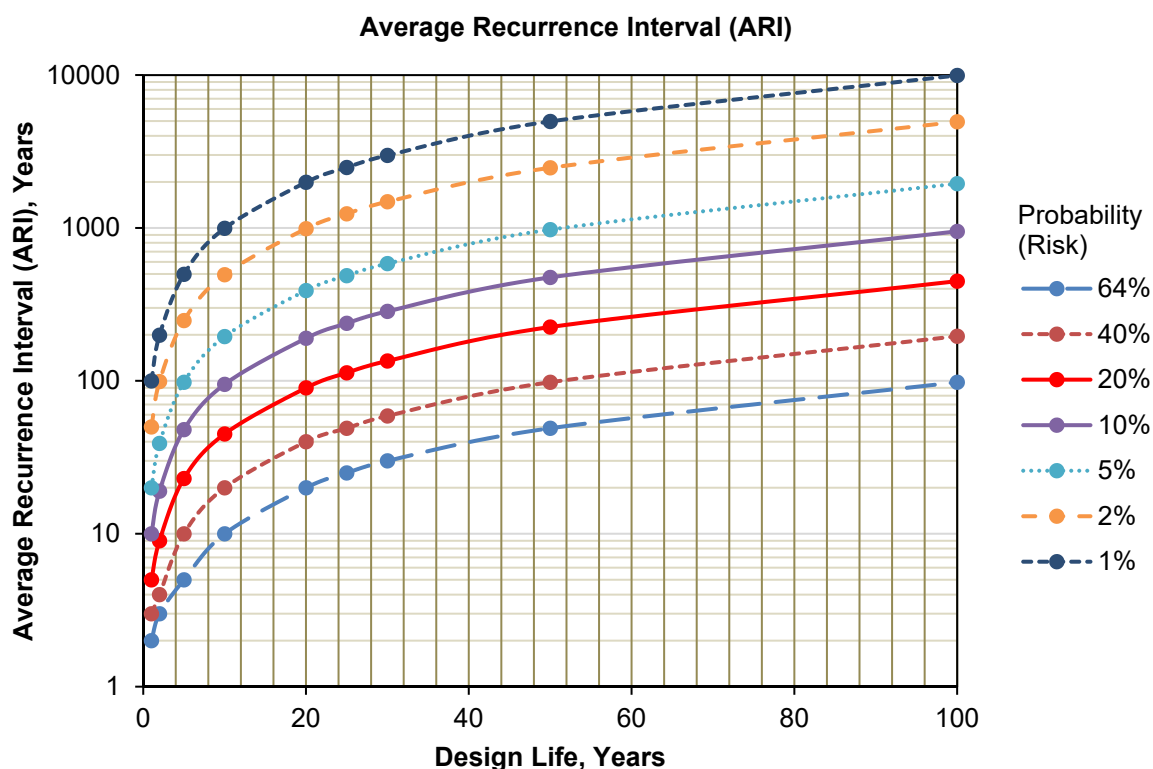


Fig. 2.5 Average Recurrence Interval (AS4997, 2005)

2.2.2 Design Life

The design life is the period for which an offshore structure or a structural component remains fit for use for its intended purpose with appropriate maintenance. The design life of structures is approximately 25 - 50 years of which relation to the average recurrence interval (ARI) as the probability of conditions with environmental effects occurring within design lifetime of structures such as wind, wave, current, storm surge and tsunami. The ARI is the design return period for environmental conditions with applies for structural analysis and geometric design with a range from 488 - 975 years (design life 25 – 50 years) of a probability (Risk) 5% as shown in Fig 2.5.

The mooring analyses are evaluating the effects of environmental conditions with wind wave, swell waves and current on the moored vessels at the wharf and platform. The mooring analysis is a preliminary assessment of the adequacy of the mooring arrangements and fendering at the wharf by comparing the calculated mooring line tension loads, vessel movements while moored, and fender breasting forces with allowable limits. The analysis results provide input for the selection of quick release hook and marine bollards, the results are include mooring line load with the percentage of mooring lines breaking strength.

2.2.3 Design Conditions

The design conditions are including the operation condition and extreme condition. The operation condition is operable port design with considered the normal wind wave in 1-5 year ARI and the operation load (crane-travelling load, truckload, uniformly distributed live load etc.). The operation conditions are safety for a port worker in offshore berth area, with low risk from strong wind wave and ship movement according to international guidelines as shown in Fig. 2.6 and Table 2.1. The extreme condition is the environmental load condition for port design with considered the severe wind and wave due to a tropical cyclone and this condition is a risk in port safety and human lives so the vessel shall be move from the offshore berth to the evacuation area.

Table 2.1 Vessel Motion Criteria for Safe Working Condition (PIANC, 1995)

Ship Type	Cargo Handling Equipment	Surge (m)	Sway (m)	Heave (m)	Yaw (Deg.)	Pitch (Deg.)	Roll (Deg.)
Fishing Vessels	Elevator crane	0.15	0.15	0.4	3.0	3.0	3.0
	Lift-on-lift-off	1.0	1.0	0.4	3.0	3.0	3.0
	Suction pump	2.0	1.0	0.4	3.0	3.0	3.0
Freighters, coasters	Ship's gear	1.0	1.2	0.6	1.0	1.0	2.0
	Quarry cranes	1.0	1.2	0.8	2.0	1.0	3.0
Ferries, Ro-Ro	Side ramp	0.6	0.6	0.6	1.0	1.0	2.0
	Dew/storm	0.8	0.6	0.8	1.0	1.0	4.0
	Ramp Linkspan	0.4	0.6	0.8	3.0	2.0	4.0
	Rail ramp	0.1	0.1	0.4	-	1.0	1.0
General Cargo	-	2.0	1.5	1.0	3.0	2.0	5.0
Container vessels	100Z efficiency	1.0	0.6	0.8	1.0	1.0	3.0
	50Z efficiency	2.0	1.2	1.2	1.5	2.0	6.0
Bulk Carriers	Cranes	2.0	1.0	1.0	2.0	2.0	6.0
	Elevator/bucket-wheel	1.0	0.5	1.0	2.0	2.0	2.0
	Conveyor belt	5.0	2.5	-	3.0	-	-
Oil tankers	Loading arms	3.0	±3.0	-	-	-	-
Gas tankers	Loading arms	3.0	±3.0	-	2.0	2.0	2.0

2.2.4 Functional Requirements

The functional requirements are according to the port operation and kind of facilities such as liquid cargo terminal, general cargo terminal and container terminal with loading and unloading materials between offshore and onshore facilities. The liquid material is loading and unloading done through pipelines for all materials and water supply, the container is transported by truck between offshore berth to onshore container yard and dry bulk material loaded and unloaded by conveyor belt between the vessel and onshore material stockyard. The operational parameters are importance to the port function design, and the parameters are included the material through put and loading rate, working hours per day, working days per week, a maximum number of vessel move in and out at offshore berth per year and the maximum loading time per vessel. The operational parameters are determinant the berth number in port facilities with considered the berth occupancy and vessel waiting time also met-ocean in monsoon season.

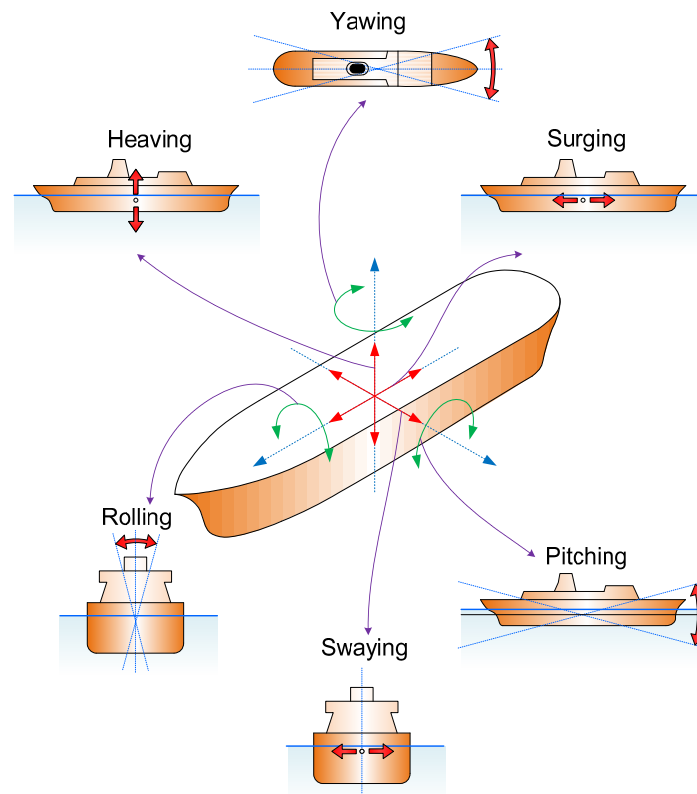


Fig. 2.6 Vessel Motions (Port and Airport Research Institute, PARI)

2.2.5 Jetties

The liquid cargo terminals are consisting of many offshore berths with called “jetties”. The jetties for liquid material loading and unloading are island types with included platform, breasting dolphins, and mooring dolphins. The jetties designed to accommodate the berthing and mooring of vessels up to a maximum size of 120,000 DWT with a minimum size of 1,000 DWT. These ranges of vessel sizes are generally oil tanker operated in Thailand.

2.2.6 Platform

The platform is a middle structure of jetties with support a marine loading arm, gangway tower, firefighting tower and other oil and gas equipment. The fender is located at the middle pier which absorbs the energy from a small vessel crushed and the vessel spring line can be used a quick release hook unit with minimum double hooks per unit on the platform.

2.2.7 Breasting Dolphins

Breasting dolphin is equipped with a rubber fender and a steel frontal frame with low friction face pads. Each dolphin will also be equipped the minimum triple quick release hook per unit at the middle on top of the mooring dolphin.

2.2.8 Mooring Dolphins

Mooring dolphins are located in the position at the left and right side of the jetties. Each of these dolphins is equipped with quick release hook unit with three hooks, which used for head/stern lines for vessels on either side of the jetties. Since the jetties have been installing a walkway from platform to the dolphins for access on operation time and maintenance with safety procedure.

2.2.9 Trestle

The trestles run from the jetties to join the onshore access road with minimum 5 m width for a single lane. The trestle is included the parking bay area along the trestle which distances 150 to 200 m. Provision will be made for trestle to be traveled by a 50t rough terrain crane. The pipe rack runs on 5 to 6 m wide and installed alongside the trestle. Features on the trestle will include piped services on pipe rack and potable water, cable tray for power and communication cables to the platform, light poles to provide lighting to road, kerbs and guardrail barriers.

2.2.10 Wharf

The wharfs are the offshore berth with a concrete deck and steel piles or concrete spun piles. The wharf structures designed for container and general cargo berth with included the ship to shore crane, conveyor belt and mobile harbor crane for loading and unloading material between the vessel and onshore facilities. The general configurations are rectangular with 30 to 50 m width and 100 to 150 m long, with according to flexible concrete joint for protected the concrete deck cracking and allows structural movement by lateral forced such as berthing forces and wave forces etc. The mooring hooks are used marine bollard with setting on concrete headstocks for mooring up to maximum vessel size. The fenders are designed for protects the wharfs structures and piles due to the berthing forces from vessel berthing, vessel passing effects and wave attack on vessel side which transfer to structures when operation at the wharfs. The fenders spacing depends on the length over all of the maximum and minimum design vessel with according to international standard and design guidelines.

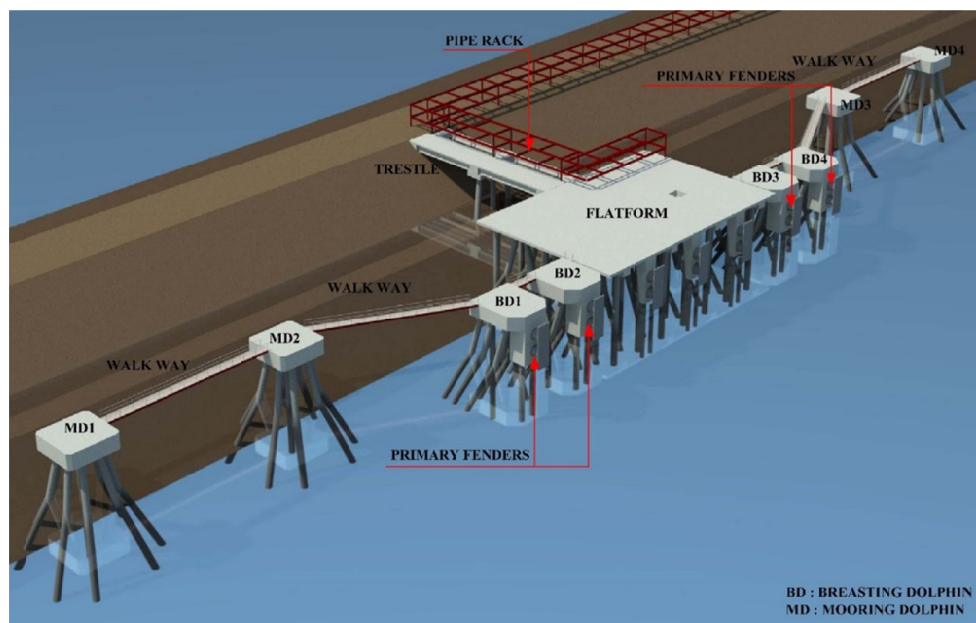


Fig. 2.7 Liquid Cargo Terminal

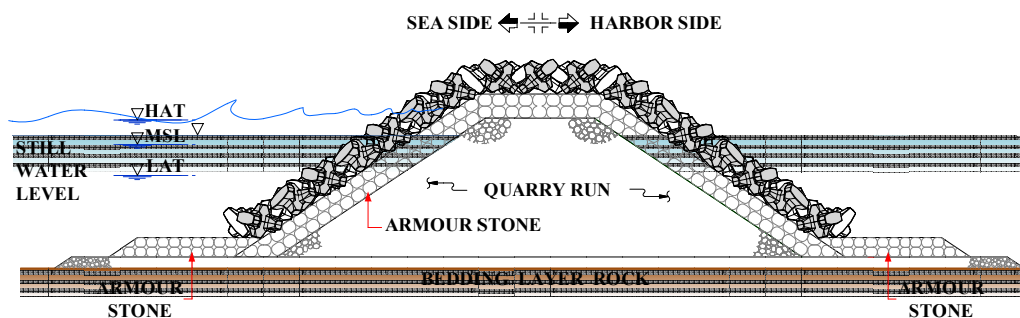


Fig. 2.8 Rubble Mound Breakwater

2.2.11 Access Bridge

The access bridges designed for truck access to the wharf with two lanes and two directions for container and material transfer to onshore facilities and customer. The access bridges are 10 to 30 m span length which made by prestressed concrete girder, concrete deck and concrete headstocks with support by steel piles or concrete piles which approximately 2.5 to 4 km long.

2.2.12 Breakwater

The breakwaters in Thailand are construction with the rubble mound breakwater for protecting port performance and port operability in monsoon season from severe wave effect to port as shown in Fig. 2.8. The breakwater design parameters are included the wave climate, port locations, bathymetry, geotechnical condition, port requirements, and economic considerations. The cost of constructing the breakwaters constitutes is a major portion of the total construction cost for the port.

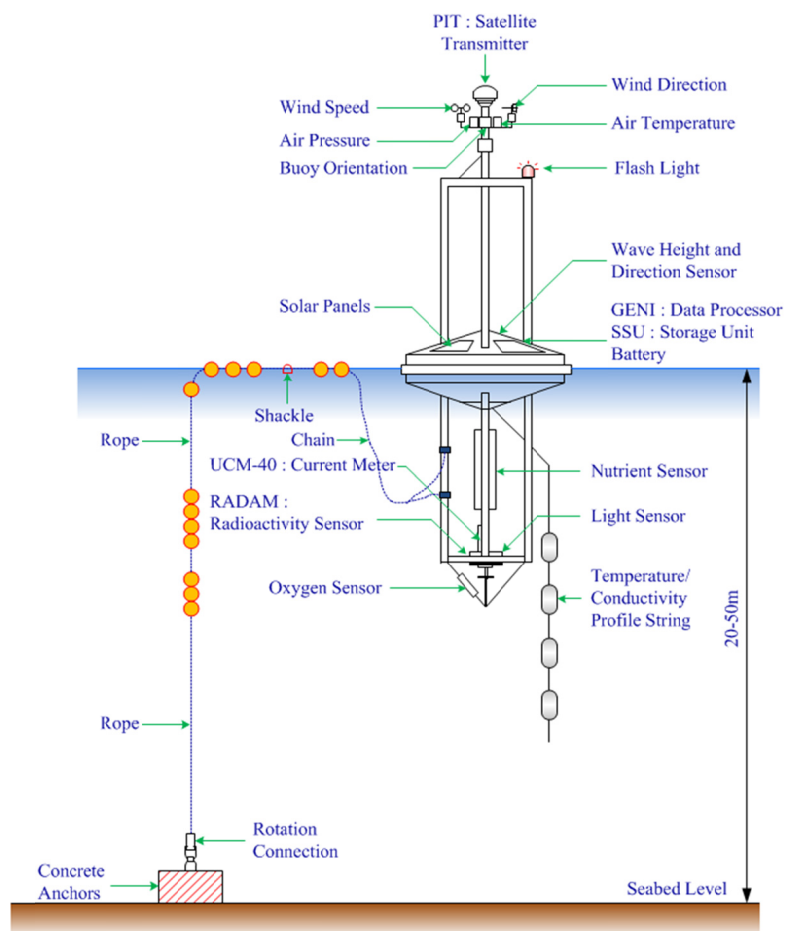


Fig. 2.9 SEAWATCH Buoy (GISTDA, 2003)

2.3 ENVIRONMENTS

The environments are direct parameters for the port design and port operation with met-ocean. The met-ocean data were obtained from Geo-Informatics and Space Technology Development Agency (Public Organization: GISTDA), and the data were recorded by the SEAWATCH buoy in the Gulf of Thailand and the Andaman Sea. The buoy is operated by GISTDA with nine stations in Gulf of Thailand and two stations in the Andaman Sea. The locations are approximate location because the buoy can be displaced to other locations that depend on sea water level and wave, the configuration

of SEAWATCH buoy as shown in Fig. 2.9. The met-ocean data used for port design and operation consideration on port operability is included operational and extreme condition.

The tidal plans published by the Maritime Department of which real-time water level, is recorded by 34 stations consisting of three locations such as river mouth, Gulf of Thailand and the Andaman Sea. The extreme design water level during storms consists two main components such as tide and surge height. The tide and storm surge when combined is referred to as the storm tide. In shallow water, wave setup and surf-beat also contribute to the extreme design water level. Storm surge is due to both of pressure surge (due to the inverse barometric effect) and wind set-up, which pushes ocean waters and raises water levels near the coastline. The still water levels are a combination of the extreme design water level, sea level rise, and error margin.

The drainage system shall be designed water drained to the sump pit and pump water to onshore for treatment in an oil/water separator. The intent is to capture the first runoff containing any oil and dust contaminants that may have spilled on the deck. The rainfall runoff on the trestle deck/roadway discharged into the sea via deck drains and scuppers.

2.4 GEOTECHNICAL AND PILING FOUNDATION

The geotechnical investigated with standard penetration test and offshore soil sample test is testing in the laboratory. The borehole locations are predicted the position of structures and according to soil layer variation for dredging and navigation channel design. The assessment of geotechnical parameters and design of structures are carried out according to the guidelines of API RP 2A-LRFD. All geotechnical parameters are selected based on recommendations and limitations in design standard. The offshore foundations based on driven open-ended circular steel piles and concrete spun piles. The information and recommendations are including soil-pile interaction assumptions with based on foundation type. The pile design considered which consist of the compression capacity, tension capacity, lateral resistance, pile driving stress and ultimate bearing capacity.

2.5 MARINE WORKS

2.5.1 Approach Channel

The width and depth of the access channel shall be in accordance with the guide for the design of approach channels of the Permanent International Association of Navigation Congress (PIANC). The parameters used to determine the channel width and depth that includes vessel speed, vessel length & beam, prevailing crosswind speed, prevailing cross and longitudinal current speeds and depth of channel relative to the draft. The depth of the access channel based on several factors such as the maximum draft of the largest vessel, tide level, wave height, a distance of the hull, and rate of sedimentation. The channel side slopes are determined in accordance with British Standard BS 6349-5 and based on the seabed sediment characteristics.

2.5.2 Navigation Aids

Navigation aids are consisting the lighting, beacons, and buoys which are installed around the jetty, trestle, approach channel and turning basin. For safety purposes, buoys positioned around the artificial reefs that are in close proximity to the access channel. The layout based on the recommendations of the International Association of Lighthouse Authorities (IALA).

2.6 SUMMARY

Maritime Department developing the offshore port are composed of the container terminal and general cargo terminal without oil and gas terminal as reduced the Environmental Health Impact Assessment (EHIA) approval process and avoid answering questions from the public in the project area. The private company developed the offshore port for oil and gas business in Eastern of

Thailand where liquid material exports to the market and imports crude oil to the refinery. The coal-fired power plant project was developing coal terminal for import coal from Indonesia and Australia with used fuel in the power plant process.

The offshore ports designed with following to the port operation and kind of material loading or unloading which separates in dry material and liquid material. The offshore berth is called “jetties” in liquid cargo terminal for liquid material loading with using pipeline from onshore tank farm to moored vessel at jetties and connected pipeline by loading arm on the platform. The coal materials are loading to the vessel and unloading to onshore coal stockyard with using coal (un)loader on the wharf and conveyor belt along the trestle. The containers are loading by ship to shore crane and transport to the onshore container yard by a truck which using the access bridge to connected the roadway. The general offshore berth is two main structures consist of wharf and jetties with connected the shoreline by access bridge and trestle, it is constructed by concrete deck and concrete headstocks with support by steel piles or concrete spun piles. The structures designed to accommodate the berthing and mooring of minimum to maximum vessel size.

Chapter 3

Wave Characteristics in East Coast of Thailand

3.1 INTRODUCTION

The met-ocean data are significant for coastal disaster prevention and mitigation with reducing the vulnerability of maritime structures such as jetties, port, harbor, and breakwater. In maritime structural design shall be carried out the hazard analysis from severe wind and wave due to a tropical storm and typhoon for prevention the damage of structures and human loss. Then, this chapter presents the statistical analysis of wind-wave data at Ko Si Chang (KS) buoy and estimation of the maximum significant wave at ports in Ao Udom Bay by using the numerical model. The met-ocean data is useful for estimation of the severe wind-wave at the port and preliminary maritime structures design and port operability.

3.2 OBSERVED DATA

3.2.1 Oceanographic Buoys

Thailand has developed the typhoon disasters mitigation system since 1993. The system consists of warning and monitoring maritime development with oceanographic buoys in Gulf of Thailand and the Andaman Sea. Oceanographic buoys are mooring buoys installed with the multi-sensor for measuring the meteorological data such as wind, wave, current speed and directions and sea surface temperature etc. The oceanographic buoys are operated by Geo-Informatics and Space Technology Development Agency (Public Organization: GISTDA) since 1991 to 2006 which 11 stations which include 9 stations in Gulf of Thailand and 2 stations in the Andaman Sea. The buoys are located in the deep sea area of 20 to 50 m depth from sea water level to the seabed. The buoy locations are shown in Fig. 3.1.

3.2.2 Met-Ocean Data Derivation

The met-ocean data derived by digitized from oceanographic buoy reports, which published by GISTDA at Ko Si Chang (KS) since 1991 to 2001. The data included four parameters such as wind speed, wind directions, significant wave heights and wave periods. The instrument is SEAWATCH buoys models to measure the data at approximate coordinates 690132.89m East, 1467755.08m North (WGS84/UTM Zone 47N). The data are not recorded continuity in time series as monthly plotted in the report, so the met-ocean is lacked in some monthly time series and the data sets

digitized based on time step of an instrument in the reports as hourly data point by linear interpolation between digitized raw data. The data sets after digitizing and linear interpolation in September 1997 are shown Fig. 3.2 and Fig. 3.3.

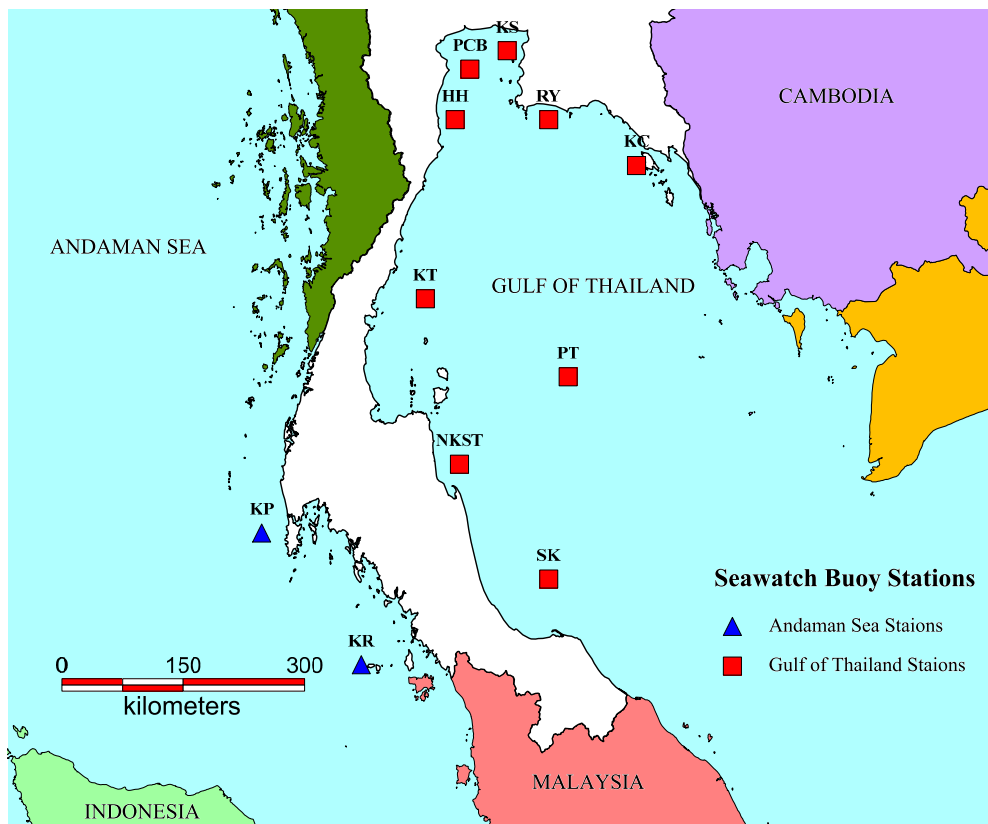


Fig. 3.1 SEAWATCH Buoy Locations (Hattha and Hiraishi, 2016)

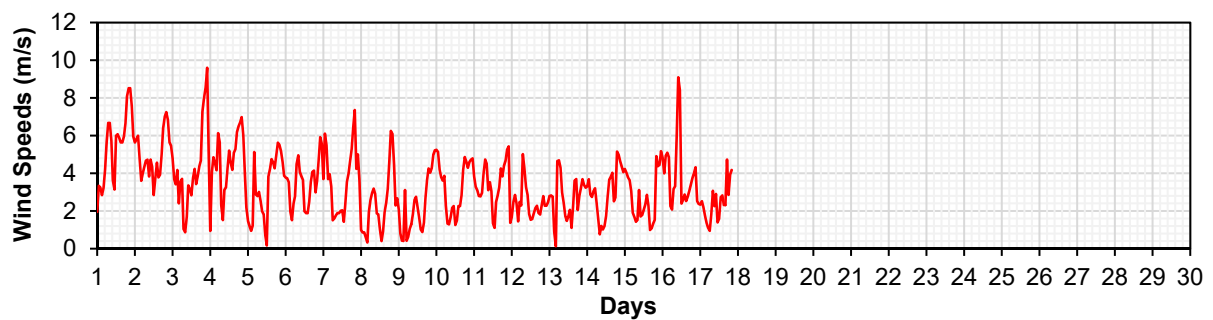


Fig. 3.2 Wind Speeds at Ko Si Chang (KS) Buoy in September 1997

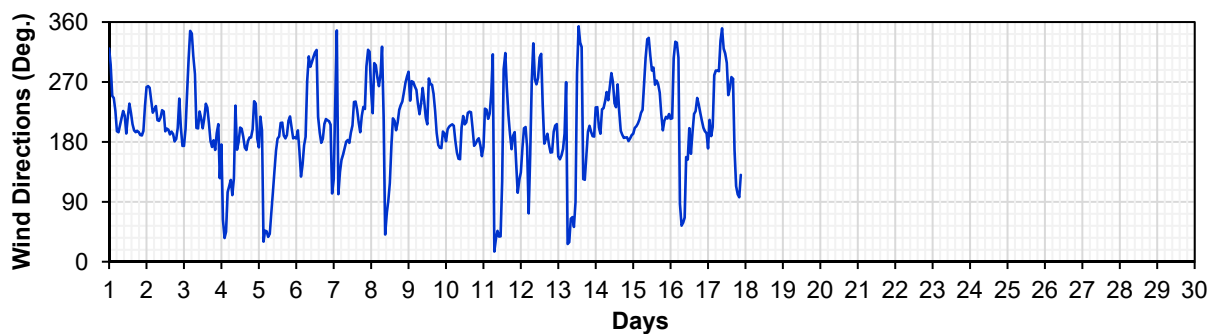
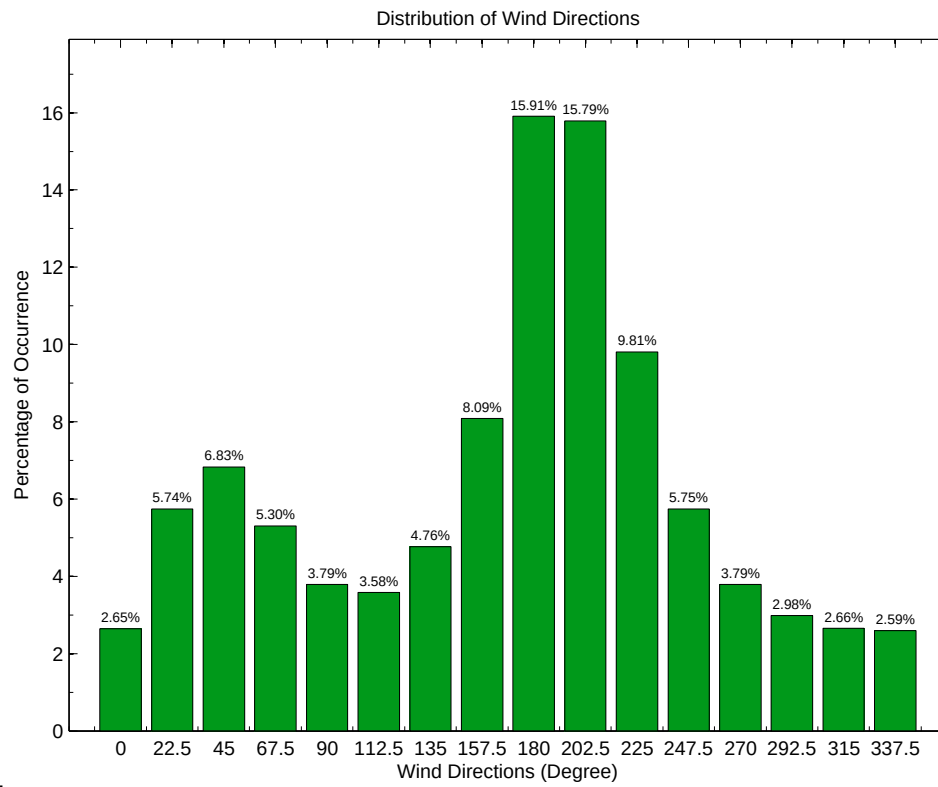


Fig. 3.3 Wind Directions at Ko Si Chang (KS) Buoy in September 1997

(a)



(b)

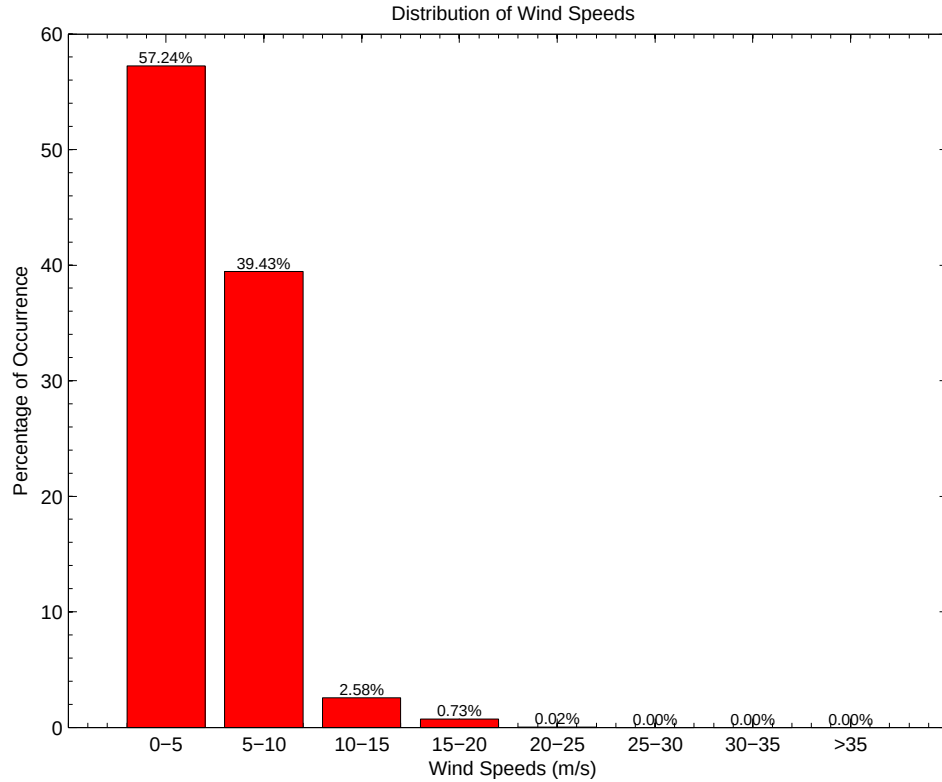


Fig. 3.4 (a) Distribution of Wind Directions and (b) Distribution of Wind Speed, 1991-2001

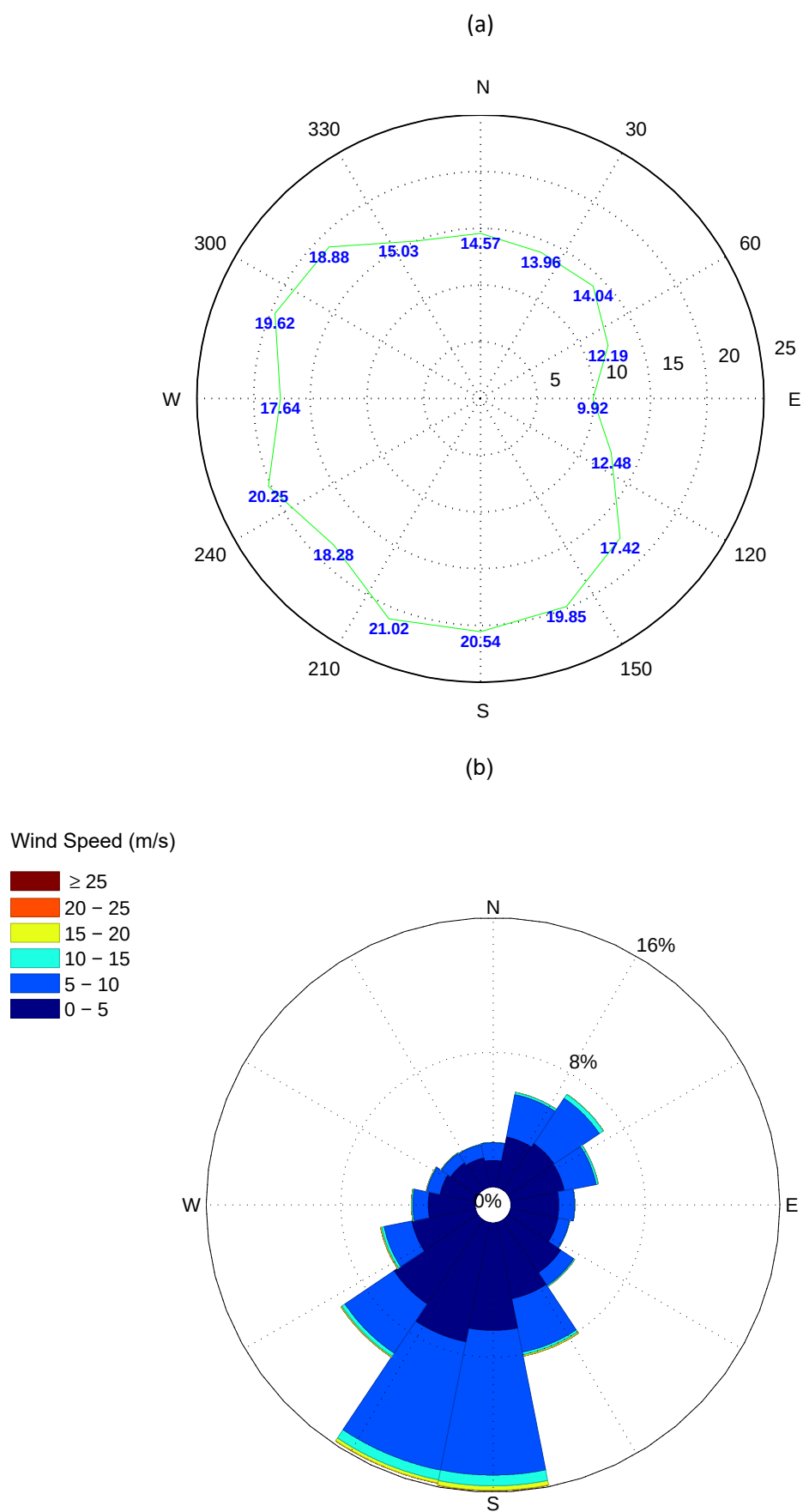
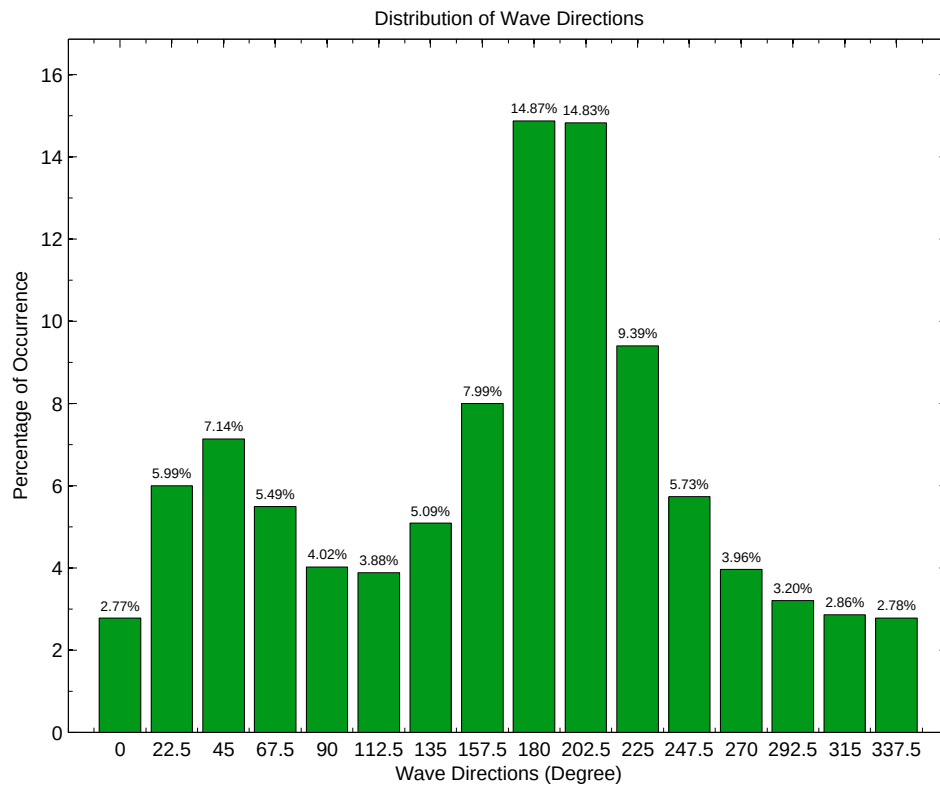


Fig. 3.5 (a) Maximum Wind Speed and (b) Wind rose Diagram, 1991-2001

(a)



(b)

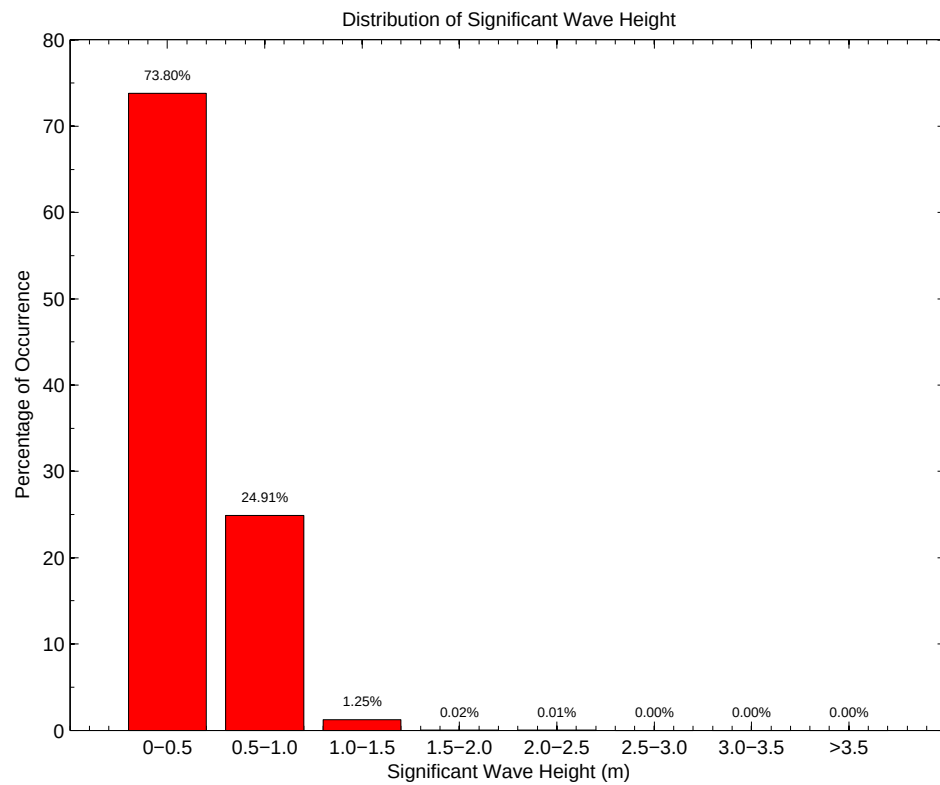


Fig. 3.6 (a) Distribution of Wave Directions and (b) Distribution of Significant Wave Height, 1991-2001

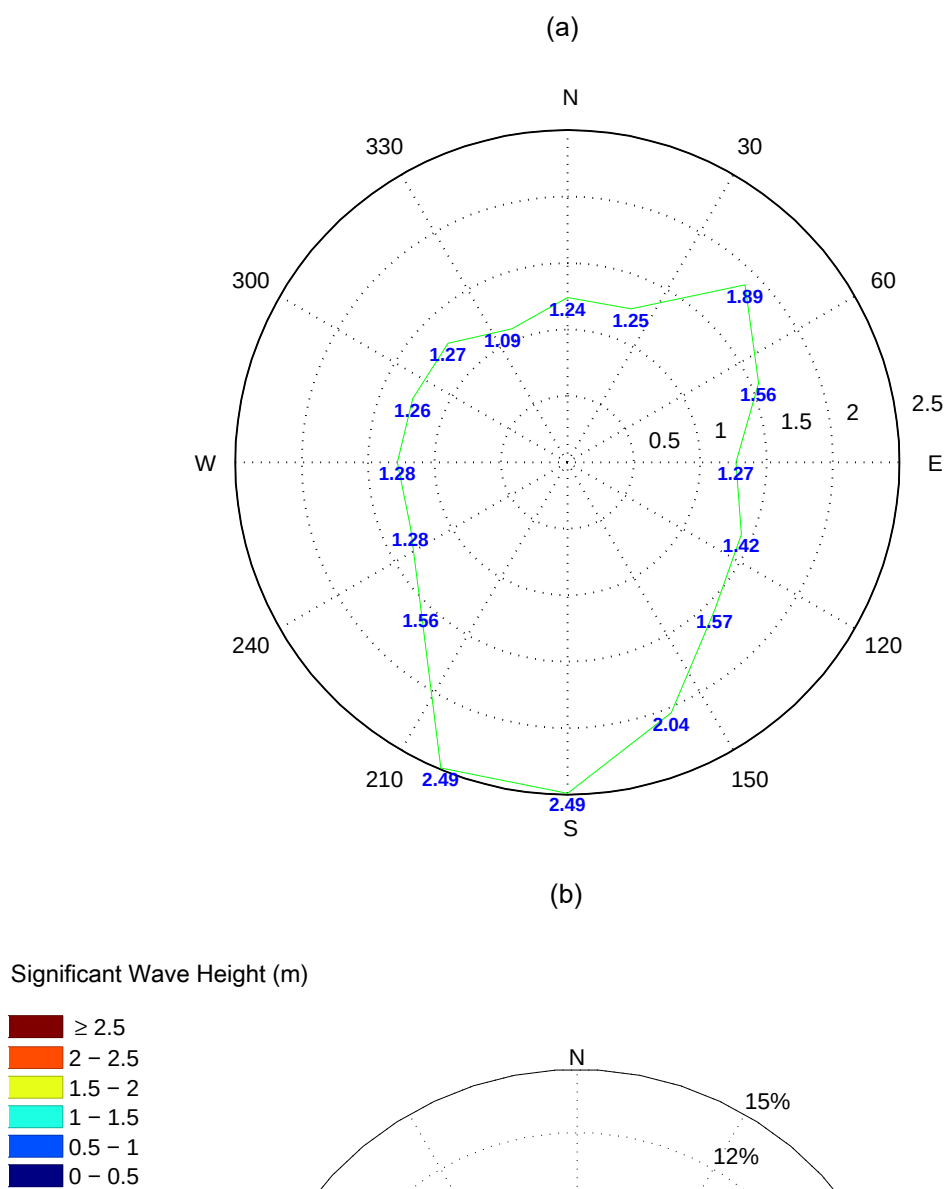


Fig. 3.7 (a) Maximum Significant Wave Height and (b) Wave Rose Diagram, 1991-2001

3.2.3 Wind Data

The hourly wind speeds at Ko Si Chang (KS) buoy presented low to moderate data, of which most hourly wind speeds are in a range $0 \leq 5$ m/s and $5 \text{ m/s} \leq 10$ m/s and percentage of occurrence of 57.24%, 39.43% respectively. The maximum wind speed, southwest monsoon direction were the intensity of 21.02 m/s (202.5°). The distribution of wind directions showed wind coming on 180° and 202.5° whereas the percentage of occurrence of 15.91% and 15.79%, which is the Southwest monsoon direction. The wind data sets are analyzed by statistical analysis as shown in Fig. 3.4 and Fig. 3.5. The wind diagram showed the wind speeds class and cumulative percentage of occurrence by the intensity and directions as shown in Fig.3.5 (b).

3.2.4 Wave Data

The significant wave height at Ko Si Chang (KS) buoy was recorded in every three hours which mostly distributed from $0 \leq 0.5$ m by shown as a percentage of occurrences of 73.80%. The percentage of occurrence of 24.91% are a distribution from $0.5 \leq 1.0$ m, the wave is mostly distributed in South (180°) and Southwest (202.5°) direction, which is equal to 14.87% and 14.83% of the percentage of occurrence. The maximum significant wave height is equal to 2.49 m in Southwest monsoon direction (202.5°). The distributions of significant wave datasets are shown in Fig. 3.6. The wave directions will assume similarity to the wind direction for all datasets. Because SEAWATCH buoys are not recorded the wave directions.

3.3 WAVE MODEL

The propagation of waves from the offshore to the port and nearshore site modeled using a numerical wave model. The waves undergo wave refraction and diffraction around some offshore islands and reefs as well as shoaling over the shallower nearshore bathymetry. The “Delft3D-WAVE” is the application for set-up the numerical model for this study. The wave model bathymetry is based on coarse navigation charts in the offshore regions and on the detailed navigation charts in the nearshore regions. The wind-wave boundary is derived from Ko Si Chang (KS) buoy for assigned on the west open boundary, but for other uniform wave boundary is calculate the significant wave height and peak wave period by using the JONSWAP spectrum. The numerical wave modeling is an objective to estimate the significant wave height at the port in Ao Udom Bay, the location of the port and Ko Si Chang (KS) buoy tabulated in Table 3.1.

The “Delft3D-WAVE” is using the SWAN (Simulating Waves Nearshore) source code. SWAN model is a third-generation numerical wave model to compute wind generated waves in shallow water areas. Physical process in SWAN includes wave generation by wind and dissipation by whitecapping, bottom friction and depth-induced breaking and also non-linear wave-wave interaction (quadruplets and triads). In additional wave propagation through obstacles and wave-induced set-up of the mean sea surface can be computed in SWAN. In SWAN the waves are described with the two-dimensional wave action density spectrum, even when non-linear phenomena dominate. The spectrum considered in SWAN is the action density spectrum $N(\sigma, \theta)$ rather than the energy density spectrum $E(\sigma, \theta)$ since in the presence of currents, action density is conserved whereas energy density is not (Whitham, 1974). Therefore, the action density is equal to the energy density divided by the relative frequency as expressed below.

$$N(\sigma, \theta) = \frac{E(\sigma, \theta)}{\sigma} \quad (3.1)$$

Where σ is the relative frequency (independent variables), and θ is wave direction.

The evolution of the wave spectrum is the governing equation of Delft3D-WAVE or SWAN as described by the spectral action balance equation which for Cartesian coordinates is

$$\frac{\partial}{\partial t} N + \frac{\partial}{\partial x} c_x N + \frac{\partial}{\partial y} c_y N + \frac{\partial}{\partial \sigma} c_\sigma N + \frac{\partial}{\partial \theta} c_\theta N = \frac{S}{\sigma} \quad (3.2)$$

Where

$\frac{\partial}{\partial t} N$ = Local rate of change of action density in time.

$\frac{\partial}{\partial x} c_x N$ = Propagation of action in geographical space (with propagation velocities c_x in x space).

$\frac{\partial}{\partial y} c_y N$ = Propagation of action in geographical space (with propagation velocities c_y in y space).

$\frac{\partial}{\partial \sigma} c_\sigma N$ = Shifting of the relative frequency due to variations in depths and currents (with propagation velocity c_σ in σ space).

$\frac{\partial}{\partial \theta} c_\theta N$ = Depth-induced and current induced refraction (with propagation velocity c_θ in θ space).

$S(=S(\sigma, \theta))$ = Source term in terms of energy density representing the effects of generation, dissipation and non-linear wave-wave interactions.

Table 3.1 Port Location

No.	Location Description	East* (m)	North* (m)
1	Laem Chabang Port breakwater (LCP)	703105.54	1444650.10
2	PTT Jetty (PTT)	702027.26	1448274.33
3	Thai Oil Jetty (TOP)	703622.36	1451260.61
4	Kerry Siam Seaport (KSSP)	703105.53	1452552.67
5	Sriracha Harbour (SRH)	704013.77	1455345.17
6	Ko Sichang Buoy (KS)	690132.89	1467755.08

Note: WGS84/UTM Zone 47N coordinates*

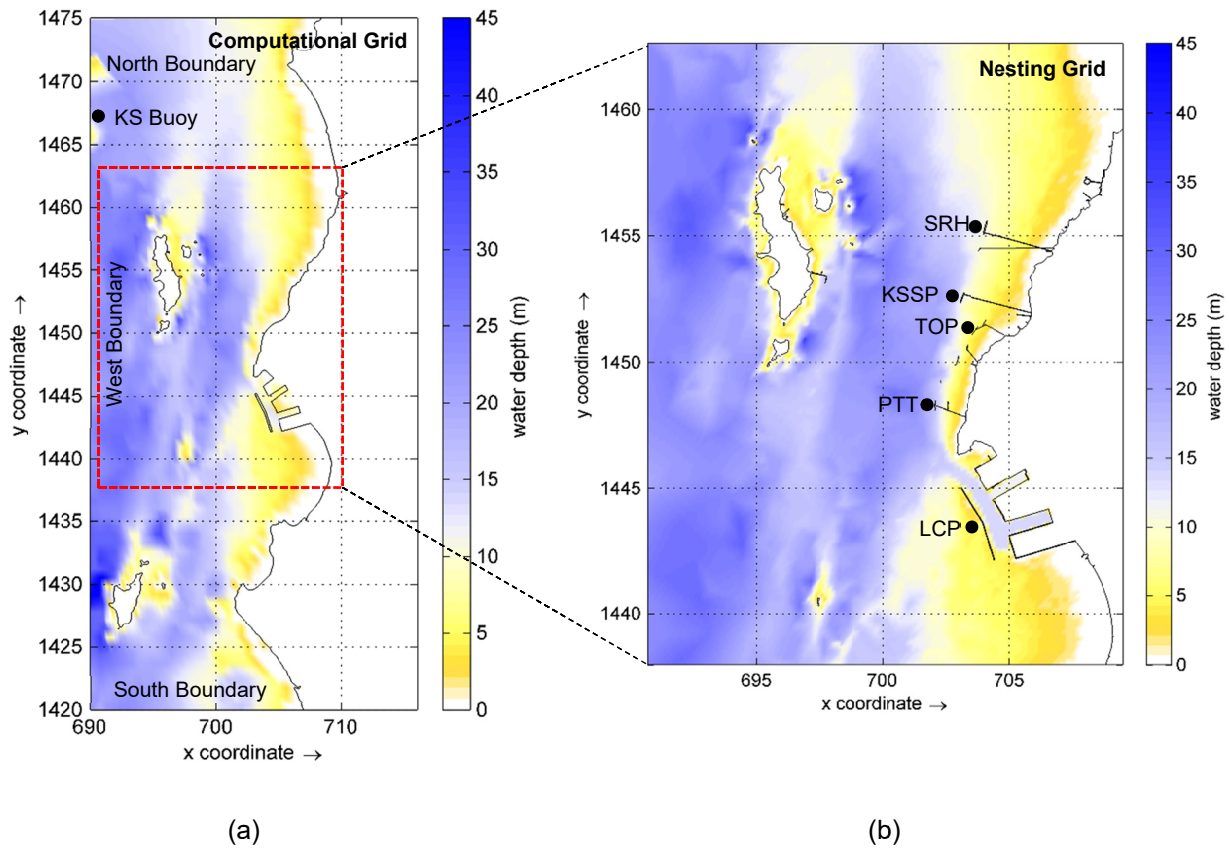


Fig. 3.8 (a) Bathymetry THA Chart 142 and (b) Bathymetry THA Chart 164

3.3.1 Wave Model Set-Up

Delft3D-WAVE multi-grid wave model has been set up to estimate wave generation, propagation, and transformation to the port for the maximum wind speeds and the maximum significant wave height in northeast monsoon and southwest monsoon directions. The wave model bathymetry has been based on navigation charts (THA Chart 142 - Paknam Chao Phraya to Ko Raet, THA Chart 164 - Si Racha and Approaches) and the General Bathymetric Chart of the Oceans (GEBCO, 2014) dataset of bathymetry. The main grid generated by using THA Chart 142, which covered the detail grid, and the detail grid generated by THA Chart 164 as shown in Fig. 3.8, Fig.3.9 and the computational grid details are tabulated in Table 3.2.

Table 3.2 Wave Computational Grid Details at Ao Udom Bay

Grid	Grid Size	Cell Size	Cell Number x- Direction	Cell Number y- Direction	Origin x, y (m) WGS84	Rotation (Deg.)
Computational Grid - THA Chart 142	26kmx55km	880x680m	109	55	689811.94, 1419546.00	0
Nesting Grid – THA Chart 164	18.8kmx24.6km	330x480m	163	163	690671.63, 1437774.0	0

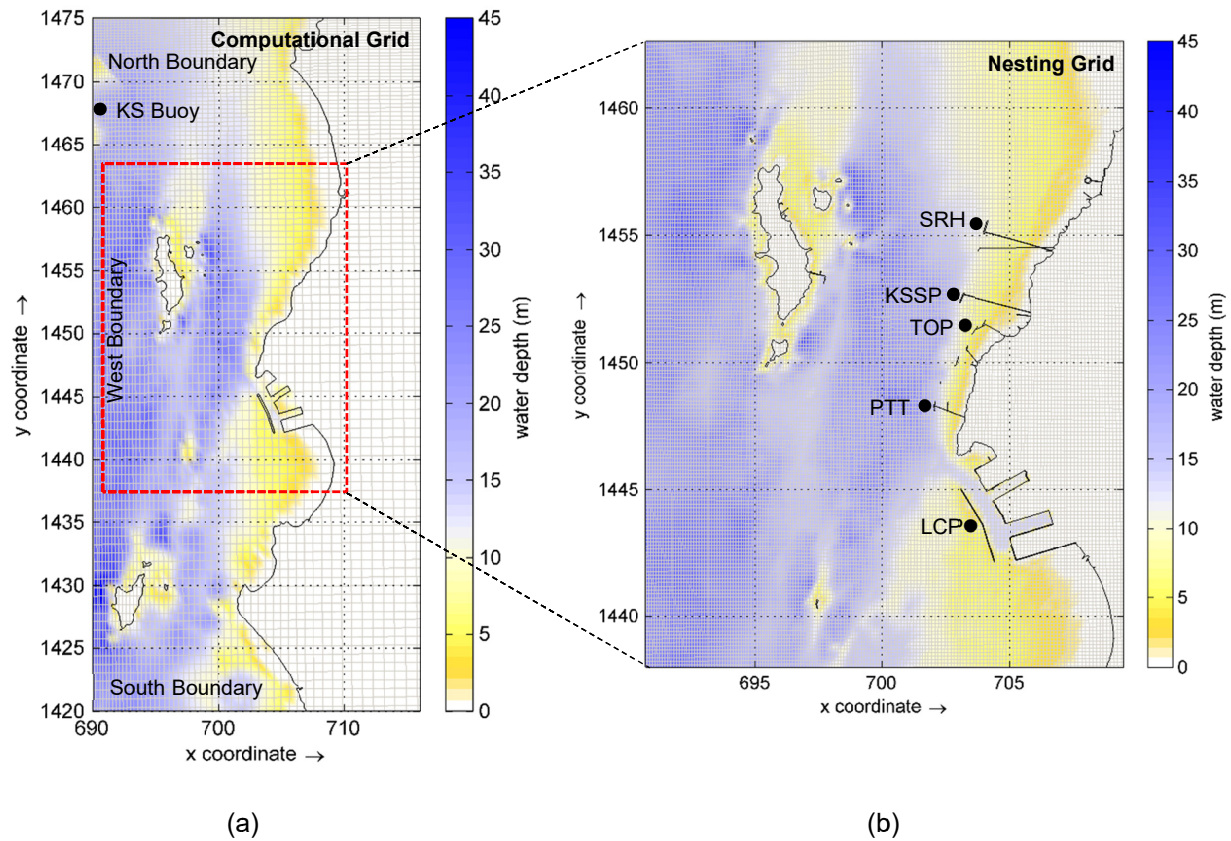


Fig. 3.9 (a) Computational Grid - THA Chart 142 and (b) Nesting Grid - THA Chart 164

The estimated significant wave height was calculated by the numerical wave model. The offshore wave data has been assigned to the wave boundary condition in the computational grid, the offshore wave being transformed to the nearshore and port by the wave model. The analysis cases of a wave model are tabulated in Table 3.3.

3.3.2 Wave Model Results

The results show that the significant wave height of case 1 to case 15 at each location, the maximum significant wave height are generated by the maximum wind speed of case 2 as indicated in Table 3.3, Table 3.4 and Fig. 3.10 to Fig. 3.12. The significant wave height is equal to 2.17 m at near the front of Laem Chabang Port breakwaters (LCP) and appears the highest at PTT Jetty (PTT), which cause that result of PTT Jetty (PTT) is not sheltered by Ko Si Chang Island when event becomes severe as wind-wave propagate from offshore to the port in southwest direction. However, Thai Oil Jetty (TOP) is located in the shelter by Ko Si Chang Island and also the seabed level shallower than all locations, thus the significant wave results are smallest.

Table 3.3 Boundary Conditions for Delf3D-WAVE Model

Case	Wind Speed (m/s)	Wind Direction (Deg.)	Significant Wave Height (m)	Peak Wave Period (sec)	Wave Direction (Deg.)	Water Level (m, LLW)
1	20.54	177.72	2.49	9.68	157.72	2.48
2	21.02	192.68	2.49	9.68	172.68	2.48
3	17.60	161.94	2.04	9.68	151.94	2.48
4	11.26	36.79	1.89	9.71	6.79	2.48
5	10.57	177.26	0.94	3.41	177.26	2.48
6	10.81	199.66	0.79	3.11	169.66	2.48
7	9.40	233.67	0.95	3.65	233.67	2.48
8	10.21	165.95	0.78	3.45	135.95	2.48
9	14.04	49.82	1.08	3.78	79.82	2.48
10	10.29	225.60	1.56	4.42	205.60	2.48
11	3.25	124.99	1.57	7.85	124.99	2.48
12	4.18	36.79	1.89	9.71	6.79	2.48
13	5.99	161.94	2.04	9.68	191.94	2.48
14	2.23	192.68	2.49	9.68	222.68	2.48
15	3.16	177.72	2.49	9.68	207.72	2.48

Table 3.4 Wave Model Results (Significant Wave Height)

Case	Locations					
	LCP H _s (m)	PTT H _s (m)	TOP H _s (m)	KSSP H _s (m)	SRH H _s (m)	KS H _s (m)
1	2.03	2.24	1.67	1.99	2.06	2.42
2	2.17	2.49	1.97	2.26	2.35	2.59
3	1.50	1.72	1.17	1.51	1.54	2.04
4	0.60	1.06	1.05	1.17	1.21	1.74
5	0.90	1.04	0.74	0.94	0.93	1.07
6	0.98	1.11	0.84	1.01	1.02	0.93
7	0.95	1.03	0.89	0.93	0.91	1.02
8	0.76	0.88	0.62	0.80	0.80	0.95
9	0.49	1.01	0.91	1.01	0.96	1.26
10	1.13	1.29	1.09	1.19	1.14	1.54
11	0.74	0.89	0.78	0.82	0.77	1.56
12	0.45	0.72	0.83	0.98	1.18	1.81
13	0.85	0.98	0.83	0.91	0.90	1.79
14	1.58	1.71	1.47	1.43	1.24	2.59
15	1.25	1.39	1.24	1.26	1.15	2.43

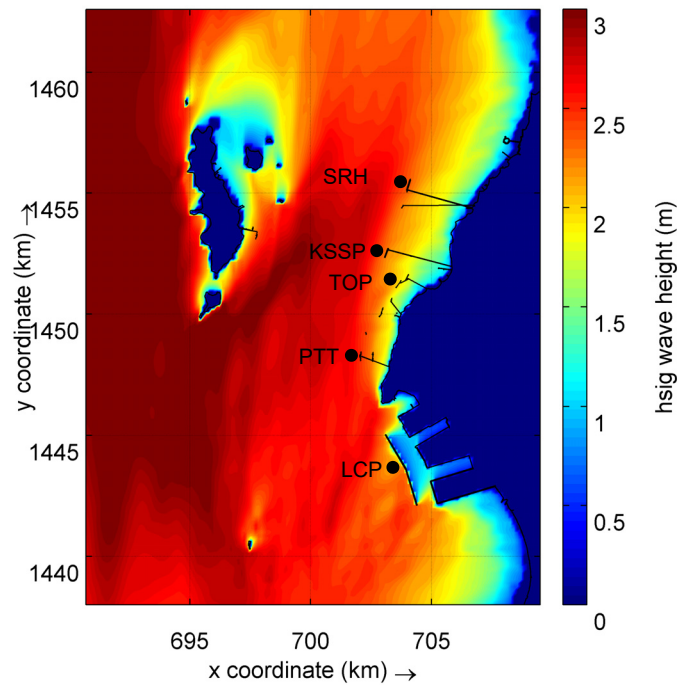


Fig. 3.10 Significant Wave Height of Nesting Grid (THA Chart 164) - Case 2
(hsig: Significant Wave Height)

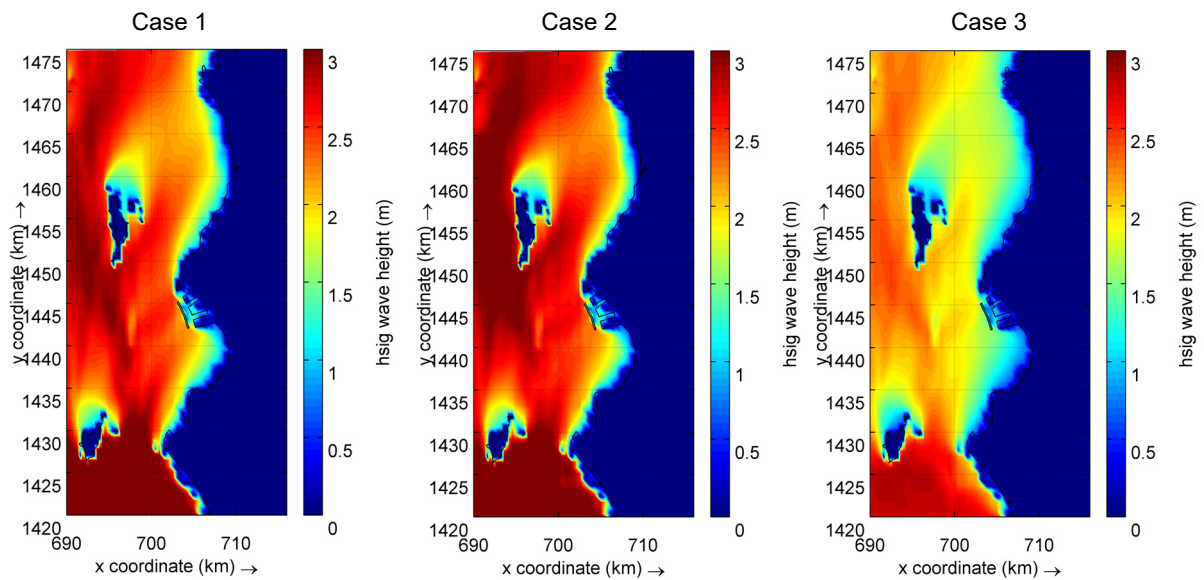


Fig. 3.11 Significant Wave Height Snapshot of Computational Grid (THA Chart 142)

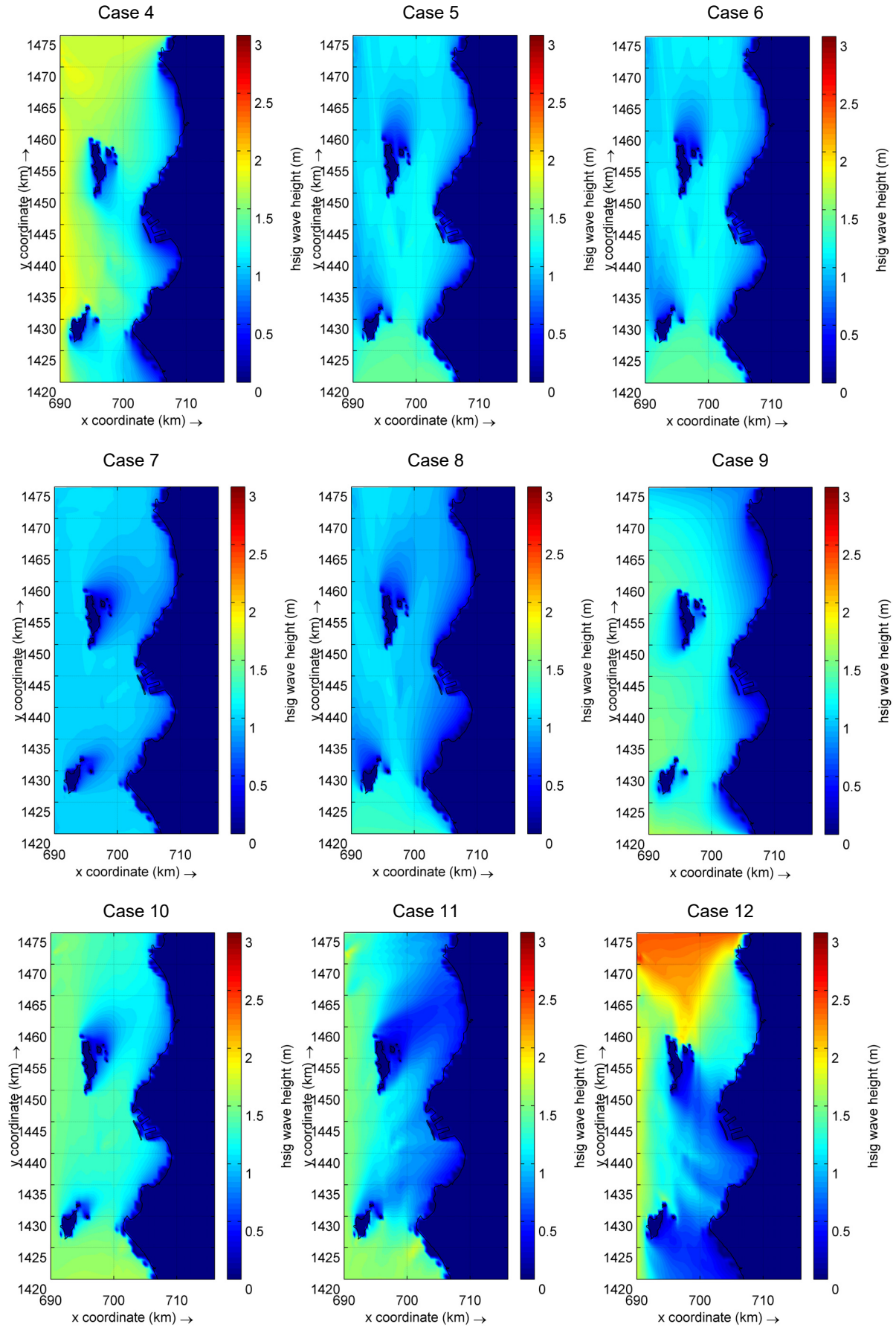


Fig. 3.11 (Cont.) Significant Wave Height Snapshot of Computational Grid (THA Chart 142)

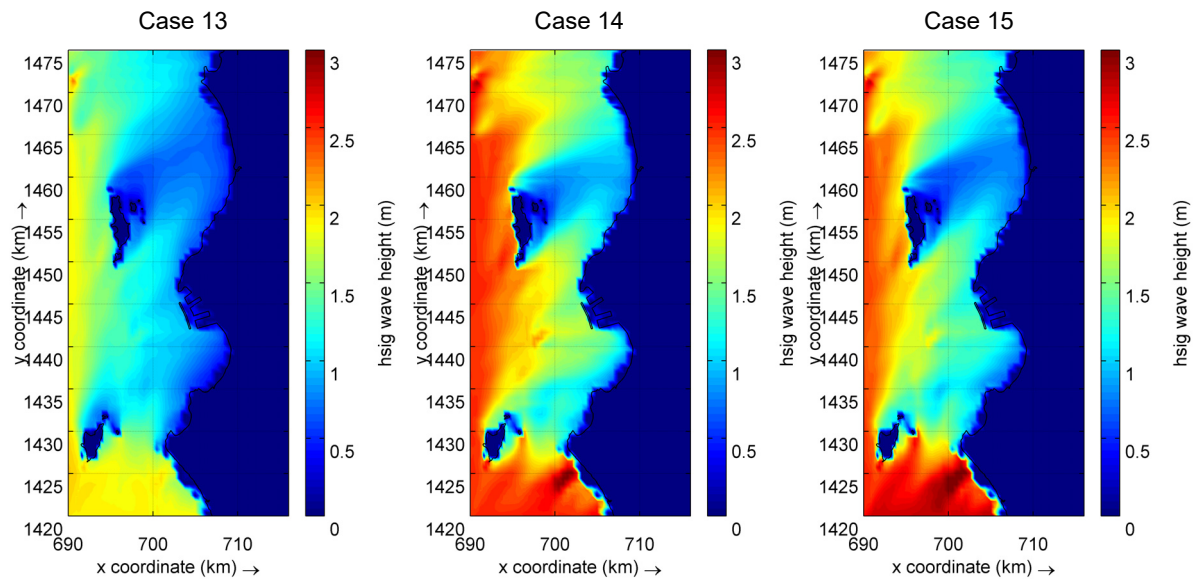


Fig. 3.11 (Cont.) Significant Wave Height Snapshot of Computational Grid (THA Chart 142)

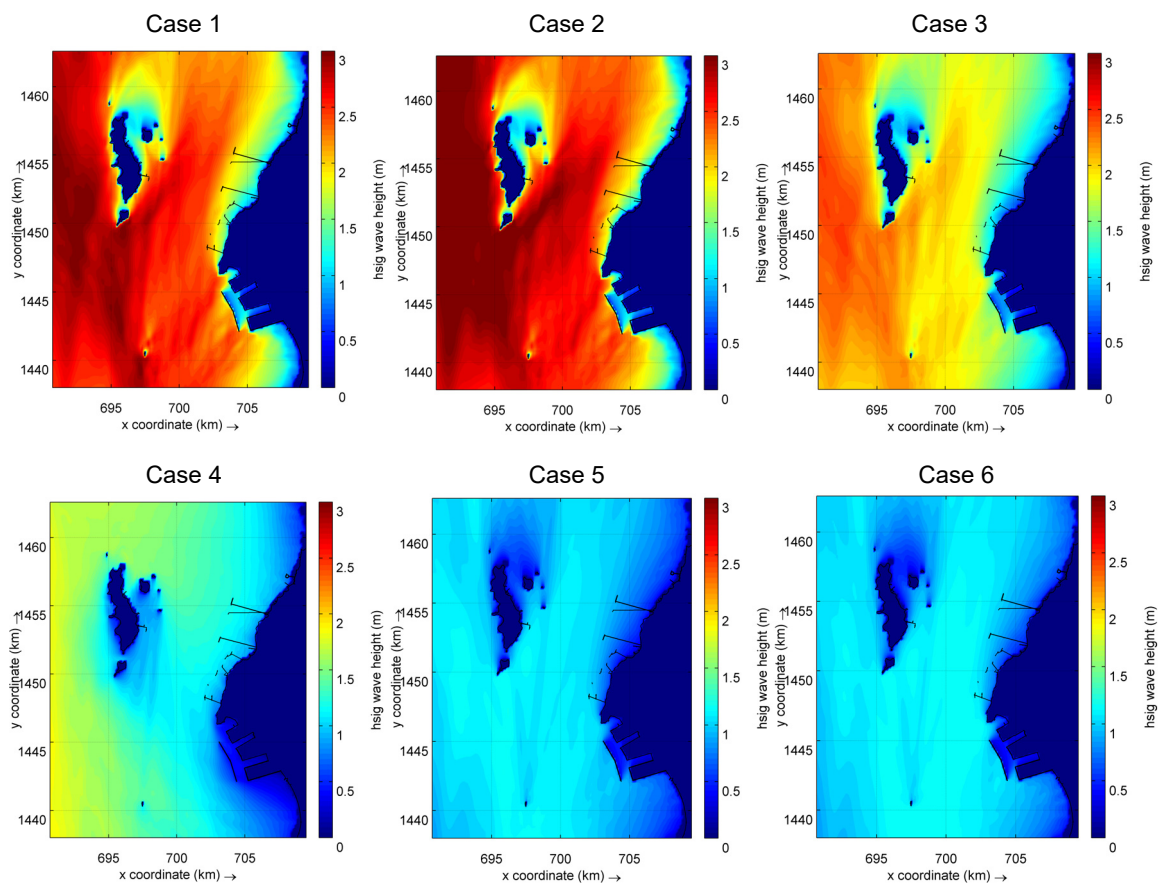


Fig. 3.12 Significant Wave Height Snapshot of Nesting Grid (THA Chart 164)

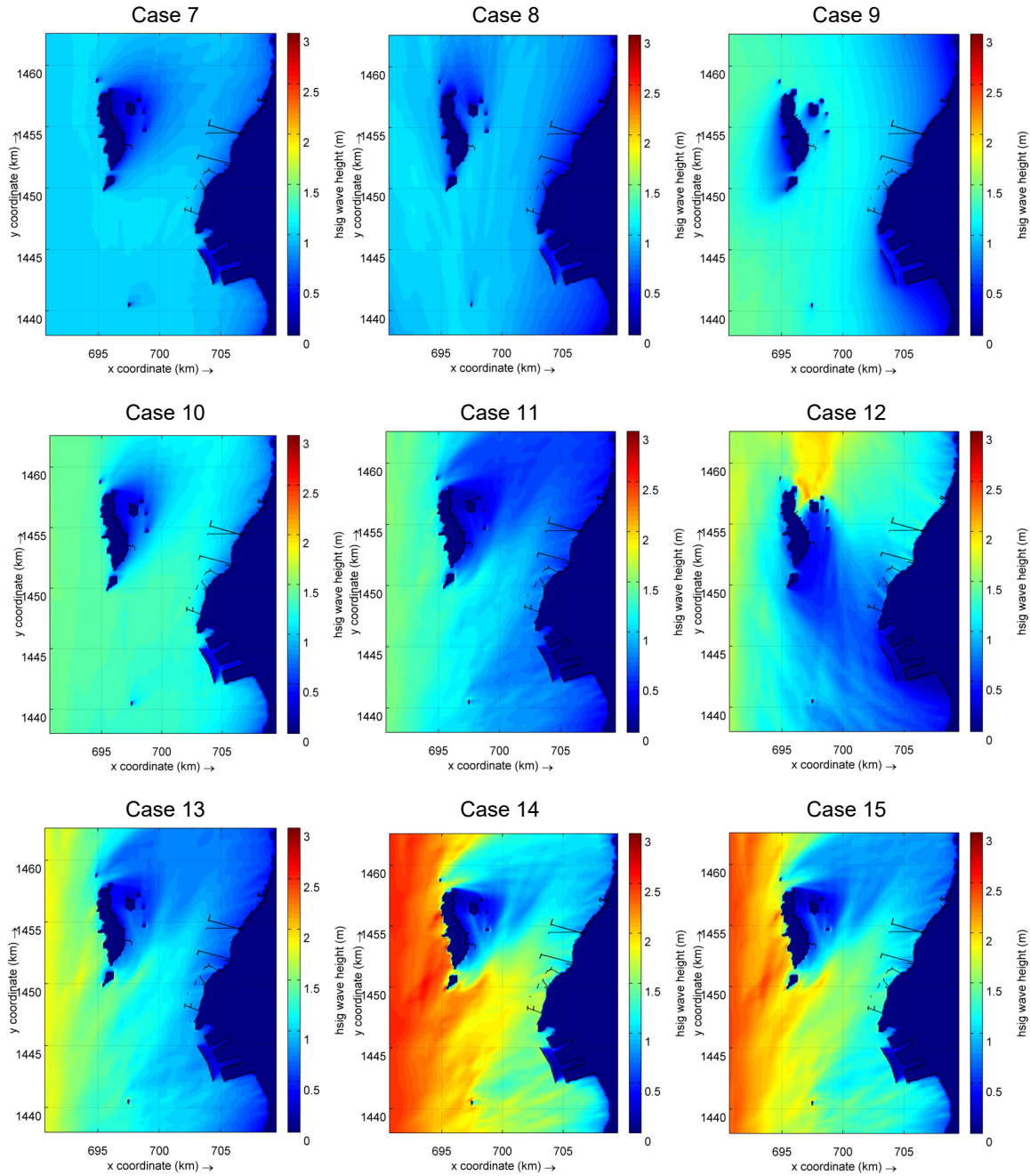


Fig. 3.12 (Cont.) Significant Wave Height Snapshot of Nesting Grid (THA Chart 164)

3.3.3 Wave Model Validation

The wave model is using the observed significant wave height and peak wave applied to the West boundary, while the significant wave height and peak wave period on the North and South boundary are calculated by JONSWAP spectrum. Therefore, the wave model validation is a comparison between the observed data and wave model results at Ko Si Chang (KS) buoy with each scenario on the West boundary, because the study area is no the observed data at the port and nearshore. The maximum percentage of difference of significant wave height is equal to 17.89% and the minimum of 0.64%, and the differential of significant wave height and peak wave period can be represented in R-square of plotted the observed data and wave model results of each scenario on the West boundary as shown in Fig. 3.13 and Fig. 3.14. R-square is equal to 0.97, that represents the wave model is a good agreement for used estimation the significant wave height of each scenario.

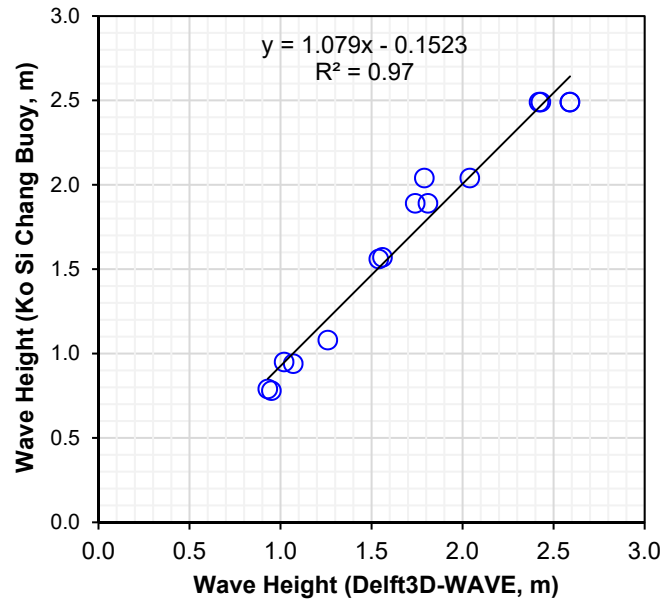


Fig. 3.13 Comparison of Significant Wave Height

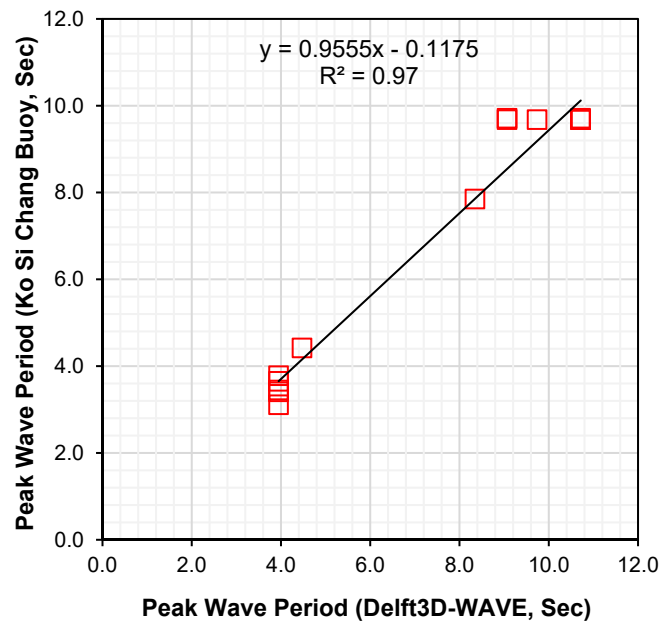


Fig. 3.14 Comparison of Peak Wave Period

3.4 SUMMARY

This study was carried out digitizing time series data in the GISDA's reports from 1991 to 2001 at Ko Si Chang (KS) buoy, also statistical analysis for indicating wind-wave distribution in 16 sectors and distribution of wind-wave class. The maximum significant wave height and maximum wind speed at Ko Si Chang (KS) buoy in northeast directions is equal to 1.89 m and 14.04 m/s also the percentage of occurrence of 7.14% and 6.83%, while the southwest directions is equal 2.49 m and 21.02 m/s which percentage of occurrence of 14.83% and 15.79% respectively. The maximum significant wave height at port in Ao Udom Bay, are intensity at the level of 2.17 m at the front of Laem Chabang Port breakwater (LCP), 2.19 m at PTT Jetty (PTT), 1.97 m at Thai Oil Jetty (TOP), 2.26 m at Kerry Siam Seaport (KSSP) and 2.35 m at Sriracha Harbour (SRH). Ko Si Chang Island has screened the offshore ports when the severe wind-wave coming in southwest directions.

Berth Operability and Port Downtime due to Met-Ocean in East Coast of Thailand

4.1 INTRODUCTION

The level of wave action corresponds to causing issues with the safe berthing, mooring, and operations downtime during severe weather conditions. The (un)loading of vessels depends on a large number of factors with including berthing arrangement, mooring arrangement, size of vessel, number of mooring lines, mooring stiffness, port arrangement, characteristics of cargoes, (un)loading equipment, wave height, wave period, wave direction, water depth and also coincident wind and tidal currents.

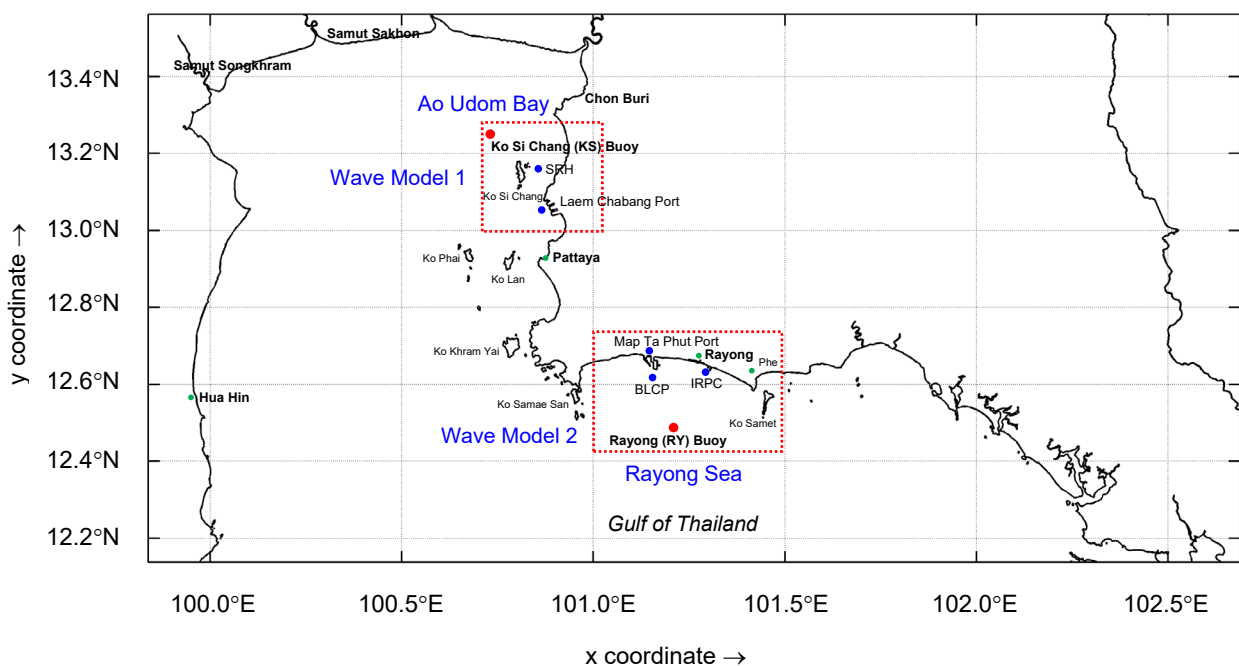


Fig. 4.1 Port Locations

The operation downtime affects to throughput capacity of the refinery, coal stock yard of coal-fired power plant and coal mine, which cause a risk in port operation and increase of construction cost. The criteria for operation of port in this study are based on limiting environmental operating conditions at quays and jetties, undertaken using the following coarse wind speed and significant wave height criteria as recommended in Guidelines MarCom Working Group report No. 121 – 2014, Harbour Approach Channels Design Guidelines (PIANC, 2014). The ports classified by the characteristics of cargoes, port arrangement, type of structures and vessel size. The criteria are tabulated in Table 4.1 as a just short list for this study. The areas of study are selected ports at Ao Udom Bay and ports at Rayong Sea as shown in Fig. 4.1.

Table 4.1 Limiting Environmental Operating Conditions at Quays and Jetties (PIANC 2014)

Description	$V_{W, 1 \text{ min}}$ (m/s)	$V_{F, 1 \text{ min}}$ (m/s)	H_s (m)
Loading and unloading operation stoppage (conventional equipment)			
Forces longitudinal to the quay			
- Oil tankers			
< 30,000 DWT	22.0	1.5	1.5
30,000 DWT – 200,000 DWT	22.0	1.5	2.0
- Bulk carriers			
Loading	22.0	1.5	1.5
Unloading	22.0	1.5	1.0
Forces transverse to the quay			
- Oil tankers			
< 30,000 DWT	20.0	0.7	1.0
30,000 DWT – 200,000 DWT	20.0	0.7	1.2
- Bulk carriers			
Loading	22.0	0.7	1.0
Unloading	22.0	0.7	0.8

Notes: $V_{W, 1 \text{ min}}$: Wind velocity at a height of 10 m above sea level, as a 1-minute average

$V_{F, 1 \text{ min}}$: Current velocity at a depth of half the vessel's draught, as a 1-minute average

H_s : Significant wave height

Table 4.2 Port Locations and Characteristics of Cargoes

No.	Port Name	Characteristics of Cargoes	*East (m)	*North (m)
1	SRH	Bulk carriers	702027.26	1448274.33
2	KSSP	Bulk carriers	703622.36	1451260.61
3	TOP	Oil tankers	703105.53	1452552.67
4	PTT	Oil tankers	704013.77	1455345.17
5	IRPC	Oil tankers	750173.15	1398097.88
6	BLCP	Bulk carriers	734194.79	1398274.93

Note: WGS84/UTM Zone 47N coordinates*

The areas of study are economic zone of Eastern seaboard of Thailand that consists of Sriracha Harbour (SRH), Kerry Siam Seaport (KSSP), Thai Oil Jetty (TOP), PTT Jetty (PTT), IRPC Port (IRPC) and BLCP Coal Fired Power Plant Port (BLCP) at Map Ta Phut Port. The specific port locations are presented as the Universal Transverse Mercator coordinate system (WGS 84 Zone 47N) which is classified by characteristics of cargoes as tabulated in Table 4.2.

4.2 OBSERVED DATA

The met-ocean data records by oceanographic buoys at an approximate water depth of 20 to 50 m. The oceanographic buoys are operated by Geo-Informatics and Space Technology Development Agency (Public Organization: GISTDA) from 1991 to 2006. The oceanographic buoys recorded the hourly wind speeds at 10 min duration, three-hour significant wave height and hourly current speeds. The met-ocean database is absence in ASCII files, and time series data plotted as a graph in linear scale exist in GISTDA reports from 1991 to 2006. The data point in each hour was collected by digitizing manually from the reports. The linear interpolation between data point was applied, for estimating the observation data according to the recording instruments in each time step from 1991 to 2002 of two oceanographic buoys which consist of Ko Si Chang (KS) and Rayong (RY) buoy in the Gulf of Thailand as shown in Fig. 4.1 and Fig. 3.1. The wave direction is unable to be recorded by using the SEAWATCH buoy, because the buoys have no wave direction sensors, therefore the wave direction would be assumed as similarity with wind direction.

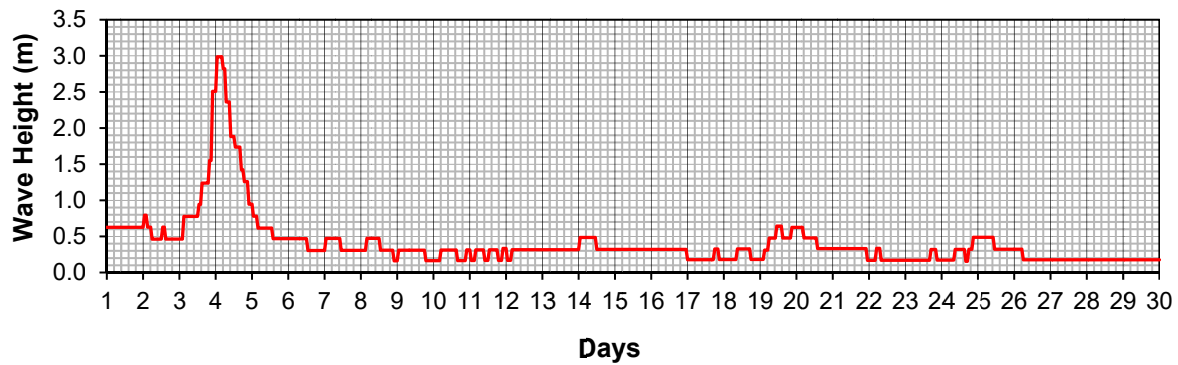


Fig. 4.2 Significant Wave Height Time Series at Rayong (RY) buoy in November 1997
(Manually Digitized)

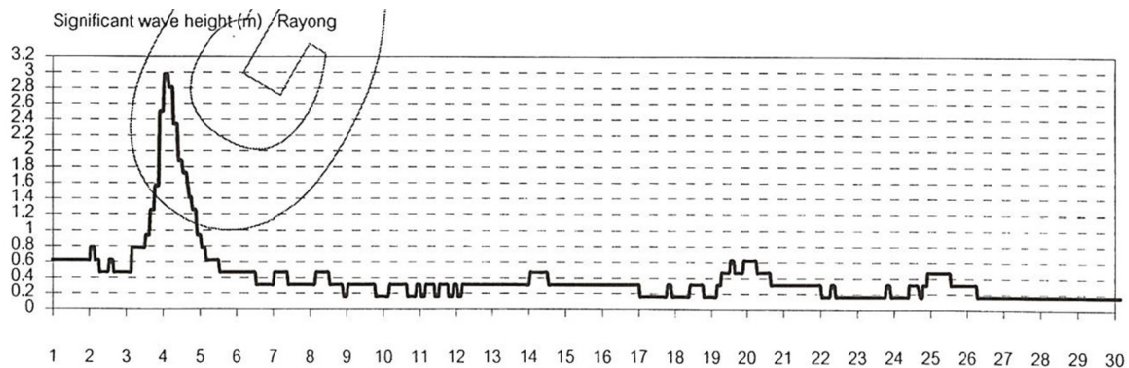
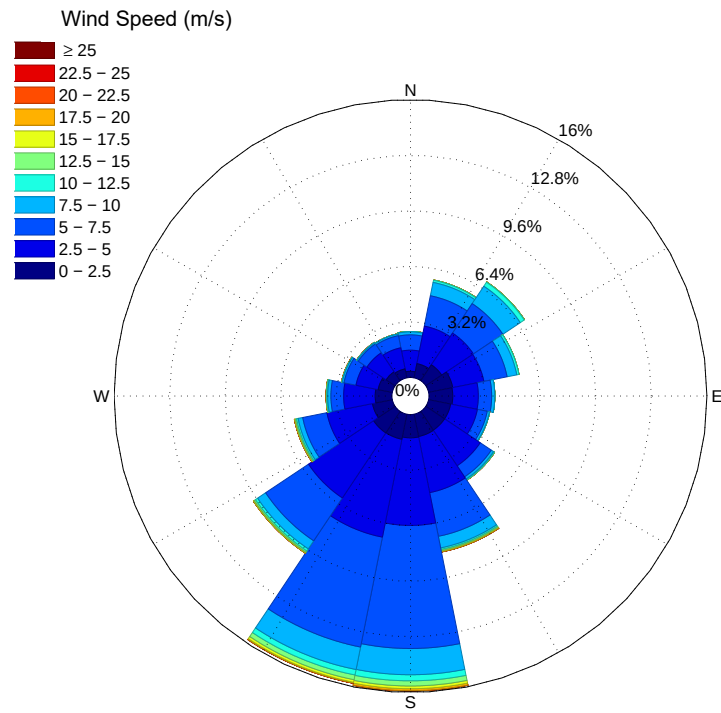
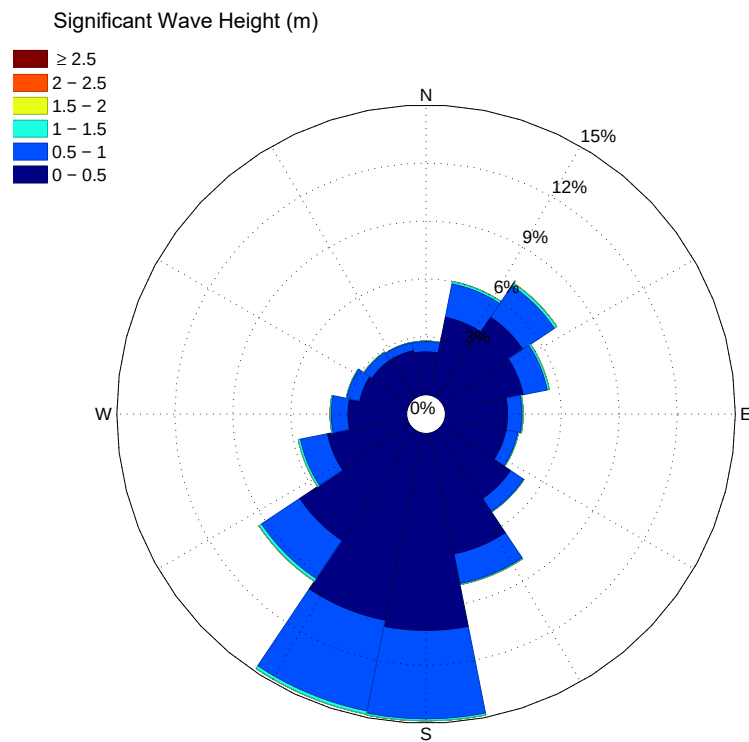


Fig. 4.3 Significant Wave Height Time Series at Rayong (RY) buoy in November 1997
(GISTDA Reports)

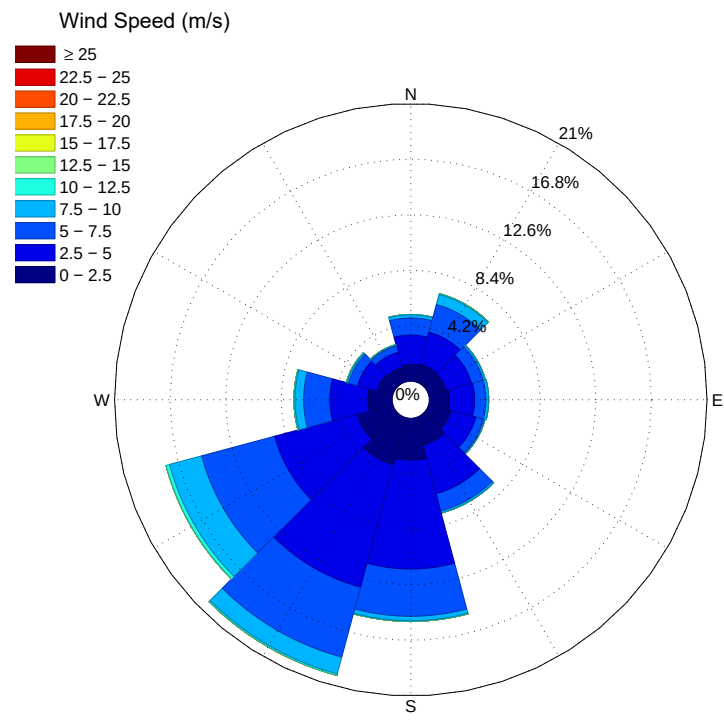


(a)

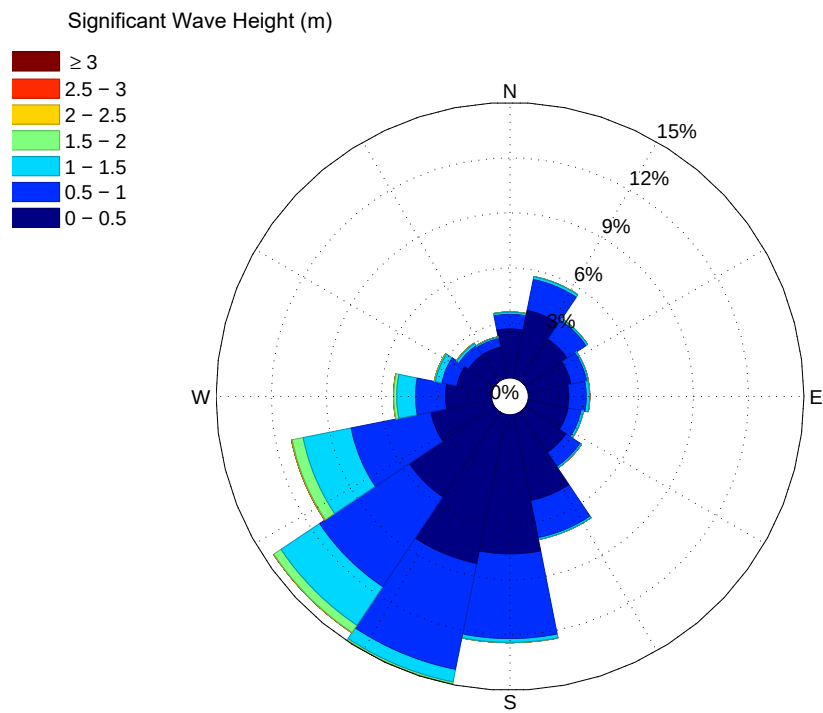


(b)

Fig. 4.4 (a) Wind Rose Diagram and (b) Wave Rose Diagram at Ko Si Chang (KS) Buoy, 1991-2001 (Hattha and Hiraishi, 2016)

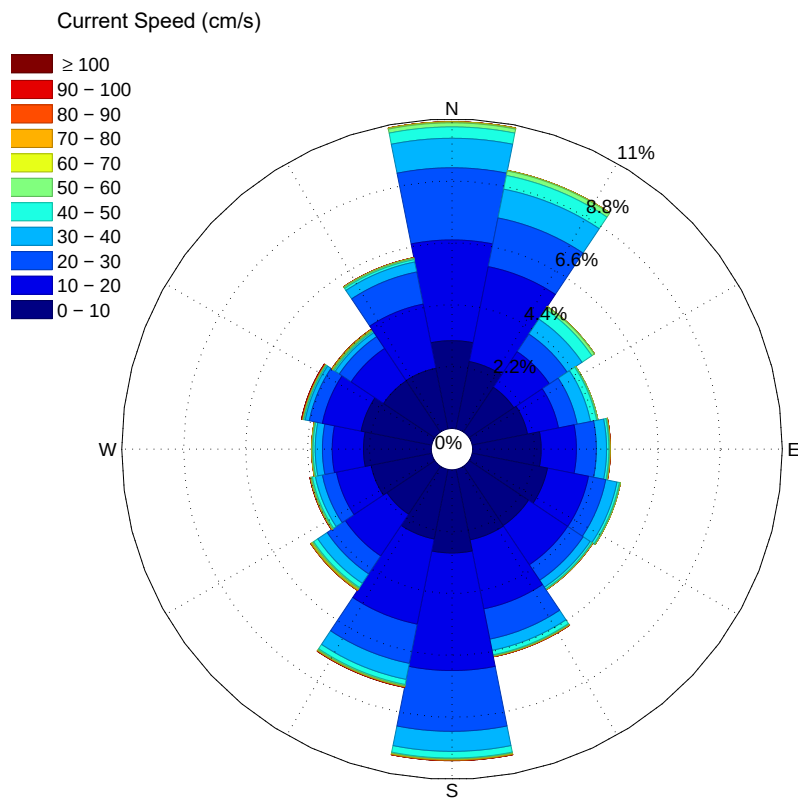


(a)

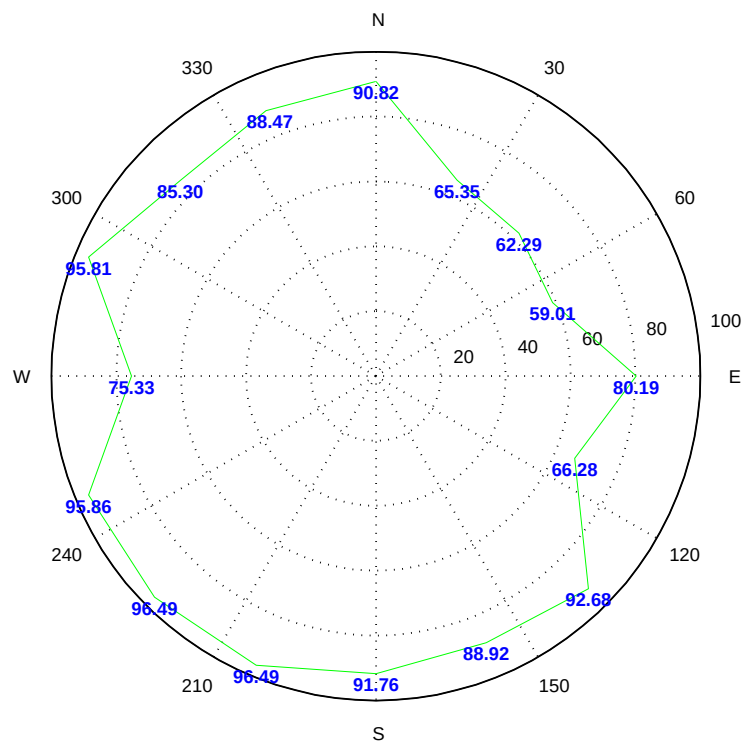


(b)

Fig. 4.5 (a) Wind Rose Diagram and (b) Wave Rose Diagram at Rayong (RY) Buoy, 1991-2002

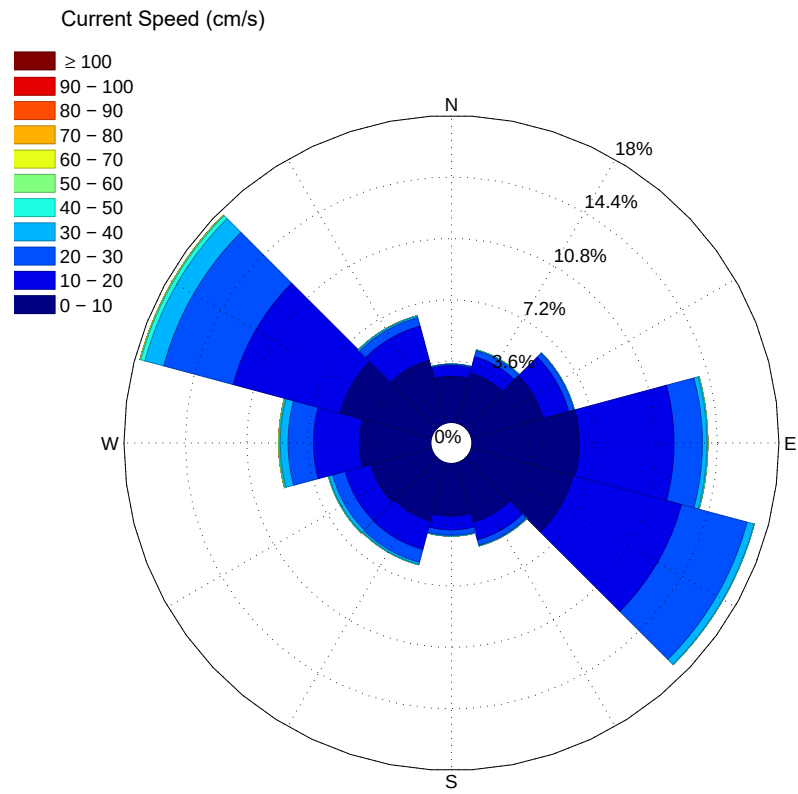


(a)

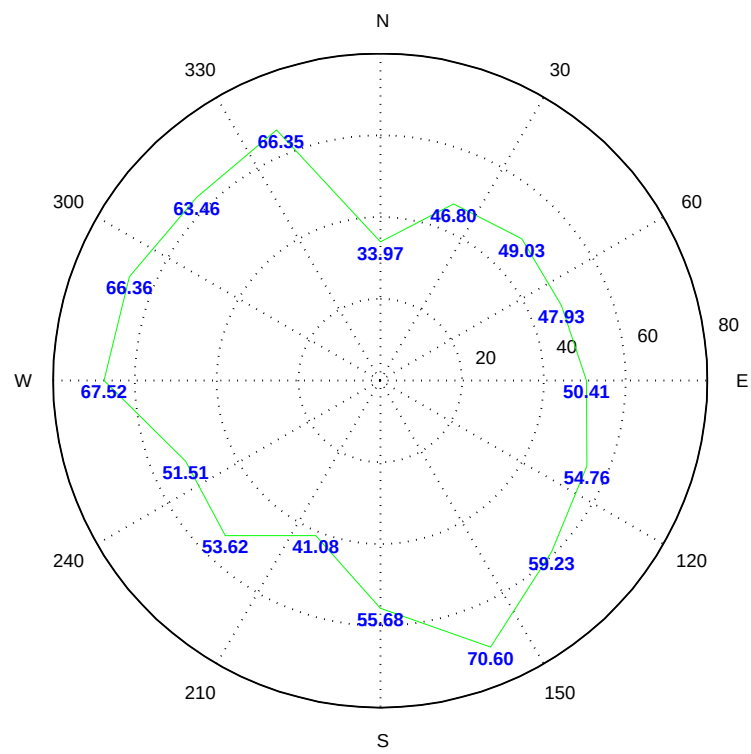


(b)

Fig. 4.6 (a) Currents Rose Diagram and (b) Maximum Currents Speed (cm/s) in Each Direction at Ko Si Chang (KS) Buoy, 1991-2001



(a)



(b)

Fig. 4.7 (a) Currents Rose Diagram and (b) Maximum Currents Speed (cm/s) in Each Direction at Rayong (RY) buoy, 1991-2002

The met-ocean datasets analyzed by using statistical analysis for classifying the wind speeds, wind direction, wave height, wave direction, currents speeds and currents direction distribution with the percentage of occurrence for representing the annual intensity of the wind, wave and currents at buoys. The analysis results can be used the cumulative percentage of occurrence in 16 directions represented the intensity of wind speeds, significant wave height and currents speed at Ko Si Chang (KS) and Rayong (RY) buoy as shown in Fig. 4.4, Fig. 4.5, Fig. 4.6 and Fig. 4.7 as a rose diagram.

The wind recorded at Ko Si Chang (KS) and Rayong (RY) buoys represent the southwest component are dominant during southwest monsoon season which maximum wind speed, is equal to 21.02 m/s and 14.45 m/s respectively. The wave transformations from offshore to Ko Si Chang (KS) and Rayong (RY) buoys are assumed to have similar directions of the wind, and the maximum significant wave height is equal to 2.49 m and 2.99 m respectively.

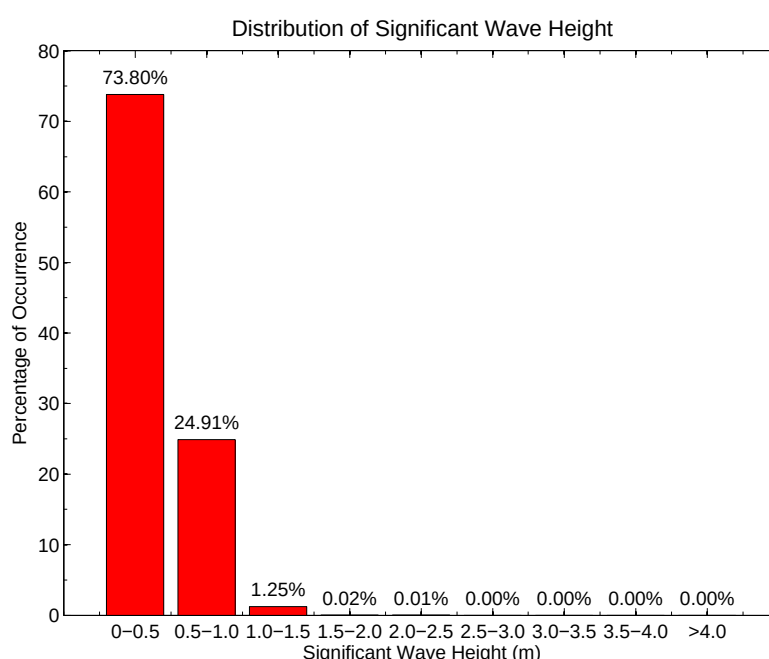


Fig. 4.8 Distribution of Significant Wave Height at Ko Si Chang (KS) Buoy, 1991-2001 (Hattha and Hiraishi, 2016)

The currents speed at Ko Si Chang (KS) and Rayong (RY) buoy represent the peak currents speeds of 0.96 m/s and 0.71 m/s respectively. The dominant direction is North-North-East to South-South-West at Ko Si Chang (KS) buoy as shown in Fig. 4.6, and the dominant direction at Rayong (RY) buoy is North-West to South-East as shown in Fig. 4.7.

The distribution of significant wave height at Ko Si Chang (KS) buoy is presented in Fig. 4.9, which has classified the wave height dataset from 0.5 to 3.5 m, the wave height less than or equal 1 m has the percentage of occurrence 98.72% while larger than 1 m occur up to 1.28%. The significant wave height at Rayong (RY) buoy are higher than Ko Si Chang (KS) buoy which compared with rose diagram and the distribution of significant wave height as shown in Fig. 4.8 and Fig. 4.9. The distribution of wave height at Rayong (RY) buoy is larger than 1.0 m up to 10.32% and 89.68% lower than 1 m.

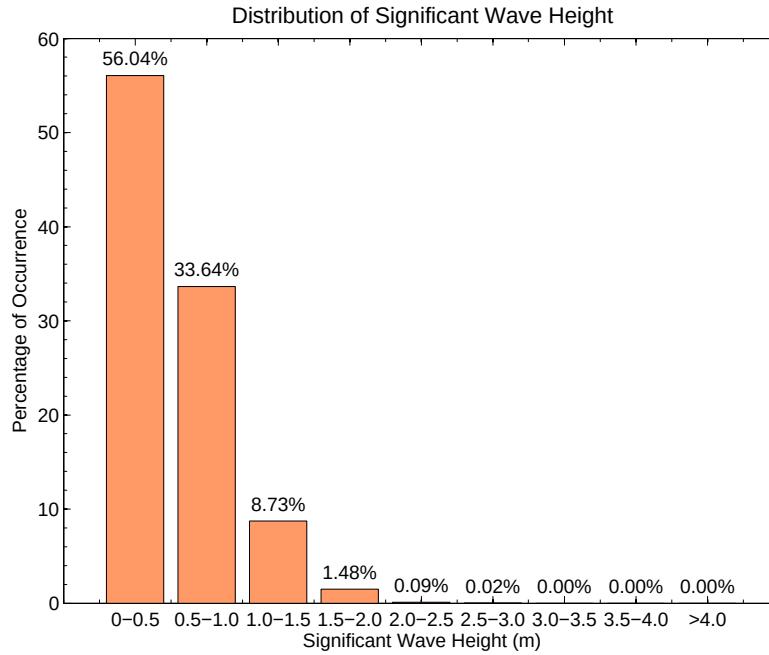


Fig. 4.9 Distribution of Significant Wave Height at Rayong Buoy in 1991-2002

4.3 WAVE MODEL

The propagation of wave transformation from the offshore to the nearshore site was modeled by using a numerical wave model. The numerical wave model carried out using Delft3D-WAVE (Open Source) software package. Delft3D-WAVE (Open Source) was developed by the Delft Technical University which used “Simulating Wave Nearshore” (SWAN) source codes.

4.3.1 Model Setup

The wave model has developed to simulate significant wave height at the port as multi-grid wave model. The model has been setup to the calculation for wave generation, propagation and transformation from offshore to nearshore at Ao Udom Bay (Wave model 1) and Rayong Sea (Wave model 2) as shown in Fig. 4.1. The wave model bathymetry based on THAI nautical charts and the General Bathymetric Chart of the Oceans (GEBCO2014) dataset of bathymetry as shown in Fig. 4.10 and Fig. 4.11. The nautical charts surveyed by Hydrographic Department, Royal Thai Navy consists of THA-142 and THA-164 chart for wave model 1 at Ao Udom Bay and wave model 2 at Rayong Sea THA-142, THA-157 and THA-170 respectively were employed.

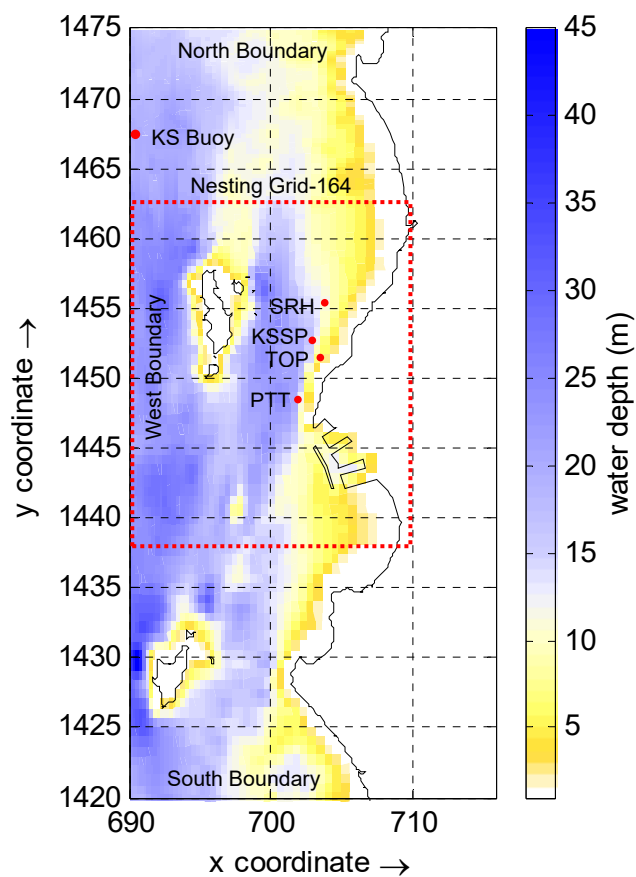


Fig. 4.10 Computational Grid of Wave Model 1 and Nesting Grid-164

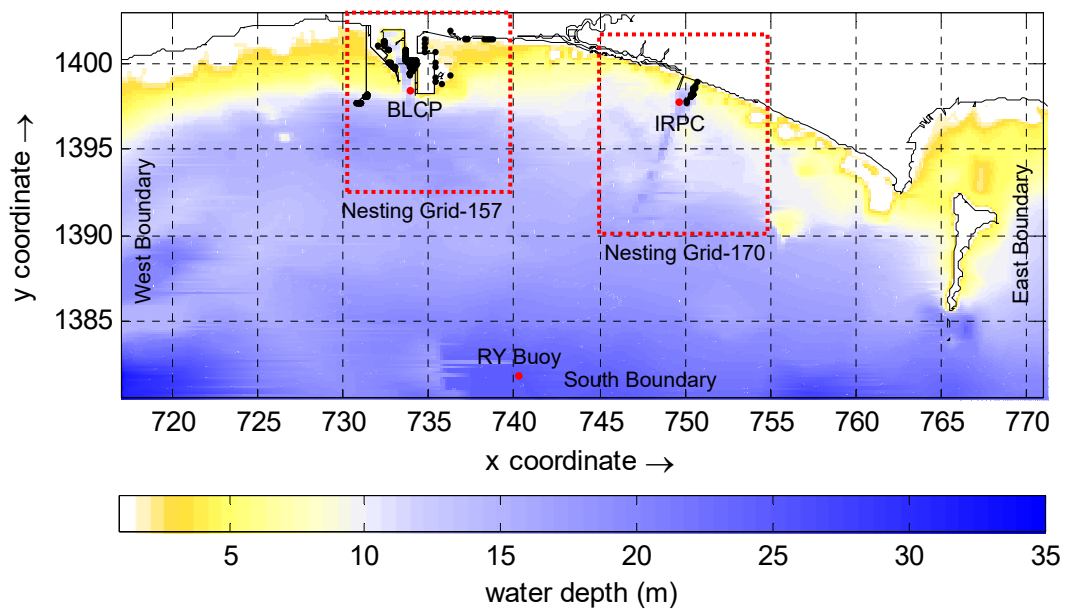


Fig. 4.11 Computational Grid of Wave Model 2, Nesting Grid-157 and Nesting Grid-170

Two model computational grid has been used for gradually increase the accuracy of the model at the site, and thus to obtain a better estimation of the wave characteristics at the ports. The computation grid at Ao Udom Bay (computational grid of wave model 1) extends approximately 20 km west of site to allow calibration and validation wave model to limit wave measurements obtained from Ko Si Chang (KS) buoy. The computation grid size of wave model 1 is 880 x 680 m, and nesting grid-164 is 330x480m as shown in Fig. 4.10. The computational grid at Rayong Sea (computational grid of wave model 2) are two nesting grid included nesting grid-157 and nesting grid-170 as illustrated in Fig. 4.11. The coarse grid size is 203 x 195 m, and nesting grid, 67 x 68 m and 149 x 136 m, also the computational grid are extended approximately 20 km south of site to allow calibration and validation wave model to limited wave measurements obtained from Rayong (RY) buoy.

4.3.2 Input Data

The wind speeds and significant wave height applied for input parameters in wave model. The data recorded by oceanographic buoys from 1991 to 2002 at Ko Si Chang (KS) and Rayong (RY) buoy. The wave model computing the wave transformation in time series over 10 years takes more time for computer program running, while this study is selected wind-wave scenario by consideration of significant wave height exceedance values from 1991 to 2002 at Ko Si Chang (KS) and Rayong (RY) buoys as tabulated in Table 4.3 and Table 4.4.

Table 4.3 Significant Wave Height Exceedance Values from 1991 to 2001 at Ko Si Chang (KS) Buoy

Dir. (Deg.)	0 - 0.5 (m)	0.5 - 1.0 (m)	1.0 - 1.5 (m)	1.5 - 2.0 (m)	2.0 - 2.5 (m)	2.5 - 3.0 (m)	3.0 - 3.5 (m)	Total
0	2.2%	0.5%	0.0%	0%	0%	0%	0%	2.8%
22.5	4.1%	1.8%	0.1%	0%	0%	0%	0%	6.0%
45	5.0%	2.0%	0.1%	0%	0%	0%	0%	7.1%
67.5	4.1%	1.3%	0.1%	0%	0%	0%	0%	5.5%
90	3.2%	0.7%	0.1%	0%	0%	0%	0%	4.0%
112.5	3.2%	0.6%	0.0%	0%	0%	0%	0%	3.9%
135	4.2%	0.8%	0.0%	0%	0%	0%	0%	5.1%
157.5	6.4%	1.6%	0.1%	0%	0%	0%	0%	8.0%
180	10.2%	4.6%	0.1%	0%	0%	0%	0%	14.9%
202.5	9.9%	4.8%	0.2%	0%	0%	0%	0%	14.8%
225	6.8%	2.4%	0.2%	0%	0%	0%	0%	9.4%
247.5	4.2%	1.4%	0.1%	0%	0%	0%	0%	5.7%
270	3.0%	0.9%	0.1%	0%	0%	0%	0%	4.0%
292.5	2.5%	0.7%	0.0%	0%	0%	0%	0%	3.2%
315	2.3%	0.5%	0.0%	0%	0%	0%	0%	2.9%
337.5	2.3%	0.4%	0.0%	0%	0%	0%	0%	2.8%
Total								100%

Note: Total events of significant wave height database is 37,804 event

Table 4.4 Significant Wave Height Exceedance Values from 1991 to 2002 at Rayong (RY) Buoy

Dir. (Deg.)	0 - 0.5 (m)	0.5 - 1.0 (m)	1.0 - 1.5 (m)	1.5 - 2.0 (m)	2.0 - 2.5 (m)	2.5 - 3.0 (m)	3.0 - 3.5 (m)	Total
0	2.7%	0.8%	0.1%	0%	0%	0%	0%	3.6%
22.5	3.8%	1.7%	0.2%	0%	0%	0%	0%	5.7%
45	2.7%	1.2%	0.1%	0%	0%	0%	0%	4.1%
67.5	2.4%	0.9%	0.1%	0%	0%	0%	0%	3.4%
90	2.2%	1.0%	0.2%	0%	0%	0%	0.0%	3.3%
112.5	2.2%	0.7%	0.1%	0%	0%	0%	0.0%	3.1%
135	2.7%	0.9%	0.1%	0%	0%	0%	0%	3.7%
157.5	4.8%	2.1%	0.1%	0%	0%	0%	0%	6.9%
180	7.6%	4.6%	0.2%	0%	0%	0%	0%	12.4%
202.5	8.3%	5.9%	0.7%	0.1%	0%	0%	0%	15.0%
225	5.6%	5.9%	2.5%	0.5%	0%	0%	0%	14.5%
247.5	3.4%	4.4%	2.7%	0.6%	0%	0%	0%	11.1%
270	2.5%	1.6%	1.0%	0.2%	0%	0%	0%	5.3%
292.5	1.9%	0.8%	0.4%	0.1%	0%	0%	0%	3.2%
315	1.7%	0.6%	0.2%	0%	0%	0%	0%	2.5%
337.5	1.7%	0.5%	0.1%	0%	0%	0%	0%	2.3%
Total								100%

Note: Total events of significant wave height database is 48,383event

The wind-wave scenarios for wave model input are derived from wind-wave data with the dominant direction of significant wave height, which as southwest monsoon and northeast monsoon season as shown in Table 4.5 and Table 4.6. These represent the total scenario of 106 events and 2 additional events for wave model 1, 117 events and 4 additional events for wave model 2. The scenario is selected from the wind-wave database of oceanographic buoys for inputting in wave model as physical parameters and initial wave boundary.

Table 4.5 Scenarios for Wave Model at Ao Udom Bay

Dir. (Deg.)	0 - 0.5 (m)	0.5 - 1.0 (m)	1.0 - 1.5 (m)	1.5 - 2.0 (m)	2.0 - 2.5 (m)	2.5 - 3.0 (m)	3.0 - 3.5 (m)	Total
22.5	7	3	1	0	0	11	7	3
45	9	3	1	1	0	14	9	3
67.5	7	2	1	0	0	10	7	2
180	18	8	1	0	0	27	18	8
202.5	17	8	1	0	0	26	17	8
225	12	4	1	1	0	18	12	4
Total								106

Table 4.6 Scenarios for Wave Model at Rayong Sea

Dir. (Deg.)	0 - 0.5 (m)	0.5 - 1.0 (m)	1.0 - 1.5 (m)	1.5 - 2.0 (m)	2.0 - 2.5 (m)	2.5 - 3.0 (m)	3.0 - 3.5 (m)	Total
90	3	1	1	1	0	1	7	3
112.5	3	1	1	0	0	0	5	3
135	4	1	1	1	0	1	8	4
157.5	7	3	1	0	0	0	11	7
180	10	6	1	1	1	0	19	10
202.5	11	8	1	1	1	0	22	11
225	7	8	3	1	1	0	20	7
247.5	5	6	4	1	1	0	17	5
270	3	2	1	1	1	0	8	3
90	3	1	1	1	0	1	7	3
Total								117

The water level was assumed to mean sea level for every scenario that above lowest low water level (LLW). The mean sea level was taken from THAI nautical chart and observed tide station at Rayong and Ao Udom. The water level assigned to wave model 1 is equal to 2.48m (LLW) and 1.67m (LLW) for wave model 2.

4.3.3 Model Parameters

The wave induce-breaking factor should be used B&J model of which Alpha equal to 1.0 and Gamma of 0.73. The bottom friction using the JONSWAP bottom friction parameters, of which coefficient of $0.067 \text{ m}^2\text{s}^{-3}$. Whitecapping is primarily controlled by wave steepness, and in the wave model it is selected as whitecapping given by Van der Westhuysen et al. (2007). The diffraction is setting to default which smoothing coefficient of 0.2 and smoothing steps 5, also selected adapt propagation. Wave propagation through breakwater or obstacles is assigned to the coefficients depending on the shape of breakwater as a dam with slope 1:3/2. The coefficient is given by Seeling (1979), and Alpha equal to 2.6 and Beta to 0.15.

The boundary condition was assigned on non-zero wave boundary as uniformly along boundary orientation in the computational grid by using offshore wave and wind conditions, the wave parameters consisting the significant wave height, wave direction and peak wave period. Then, wave and wind parameters are selected from the met-ocean database at oceanographic buoy based on the scenario as tabulated in Table 4.5 and Table 4.6, therefore the environmental condition for Wave Model at Ao Udom Bay and Rayong Sae are tabulated in Table 4.7 and Table 4.8. The non-zero wave boundaries far away from buoy position are estimated of the wave height and peak wave period by using SPM-method (Shore Protection Manual, 1984).

Table 4.7 Environmental Conditions for Wave Model at Ao Udom Bay

No.	Wind Speed (m/s)	Wind Dir. (Deg.)	Significant Wave Height (m)	Peak Wave Period (Sec)	No.	Wind Speed (m/s)	Wind Dir. (Deg.)	Significant Wave Height (m)	Peak Wave Period (Sec)
1	6.78	22.50	0.48	2.97	36	4.95	179.25	0.48	3.10
2	4.71	21.00	0.48	2.95	37	4.81	178.36	0.48	3.38
3	6.26	25.95	0.48	2.66	38	4.91	177.12	0.48	3.43
4	4.98	22.71	0.48	2.98	39	3.95	180.12	0.48	3.60
5	4.82	23.14	0.48	3.31	40	4.63	177.70	0.48	3.37
6	4.90	22.78	0.47	3.11	41	5.12	176.09	0.48	3.24
7	3.79	22.22	0.48	2.98	42	4.89	179.67	0.48	3.16
8	7.93	18.35	0.94	3.64	43	5.25	183.51	0.48	4.02
9	12.22	28.48	0.94	3.66	44	4.89	178.74	0.48	3.00
10	10.30	26.22	0.94	3.60	45	4.57	179.10	0.48	3.31
11	13.67	13.92	1.24	3.98	46	4.04	181.80	0.48	2.99
12	4.69	45.74	0.48	2.95	47	4.21	182.06	0.48	3.28
13	4.73	43.59	0.48	3.31	48	4.37	177.35	0.49	3.32
14	5.13	46.65	0.48	3.27	49	4.13	185.00	0.49	3.32
15	5.63	47.94	0.48	3.26	50	4.53	175.03	0.49	3.32
16	4.67	43.42	0.48	2.98	51	5.10	177.06	0.49	3.12
17	5.15	40.29	0.48	2.96	52	5.81	181.09	0.49	2.84
18	4.54	41.24	0.48	3.32	53	4.60	183.63	0.49	3.17
19	5.63	42.10	0.49	3.00	54	7.30	180.86	0.98	3.94
20	5.07	43.36	0.50	3.01	55	7.40	184.09	0.96	3.94
21	12.03	46.48	0.88	3.66	56	7.60	182.96	0.96	3.95
22	11.89	45.61	0.79	3.65	57	7.35	184.05	0.96	3.95
23	7.46	44.89	0.94	3.94	58	7.47	182.72	0.96	3.95
24	14.04	36.79	1.89	10.22	59	7.58	181.04	0.96	3.94
25	9.89	44.46	1.27	3.99	60	7.68	183.54	0.95	3.63
26	4.82	66.89	0.47	2.98	61	8.26	178.20	0.96	3.69
27	4.77	65.12	0.47	3.15	62	5.16	182.25	1.27	4.29
28	5.18	68.23	0.48	2.95	63	4.06	202.90	0.47	2.92
29	4.74	68.79	0.48	2.93	64	5.10	200.04	0.47	3.66
30	5.26	69.10	0.48	2.94	65	4.57	201.83	0.48	3.65
31	5.12	67.67	0.48	3.34	66	4.74	200.99	0.48	2.89
32	5.19	66.16	0.48	3.00	67	4.25	204.37	0.48	3.31
33	8.00	66.62	0.95	3.62	68	4.14	200.97	0.48	2.62
34	6.51	66.66	0.99	3.96	69	4.03	203.03	0.48	3.30
35	6.10	78.15	1.41	4.34	70	5.64	203.63	0.48	2.99

Table 4.7 (Cont.) Environmental Conditions for Wave Model at Ao Udom Bay

No.	Wind Speed (m/s)	Wind Dir. (Deg.)	Significant Wave Height (m)	Peak Wave Period (Sec)	No.	Wind Speed (m/s)	Wind Dir. (Deg.)	Significant Wave Height (m)	Peak Wave Period (Sec)
71	5.60	203.60	0.48	3.34	98	4.96	220.50	0.49	3.17
72	4.47	203.64	0.48	3.20	99	4.20	221.23	0.49	3.02
73	4.57	203.10	0.48	3.01	100	4.05	227.47	0.50	3.43
74	5.50	201.54	0.48	2.95	101	15.48	221.28	0.96	3.68
75	5.68	202.50	0.48	3.06	102	10.28	223.77	0.94	4.01
76	4.66	205.03	0.49	3.01	103	9.01	224.14	0.95	3.96
77	5.74	204.40	0.49	3.51	104	8.75	228.45	0.95	3.29
78	4.76	203.43	0.49	2.99	105	10.03	221.77	1.26	4.30
79	5.51	201.71	0.50	3.05	106	8.99	225.60	1.56	4.65
80	6.76	204.34	0.96	3.95	<i>Additional Scenarios</i>				
81	8.63	203.10	0.95	3.99	107	3.16	177.72	2.49	10.19
82	8.36	202.69	0.95	3.99	108	2.23	192.68	2.49	10.19
83	14.81	200.53	0.94	3.60					
84	14.00	202.68	0.94	3.60					
85	9.47	200.82	0.96	3.98					
86	14.99	202.23	0.95	4.08					
87	8.47	204.96	0.95	3.65					
88	8.46	202.65	1.28	4.38					
89	4.85	226.88	0.48	3.30					
90	4.83	223.08	0.48	3.34					
91	4.91	224.06	0.48	2.63					
92	4.99	224.41	0.48	2.97					
93	4.14	227.87	0.48	3.55					
94	4.78	228.97	0.48	3.33					
95	4.75	226.98	0.48	2.95					
96	4.46	221.62	0.48	3.32					
97	5.03	229.32	0.49	3.25					

Table 4.8 Environmental Conditions for Wave Model at Rayong Sea

No.	Wind Speed (m/s)	Wind Dir. (Deg.)	Significant Wave Height (m)	Peak Wave Period (Sec)	No.	Wind Speed (m/s)	Wind Dir. (Deg.)	Significant Wave Height (m)	Peak Wave Period (Sec)
1	5.12	89.00	0.48	4.33	36	3.88	186.19	0.49	3.65
2	5.39	99.56	0.48	3.26	37	4.57	188.57	0.49	3.22
3	5.47	81.75	0.49	3.47	38	4.27	170.70	0.49	3.07
4	9.79	94.99	0.78	2.94	39	3.51	175.11	0.49	3.48
5	6.67	89.47	0.95	4.35	40	4.25	184.24	0.49	3.51
6	9.74	85.99	1.88	5.29	41	4.02	175.70	0.49	3.80
7	9.01	95.48	2.99	5.94	42	6.23	189.78	0.97	4.19
8	5.45	117.16	0.49	2.73	43	6.55	172.82	0.96	5.01
9	4.33	102.66	0.49	3.08	44	5.49	184.89	0.99	3.96
10	5.64	118.31	0.49	3.00	45	6.67	189.31	0.95	4.35
11	6.61	109.82	0.98	4.72	46	7.24	177.48	0.97	3.80
12	7.91	123.22	1.40	4.66	47	6.04	170.02	0.96	3.80
13	4.17	144.62	0.50	2.92	48	6.95	188.29	1.43	4.28
14	4.11	145.92	0.49	3.93	49	7.94	183.39	1.55	4.60
15	4.90	131.59	0.50	2.93	50	2.65	170.39	2.04	10.20
16	5.64	139.29	0.50	2.93	51	4.13	203.08	0.49	3.15
17	8.77	127.86	0.99	4.71	52	4.14	195.85	0.49	3.72
18	8.89	143.21	1.41	4.64	53	4.50	201.34	0.49	3.39
19	8.14	143.34	1.58	5.00	54	4.06	209.80	0.49	3.78
20	11.73	131.54	2.99	5.94	55	4.01	198.24	0.49	3.12
21	4.73	167.23	0.48	3.06	56	3.98	200.27	0.49	3.65
22	3.34	154.14	0.48	3.93	57	3.80	204.16	0.49	3.57
23	4.59	155.50	0.49	3.31	58	3.67	204.27	0.49	3.54
24	4.39	163.01	0.49	3.26	59	4.02	200.47	0.49	3.74
25	5.46	158.29	0.49	3.21	60	4.25	199.41	0.49	3.75
26	6.47	148.51	0.50	3.07	61	4.22	201.07	0.49	3.60
27	5.54	167.71	0.48	3.34	62	5.60	204.29	0.99	3.35
28	4.92	161.77	0.95	4.67	63	9.38	203.44	0.96	4.03
29	7.16	163.58	0.95	3.80	64	7.82	200.23	0.95	3.76
30	7.64	159.41	0.97	3.66	65	7.94	204.32	0.95	3.95
31	7.34	164.81	1.30	4.61	66	6.60	204.88	0.95	3.95
32	4.02	186.96	0.49	3.32	67	6.02	204.13	0.99	4.08
33	3.72	184.60	0.49	3.80	68	7.72	200.10	0.98	3.86
34	3.96	169.85	0.49	3.43	69	5.49	204.20	0.96	4.31
35	4.20	181.35	0.49	3.79	70	8.44	203.79	1.49	4.60

Table 4.8 (Cont.) Environmental Conditions for Wave Model at Rayong Sea

No.	Wind Speed (m/s)	Wind Dir. (Deg.)	Significant Wave Height (m)	Peak Wave Period (Sec)	No.	Wind Speed (m/s)	Wind Dir. (Deg.)	Significant Wave Height (m)	Peak Wave Period (Sec)
71	9.94	203.02	1.88	5.28	98	6.61	242.36	0.97	3.72
72	10.02	206.82	2.21	5.27	99	7.24	241.70	0.99	4.04
73	4.71	221.83	0.49	3.50	100	6.84	243.32	0.99	3.98
74	4.14	216.82	0.49	3.17	101	7.20	245.38	0.98	3.95
75	4.83	217.01	0.49	3.00	102	9.11	246.95	0.98	3.94
76	4.03	227.28	0.49	3.29	103	8.02	242.37	0.98	3.99
77	3.58	220.56	0.49	3.20	104	8.83	242.77	1.49	4.79
78	4.73	229.22	0.49	3.91	105	10.12	245.85	1.49	4.62
79	4.58	219.86	0.49	2.92	106	9.30	247.32	1.49	5.00
80	7.02	229.42	0.99	4.29	107	9.40	243.05	1.49	4.39
81	7.94	231.58	0.99	4.18	108	7.80	248.27	1.99	4.96
82	6.70	225.98	0.99	4.12	109	9.31	246.05	2.04	5.33
83	10.52	232.27	0.99	4.18	110	6.35	273.50	0.48	2.98
84	7.59	225.75	0.98	3.96	111	5.62	278.27	0.48	3.92
85	6.47	229.91	0.99	4.02	112	5.19	266.52	0.49	3.64
86	7.37	214.75	0.99	3.97	113	7.88	268.25	1.00	4.24
87	8.16	234.61	0.99	4.30	114	8.61	271.89	1.00	4.27
88	8.72	230.91	1.49	4.71	115	10.49	267.14	1.46	4.30
89	10.59	231.28	1.47	4.61	116	10.73	261.82	1.89	4.63
90	8.08	217.54	1.49	4.57	117	9.48	276.49	2.19	5.23
91	6.54	227.37	1.98	4.92	<i>Additional Scenarios</i>				
92	4.22	219.57	2.33	10.16	118	8.82	132.58	2.99	5.94
93	5.31	240.66	0.48	3.29	119	9.53	122.71	2.82	5.94
94	5.56	243.95	0.49	3.31	120	10.73	133.65	2.82	5.94
95	5.16	249.99	0.48	3.31	121	11.17	91.99	2.51	5.94
96	5.24	242.67	0.48	3.30					
97	5.11	244.96	0.48	3.66					

4.3.4 Model Results

The model outputs are selected one point in the port area as tabulated in Table 4.2 and shown in Fig. 4.12 to Fig. 4.14. The significant wave height, wave direction and peak wave period are selected from the nesting grid for accurate results. The nearshore significant wave height does not exceed 1.8 m at the port in Ao Udom Bay and Rayong Sea as shown in Fig. 4.14 to Fig. 4.16, and the significant wave height are plotted as a rose diagram at each port for represents wave height intensity with a cumulative percentage of occurrence and direction. The wave direction at each port at Ao Udom Bay and Rayong Sea is southwest direction dominant that similar to buoys data.

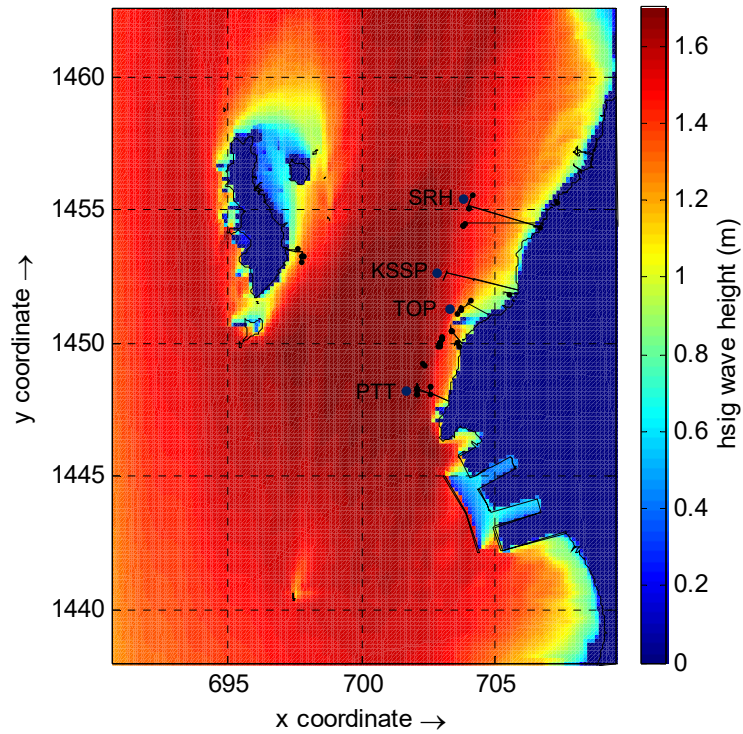


Fig. 4.12 Significant Wave Height of Nesting Grid-164, Case 106 with Input Wind Speed of 8.99 m/s, Wind Direction of 225.60°, Wave Height of 1.56 m and Wave Direction of 225.60°

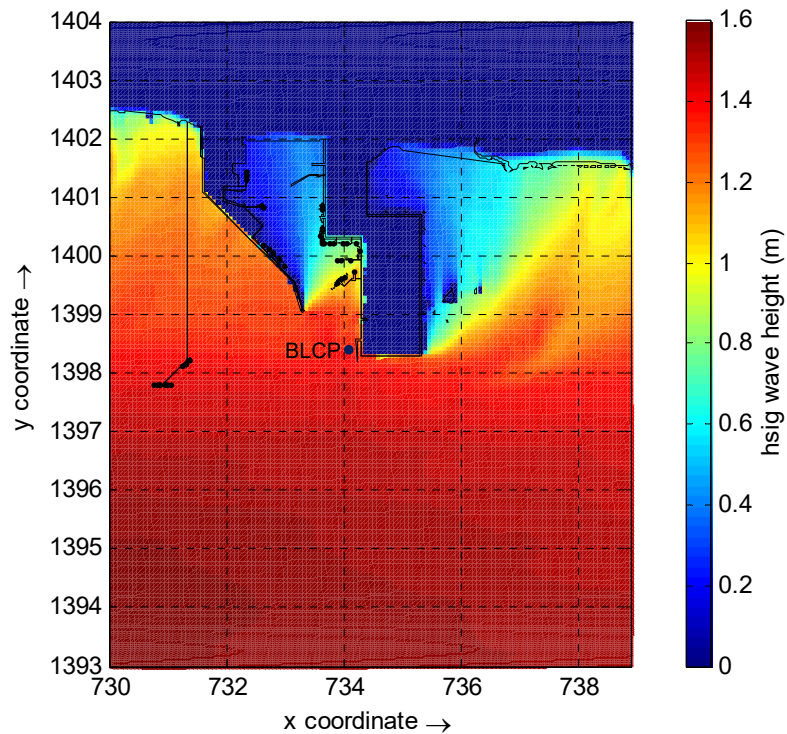


Fig. 4.13 Significant Wave Height of Nesting Grid-157, Case 89 with Input Wind Speed of 10.59 m/s, Wind Direction of 231.28°, Wave height of 1.47 m and Wave Direction of 231.28°

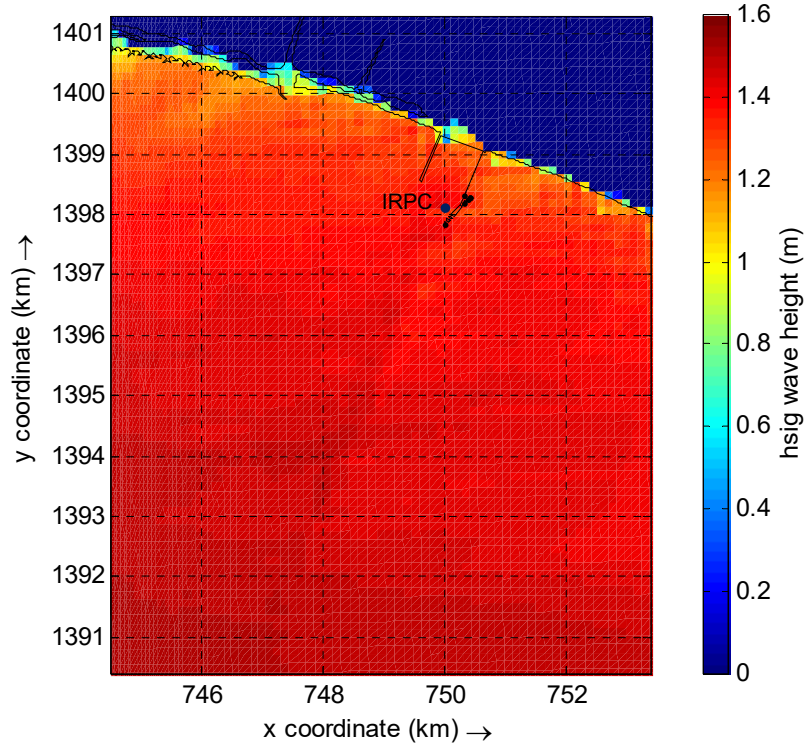


Fig. 4.14 Significant Wave Height of Nesting Grid-170, Case 89 with Input Wind Speed of 10.59 m/m, Wind Direction of 231.28°, Wave Height of 1.47 m and Wave Direction of 231.28°

The percentage of occurrence at the port is presented in Table 4.8 as classes of significant wave height from 0 to 2 m if compared the significant wave height by the percentage of occurrence at ports, the wave height larger than 1 m occur more than the wave height at oceanographic buoys. The maximum significant wave height at the port have been extracted from the wave model 1 and model 2 generating from 108 scenarios at Ao Udom Bay and 121 scenarios at Rayong Sea represented in Table 4.9.

The nearshore wave heights and wave direction results show in the wave rose diagram in Fig. 4.15 and Fig. 4.16, the results show that the ambient waves typically approach the berth from a southwest owing to the dominant wind direction being from the southwest.

Table 4.9 Maximum Significant Wave Height at Port

No.	Port Name	Maximum Significant Wave Height (m)	Peak Wave Period (sec)	Wave Direction (Deg.)
1	SRH	1.54	5.07	221.32
2	KSSP	1.57	5.07	222.14
3	TOP	1.28	5.07	239.33
4	PTT	1.70	5.07	220.49
5	IRPC	1.67	6.50	160.65
6	BLCP	1.75	6.50	164.94

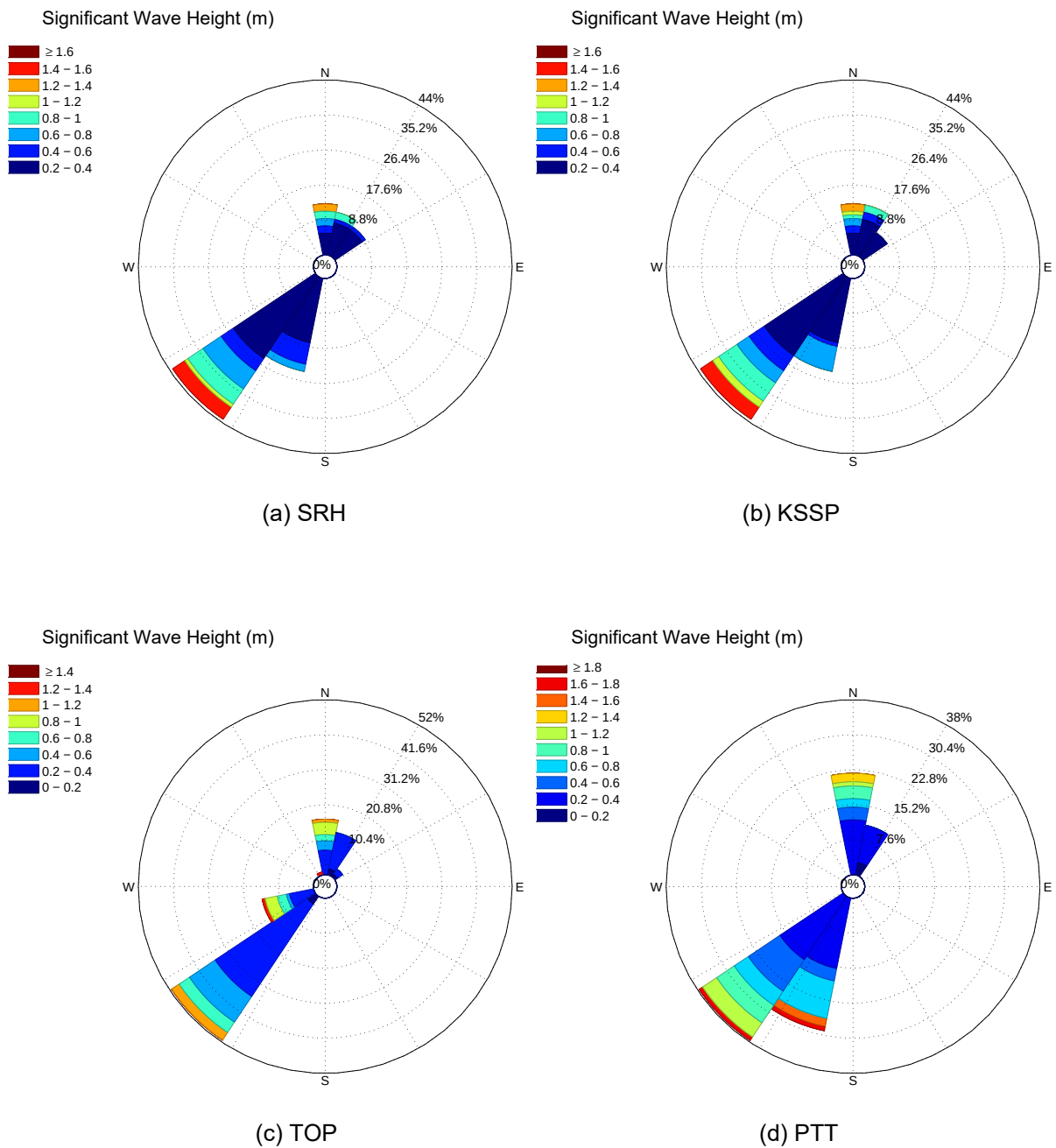


Fig. 4.15 Wave Rose Diagram of Output Results (Nesting Grid-164) at Port in Ao Udom Bay

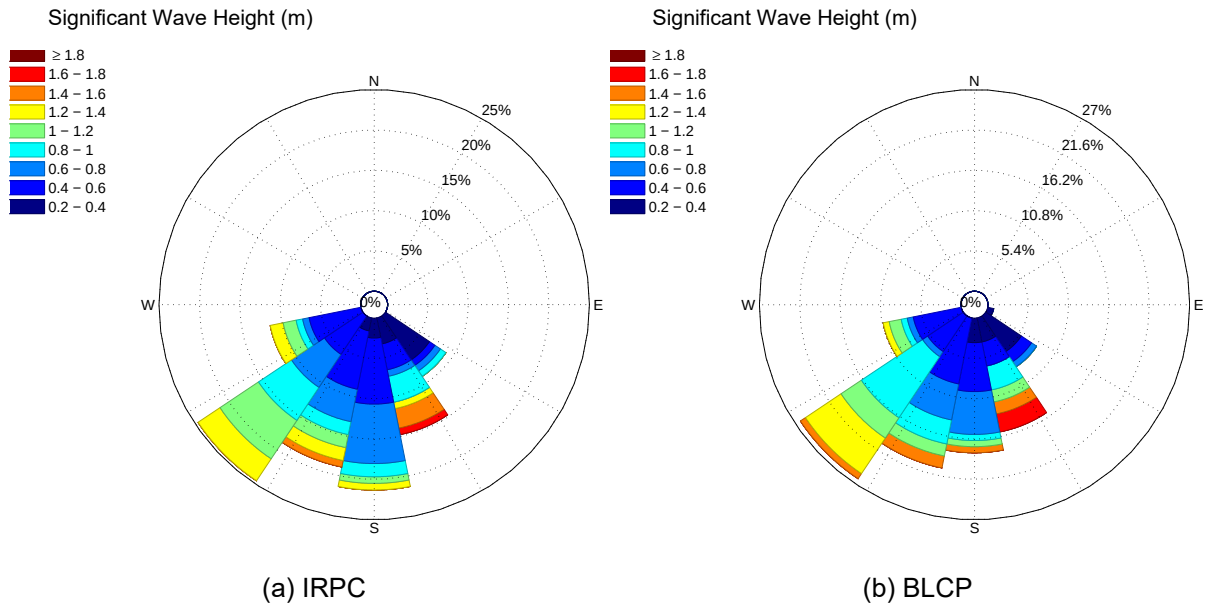


Fig. 4.16 (a) Wave Rose Diagram of Output Results (Grid-170) at IRPC Port and (b) Wave Rose Diagram of Output Results (Grid-157) at BLCP Port in Rayong Sea

Table 4.10 Percentage of Occurrence at Port

Port Name	0 - 0.5 (m)	0.5 - 1.0 (m)	1.0 - 1.5 (m)	1.5 - 2.0 (m)	Total
SRH	68.81%	24.77%	4.59%	1.83%	100%
KSSP	68.81%	22.94%	6.42%	1.83%	100%
TOP	77.98%	16.52%	5.50%	0.00%	100%
PTT	68.81%	21.10%	7.34%	2.75%	100%
IRPC	43.44%	34.43%	19.67%	2.46%	100%
BLCP	40.98%	36.07%	18.03%	4.92%	100%

Significant wave height larger than 1 m occurs for up to 6.42%, 8.25%, 5.50%, 10.09%, 22.13% and 22.95% of SRH, KSSP, TOP, PTT, IRPC and BLCP respectively. The results represent the wave height at Rayong Sea are larger than the wave height at Ao Udom Bay as tabulated in Table 4.10.

4.3.5 Model Validation

The wave model validation was compared to a limited dataset of wave measurements by oceanographic buoys with wave modelings results, for giving some confidence of wave model results. The comparison is used the wave model results by significant wave height of 108 and 121 scenarios with the significant wave height recorded by Ko Si Chang (KS) and Rayong (RY) buoy respectively as shown in Fig. 4.17 and Fig. 4.18. The different wave height between wave model results and wave measurements are an average of 0.11 m and 0.07 m at Ko Si Chang (KS) and Rayong (RY) buoy respectively. The scenario of wave model results represented wave height lower than wave measurements because the wind is low speeds on that time when wave transformation from offshore to buoy. The comparison of wave model 2 is good agreement as shown in Fig. 4.18, and the differential of significant wave height is low if compared with wave model 1 as shown in Fig. 4.17.

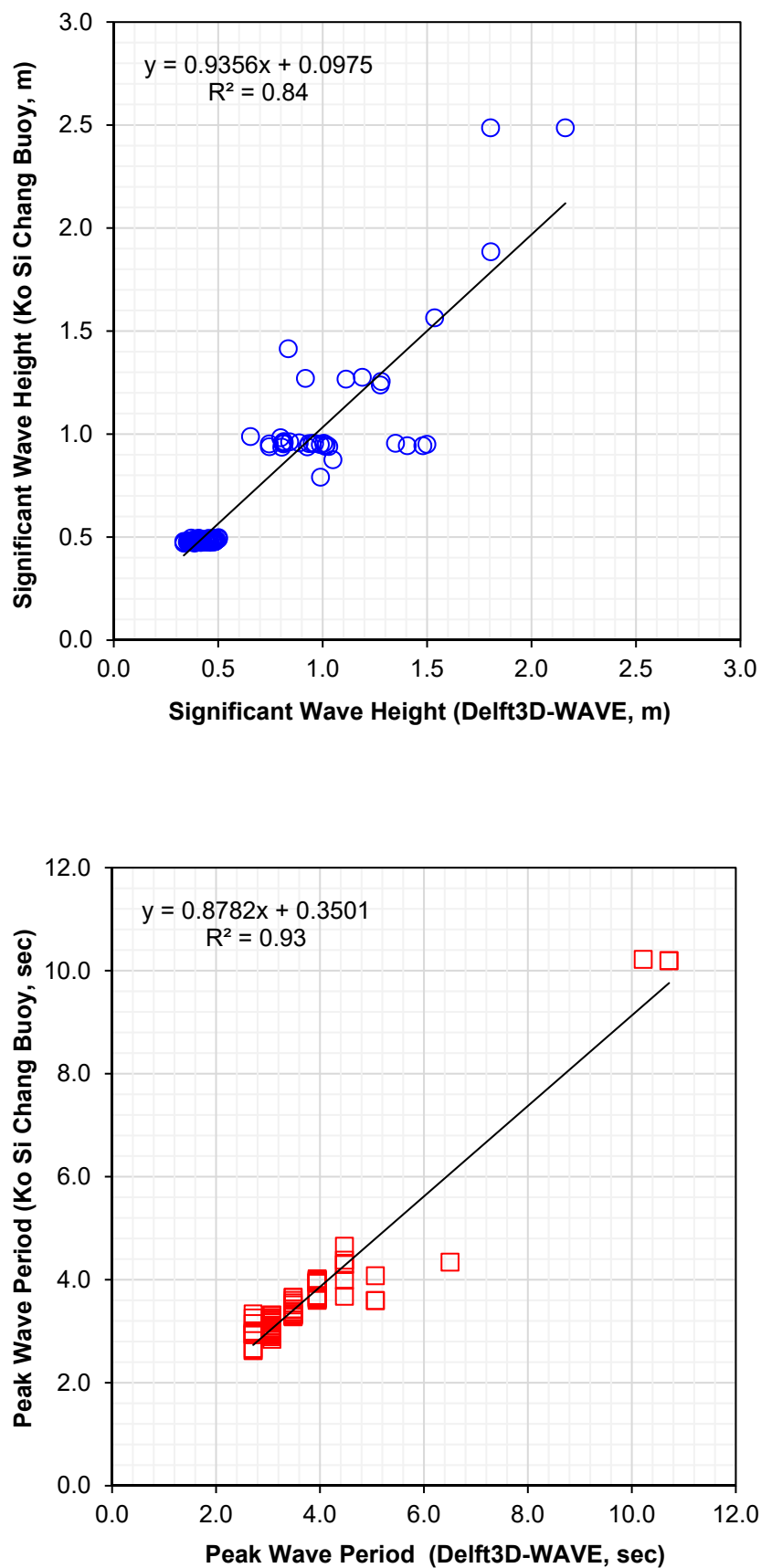


Fig. 4.17 Comparison of Significant Wave Height and Peak Wave Period at Ko Si Chang (KS) Buoy with Wave Model Results

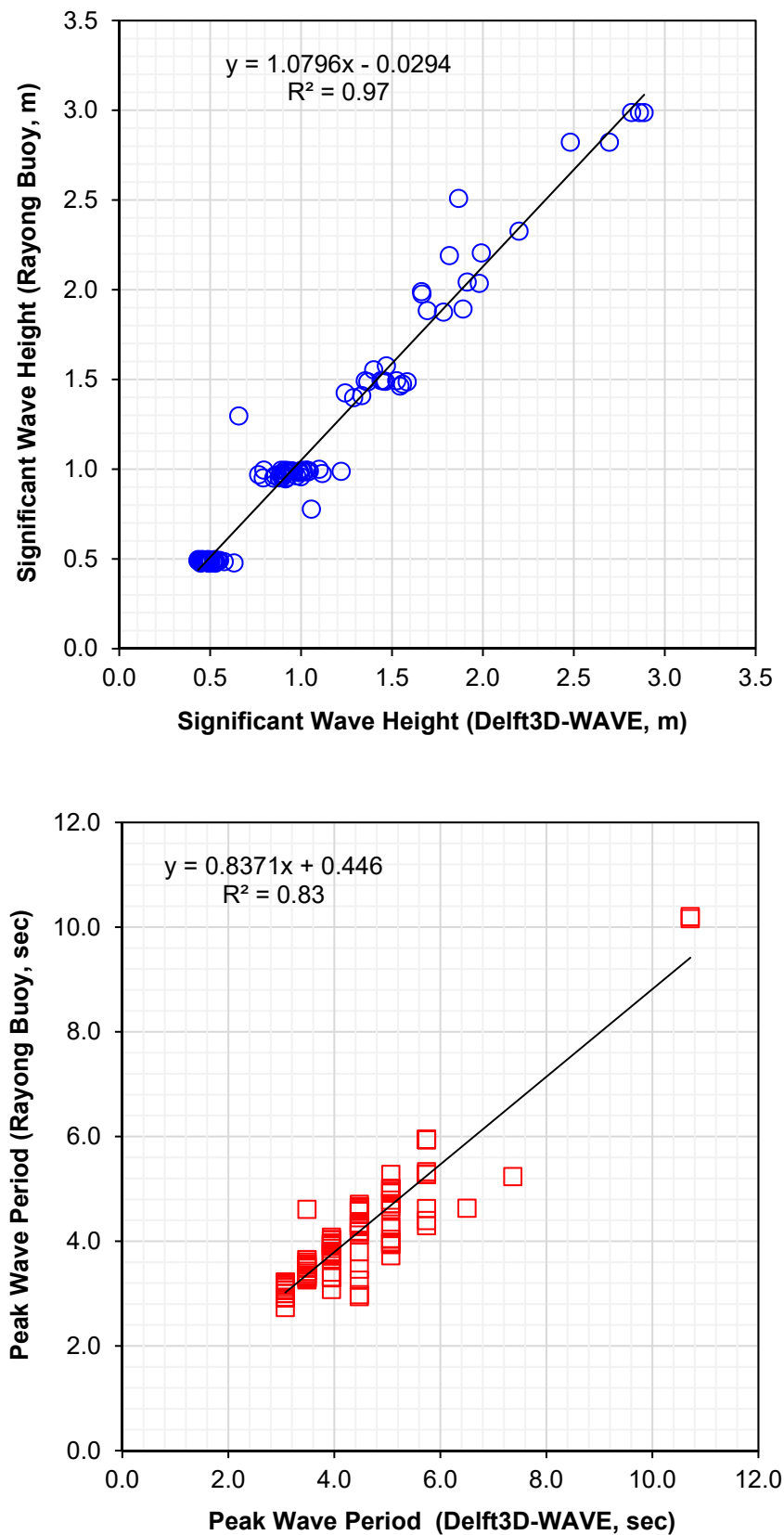


Fig. 4.18 Comparison of Significant Wave Height and Peak Wave Period at Rayong (RY) Buoy with Wave Model Results

The validation are comparison between the observed data and wave model results of the significant wave height and peak wave period at the position of the oceanographic buoy. It is better than this, if the observed data at each port are available for validation that represents the wave transformations in nearshore region, but this study the wave model calculated the significant wave is varied direction and the computation results show good agreement.

4.4 BERTH OPERABILITY AND PORT DOWNTIME

The berth operability and port downtime are affected by the environmental condition such as the wind, wave and currents during severe weather conditions. The level of significant wave height, wind speeds and currents speed can cause issues to a safe mooring, berthing and (un)loading of the vessel at the port. The allowable environmental conditions for port operation depend on a considerable number of variables. This study will be using the guidance limiting environmental operating conditions at quays and jetties provided in PIANC (2014), for calculation of berth operability and port downtime in Ao Udom Bay and Rayong Sea. The limiting of environmental operating conditions represented the level of three parameters with included wind speed, currents speed and significant wave height as tabulated in Table 4.1. The environmental operating conditions at the port will be using the met-ocean dataset at Ko Si Chang (KS) and Rayong (RY) buoy for wind disruptions and current disruptions, while wave disruptions are used wave model results estimates the berth operability and port downtime. The limitation of environmental operating conditions is selected with lower bound conditions as provided in PIANC (2014) at each port as tabulated in Table 4.11 because the information of vessel size varies and defined forces direction transverse to the jetties and quay.

Table 4.11 Limiting Environmental Operating Conditions at Port

Port Name	Characteristics of Cargoes	$V_{W, 1 \text{ min}}$ (m/s)	$V_{F, 1 \text{ min}}$ (m/s)	H_s (m)
SRH	Bulk carriers	22.0	0.7	0.8
KSSP	Bulk carriers	22.0	0.7	0.8
TOP	Oil tankers	22.0	0.7	1.0
PTT	Oil tankers	20.0	0.7	1.0
IRPC	Oil tankers	20.0	0.7	1.0
BLCP	Bulk carriers	22.0	0.7	0.8

4.4.1 Berth Operability - Wave Disruptions

The exposed nature of the berth and the fact that the berth is required for (un)loading, means that wave disruption of the port operations may be a critical issue. Therefore, the wave height limitation is provided in PIANC (2014) will be used for estimating the berth operability by wave disruption in the order of 0.8 to 1 m as cause severe issues with the berthing and mooring of a vessel and wave impacts also need to be jointly evaluated with concurrent wind and current loads. The wave model results are presented the significant wave height at SRH, KSSP and BLCP, with larger than 0.8 m occur for up to 14.68%, 16.51% and 40.98% respectively, while wave height larger than 1 m occur for up to 5.50%, 10.09% and 22.13% at TOP, PTT and IRPC respectively.

4.4.2 Berth Operability - Wind Disruptions

The wind speeds at Ko Si Chang (KS) buoy used for considering berth operability by wind disruptions at the port such as SRH, KSSP, TOP and PTT, which mean hourly wind speeds higher than 20 m/s up to 0.01% of the percentage of occurrence. The percentage of occurrence is analyzed wind speed dataset recorded by buoy from 1991 to 2001. Then, the percentage of occurrence of 1-minute

average wind speeds is higher than 20 m/s up to 0.76%. Ambient wind speeds at Rayong (RY) buoy are typically not severe, as hourly wind speeds not reached to 20 m/s, so the berth operability absence wind disruptions at IRPC and BLCP port.

4.4.3 Berth Operability - Currents Disruptions

This study is absence the hydrodynamics model for forecasting the tidal currents at the port. Therefore, the berth operability by currents disruptions is used the currents measurements by oceanographic buoy representative. The currents at the port in Ao Udom Bay are assumed similarly to Ko Si Chang (KS) buoy, with peak currents in the order of 0.9 to 1 m/s and percentage of occurrence up to 0.07%. While peak currents at Rayong (RY) buoy are in the order of 0.8 to 0.9 m/s and no currents speed reached to 1 m/s, also the currents speed is higher than 0.7 m/s up to 0.67% at SRH, KSSP, TOP and PTT port, and 0.06% at IRPC and BLCP port.

4.5 SUMMARY

Ambient wind speeds at the port are typically not severe, with mean hourly wind speeds, 4.89 – 10 m/s. Wind speeds in excess of 20 m/s typically occur much less than 1% of the time, even during the monsoon. The significant wave higher than 0.8 m occurs for up to 14.68%, 16.51% and 40.98% for SRH, KSSP and BLCP respectively, while wave higher than 1 m occur for up to 5.50%, 10.09% and 22.13% at TOP, PTT and IRPC respectively. The currents speed at Ko Si Chang (KS) buoy is higher than the currents speed at Rayong (RY) buoy.

The wave modeling suggests the port is exposed to moderate wave activity as appeared the wave height occur less than 0.7 m of 81% at the port in Ao Udom Bay, but the southwest monsoon season is more severe. Furthermore, the wave height occurs less than 0.7 m of 49.59% at the port in Rayong Sea, so wave at the port in Rayong Sea are higher than wave at the port in Ao Udom Bay because port sheltered by Ko Si Chang island. The berth is vulnerable to extended periods of downtime, due to the exposed location and the nature of (un)loading operation and equipment. The disruption caused by the wave is a significant issue of berth operability and port downtime, while the disruption caused by wind and currents is not a significant issue, and is a lesser issue than wave disruption.

The low-frequency wave effect to berth operability and port downtime is not included in this study. The study is limited to coarse berth operability and port downtime following to PIANC (2014) criteria. The low-frequency wave effect can be studied by limiting the moored ship motions, which are the results of moored ship analysis with considering the ship motions. However, the berth operability and port downtime will need jointly evaluated under combined wave, wind and currents loads by using the moored ship motions analysis method.

Chapter 5

Storm Surge and Wind-Wave due to Tropical Cyclone Linda

5.1 INTRODUCTION

The study on berth operability is significant to the downtime at the port, which derived by course berth operability and detailed berth operability. The course berth operability is the limiting of the environmental condition at the port such as wind speed, current speed, and the significant wave height, this method is not combine the environmental condition, it may not safe operability as presents in the Chapter 4. This method is simplified method for calculating the berth operability in the long term, which includes the severe environments due to the tropical cyclone. The port downtime caused by a tropical cyclone is the worst scenario in the computation case, so the mooring analysis is tools for estimation of the port downtime, which the mooring analysis is necessary for the detailed study of berth operability and port downtime with limiting the motions of moored ship at port. The ship motions analysis are the combination of environmental forces exposed to the moored ship, then the study includes the ship motions effects from the tropical cyclone Linda, it is the major tropical cyclone events to impact the port in Upper Gulf of Thailand. Tropical Cyclone Linda was formed on 31st October 1997 in the South China Sea and strengthening as it moved westward. There is a strength to a tropical depression on 1st November and moved past to Southern Vietnam on 2nd November and enters to the Gulf of Thailand on 3rd November, it strengthened further to the typhoon and moved across the Gulf of Thailand onto the northwest. It weakened to a tropical storm on 4th November before landfall at Thap Sakae coastline, Prachuap Khiri Khan Province and moved into the Bay of Bengal. Tropical Cyclone Linda caused to heavy rainfall and flooding in Chumphon, Prachuap Khiri Khan, Phetchaburi, Ratchaburi, Kanchanaburi, and Ranong. (Thai Marine Meteorology)

Ship mooring analysis during the storm, it is necessary to obtain the water level change and strong wind-wave generated by tropical cyclone for estimation of the environmental forces on the moored ship. Therefore, the study of ship motions event storm should be set-up the wave model and hydrodynamics model for estimate the wave propagation from the offshore to port, tidal current and extreme current at a port. The wave model and hydrodynamics model will be set-up by using the application called “Delft3D-WAVE” and “Delft3D-FLOW”, the study does not couple FLOW-WAVE as the model it only set-up separately for estimate significant wave height and current speed at port, but the wind speed is used the observed data. The applications are the open source version.

5.2 OBSERVED DATA

The numerical model was used to simulate the wave, sea water level and current induced by Tropical Cyclone Linda which enters to the Gulf of Thailand in November 1997, the observed data are taken for set-up the model and model validation with used two sources of data, the data is consist of observed sea water level, wind, wave and current. The observed data are represented in Appendix C.

5.2.1 Tide

The tides in the region are predominantly semi-diurnal in nature, with typically two high and two low tides each day (Diurnal Inequality). Tidal levels for the port have been based on a number of sources, including the 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).

5.2.2 Met-Ocean

The met-ocean data was collected by digitizing manually in time series from GISTDA reports, which includes wind speed, wind direction, significant wave height, wave period and air pressure. The time series data was digitized from 1st November 1997 to 6th November 1997, which is during tropical cyclone enters to the Gulf of Thailand. The buoys locations are consisting Ko Si Chang (KS), Rayong (RY), Hua Hin and Ko Chang (KC) Buoy.

5.3 WAVE MODEL

5.3.1 Model Set-Up

Typhoon wave generation and propagation in the upper Gulf and between the islands offshore of the site has been modeled using a numerical wave model. The typhoon waves undergo wave refraction and diffraction around the offshore islands as well as shoaling and breaking over the complex nearshore bathymetry. A numerical model has been developed to estimate the growth of wind-waves and to transform the waves to the nearshore. The numerical wave model "Delft3D-WAVE" is the application for wave model, the Delft3D-WAVE is the new version of "Simulating Wave Nearshore" (SWAN) 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, 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.

- Bathymetry

The bathymetry is based on two sources data. The first one is from THAI nautical charts, which are relative to Lowest Low Water (LLW) as mentioned in Chapter 3 and Chapter 4. Another one is height resolution bathymetry (30"x30") obtained from General Bathymetric Chart of the Oceans (GEBCO, 2014). The wave model bathymetry is Fig. 5.1, Fig 5.2 and Fig. 5.3.

- Computational Grid

The model grid is curvilinear of the rectangular grid cell in UTM coordinate system that includes three non-zero wave boundaries. A number of model grids have been used, the first coarse grid is large to grow waves within the Gulf of Thailand, and the nested calculation grids have been developed in addition to this coarse grid, to gradually increase the accuracy of the model at the port, and thus to obtain a better estimation of the wave characteristics at the port. The summaries of grid characteristics are tabulated in Table 5.1

- Boundary Condition

The boundary conditions are the observed time series data that assigned at the uniform boundary, which is wind speed, wind direction, significant wave height and peak wave period at the west boundary of the computational grid AU1 and south boundary of the computational grid RY1. The wave data for assigned at the other boundary are calculated by following the JONSWAP spectrum by using observed wind speed for derivation the significant wave height and peak wave period at two non-zero wave boundaries of the computational grid.

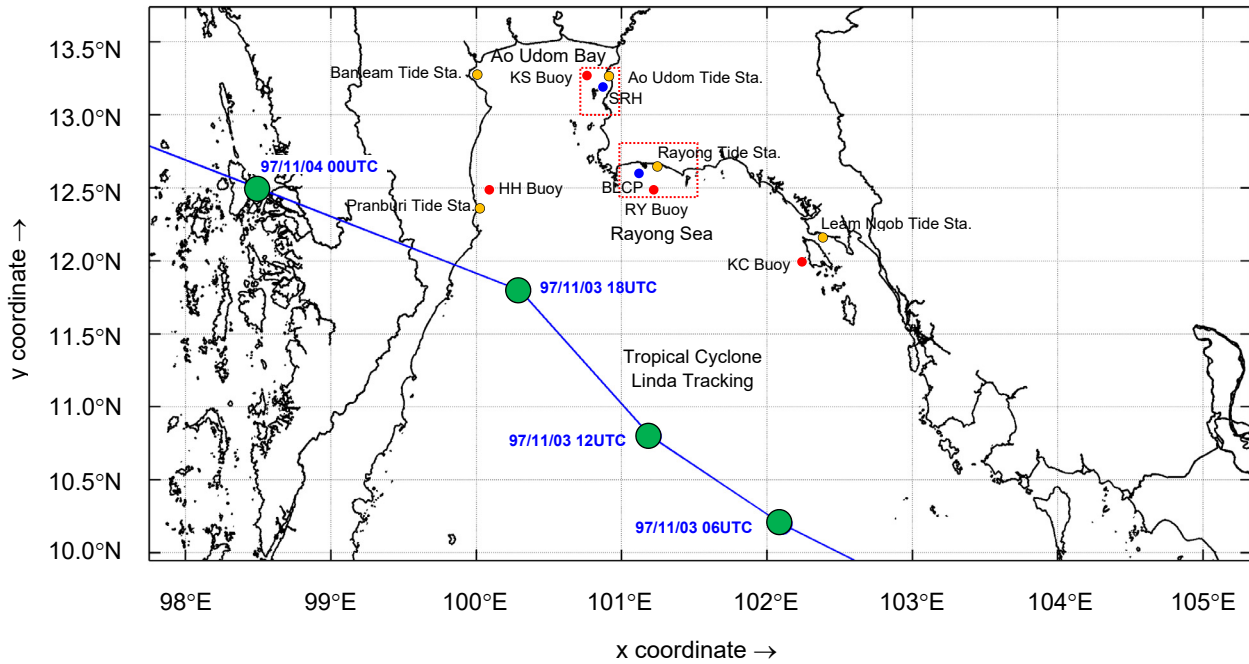


Fig. 5.1 Wave Computational Grid Locations

Table 5.1 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	26kmx55km	880x680m	109	55	689811.94, 1419546.00	0
Grid AU2	18.8kmx24.6km	330x480m	163	163	690671.63, 1437774.0	0
Wave Model 2: Rayong Sea						
Grid RY1	54kmx22.5km	203mx195m	325	167	716938.81, 1380070.0	0
Grid RY2	8.9kmx11km	67mx68m	136	190	729906.63, 1392941.5	0
Grid RY3	8.9kmx10.9km	149mx136m	82	82	744447.19, 1390309.4	0

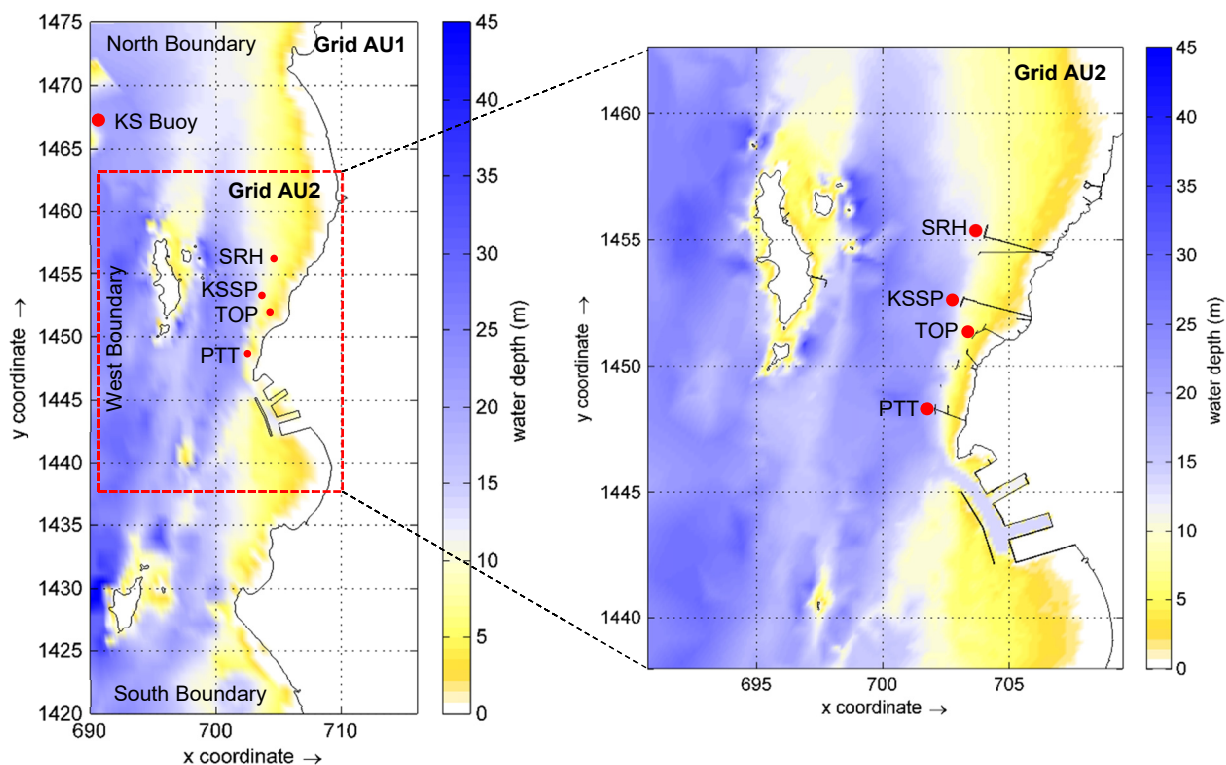


Fig. 5.2 Computational Grid AU1 and Grid AU2

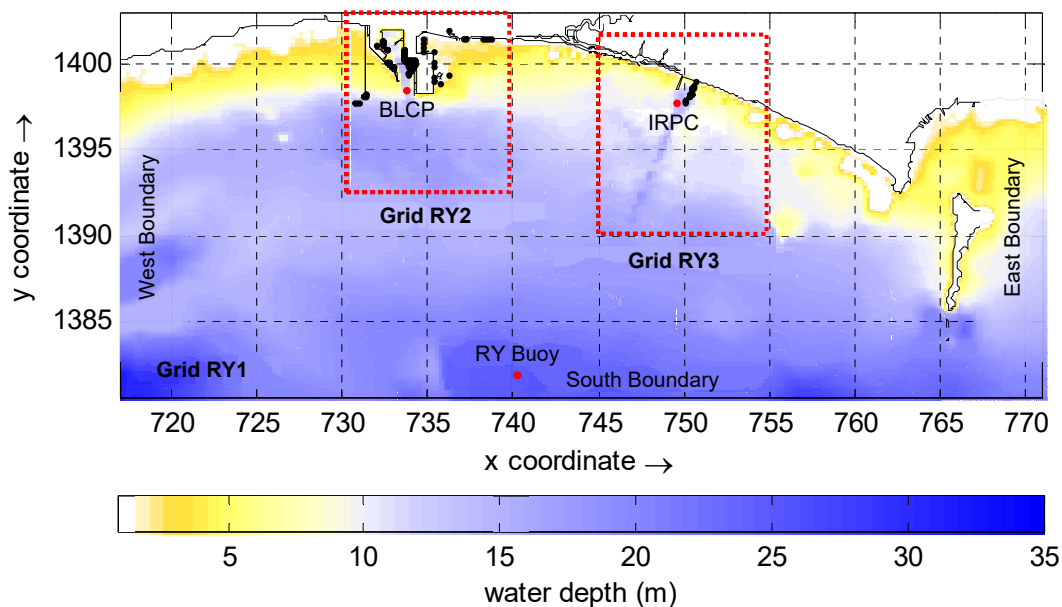


Fig. 5.3 Computational Grid RY1, Nesting Grid RY2 and Nesting Grid RY3

5.3.2 Model Results

The model results have selected the point of locations at Sriracha Harbour Port (SRH) and BLCP Coal-Fired Power Plant Port (BLCP), which obtained the significant wave height, wave period and wave direction as necessary to assign the input parameters for ship mooring analysis. The other locations are represented in Appendix B with shown in time series from 1st November 1997, 00:00:00 (+7UTC) to 6th November 1997, 00:00:00 (+7UTC). The model results show the significant wave height at Ao Udom Bay is smaller than the wave height at Rayong Sea as shown in Fig. 5.4 and Fig. 5.5. Additionally, the model results include the significant wave height at Kerry Siam Seaport (KSSP), Thai Oil Jetty (TOP), PTT Jetty (PTT) and IRPC Port (IRPC) for representing the wave height at the port in Ao Udom Bay and Rayong Sea.

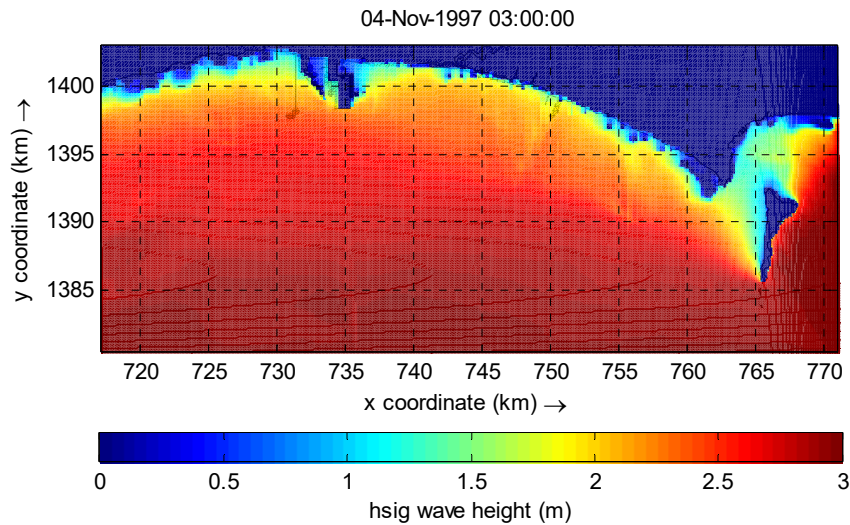


Fig. 5.4 Significant Wave Height Snapshot of Computational Grid RY1

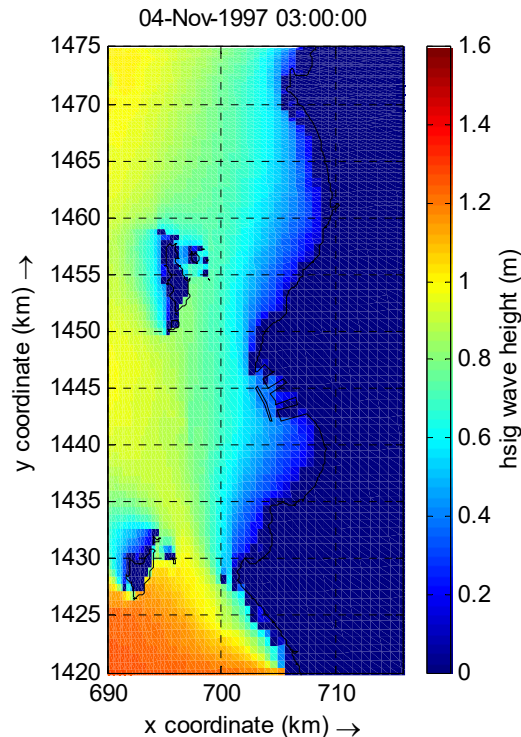


Fig. 5.5 Significant Wave Height Snapshot of Computational Grid AU1

5.3.3 Model Validation

The wave model validation is a comparison between the observed significant wave height and wave model results at Ko Si Chang (KS) and Rayong (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 Ko Si Chang (KS) and Rayong (RY) buoy are in agreement as shown in Fig. 5.6 to Fig. 5.11, and R-square is 0.96 of wave height at Ko Si Chang (KS) buoy, and 0.92 of wave height at Rayong (RY) buoy.

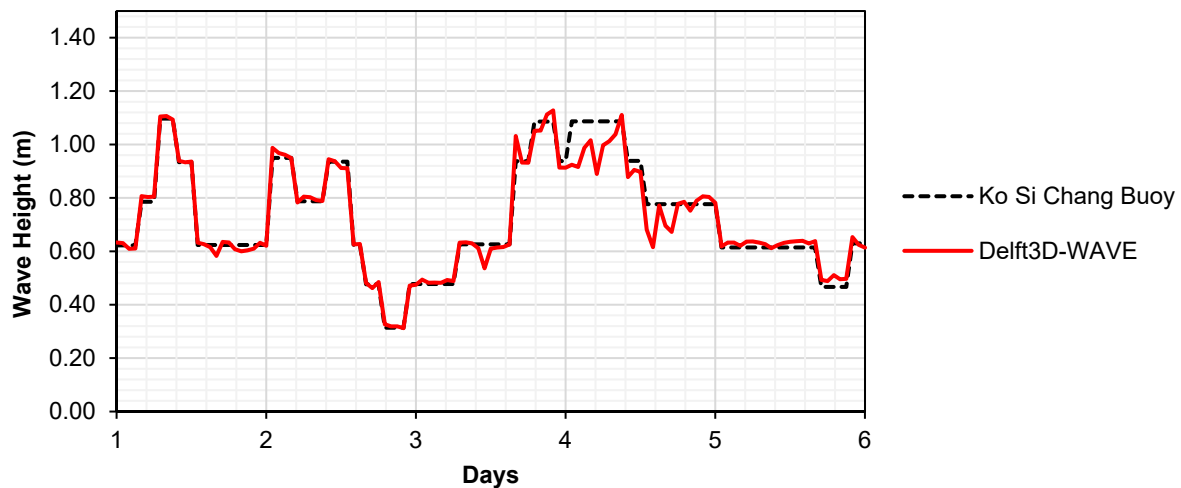


Fig. 5.6 Observed Significant Wave Height and Wave Model Result at Ko Si Chang (KS) Buoy

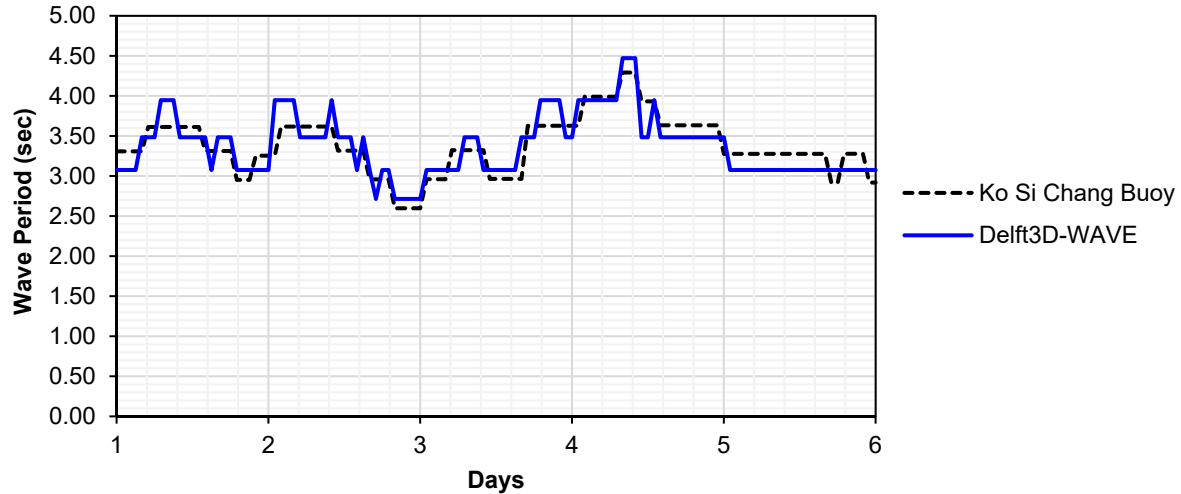


Fig. 5.7 Observed Wave Period and Wave Model Result at Ko Si Chang (KS) Buoy

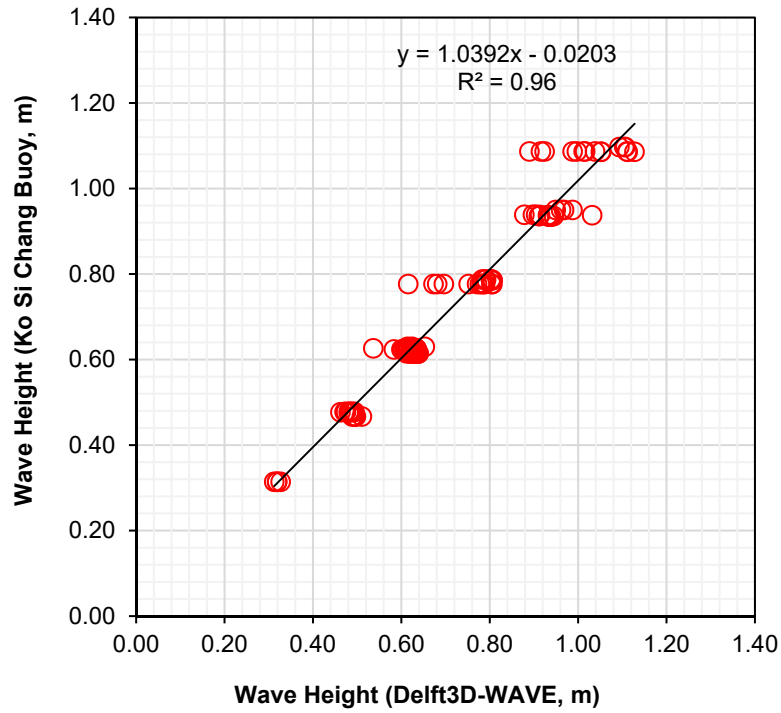


Fig. 5.8 Significant Wave Height Comparison at Ko Si Chang (KS) Buoy

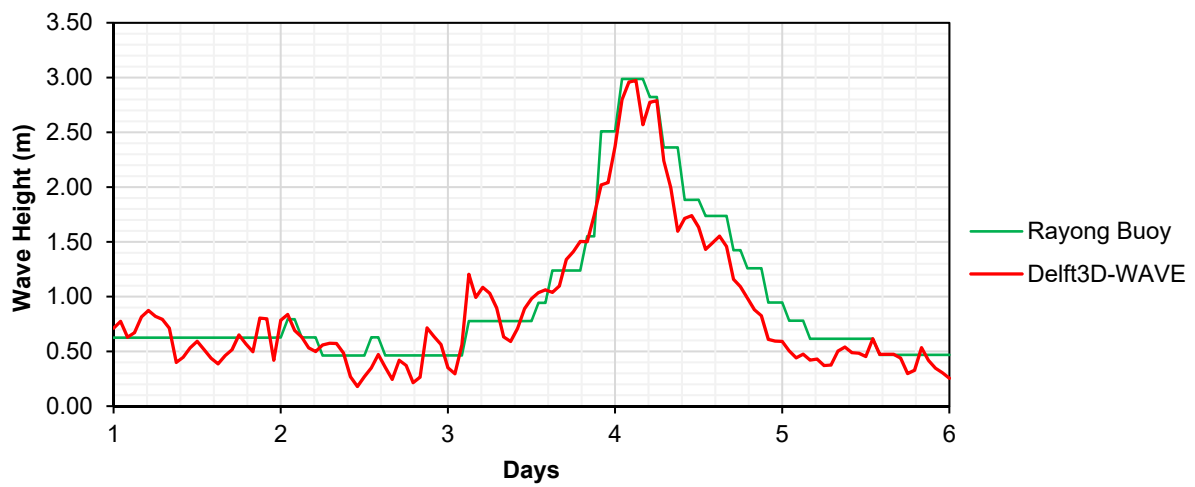


Fig. 5.9 Observed Significant Wave Height and Wave Model Result

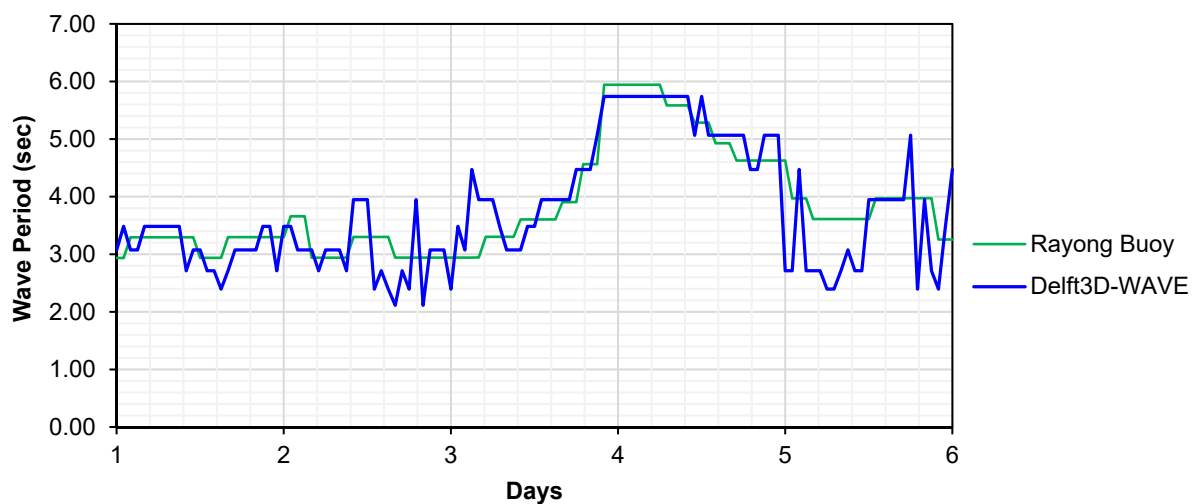


Fig. 5.10 Observed Wave Period and Wave Model Result at Rayong (RY) Buoy

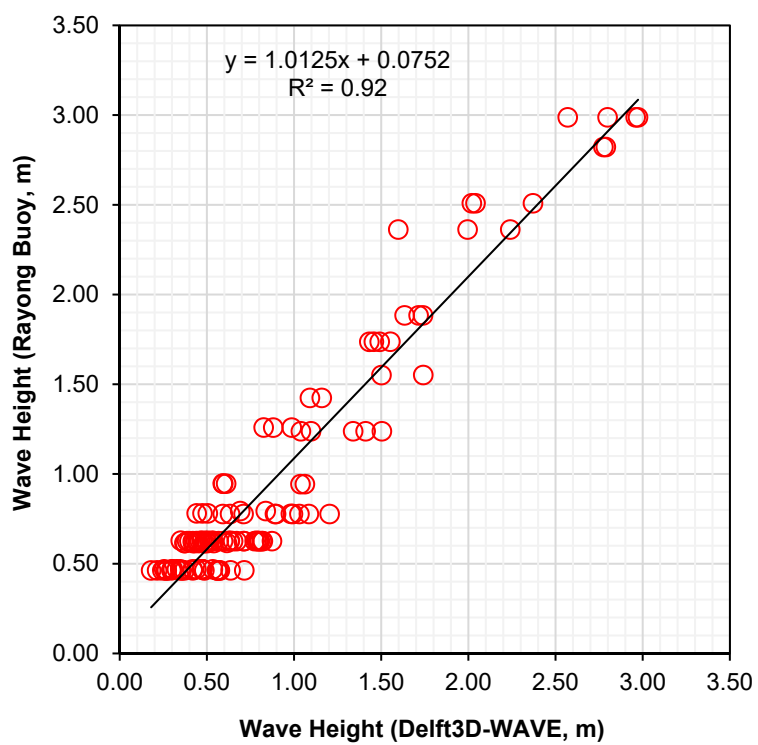


Fig. 5.11 Significant Wave Height Comparison at Rayong (RY) Buoy

5.4 STROM SURGE 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 Deltares. The storm surge is the combination of the wind and barometric set-up, which pushes ocean waters and raises water levels near the coast. 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 (due to the inverse barometric effect) also raises the water level.

The hydrodynamics model of the continent shelf in the storm condition is simulated by solving the system of two-dimensional of shallow water equations that consist two horizontal momentum equations and one continuity equations. (Vu Thi Thu Thuy, 2003)

Conservation of momentum in x-direction (depth and density averaged) (Vu Thi Thu Thuy, 2003)

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + g \frac{\partial \eta}{\partial x} - f v + \frac{1}{\rho} \frac{\partial p_a}{\partial x} + \frac{g|U|u}{C^2(d+\eta)} - \frac{\tau_{wx}}{\rho_w(d+\eta)} - \varepsilon \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) = 0 \quad (5.1)$$

(1) (2) (3) (4) (5) (6) (7) (8) (9)

Conservation of momentum in y-direction (depth and density averaged) (Vu Thi Thu Thuy, 2003)

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + g \frac{\partial \eta}{\partial y} + f u + \frac{1}{\rho} \frac{\partial p_a}{\partial y} + \frac{g|U|v}{C^2(d+\eta)} - \frac{\tau_{wy}}{\rho_w(d+\eta)} - \varepsilon \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) = 0 \quad (5.2)$$

(1) (2) (3) (4) (5) (6) (7) (8) (9)

The depth and density averaged continuity equation is expressed by (Vu Thi Thu Thuy, 2003)

$$\frac{\partial \eta}{\partial t} + \frac{\partial (d+\eta)u}{\partial x} + \frac{\partial (d+\eta)v}{\partial y} = 0 \quad (5.3)$$

The formula can be expressed as the following (Vu Thi Thu Thuy, 2003)

- | | |
|----------------------------------|--|
| (1) Local accelerations | (6) Atmospheric pressure gradient |
| (2), (3) Convective acceleration | (7) Bottom friction |
| (4) Surface slope | (8) External force by wind |
| (5) Coriolis force | (9) Depth averaged turbulent viscosity |

Where:

C = Chézy coefficient

d = Bottom depth

f = Coriolis parameter

ε = Diffusion coefficient (Eddy viscosity)

U = Absolute magnitude of total velocity, $U = \sqrt{u^2 + v^2}$

η = Water level above a reference level

u, v = Depth average velocity

ρ_w = Mass density of water

τ_{wx} = Wind shear stress in x-direction, $\tau_{wx} = \rho_a C_d W_x^2$

τ_{wy} = Wind shear stress in y-direction, $\tau_{wy} = \rho_a C_d W_y^2$

ρ_a = Air density

C_d = Drag coefficient

W_x = Wind speed in x direction at 10 m above free surface

W_y = Wind speed in y direction at 10 m above free surface

5.4.1 Model Set-Up

The data of wind speed and low pressure of Tropical Cyclone Linda can be collected from the Joint Typhoon Warning Centre (JTWC), Japanese Meteorological Agency (JMA) and Hong Kong Observatory. The best track of three sources is different in time and the position of the typhoon center. This study selected the best track and database given by the Japanese Meteorological Agency (JMA), the center of Typhoon position and path are shown in Fig. 5.12 and detailed best track as tabulated in Table 5.2. 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. 5.13 showed the Delft3D-FLOW model computational grid for normal condition (tidal forcing) flow model and extreme model (storm surge).

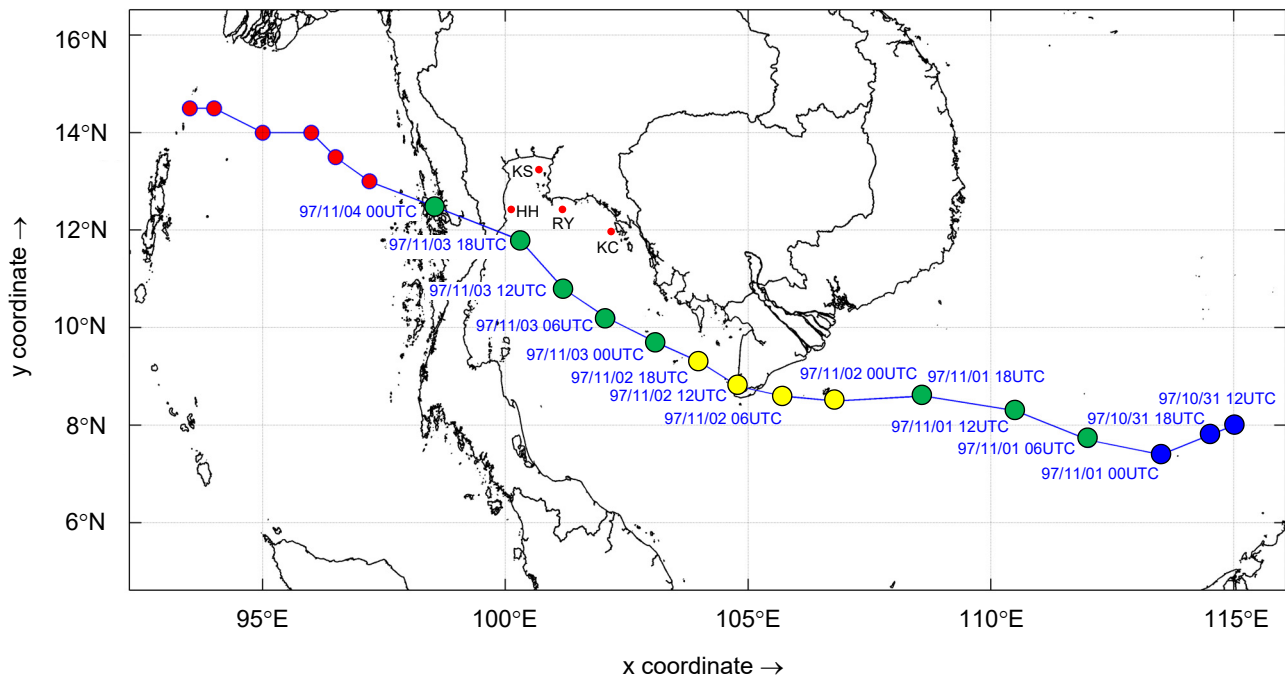


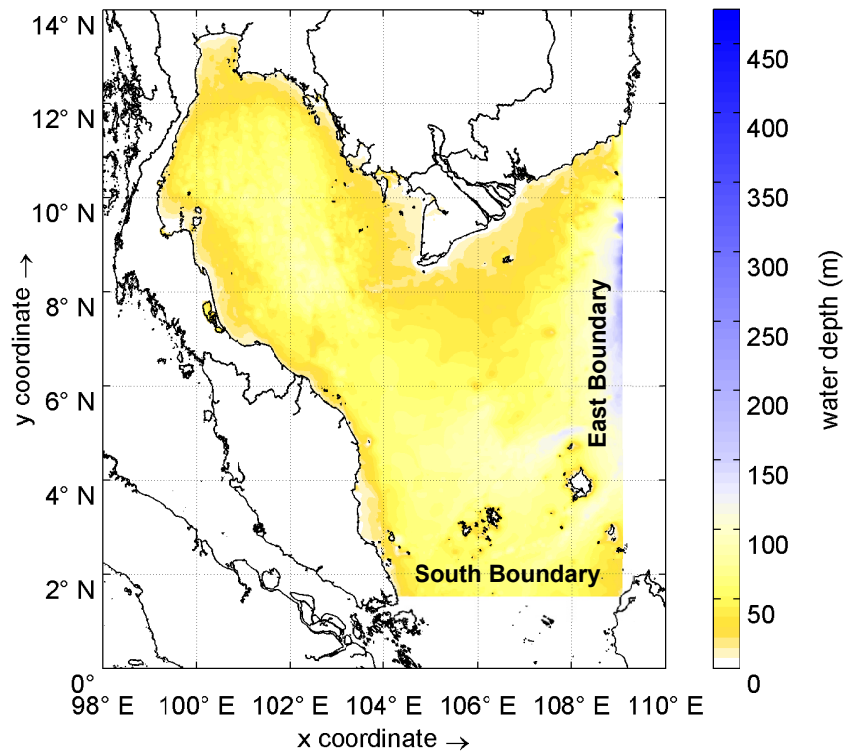
Fig. 5.12 Tropical Cyclone Linda Tracking

Table 5.2 Detailed Best Track of Tropical Cyclone Linda (JMA)

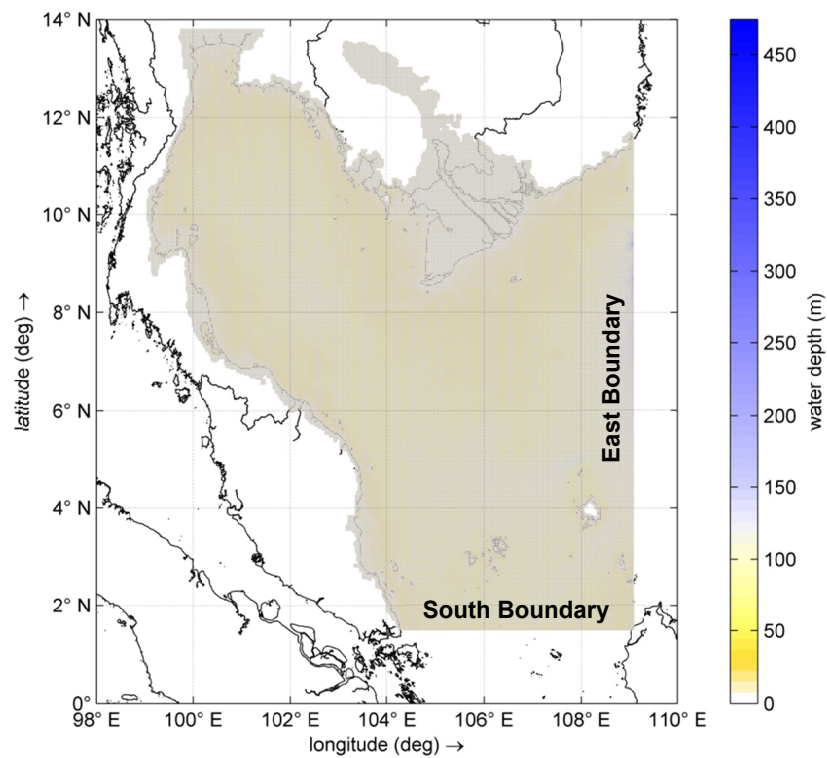
Year	Month	Day	Hour	Lat.	Long	Pressure (hPa)	Wind (knot)	Class
1997	10	31	12	8.0	115.0	1006	0	2
1997	10	31	18	7.8	114.5	1004	0	2
1997	11	01	00	7.4	113.5	1000	0	2
1997	11	01	06	7.7	112.0	996	35	3
1997	11	01	12	8.3	110.5	994	40	3
1997	11	01	18	8.6	108.6	992	45	3
1997	11	02	00	8.5	106.8	985	50	4
1997	11	02	06	8.6	105.7	985	50	4
1997	11	02	12	8.8	104.8	985	50	4
1997	11	02	18	9.3	104.0	985	50	4
1997	11	03	00	9.7	103.1	990	45	3
1997	11	03	06	10.2	102.1	990	45	3
1997	11	03	12	10.8	101.2	992	40	3
1997	11	03	18	11.8	100.3	998	35	3
1997	11	04	00	12.5	98.5	998	35	3

5.4.2 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. 5.13. 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 (Schawiderski, E.W., 1978) and Global Tidal Solution (TPXO-8.0). The tidal constituents are represented in term of amplitude (meter) and phase angle (degree) in Coordinated Universal Time (UTC), this study is used the eight main tidal constituents which include M2, S2, N2, K2, K1, O1, P1 and Q1.



(a) Depth



(b) Grid Cell Resolution

Fig. 5.13 Delft3D-FLOW Model Computation Grid

5.4.3 Wind Model and Pressure Model

The wind model and pressures model are used the Holland (1980) that derived the wind speed and air pressure. The radius of maximum wind speed is assumed to be 30 km as applied in the model, the radius is obtained by trial and error by comparison between the model results and observed data, and also the maximum radius is assumed to 500 km from the center of the typhoon.

The Holland's pressure model can be expressed as

$$p = p_c + (p_n - p_c) \cdot \exp\left[\frac{-A}{r^B}\right] \quad (5.4)$$

Where:

p = Pressure at radius r (N/m^2)

r = Radius (km)

A = Scaling parameters

B = Scaling parameters

p_n = Ambient pressure (N/m^2)

p_c = Central pressure (N/m^2)

The Holland's wind model can be expressed as

$$V_g = \sqrt{\left[AB(p_n - p_c) \left[\exp\left(\frac{-A}{r^B}\right) + \frac{r^2 f^2}{4} \right] + \frac{r f}{2} \right]} \quad (5.5)$$

Where:

V_g = Gradient wind at radius r (m/s)

f = Coriolis parameter

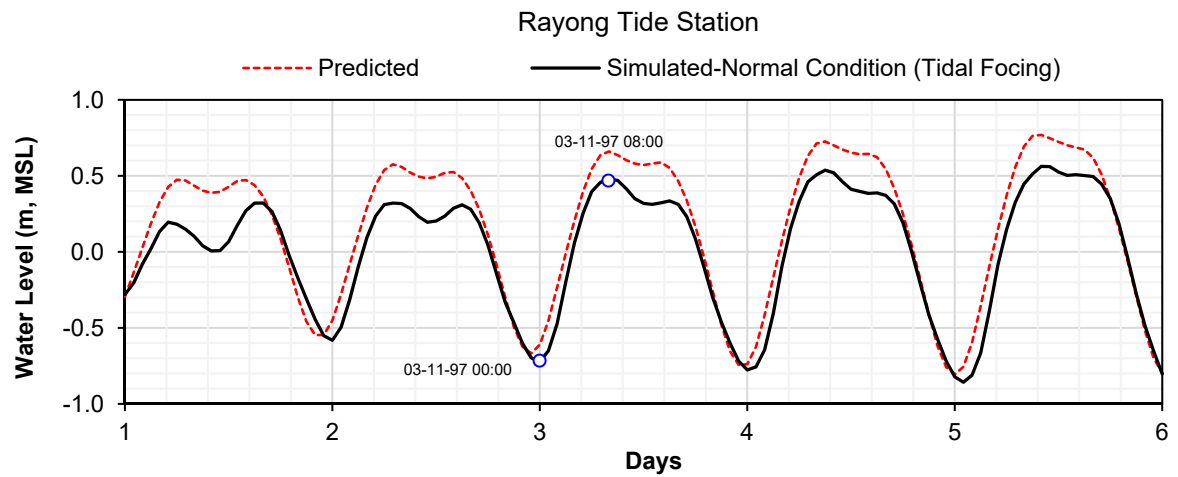
ρ = Surface air density (1.15 kg/m^3)

The radius of maximum wind speed is

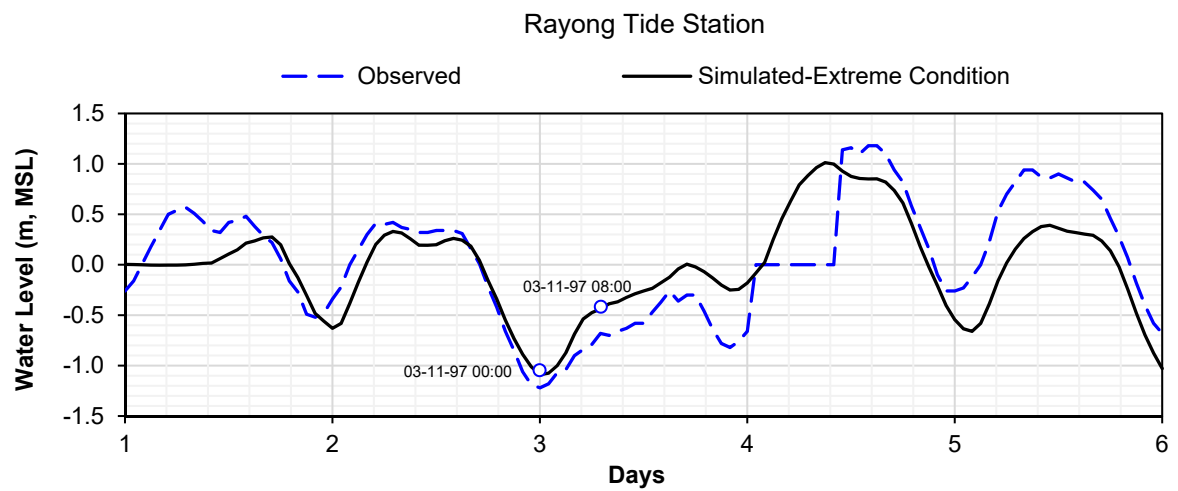
$$R_w = A^{1/B} \quad (5.6)$$

The scaling parameters B can be obtained from

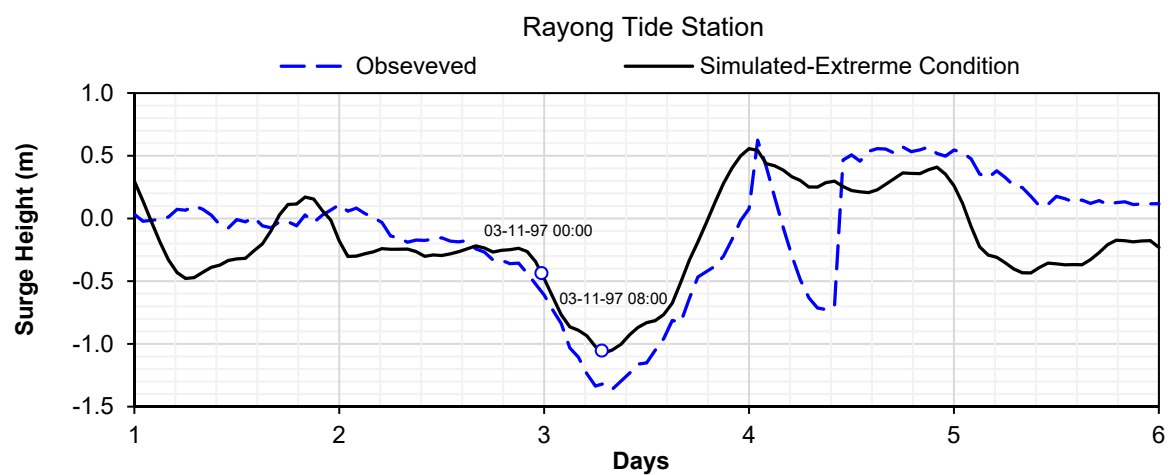
$$B = 2 - \frac{p_c - 900}{160} \quad \text{for } 1.0 < B < 2.5 \quad (5.7)$$



(a) Water Level (Normal Condition: +7UTC)



(b) Water Level (Extreme Condition: +7UTC)



(c) Surge Height (+7UTC)

Fig. 5.14 Hydrodynamics Model Results at Rayong Tide Station

5.4.4 Results

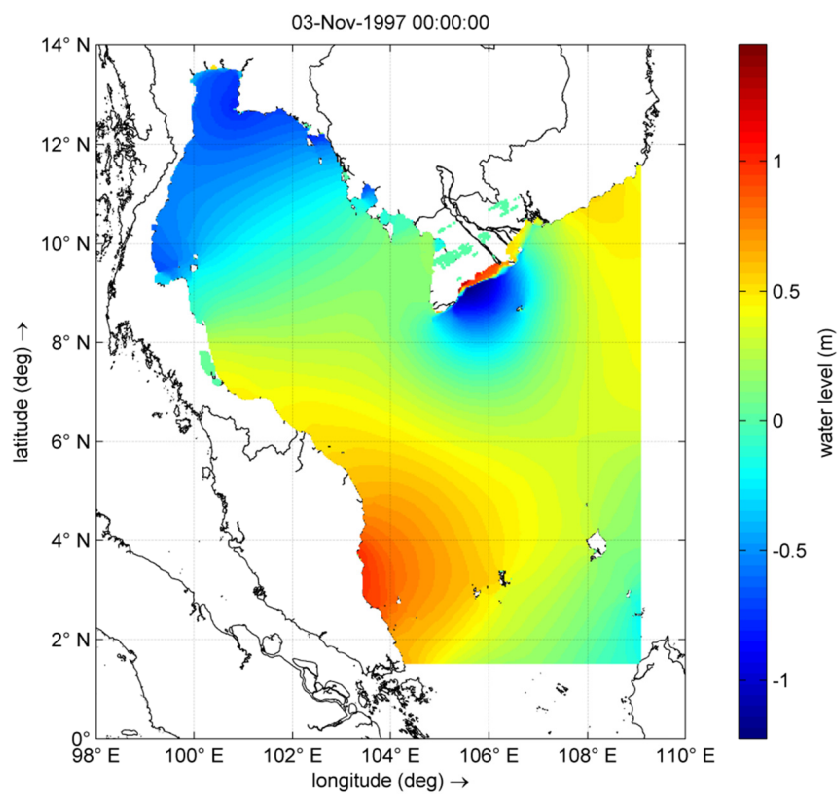
The model results present the water level, tidal current of the normal condition (tidal forcing) and extreme condition in time series as represents in Appendix C. The normal condition runs in one month (November 1997), which is the sensitivity analysis, and the model results shown a water level and tidal current by tidal forcing without the effects of wind and wave. These results can be used for prediction the water level at the location of interest and used for model validation, the model results at Rayong Tide Station is shown in Fig. 5.14. The water level is shown in Fig. 5.15 as predicted water level of low water level and high water level on 3rd November 1997. The water level is changing the characteristic due to low air pressure and strong wind, these phenomena are the typhoon-induced negative surge of water level as shown in Fig. 5.14 (b) and Fig. 5.14 (c). The model results of the extreme condition represent the extreme water level, air pressure and wind speed as shown in Fig. 5.16 to Fig. 5.18. The water level is changed when typhoon moves to the Gulf of Thailand on 3rd November 1997 07:00, that event is the initial influences induced the strong wind, low air pressure and the negative surge in Rayong Sea and Ao Udom Bay. The typhoon is induced the highest wind speed, lowest air pressure and the negative surge in the upper Gulf on 3rd November 1997 15:00, and also highest positive surge on 4th November 1997 01:00 until landfall time on 4th November 1997 09:00. However, the model results represented in a local time (+7UTC).

5.4.5 Validation

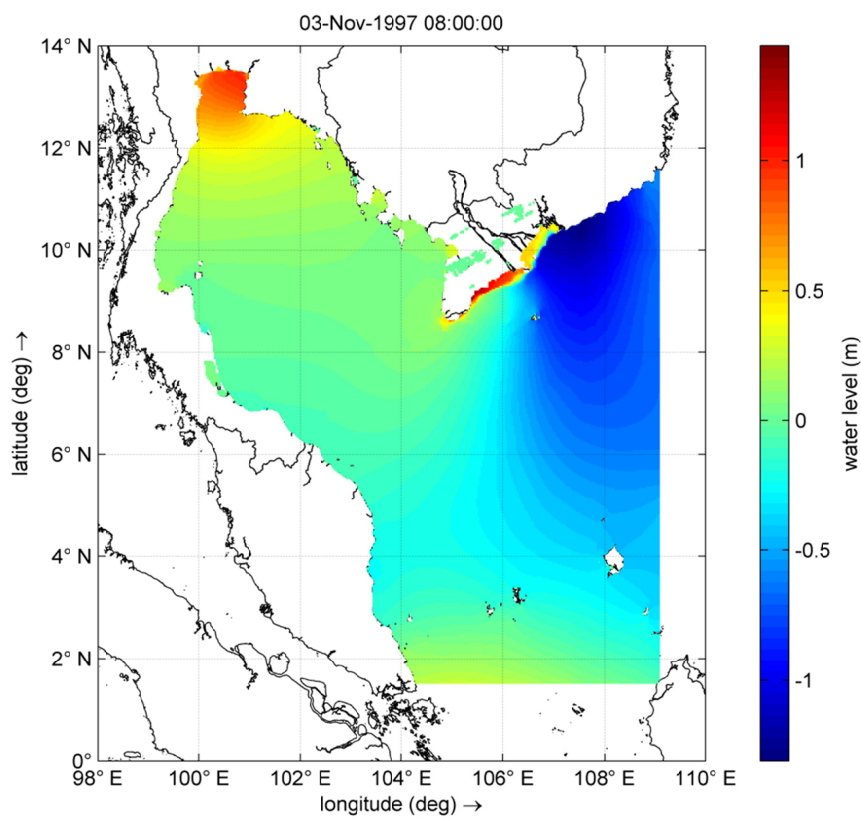
Validation of the hydrodynamics model has been undertaken for tidal conditions, to ensure the model can reproduce actual conditions with confidence. A comparison of tide levels at Pranburi Tide Station, Banleam Tide Station, Rayong Tide Station and Leam Ngob Tide Station were undertaken with water levels 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 Rayong (RY), Hua Hin (HH) and Ko Chang (KC) Buoy. The comparison shows good agreement as shown in Fig. 5.14 and represent in Appendix C.

5.5 SUMMARY

The significant wave height at port is the results 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 between 0.50 to 1.30 m and negative surge 1.10 to 2.00 m.



(a) Low Tide at Port



(b) High Tide at Port

Fig. 5.15 Water Level Snapshot in Normal Condition

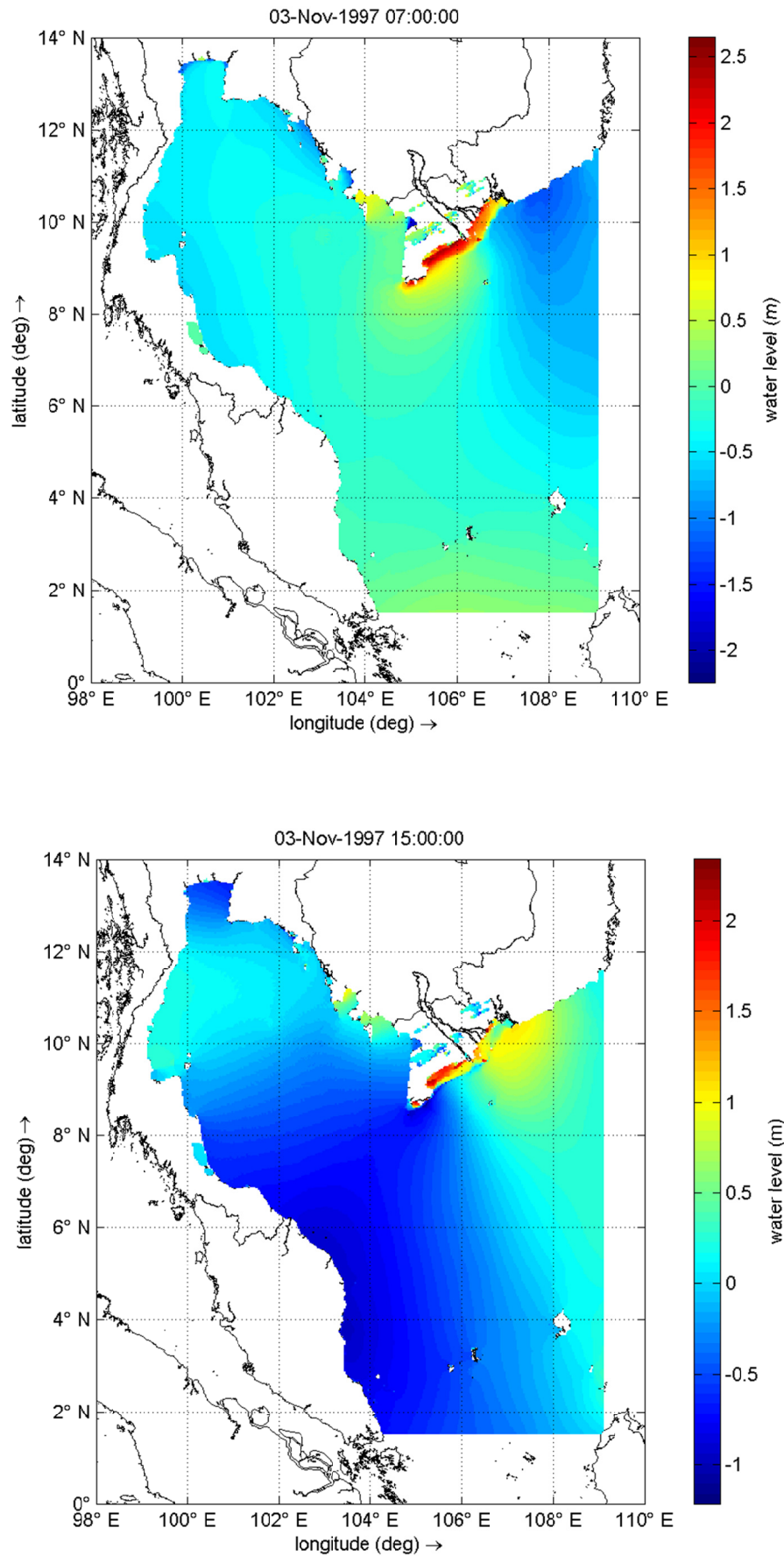


Fig. 5.16 Storm Water Level Snapshot in Extreme Condition

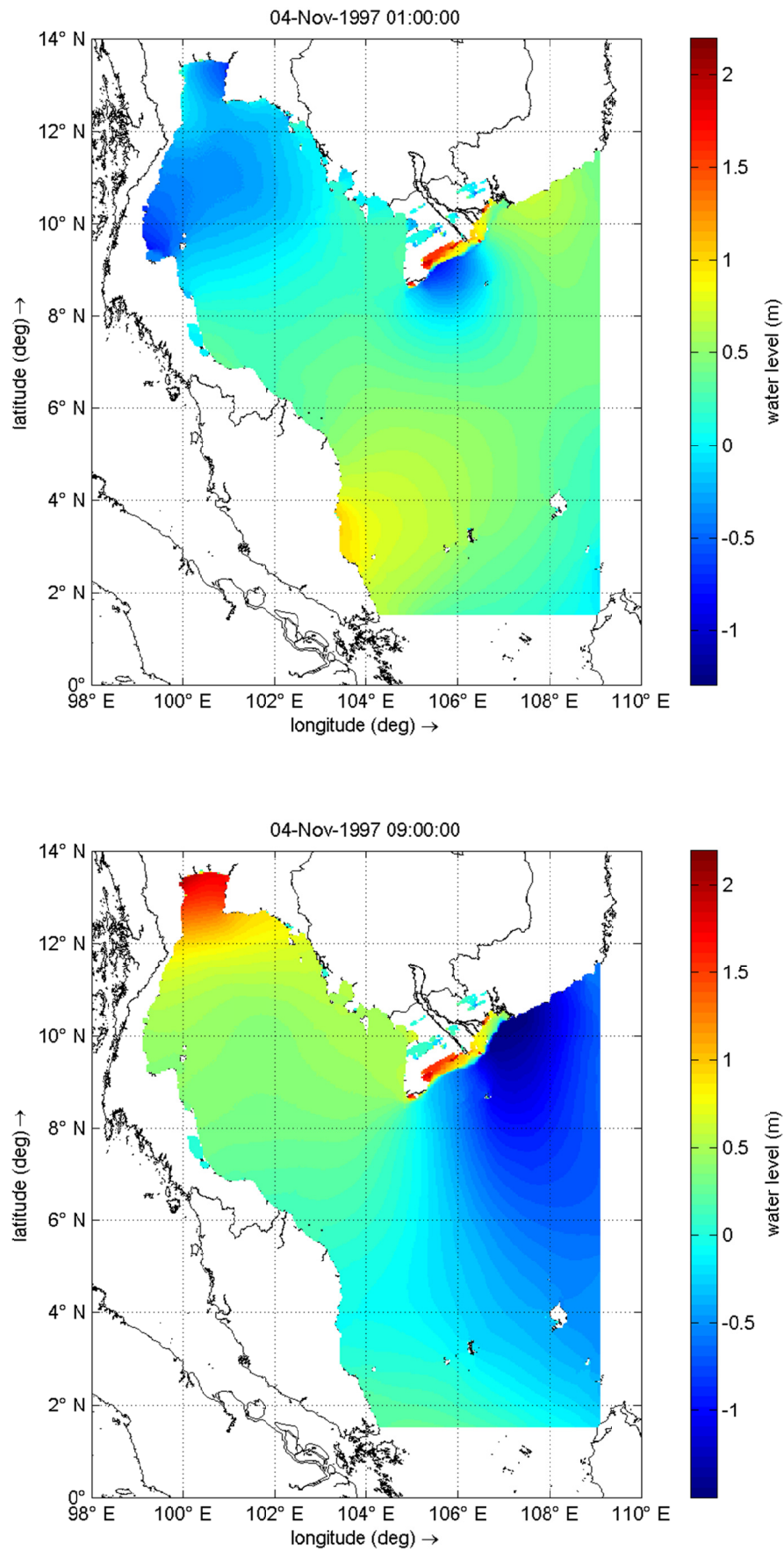


Fig. 5.16 (Cont.) Storm Water Level Snapshot in Extreme Condition

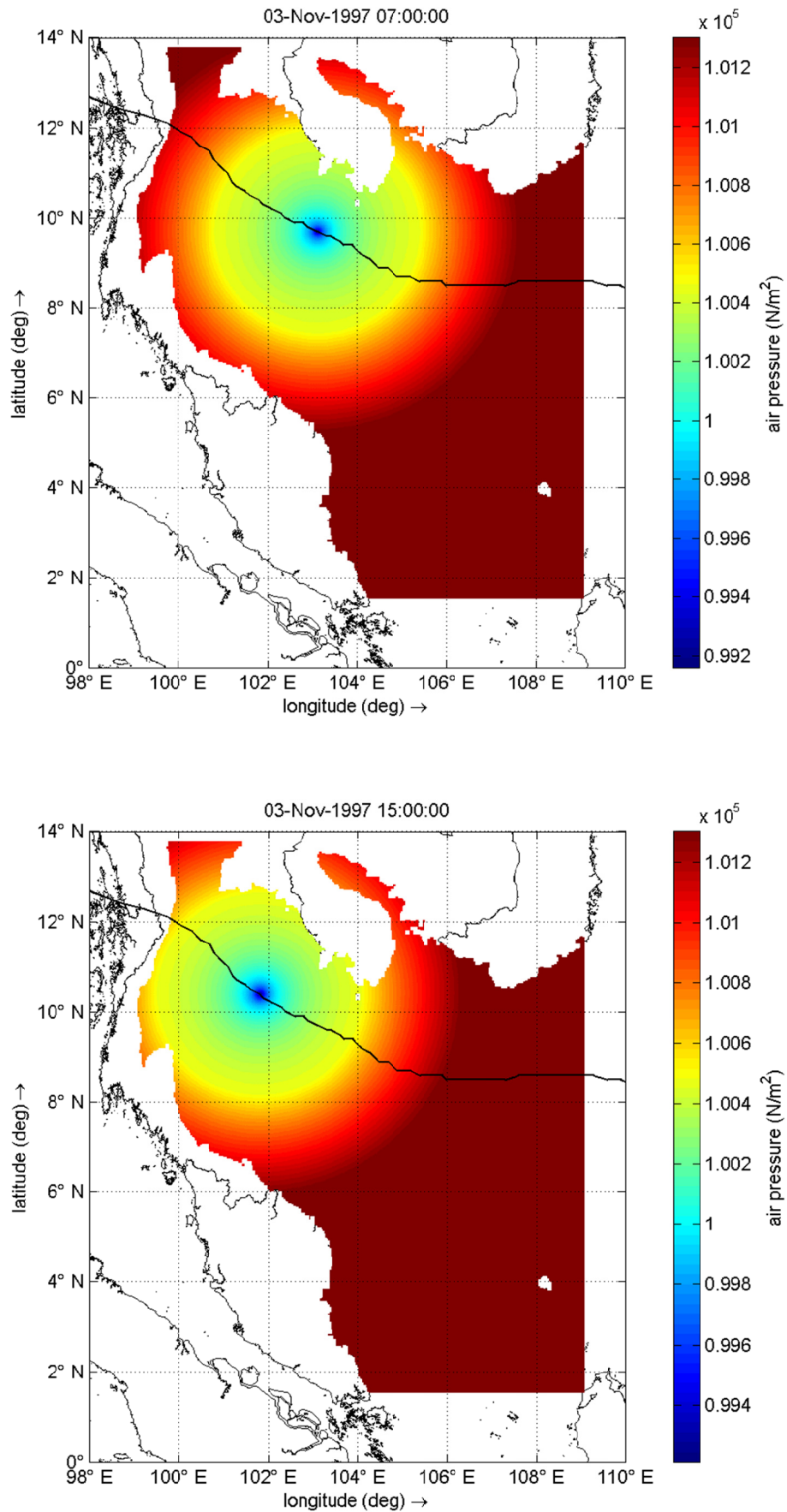


Fig. 5.17 Air Pressure in Extreme Condition

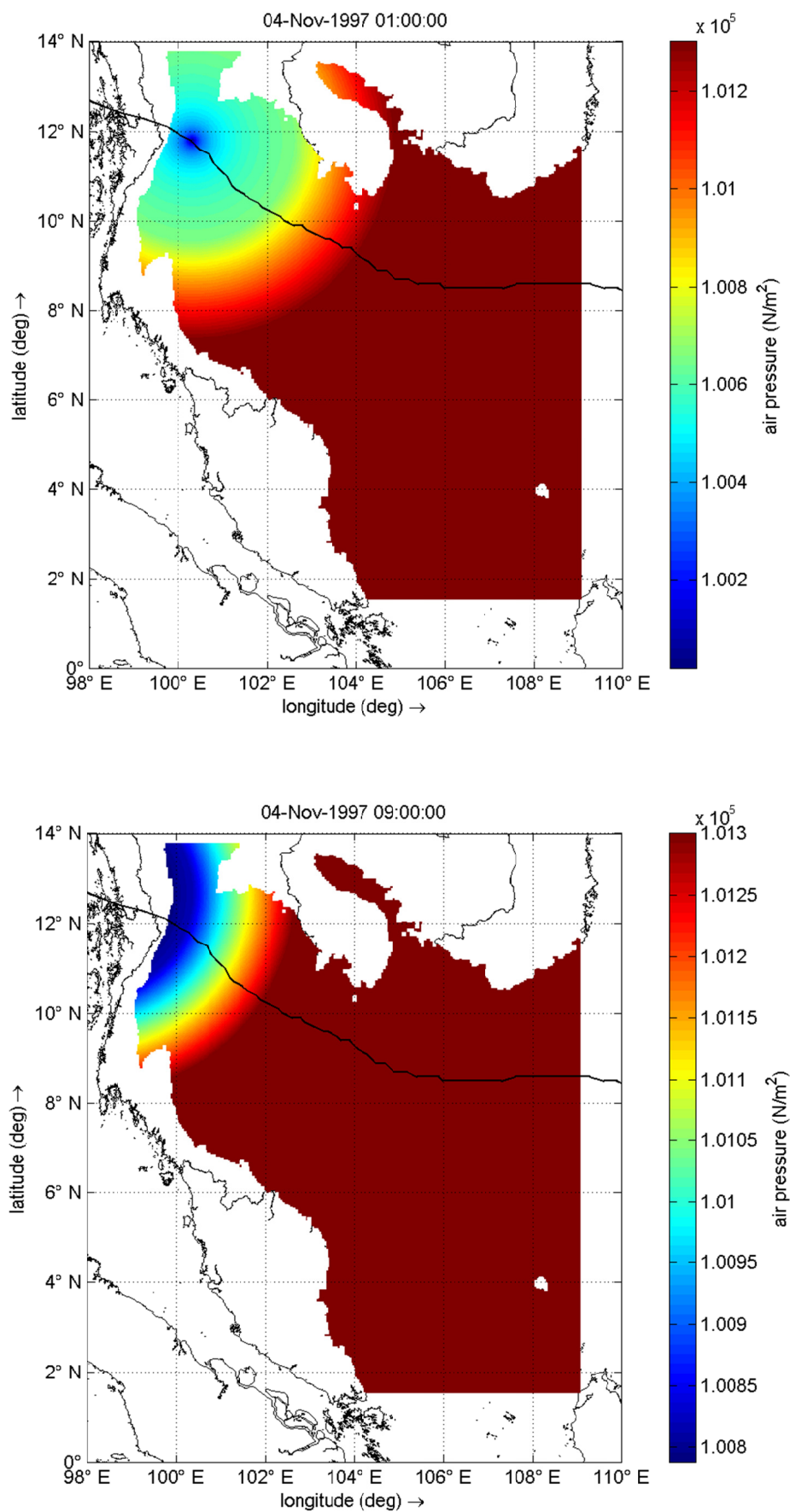


Fig. 5.17 (Cont.) Air Pressure in Extreme Condition

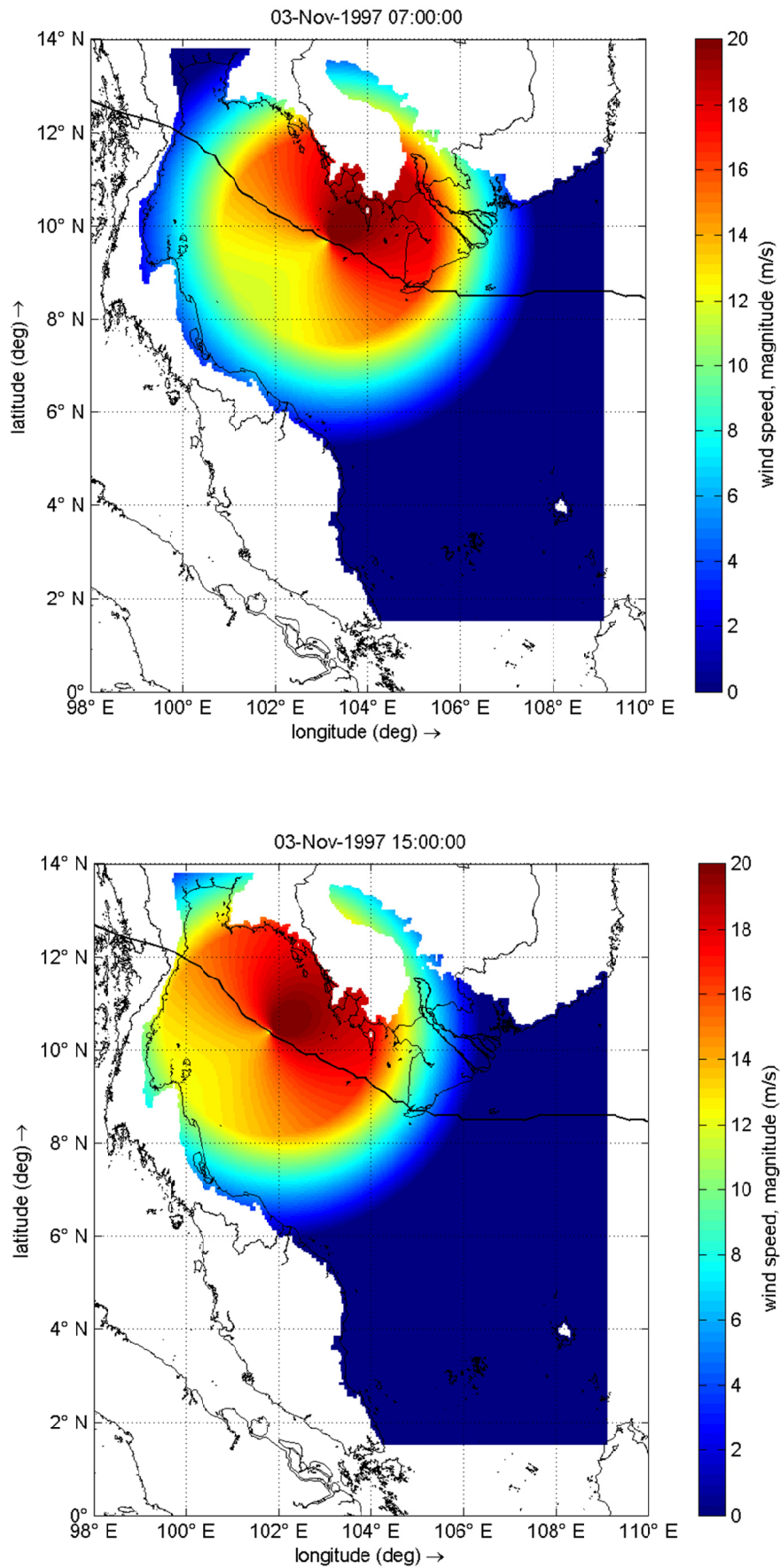


Fig. 5.18 Wind Speed in Extreme Condition

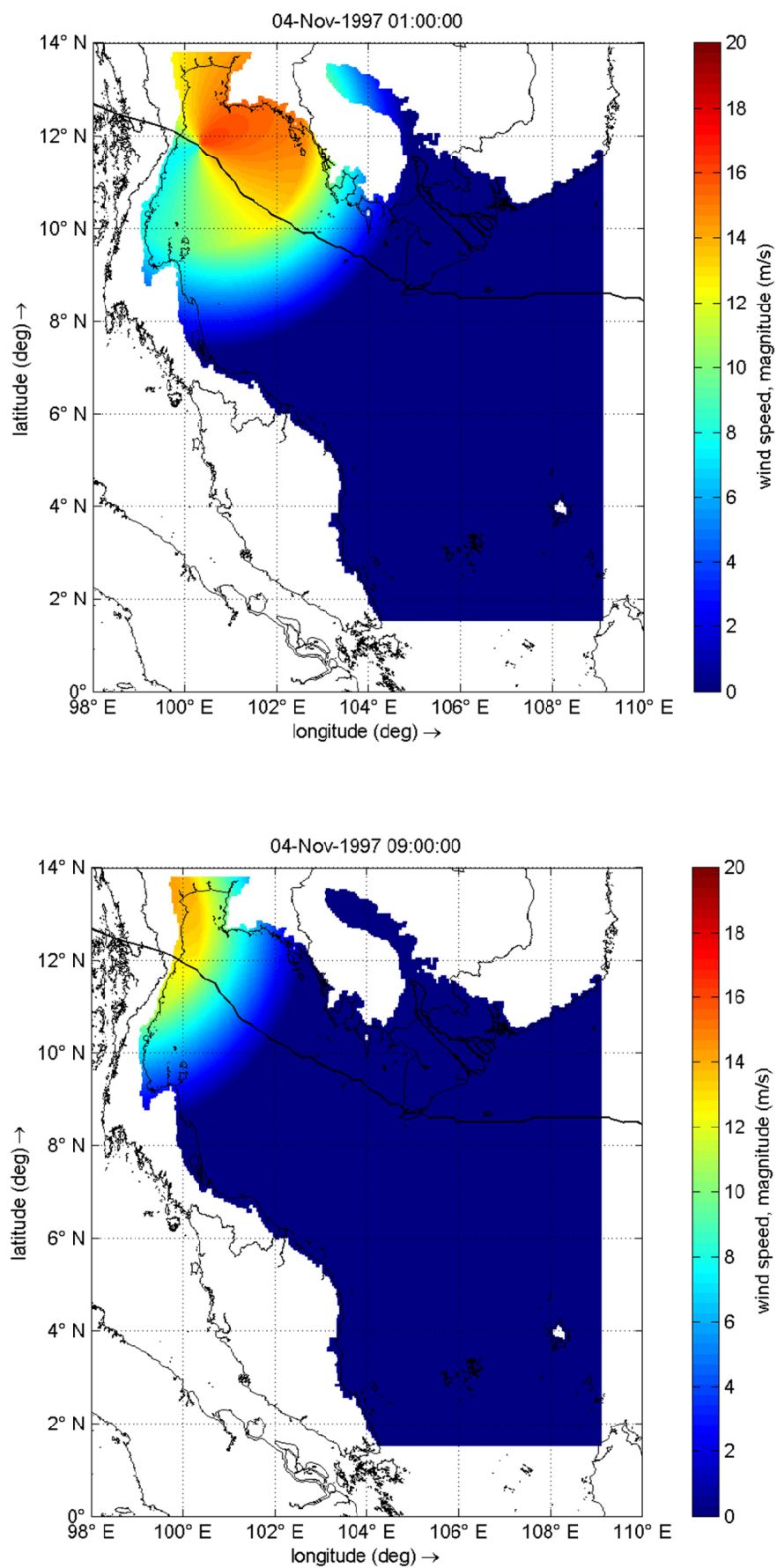


Fig. 5.18 (Cont.) Wind Speed in Extreme Condition

Chapter 6

Static Moored Ship Motions due to Tropical Cyclone Linda

6.1 INTRODUCTION

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 Chapter 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 Sriracha Harbour Port (SRH) and BLCP Coal-Fired Power Plant Port (BLCP) and subject to the static environmental load on the ship in accordance with Spanish Standard (ROM 0.2-1990). The environmental conditions are derived from the wave model and hydrodynamics model using the application of Delft3D-WAVE and Delft3D-FLOW as described in Chapter 5. The model location includes Ao Udom Bay and Rayong Sea.

6.2 FORMULATION OF MOORING PROBLEM

The formulation of mooring problem follows the study of R. Natarajan and C. Ganapathy (1998), 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), British Standard (BS6349) and Oil Companies International Marine Forum (OCIMF) guidelines as shown in Fig. 6.1. The numbers of mooring lines depend on the external forces subject to the wind, wave, current and tide with includes considering the operation conditions at the fully loaded and ballasted condition as shown in Fig. 6.2. The behavior of mooring poses is complicated in a nonlinear problem, which the mooring lines hang in the air as non-coplanar catenaries, the assumption of the formulation assumed to straight mooring lines non-hanging in the air, and the constant stiffness of mooring line. The moored ship in shallow water may have an effect on water depth and draft of a ship ratio, which is influences of the current static force on the moored ship and change in the elevation of tide level as shown in Fig. 6.3.

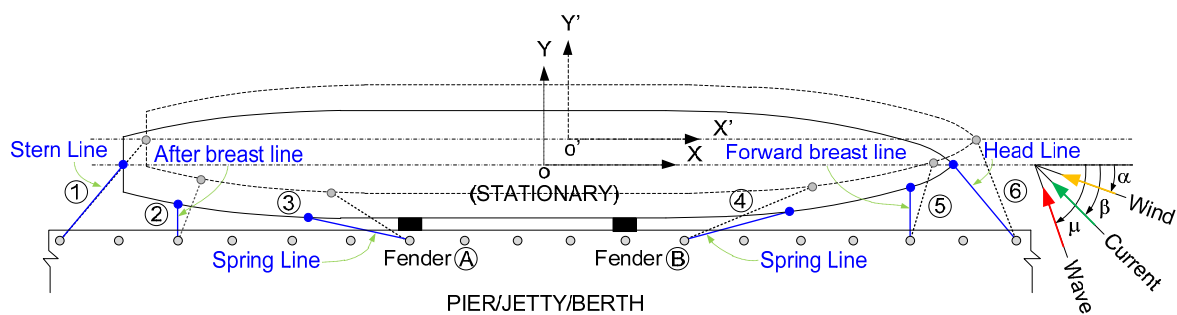


Fig. 6.1 Mooring Arrangements (R. Natarajan and C. Ganapathy, 1998)

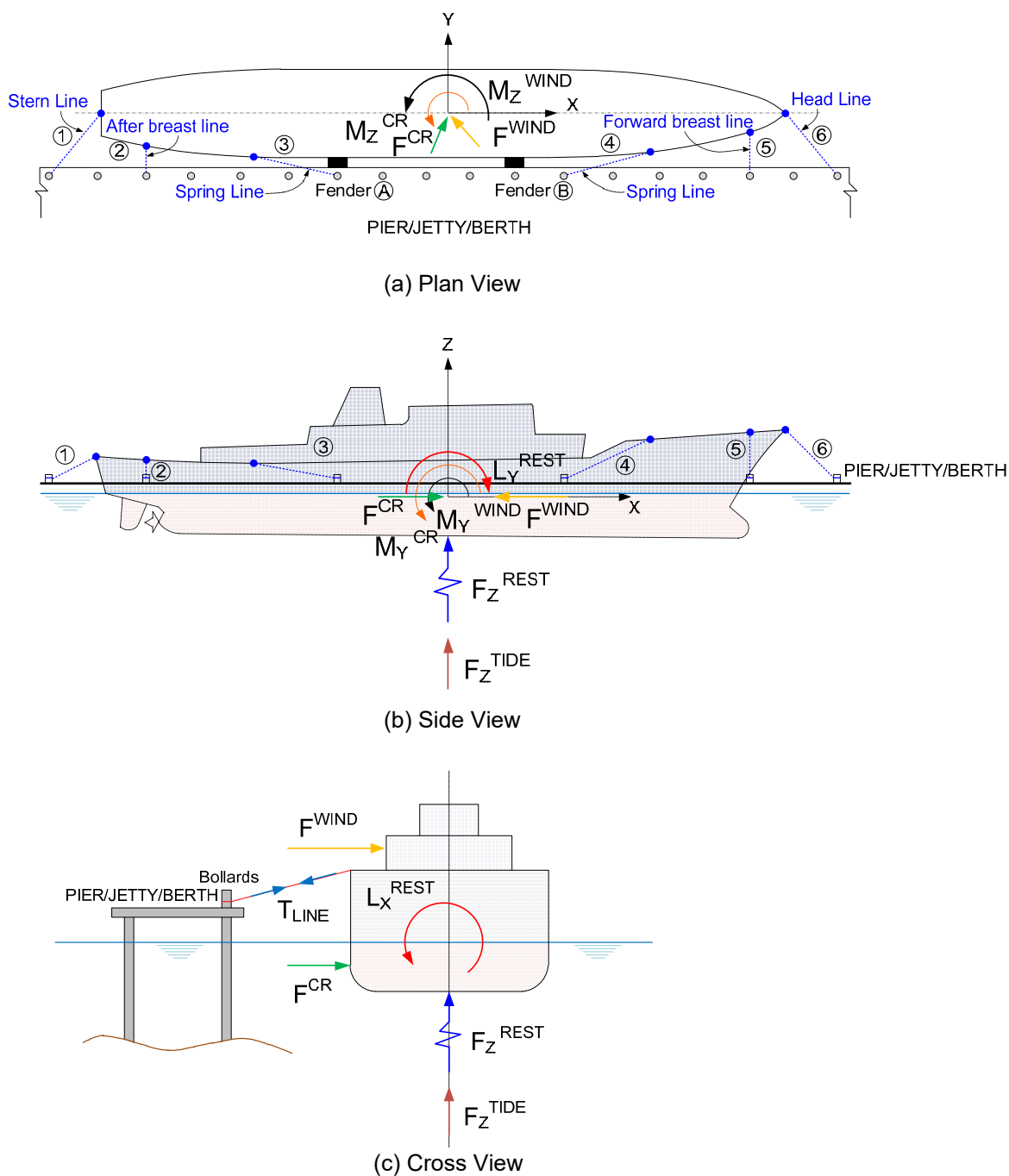
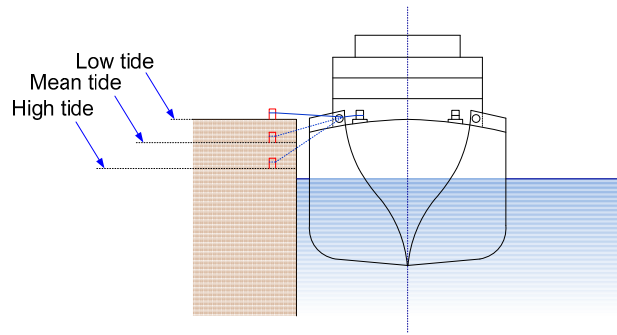
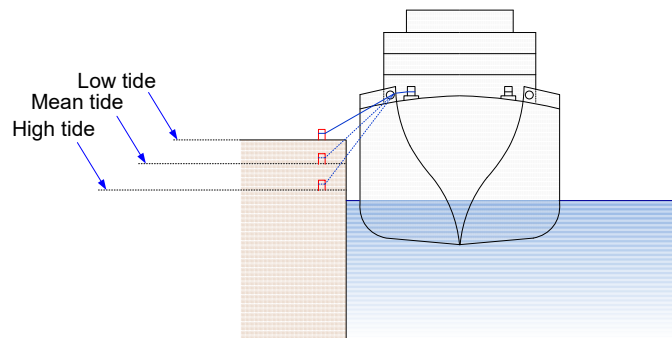


Fig. 6.2 External and Buoyant Restoring Forces (R. Natarajan and C. Ganapathy, 1998)



(a) Full Loaded Condition



(b) Ballasted Condition

Fig. 6.3 Operation Condition as Variation of Tide Level (BS 6349)

Table 6.1 Motions Criteria for Safe Working Condition (PIANC, 1995)

Ship Type	Cargo Handling	Surge (m)	Sway (m)	Heave (m)	Yaw (Deg.)	Pitch (Deg.)	Roll (Deg.)
Fishing Vessel	Elevator Crane	0.15	0.15	0.4	3.0	3.0	3.0
	Lift-On-Lift-Off	1.0	1.0	0.4	3.0	3.0	3.0
	Suction Pumps	2.0	1.0	0.4	3.0	3.0	3.0
Freighters, Coasters	Ship's Gear	1.0	1.2	0.6	1.0	1.0	2.0
	Quarry Cranes	1.0	1.2	0.8	2.0	1.0	3.0
Ferries, Ro Ro	Side Ramp	0.6	0.6	0.6	1.0	1.0	2.0
	Dew/Storm Ramp	0.8	0.6	0.8	1.0	1.0	4.0
	Linkspan	0.4	0.6	0.8	3.0	2.0	4.0
	Rail Ramp	0.1	0.1	0.4	-	1.0	1.0
General Cargo	-	2.0	1.5	1.0	3.0	2.0	5.0
Container Vessels	100Z Efficiency	1.0	0.6	0.8	1.0	1.0	3.0
	50Z Efficiency	2.0	1.2	1.2	1.5	2.0	6.0
Bulk Carriers	Crane	2.0	1.0	1.0	2.0	2.0	6.0
	Elevator/Bucket Wheel	1.0	0.5	1.0	2.0	2.0	2.0
	Conveyor Belt	5.0	2.5	-	3.0	-	-
Oil Tankers	Loading Arms	3.0	±3.0	-	-	-	-
Gas Tankers	Loading Arms	3.0	±3.0	-	2.0	2.0	2.0

The mooring system analyzed in a six-degrees-of-freedom system, which considered the hydrostatic restoring forces such as heel moment, trim moment and immersion displacements as shown in Fig. 6.2, the hydrostatic restoring forces assumed to vary linearly with the vessel movement (R. Natarajan and C. Ganapathy, 1998).

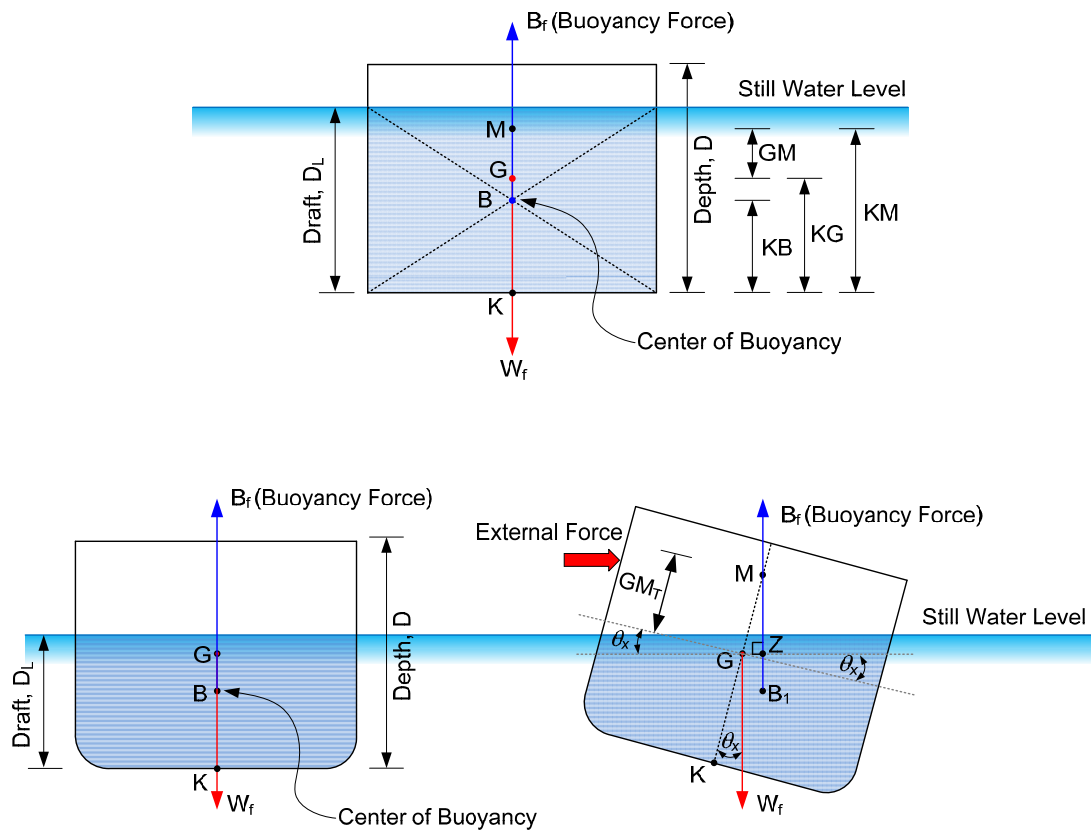


Fig. 6.4 Ship Stability (Course of Ship's Stability)

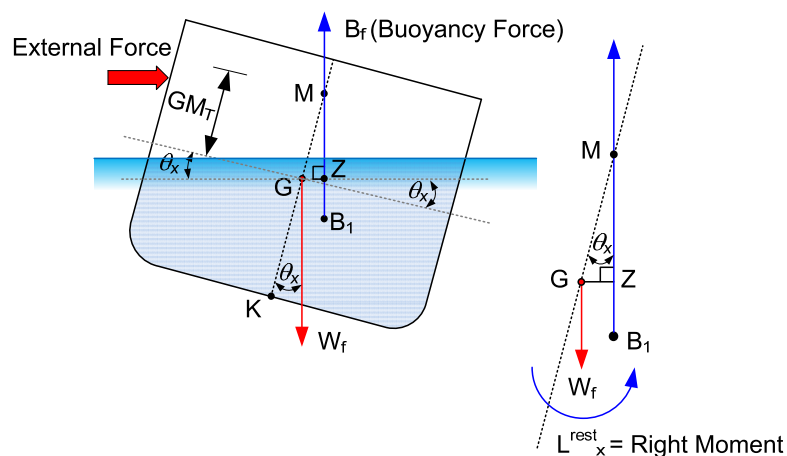


Fig. 6.5 Moment of Static Stability (Course of Ship's Stability)

6.2.1 Restoring Force

The restoring heel moment and trim moment proved by using the ship stability definition, for finding the solution of transverse metacentric height, longitudinal metacentric height and the moment of stability of the ship is expressed as shown in Fig. 6.4 and Fig. 6.5, shows the metacentric height expressed in Equation (6.1).

$$GM = KM - KG \quad (6.1)$$

Where:

GM = Metacentric height of the ship (m)

The moment of static stability (right moment) is equal to the distance between the center of gravity of the ship and point z as shown in Fig. 6.5 multiply to the displacement of the ship, as expressed below. (Course of Ship's Stability)

$$\text{Right Moment} = GZ (m) \cdot \text{Displacement } (t) \quad (6.2a)$$

$$\sin \theta_x = \frac{GZ}{GM} \quad (6.2b)$$

$$GZ = GM \cdot \sin \theta_x \quad (6.2c)$$

Assumed θ_x very small assumed then, $\sin \theta_x = \theta_x$

$$\text{Right moment} = L_x^{rest} = W \cdot GM_T \cdot \sin \theta_x \quad (6.2d)$$

$$L_x^{rest} = W \cdot GM_T \cdot \theta_x \quad (6.2e)$$

Where:

L_x^{rest} = Restoring heel moment (Ton-m)

GM_T = Transverse metacentric height of the ship (m)

θ_x = Angular displacement of the ship due to heel (rad)

In which, the restoring trim moment can be expressed by (R. Natarajan and C. Ganapathy, 1998)

$$L_y^{rest} = W \cdot GM_L \cdot \theta_y \quad (6.3)$$

Where:

L_y^{rest} = Restoring trim moment (Ton-m)

GM_L = Longitudinal metacentric height of the ship (m)

θ_y = Angular displacement of the ship due to trim (rad)

When the vessel displaced downward along the vertical z-axis by a distance U_z from its position of equilibrium, the immersion force becomes (R. Natarajan and C. Ganapathy, 1998)

$$F_{rest} = \rho_w \times g \times A_w \times U_z \quad (6.4)$$

Where:

F_{rest} = Immersion force (N)

ρ_w = Mass density of seawater (1,025 kg/m³)

g = Acceleration due to gravity (9.81 m/s²)

A_w = Waterplane area of the ship (m²)

U_z = Translation of any point of the ship along the z-axis (m)

6.2.2 Space Mooring Lines Stiffness

The mooring equation is performed as 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. 6.6. Then, the elastic stiffness of the mooring lines on its principal direction is represented by (R. Natarajan and C. Ganapathy, 1998)

$$k = \left[\frac{EA}{L} \right] \quad (6.5)$$

Where:

k = Stiffness of the mooring line along its own axis (kN/m²)

E = Young's modulus of the mooring line (kN/m²)

E = Cross-sectional area of the mooring line (m²)

L = Length of mooring line from the mooring bitt to the bollard (m)

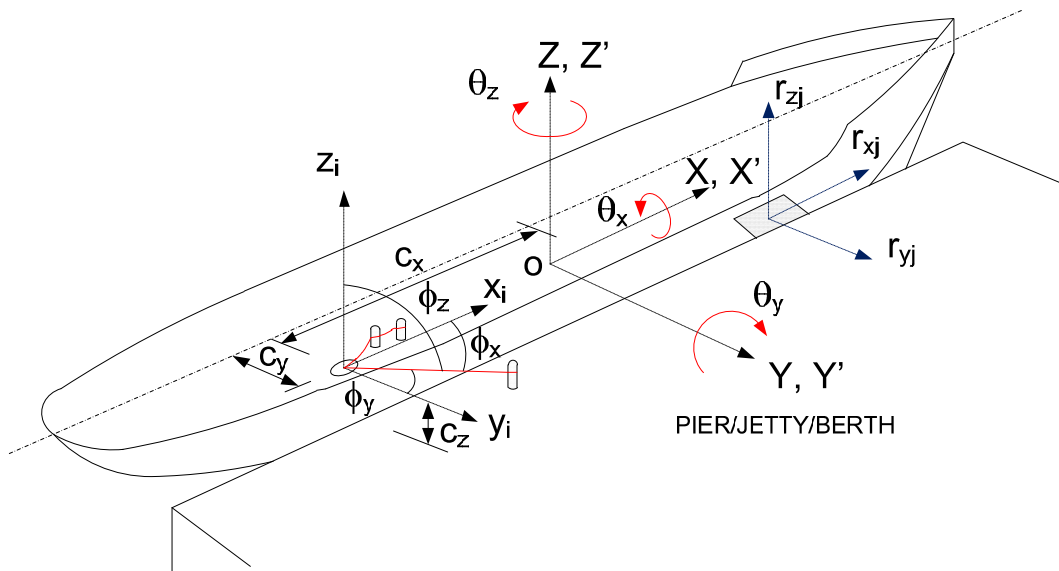
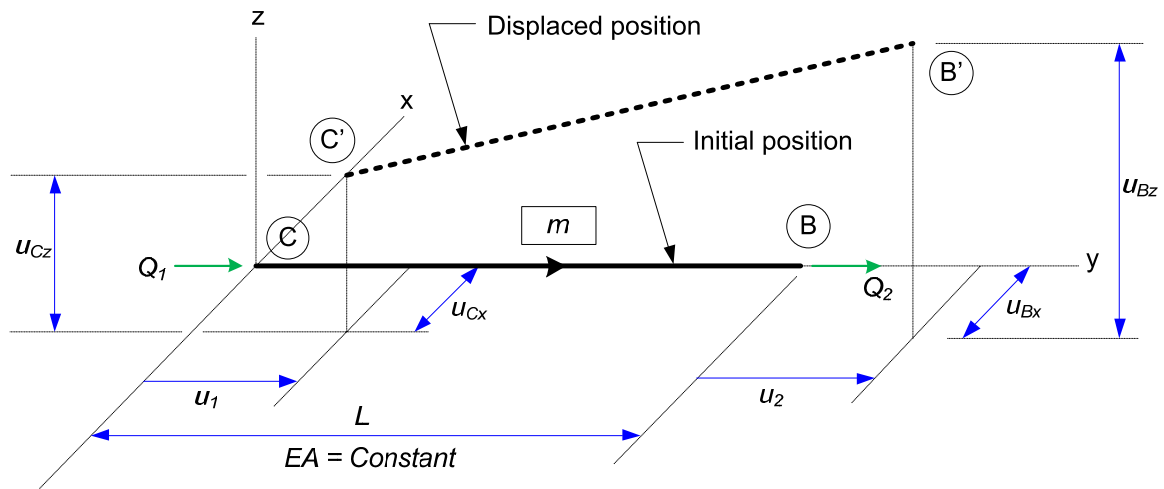
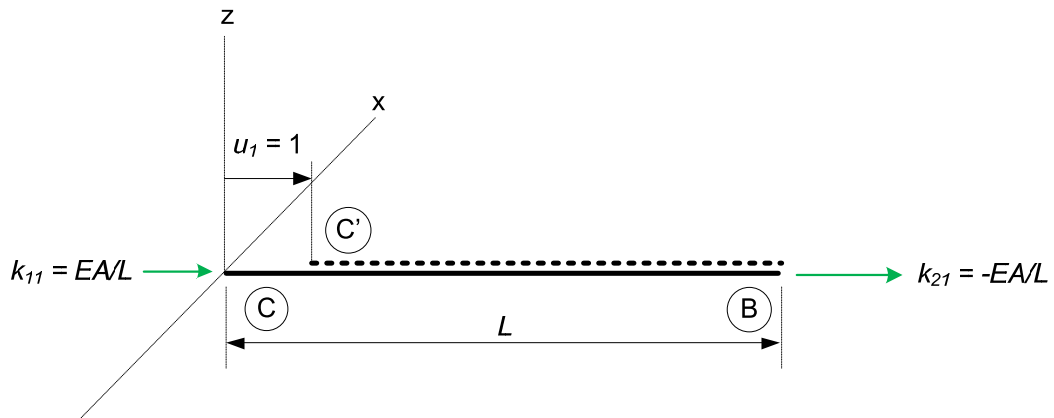


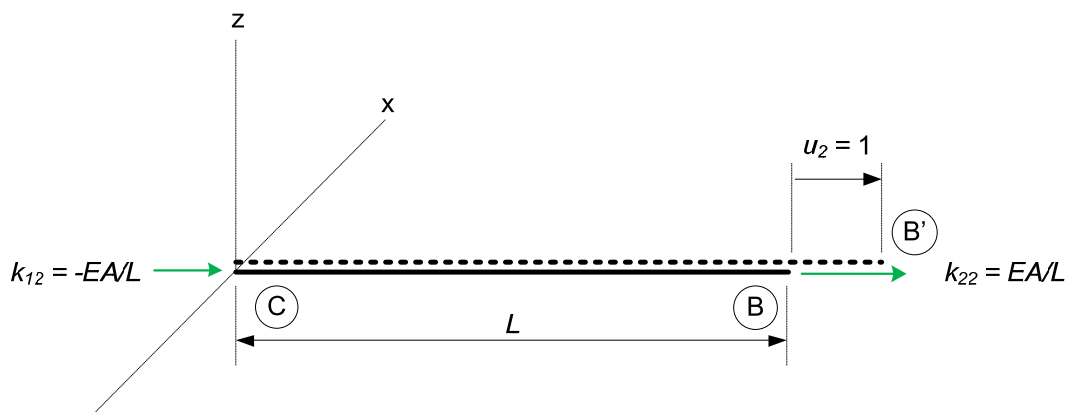
Fig. 6.6 Mooring Coordinates (R. Natarajan and C. Ganapathy, 1998)



(a)



(b)



(c)

Fig. 6.7 Member Forces and Displacement in the Local Coordinate System (Aslam Kassimali, 1999)

The local end displacement vector u for a member of a space mooring line expressed as (Aslam Kassimali, 1999)

$$\{u\} = \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} \quad (6.6)$$

Where:

u = Local end displacement vector

u_1 = End displacement at point/node C

u_2 = End displacement at point/node B

The relation between the local end forces Q and the end displacements u , for the members of space mooring lines, is written as (Aslam Kassimali, 1999)

$$Q = ku \quad (6.7)$$

In which k represents the 2x2 member stiffness matrix in the local coordinate system. The explicit form of k is obtained by subjecting the member to the unit end displacements, $u_1 = 1$ and $u_2 = 1$, as shown in Fig. 6.7 (b) and Fig. 6.7 (c) respectively, and evaluating the corresponding member end forces. Thus, the local stiffness matrix for member of space mooring lines explicitly expressed as

$$k = \frac{EA}{L} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \quad (6.8)$$

6.2.3 Coordinate Transformations

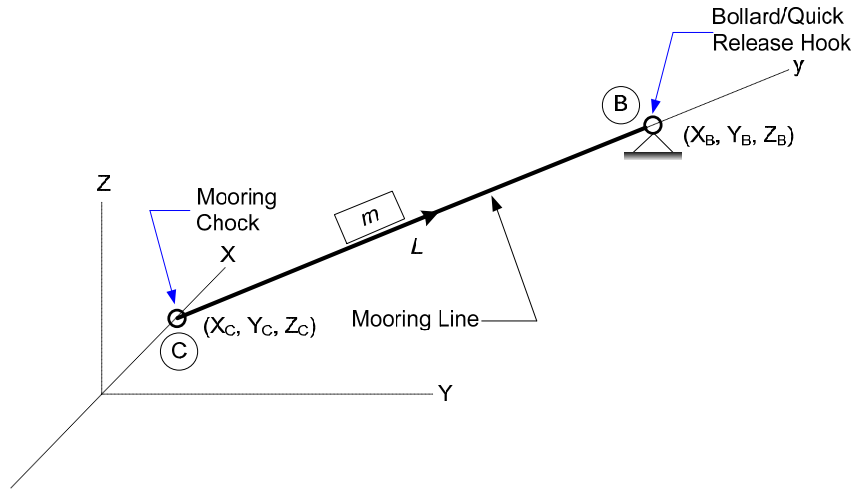
Consider an arbitrary member m of a space mooring lines as shown in Fig. 6.8 (a), and let X_C, Y_C, Z_C and X_B, Y_B, Z_B be the global coordinate of the joints to which the member and C and B respectively. Cosines of the member expressed in terms of the global coordinate its end by the following relationships:

$$L = \sqrt{(X_C - X_B)^2 + (Y_C - Y_B)^2 + (Z_C - Z_B)^2} \quad (6.9)$$

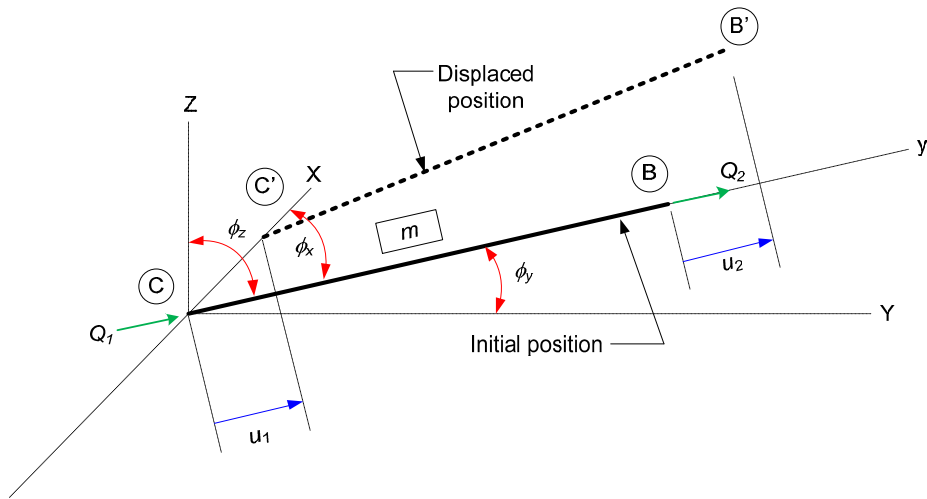
$$\cos \phi_x = \frac{X_C - X_B}{L} \quad (6.10)$$

$$\cos \phi_z = \frac{Z_C - Z_B}{L} \quad (6.11)$$

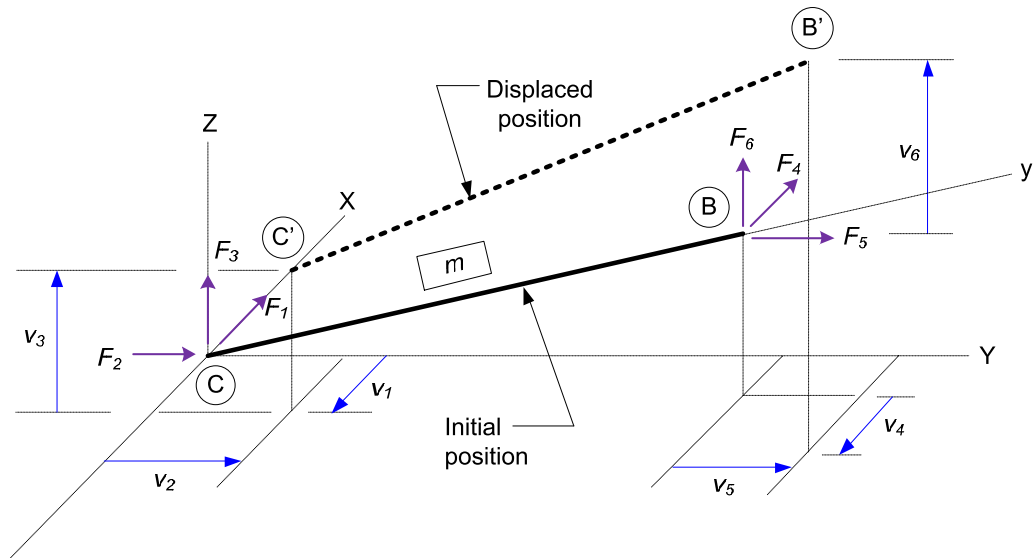
$$\cos \phi_y = \frac{Y_C - Y_B}{L} \quad (6.12)$$



(a) Space Mooring Lines



(b) Member End Forces and End Displacement in the Local Coordinate System



(c) Member End Forces and End Displacement in the Global Coordinate System

Fig. 6.8 Mooring Lines Coordinate Transformations (Aslam Kassimali, 1999)

The transformation of the member and end force and end displacements from a global to the local coordinate system. By comparing Fig. 6.8 (b) and Fig. 6.8 (c), we observe that at end C of the member, the local force Q_1 must be equal to the algebraic sum of components of the global forces F_1 , F_2 and F_3 in the direction of the local y-axis; that is (Aslam Kassimali, 1999)

$$Q_1 = F_1 \cdot \cos \phi_x + F_2 \cdot \cos \phi_y + F_3 \cdot \cos \phi_z \quad (6.13)$$

Similarly, at end B of the member, we can express Q_2 in term of F_4 , F_5 and F_6 as

$$Q_2 = F_4 \cdot \cos \phi_x + F_5 \cdot \cos \phi_y + F_6 \cdot \cos \phi_z \quad (6.14)$$

Equation (6.13) and (6.14) written in matrix form as

$$\begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} = \begin{bmatrix} \cos \phi_x & \cos \phi_y & \cos \phi_z & 0 & 0 & 0 \\ 0 & 0 & 0 & \cos \phi_x & \cos \phi_y & \cos \phi_z \end{bmatrix} \begin{Bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \end{Bmatrix} \quad (6.15)$$

Equation (6.15) can be symbolically expressed as $Q = TF$, with the 2x6 transformation matrix T given by

$$T = \begin{bmatrix} \cos \phi_x & \cos \phi_y & \cos \phi_z & 0 & 0 & 0 \\ 0 & 0 & 0 & \cos \phi_x & \cos \phi_y & \cos \phi_z \end{bmatrix} \quad (6.16)$$

Since member end displacements, like end forces, are vector, which is defined in the same directions as the corresponding force, forgoing transformation matrix T can also be used to transform member end displacements from the global to local coordinate system, that is

$$u = TV \quad (6.17)$$

$$\begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = \begin{bmatrix} \cos \phi_x & \cos \phi_y & \cos \phi_z & 0 & 0 & 0 \\ 0 & 0 & 0 & \cos \phi_x & \cos \phi_y & \cos \phi_z \end{bmatrix} \begin{Bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \end{Bmatrix} \quad (6.18)$$

Next, we examine the transformation of member end forces from the local to the global coordinate system. A comparison of Fig. 6.8 (b) and Fig. 6.8 (c) indicates that end C of the member, the global forces F_1 , F_2 and F_3 must be components of the local force Q_1 in the direction of global X, Y and Z axes, respectively; that is (Aslam Kassimali, 1999)

$$F_1 = Q_1 \cdot \cos \phi_x \quad (6.19a)$$

$$F_2 = Q_1 \cdot \cos \phi_y \quad (6.19b)$$

$$F_3 = Q_1 \cdot \cos \phi_z \quad (6.19c)$$

Similarly, at end B of the member, the global forces F_4 , F_5 and F_6 can be expressed as the components of the local force Q_2 as

$$F_4 = Q_2 \cdot \cos \phi_x \quad (6.20a)$$

$$F_5 = Q_2 \cdot \cos \phi_y \quad (6.20b)$$

$$F_6 = Q_2 \cdot \cos \phi_z \quad (6.20c)$$

We can write Equation (6.19) and (6.20) in a matrix form as

$$\begin{Bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \end{Bmatrix} = \begin{bmatrix} \cos \phi_x & 0 \\ \cos \phi_y & 0 \\ \cos \phi_z & 0 \\ 0 & \cos \phi_x \\ 0 & \cos \phi_y \\ 0 & \cos \phi_z \end{bmatrix} \begin{Bmatrix} Q_1 \\ Q_2 \end{Bmatrix} \quad (6.21)$$

As the first matrix on the right side of Equation (6.21) is the transpose of the transformation matrix T (Eq. 6.16), the equation symbolically expressed

$$[F]_{6 \times 1} = [T^T]_{6 \times 2} [Q]_{2 \times 1} \quad (6.22)$$

6.2.4 Member Stiffness Relation in the Global Coordinate System

As in the case of plane mooring line, the relationship between the global end forces F and the end displacement v for the members of space mooring lines is expressed $F = Kv$, with the member global; stiffness matrix K given by the equation

$$Kv = T^T ku \quad (6.23a)$$

$$K = T^T kT \quad (6.23b)$$

$$K = \frac{EA}{L} \begin{bmatrix} \cos \phi_x & 0 \\ \cos \phi_y & 0 \\ \cos \phi_z & 0 \\ 0 & \cos \phi_x \\ 0 & \cos \phi_y \\ 0 & \cos \phi_z \end{bmatrix} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} \cos \phi_x & \cos \phi_y & \cos \phi_z & 0 & 0 & 0 \\ 0 & 0 & 0 & \cos \phi_x & \cos \phi_y & \cos \phi_z \end{bmatrix} \quad (6.24a)$$

$$K = \frac{EA}{L} \begin{bmatrix} \cos \phi_x & 0 \\ \cos \phi_y & 0 \\ \cos \phi_z & 0 \\ 0 & \cos \phi_x \\ 0 & \cos \phi_y \\ 0 & \cos \phi_z \end{bmatrix} \begin{bmatrix} \cos \phi_x & \cos \phi_y & \cos \phi_z & -\cos \phi_x & -\cos \phi_y & -\cos \phi_z \\ -\cos \phi_x & -\cos \phi_y & -\cos \phi_z & \cos \phi_x & \cos \phi_y & \cos \phi_z \end{bmatrix} \quad (6.24b)$$

$$K = \frac{EA}{L} \begin{bmatrix} \cos^2 \phi_x & \cos \phi_x \cos \phi_y & \cos \phi_x \cos \phi_z & -\cos^2 \phi_x & -\cos \phi_x \cos \phi_y & -\cos \phi_x \cos \phi_z \\ \cos \phi_x \cos \phi_y & \cos^2 \phi_y & \cos \phi_y \cos \phi_z & -\cos \phi_x \cos \phi_y & -\cos^2 \phi_y & -\cos \phi_y \cos \phi_z \\ \cos \phi_x \cos \phi_z & \cos \phi_y \cos \phi_z & \cos^2 \phi_z & -\cos \phi_x \cos \phi_z & -\cos \phi_y \cos \phi_z & -\cos^2 \phi_z \\ -\cos^2 \phi_x & -\cos \phi_x \cos \phi_y & -\cos \phi_x \cos \phi_z & \cos^2 \phi_x & \cos \phi_x \cos \phi_y & \cos \phi_x \cos \phi_z \\ -\cos \phi_x \cos \phi_y & -\cos^2 \phi_y & -\cos \phi_y \cos \phi_z & \cos \phi_x \cos \phi_y & \cos^2 \phi_y & \cos \phi_y \cos \phi_z \\ -\cos \phi_x \cos \phi_z & -\cos \phi_y \cos \phi_z & -\cos^2 \phi_z & \cos \phi_x \cos \phi_z & \cos \phi_y \cos \phi_z & \cos^2 \phi_z \end{bmatrix} \quad (6.24c)$$

The translations in the global coordinate system at bollard are zero. Then, the global stiffness matrix of mooring lines expressed as

$$K = \frac{EA}{L} \begin{bmatrix} \cos^2 \phi_x & \cos \phi_x \cos \phi_y & \cos \phi_x \cos \phi_z \\ \cos \phi_x \cos \phi_y & \cos^2 \phi_y & \cos \phi_y \cos \phi_z \\ \cos \phi_x \cos \phi_z & \cos \phi_y \cos \phi_z & \cos^2 \phi_z \end{bmatrix} \quad (6.24d)$$

6.3 SOLUTION OF MOORING EQUATIONS

The solution of mooring equations is solved the global stiffness matrix of mooring line as expressed in Equation (6.24d) with included reactive forces and external forces as in equilibrium equations.

6.3.1 Mooring Lines Stiffness Matrix in the Global Coordinate System

The global stiffness matrix K of i th mooring line expressed as

$$[K]_i = \frac{EA}{L} \begin{bmatrix} \cos^2 \phi_x & \cos \phi_x \cos \phi_y & \cos \phi_x \cos \phi_z \\ \cos \phi_x \cos \phi_y & \cos^2 \phi_y & \cos \phi_y \cos \phi_z \\ \cos \phi_x \cos \phi_z & \cos \phi_y \cos \phi_z & \cos^2 \phi_z \end{bmatrix}_i \quad (6.25)$$

Hence

$$[K]_i = \begin{bmatrix} K_{xx} & K_{xy} & K_{xz} \\ K_{xy} & K_{yy} & K_{yz} \\ K_{xz} & K_{yz} & K_{zz} \end{bmatrix}_i \quad (6.26)$$

The translation and rotation at center of ship expressed as (R. Natarajan and C. Ganapathy, 1998)

$$\{\theta_c\} = \begin{Bmatrix} \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix} \quad (6.27a)$$

$$\{U_c\} = \begin{Bmatrix} U_x \\ U_y \\ U_z \end{Bmatrix} \quad (6.27b)$$

Reactive forces at the center of gravity of ship (R. Natarajan and C. Ganapathy, 1998)

$$[\bar{F}] = \sum_{i=1}^n ([K]_i \times \{U_c\} + [A]_i \{\theta_c\}) \quad (6.28)$$

Where $[A]_i = -[K]_i \times [C]_i$ and $[C]_i$ is a coordinated matrix of the i th mooring chock in the x, y and z directions (R. Natarajan and C. Ganapathy, 1998)

$$[C]_i = \begin{bmatrix} 0 & -C_z & C_y \\ C_z & 0 & -C_x \\ -C_y & C_x & 0 \end{bmatrix}_i \quad (6.29)$$

Where C_x , C_y and C_z are point coordinates of the i th mooring chock from the center of ship

The reactive moment about the center of gravity of the ship given by (R. Natarajan and C. Ganapathy, 1998)

$$[\bar{L}] = \sum_{i=1}^n ([A]_i^T \times \{U_c\} + [B]_i \{\theta_c\}) \quad (6.30)$$

Where $[B]_i = [C]_i \times [A]_i$ and the superscript T signifies a transposed matrix

In which $[A]_i = -[K]_i \times [C]_i$, Then

$$[A]_i = - \begin{bmatrix} K_{xx} & K_{xy} & K_{xz} \\ K_{xy} & K_{yy} & K_{yz} \\ K_{xz} & K_{yz} & K_{zz} \end{bmatrix}_i \begin{bmatrix} 0 & -C_z & C_y \\ C_z & 0 & -C_x \\ -C_y & C_x & 0 \end{bmatrix}_i \quad (6.31a)$$

$$\therefore [A]_i = \begin{bmatrix} K_{xz}C_y - K_{xy}C_z & K_{xx}C_z - K_{xz}C_x & K_{xy}C_x - K_{xx}C_y \\ K_{yz}C_y - K_{yy}C_z & K_{xy}C_z - K_{yz}C_x & K_{yy}C_x - K_{xy}C_y \\ K_{zz}C_y - K_{yz}C_z & K_{xz}C_z - K_{zz}C_x & K_{yz}C_x - K_{xz}C_y \end{bmatrix}_i \quad (6.31b)$$

$$[A]_i^T = \begin{bmatrix} K_{xz}C_y - K_{xy}C_z & K_{yz}C_y - K_{yy}C_z & K_{zz}C_y - K_{yz}C_z \\ K_{xx}C_z - K_{xz}C_x & K_{xy}C_z - K_{yz}C_x & K_{xz}C_z - K_{zz}C_x \\ K_{xy}C_x - K_{xx}C_y & K_{yy}C_x - K_{xy}C_y & K_{yz}C_x - K_{xz}C_y \end{bmatrix}_i \quad (6.32)$$

In which $[B]_i = [C]_i \times [A]_i$

$$[B]_i = \begin{bmatrix} 0 & -C_z & C_y \\ C_z & 0 & -C_x \\ -C_y & C_x & 0 \end{bmatrix}_i \begin{bmatrix} K_{xz}C_y - K_{xy}C_z & K_{xx}C_z - K_{xz}C_x & K_{xy}C_x - K_{xx}C_y \\ K_{yz}C_y - K_{yy}C_z & K_{xy}C_z - K_{yz}C_x & K_{yy}C_x - K_{xy}C_y \\ K_{zz}C_y - K_{yz}C_z & K_{xz}C_z - K_{zz}C_x & K_{yz}C_x - K_{xz}C_y \end{bmatrix}_i \quad (6.33a)$$

$$[B]_i = \begin{bmatrix} K_{yy}C_z^2 + K_{zz}C_y^2 - 2K_{yz}C_yC_z & K_{xz}C_yC_z + K_{yz}C_xC_z - K_{zz}C_xC_y - K_{xy}C_z^2 & K_{xy}C_yC_z + K_{yz}C_xC_y - K_{yy}C_xC_z - K_{xz}C_y^2 \\ K_{xz}C_yC_z - K_{xy}C_z^2 + K_{yz}C_xC_z - K_{zz}C_xC_y & K_{xx}C_z^2 + K_{zz}C_x^2 - 2K_{xz}C_xC_z & K_{xy}C_xC_z + K_{xz}C_xC_y - K_{xx}C_yC_z - K_{yz}C_x^2 \\ K_{xy}C_yC_z + K_{yz}C_xC_y - K_{yy}C_xC_z - K_{xz}C_y^2 & K_{xy}C_xC_z + K_{xz}C_xC_y - K_{xx}C_yC_z - K_{yz}C_x^2 & K_{xx}C_y^2 + K_{yy}C_x^2 - 2K_{xy}C_xC_y \end{bmatrix}_i \quad (6.33b)$$

The static equation is obtained by considering the equilibrium of a moored ship subjected to external force ($\bar{F}_{ext}$) and elastic force ($\bar{F}_{elast}$) and hydrostatic restoring force ($\bar{F}_{rest}$), respectively (R. Natarajan and C. Ganapathy, 1998)

$$[\bar{F}_{elast}] + [\bar{F}_{rest}] = [\bar{F}_{ext}] \quad (6.34)$$

$$[\bar{F}_{elast}] = \begin{bmatrix} K_{xx} & K_{xy} & K_{xz} & A_{11} & A_{12} & A_{13} \\ K_{xy} & K_{yy} & K_{yz} & A_{21} & A_{22} & A_{23} \\ K_{xz} & K_{yz} & K_{zz} & A_{31} & A_{32} & A_{33} \\ A_{11}^* & A_{12}^* & A_{13}^* & B_{11} & B_{12} & B_{13} \\ A_{21}^* & A_{22}^* & A_{23}^* & B_{21} & B_{22} & B_{23} \\ A_{31}^* & A_{32}^* & A_{33}^* & B_{31} & B_{32} & B_{33} \end{bmatrix}_{i=1} \begin{Bmatrix} U_x \\ U_y \\ U_z \\ \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix} + \dots + \begin{bmatrix} K_{xx} & K_{xy} & K_{xz} & A_{11} & A_{12} & A_{13} \\ K_{xy} & K_{yy} & K_{yz} & A_{21} & A_{22} & A_{23} \\ K_{xz} & K_{yz} & K_{zz} & A_{31} & A_{32} & A_{33} \\ A_{11}^* & A_{12}^* & A_{13}^* & B_{11} & B_{12} & B_{13} \\ A_{21}^* & A_{22}^* & A_{23}^* & B_{21} & B_{22} & B_{23} \\ A_{31}^* & A_{32}^* & A_{33}^* & B_{31} & B_{32} & B_{33} \end{bmatrix}_{i=n} \begin{Bmatrix} U_x \\ U_y \\ U_z \\ \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix} \quad (6.35)$$

$$[\bar{F}_{rest}] = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & (\rho_w \cdot g \cdot A_w)/1000 & 0 & 0 & 0 \\ 0 & 0 & 0 & (W \cdot GM_T) \cdot 9.81 & 0 & 0 \\ 0 & 0 & 0 & 0 & (W \cdot GM_L) \cdot 9.81 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{Bmatrix} U_x \\ U_y \\ U_z \\ \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix} \begin{matrix} (kN) \\ (kN) \\ (kN) \\ (kN - m) \\ (kN - m) \\ (kN - m) \end{matrix}$$

(6.36)

$$\{\bar{F}_{ext}\} = \begin{bmatrix} F_x wind + F_x current + F_x wave \\ F_y wind + F_y current + F_y wave \\ F_z tide + F_z load / unload + F_z wave \\ M_x wind + M_x current + M_x wave \\ M_y wind + M_y current + M_y wave \\ M_z wind + M_z current + M_z wave \end{bmatrix} = Q \quad (6.37)$$

Hence

$$K \times U_i = Q \quad (6.38)$$

The two-dimensional ship motions are assumed the vertical translation (U_z), angular displacement of the ship due to heel (θ_x) and angular displacement of the ship due to trim (θ_y) are equal to zero, therefore the mooring equations expressed as

$$[\bar{F}_{elast}] = [\bar{F}_{ext}] \quad (6.39a)$$

$$\left[\begin{bmatrix} K_{xx} & K_{xy} & A_{13} \\ K_{xy} & K_{yy} & A_{23} \\ A_{31}^* & A_{32}^* & B_{33} \end{bmatrix}_{i=1} + \dots + \begin{bmatrix} K_{xx} & K_{xy} & A_{13} \\ K_{xy} & K_{yy} & A_{23} \\ A_{31}^* & A_{32}^* & B_{33} \end{bmatrix}_{i=n} \right] \begin{Bmatrix} U_x \\ U_y \\ \theta_z \end{Bmatrix} = \begin{Bmatrix} F_x wind + F_x current + F_x wave \\ F_y wind + F_y current + F_y wave \\ M_z wind + M_z current + M_z wave \end{Bmatrix} \quad (6.39b)$$

MATLAB Computer Program is an application written for the mooring equation as in the matrix and solved using the equation of motion for obtained the moored ship motions in the two-dimensional plan. Flow chart of the MATLAB Computer Program modified the flow chart of a SHIP MOOR computer program, which was the study of R. Natarajan and C. Ganapathy (1998) as shown in Fig. 6.9.

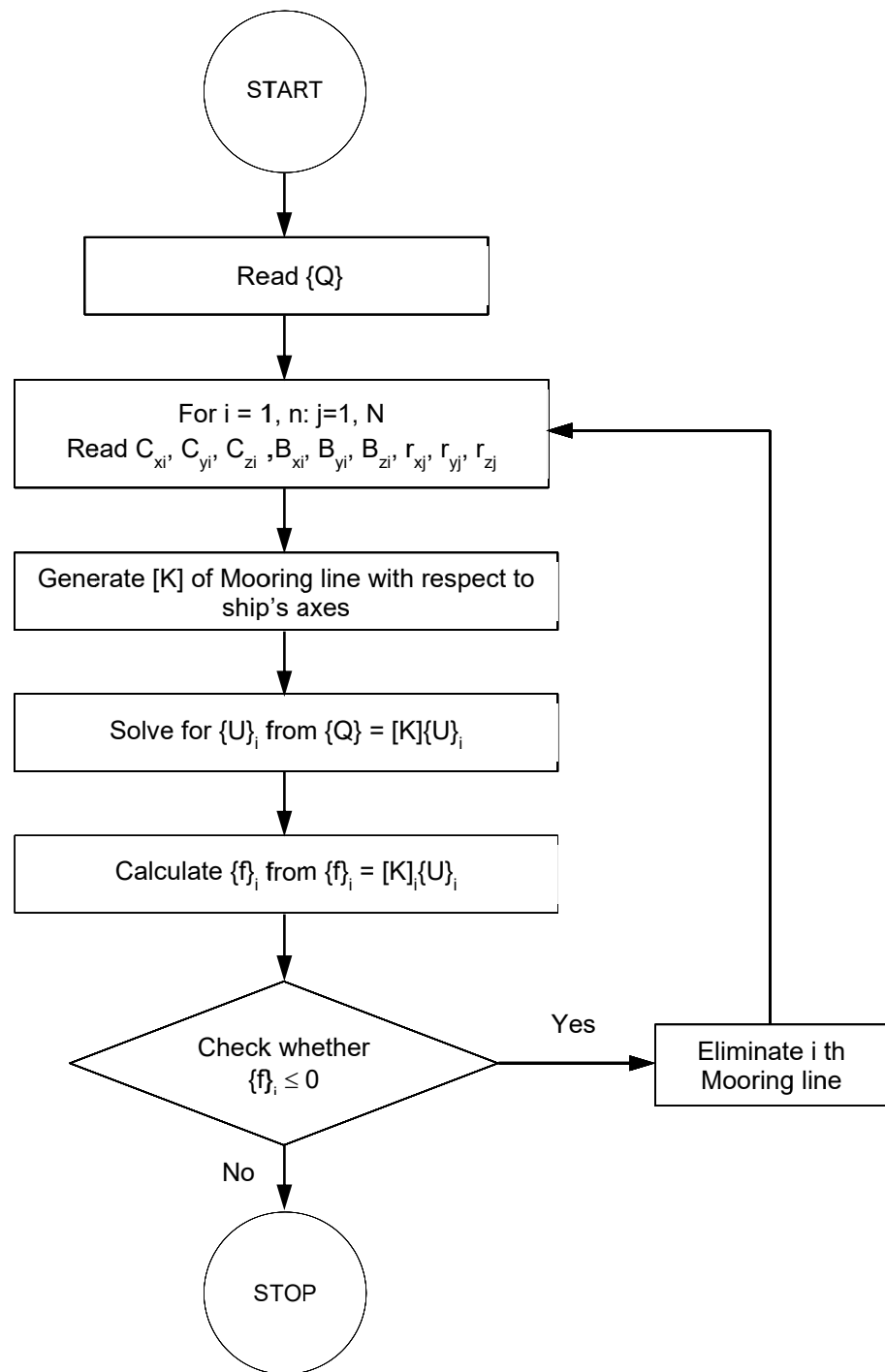


Fig. 6.9 MATLAB Computer Program Flow Chart

6.4 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 follow the maritime design standard and design guidelines such as Spanish Standard (ROM 0.2-1990), British Standard (BS6349) and Oil Companies International Marine Forum (OCIMF), 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 6.2. In this study, the equivalent static forces are calculated according to the Spanish Standard (ROM 0.2-1990) 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. In this study, the equivalent static forces are calculated according to the Spanish Standard (ROM 0.2-1990) for the environmental forces on the moored ship with included static wind force, static current force, static current drag force and static wave force.

Table 6.2 Static Forces Comparison of Design Standards

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

6.4.1 Static Wind Force

The wind force is the uniform on the moored ship surface which based on uniform wind speed at 10 m elevation above the water surface and wind force can cause the large mooring force in ballasted condition or light draught condition. (ROM 0.2-1990)

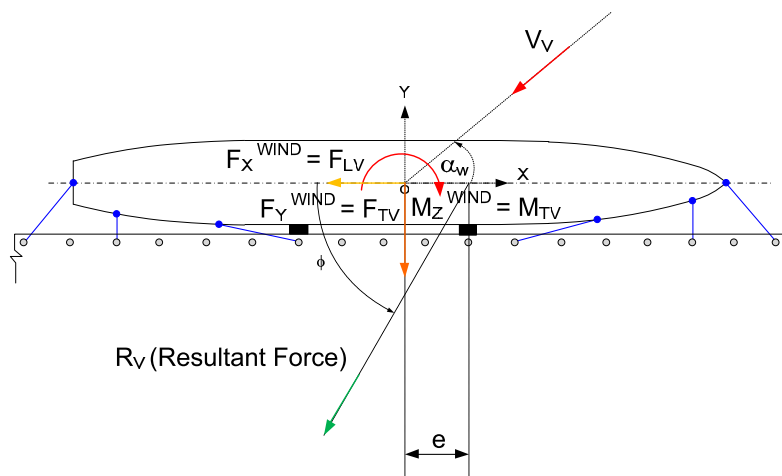


Fig. 6.10 Static Wind Force on Moored Ship (ROM 0.2-1990)

$$R_V = \frac{\rho_a}{2g} \cdot C_V \cdot V_V^2 \cdot (A_T \cos^2 \alpha_w + A_L \sin^2 \alpha_w) = \frac{C_V \cdot V_V^2}{16,000} (A_T \cos^2 \alpha_w + A_L \sin^2 \alpha_w) \quad (6.40a)$$

$$F_{LV} = R_V \cdot \cos \phi \quad (6.40b)$$

$$F_{TV} = R_V \cdot \sin \phi \quad (6.40c)$$

$$M_{TV} = F_{TV} \cdot e = F_{TV} \cdot K_e \cdot L \quad (6.40d)$$

$$\tan \phi = \frac{A_L}{A_T} \cdot \tan \alpha \quad (6.40e)$$

Where:

R_V = Resultant wind force on a ship (N)

ϕ = Angle between the ship's longitudinal axis, considered from bow to stern, and the resultant wind force on the ship (degrees)

F_{TV} = Transverse component of wind force on a ship (N)

F_{LV} = Longitudinal component of wind force on a ship (N)

M_{TV} = Resultant wind moment on a ship, relative to a vertical axis at the ship's center of gravity (N-m)

ρ_a = Specific weight of the air (1.225 kg/m³)

g = Acceleration of gravity (9.81 m/s²)

C_v = Shape factor (dimensionless), varies between 1.0 to 1.3, lacking a more precise determination through model studies, a value of 1.3 shall be adopted for any kind of ship and wind action direction

α_w = Angle between the longitudinal axis of the ship, considered from bow to stern, and the wind direction (degrees). Any wind direction can be considered

V_v = Design wind velocity at height 10 meters (m/s), considered constant all along the height the mean wind velocity determined in the shortest interval (gust) capable of overcoming the ship's inertia shall be adopted as the basic velocity. A mean velocity corresponding to the following gust values shall be adopted

- 1 minute for ship of length equal to or greater than 25 m

- 15 seconds for ships of length less than 25 m

For installations that consider that the ships remain moored at all times, the value corresponding to the extreme value associated with maximum admissible risk (V_{V15s} or V_{V1min} according to the type of ship) shall be adopted as the basic value (V_v)

For minimum light ships, the draught may be approximated by:

$$\text{Light draught} = \alpha \cdot (\text{maximum draught})^\beta \quad (6.40f)$$

For the following values of α and β , and draughts (m)

K_e = Eccentricity coefficient (non-dimensional)

L = Ship length (m)

When various ships are moored on both sides of a berth or range alongside one another, the resultant forces of the wind upon the protected ship shall be approximated as 50% of obtained for exposed ship.

Table 6.3 Coefficient for Approximate Light Draught of Ship (ROM 0.2-1990)

Type of Ship	α	β
Bulk Carrier up to 200,000 DWT	0.551	0.993
Oil Tanker up to 300,000 DWT	0.548	0.966
General Cargo up to 50,000 DWT	0.352	1.172

The values of eccentricity coefficient shall be approximated from the following Table 6.4, lacking other specific data.

Table 6.4 Eccentricity Coefficients for Ships with Superstructure Amidships (ROM 0.2-1990)

α_w (Deg.)	K_e : Light Ship	K_e : Fully Loaded Ship
0	0.00	0.00
30	0.15	0.10
60	0.05	0.03
90	-0.02	-0.02
120	-0.10	-0.10
150	-0.20	0.20
180	0.00	0.00

Table 6.5 Eccentricity Coefficients for Ships with Superstructure All Aft (ROM 0.2-1990)

α_w (Deg.)	K_e : Light Ship	K_e : Fully Loaded Ship
0	0.00	0.00
30	0.16	0.10
60	0.05	0.12
90	-0.04	-0.16
120	-0.18	-0.27
150	-0.33	-0.37
180	0.00	0.00

6.4.2 Static Current Force

Static current force represents the following equation as provided in Spanish Standard (ROM 0.2-1990)

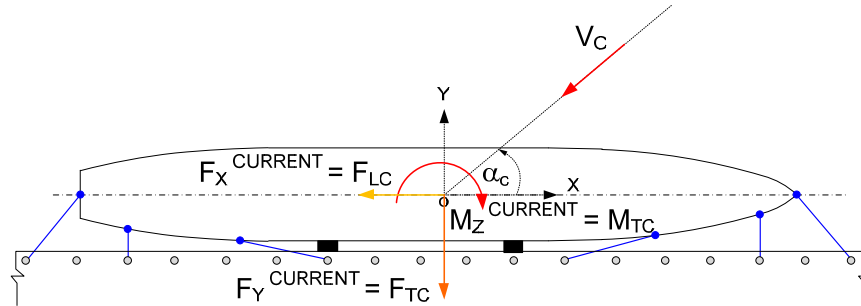


Fig. 6.11 Static Current Force on Moored Ship (ROM 0.2-1990)

$$F_{TC} = \frac{\gamma_w}{2g} \cdot C_{TC} \cdot V_C^2 \cdot A_{LC} \cdot \sin \alpha_c \quad (6.41a)$$

$$F_{LC} = \pm \frac{\gamma_w}{2g} \cdot C_{LC} \cdot V_C^2 \cdot A_{TC} \quad (6.41b)$$

$$M_{TC} = F_{TC} \cdot e = F_{TC} \cdot K_{ec} \cdot L \quad (6.41c)$$

Where:

F_{TC} = Transverse component of current force on ship (N)

F_{LC} = Longitudinal component of current force on a ship (N).

As a simplification, it is assumed that the magnitude of the longitudinal force is independent of the performance angle of the current, so a + or – sign can be applied indistinctly. The sign that causes the most unfavorable effects upon the structure shall be applied.

M_{TC} = Resultant current moment on a ship, relative to a vertical axis at the ship's center of gravity (N-m)

γ_w = Specific weight of the water (1,030 kg/m³ salt water, 1,000 kg/m³ fresh water)

g = Acceleration of gravity (9.81 m/s²)

α_c = Angle between the longitudinal axis of a ship, considered from bow to stern, and the direction of the current (degrees)

V_C = Design horizontal current velocity at depth of 50% of the ship's draught, considered constant all along the depth (m/s)

L = Ship length (m)

C_{TC} = Shape factor for the calculation of transverse current force on a ship (dimensionless). This factor depends on the ratio of Water depth/Design ship draught, increasing as the value of this ratio approaches 1.00. It can vary between 1.00 for deep waters and 6.00 for (Water depth/Draught) ratio ≈ 1.00 according to the following graph, for any kind of ship and current direction

C_{LC} = Shape factor for the calculation of longitudinal current force on a ship (dimensionless). This factor depends on the geometry of the ship's bow. It can vary between 0.2 to 0.6. Lacking a more precise determination, a value of 0.6 is adopted for conventional bows.

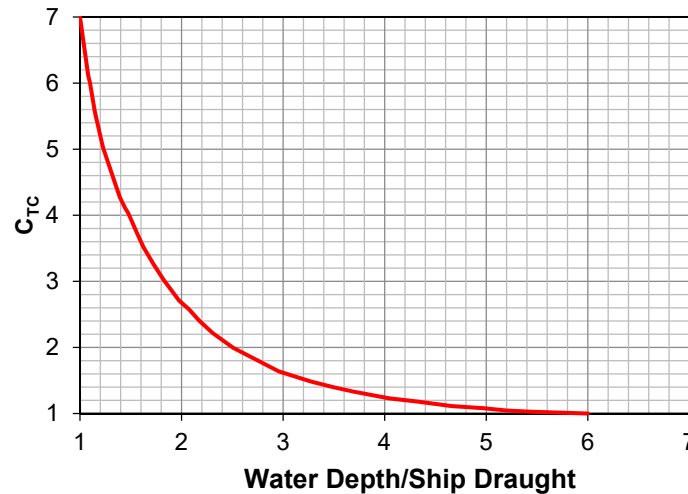


Fig. 6.12 Shape Factor for the Calculation of Transverse Current Force (ROM 0.2-1990)

A_{LC} = Submerged longitudinal projected area of a ship exposed to current (m^2)

A_{TC} = Submerged transverse projected area of a ship exposed to current (m^2). Lacking known values, these areas may be approximated by means of the following expressions:

$$A_{LC} = L_{pp} \cdot D \quad (6.41d)$$

$$A_{TC} = B \cdot D \quad (6.41e)$$

L_{pp} = Length between perpendiculars

D = Ship's draught (m)

B = Ship's beam (m)

K_{ec} = Eccentricity coefficient (dimensionless)

The values of eccentricity coefficient shall be approximated based on the following table lacking other specific data:

Table 6.6 Eccentricity Coefficients for Resultant Current Moment Calculation (ROM 0.2-1990)

α_c (Deg.)	K_{ec}
0	0.00
30	0.17
60	0.09
90	0.00
120	-0.09
150	-0.17
180	0.00

6.4.3 Current Drag Force

Current drag force represents the following equation as provided in Spanish Standard (ROM 0.2-1990)

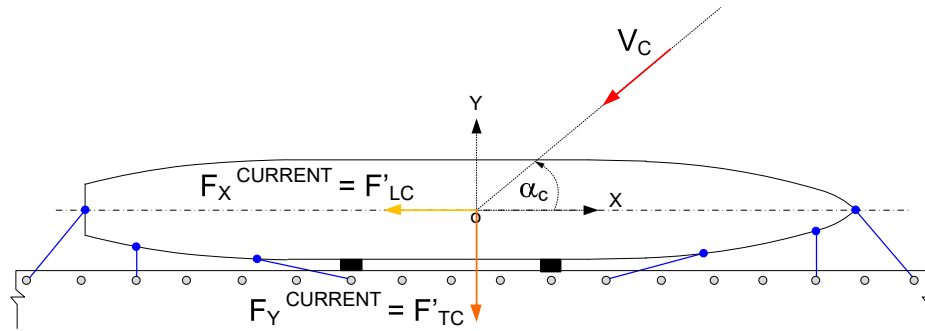


Fig. 6.13 Static Wave Force on Moored Ship (ROM 0.2-1990)

$$F'_{TC} = \frac{\gamma_w}{2g} \cdot C_r \cdot V_c^2 \cdot A'_{LC} \cdot \sin^2 \alpha_c \quad (6.42a)$$

$$F'_{LC} = \frac{\gamma_w}{2g} \cdot C_r \cdot V_c^2 \cdot A'_{TC} \cdot \cos^2 \alpha_c \quad (6.42b)$$

Where:

F'_{TC} = Transverse component of current drag force on ship (N)

F'_{LC} = Longitudinal component of current drag force on a ship (N)

C_r = Friction coefficient (dimensionless) 0.004 shall be adopted for ship in service and 0.001 for new ships (e.g. for projects in shipyards)

γ_w = Specific weight of the water (1,030 kg/m³ salt water, 1,000 kg/m³ fresh water)

g = Acceleration of gravity (9.81 m/s²)

α_c = Angle between the longitudinal axis of a ship, considered from bow to stern, and the direction of the current (degrees).

A'_{LC} = Longitudinal projected wetted surface of a ship (m^2)

A'_{TC} = Transverse projected wetted surface of a ship (m^2)

Lacking other known values of these areas, they can be approximated by the following expressions:

$$A'_{LC} = (B + 2D) \cdot L_{pp} \quad (6.42c)$$

$$A'_{TC} = (L_{pp} + 2D) \cdot B \quad (6.42d)$$

L_{pp} = Length between perpendiculars

D = Ship's draught (m)

B = Ship's beam (m)

6.4.4 Static Wave Force

Static wave force represents the following equation as provided in Spanish Standard (ROM 0.2-1990)

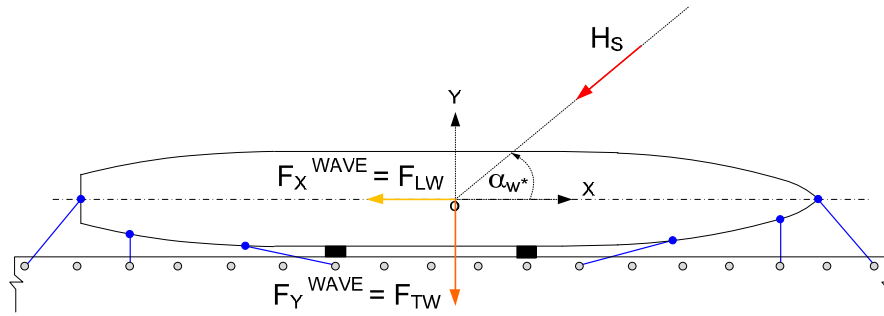


Fig. 6.14 Static Wave Force on Moored Ship (ROM 0.2-1990)

$$F_{TW} = C_{fW} \cdot C_{dw} \cdot \gamma_w \cdot H_S^2 \cdot D' \cdot \sin \alpha_w \quad (6.43a)$$

$$F_{LW} = C_{fW} \cdot C_{dw} \cdot \gamma_w \cdot H_S^2 \cdot D' \cdot \cos \alpha_w \quad (6.43b)$$

$$D' = L_{pp} \cdot \sin \alpha + B \cdot \cos \alpha_w \quad (6.43c)$$

Where:

F_{TW} = Transverse component of wave force on a ship (N)

F_{LW} = Longitudinal component of wave force on a ship (N)

γ_w = Specific weight of the water (1,030 kg/m³ salt water, 1,000 kg/m³ fresh water)

α_{w*} = Angle between the longitudinal axis of a ship, considered from bow to stern, and the direction of the waves (degrees). It shall be considered that the wave action can act in any direction, except in those cases where the physical or topographical condition exists, that restrict the possible performance direction.

H_s = Design significant wave height for the specified direction at the site's depth (h) in meters.

C_{fw} = Waterplane coefficient (dimensionless). Values assigned in the following table shall be adopted in terms of a wavelength at the location depth (L_w) and the ship draught (D).

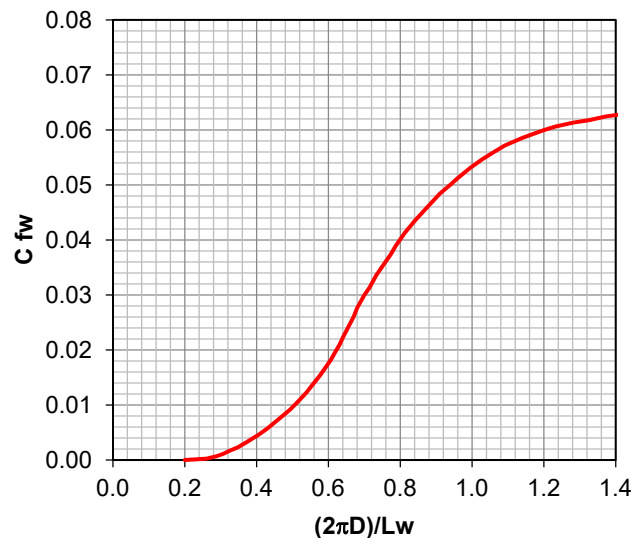


Fig. 6.15 Water Plane Coefficient (ROM 0.2-1990)

C_{dw} = Depth coefficient (dimensionless). The values of this coefficient shall be obtained from the following table, in terms of a wavelength at the location depth (L_w) and the depth of the water existing at this location (h).

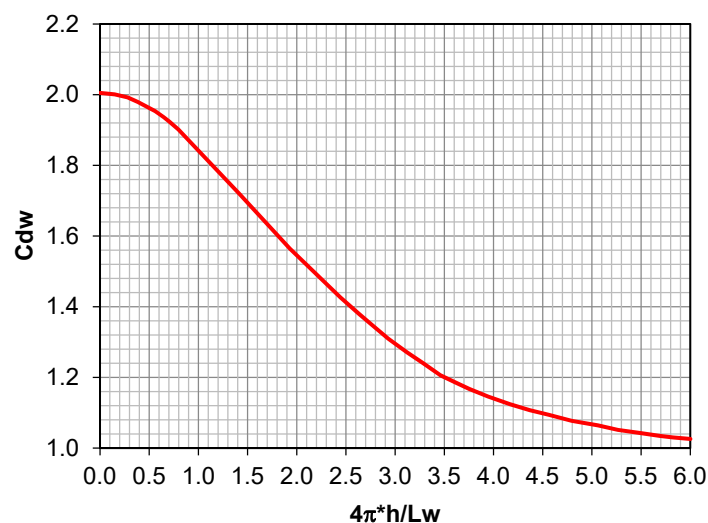


Fig. 6.16 Depth Coefficient (ROM 0.2-1990)

D' = Projection of the ship's length in the direction of incident waves (m). Lacking other known values, it shall be approximated by the following:

$$D' = L_{pp} \cdot \sin \alpha + B \cdot \cos \alpha_w \quad (6.43d)$$

L_{pp} = Length between perpendiculars (m)

B = Beam (m)

α_w = Angle of incident waves (degrees)

6.5 VALIDATION

The validation was performed based on the comparisons between of analysis results of a computer program with using MATLAB Computer Program and the analysis results of R. Natarajan and C. Ganapathy (1998), 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 SHIP MOOR. The experiment was set up the model in a wave-current flume which has over the length of 30 m and a cross-section of 2 m by 1.5 m. The complete mooring arrangement was set up the barge model as shown in Fig. 6.17 and the coordinate of mooring arrangement of the model as represented in Table 6.7.

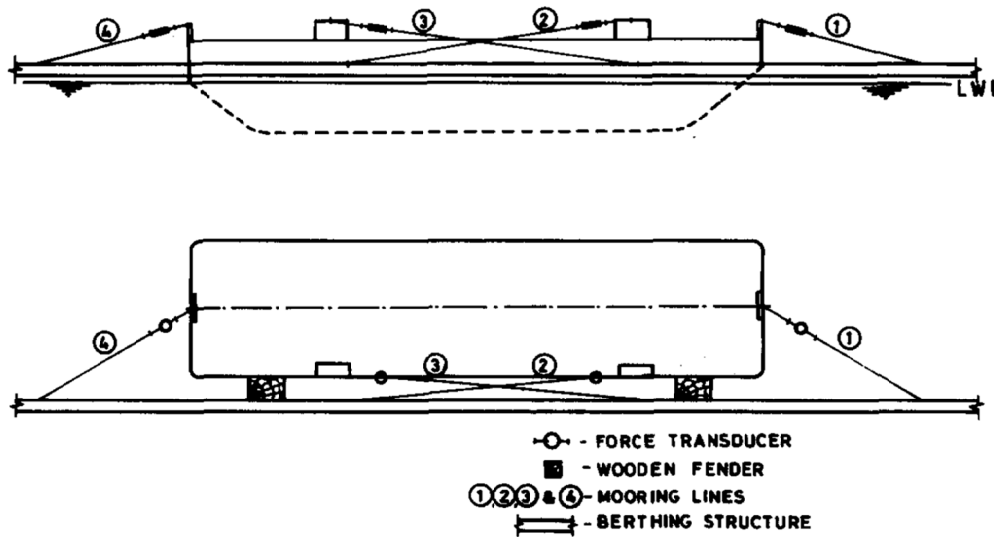


Fig. 6.17 Barge Model (R. Natarajan and C. Ganapathy 1998)

Table 6.7 Coordinate of Mooring Arrangement of the Model, R. Natarajan and C. Ganapathy (1998)

Line no.	Chock			Bollard		
	$C_{xi} (m)$	$C_{yi} (m)$	$C_{zi} (m)$	$x_i (m)$	$y_i (m)$	$z_i (m)$
1	2.40	0.00	0.12	3.15	0.42	0.02
2	1.00	0.38	0.18	-0.75	0.10	0.02
3	-1.00	0.38	0.12	1.05	0.10	0.02
4	-2.40	0.00	0.18	-3.45	0.42	0.02

Table 6.8 Experimental Results, R. Natarajan and C. Ganapathy (1998)

Mooring Particulars	Mooring Line Number ^a							
	1		2		3		4	
	I	II	I	II	I	II	I	II
<i>Condition (a) - Wave alone, Direction head sea, Wave height 7.5 cm, Period 2 s</i>								
Mooring line force (N)	10.62	11.89	14.25	13.68	9.66	10.59	10.47	11.52
Line tension (N)	12.26	12.91	14.75	14.16	10.00	11.21	14.80	15.10
Chock excursion in x-direction (m)	0.05	0.05	0.06	0.06	0.06	0.06	0.04	0.05
<i>Condition (b) - Water current alone, Velocity 0.2 m/s</i>								
Mooring line force (N)	1.81	1.75	3.04	3.16	2.54	2.41	1.66	1.16
Line tension (N)	2.10	2.02	3.16	3.28	2.63	2.49	2.32	2.66
Chock excursion in x-direction (m)	0.04	0.05	0.04	0.03	0.03	0.03	0.03	0.03
<i>Condition (c) - Combined wave and water current</i>								
Mooring line force (N)	8.89	10.67	11.50	12.08	9.47	10.03	7.07	6.79
Line tension (N)	10.26	11.85	11.91	13.45	9.80	11.27	10.20	12.01
Chock excursion in x-direction (m)	0.05	0.04	0.05	0.05	0.06	0.04	0.04	0.04

Note: a – I: Results of model experiments and II: Results of computer program (SHIP MOOR)

The results have a good agreement with the experimental model and analytical model as shown in Table 6.8. Also, R. Natarajan and C. Ganapathy (1998) were studied by varying the environmental load conditions using the computer program SHIP MOOR for investigating the characteristics of mooring lines and the behavior of a ship. The models were the following particular characteristics data of ship and the coordinate of mooring arrangement which given in Table 6.9.

Length of Ship	122.0 m
Displacement	13,416.0 tonnes
Longitudinal metacentric height	133.8 m
Transverse metacentric height	0.80 m

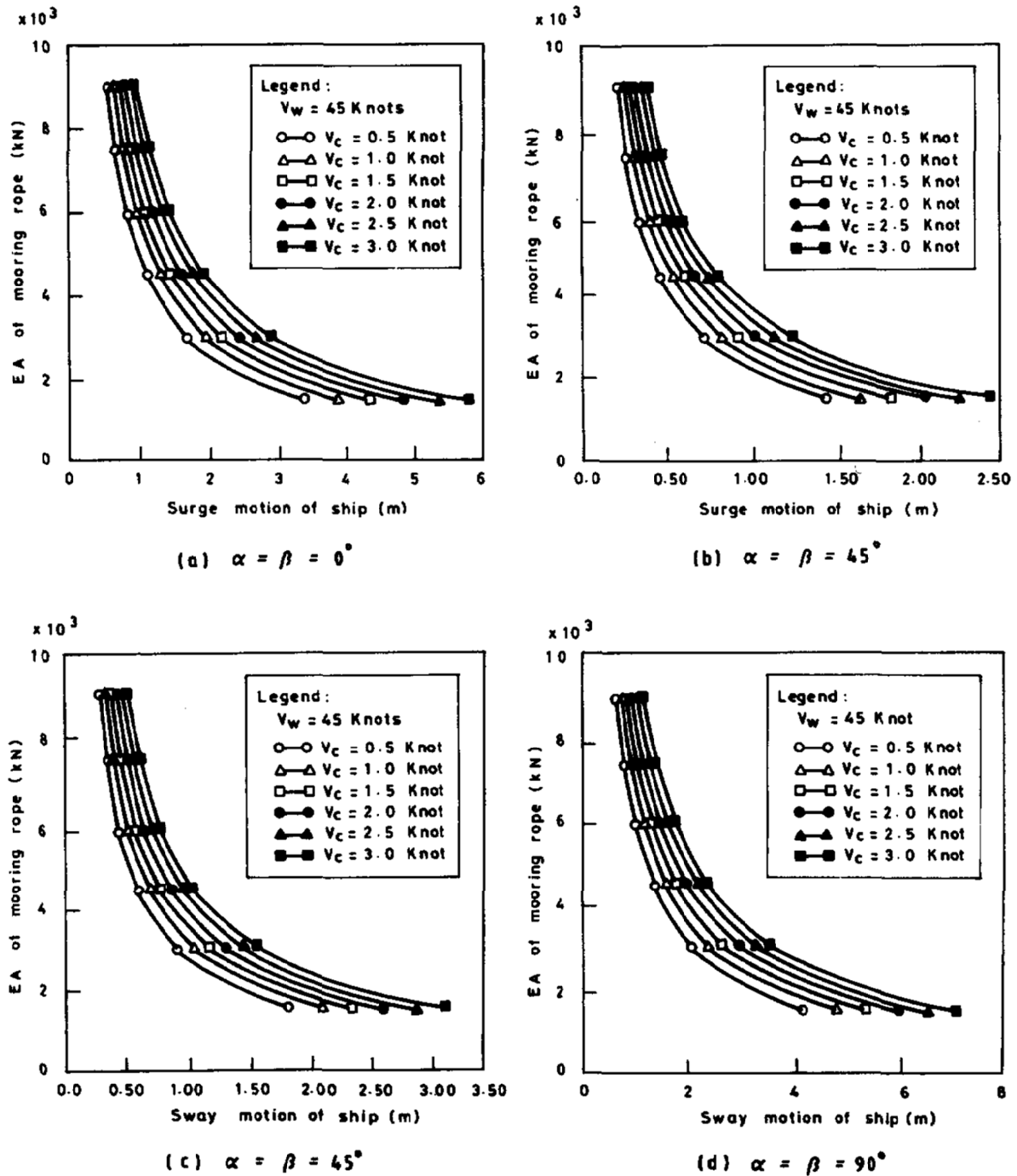


Fig. 6.18 Variation of ship motion with the stiffness of mooring rope under wind and current, (R. Natarajan and C. Ganapathy, 1998)

The validation is performed based on the comparisons between analytical results of MATLAB Computer Program and SHIP MOOR, which is the case of variation of mooring rope stiffness under wind and current. The analysis results of R. Natarajan and C. Ganapathy (1998) shown in Fig. 6.18, which represented the stiffness of mooring rope directly influences to the ship motions, when high mooring rope stiffness the ship are small motions, whereas low mooring rope stiffness becomes large motions. The environmental loads for validation are as following below and the validation also varied the stiffness of mooring rope.

- Wind speed 45 Knot (23.15 m/s)
- Wind direction: $\alpha = 45$ Deg.

- Current speed 3.0 Knot (1.54 m/s)
- Current direction: $\beta = 45$ Deg.

Table 6.9 Coordinate of Mooring Arrangement of the Ship, (R. Natarajan and C. Ganapathy, 1998)

(a) Mooring Lines

Line no.	Chock			Bollard		
	$C_{xi} (m)$	$C_{yi} (m)$	$C_{zi} (m)$	$B_{xi} (m)$	$B_{yi} (m)$	$B_{zi} (m)$
1	-65.1	0.0	3.1	-75.0	9.4	1.2
2	-54.9	5.3	3.1	-53.4	9.4	1.2
3	-36.6	8.4	3.1	38.4	9.4	1.2
4	36.6	8.4	3.4	-38.4	9.4	1.2
5	54.9	5.3	3.1	53.4	9.4	1.2
6	62.0	0.0	5.6	72.0	9.4	1.2

(b) Fenders

Fender	$r_{xj} (m)$	$r_{yj} (m)$	$r_{zj} (m)$
A	-30.0	9.0	0.5
B	30.0	9.0	0.5

The environments direction are respected to the ship axis as shown in Fig. 6.1 and Fig. 6.2. The characteristic of ship data represents by R. Natarajan and C. Ganapathy (1998) are not enough the information for static forces calculation and moored ship analysis, then the comparison is assumed the ship characteristics of the length of ship 122 m, equivalent to 10,000 DWT bulk carrier ship that provided in PIANC (2002). The ship is the confidential limit of 75% as shown in Table 6.10.

Table 6.10 Ship Tables, PIANC (2002)

(a) Ship Dimension

Ship Type	DWT/GRT (Tonnage)	Displacement M_{75} (Tonnage)	LOA (m)	LBP (m)	B (m)	F_L (m)	D_L (m)
Bulk Carrier	10,000	13,300	132	124	19.2	2.9	7.7

(b) Wind Area

Lateral Wind Area (m^2)		Front Wind Area (m^2)	
Full Load	Ballast	Full Load	Ballast
930	1,320	286	340

R. Natarajan and C. Ganapathy (1998) proposed the static wind force and current force on the moored ship could be calculated from the Equation (6.44) and Equation (6.45).

The wind force acting on moored ship expressed below

$$F_{wind}(\alpha) = \frac{\rho_a}{2} \cdot C_w(\alpha) \cdot V_w^2 \cdot (A_{wx} \cdot \cos^2 \alpha + A_{wy} \cdot \sin^2 \alpha) \quad (6.44)$$

Where:

F_{wind} = Resultants wind force (N)

A_{wx} = Projected area of the ship in the yz-plane above the waterline

A_{wy} = Projected area of the ship in the xz-plane above the waterline

C_w = Drag coefficient for wind force, longitudinal direction vary from 0.4 to 1.2 and lateral direction, vary from 0.6 to 1.4

ρ_a = Mass density of air (1.25 kg/m³)

V_w = Wind velocity (m/s)

α = Direction of wind (Deg.)

The steady current force may be evaluated from the following equation below

$$F_{current}(\beta) = \frac{\rho_w}{2} \cdot C_c(\beta) \cdot V_c^2 \cdot (A_{cx} \cdot \cos^2 \beta + A_{cy} \cdot \sin^2 \beta) \quad (6.45)$$

Where:

$F_{current}$ = Resultants current force (N)

A_{cx} = Projected area of the ship in the yz-plane below the waterline

A_{cy} = Projected area of the ship in the xz-plane below the waterline

C_c = Drag coefficient for current force, longitudinal direction, vary from 0.1 to 1.0 and lateral direction, vary from 0.5 to 1.5

ρ_w = Mass density of seawater (1,025 kg/m³)

V_c = Current velocity (m/s)

β = Direction of current (Deg.)

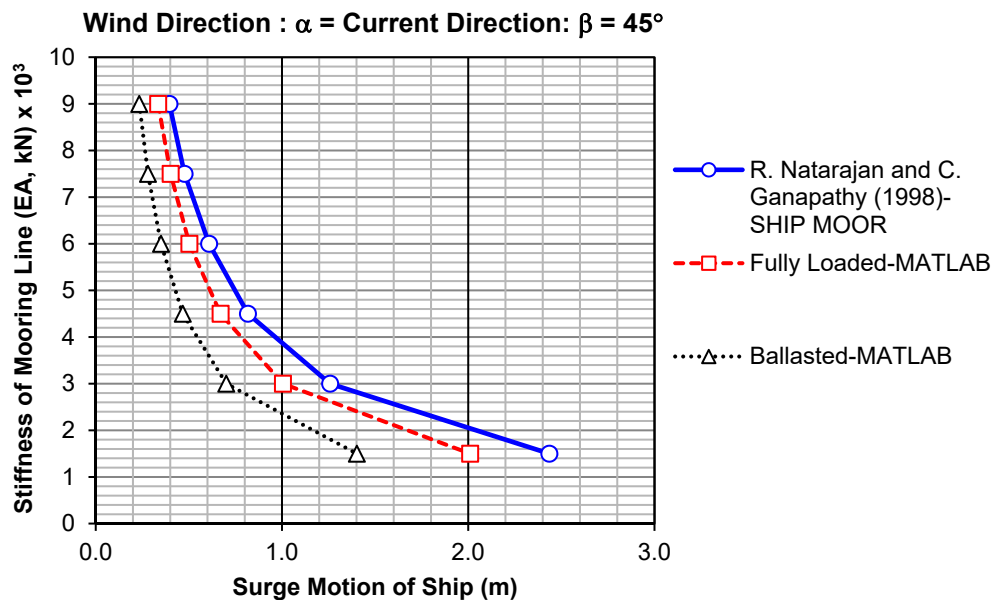
The study of R. Natarajan and C. Ganapathy (1998) did not show the drag coefficients in exact value, and then the validation is assumed the drag coefficients is equal to 1.0. The static forces on moored ship are tableted in Table 6.11, and the operation condition is assumed to the fully loaded condition if compared the freeboard of ship dimension (PIANC, 2002) and the coordinate of mooring arrangement of the Ship as tabulated in Table 6.9.

Table 6.11 Static Force on Moored Ship, Proposed by R. Natarajan and C. Ganapathy (1998)

Static Force	Wind Force		Current Force	
	Fully Loaded	Ballasted	Fully Loaded	Ballasted
F _x (kN)	77.80	89.84	153.80	83.54
F _y (kN)	253.06	357.65	993.31	539.55
M _z (kN-m)	-	-	-	-

Table 6.12 Static Force on Moored Ship - Spanish Standard (ROM 0.2-1990)

Static Force	Wind Force		Current Force	
	Fully Loaded	Ballasted	Fully Loaded	Ballasted
F _x (kN)	130.88	151.07	108.70	59.05
F _y (kN)	425.57	601.50	2,268.18	614.06
M _z (kN-m)	5,804.83	7,831.53	36,525.50	9,878.23

**Fig. 6.19** Comparison of Surge Motion of Ship

The static force calculated by following the Spanish Standard (ROM 0.2-1990) of fully loaded and ballasted condition. This method has more detailed better than the equations as represented in the papers of R. Natarajan and C. Ganapathy (1998). The papers were not expanded the influences of water depth and draft of the ship to the current force. In addition, the drag coefficient represents in varies of the direction of wind and current. Then, this comparison will be applied the static force on moored ship for calculation the ship motions that calculated by following the Spanish Standard (ROM 0.2-1990). The results in Fig. 6.19 and Fig. 6.20 presents the surge motion and sway motion of ship of fully loaded and ballasted condition by using MATLAB Computer Program and the analysis results of SHIP MOOR represented by R. Natarajan and C. Ganapathy (1998). The results are shown by variation of the stiffness of mooring line from strong stiffness to weak stiffness, and the ship motions vary from small motion to large motion. The comparison is satisfactory agreement when compared the results between SHIP MOOR program and MATLAB Computer Program of the fully loaded condition, the error is influences from the ship size data and the information of the water level because two this parameter assumed for static forces calculation.

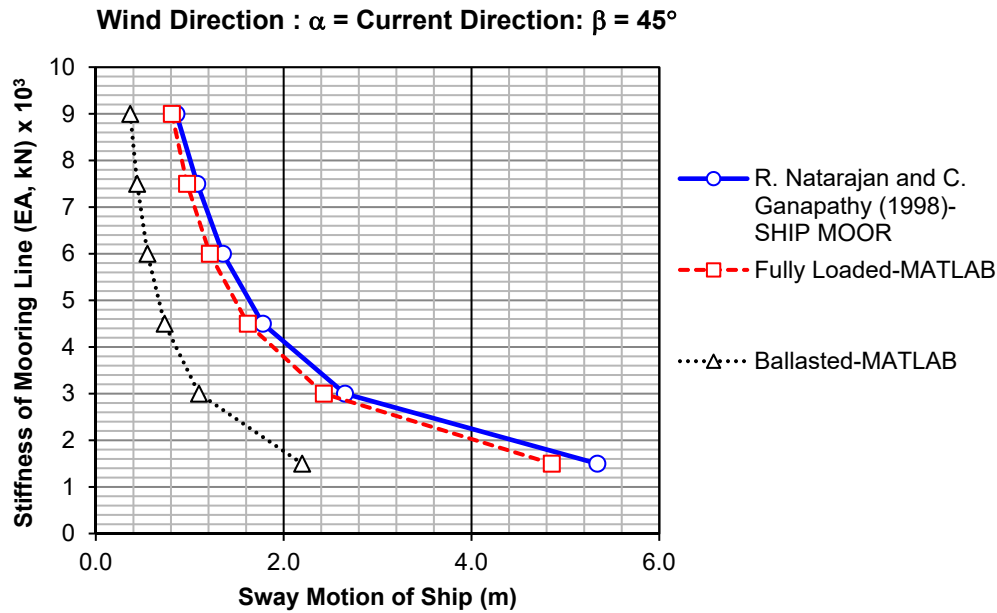


Fig. 6.20 Comparison of Sway Motion of Ship

6.6 MOORED SHIP MOTIONS

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 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 port and wharf, by comparison 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. PIANC 1995 are provided the limitation of ship motions at the port, and then this study will be used. The MATLAB computer program was employed to conduct the moored ship analysis, which is solved the mooring equations in a matrix system as discussion and explanation in section 6.2 and 6.3. The static environmental loads on the moored ships are calculated by following the Spanish Standard (ROM 0.2-1990), the analysis results are obtained the mooring forces and vessel movements in two-dimensional motions such as surge, sway and yaw as shown in Fig. 6.21. In this study, the mooring analysis are evaluated in two-dimensional motions subjected to the severe wind, wave and current during the Tropical Cyclone Linda enters the Gulf of Thailand at Sriracha Harbour Port (SRH) and BLCP Coal-Fired Power Plant Port (BLCP), the analysis is ignored the impact of passing ship on the moored ship at port.

6.6.1 Ship Movement

The ship movement can be used to specify the limitation of port safety and operation, the safety limit means the ship move exceeds a certain value. It is can results in the damage of ship and the mooring system. The degree of ship movement is a function of the mooring rope stiffness systems, that low stiffness system allows more movement than high stiffness system before mooring load exceeds their safety limit. The operational limit is a limitation of loading and unloading of the cargoes can no longer be efficiently and safely performed. The level of ship movement are allowed depends on the type of ship and cargoes handling equipment such as loading arm and gantry crane. The larger ship will be less respond to the primary wave and short wave period, while the small ship will be more respond to the primary wave and long period wave when the wavelength more than the ship length. Carl A Thoresen (2003)

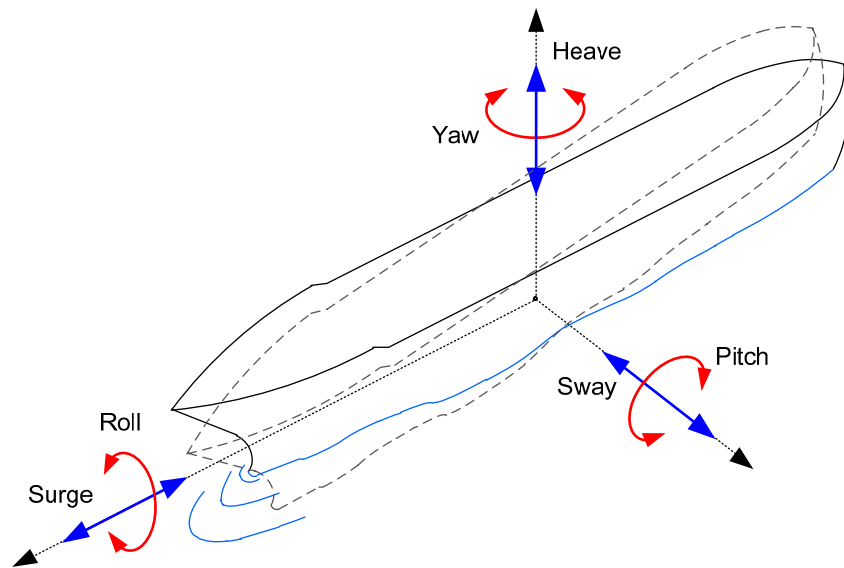


Fig. 6.21 Ship Motions (PIANC, 1995)

6.6.2 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 the port. The list of ship data shown in Table 6.13 is referred to Ship Tables in PIANC 2002 at 75% confidence limits.

Table 6.13 Ship Parameters

Parameters	Maximum Ship	Minimum Ship
Ship Type	Bulk Carrier	Bulk Carrier
Deadweight Tonnage, DWT (Tonnage)	50,000	5,000
Displacement, M_{75} (Tonnage)	59,600	6,920
Length Overall, LOA (m)	204.0	109.0
Length Between Perpendiculars, LBP (m)	194.0	101.0
Beam (m)	32.3	15.5
Freeboard (m)	4.8	2.4
Draft (m)	12.0	6.2
Lateral Wind Area (m^2) : Full Load	1,640	689
Lateral Wind Area (m^2) : Ballast	2,870	910
Front Lateral Wind Area (m^2) : Full Load	479	221
Front Lateral Wind Area (m^2) : Ballast	682	245

6.6.3 Mooring Lines Properties

The mooring ropes type is generally used for the various type of the ship, it is no specific standard for classification the rope diameter or the stiffness suitable for the type of ship and ship size. The stiffness of mooring lines depends on the diameter, the length of the line from mooring chock to the mooring point (bollards and hooks), and the material and construction of the line, and the materials used in the mooring lines includes natural-fiber lines, synthetic fiber lines, steel wires and combi-lines. High

elasticity of mooring line is desirable for reduced the moored ship movement subjected to severe environmental conditions and swell but it can cause the problem with cargoes handling equipment such kind of loading arm gantry crane. OCIMF recommends that the safety factor for steel lines should be 1.82 and 2.5 for nylon. For safety reason, the high elasticity of mooring line can be used for reduced the ship movement but the mooring forces may be overload, for prevent them from being overloaded, the terminal supervisor should monitor the mooring forces should not exceed 55% (SF = 1.82) of breaking strength for steel lines and 40% (SF = 2.5) for nylon lines. In this study, mooring line characteristics are assumed to be constant and the elastic modulus of mooring rope varies from 1,527,887.45 kN/m² to 4,583,662.36 kN/m² for a 50 mm rope diameter as tabulated in Table 6.14.

Table 6.14 Mooring Rope Properties

Rope Diameter, DIA (mm)	Rope Area, A (m ²)	Elastic Modulus (kN/m ²)	EA (kN)
50	6.25×10^{-4}	1,527,887.45	3,000
50	6.25×10^{-4}	3,055,774.91	6,000
50	6.25×10^{-4}	4,583,662.36	9,000

6.6.4 Mooring Arrangement

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, shown in Fig. 6.22 to Fig. 6.25 at Siriracha Harbour Port (SRH) and BLCP Coal-Fired Power Plant Port (BLCP) respectively.

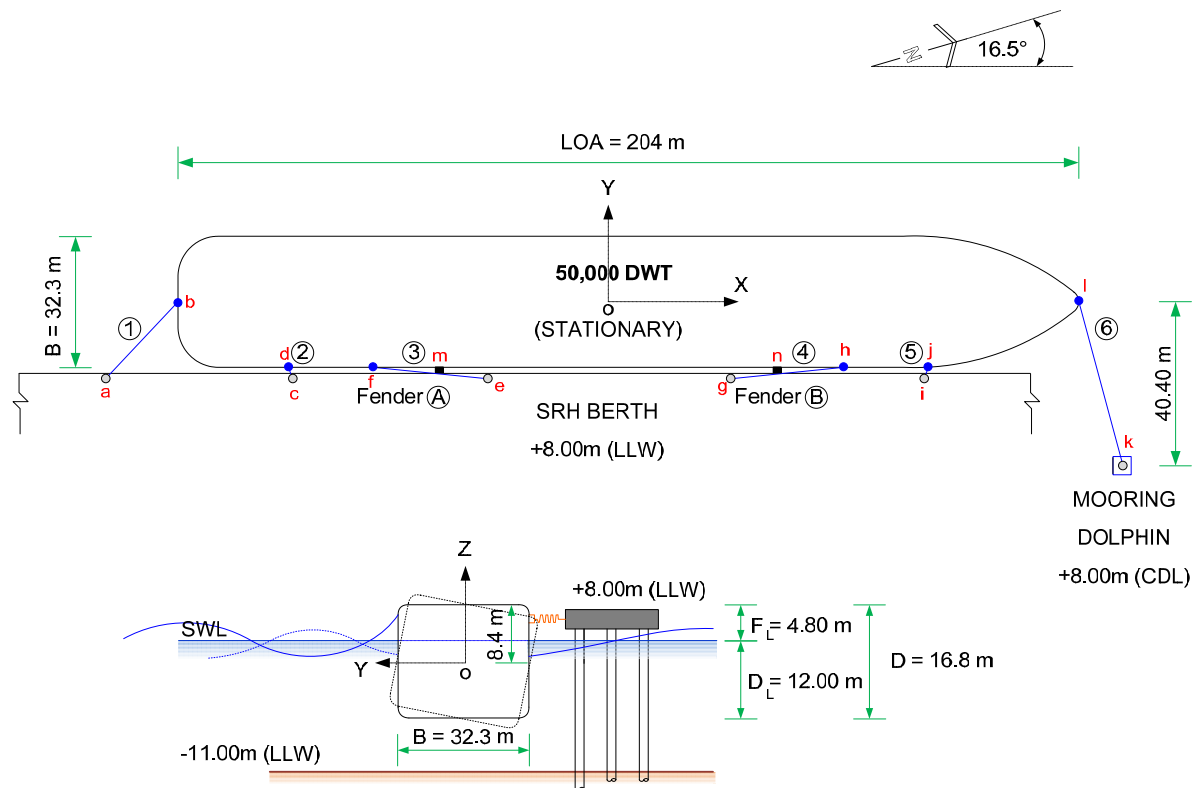


Fig. 6.22 Mooring Arrangement at Siriracha Harbour Port (SRH) of 50,000 DWT Ship

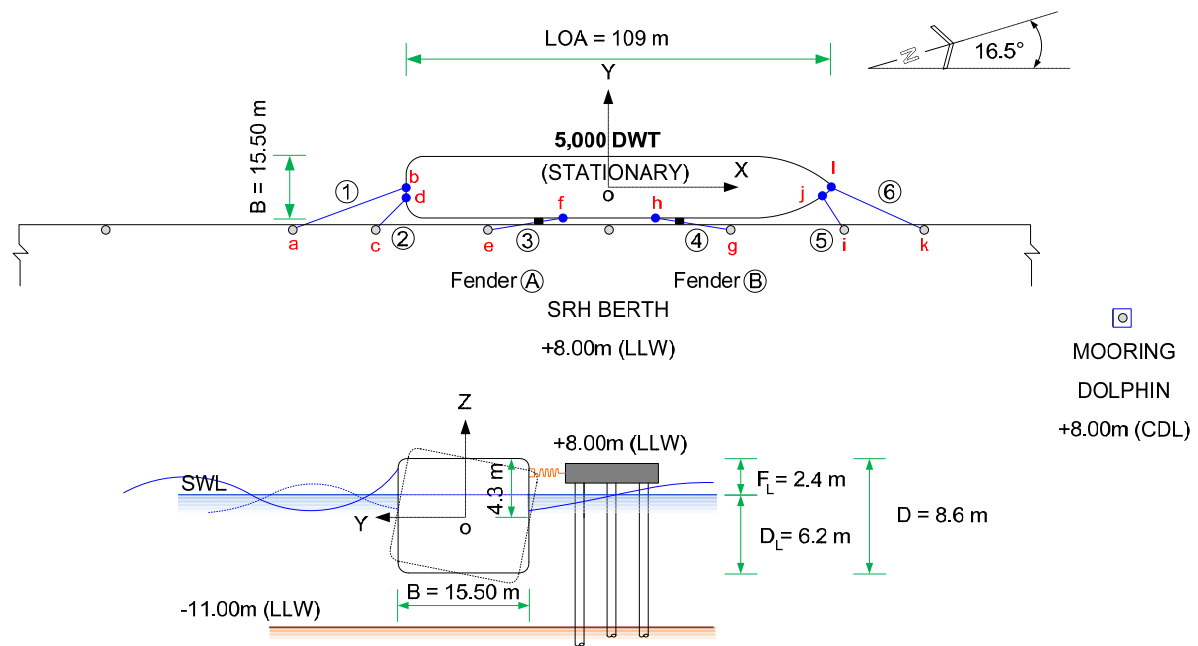


Fig. 6.23 Mooring Arrangement at Sriracha Harbour Port (SRH) of 5,000 DWT Ship

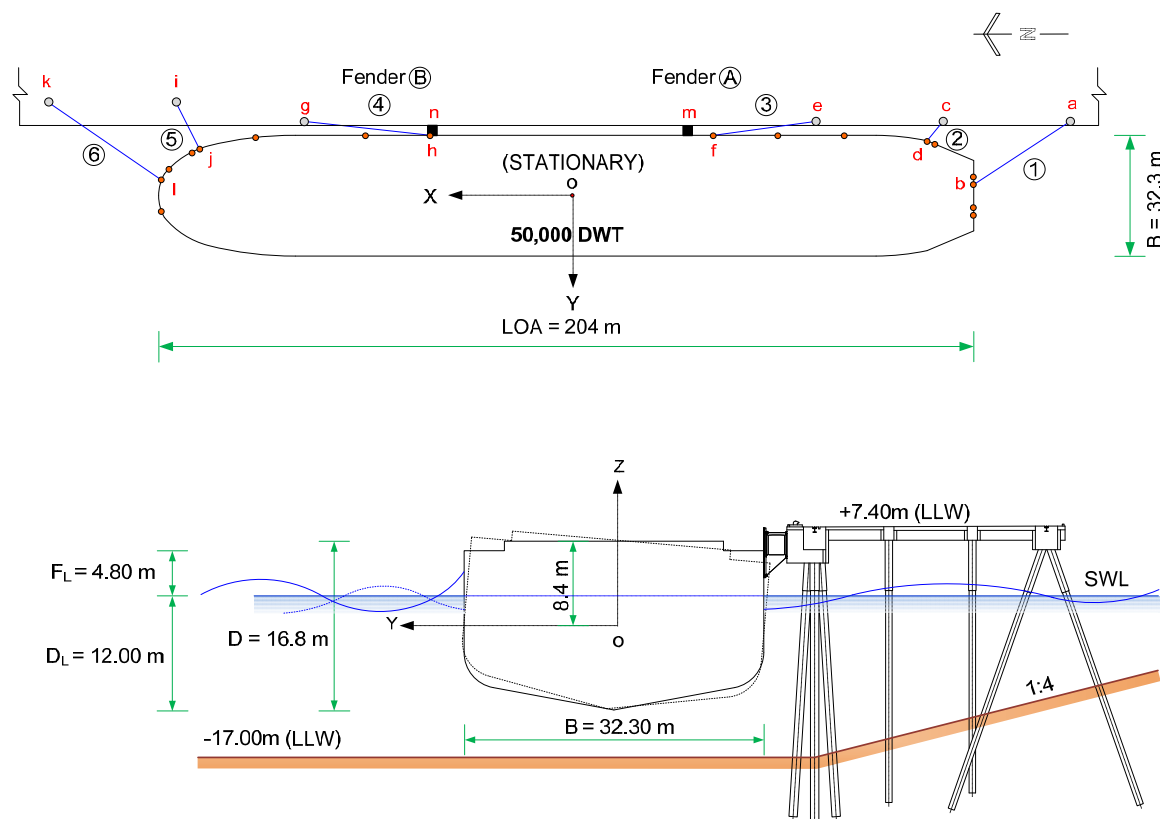


Fig. 6.24 Mooring Arrangement at BLCP Coal-Fired Power Plant Port (BLCP) of 50,000 DWT Ship

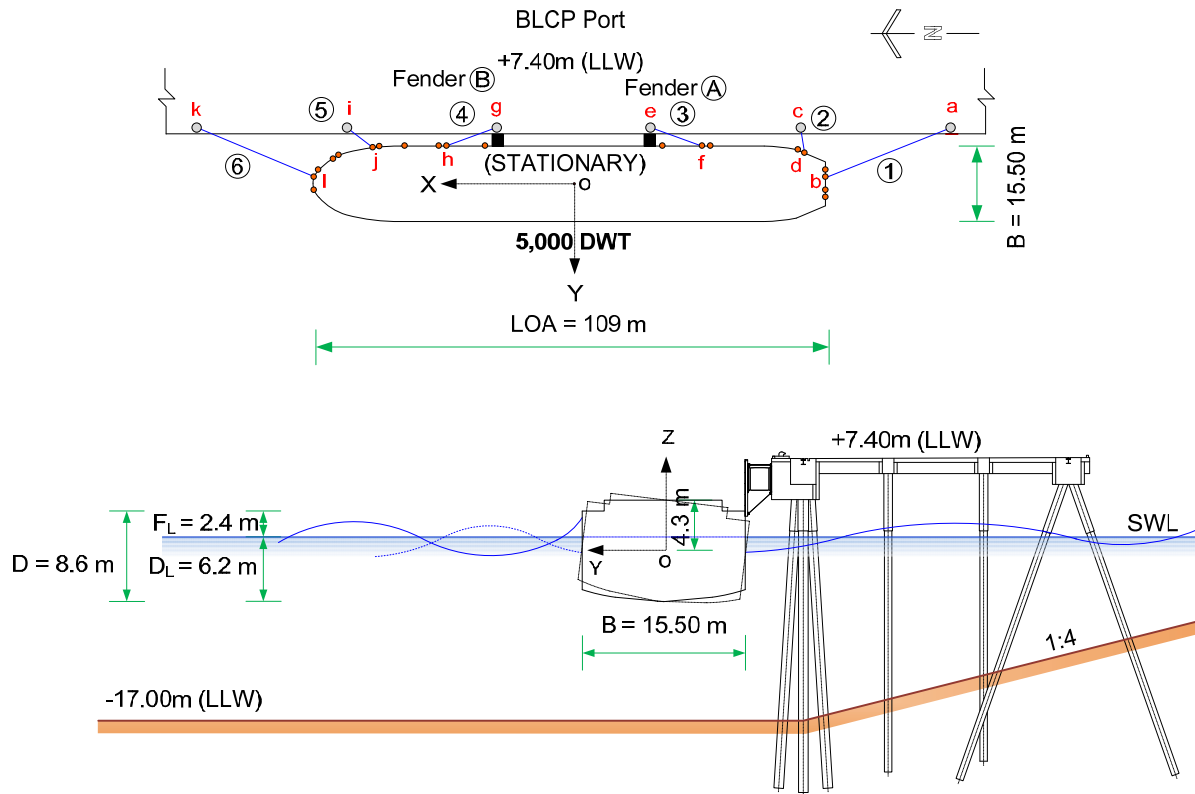


Fig. 6.25 Mooring Arrangement at BLCP Coal-Fired Power Plant Port (BLCP) of 5,000 DWT Ship

6.6.5 Environmental Conditions

The environmental conditions are the results of extreme wave model and hydrodynamics model as represented in Chapter 5. The mooring analysis starts from 3rd November 1997, 16:00 (+7UTC) to 4th November 1997, 07:00 (+7UTC) in every hour as tabulated in Table 6.15 and Table 6.16 and shown by the white mark circle in Fig. 6.26 and Fig. 6.27. In this duration, the Tropical Cyclone Linda are moved to the Upper Gulf of Thailand, therefore the port downtime is caused by the severe environmental condition and also the observed data at oceanographic buoys shown the maximum significant wave height, maximum wind speed and maximum current speed. The significant wave height is obtained from the results of wave model, the water level and current speed are the results of hydrodynamics model in extreme conditions at the port. However, the wind speed is the observed data at Ko Si Chang (KS) and Rayong (RY) Buoy. The tide level for the mooring analysis is a reference to the center of the ship at Lowest Low Water (LLW) level of the top of the platform as shown in Fig. 6.22 to Fig. 6.25. The tidal information sourced from the Thailand's Marine Department for adjusted the storm water level (MSL) to Lowest Low Water (LLW) level, at Ao Udom Tide Station for SRH and Rayong Tide Station for BLCP. The adjustment is reduced the Mean Sea Level (MSL) to Lowest Low Water (LLW) level by using the differential water level, the Lowest Low Water (LLW) level is equal to -2.47 m (MSL) at SRH Port and BLCP Port of -1.58 m (MSL). Then, the storm water level is a reference to Lowest Low Water (LLW) as shown in Fig. 6.26 and Fig. 6.27, and tabulated in Table 6.15 and Table 6.16.

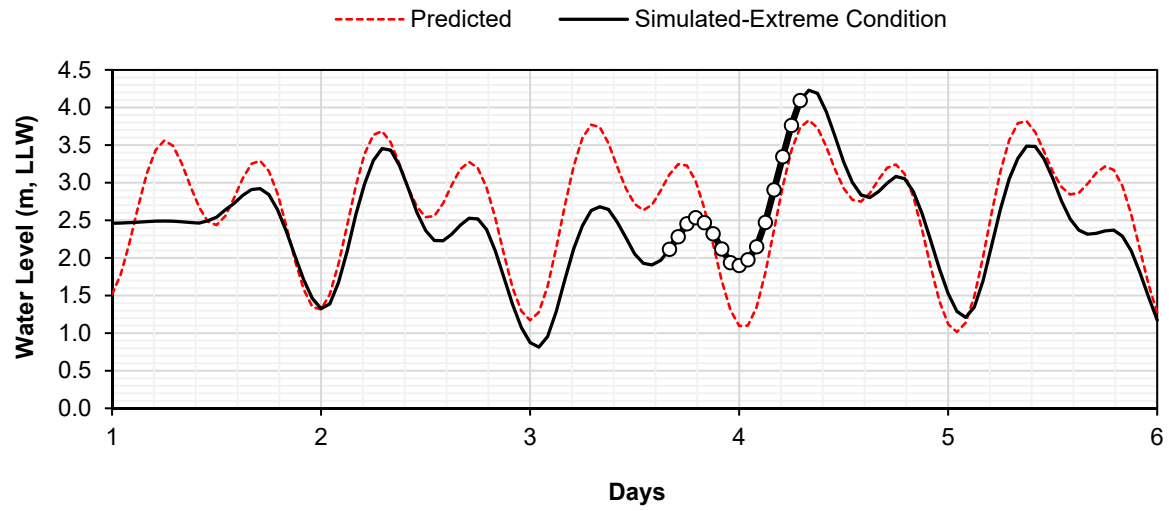


Fig. 6.26 Storm Tide at SRH Port

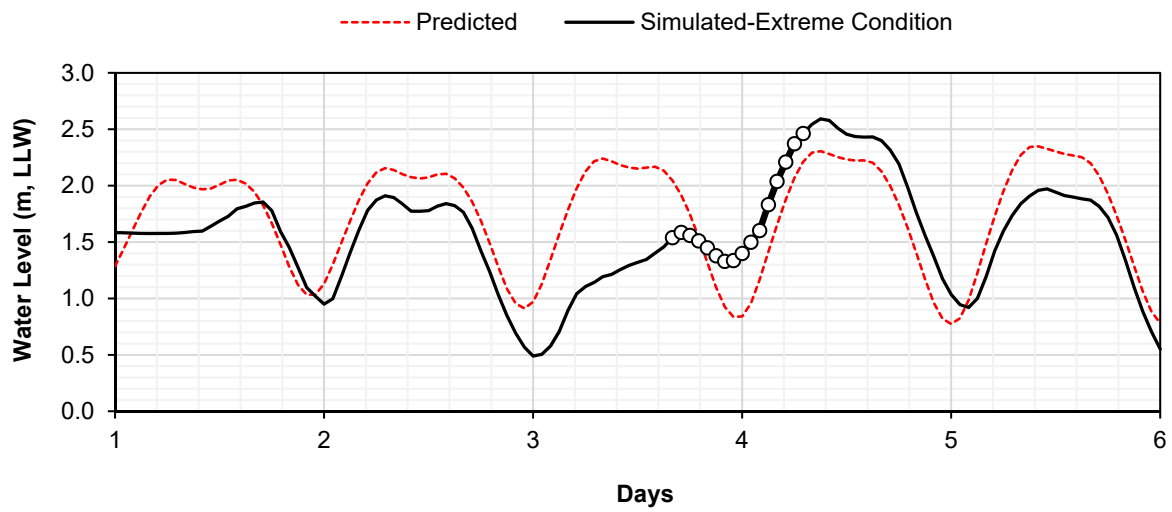


Fig. 6.27 Storm Tide at BLCP Port

Table 6.15 Environmental Conditions for Static Moored Ship Motions Analysis at SRH Port

No.	Time	Water Level (m, MSL)	Water Level (m, LLW)	Wind (600s Gust Duration)		Wave			Current	
				Speed (m/s)	Dir (Deg.)	Hs (m)	Tp (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 6.16 Environmental Conditions for Static Moored Ship Motions Analysis at BLCP Port

No.	Time	Water Level (m, MSL)	Water Level (m, LLW)	Wind (600s Gust Duration)		Wave			Current	
				Speed (m/s)	Dir (Deg.)	Hs (m)	Tp (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

6.6.6 Results

The ship motions are analyzed in terms of variation mooring rope stiffness, 50,000 DWT and 5,000 DWT ship and operation conditions include fully loaded and ballasted condition as shown in Fig. 6.28 to Fig. 6.39. The result represents the ship motions in time series from 3rd November 1997, 16:00 (+7UTC) to 4th November 1997, 07:00 (+7UTC) in every hour. The static forces are the combination of wind force, current force and wave force due to Tropical Cyclone Linda, they exert both longitudinal and transverse with respect to the ship direction. The wind force and current force are the significant issues to the moored ship motions, while the wave force to be less effect because the wavelength is less than the ship length in this situations. The ship showed large movement on 4th November 1997, this duration was severe environmental conditions and the resultant of wind and wave forces hit a ship in South-East direction, which event the ship moves off the fender, and high mooring forces.

Sriracha Harbour Port (SRH) and BLCP Coal-Fired Power Plant Port (BLCP) are using the gantry crane for cargo handling. Therefore, PIANC 1995 provided the limitation of ship motions for bulk carrier would be about 2 m of surge, 1 m of sway and 2 degrees of yaw, these limitations are used to compare the mooring analysis results of the ship motions. The ship motions at SRH Port are large in the ballasted condition, while the ship motions at BLCP Port are large in the fully loaded condition during the Tropical Cyclone Linda enters to the Gulf of Thailand. This is because of the low current speed at SRH Port would not be critical effects to the moored ship motions by current force in fully loaded condition, while the wind force becoming the critical effect in ballasted condition. In the case of EA = 3,000kN, the ship motions are exceeded the limitations of the operational limit, which is the maximum of 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 of 50,000 DWT ship. The ship motion at SRH is the maximum of surge of 0.74 m, sway of 2.50 m and yaw motion of 1.24 degrees that sway motion exceeded the limitations. The

sway motions are equal to 1.02 m of 50,000 DWT ship in fully loaded condition at BLCP Port which it exceeded the operational limit of EA = 9,000kN.

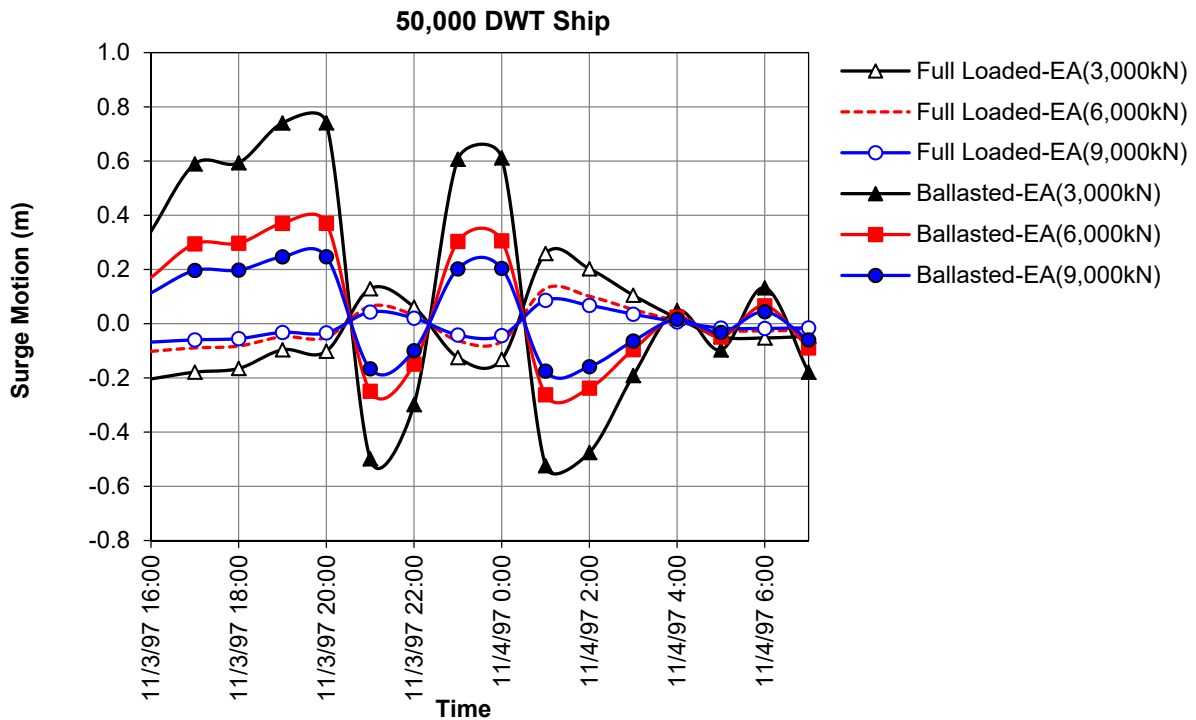


Fig. 6.28 Surge Motion of 50,000 DWT at SRH Port

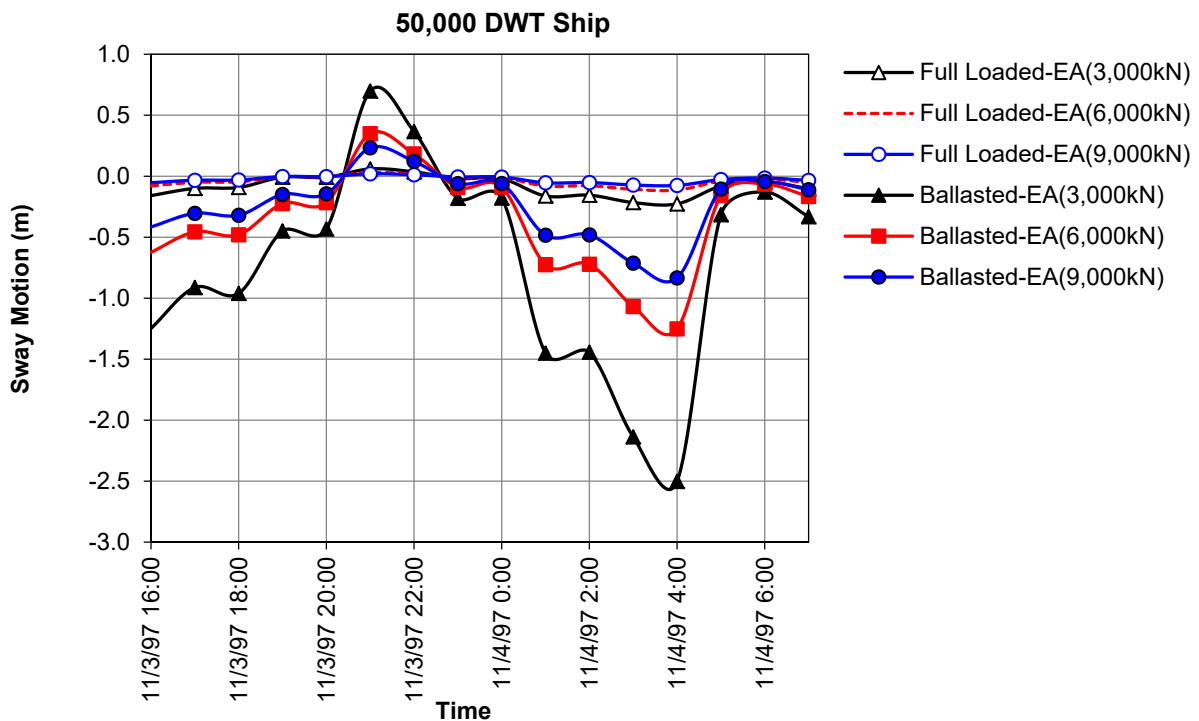


Fig. 6.29 Sway Motion of 50,000 DWT at SRH Port

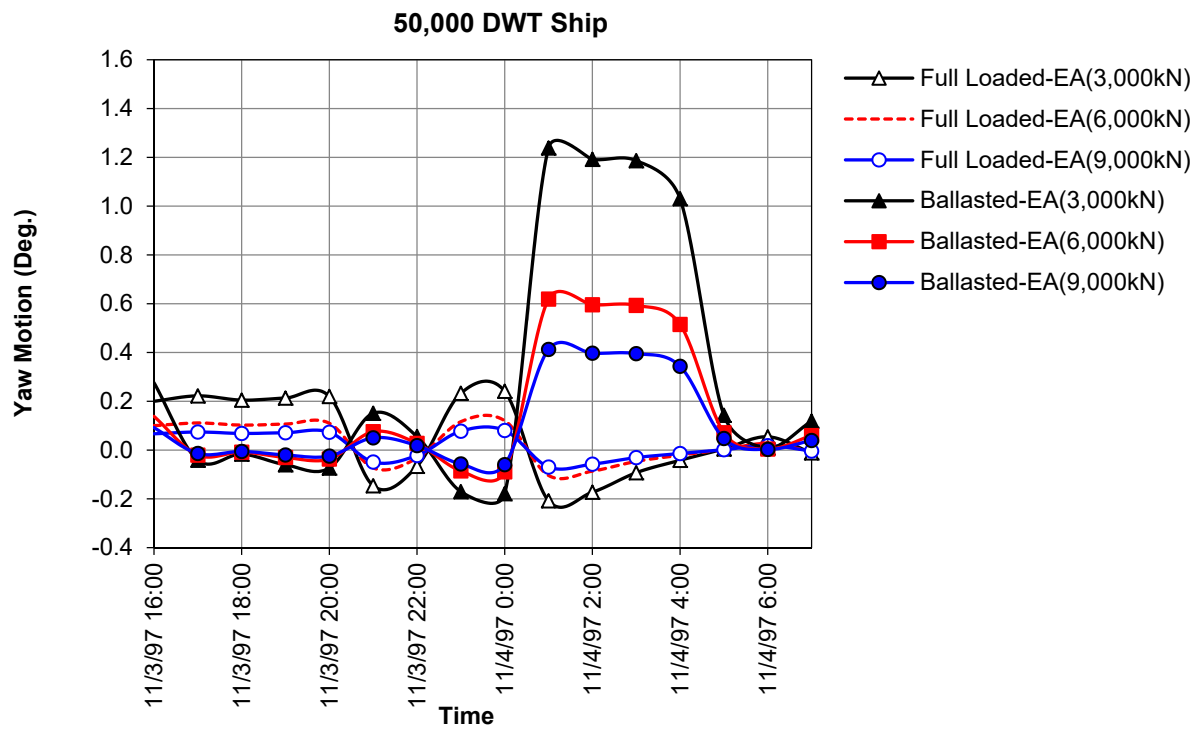


Fig. 6.30 Yaw Motion of 50,000 DWT at SRH Port

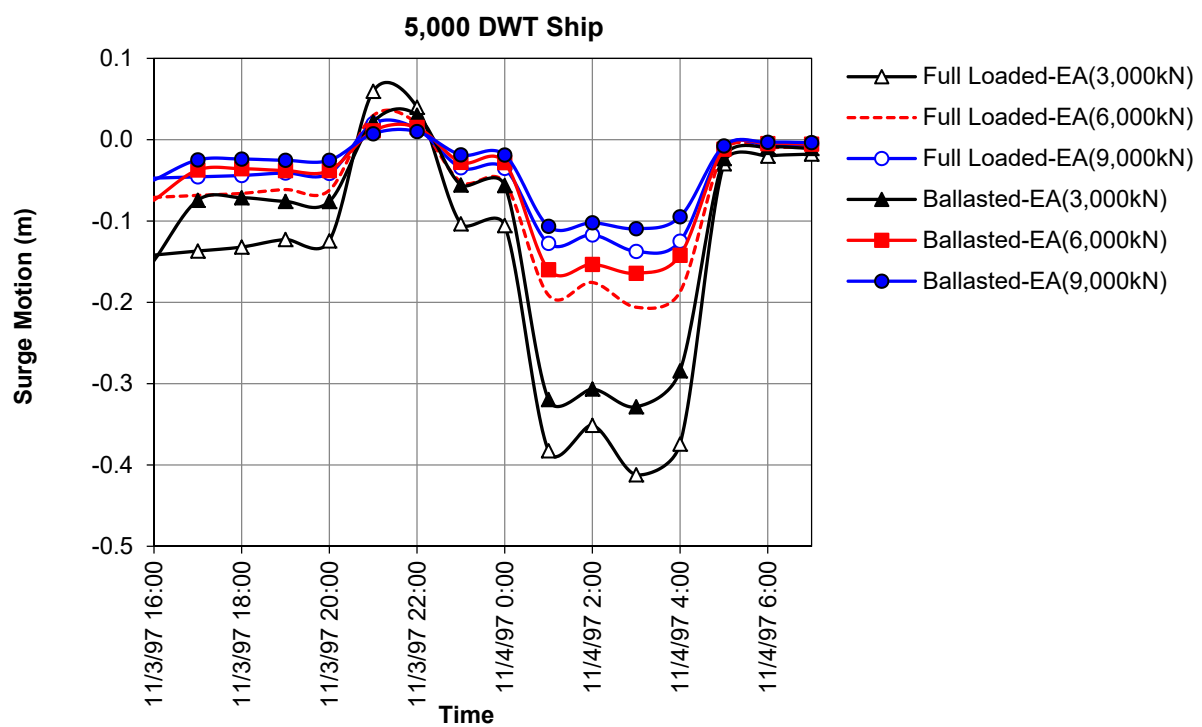


Fig. 6.31 Surge Motion of 5,000 DWT at SRH Port

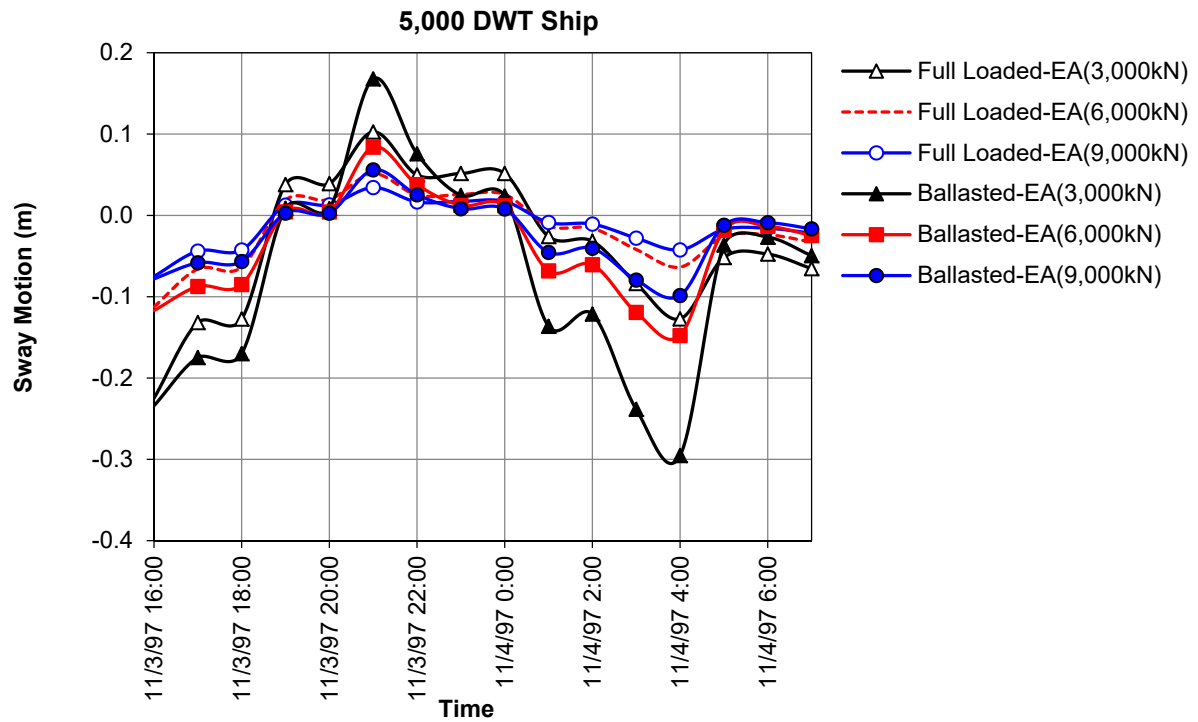


Fig. 6.32 Sway Motion of 5,000 DWT at SRH Port

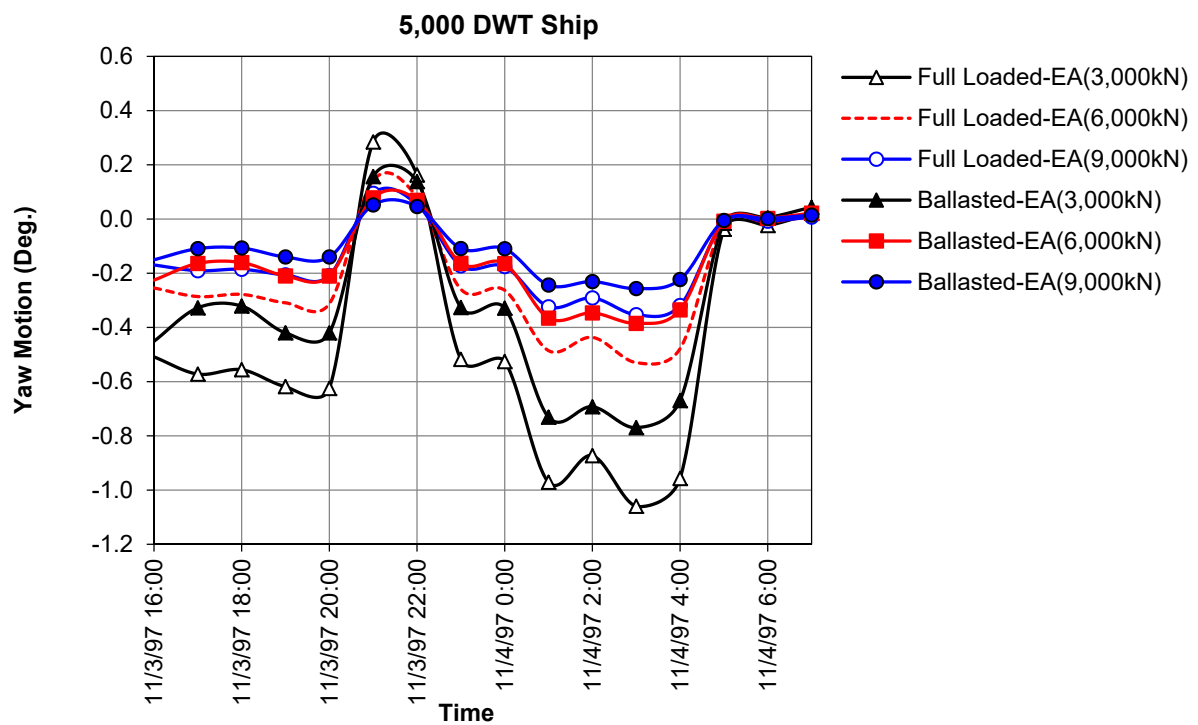


Fig. 6.33 Yaw Motion of 5,000 DWT at SRH Port

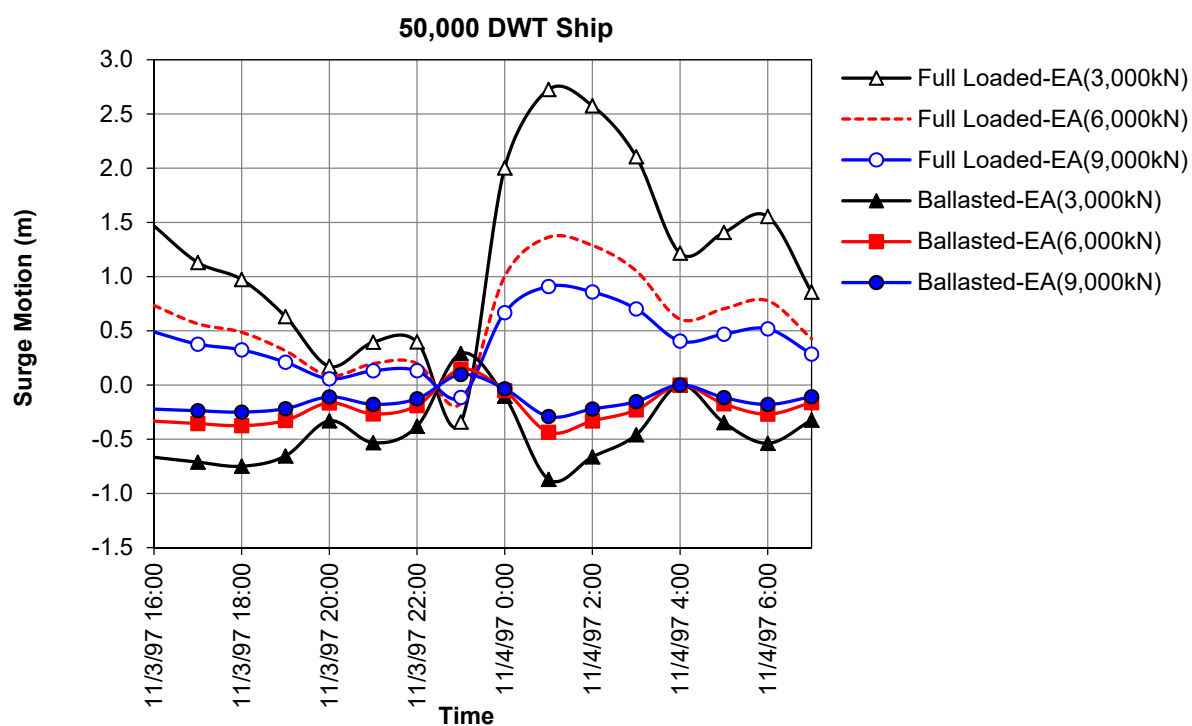


Fig. 6.34 Surge Motion of 50,000 DWT at BLCP Port

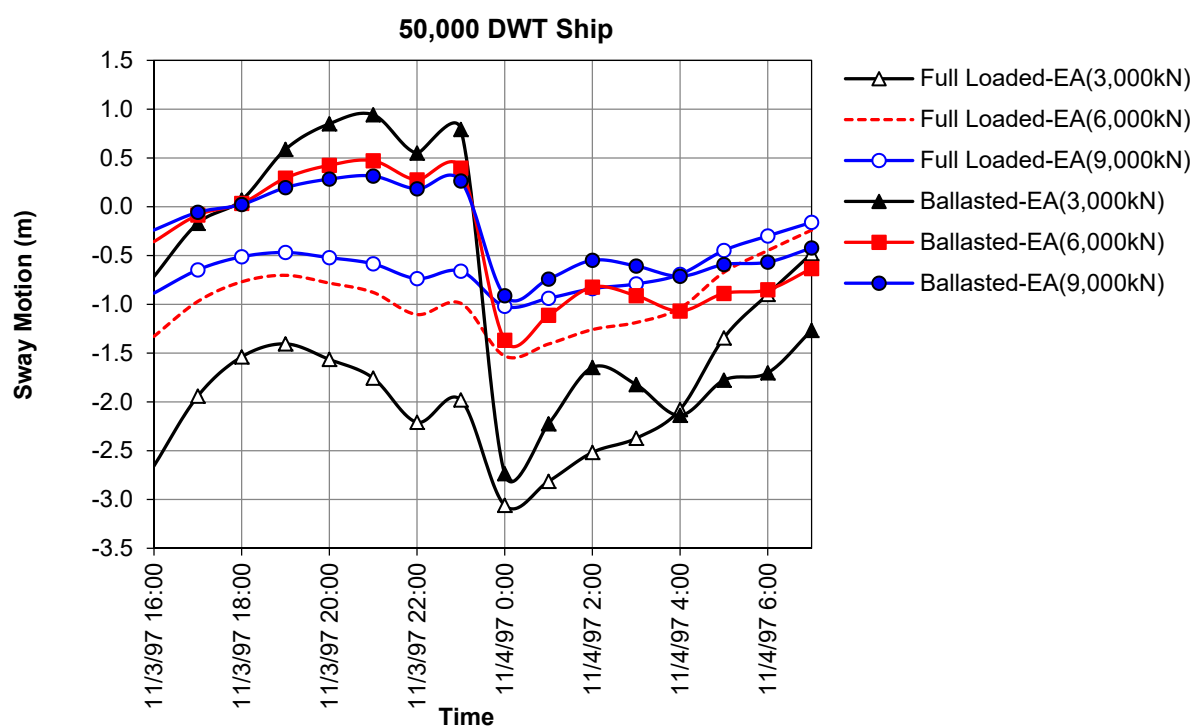


Fig. 6.35 Sway Motion of 50,000 DWT at BLCP Port

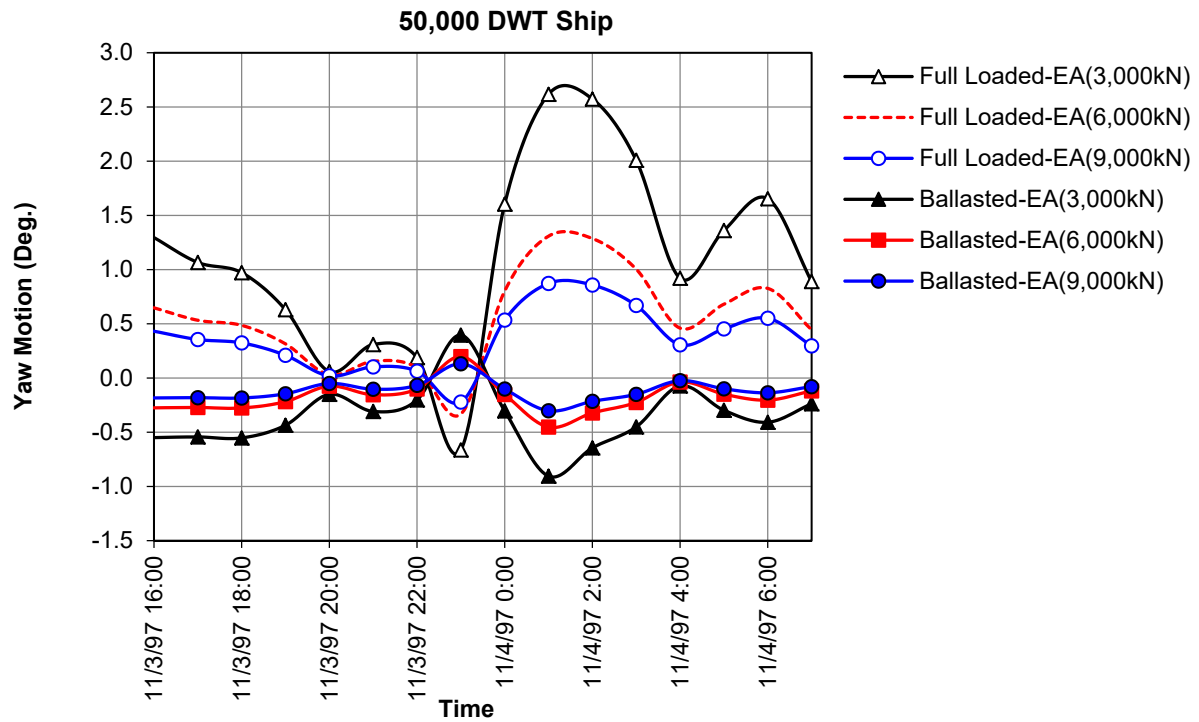


Fig. 6.36 Yaw Motion of 50,000 DWT at BLCP Port

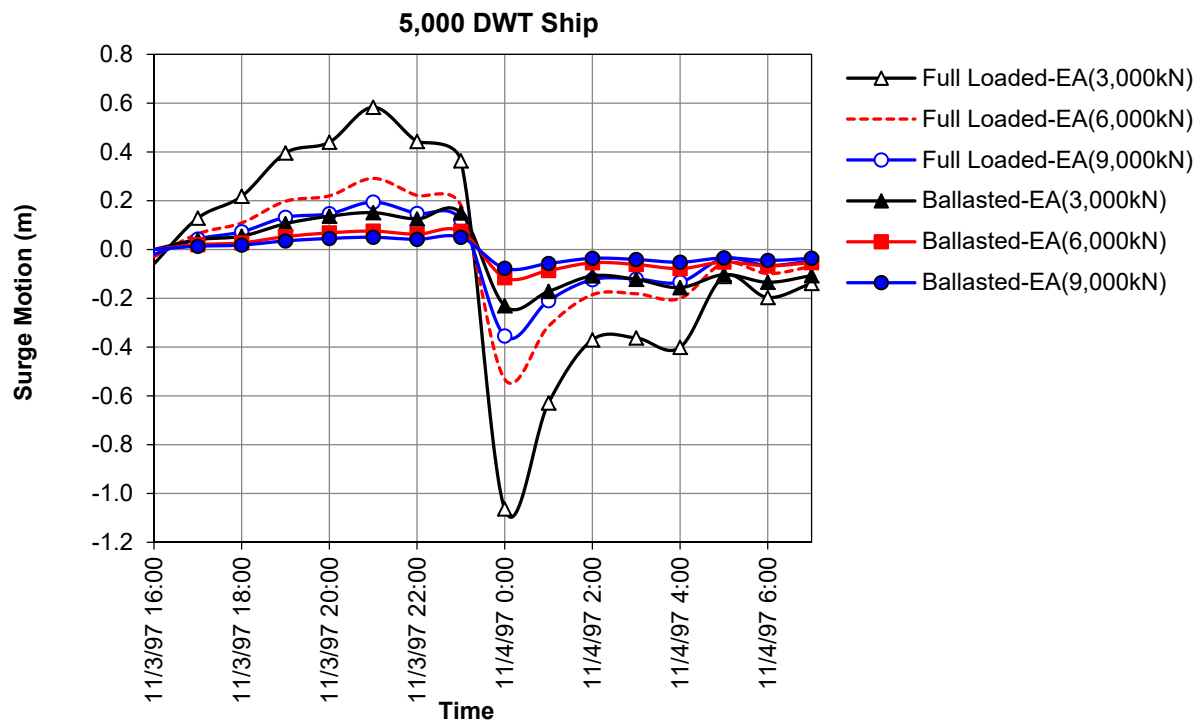


Fig. 6.37 Surge Motion of 5,000 DWT at BLCP Port

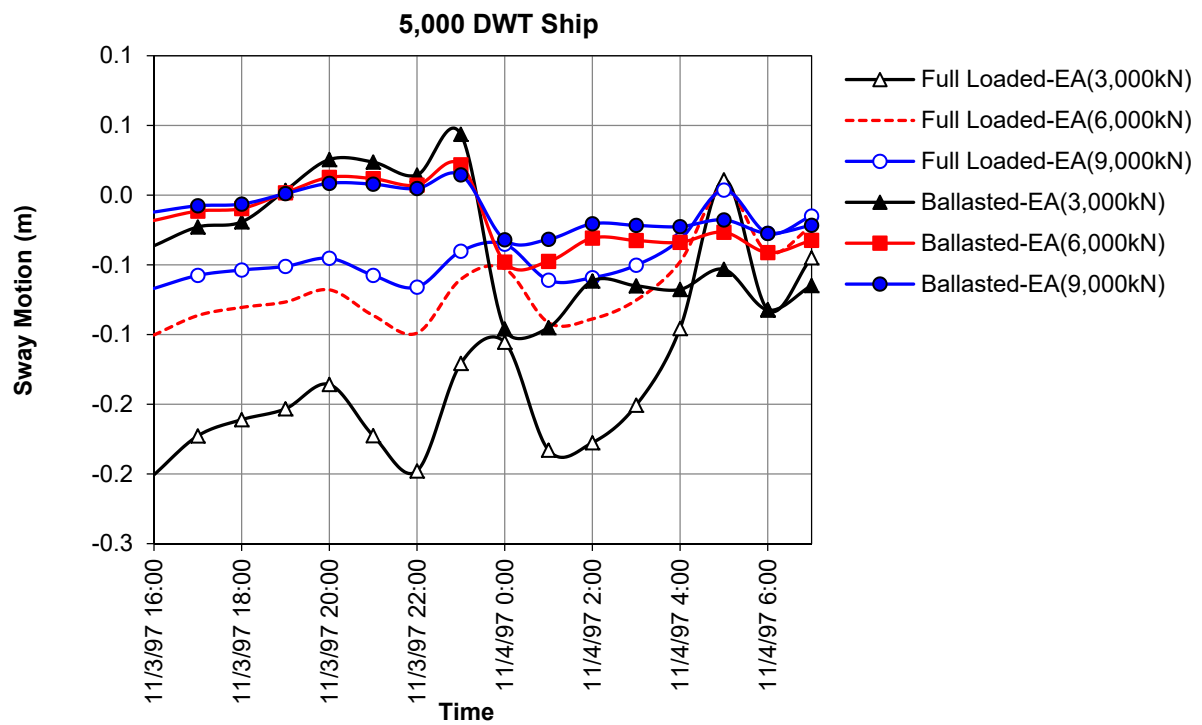


Fig. 6.38 Sway Motion of 5,000 DWT at BLCP Port

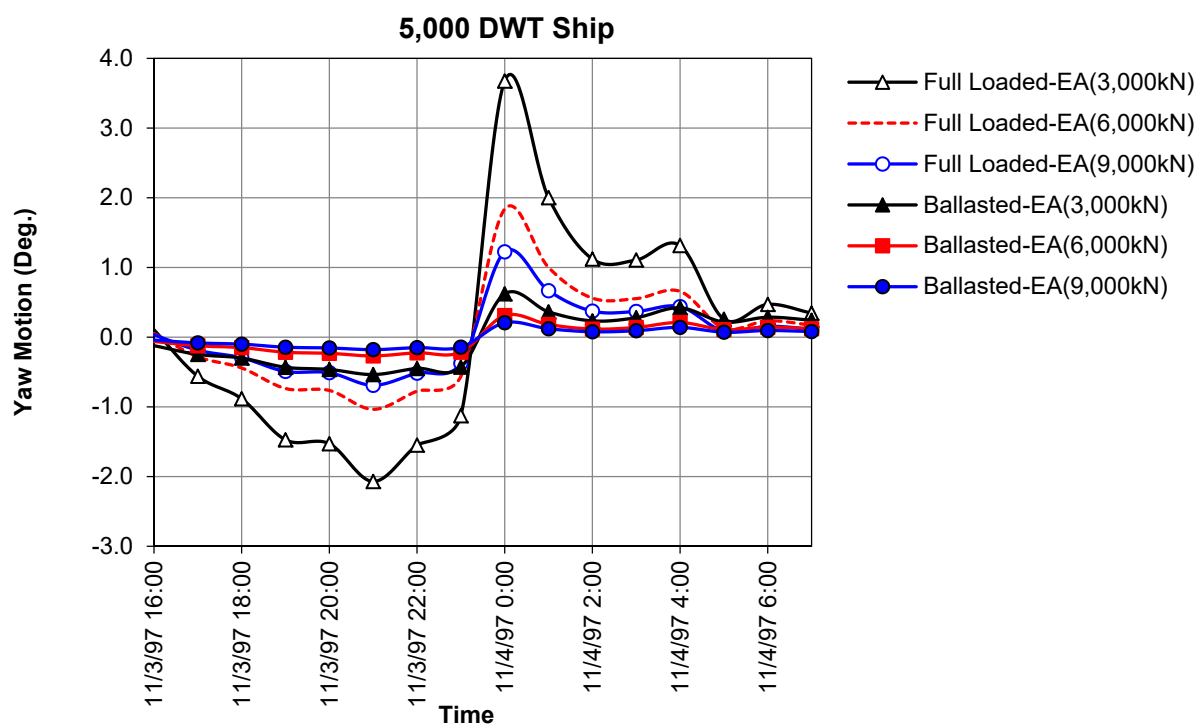


Fig. 6.39 Yaw Motion of 5,000 DWT at BLCP Port

6.7 SUMMARY

The static mooring analysis is suitable for application of evaluating the effects of the environmental conditions where the significant wave height is not severe. This method presented here can be used to calculate 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 of $EA = 3,000\text{kN}$, and $EA = 9,000\text{kN}$, the ship motions are exceeded the limitation as provided in PIANC 1995, because the wind and wave hit the moored ship in South-East directions, which event the ship moves off the fender. 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 event strong wind and low air pressure occurs. The ship motions can be reduced by increasing the stiffness of mooring rope with the synthetic material. However, for safety reason the mooring forces are not overloaded that should monitor the mooring forces for safe operation.

Chapter 7

Conclusions

This dissertation concerns the background of an offshore project in Thailand, the met-ocean data collection and estimation of the environmental conditions by the numerical model which is using the application of Delft3D-WAVE and Delft3D-FLOW. The model results are applied for estimation of the coarse berth operability and port downtime and also applied as the input data for moored ship motions analysis. The conclusion of each part is specified as below.

The port development in Thailand is classified the port operator as includes government operators and individual operators. The type of port consist the offshore port and harbor, the offshore port is consist of container terminal, general cargo terminal and oil and gas terminal. Government operator has objective to export the agriculture product and import the container cargoes, therefore they will developing the general cargo terminal and container terminal. The individual operator has port development objective for export the liquid product as the petrochemical and import coal from Indonesia and Australia. The port is mostly developing in the Eastern Coast of Thailand, these areas are called “Eastern Seaboard of Thailand”, it is an economic region that plays a key role in Thailand's economy and the center for export-oriented industries. Government operator plans developing twos large ports in the Gulf of Thailand and the Andaman Sea with connecting two ports by land transportation includes truck and train for transfer the container and dry bulk.

The met-ocean data collection in Upper Gulf of Thailand is useful for the study on berth operability and port downtime for port operation and safety. These data include the severe environmental conditions during the Tropical Cyclone Linda enters to the Gulf in 1997. The met-ocean data records by oceanographic buoys (SEAWATCH buoy) since 1991 to 2006 that operated by Geo-Informatics and Space Technology Development Agency (Public Organization: GISTDA). The met-ocean database is absence in ASCII files, and time series data plotted as a graph in linear scale exist in GISTDA reports. In this study, the data was collected by digitizing manually from the reports and using linear interpolation for obtained the observation data according to the recording instruments in each time step since 1991 to 2002 of three oceanographic buoys that consist of Ko Si Chang (KS) and Rayong (RY) Hua Hin (HH) and Ko Chang (KC) buoy.

The wave characteristic in East coast of Thailand is significant for maritime development, coastal hazard analysis, coastal disaster prevention and mitigation. The environmental conditions are obtained from Ko Si Chang (KS) buoy from 1991 to 2001 and using the statistical analysis for

indicating wind-wave distribution at Ko Si Chang (KS) buoy. The observed data are an application to estimation the wave transformations from offshore to the near shore at the port by the numerical model with using an application Delft3D-WAVE. The computational grid includes the coarse grid and the nesting grid that applied the observed wave data and calculated by JONSWAP spectrum method on the open boundary and applied the uniform wind on the computational grid. The bathymetry data consist the THAI nautical chart and GEBCO (2014), which is set up the water depth with reference to Lowest Low Water Level. The study location includes Laem Chabang Port Breakwater (LCP), PTT Jetty (PTT), Thai Oil Jetty (TOP), Kerry Siam Seaport (KSSP), Sriracha Harbour (SRH) and Ko Sichang Buoy (KS) in Ao Udom Bay. The model validation is the comparison between the observed significant wave height and wave model results on the open boundary of the computational grid, which presents by the R-square, the comparison showed wave model is reasonable for estimating the significant wave height. Significant wave height in East coast of Thailand is not severe that represent the distribution of significant wave height by classes of 0 to 0.5 m of the percentage of occurrence of 73.80%. Moreover, and the dominant direction is in the South-West and the North-East. Ko Si Chang Island is a wave obstacle, which sheltered the offshore ports when the severe wind-wave coming in the South-West directions. The maximum significant at Ko Si Chang (KS) buoy is equal to 1.89 m in the Northeast direction, 2.49 m in the Southwest direction, while the maximum wind speed is equal to 14.04 m/s in the Northeast direction and 21.02 m/s in the Southwest directions. The maximum significant wave height at ports is equal to 2.17 m at the front of LCP breakwater, PTT of 2.19 m, TOP of 1.97 m, KSSP of 2.26 m and SRH of 2.35 m.

The coarse berth operability and port downtime are studied at the offshore port in Eastern Thailand caused by a severe environmental condition such as wind speed and significant wave height. The wave transformation is calculated by numerical wave model using Delft3D-WAVE for estimating the significant wave height at each port. The coarse berth operability and port downtime are limiting the environmental conditions that provided in PIANC (2014). The environmental condition is collected the met-ocean data from Rayong (RY) and Ko Si Chang (KS) buoy. The Wind and current are the observed data, which assume wind and current at Ko Si Chang (KS) buoy are representative of port in Ao Udom Bay, wind and current at Rayong (RY) buoy are representative of port in Rayong Sea, while the significant wave height is the wave model results at the port. The limitation of environmental operating conditions is selected with lower bound conditions at each port, which limiting of wind speed is equal to 20 m/s, current speed of 0.7 m/s and wave height of 0.8 m. The wind speed at the port in Ao Udom Bay and Rayong Sea are not severe, that mean hourly wind speeds of 4.89 to 10 m/s. The wind speed exceeds of 20 m/s occur less than 1%. The significant wave height larger than 0.8 m occurs up to 14.68% of SRH, 16.51% of KSSP and 40.98% of BLCP respectively, while the significant wave height larger than 1 m occur for up to 5.50% of TOP, 10.09% of PTT and 22.13% of IRPC. The currents speed at Ko Si Chang (KS) buoy is higher than the currents speed at Rayong (RY) buoy. The currents speed are in order of 0.9 to 1 m/s and percentage of occurrence of 0.07% at the port in Ao Udom Bay. The peak current speed is in the order of 0.8 to 0.9 m/s and no currents speed reached to 1 m/s at Rayong (RY) buoy. The currents speed is higher than 0.7 m/s up to 0.67% of the percentage of occurrence at SRH, KSSP, TOP and PTT port, and 0.06% of the percentage of occurrence at IRPC and BLCP port. The berth operability is disruption by the wind, wave and current that obtained from the observed met-ocean data and wave model results, the disruption caused by the wave is a significant issue of berth operability, while the disruption caused by wind and currents is a lesser issue than wave disruption. The berth operability calculated by the limiting of environmental conditions at the port does not indicate the long period wave effects to the ship length.

Tropical Cyclone Linda was formed on 31st October 1997 in the South China Sea and strengthening as it moved westward, and moved across the Gulf of Thailand onto the northwest. The severe wind-wave due to Tropical Cyclone Linda can cause the port downtime that affects to port operations such as berthing, mooring and (un)loading cargoes between the ship and onshore facility at the port in the upper Gulf of Thailand. The ship motions are criteria for limiting the port operations, human safety and preventing the damage of port equipment and furniture. The ship motions are calculated by the

moored ship analysis at Sriracha Harbour Port (SRH) and BLCP Coal-Fired Power Plant Port (BLCP). The environmental conditions are derived from the wave model and hydrodynamics model using the application of Delft3D-WAVE and Delft3D-FLOW. The Delft3D-WAVE model at Ao Udom Bay and Rayong Sea are set-up for calculated the significant wave height at the port, and Delft3D-FLOW model of the Upper Gulf of Thailand has been developed to estimate storm water level, current speed and storm surges generated by Tropical Cyclone Linda by using the best track data from Japanese Meteorological Agency (JMA). The wind model and pressures model are used the Holland (1980) for derived the wind speed and air pressure. The radius of maximum wind speed is assumed 30 km as applied in the model that obtained by trial and error by comparison between the model results and observed data, and the maximum radius is assumed to 500 km from the center of the typhoon. The flow model includes the sensitivity analysis with water levels forced by tidal harmonics that used the eight main tidal constituents at the model boundary. The model runs in a month of November 1997 for water level validation by the comparison between simulated water level and observed water level at Pranburi Station, Banleam Station, Rayong Station and Leam Ngob Station. In the extreme condition, the validation is a comparison between simulated wind speed, air pressure and current by observed met-ocean data at Rayong (RY), Hua Hin (HH) and Ko Chang (KC) Buoy. The maximum significant wave height is equal to 1.12 m at KSSP, PTT of 1.12 m, SRH of 1.09 m, PTT of 1.09 m, SRH of 1.05 m, BLCP of 2.05 m and IRPC of 1.94 m. That results represent the significant wave height at Rayong Sea is severe more than Ao Udom Bay when tropical cyclone Linda enters to the Gulf of Thailand. The storm surge due to the tropical cyclone Linda that cause the negativlie surge and positive surge. The positive surge is a range between 0.5 to 1.3 m and negative surge 1.1 to 2 m. The severe wind-wave due to tropical cyclone Linda affected to the berth operability and caused port downtime at SRH Port and BLCP Port.

The ship motions are the criteria for limiting the berth operability in safety marine operation that limits the moored ship motions as provided in PIANC (1995). The moored ship analysis are the calculation method for obtained the ship motion with combined the effects of severe wind, current and wave hit on the moored ship effects due to the tropical cyclone Linda in November 1997. The formulation of mooring equations are used the direct stiffness method that formed the mooring line stiffness in the matrix and assumed straight mooring lines with consist one head line, two breast lines, two spring lines and one stern line with constant stiffness. MATLAB Computer Program is an application for solved the mooring equations for obtained the ship motions in the three-degree-of-freedom system such as surge motion, sway motion and yaw motion. The validation is a comparison between the analysis results of MATLAB Computer Program and the analysis results of R. Natarajan and C. Ganapathy (1998), who studied the moored ship motions by using the application SHIP MOOR, the comparison shows good agreement results of fully loaded condition. Two ship sizes are evaluated in the analysis that consist the bulk carrier of 50,000 DWT and 5,000 DWT.

Sriracha Harbour Port (SRH) and BLCP Coal-Fired Power Plant Port (BLCP) using the cranes for cargo handling along with PIANC (1995) given the limitation of ship motions for allowed the port operation are equal to 2 m of the surge, 1 m of sway and 2 degrees of yaw. The ship motions are analyzed in case of stiffness variation and the operation conditions with includes the fully loaded and ballasted condition. The maximum surge is equal to 0.74 m, sway of 2.50 m and yaw motion of 1.24 degrees at SRH, while the maximum surge of 2.73 m, sway of 3.06 m and yaw of 3.68 degrees in the fully loaded condition at BLCP Port. 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 the reason of the low current speed and high wind speed at SRH Port therefore ballasted condition become the critical effects. The ship motions at BLCP Port are larger than the ship motions at SRH Port because the location of BLCP Port near to the center of the tropical cyclone. The sway motion is too large in case of low stiffness, and ship motions have exceeds the limitation as provided in PIANC (1995) and the wind and wave hit the moored ship in South-East directions which the ship move off the fenders.

Although the environmental conditions are lower than the limitation as provided in PIANC (2014), the ship motion may exceeds the limitation as provided in PIANC (1995) because the ship motions analysis are the combinations of wind, current and wave forces. The ship motions can be reduced by increasing the stiffness of mooring rope with the synthetic material. However, for safety reason the mooring forces are not overloaded that should be monitor the mooring forces for safe operation.

Appendix A

Met-Ocean Data

This appendix is represented the results of statistically analysis of meteorological ocean data of oceanographic buoys in upper gulf of Thailand, the datasets are consist of wind, significant wave height and current. The buoy models are SEAWACH buoy which located at Ko Si Chang, Rayong and Hua Hin. The approximated locations are tabulated in Table A.1.

Table A.1 Location of Buoys

Location	Latitude	Longitude
Ko Si Chang (KS)	13° 15' N	100° 45 ' E
Rayong (RY)	12° 30' N	101° 13' E
Hua Hin (HH)	12° 30' N	100° 10' E
Ko Chang (KC)*	12° 00' N	102° 12' E

Note: The meteorological ocean data at Ko Chang are not mainly used for this study, but used some environmental data at this location for validation of storm surge model event tropical cyclone Linda.

A.1 METEOROLOGICAL OCEAN DATA AT KO SI CHANG (KS) BUOY

A.1.1 Wind

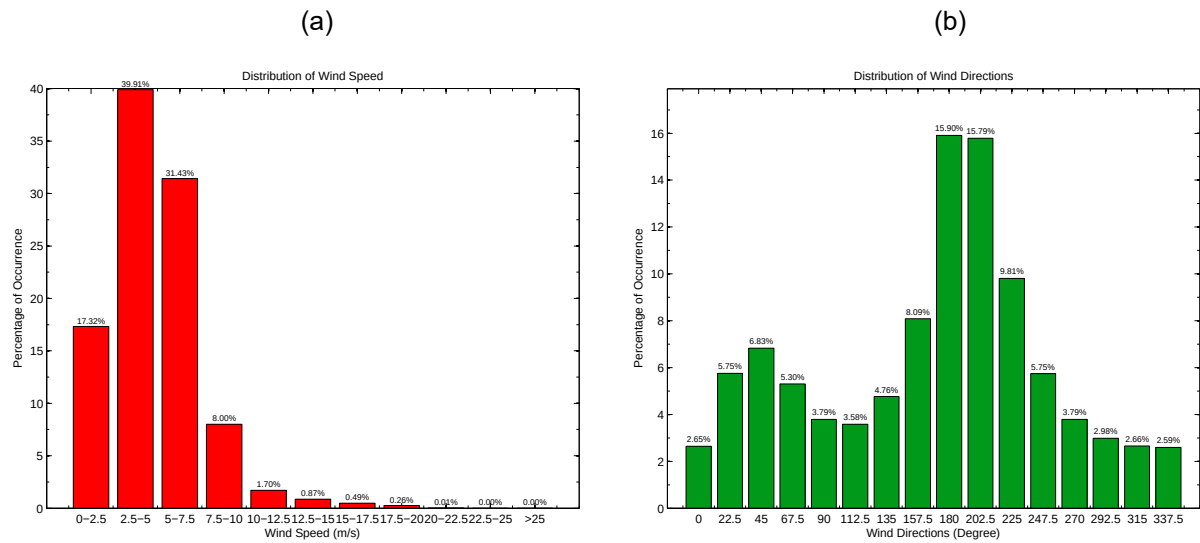


Fig. A.1 (a) Distribution of Wind Speed Classes, (b) Distribution of Wind Directions at Ko Si Chang (KS) Buoy, (1991-2001)

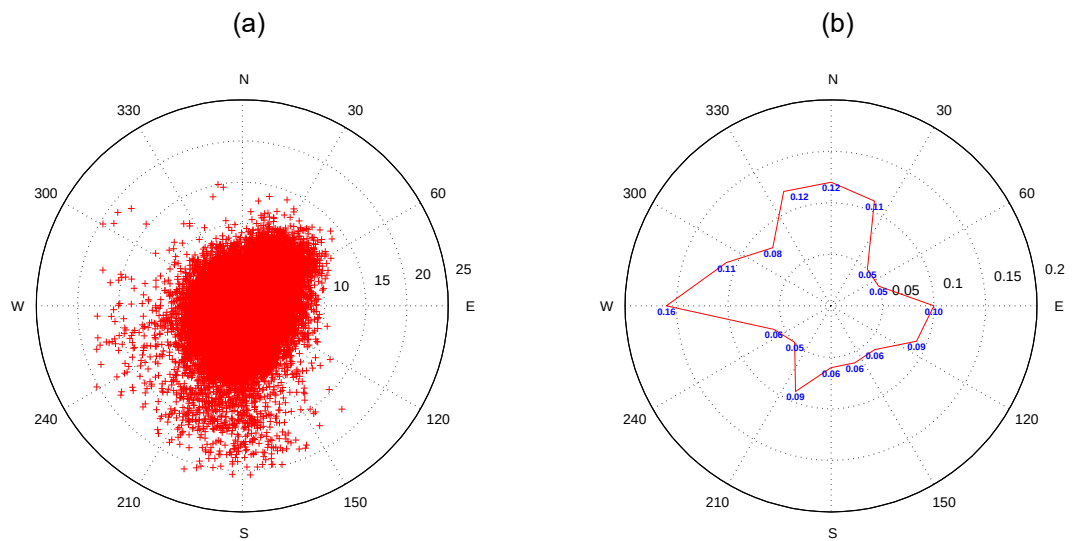


Fig. A.2 (a) Wind Speed Distribution (m/s), (b) Minimum Wind Speed (m/s) at Ko Si Chang (KS) Buoy, (1991-2001)

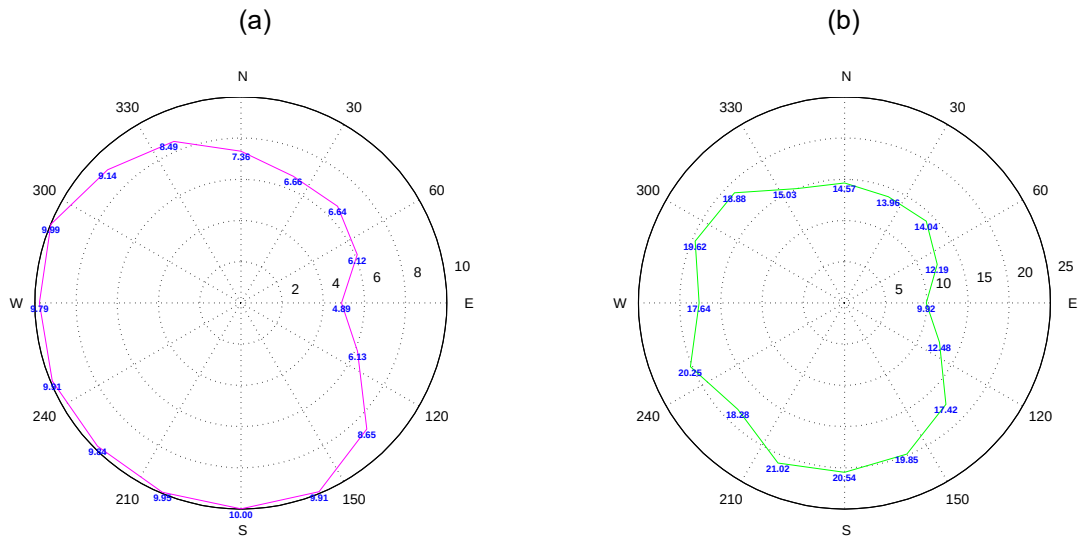


Fig. A.3 (a) Average Wind Speed (m/s), (b) Maximum Wind Speed (m/s) at Ko Si Chang (KS) Buoy, (1991-2001)

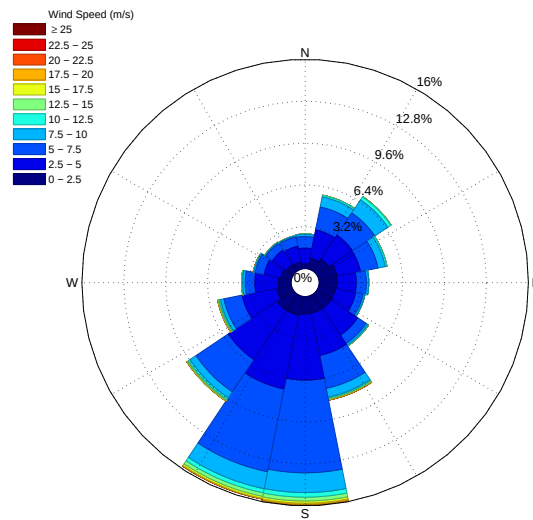


Fig. A.4 Wind Rose Diagram (m/s) at Ko Si Chang (KS) Buoy, (1991-2001)

Table A.2 Distribution of Wind Speed from 1991 to 2001 at Ko Si Chang (KS) Buoy

Dir. (Deg.)	$0.0 \leq W_s < 2.5$	$2.5 \leq W_s < 5.0$	$5.0 \leq W_s < 7.5$	$7.5 \leq W_s < 10$	$10 \leq W_s < 12.5$	$12.5 \leq W_s < 15.0$	$15.0 \leq W_s < 17.5$	$17.5 \leq W_s < 20.0$	$20.0 \leq W_s < 22.5$	$22.5 \leq W_s < 25.0$	$W_s \geq 25.0$	Max. Wind Speed (m/s)	Average Wind Speed (m/s)	Min. Wind Speed (m/s)	Number of Events	Events (%)
0	107	365	265	52	4	2	0	0	0	0	0	14.57	7.36	0.12	795	2.65
22.5	250	663	535	236	38	4	0	2	2	0	0	13.96	6.66	0.11	1,728	5.75
45	329	660	613	362	83	5	0	0	0	0	0	14.04	6.64	0.05	2,052	6.83
67.5	425	549	410	171	38	0	0	0	0	0	0	12.19	6.12	0.05	1,593	5.30
90	411	442	231	54	0	0	0	0	0	0	0	9.92	4.89	0.10	1,138	3.79
112.5	388	472	173	40	4	0	0	0	0	0	0	12.48	6.13	0.09	1,077	3.58
135	388	743	231	46	18	3	2	0	0	0	0	17.42	8.65	0.06	1,431	4.76
157.5	392	991	771	204	25	21	13	0	0	0	0	19.85	9.91	0.06	2,430	8.09
180	402	1,516	2,130	454	105	89	48	0	0	0	0	20.54	10.00	0.06	4,780	15.9
202.5	441	1,728	1,939	397	96	83	45	0	0	0	0	21.02	9.95	0.09	4,746	15.79
225	446	1,354	892	168	44	26	15	0	0	0	0	18.28	9.84	0.05	2,948	9.81
247.5	349	804	427	81	27	21	13	0	0	0	0	20.25	9.91	0.06	1,727	5.75
270	289	546	220	56	16	5	5	0	0	0	0	17.64	9.79	0.16	1,138	3.79
292.5	249	391	212	31	5	2	4	0	0	0	0	19.62	9.99	0.11	896	2.98
315	184	398	183	24	6	0	1	0	0	0	0	18.88	9.14	0.08	798	2.66
337.5	157	373	214	29	3	1	1	0	0	0	0	15.03	8.49	0.12	778	2.59
Total															30,055	100.00

A.1.2 Significant Wave Height

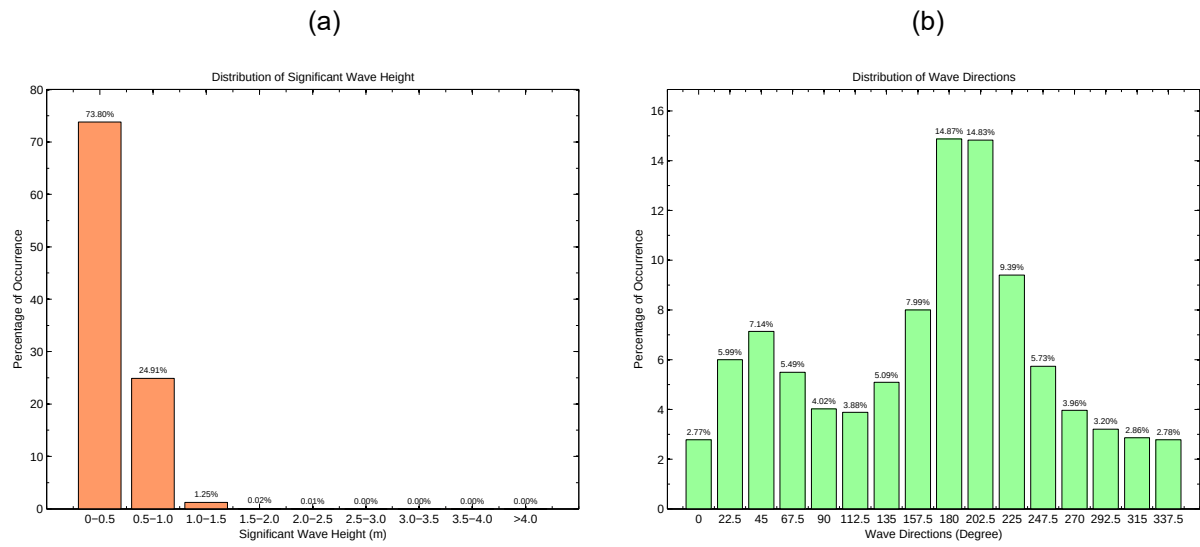


Fig. A.5 (a) Distribution of Significant Wave Height Classes, (b) Distribution of Wave Directions at Ko Si Chang (KS) Buoy, (1991-2001)

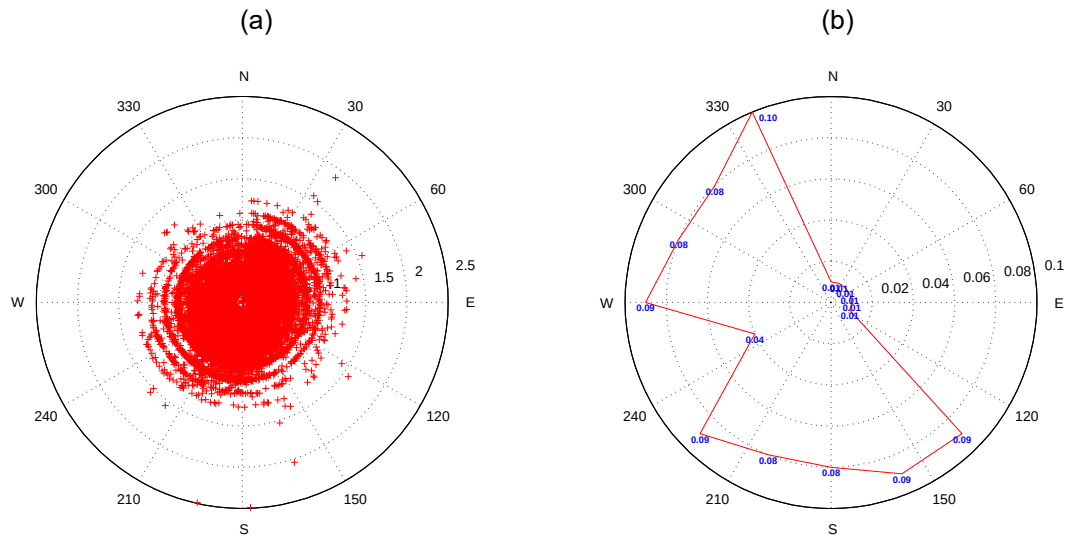


Fig. A.6 (a) Significant Wave Height Distribution (m), (b) Minimum Significant Wave Height (m) at Ko Si Chang (KS) Buoy, (1991-2001)

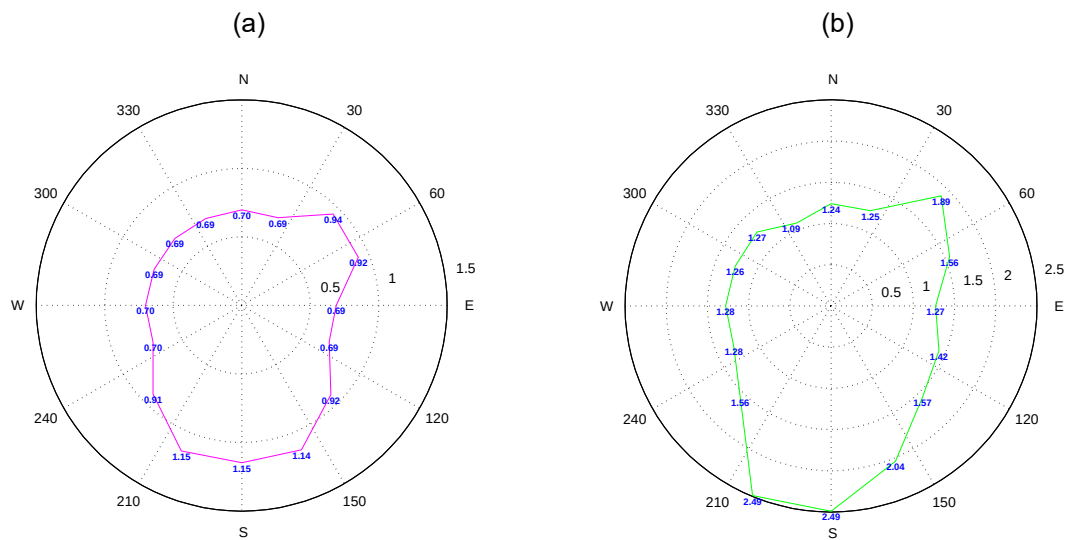


Fig. A.7 (a) Average Significant Wave Height (m), (b) Maximum Significant Wave Height (m) at Ko Si Chang (KS) Buoy, (1991-2001)

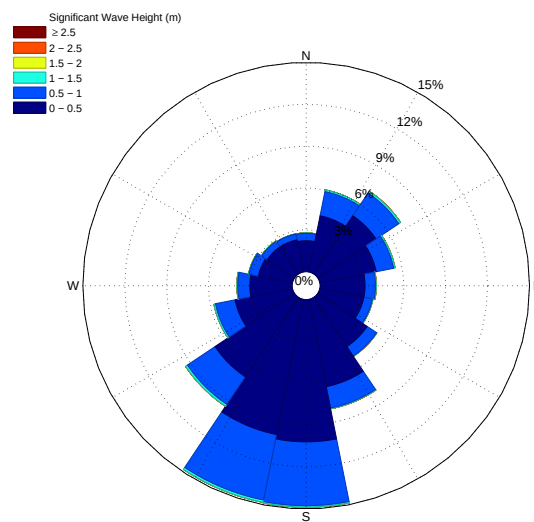


Fig. A.8 Wave Rose Diagram (m) at Ko Si Chang (KS) Buoy, (1991-2001)

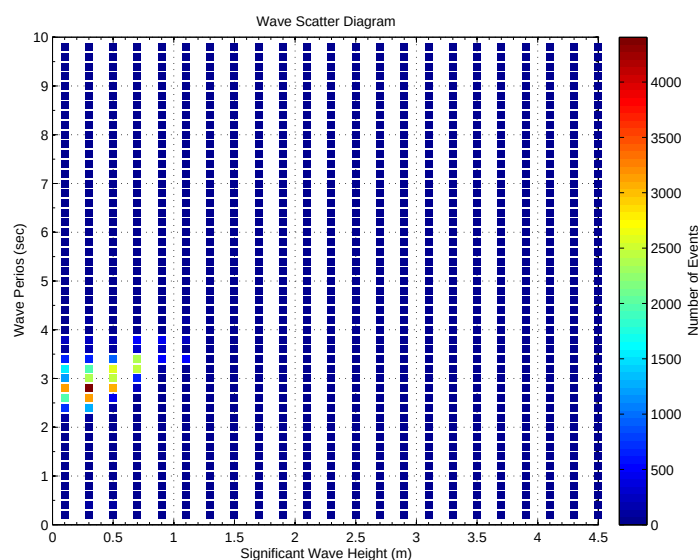


Fig. A.9 Wave Scatter Diagram at Ko Si Chang (KS) Buoy, (1991-2001)

Table A.3 Distribution of Significant Wave Height from 1991 to 2001 at Ko Si Chang (KS) Buoy

Dir. (Deg.)	$0 \leq H_s < 0.5$	$0.5 \leq H_s < 1.0$	$1.0 \leq H_s < 1.5$	$1.5 \leq H_s < 2.0$	$2.0 \leq H_s < 2.5$	$2.5 \leq H_s < 3.0$	$3.0 \leq H_s < 3.5$	$3.5 \leq H_s < 4.0$	$H_s \geq 4.0$	Max. Significant Wave Height (m)	Average Significant Wave Height (m)	Min. Significant Wave Height (m)	Number of Events	Events (%)
0	838	202	9	0	0	0	0	0	0	1.24	0.70	0.01	1,049	2.77
22.5	1,551	667	48	0	0	0	0	0	0	1.25	0.69	0.01	2,266	5.99
45	1,897	742	56	3	0	0	0	0	0	1.89	0.94	0.01	2,698	7.14
67.5	1,556	481	39	1	0	0	0	0	0	1.56	0.92	0.01	2,077	5.49
90	1,216	282	22	0	0	0	0	0	0	1.27	0.69	0.01	1,520	4.02
112.5	1,215	235	15	0	0	0	0	0	0	1.42	0.69	0.01	1,465	3.88
135	1,605	308	9	1	0	0	0	0	0	1.57	0.92	0.09	1,923	5.09
157.5	2,409	591	20	1	1	0	0	0	0	2.04	1.14	0.09	3,022	7.99
180	3,852	1,729	38	0	1	0	0	0	0	2.49	1.15	0.08	5,620	14.87
202.5	3,732	1,809	63	0	1	0	0	0	0	2.49	1.15	0.08	5,605	14.83
225	2,588	899	61	3	0	0	0	0	0	1.56	0.91	0.09	3,551	9.39
247.5	1,583	540	44	0	0	0	0	0	0	1.28	0.70	0.04	2,167	5.73
270	1,146	328	23	0	0	0	0	0	0	1.28	0.70	0.09	1,497	3.96
292.5	939	262	10	0	0	0	0	0	0	1.26	0.69	0.08	1,211	3.2
315	888	181	13	0	0	0	0	0	0	1.27	0.69	0.08	1,082	2.86
337.5	885	162	4	0	0	0	0	0	0	1.09	0.69	0.10	1,051	2.78
Total													37,804	100.00

A.1.3 Current

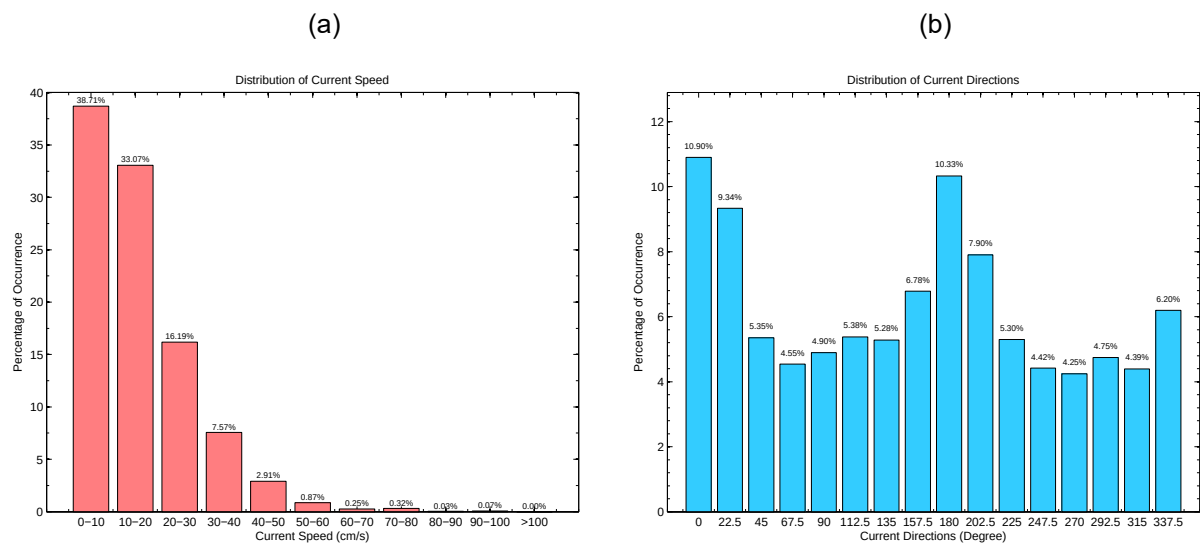


Fig. A.10 (a) Distribution of Current Speed Classes, (b) Distribution of Current Directions at Ko Si Chang (KS) Buoy, (1991-2001)

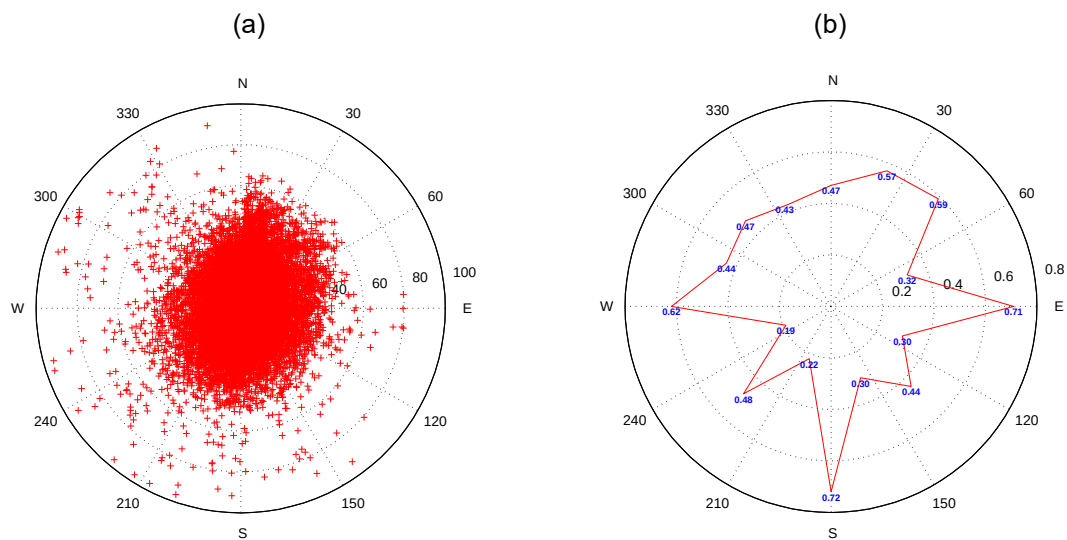


Fig. A.11 (a) Current Speed Distribution (cm/s), (b) Minimum Current Speed (cm/s) at Ko Si Chang (KS) Buoy, (1991-2001)

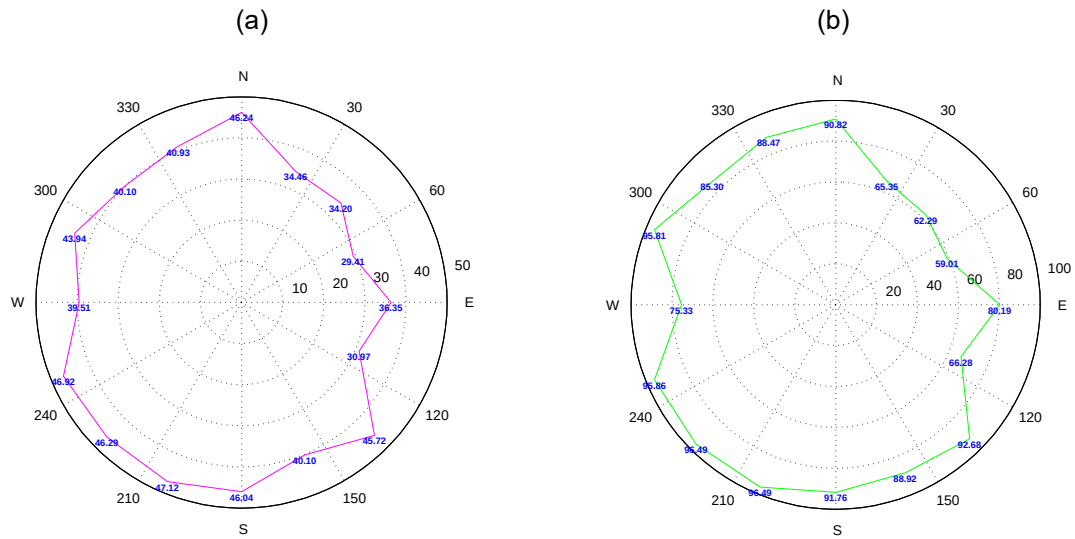


Fig. A.12 (a) Average Current Speed (cm/s), (b) Maximum Current Speed (cm/s) at Ko Si Chang (KS) Buoy, (1991-2001)

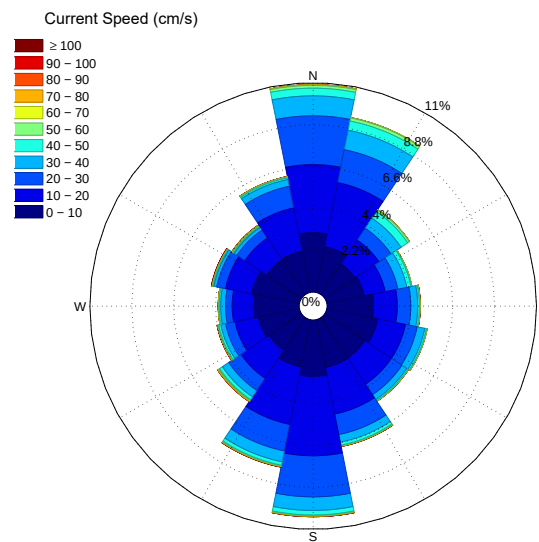


Fig. A.13 Current Rose Diagram (cm/s) at Ko Si Chang (KS) Buoy, (1991-2001)

Table A.4 Distribution of Current Speed from 1991 to 2001 at Ko Si Chang (KS) Buoy

Dir. (Deg.)	$0 \leq C_s < 10$	$10 \leq C_s < 20$	$20 \leq C_s < 30$	$30 \leq C_s < 40$	$40 \leq C_s < 50$	$50 \leq C_s < 60$	$60 \leq C_s < 70$	$70 \leq C_s < 80$	$80 \leq C_s < 90$	$90 \leq C_s < 100$	$C_s \geq 100$	Max. Current Speed (cm/s)	Average Current Speed (cm/s)	Min. Current Speed (cm/s)	Number of Events	Events (%)
0	844	966	693	283	109	39	8	0	0	1	0	90.82	46.24	0.47	2,945	10.90
22.5	656	928	476	281	134	44	4	0	0	0	0	65.35	34.46	0.57	2,523	9.34
45	515	411	203	172	113	29	2	0	0	0	0	62.29	34.20	0.59	1,445	5.35
67.5	540	303	183	130	60	12	0	0	0	0	0	59.01	29.41	0.32	1,228	4.55
90	657	338	191	98	22	8	2	2	2	0	0	80.19	36.35	0.71	1,323	4.90
112.5	735	401	169	110	23	9	2	4	4	0	0	66.28	30.97	0.30	1,453	5.38
135	683	452	179	81	20	4	4	0	0	1	0	92.68	45.72	0.44	1,427	5.28
157.5	688	675	296	110	44	8	3	0	0	0	0	88.92	40.10	0.30	1,832	6.78
180	797	1,128	583	192	64	7	7	0	0	1	0	91.76	46.04	0.72	2,790	10.33
202.5	680	832	384	157	50	12	5	0	0	4	0	96.49	47.12	0.22	2,135	7.90
225	551	481	208	109	48	12	12	0	0	1	0	96.49	46.29	0.48	1,432	5.30
247.5	592	339	137	69	30	12	3	0	0	3	0	95.86	46.92	0.19	1,194	4.42
270	650	300	94	69	20	8	4	0	0	0	0	75.33	39.51	0.62	1,147	4.25
292.5	689	379	128	40	13	6	3	3	3	7	0	95.81	43.94	0.44	1,282	4.75
315	590	374	136	47	14	11	7	0	0	0	0	85.30	40.10	0.47	1,187	4.39
337.5	592	628	314	98	23	13	2	0	0	0	0	88.47	40.93	0.43	1,674	6.20
Total															27,017	100.00

A.2 METEOROLOGICAL OCEAN DATA AT RAYONG (RY) BUOY

A.2.1 Wind

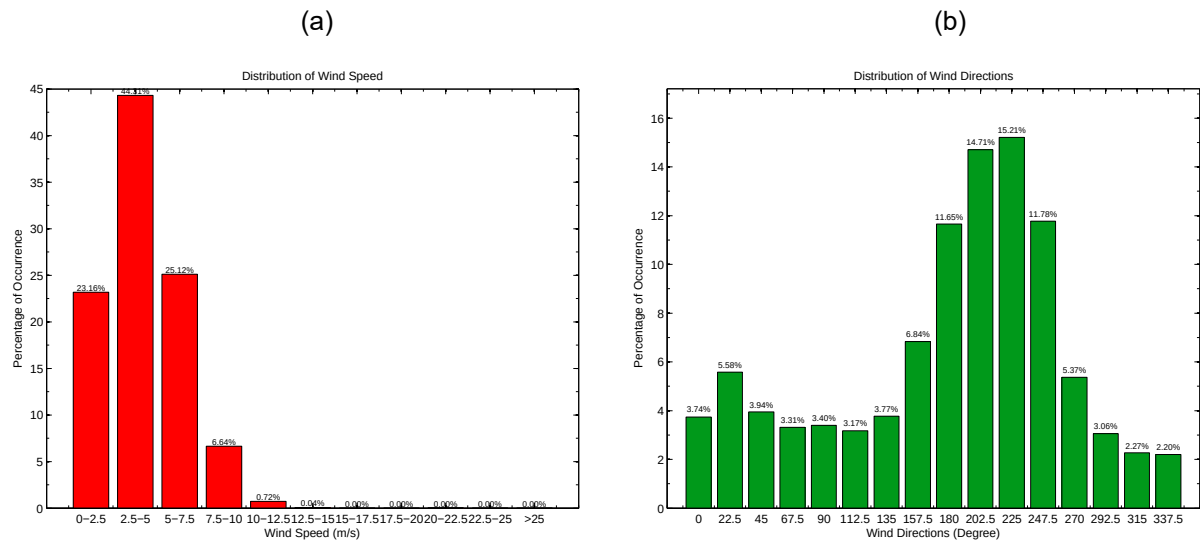


Fig. A.14 (a) Distribution of Wind Speed Classes, (b) Distribution of Wind Directions at Rayong (RY) Buoy, (1991-2002)

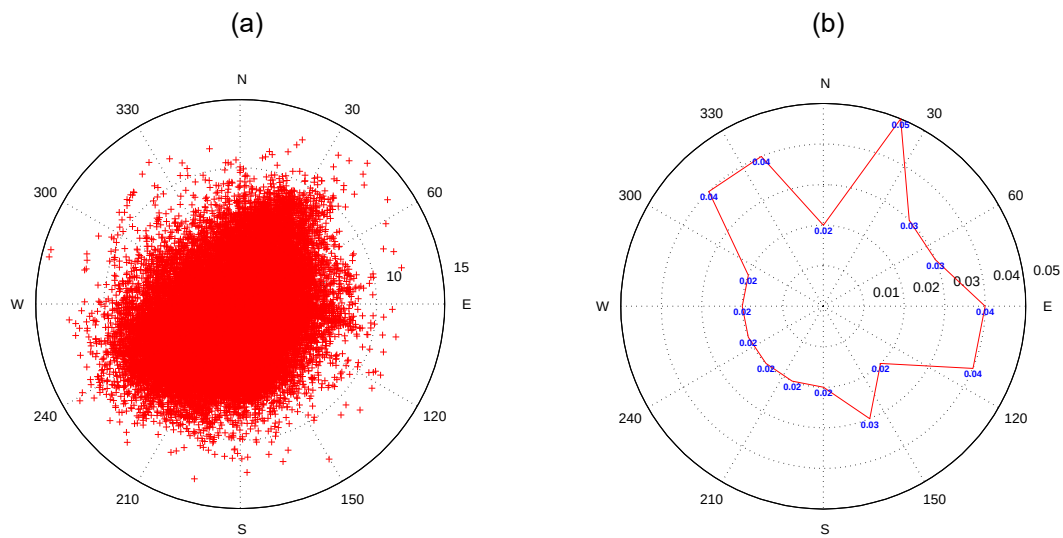


Fig. A.15 (a) Wind Speed Distribution (m/s), (b) Minimum Wind Speed (m/s) at Rayong (RY) Buoy (1991-2002)

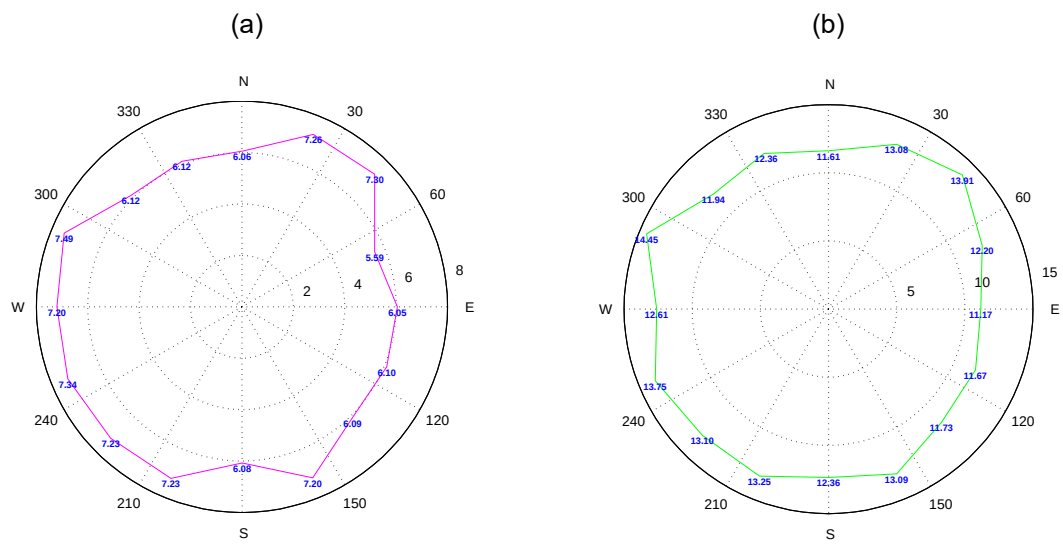


Fig. A.16 (a) Average Wind Speed (m/s), (b) Maximum Wind Speed (m/s) at at Rayong (RY) Buoy, (1991-2002)

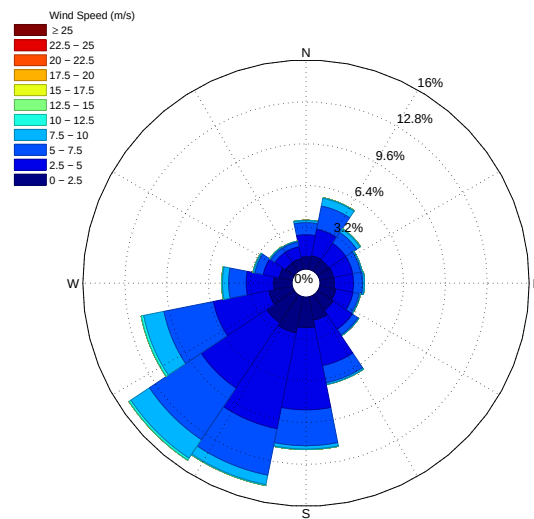


Fig. A.17 Wind Rose Diagram (m/s) at Rayong (RY) Buoy, (1991-2002)

Table A.5 Distribution of Wind Speed from 1991 to 2002 at Rayong (RY) Buoy

Dir. (Deg.)	$0.0 \leq W_s < 2.5$	$2.5 \leq W_s < 5.0$	$5.0 \leq W_s < 7.5$	$7.5 \leq W_s < 10$	$10 \leq W_s < 12.5$	$12.5 \leq W_s < 15.0$	$15.0 \leq W_s < 17.5$	$17.5 \leq W_s < 20.0$	$20.0 \leq W_s < 22.5$	$22.5 \leq W_s < 25.0$	$W_s \geq 25.0$	Max. Wind Speed (m/s)	Average Wind Speed (m/s)	Min. Wind Speed (m/s)	Number of Events	Events (%)
0	410	732	405	71	9	0	0	0	0	0	0	11.61	6.06	0.02	1,627	3.74
22.5	461	899	790	264	15	2	0	0	0	0	0	13.08	7.26	0.05	2,431	5.58
45	438	688	434	138	14	5	0	0	0	0	0	13.91	7.30	0.03	1,717	3.94
67.5	462	658	271	44	5	0	0	2	2	0	0	12.20	5.59	0.03	1,442	3.31
90	477	636	306	58	2	0	0	0	0	0	0	11.17	6.05	0.04	1,479	3.40
112.5	545	582	207	37	9	0	0	0	0	0	0	11.67	6.10	0.04	1,380	3.17
135	616	767	226	32	3	0	0	0	0	0	0	11.73	6.09	0.02	1,644	3.77
157.5	789	1,544	582	56	5	1	0	0	0	0	0	13.09	7.20	0.03	2,977	6.84
180	1,016	2,738	1,195	111	15	0	0	0	0	0	0	12.36	6.08	0.02	5,075	11.65
202.5	1,220	3,258	1,577	325	25	1	0	0	0	0	0	13.25	7.23	0.02	6,406	14.71
225	1,109	2,622	2,072	745	74	3	0	0	0	0	0	13.10	7.23	0.02	6,625	15.21
247.5	794	1,883	1,677	692	81	3	0	0	0	0	0	13.75	7.34	0.02	5,130	11.78
270	610	915	585	206	22	1	0	0	0	0	0	12.61	7.20	0.02	2,339	5.37
292.5	442	542	282	52	13	2	0	0	0	0	0	14.45	7.49	0.02	1,333	3.06
315	342	427	169	35	15	0	0	0	0	0	0	11.94	6.12	0.04	988	2.27
337.5	358	407	163	26	6	0	0	0	0	0	0	12.36	6.12	0.04	960	2.20
														Total	43,553	100.00

A.2.2 Significant Wave Height

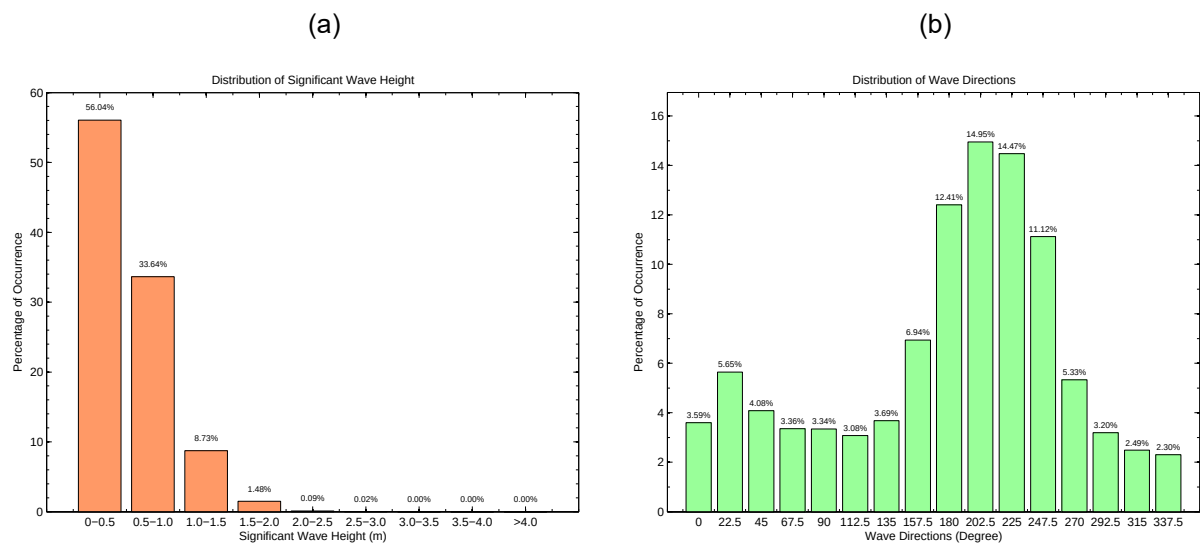


Fig. A.18 (a) Distribution of Significant Wave Height Classes, (b) Distribution of Wave Directions at Rayong (RY) Buoy, (1991-2002)

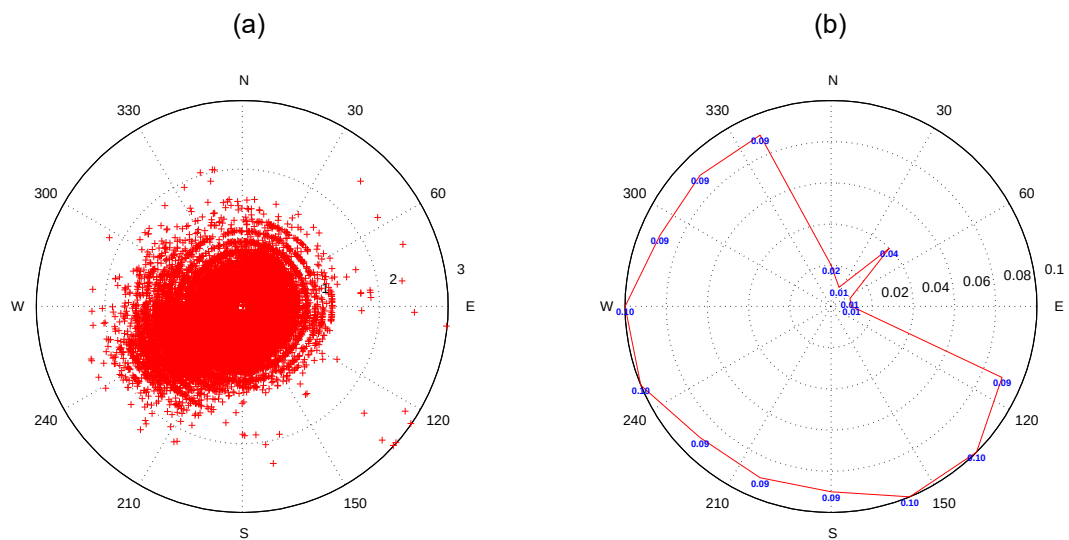


Fig. A.19 (a) Significant Wave Height Distribution (m), (b) Minimum Significant Wave Height (m) at Rayong (RY) Buoy, (1991-2002)

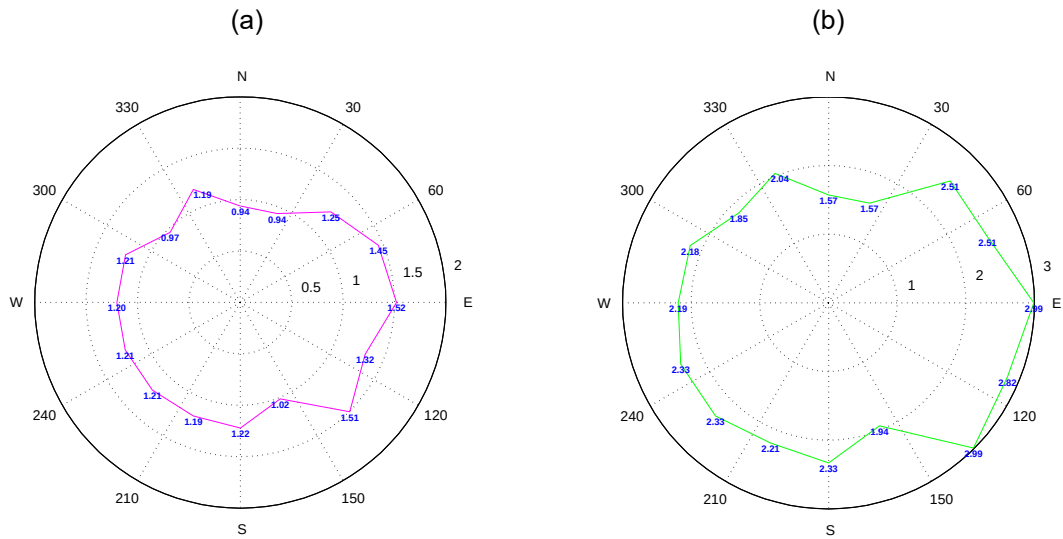


Fig. A.20 (a) Average Significant Wave Height (m), (b) Maximum Significant Wave Height (m) at Rayong (RY) Buoy, (1991-2002)

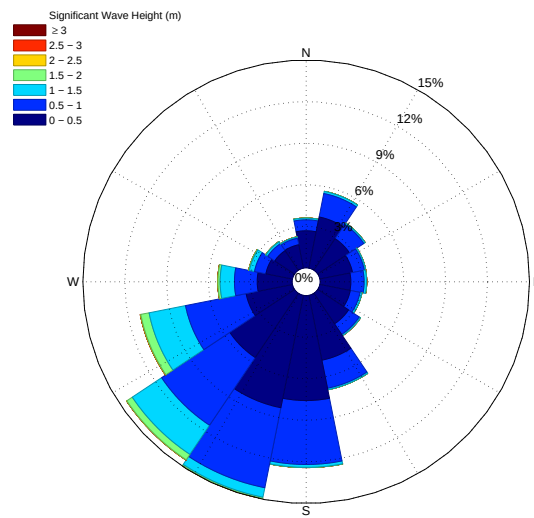


Fig. A.21 Wave Rose Diagram (m) at Rayong (RY) Buoy, (1991-2002)

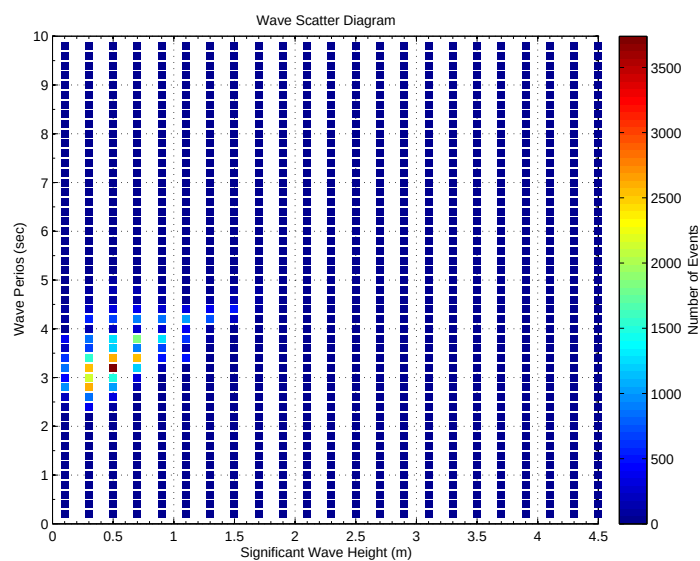


Fig. A.22 Wave Scatter Diagram at Ko Si Chang (KS) Buoy, (1991-2001)

Table A.6 Distribution of Significant Wave Height from 1991 to 2002 at Rayong (RY) Buoy

Dir. (Deg.)	$0 \leq H_s < 0.5$	$0.5 \leq H_s < 1.0$	$1.0 \leq H_s < 1.5$	$1.5 \leq H_s < 2.0$	$2.0 \leq H_s < 2.5$	$2.5 \leq H_s < 3.0$	$3.0 \leq H_s < 3.5$	$3.5 \leq H_s < 4.0$	$H_s \geq 4.0$	Max. Significant Wave Height (m)	Average Significant Wave Height (m)	Min. Significant Wave Height (m)	Number of Events	Events (%)
0	1,293	384	56	6	0	0	0	0	0	1.57	0.94	0.02	1,739	3.59
22.5	1,820	836	76	2	0	0	0	0	0	1.57	0.94	0.01	2,734	5.65
45	1,322	597	53	2	0	1	0	0	0	2.51	1.25	0.04	1,975	4.08
67.5	1,154	419	47	2	1	1	0	0	0	2.51	1.45	0.01	1,624	3.36
90	1,064	461	84	6	1	2	0	0	0	2.99	1.52	0.01	1,618	3.34
112.5	1,074	345	67	1	0	1	0	0	0	2.82	1.32	0.09	1,488	3.08
135	1,283	446	47	2	1	4	0	0	0	2.99	1.51	0.10	1,783	3.69
157.5	2,307	999	52	1	0	0	0	0	0	1.94	1.02	0.10	3,359	6.94
180	3,663	2,233	100	5	2	0	0	0	0	2.33	1.22	0.09	6,003	12.41
202.5	4,000	2,848	337	47	3	0	0	0	0	2.21	1.19	0.09	7,235	14.95
225	2,695	2,847	1,223	230	8	0	0	0	0	2.33	1.21	0.09	7,003	14.47
247.5	1,637	2,142	1,289	293	18	0	0	0	0	2.33	1.21	0.10	5,379	11.12
270	1,211	791	495	76	6	0	0	0	0	2.19	1.20	0.10	2,579	5.33
292.5	937	404	179	25	1	0	0	0	0	2.18	1.21	0.09	1,546	3.20
315	822	294	77	11	0	0	0	0	0	1.85	0.97	0.09	1,204	2.49
337.5	831	232	43	5	3	0	0	0	0	2.04	1.19	0.09	1,114	2.30
Total													48,383	100.00

A.2.3 Current

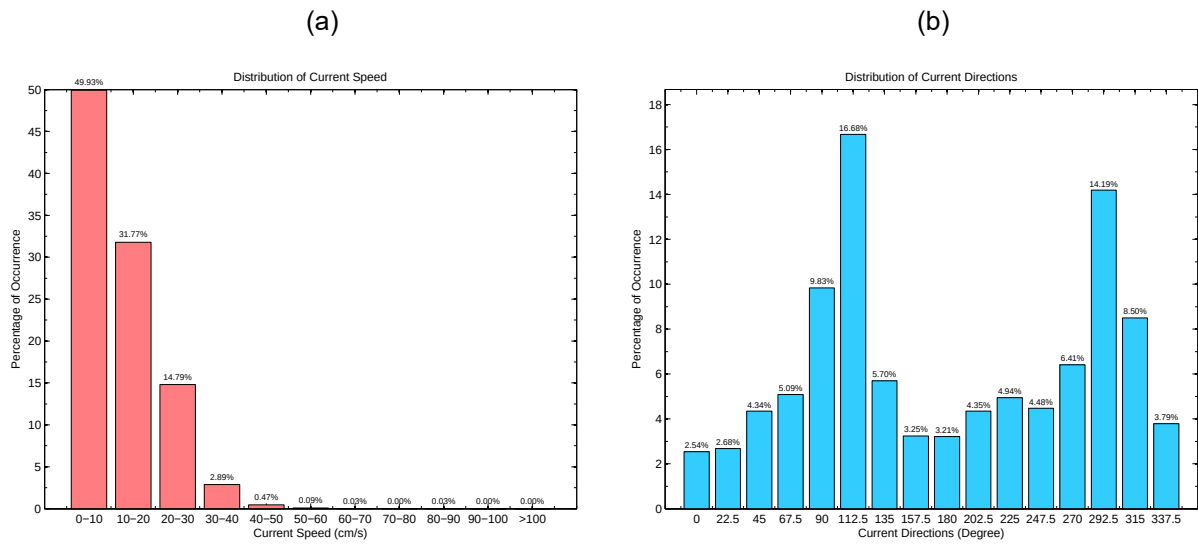


Fig. A.23 (a) Distribution of Current Speed Classes, (b) Distribution of Current Directions at Rayong (RY) Buoy, (1991-2002)

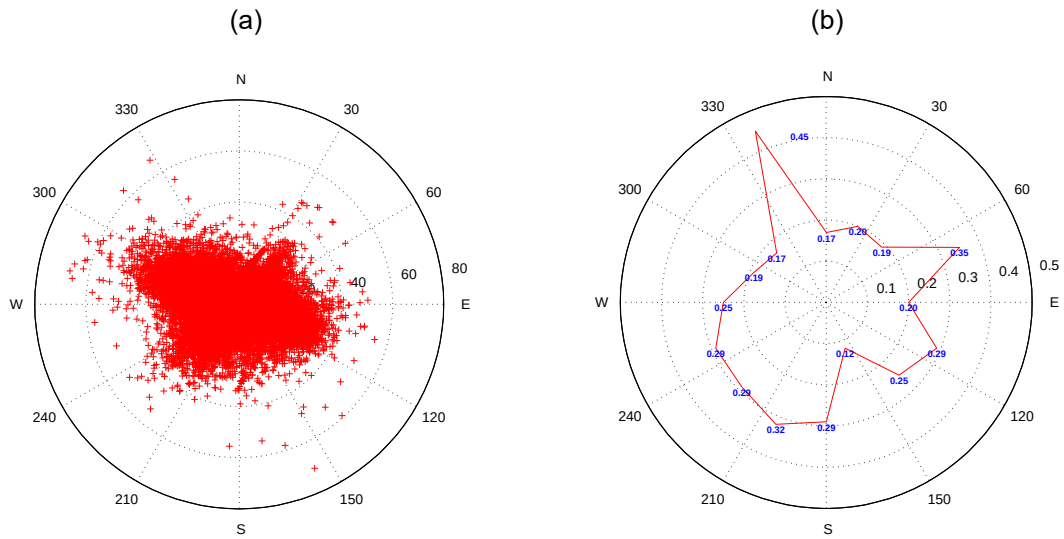


Fig. A.24 (a) Current Speed Distribution (cm/s), (b) Minimum Current Speed (cm/s) at Rayong (RY) Buoy, (1991-2002)

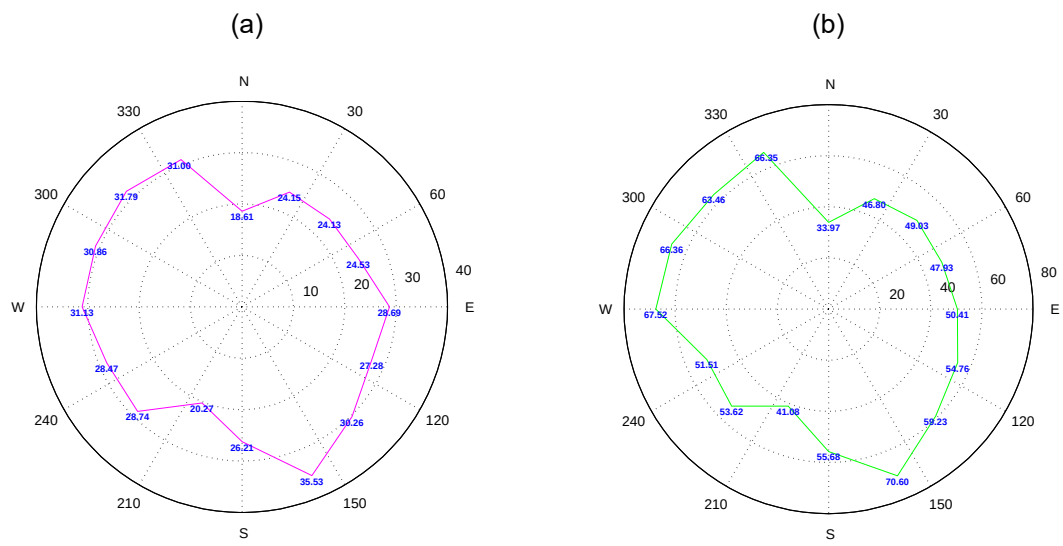


Fig. A.25 (a) Average Current Speed (cm/s), (b) Maximum Current Speed (cm/s) at Rayong (RY) Buoy, (1991-2002)

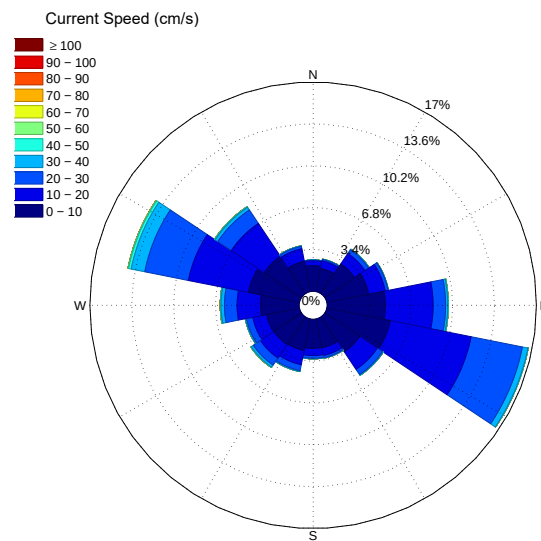


Fig. A.26 Current Rose Diagram (cm/s) at Rayong (RY) Buoy, (1991-2002)

Table A.7 Distribution of Current Speed from 1991 to 2002 at Rayong (RY) Buoy

Dir. (Deg.)	$0 \leq C_s < 10$	$10 \leq C_s < 20$	$20 \leq C_s < 30$	$30 \leq C_s < 40$	$40 \leq C_s < 50$	$50 \leq C_s < 60$	$60 \leq C_s < 70$	$70 \leq C_s < 80$	$80 \leq C_s < 90$	$90 \leq C_s < 100$	$C_s \geq 100$	Max. Current Speed (cm/s)	Average Current Speed (cm/s)	Min. Current Speed (cm/s)	Number of Events	Events (%)
0	785	148	22	4	0	0	0	0	0	0	0	33.97	18.61	0.17	959	2.54
22.5	725	233	46	4	5	0	0	0	0	0	0	46.80	24.15	0.20	1,013	2.68
45	1,093	389	137	14	7	0	0	0	0	0	0	49.03	24.13	0.19	1,640	4.34
67.5	1,307	516	90	8	2	0	0	0	0	0	0	47.93	24.53	0.35	1,923	5.09
90	1,784	1,464	384	65	15	1	0	0	0	0	0	50.41	28.69	0.20	3,713	9.83
112.5	1,978	2,531	1,604	171	7	2	0	5	5	0	0	54.76	27.28	0.29	6,298	16.68
135	1,282	654	189	25	1	2	0	0	0	0	0	59.23	30.26	0.25	2,153	5.70
157.5	899	243	71	8	3	1	0	0	0	0	0	70.60	35.53	0.12	1,226	3.25
180	888	226	82	15	0	2	0	0	0	0	0	55.68	26.21	0.29	1,213	3.21
202.5	983	445	183	30	1	0	0	1	1	0	0	41.08	20.27	0.32	1,643	4.35
225	1,012	501	264	73	15	2	0	0	0	0	0	53.62	28.74	0.29	1,867	4.94
247.5	1,023	435	194	35	2	2	0	0	0	0	0	51.51	28.47	0.29	1,691	4.48
270	1,184	720	386	105	16	6	2	1	1	0	0	67.52	31.13	0.25	2,420	6.41
292.5	1,592	1,879	1,363	424	82	11	7	1	1	0	0	66.36	30.86	0.19	5,359	14.19
315	1,372	1,218	497	97	20	3	1	2	2	0	0	63.46	31.79	0.17	3,210	8.50
337.5	945	393	74	14	1	1	1	1	1	0	0	66.35	31.00	0.45	1,430	3.79
Total															37,758	100.00

A.3 METEOROLOGICAL OCEAN DATA AT HUA HIN (HH) BUOY

A.3.1 Wind

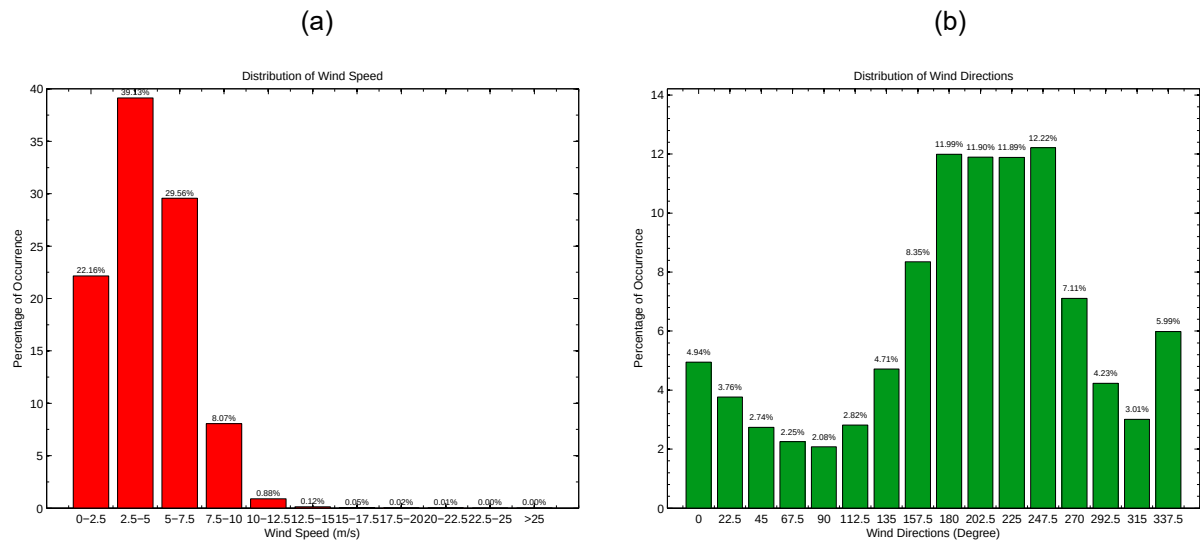


Fig. A.27 (a) Distribution of Wind Speed Classes, (b) Distribution of Wind Directions at at Hua Hin (HH) Buoy, (1993-2002)

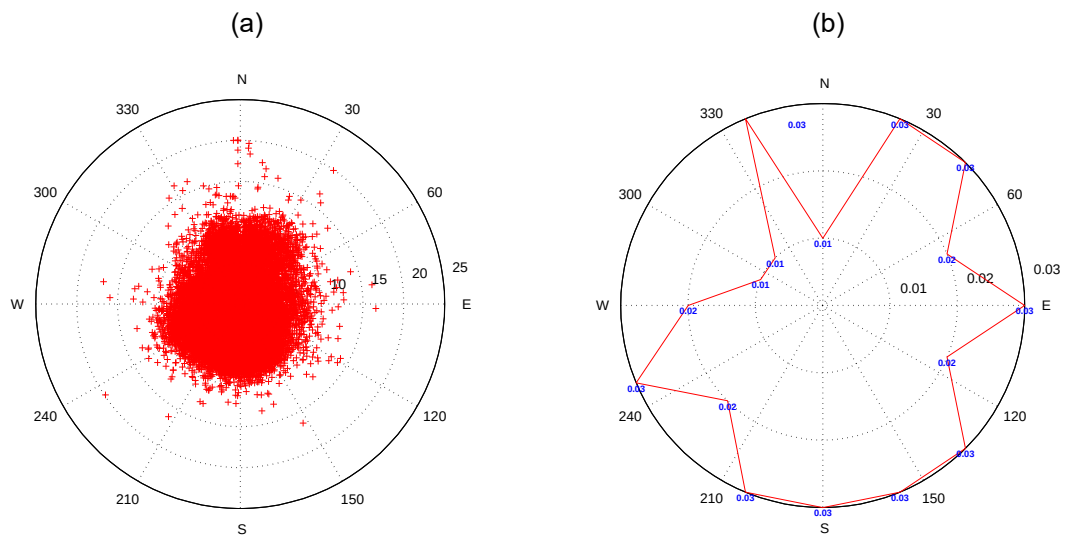


Fig. A.28 (a) Wind Speed Distribution (m/s), (b) Minimum Wind Speed (m/s) at Hua Hin (HH) Buoy, (1993-2002)

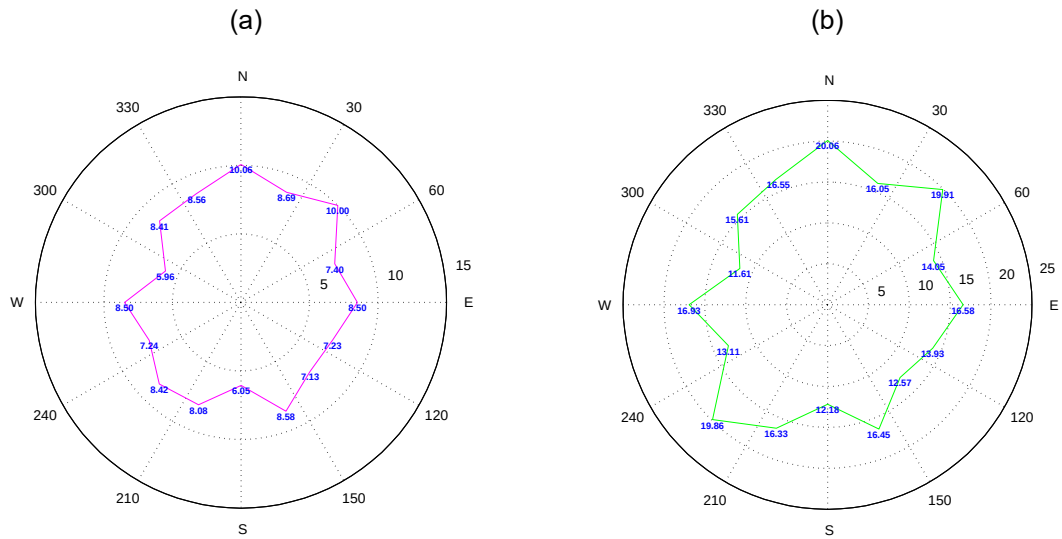


Fig. A.29 (a) Average Wind Speed (m/s), (b) Maximum Wind Speed (m/s) at Hua Hin (HH) Buoy, (1993-2002)

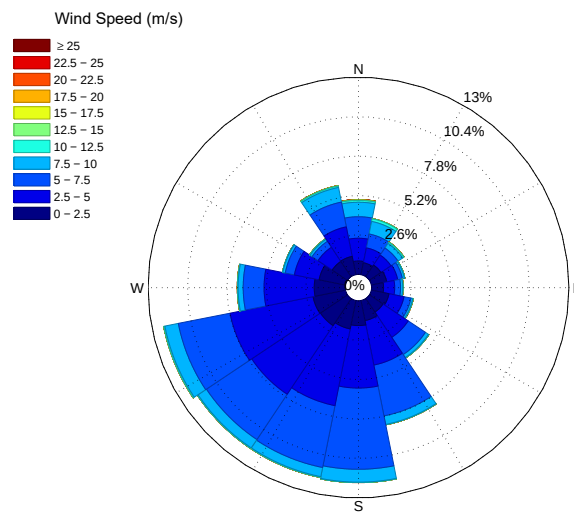


Fig. A.30 Wind Rose Diagram (m/s) at Hua Hin (HH) Buoy, (1993-2002)

Table A.8 Distribution of Wind Speed from 1993 to 2002 at Hua Hin (HH) Buoy

Dir. (Deg.)	$0.0 \leq W_s < 2.5$	$2.5 \leq W_s < 5.0$	$5.0 \leq W_s < 7.5$	$7.5 \leq W_s < 10$	$10 \leq W_s < 12.5$	$12.5 \leq W_s < 15.0$	$15.0 \leq W_s < 17.5$	$17.5 \leq W_s < 20.0$	$20.0 \leq W_s < 22.5$	$22.5 \leq W_s < 25.0$	$W_s \geq 25.0$	Max. Wind Speed (m/s)	Average Wind Speed (m/s)	Min. Wind Speed (m/s)	Number of Events	Events (%)
0	325	556	522	352	44	9	4	0	0	0	0	20.06	10.06	0.01	1,819	4.94
22.5	295	366	342	311	65	4	1	0	0	0	0	16.05	8.69	0.03	1,384	3.76
45	337	291	206	134	35	3	2	0	0	0	0	19.91	10.00	0.03	1,009	2.74
67.5	381	270	116	50	10	1	0	0	0	0	0	14.05	7.40	0.02	828	2.25
90	290	270	142	53	7	2	2	0	0	0	0	16.58	8.50	0.03	766	2.08
112.5	436	370	172	46	8	5	0	0	0	0	0	13.93	7.23	0.02	1,037	2.82
135	396	738	500	89	10	1	0	0	0	0	0	12.57	7.13	0.03	1,734	4.71
157.5	496	1,100	1,258	211	6	2	1	0	0	0	0	16.45	8.58	0.03	3,074	8.35
180	602	1,515	1,971	312	11	0	0	2	2	0	0	12.18	6.05	0.03	4,413	11.99
202.5	702	1,898	1,530	227	17	2	1	2	2	0	0	16.33	8.08	0.03	4,379	11.90
225	788	2,004	1,321	245	17	0	0	0	0	0	0	19.86	8.42	0.02	4,376	11.89
247.5	803	2,052	1,280	332	25	4	0	0	0	0	0	13.11	7.24	0.03	4,496	12.22
270	753	1,216	506	124	13	3	2	0	0	0	0	16.93	8.50	0.02	2,617	7.11
292.5	653	611	226	62	6	0	0	0	0	0	0	11.61	5.96	0.01	1,558	4.23
315	445	413	174	59	14	2	1	0	0	0	0	15.61	8.41	0.01	1,108	3.01
337.5	452	731	612	362	35	8	4	0	0	0	0	16.55	8.56	0.03	2,204	5.99
Total															36,802	100.00

A.3.2 Significant Wave Height

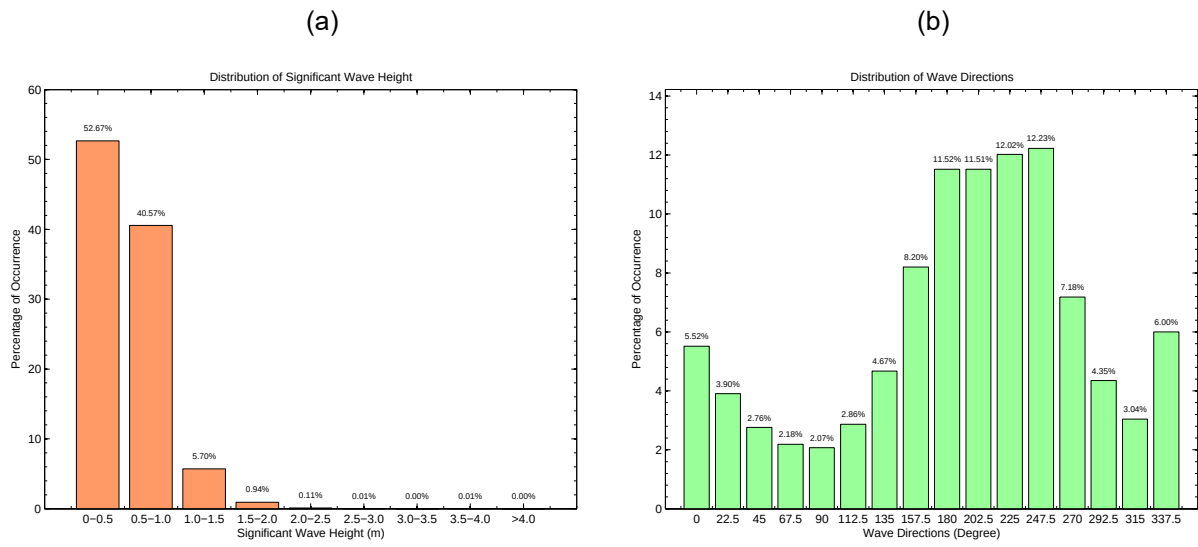


Fig. A.31 (a) Distribution of Significant Wave Height Classes, (b) Distribution of Wave Directions at Hua Hin (HH) Buoy, (1993-2002)

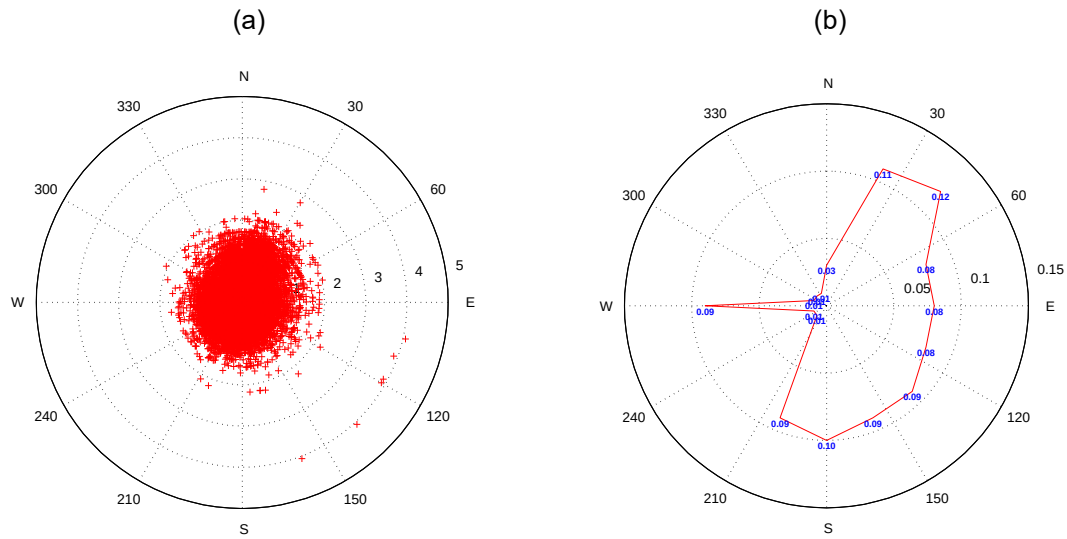


Fig. A.32 (a) Significant Wave Height Distribution (m), (b) Minimum Significant Wave Height (m) at Hua Hin (HH) Buoy, (1993-2002)

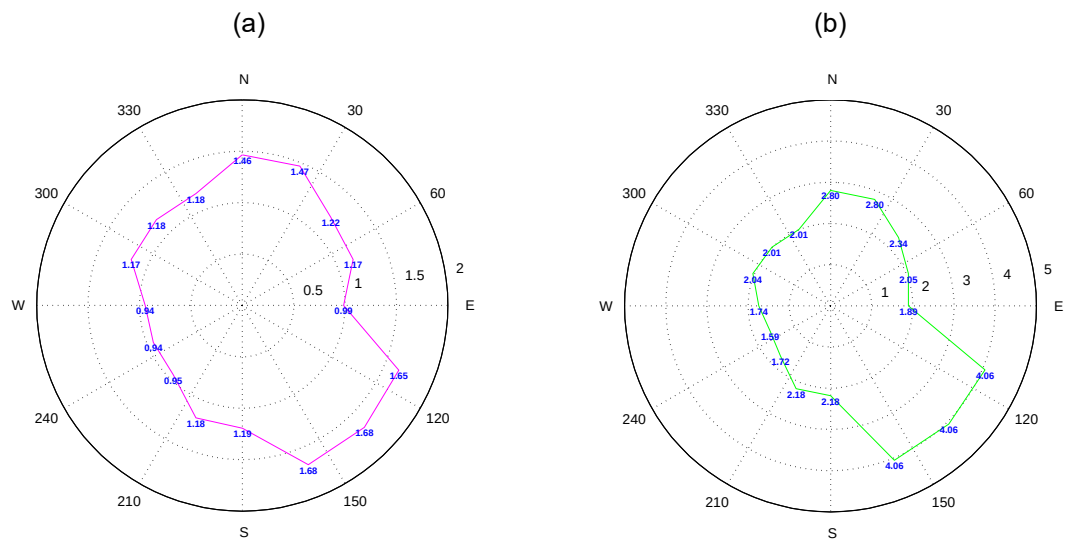


Fig. A.33 (a) Average Significant Wave Height (m), (b) Maximum Significant Wave Height (m) at Hua Hin (HH) Buoy, (1993-2002)

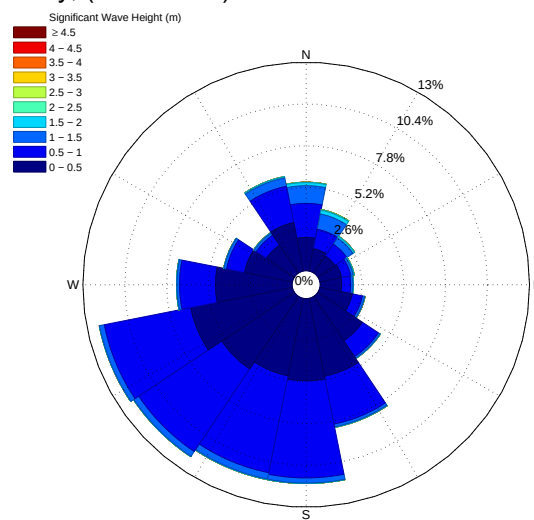


Fig. A.34 Wave Rose Diagram (m) at Hua Hin (HH) Buoy, (1993-2002)

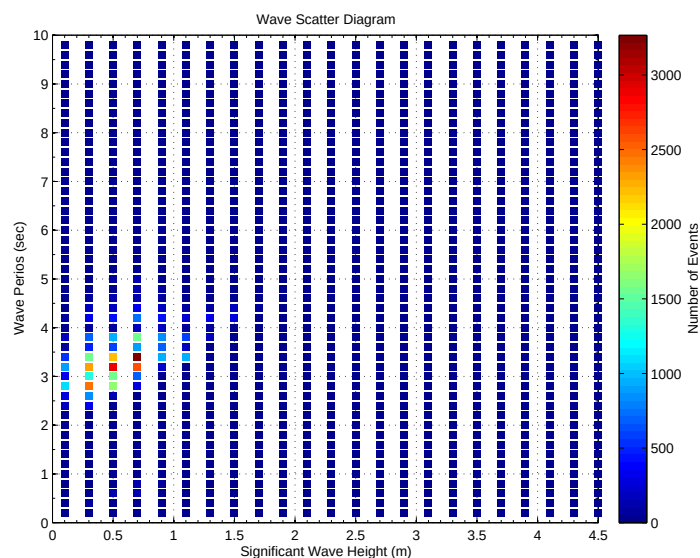


Fig. A.35 Wave Scatter Diagram at Hua Hin (HH) Buoy, (1993-2002)

Table A.9 Distribution of Significant Wave Height from 1993 to 2002 at Hua Hin (HH) Buoy

Dir. (Deg.)	$0 \leq H_s < 0.5$	$0.5 \leq H_s < 1.0$	$1.0 \leq H_s < 1.5$	$1.5 \leq H_s < 2.0$	$2.0 \leq H_s < 2.5$	$2.5 \leq H_s < 3.0$	$3.0 \leq H_s < 3.5$	$3.5 \leq H_s < 4.0$	$H_s \geq 4.0$	Max. Significant Wave Height (m)	Average Significant Wave Height (m)	Min. Significant Wave Height (m)	Number of Events	Events (%)
0	898	918	476	85	7	2	0	0	0	2.80	1.46	0.03	2,386	5.52
22.5	614	534	421	103	16	1	0	0	0	2.80	1.47	0.11	1,689	3.90
45	552	386	200	49	6	0	0	0	0	2.34	1.22	0.12	1,193	2.76
67.5	595	249	69	26	5	0	0	0	0	2.05	1.17	0.08	944	2.18
90	578	242	59	16	0	0	0	0	0	1.89	0.99	0.08	895	2.07
112.5	886	277	62	6	3	0	0	4	0	4.06	1.65	0.08	1,238	2.86
135	1,439	517	52	9	1	0	0	1	0	4.06	1.68	0.09	2,019	4.67
157.5	2,139	1,316	76	11	3	0	0	1	0	4.06	1.68	0.09	3,546	8.20
180	2,213	2,619	138	11	1	0	0	0	0	2.18	1.19	0.10	4,982	11.52
202.5	2,127	2,662	176	13	2	0	0	0	0	2.18	1.18	0.09	4,980	11.51
225	2,351	2,680	159	8	0	0	0	0	0	1.72	0.95	0.01	5,198	12.02
247.5	2,785	2,366	132	6	0	0	0	0	0	1.59	0.94	0.01	5,289	12.23
270	2,058	965	72	10	0	0	0	0	0	1.74	0.94	0.09	3,105	7.18
292.5	1,312	490	72	5	1	0	0	0	0	2.04	1.17	0.01	1,880	4.35
315	905	327	69	14	1	0	0	0	0	2.01	1.18	0.01	1,316	3.04
337.5	1,330	999	231	33	3	0	0	0	0	2.01	1.18	0.01	2,596	6.00
Total													43,256	100.00

A.3.3 Current

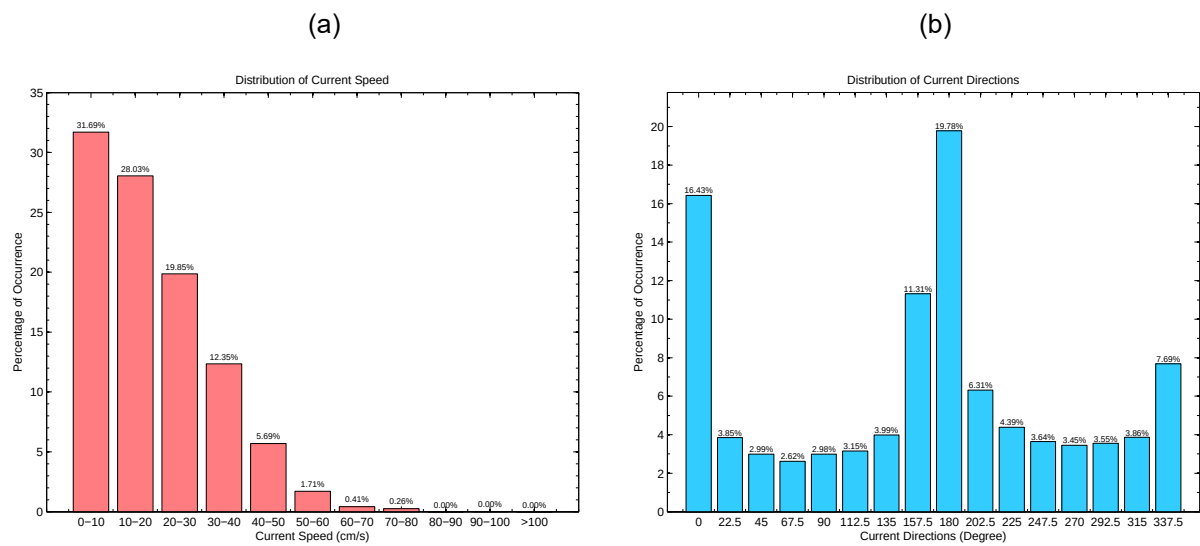


Fig. A.36 (a) Distribution of Current Speed Classes, (b) Distribution of Current Directions at Hua Hin (HH) Buoy, (1993-2002)

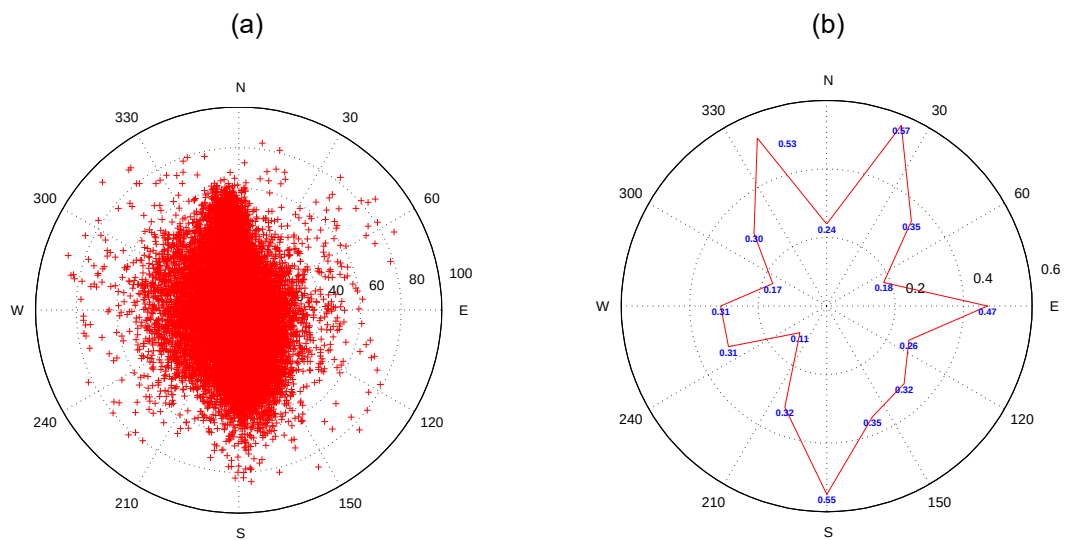


Fig. A.37 (a) Current Speed Distribution (cm/s), (b) Minimum Current Speed (cm/s) at Hua Hin (HH) Buoy, (1993-2002)

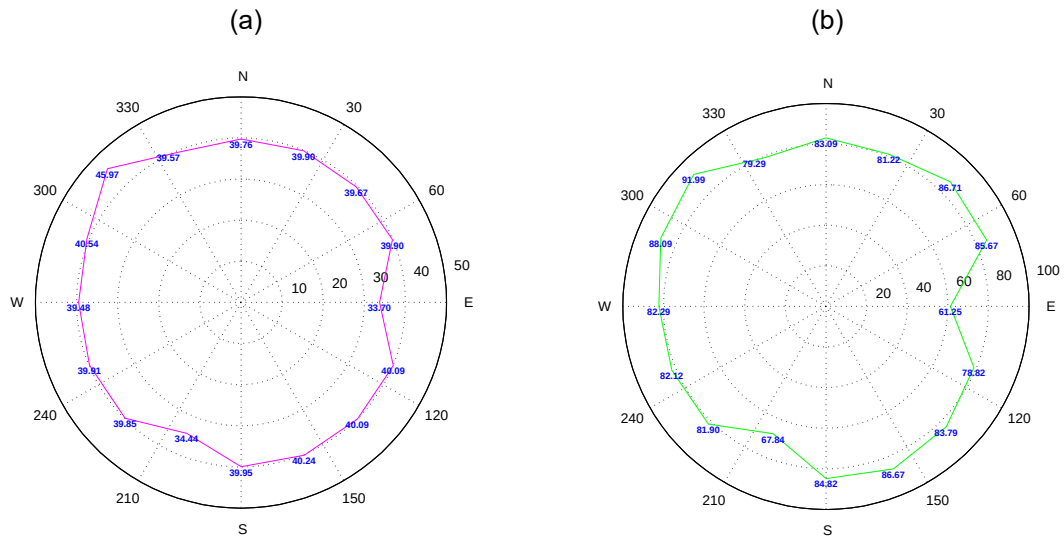


Fig. A.38 (a) Average Current Speed (cm/s), (b) Maximum Current Speed (cm/s) at Hua Hin (HH) Buoy, (1993-2002)

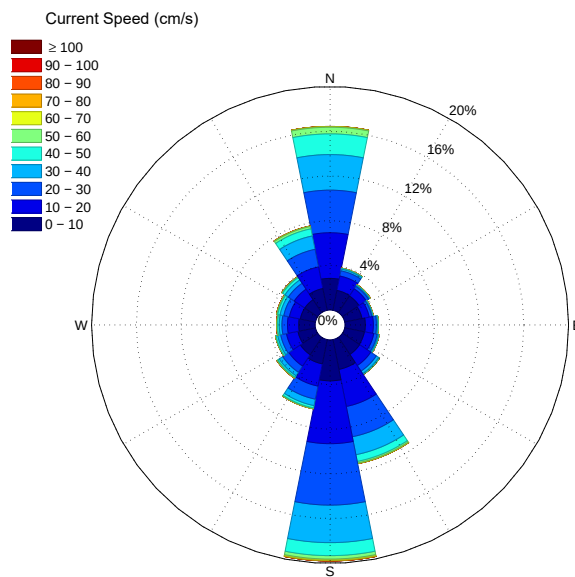


Fig. A.39 Current Rose Diagram (cm/s) at Hua Hin (HH) Buoy, (1993-2002)

Table A.10 Distribution of Current Speed from 1993 to 2002 at Hua Hin (HH) Buoy

Dir. (Deg.)	$0 \leq C_s < 10$	$10 \leq C_s < 20$	$20 \leq C_s < 30$	$30 \leq C_s < 40$	$40 \leq C_s < 50$	$50 \leq C_s < 60$	$60 \leq C_s < 70$	$70 \leq C_s < 80$	$80 \leq C_s < 90$	$90 \leq C_s < 100$	$C_s \geq 100$	Max. Current Speed (cm/s)	Average Current Speed (cm/s)	Min. Current Speed (cm/s)	Number of Events	Events (%)
0	1,093	1,578	1,472	1,230	714	233	24	0	0	0	0	83.09	39.76	0.24	6,346	16.43
22.5	699	509	183	60	22	7	4	0	0	0	0	81.22	39.90	0.57	1,487	3.85
45	686	299	101	33	14	10	6	0	0	0	0	86.71	39.67	0.35	1,157	2.99
67.5	608	256	90	28	12	11	1	0	0	0	0	85.67	39.90	0.18	1,012	2.62
90	701	279	106	32	23	10	2	0	0	0	0	61.25	33.70	0.47	1,153	2.98
112.5	692	330	120	39	21	6	4	0	0	0	0	78.82	40.09	0.26	1,216	3.15
135	710	463	232	100	22	9	2	0	0	0	0	83.79	40.09	0.32	1,542	3.99
157.5	1,049	1,307	1,068	633	236	54	21	0	0	0	0	86.67	40.24	0.35	4,371	11.31
180	1,415	2,174	2,122	1,298	449	119	43	0	0	0	0	84.82	39.95	0.55	7,641	19.78
202.5	855	783	461	227	81	21	10	0	0	0	0	67.84	34.44	0.32	2,438	6.31
225	720	474	257	146	59	24	9	0	0	0	0	81.90	39.85	0.11	1,696	4.39
247.5	615	405	204	105	57	14	6	0	0	0	0	82.12	39.91	0.31	1,408	3.64
270	568	389	190	95	57	17	5	0	0	0	0	82.29	39.48	0.31	1,333	3.45
292.5	532	385	198	131	83	24	7	0	0	0	0	88.09	40.54	0.17	1,372	3.55
315	534	438	245	141	98	22	6	0	0	1	0	91.99	45.97	0.30	1,493	3.86
337.5	765	762	621	472	251	81	10	0	0	0	0	79.29	39.57	0.53	2,970	7.69
															Total	38,635
																100.00

Table A.11 Oceanographic Buoy Instrument Detail

Instrument	Parameters	Record interval	Number of record in interval	Records time	Record time step	Record range	Accuracy	Error	Signal frequency
Wind Speed Sensor 2740	Wind speed	10 min.	Real time	10 min.	1 hr.	Min. 76 m/s	N/A	± 2 or ± 20 cm/s	N/A
Wind Direction Sensor 2750	Wind direction	0	1	10 min.	1 hr.	$0^\circ - 360^\circ$	N/A	Min. $\pm 5^\circ$	N/A
Buoy Orientation Sensor 2864	Buoy orientation	0	1	10 min.	1 hr.	$0^\circ - 360^\circ$	N/A	Min. $\pm 5^\circ$	N/A
Wave Sensor	Wave height	1024 sec.	2048	0.5 sec.	3 hr.	0 – 40 sec.	N/A	10 cm.	N/A
UCM-40 Current Meter	Current speed	10 min.	32x60x10	1/32 sec.	1 hr.	0 – ± 6 m/s	1 mm./sec.	3% of measure	N/A
	Tilt	10 min.	32x60x10	1/32 sec.	1 hr.	$\pm 30^\circ$	1°	$\pm 10\%$ of measure	N/A
	Fluxgate	10 min.	32x60x10	1/32 sec.	1 hr.	N/A	1°	$\pm 2^\circ$	N/A
Sensor Scanning Unit 3010	Record data	N/A	N/A	N/A	N/A	N/A	10 bit	± 1 bit	N/A
ARGOS Transmitter	Transmitter of ARGOS System	N/A	N/A	90 min.	N/A	N/A	N/A	N/A	401 – 650 MHz
INMARSAT Transmitter	Transmitter of INMARSAT System	N/A	1	1 hr.	N/A	N/A	N/A	N/A	1626.5-1646.5 MHz

Appendix B

Wave Model Results due to Tropical Cyclone Linda

Wave model presented in Chapter 5 that represented results in time series in this appendix. The results showed the significant wave height, peak wave period and wave direction at port in Ao Udom Bay and Rayong Sea. The function of time is a local time of +7UTC, on 1st November 1997, 00:00 (+7UTC) to 6th November 1997, 00:00 (+7UTC)

B.1 AO UDOM BAY

B.1.1 KSSP Port

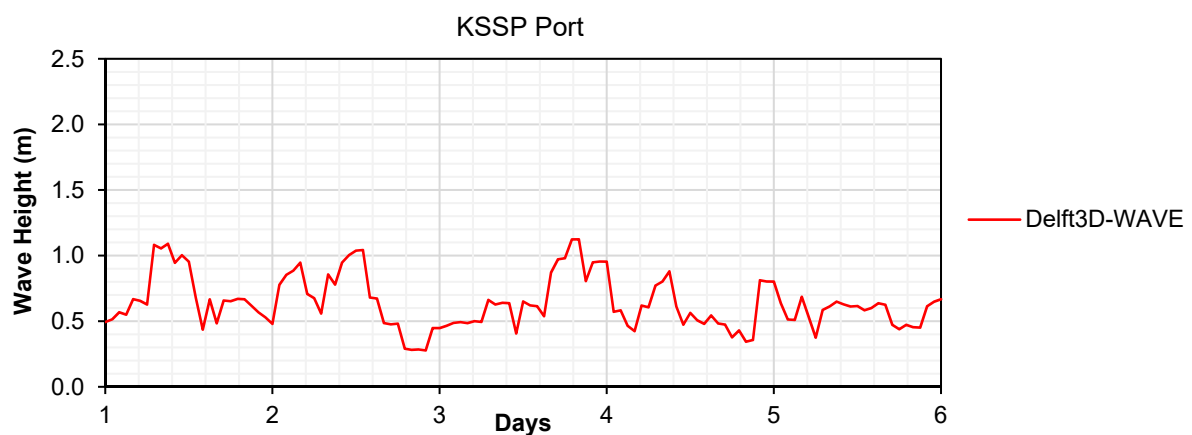


Fig. B.1 Significant Wave Height at KSSP Port

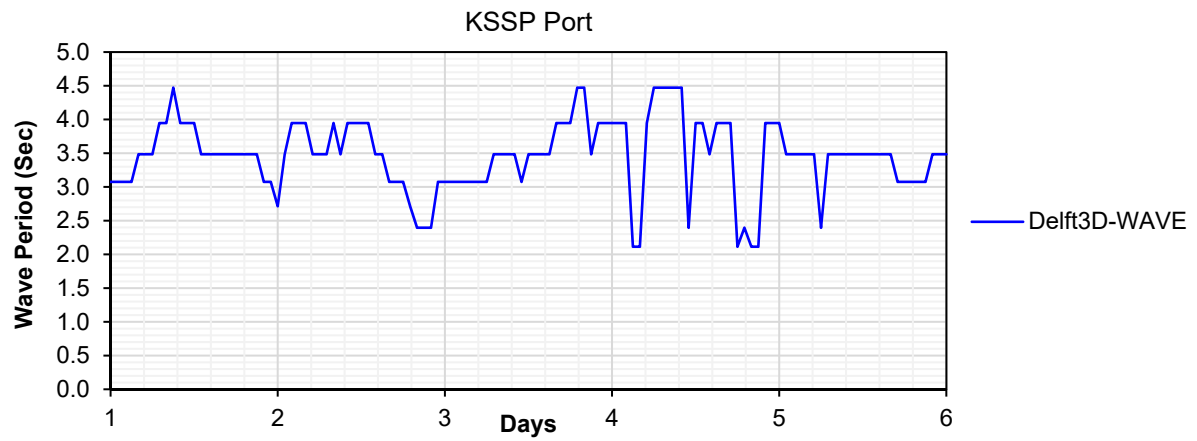


Fig. B.2 Peak Wave Period at KSSP Port

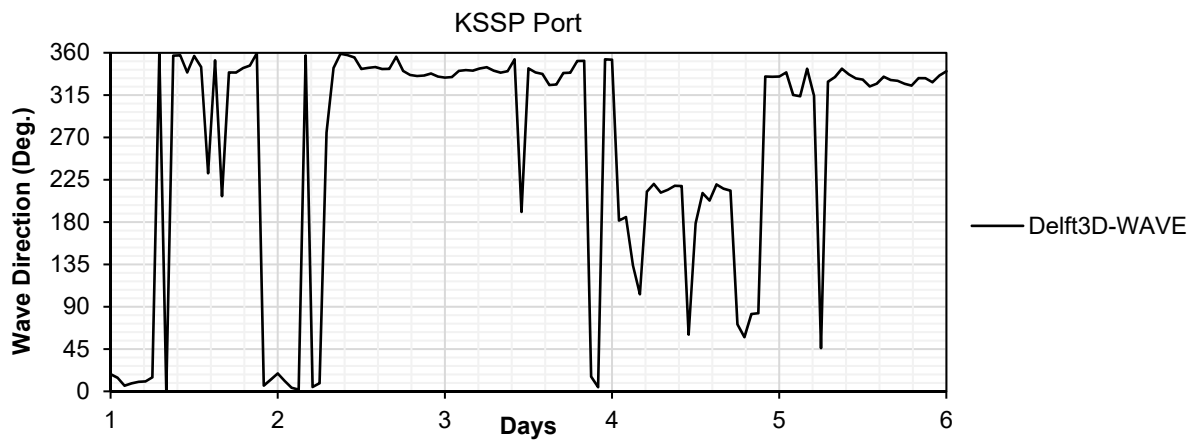


Fig. B.3 Wave Direction at KSSP Port

B.1.2 PTT Port

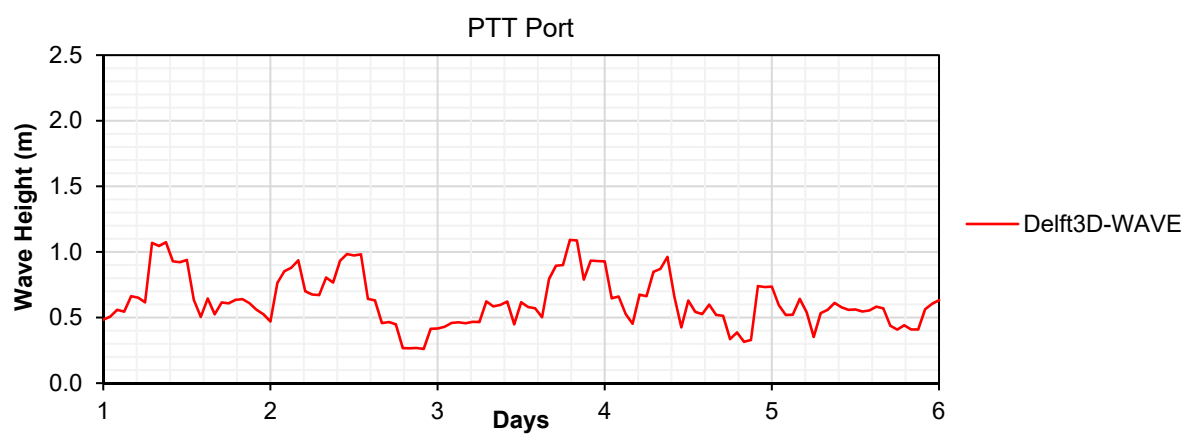


Fig. B.4 Significant Wave Height at PTT Port

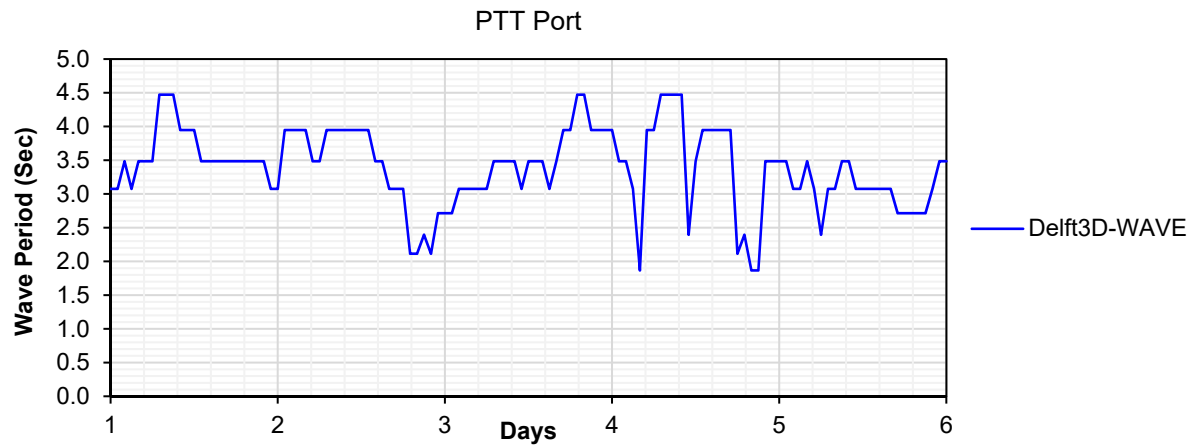


Fig. B.5 Peak Wave Period at PTT Port

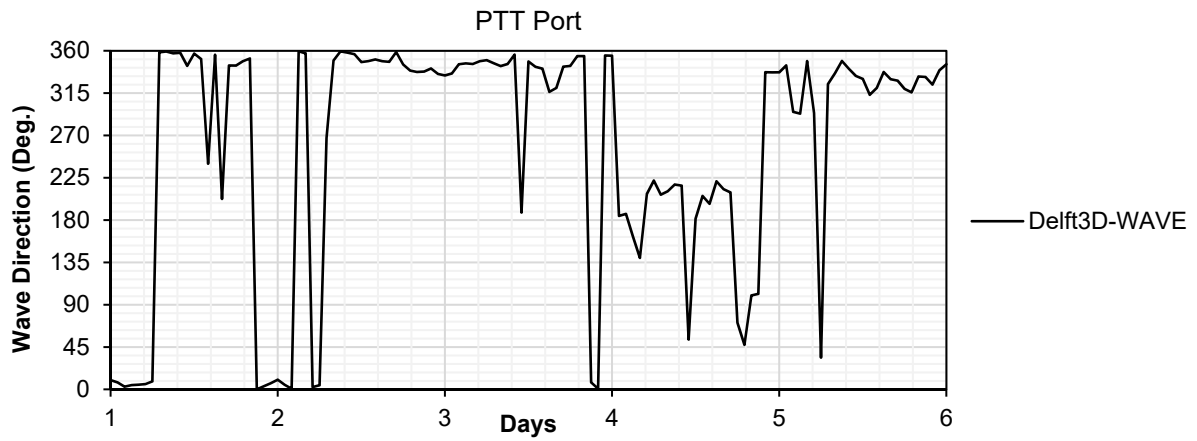


Fig. B.6 Wave Direction at PTT Port

B.1.3 SRH Port

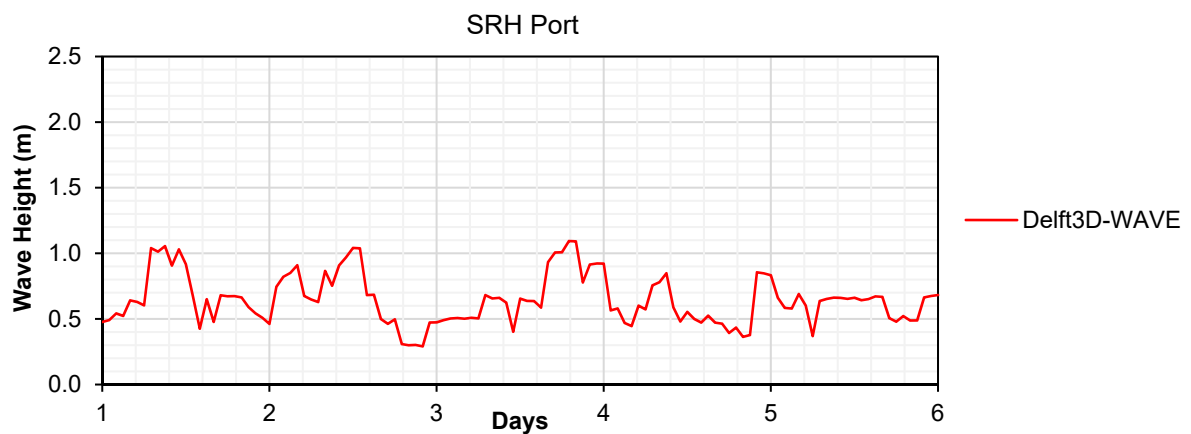


Fig. B.7 Significant Wave Height at SRH Port

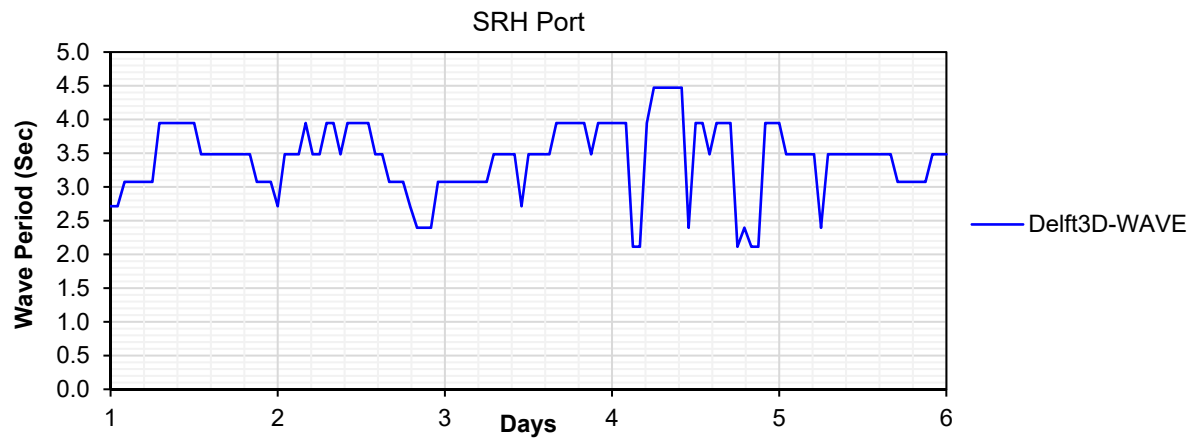


Fig. B.8 Peak Wave Period at SRH Port

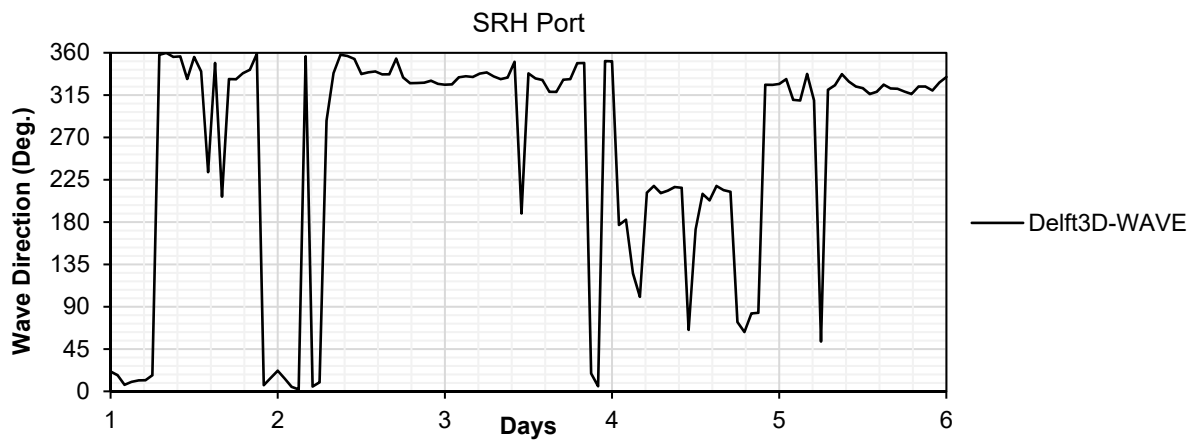


Fig. B.9 Wave Direction at SRH Port

B.1.4 TOP Port

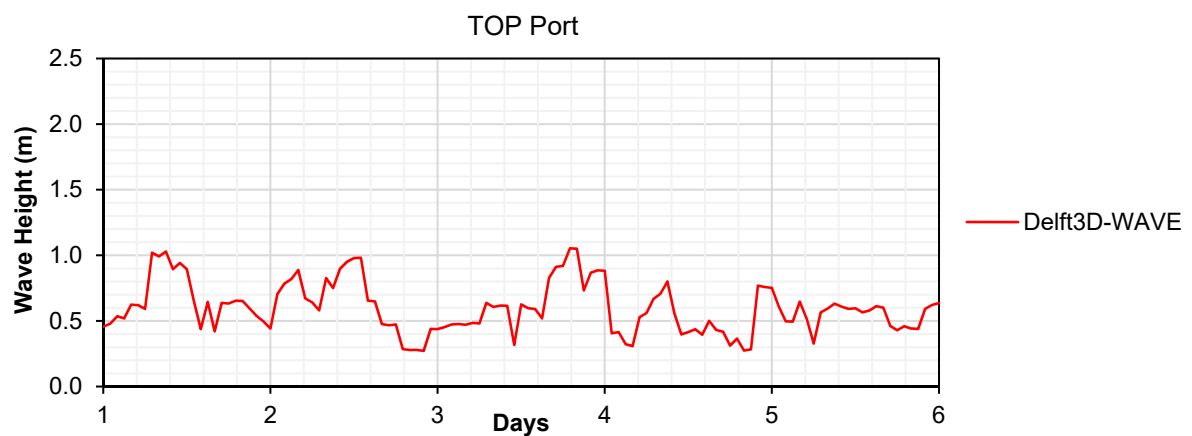


Fig. B.10 Significant Wave Height at TOP Port

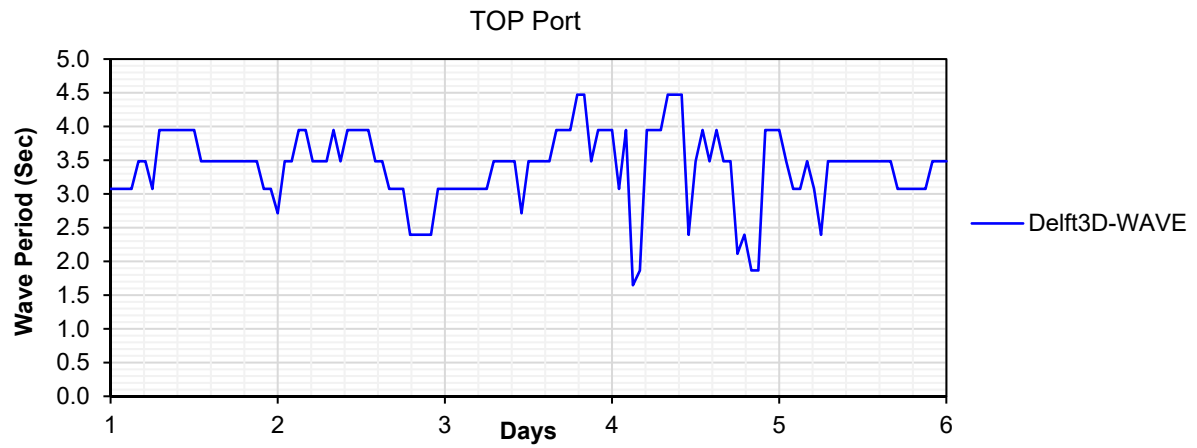


Fig. B.11 Peak Wave Period at TOP Port

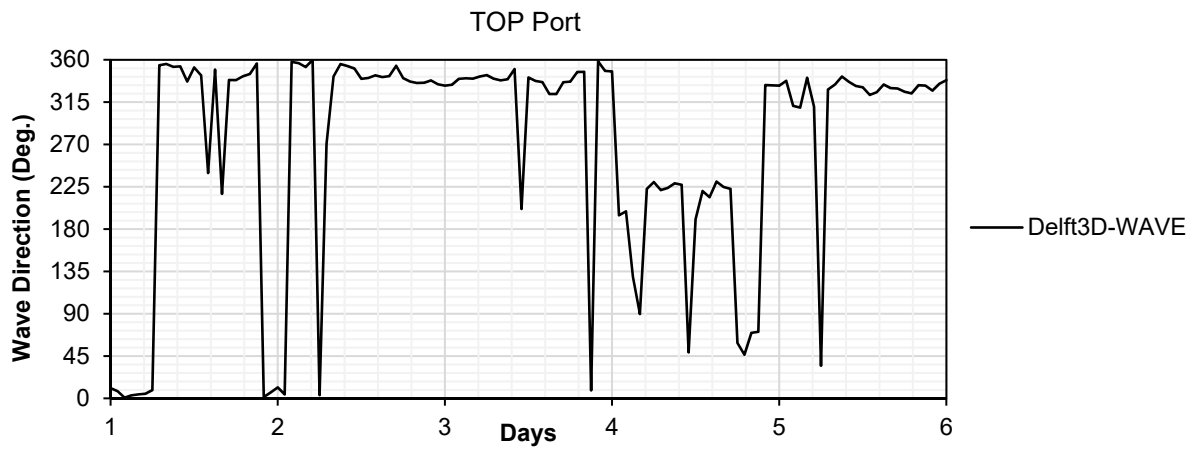


Fig. B.12 Wave Direction at TOP Port

B.2 RAYONG SEA

B.2.1 BLCP Port

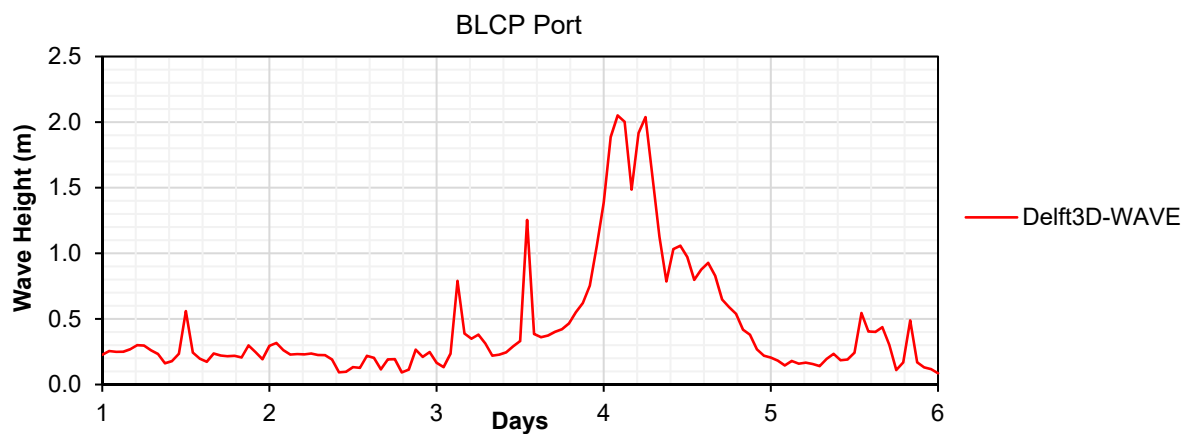


Fig. B.13 Significant Wave Height at BLCP Port

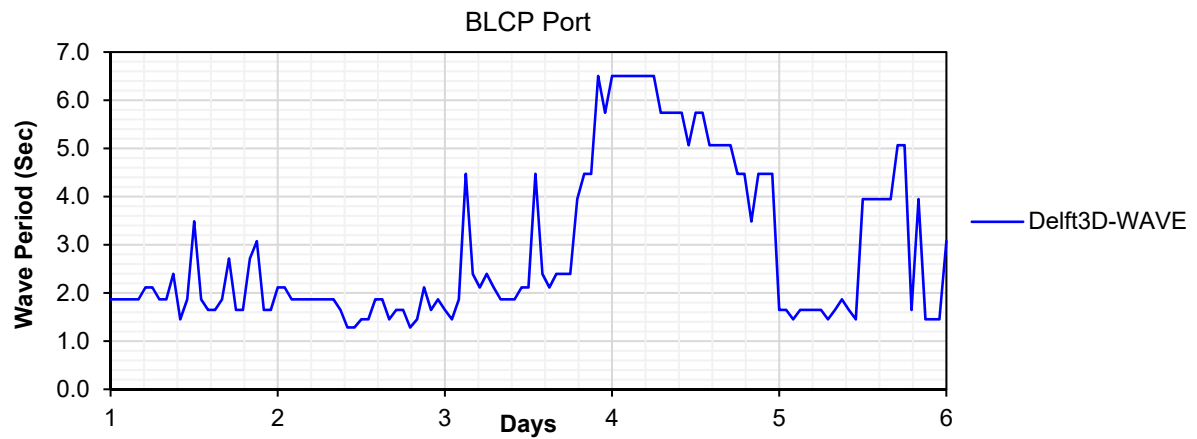


Fig. B.14 Peak Wave Period at BLCP Port

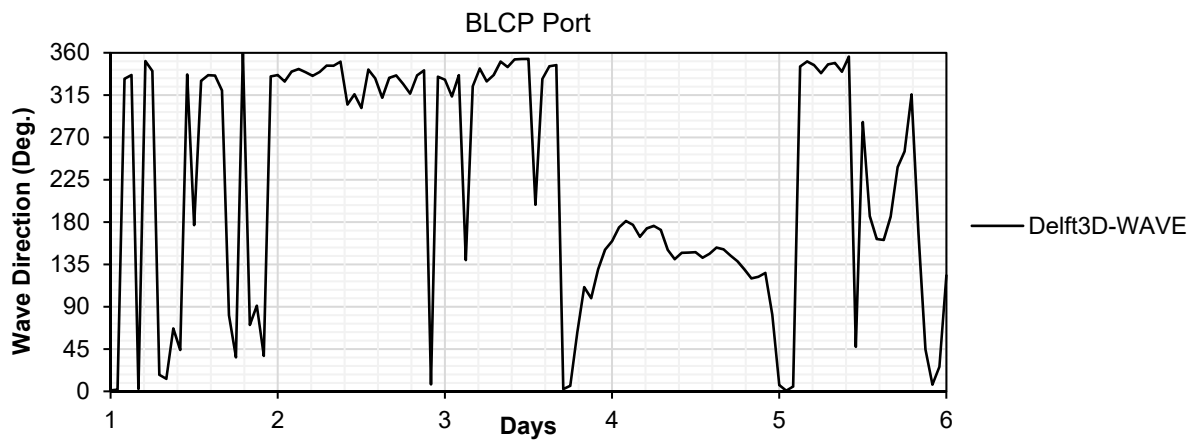


Fig. B.15 Wave Direction at BLCP Port

B.2.2 IRPC Port

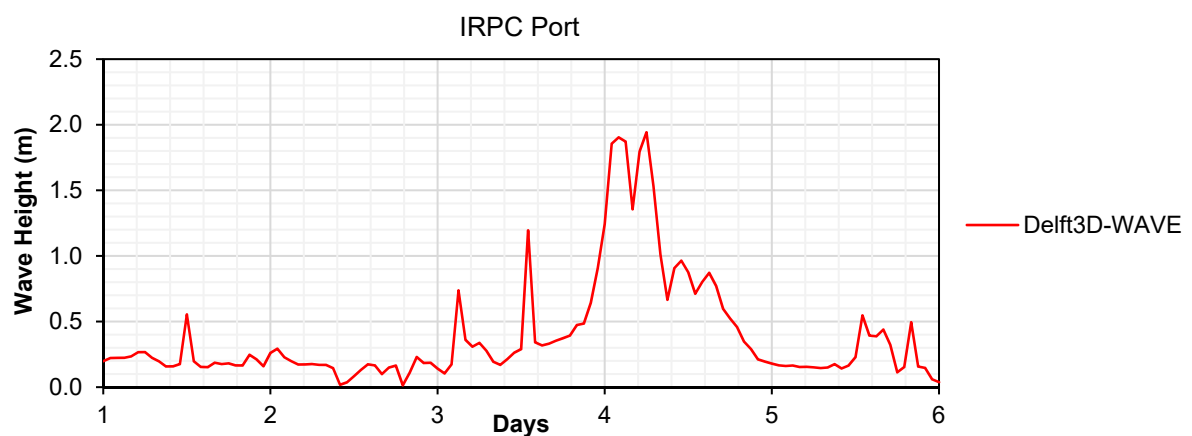


Fig. B.16 Significant Wave Height at IRPC Port

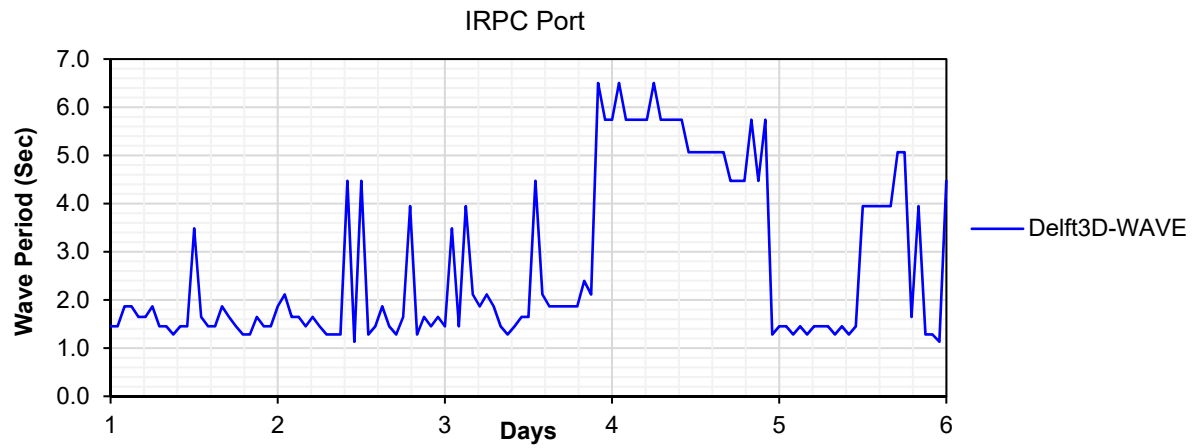


Fig. B.17 Peak Wave Period at IRPC Port

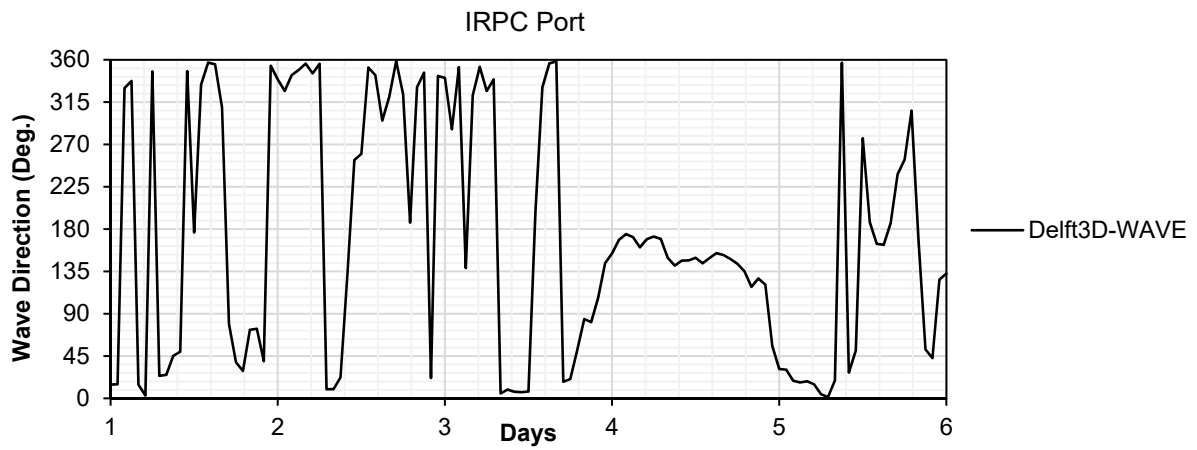


Fig. B.18 Wave Direction at IRPC Port

Appendix C

Hydrodynamics Model Results

The hydrodynamic model as presented in Chapter 5 is represented a results in this appendix, that included hydrodynamics model results by tidal forcing and subjected to tropical cyclone Linda.

C.1 PRANBURI TIDE STATION

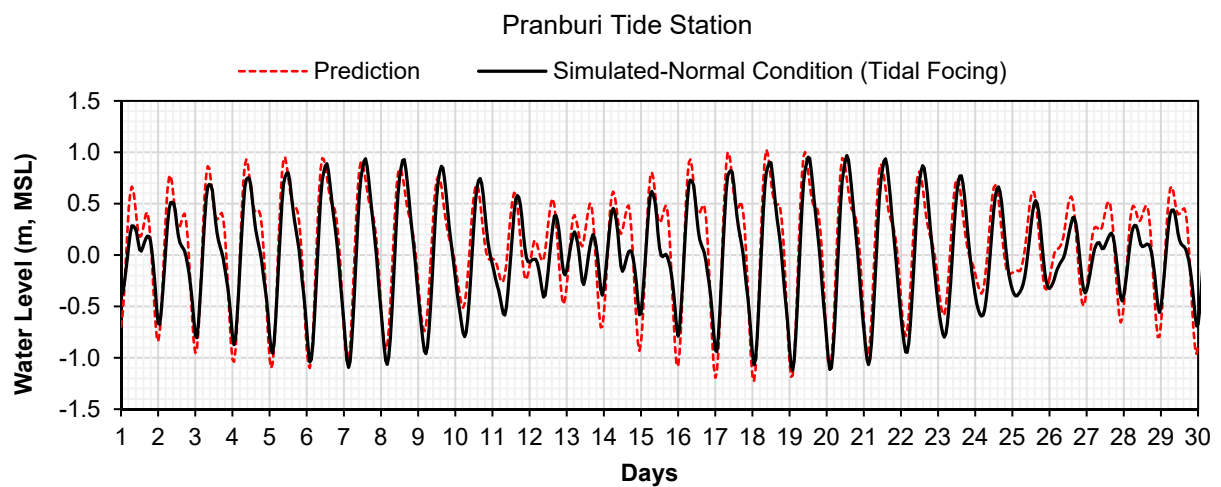


Fig. C.1 Water Level at Panburi Tide Station from 1st November to 30th November 1997 (+7UTC) - Normal Condition (Tidal Focusing)

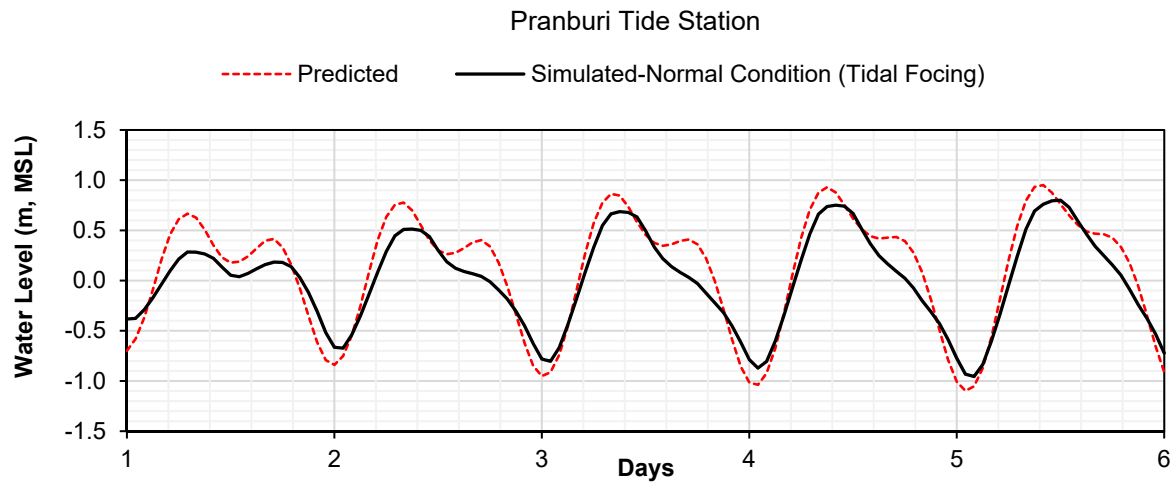


Fig. C.2 Water Level at Panburi Tide Station from 1st November to 6th November 1997 (+7UTC) - Normal Condition (Tidal Focing)

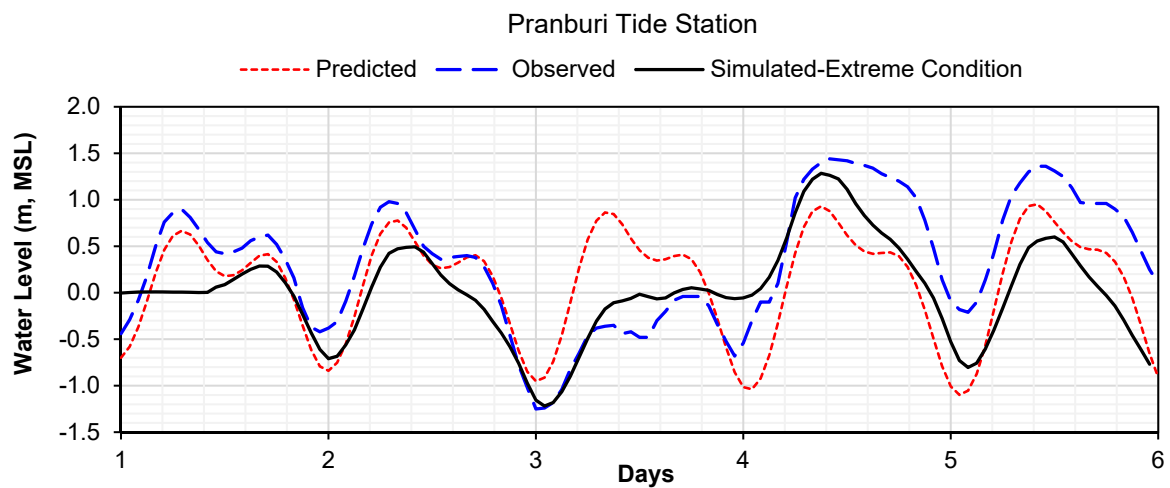


Fig. C.3 Water Level at Panburi Tide Station from 1st November to 6th November 1997 (+7UTC) - Extreme Condition

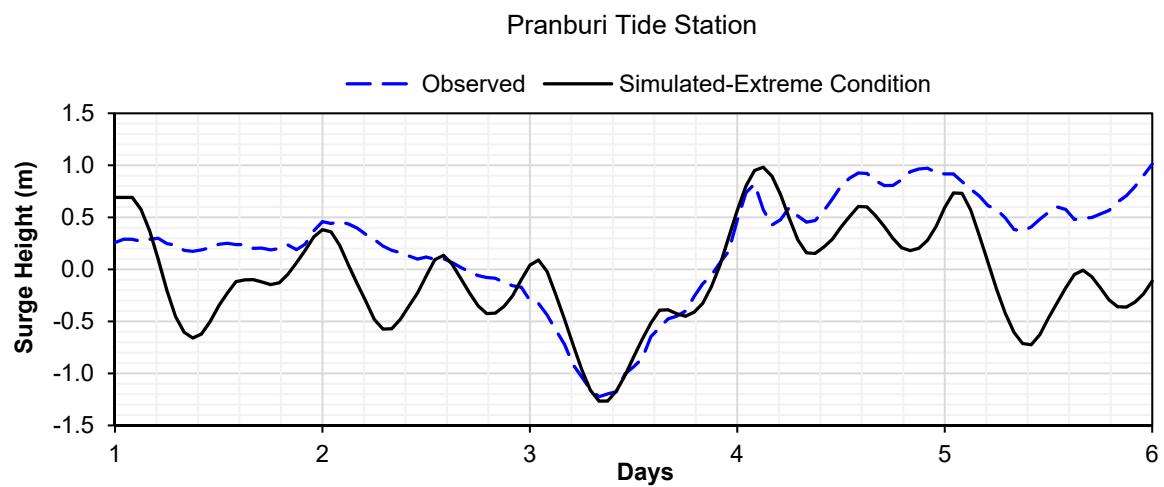


Fig. C.4 Surge Height at Panburi Tide Station from 1st November to 6th November 1997 (+7UTC)

C.2 BANLEAM TIDE STATION

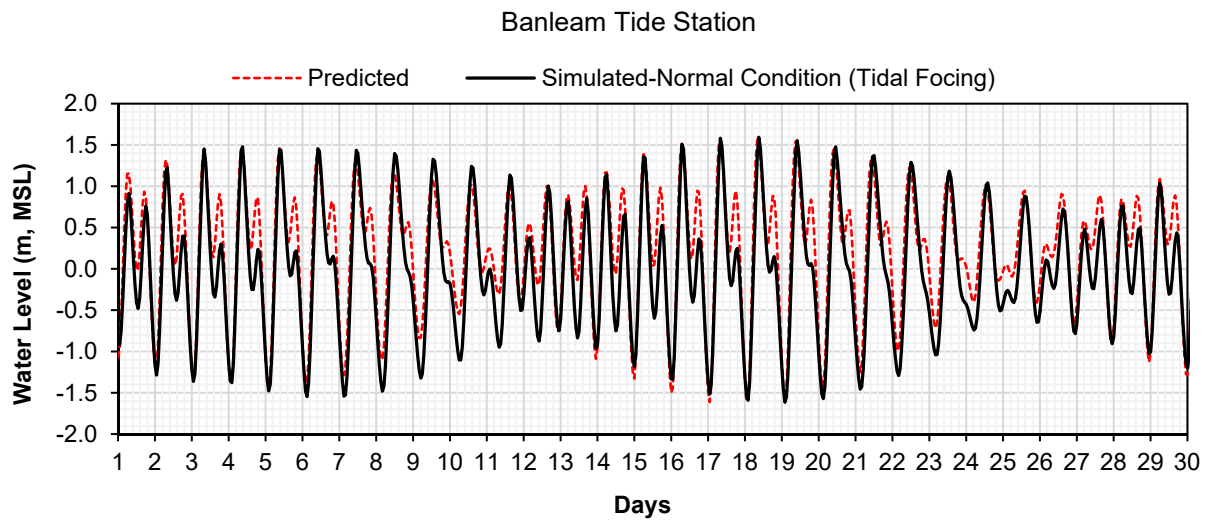


Fig. C.5 Water Level at Banleam Tide Station from 1st November to 30th November 1997 (+7UTC) - Normal Condition (Tidal Focusing)

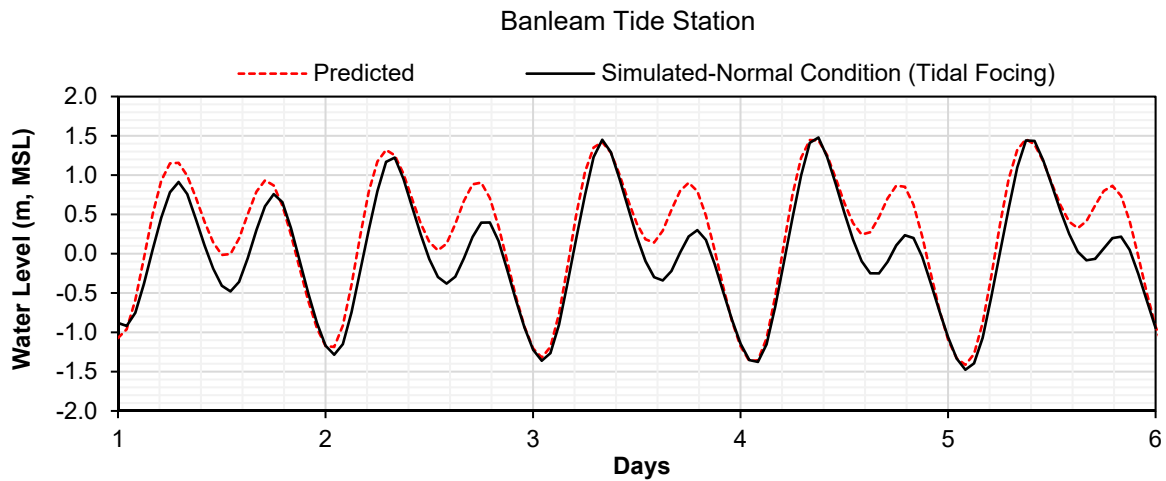


Fig. C.6 Water Level at Banleam Tide Station from 1st November to 6th November 1997 (+7UTC) - Normal Condition (Tidal Focusing)

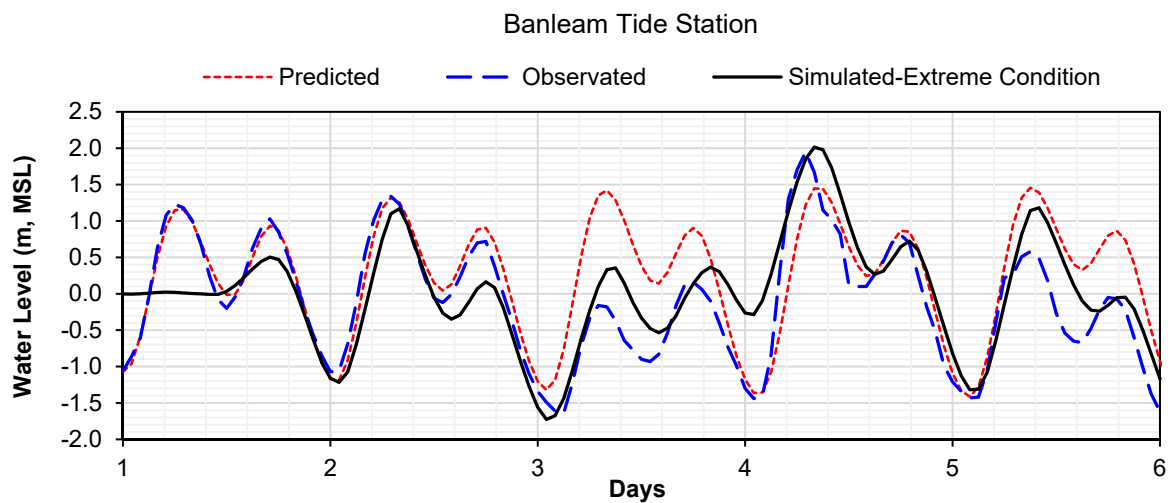


Fig. C.7 Water Level at Banleam Tide Station from 1st November to 6th November 1997 (+7UTC) - Extreme Condition

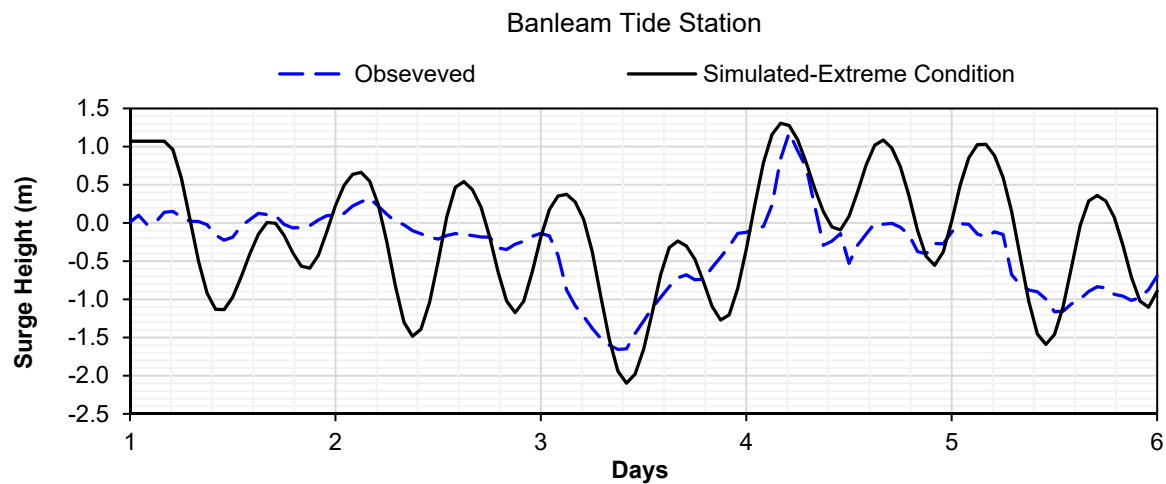


Fig. C.8 Surge Height at Banleam Tide Station from 1st November to 6th November 1997 (+7UTC)

C.3 RAYONG TIDE STATION

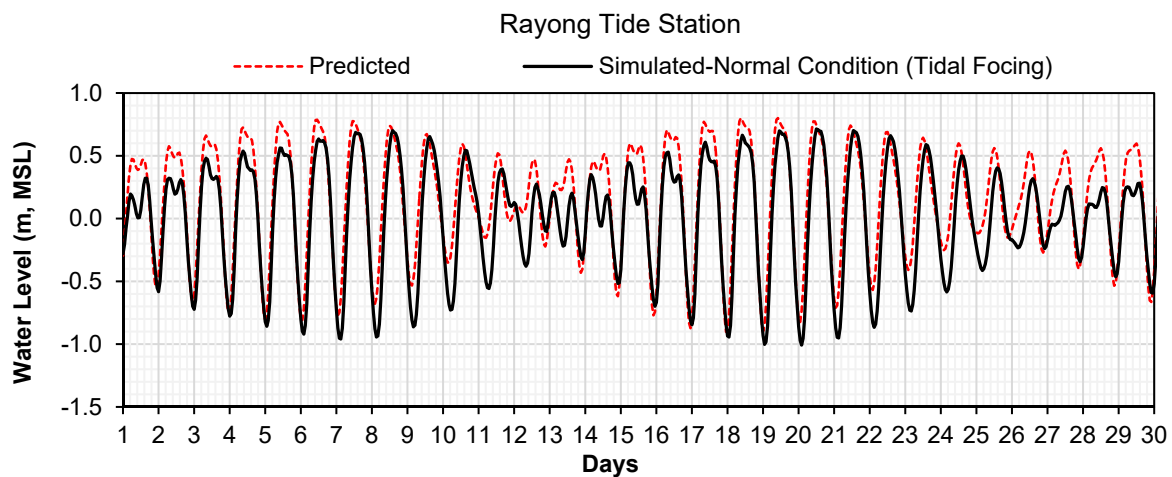


Fig. C.9 Water Level at Rayong Tide Station from 1st November to 30th November 1997 (+7UTC) - Normal Condition (Tidal Forcing)

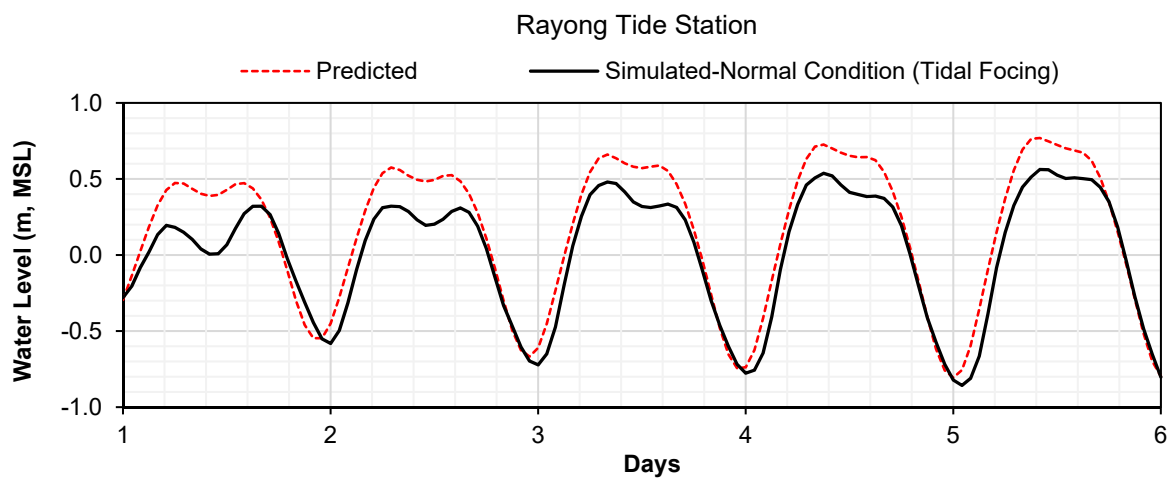


Fig. C.10 Water Level Rayong Tide Station from 1st November to 6th November 1997 (+7UTC) - Normal Condition (Tidal Forcing)

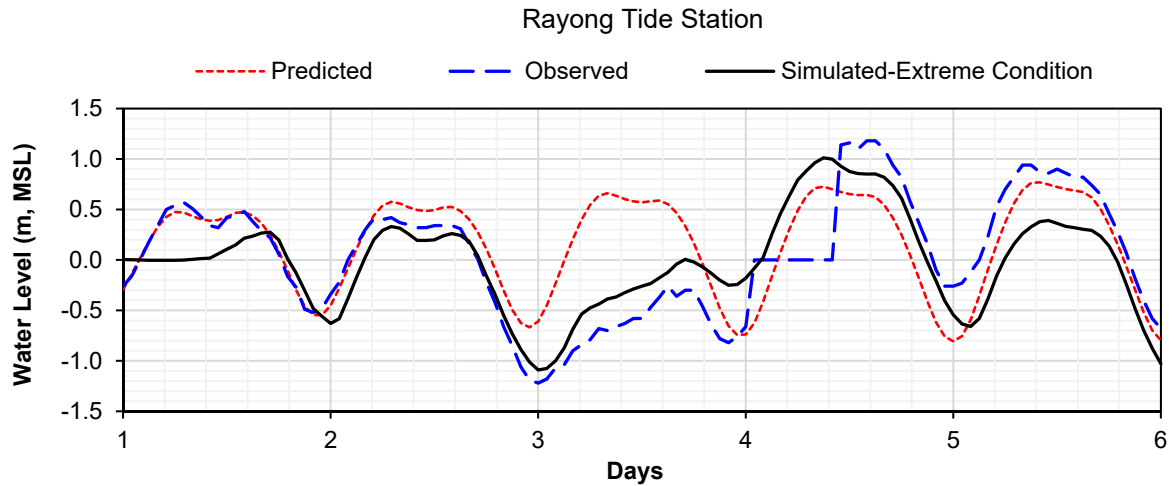


Fig. C.11 Water Level at Rayong Tide Station from 1st November to 6th November 1997 (+7UTC) - Extreme Condition

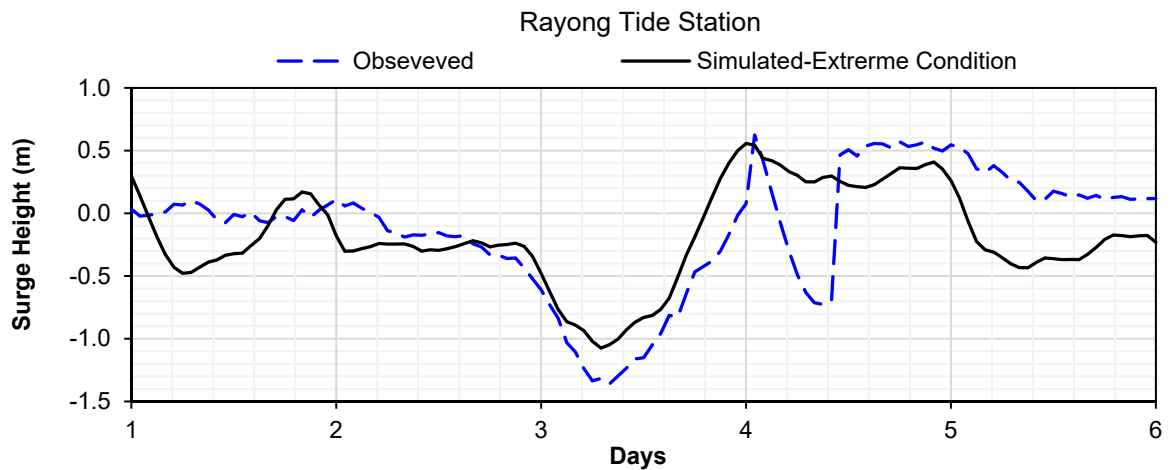


Fig. C.12 Surge Height at Rayong Tide Station from 1st November to 6th November 1997 (+7UTC)

C.4 LEAM NGOB TIDE STATION

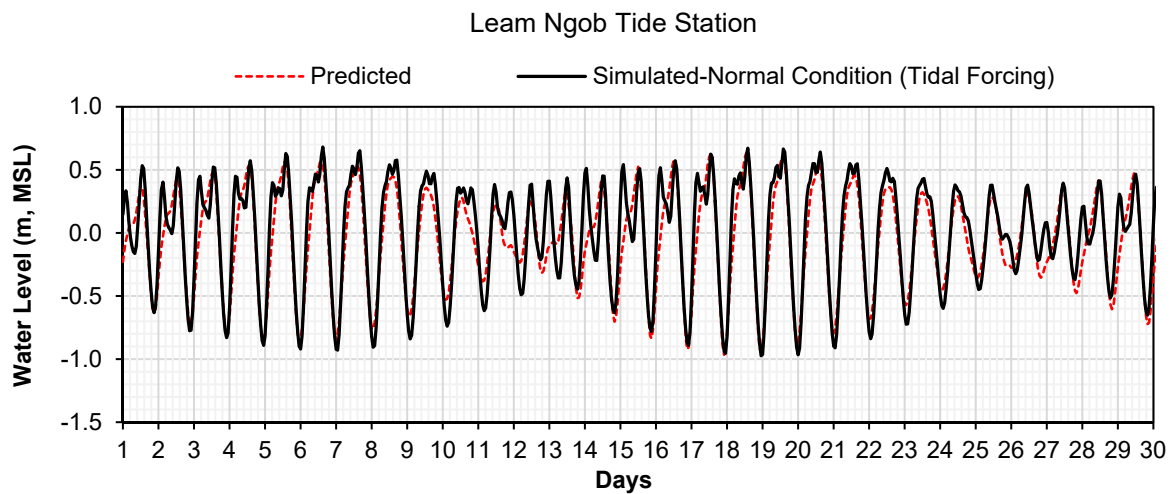


Fig. C.13 Water Level at Leam Ngob Tide Station from 1st November to 30th November 1997 (+7UTC) - Normal Condition (Tidal Forcing)

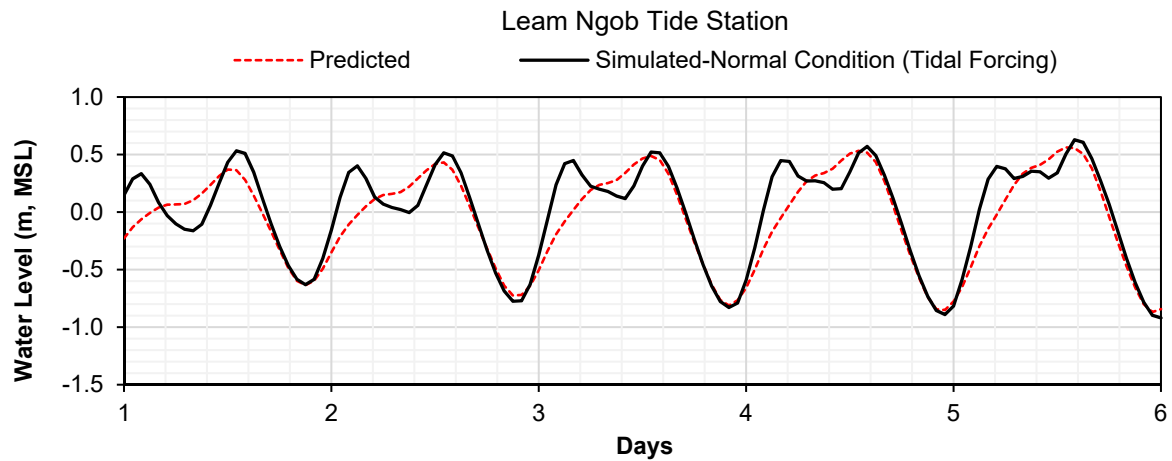


Fig. C.14 Water Level Leam Ngob Tide Station from 1st November to 6th November 1997 (+7UTC) - Normal Condition (Tidal Forcing)

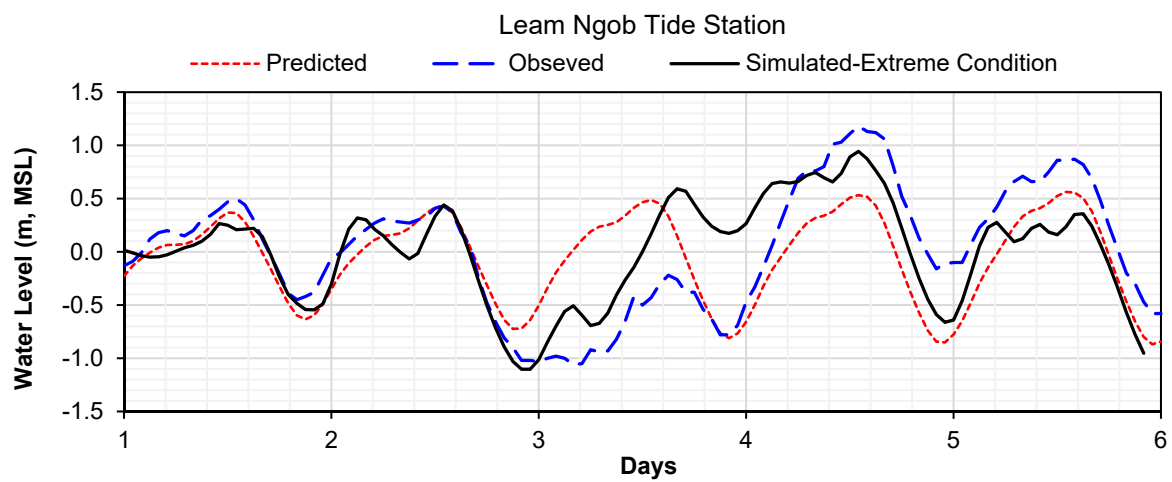


Fig. C.15 Water Level at Leam Ngob Tide Station from 1st November to 6th November 1997 (+7UTC) - Extreme Condition

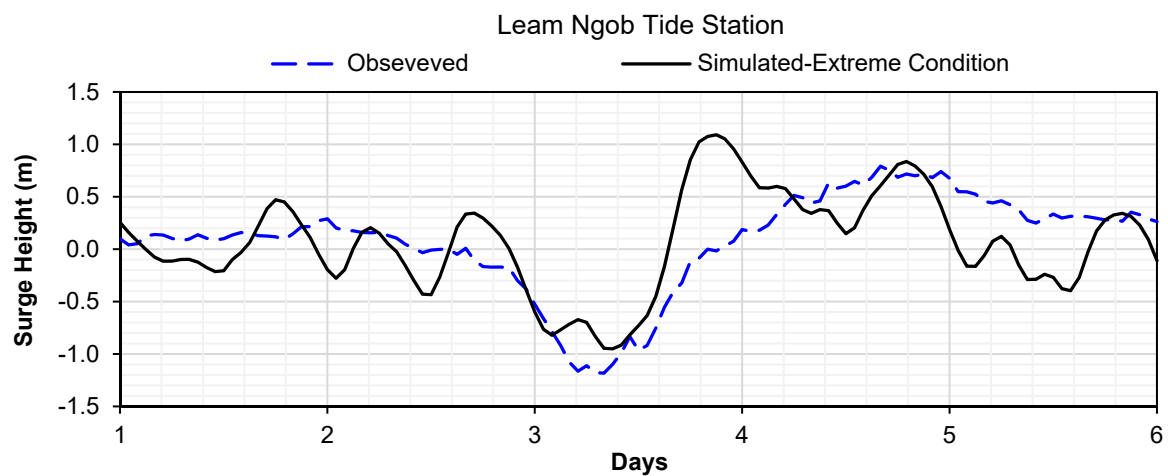


Fig. C.16 Surge Height at Leam Ngob Tide Station from 1st November to 6th November 1997 (+7UTC)

C.5 AO UDOM TIDE STATION

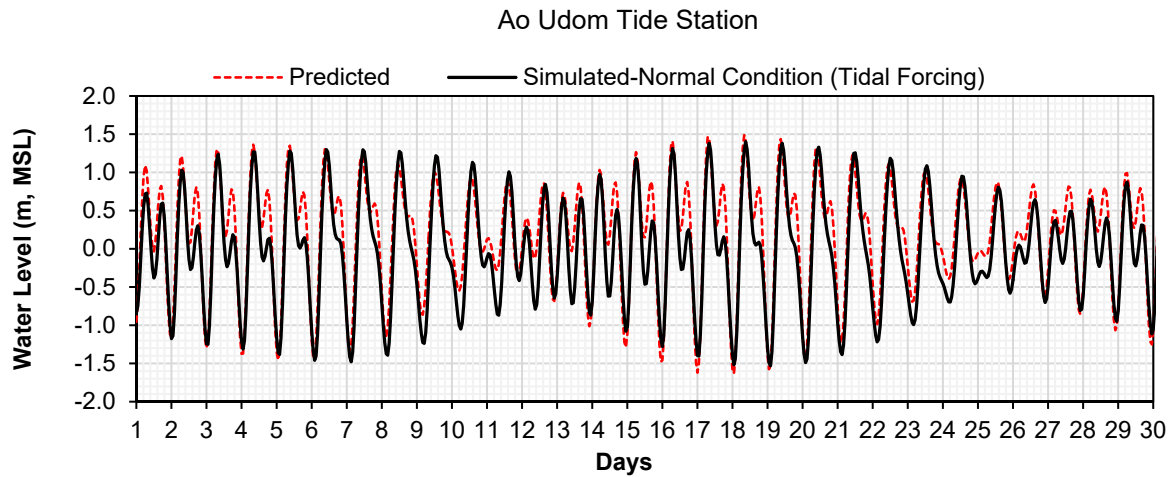


Fig. C.17 Water Level at Ao Udom Tide Station from 1st November to 30th November 1997 (+7UTC) - Normal Condition (Tidal Forcing)

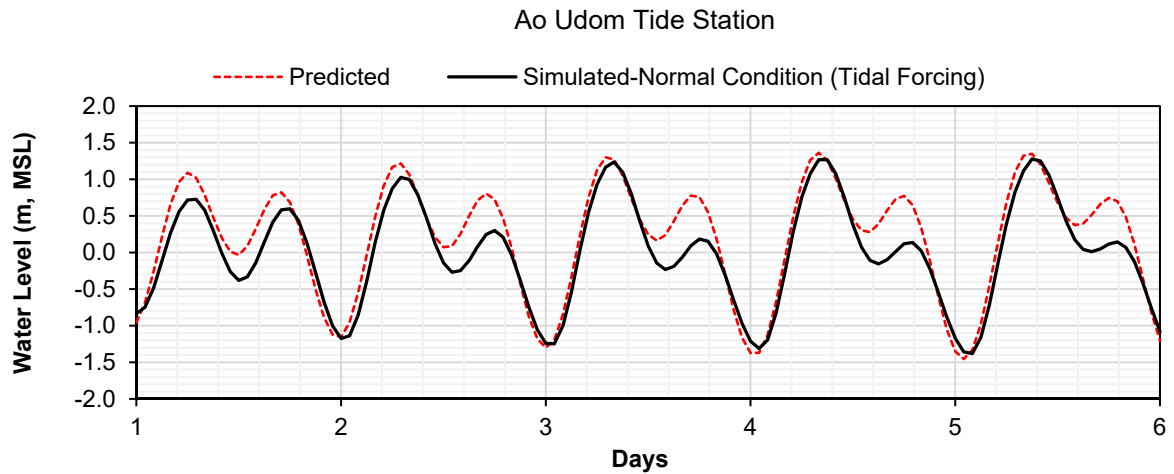


Fig. C.18 Water Level at Ao Udom Tide Station from 1st November to 6th November 1997 (+7UTC) - Normal Condition (Tidal Forcing)

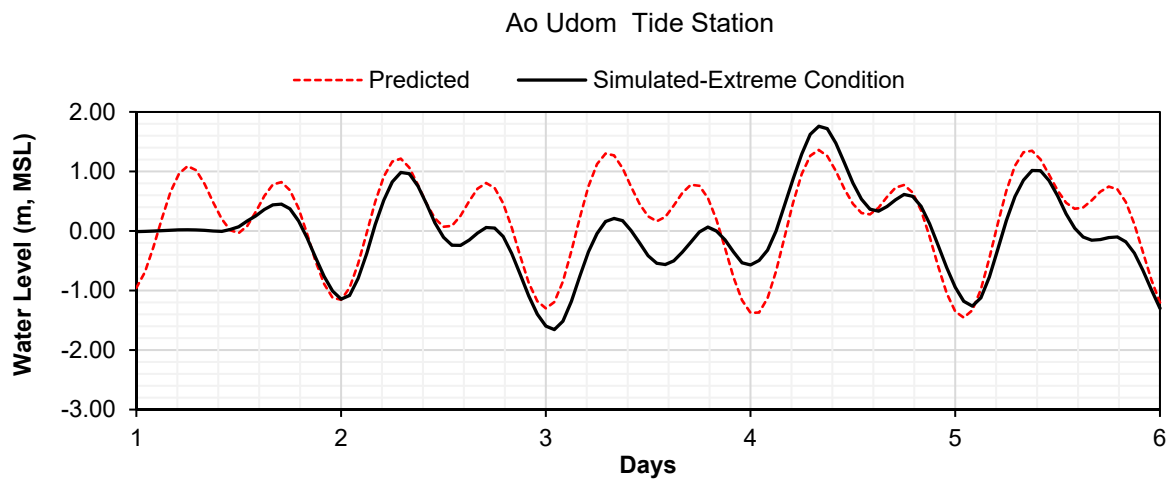


Fig. C.19 Water Level at Ao Udom Tide Station from 1st November to 6th November 1997 (+7UTC) - Extreme Condition

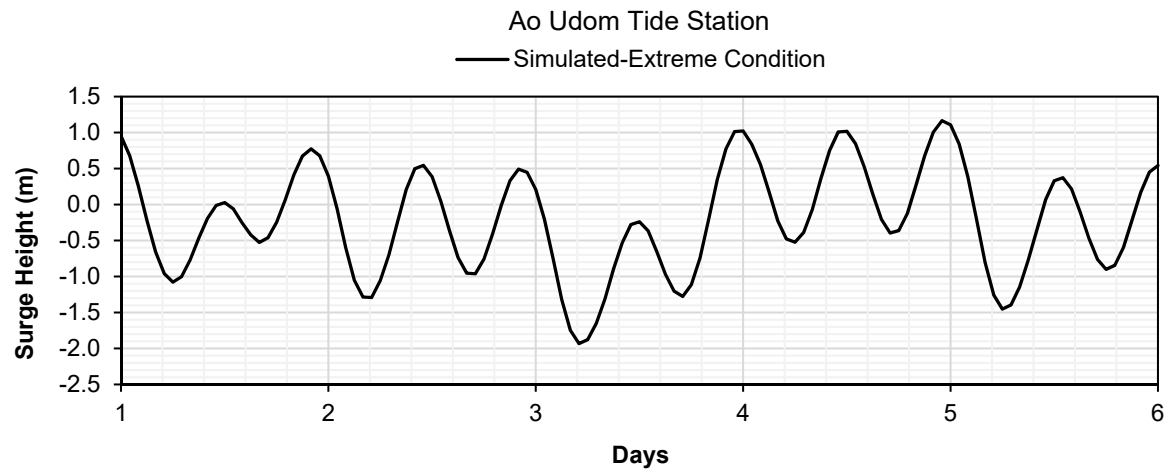


Fig. C.20 Surge Height at Ao Udom Tide Station from 1st November to 6th November 1997 (+7UTC)

C.6 RAYONG BUOY

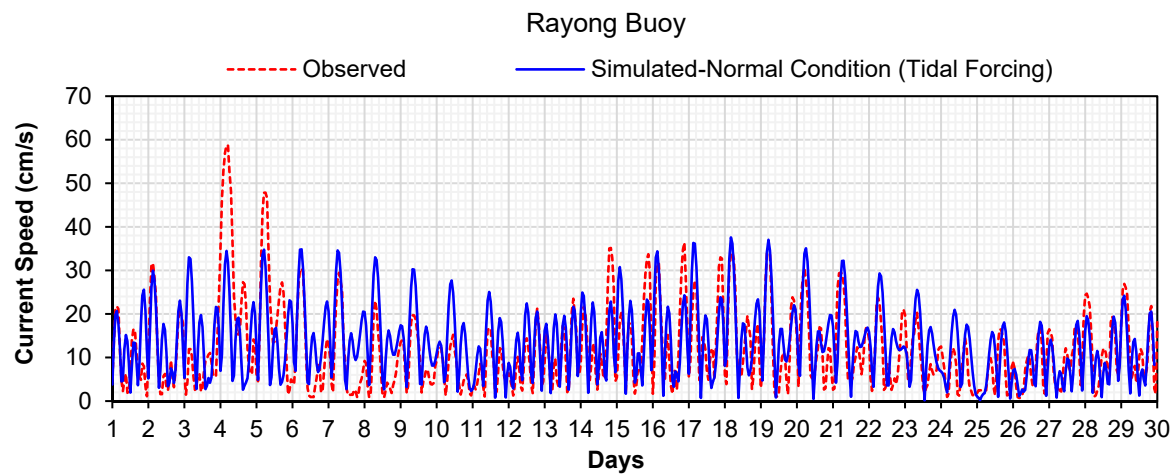


Fig. C.21 Current Speed at Rayong Buoy from 1st November to 30th November 1997 (+7UTC) – Normal Condition (Tidal Forcing)

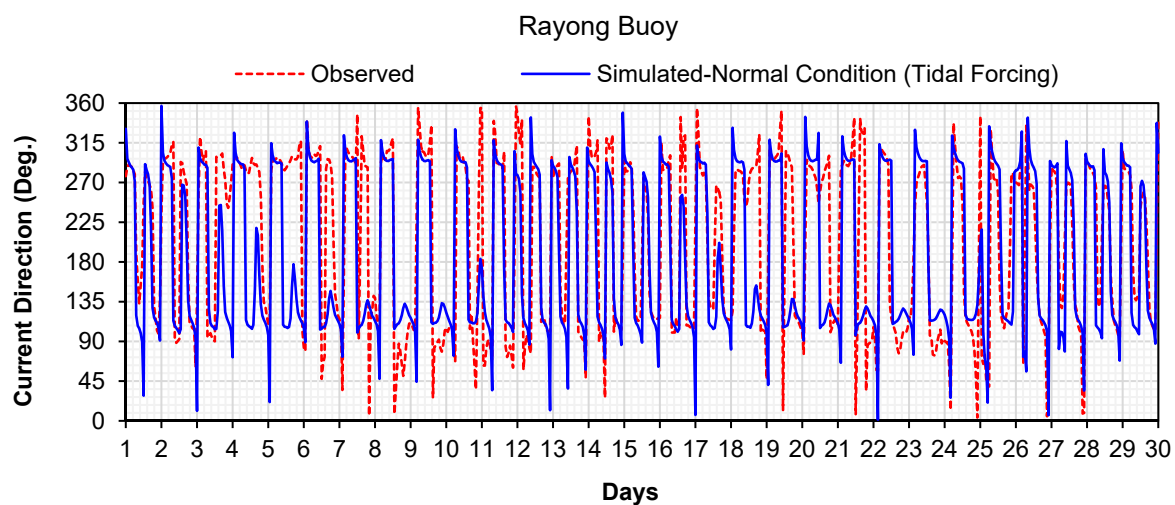


Fig. C.22 Current Direction at Rayong Buoy from 1st November to 30th November 1997 (+7UTC) – Normal Condition (Tidal Forcing)

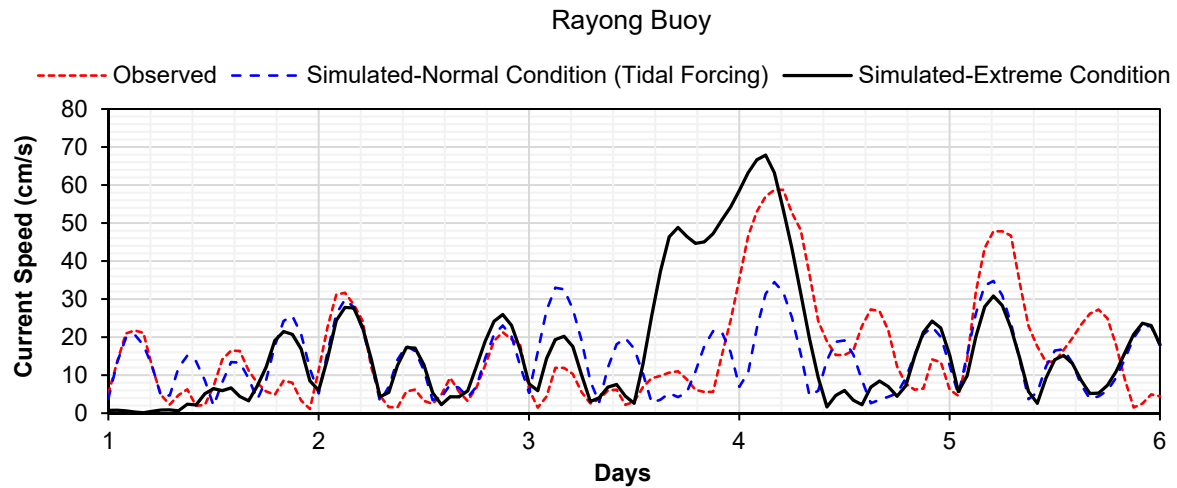


Fig. C.23 Current Speed at Rayong Buoy from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

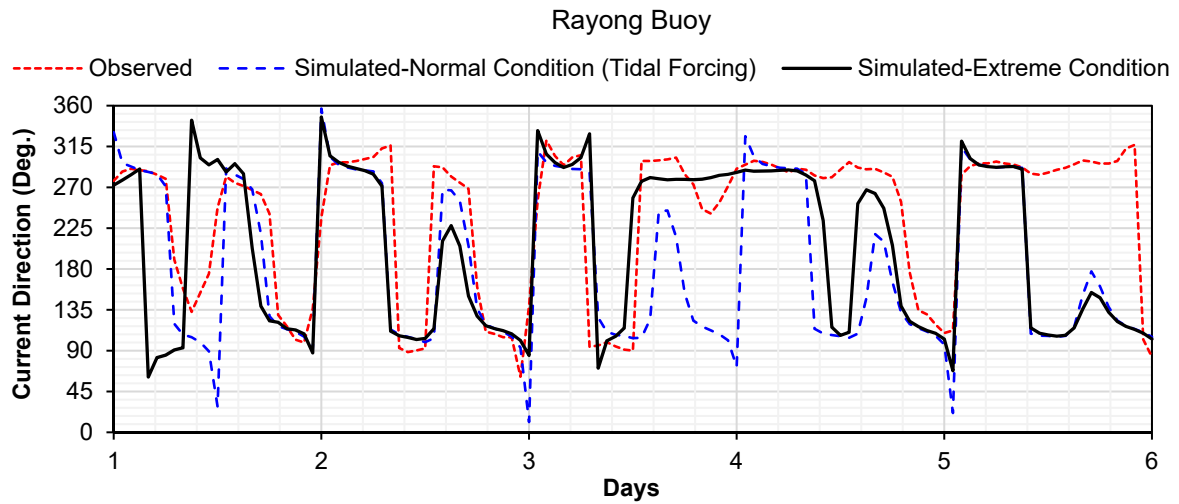


Fig. C.24 Current Direction at Rayong Buoy from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

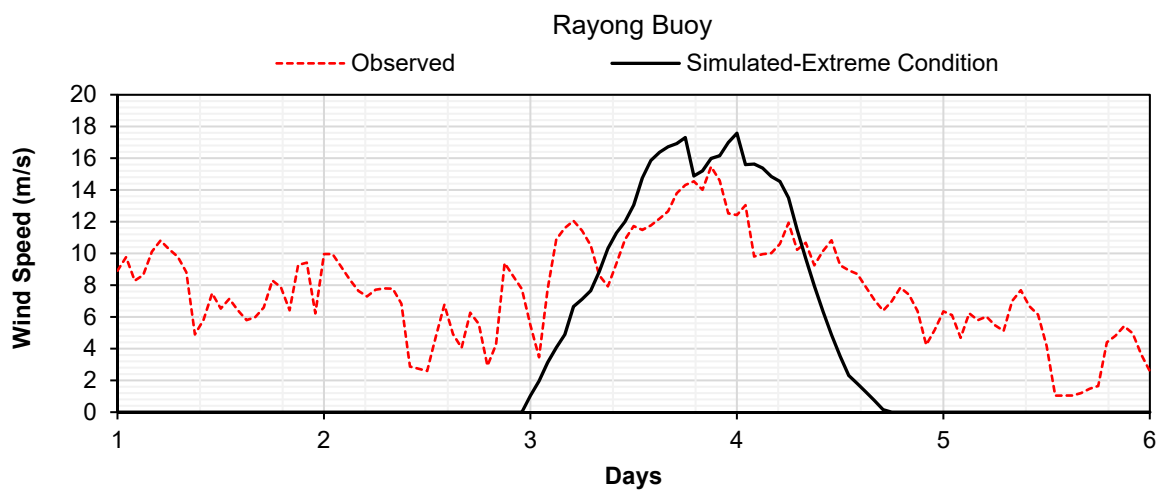


Fig. C.25 Wind Speed at Rayong Buoy from 1st November to 6th November 1997 (+7:00 UTC) – Extreme Condition

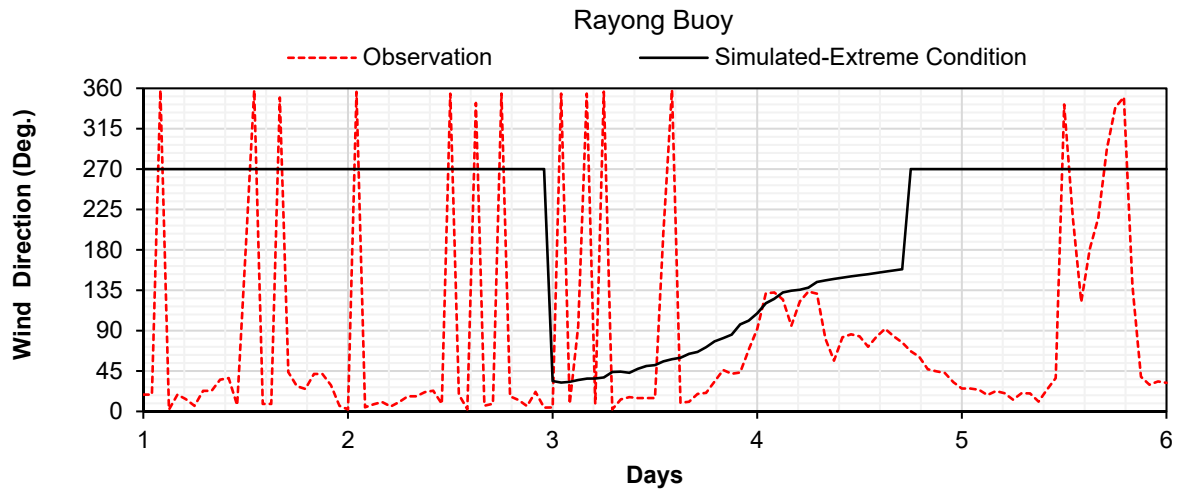


Fig. C.26 Wind Direction at Rayong Buoy from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

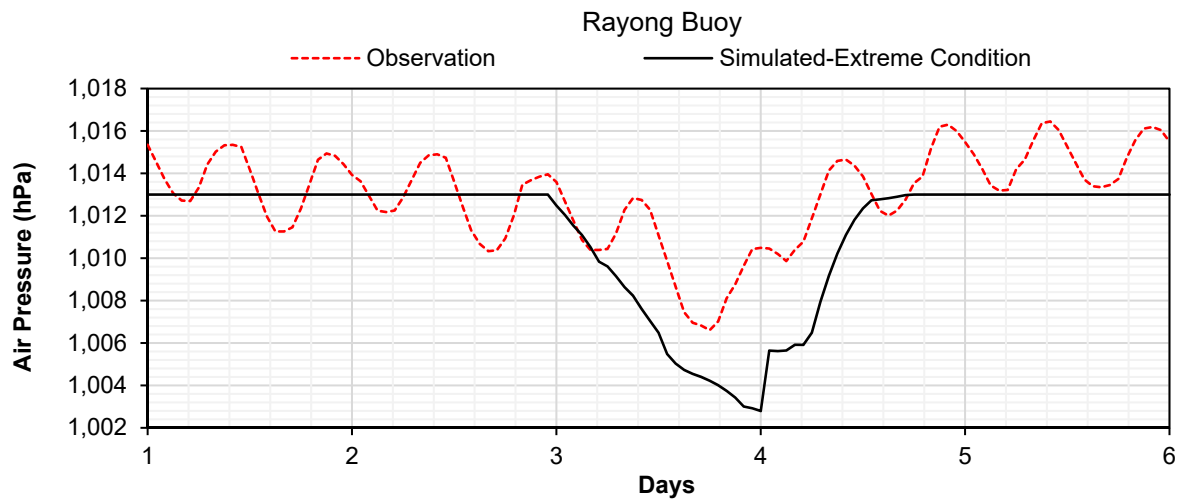


Fig. C.27 Air Pressure at Rayong Buoy from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

C.7 HUA HIN BUOY

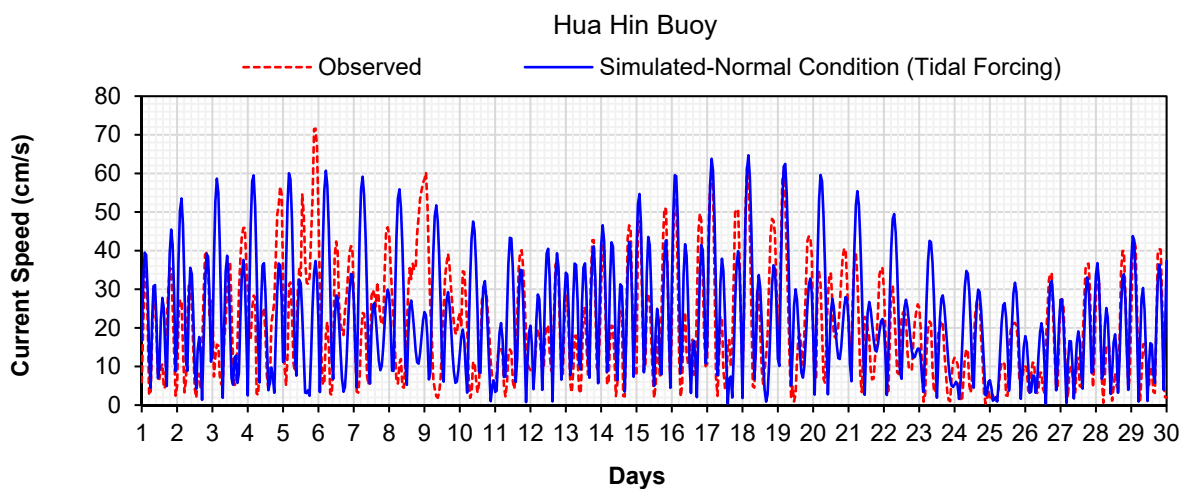


Fig. C.28 Current Speed at Hua Hin Buoy from 1st November to 30th November 1997 (+7UTC) - Normal Condition (Tidal Forcing)

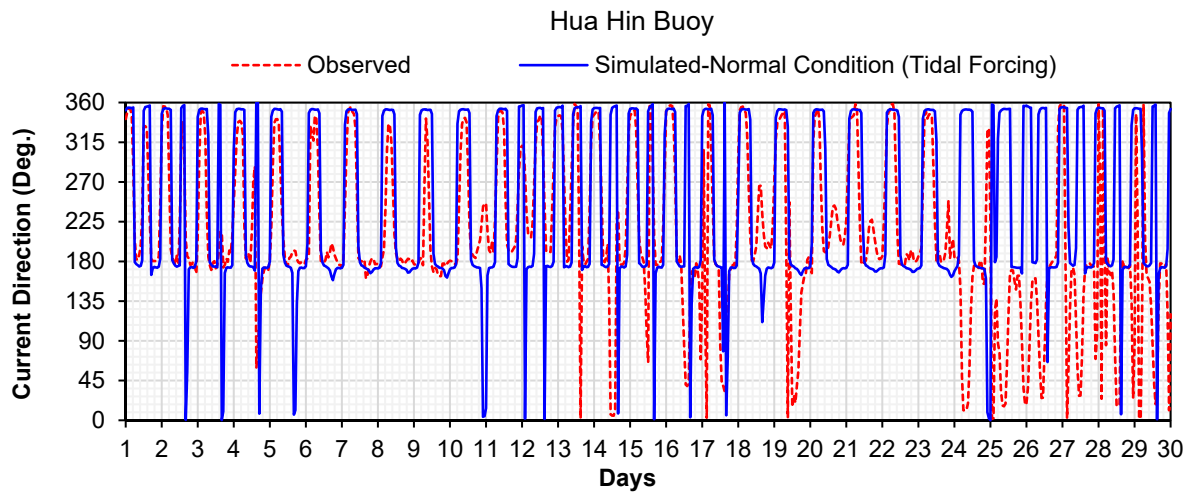


Fig. C.29 Current Direction at Hua Hin Buoy from 1st November to 30th November 1997 (+7UTC) - Normal Condition (Tidal Forcing)

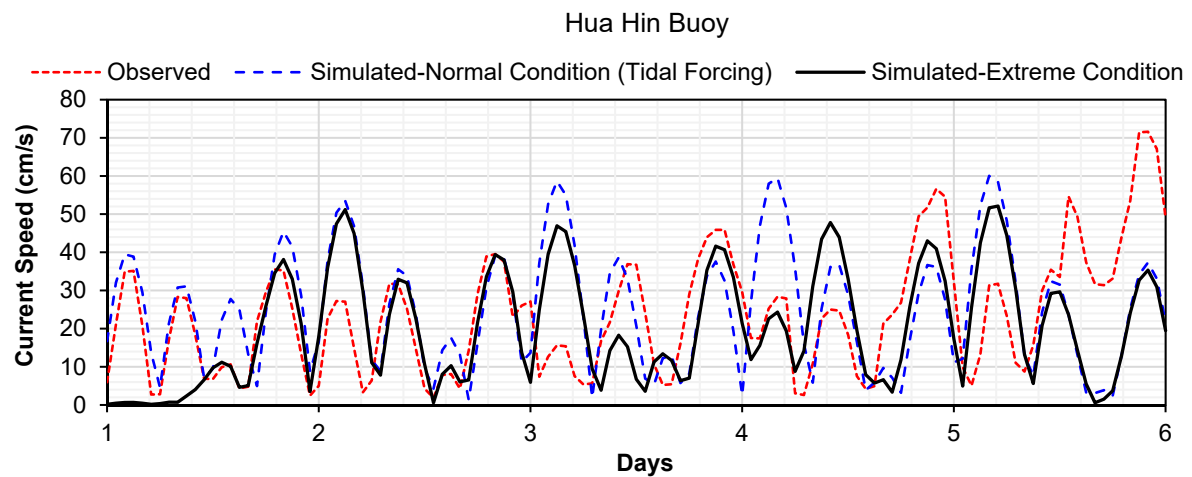


Fig. C.30 Current Speed at Hua Hin Buoy from 1st November to 6th November 1997 (+7UTC) - Extreme Condition

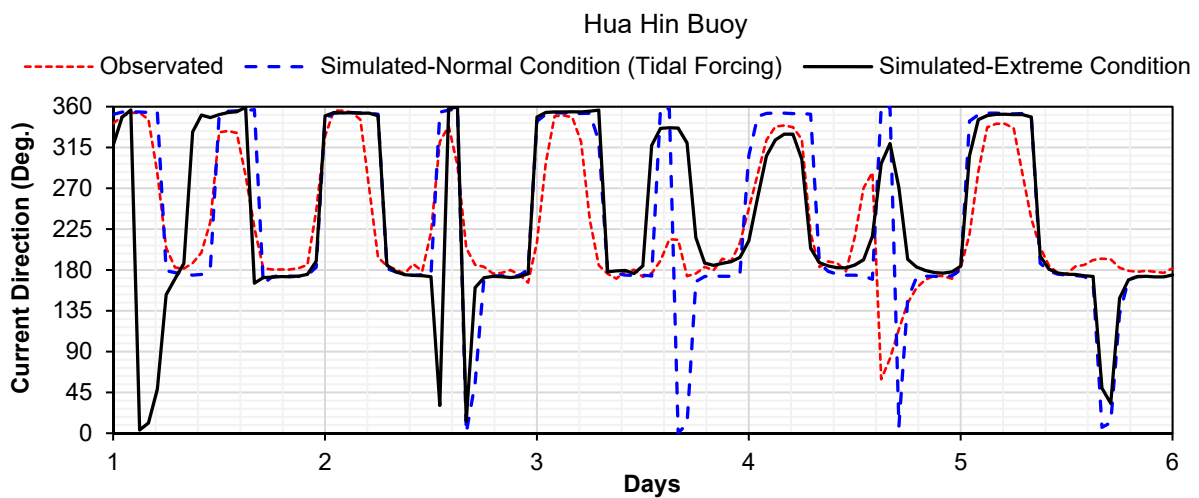


Fig. C.31 Current Direction at Hua Hin Buoy from 1st November to 6th November 1997 (+7UTC) - Extreme Condition

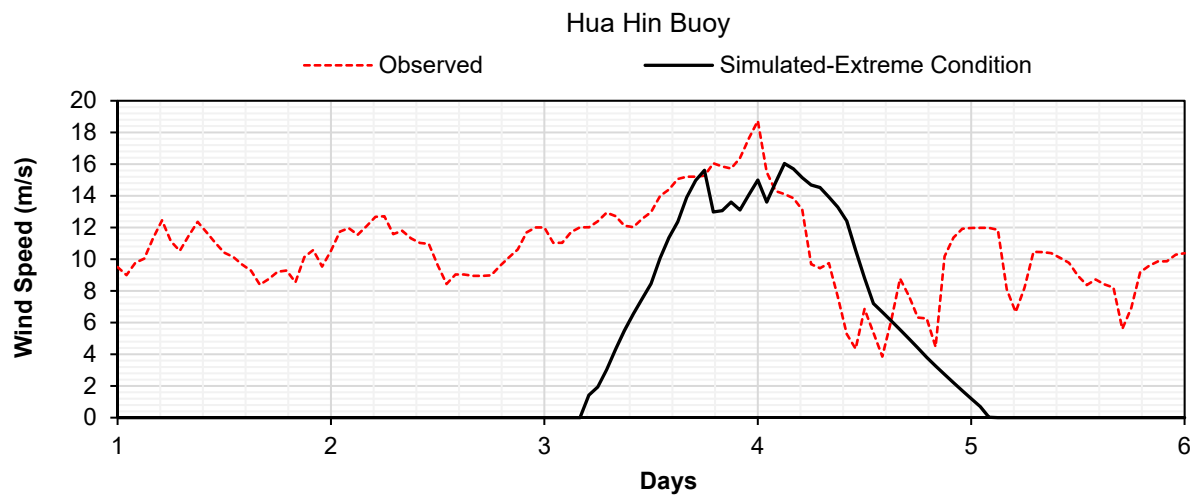


Fig. C.32 Wind Speed at Hua Hin Buoy from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

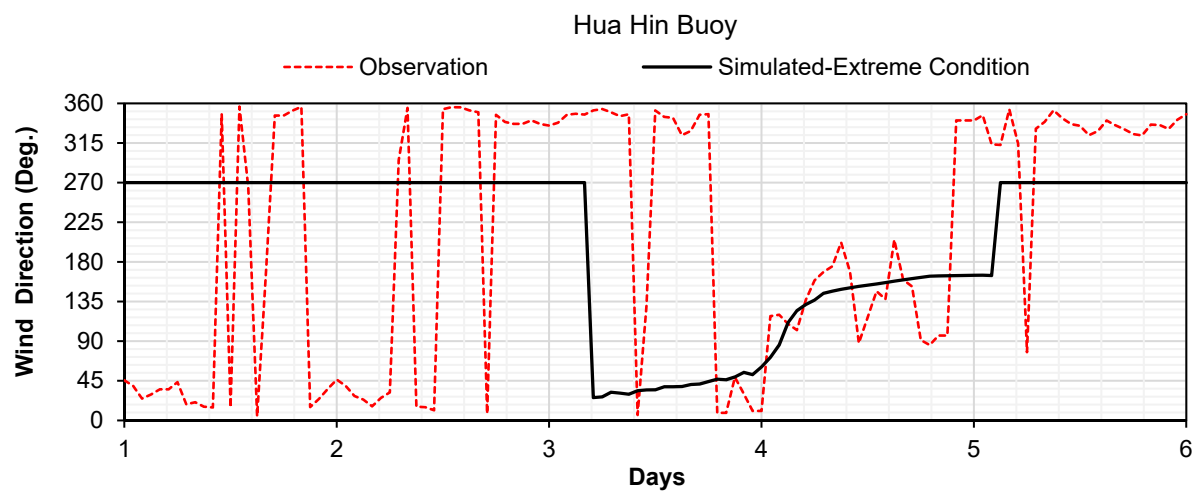


Fig. C.33 Wind Direction at Hua Hin Buoy from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

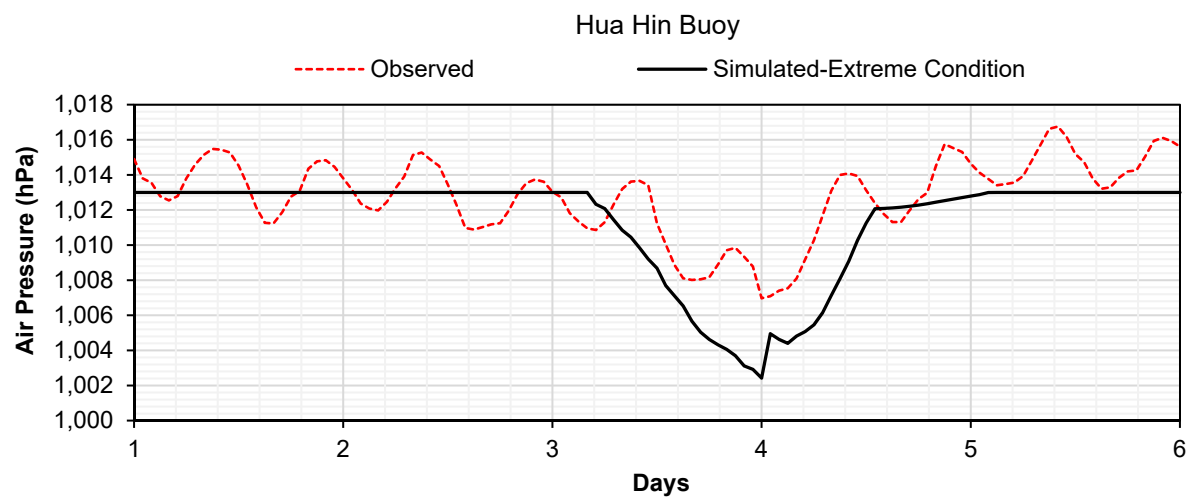


Fig. C.34 Air Pressure at Hua Hin Buoy from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

C.8 KO CHANG BUOY

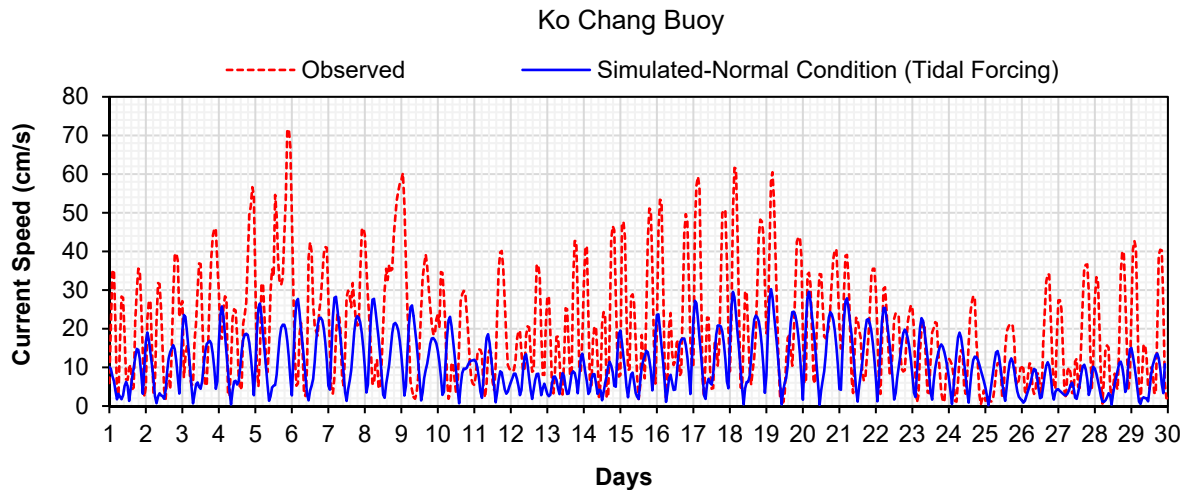


Fig. C.35 Current Speed at Ko Chang Buoy from 1st November to 30th November 1997 (+7UTC) – Normal Condition (Tidal Forcing)

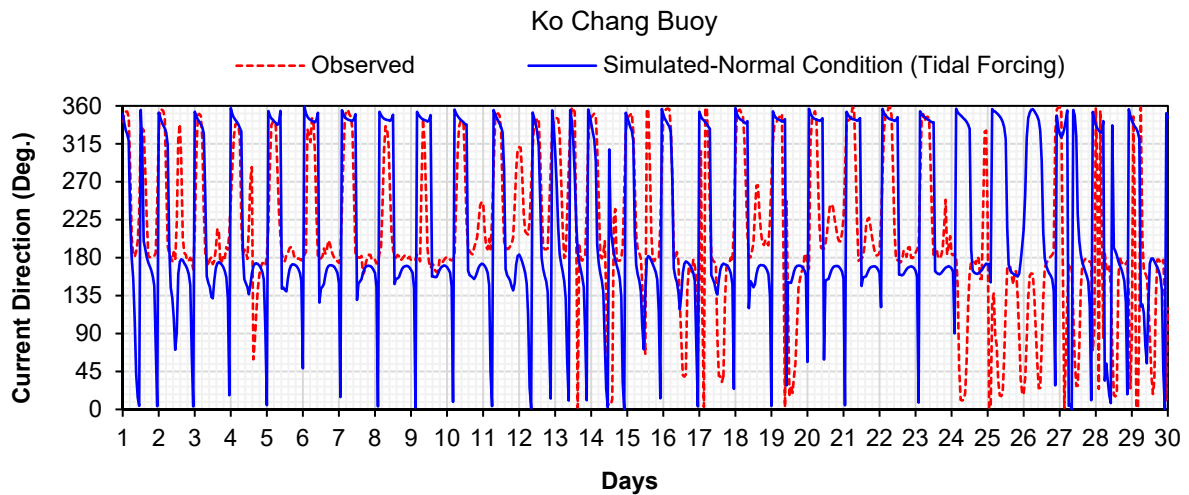


Fig. C.36 Current Direction at Ko Chang Buoy from 1st November to 30th November 1997 (+7UTC) – Normal Condition (Tidal Forcing)

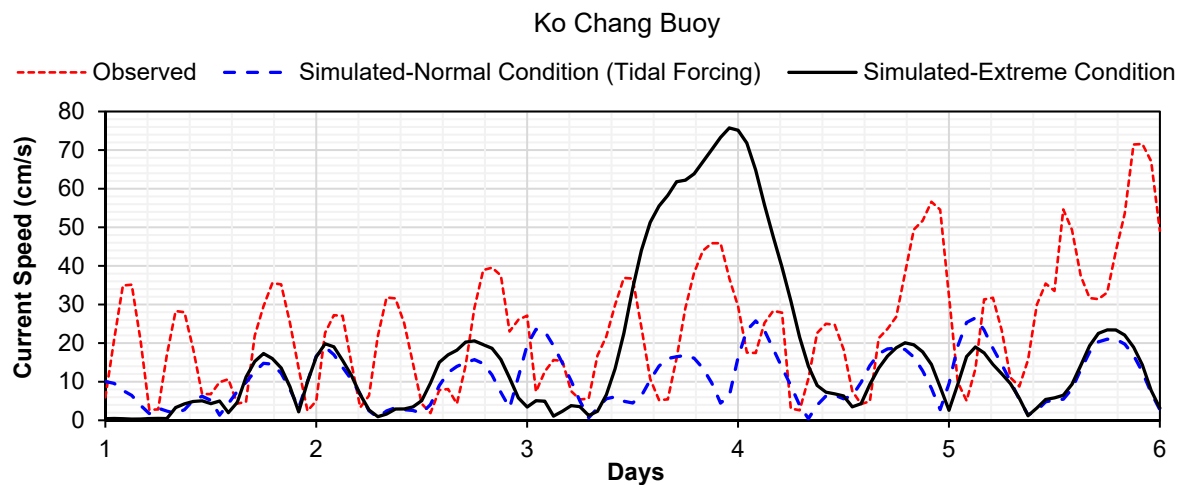


Fig. C.37 Current Speed at Ko Chang Buoy from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

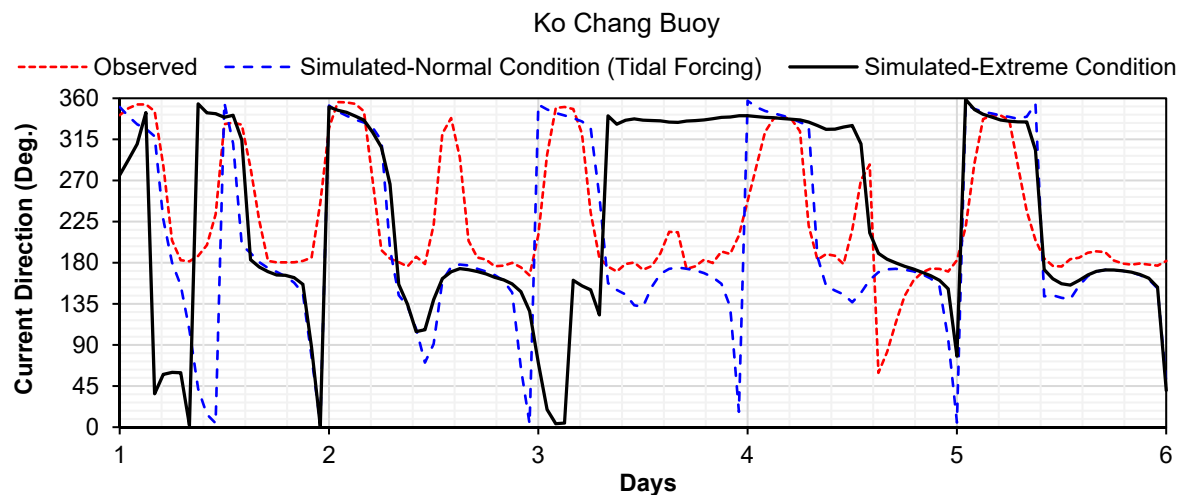


Fig. C.38 Current Direction at Ko Chang Buoy from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

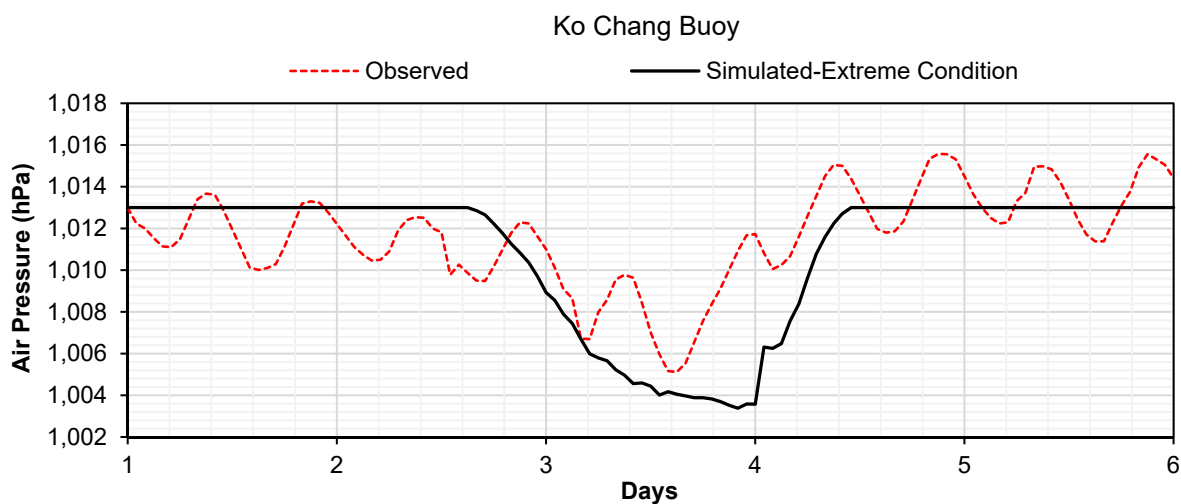


Fig. C.39 Air Pressure at Ko Chang Buoy from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

C.9 KO SI CHANG BUOY

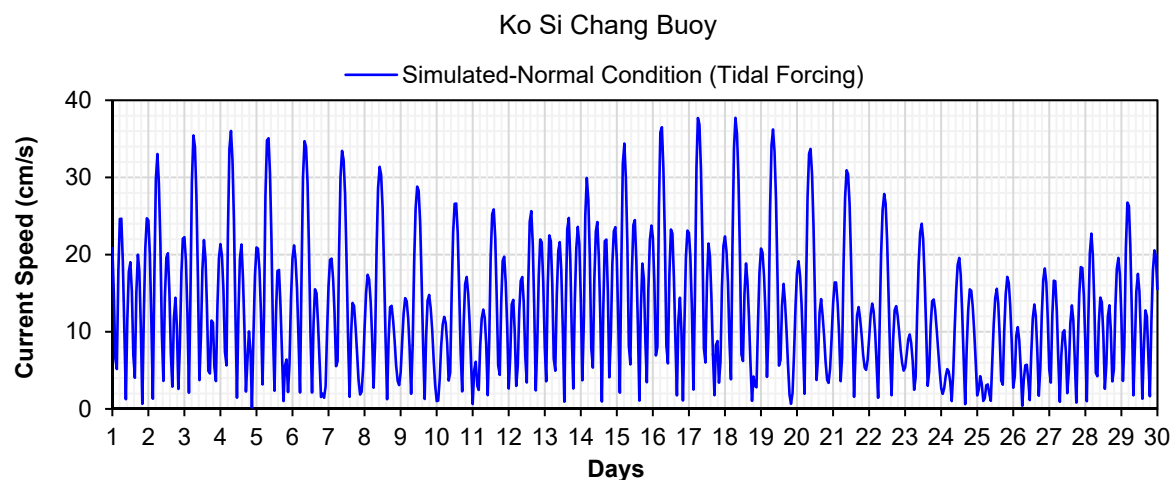


Fig. C.40 Current Speed at Ko Si Chang Buoy from 1st November to 30th November 1997 (+7UTC) – Normal Condition (Tidal Forcing)

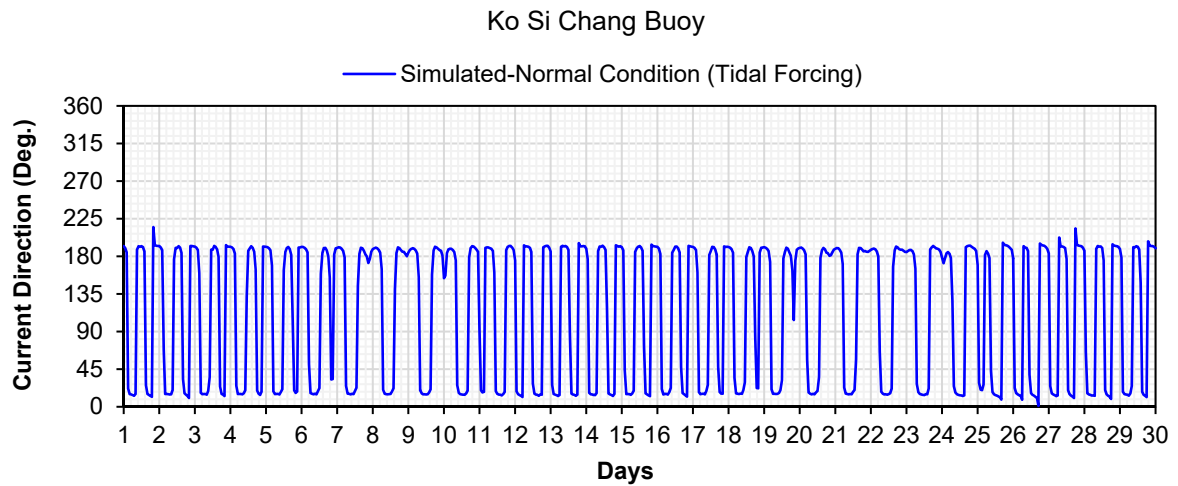


Fig. C.41 Current Direction at Ko Si Chang Buoy from 1st November to 30th November 1997 (+7UTC)
- Normal Condition (Tidal Forcing)

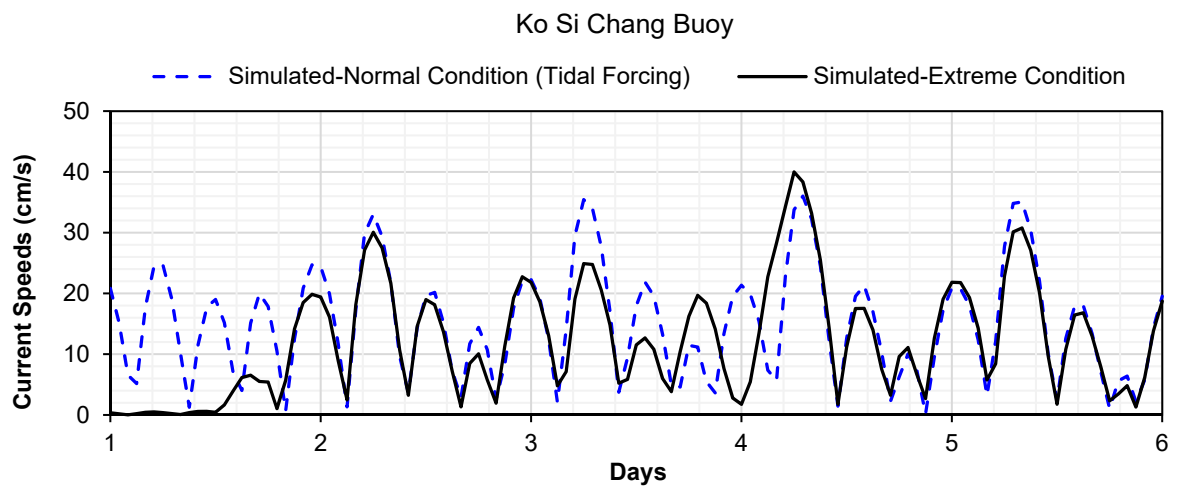


Fig. C.42 Current Speed at Ko Si Chang Buoy from 1st November to 6th November 1997 (+7UTC)
- Extreme Condition

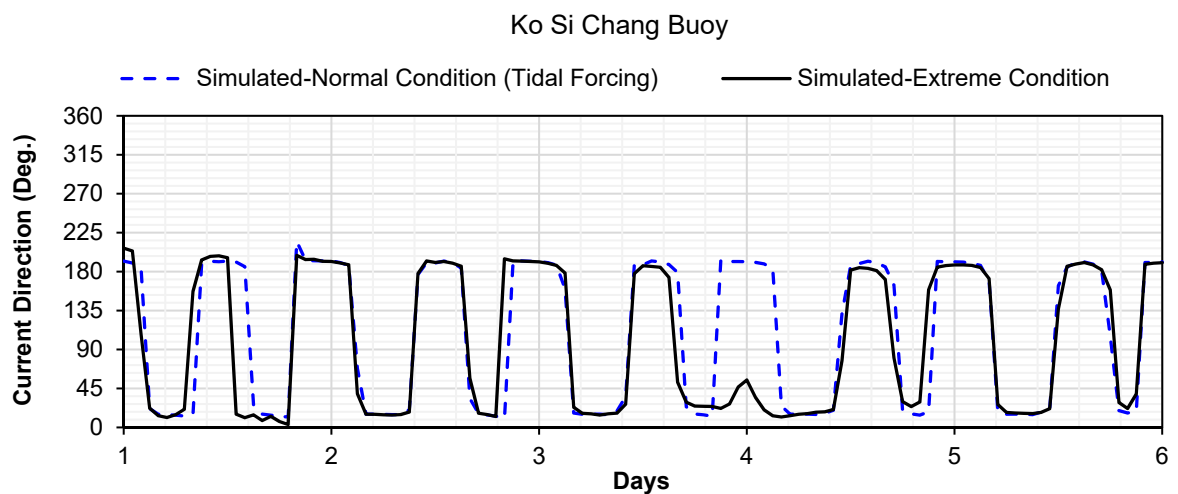


Fig. C.43 Current Direction at Ko Si Chang Buoy from 1st November to 6th November 1997 (+7UTC)
- Extreme Condition

C.10 SRIRACHA HARBOUR PORT (SRH)

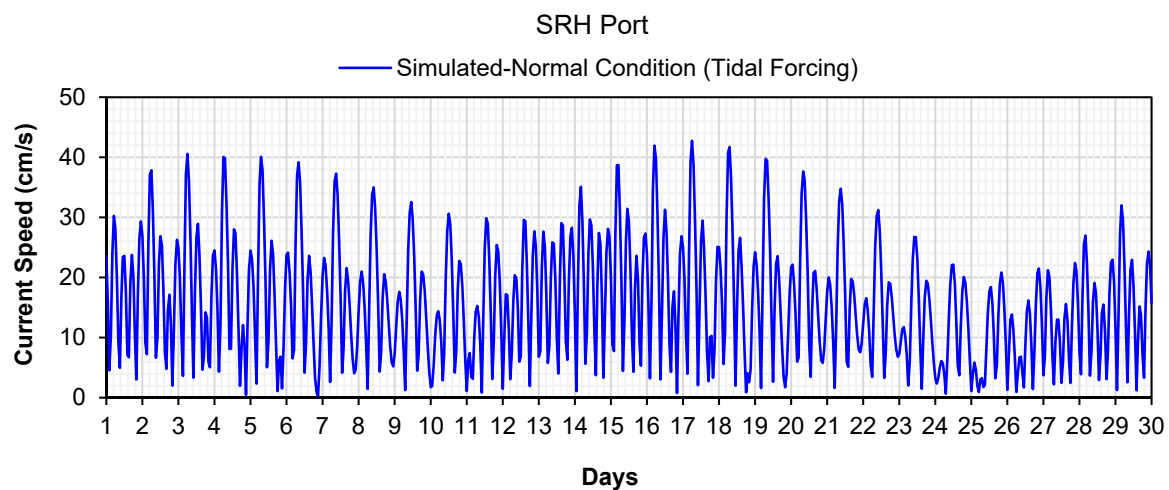


Fig. C.44 Current Speed at SRH Port from 1st November to 30th November 1997 (+7UTC) – Normal Condition (Tidal Forcing)

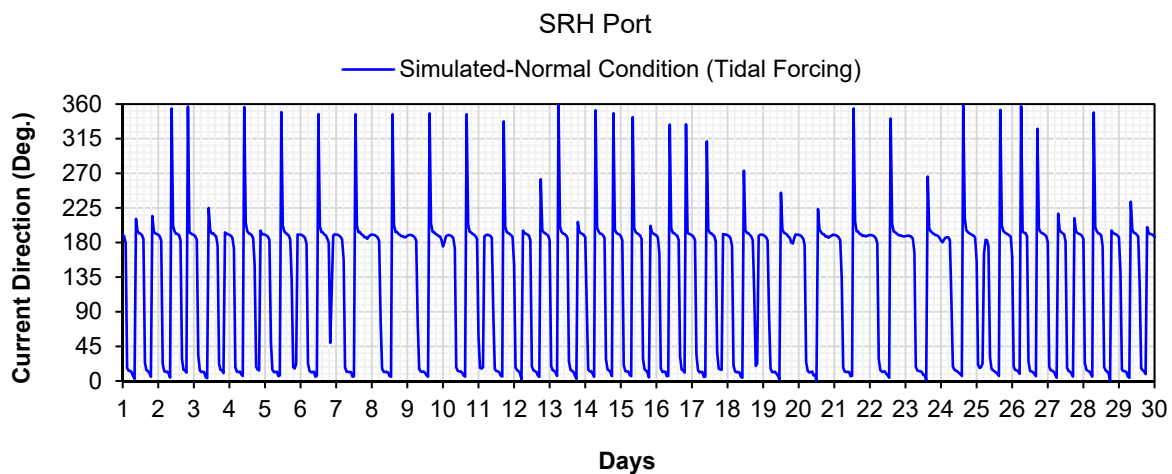


Fig. C.45 Current Direction at SRH Port from 1st November to 30th November 1997 (+7UTC) – Normal Condition (Tidal Forcing)

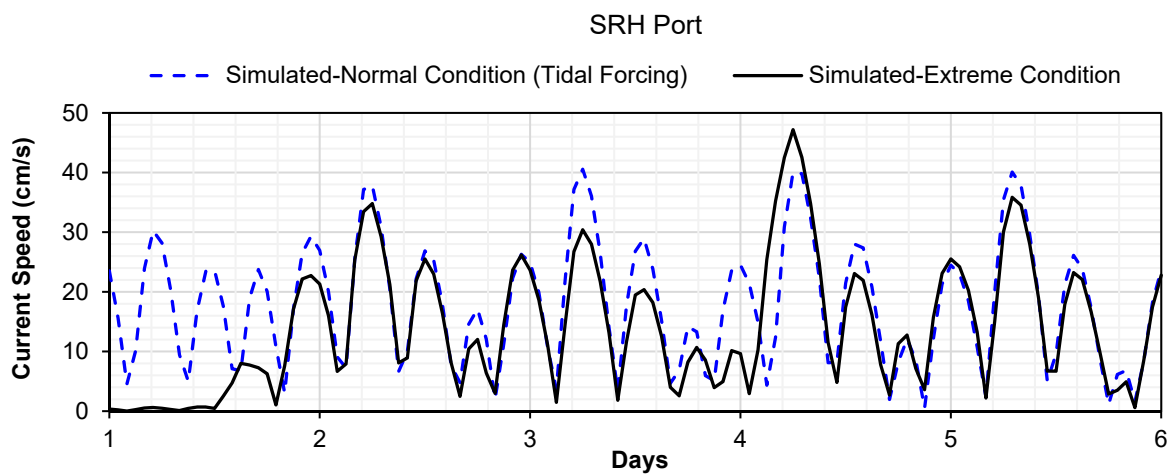


Fig. C.46 Current Speed at SRH Port from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

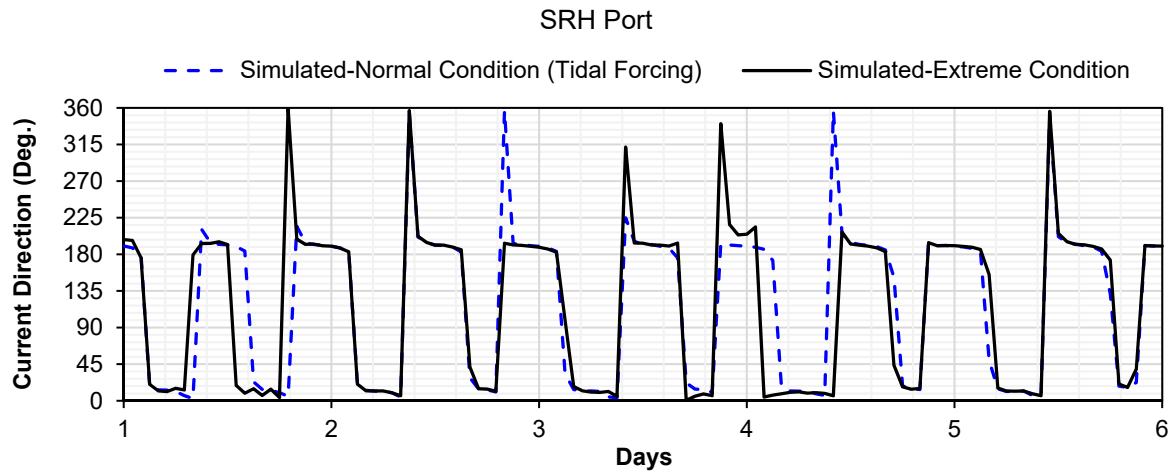


Fig. C.47 Current Direction at SRH Port from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

C.11 MAP TA PHUT PORT (BLCP)

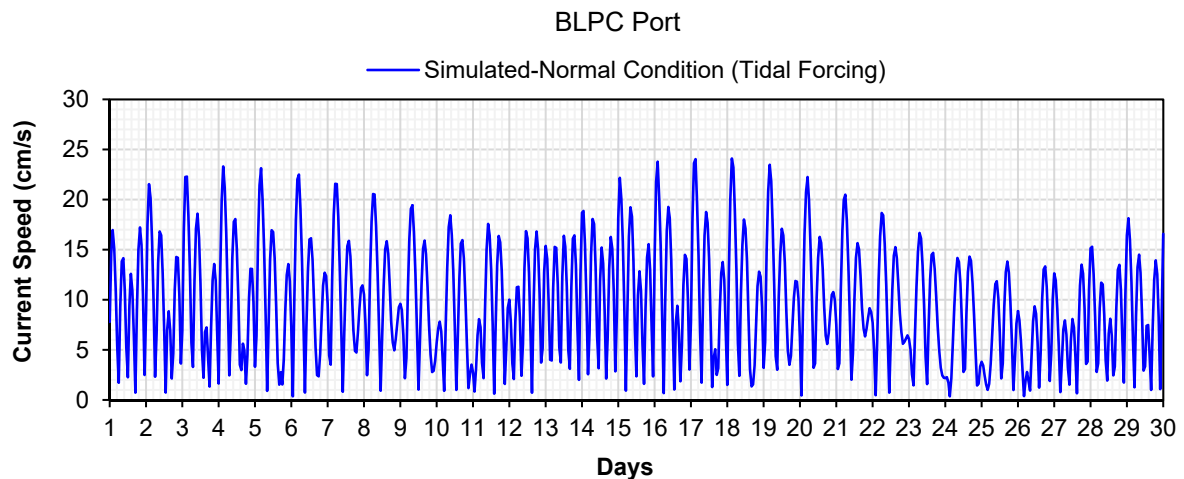


Fig. C.48 Current Speed at BLCP Port from 1st November to 30th November 1997 (+7UTC) – Normal Condition (Tidal Forcing)

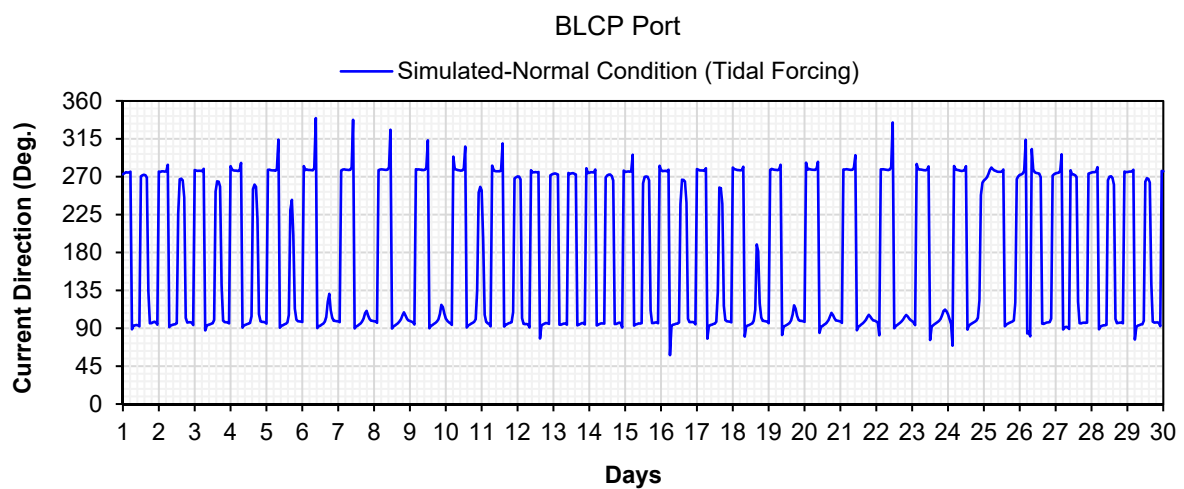


Fig. C.49 Current Direction at BLCP Port from 1st November to 30th November 1997 (+7UTC) – Normal Condition (Tidal Forcing)

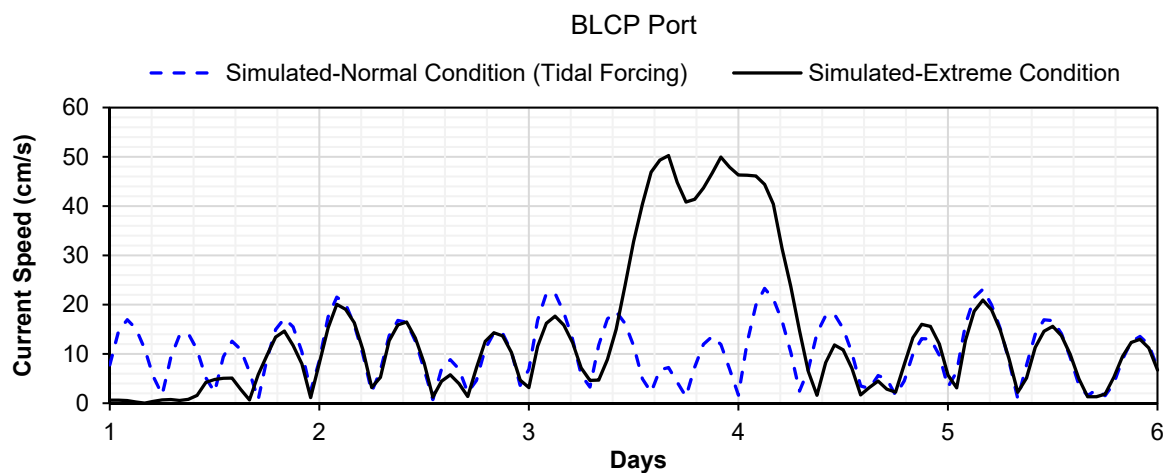


Fig. C.50 Current Speed at BLCP Port from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

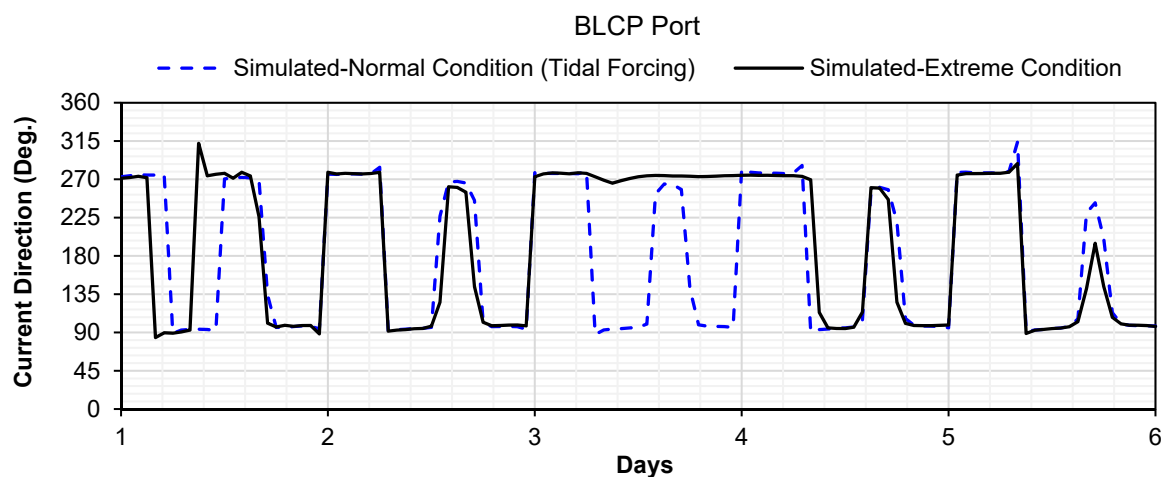


Fig. C.51 Current Direction at BLCP Port from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

C.12 IRPC PORT (IRPC)

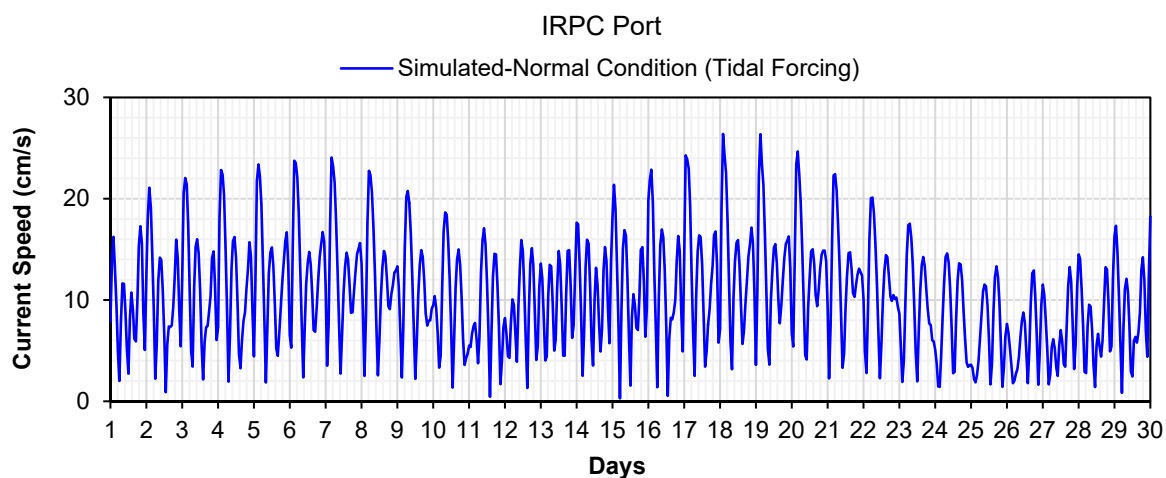


Fig. C.52 Current Speed at IRPC Port from 1st November to 30th November 1997 (+7UTC) – Normal Condition (Tidal Forcing)

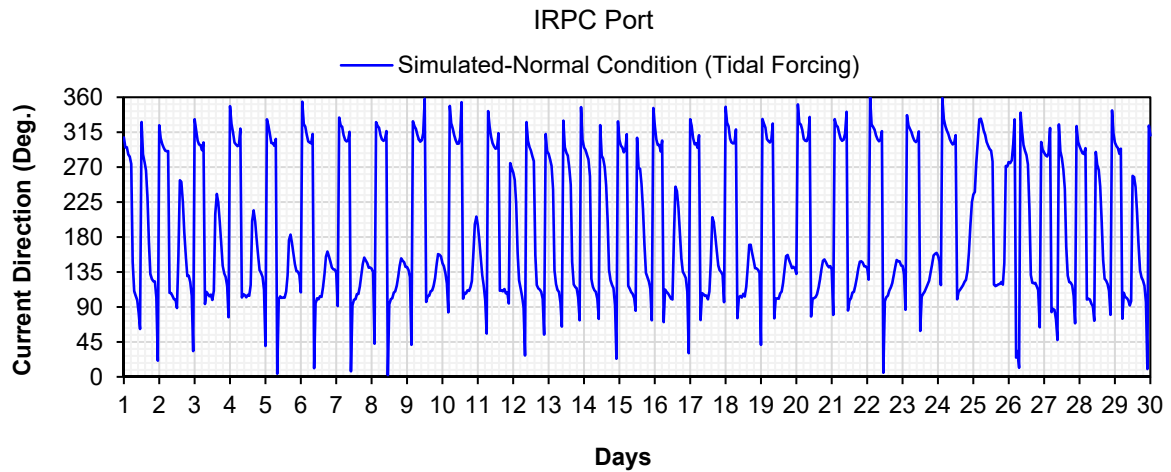


Fig. C.53 Current Direction at IRPC Port from 1st November to 30th November 1997 (+7UTC) – Normal Condition (Tidal Forcing)

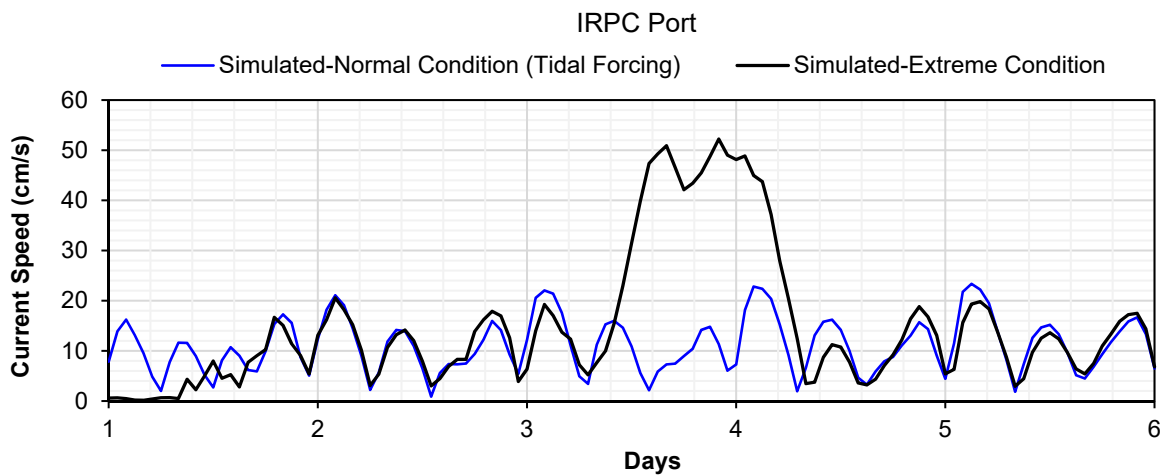


Fig. C.54 Current Speed at IRPC Port from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

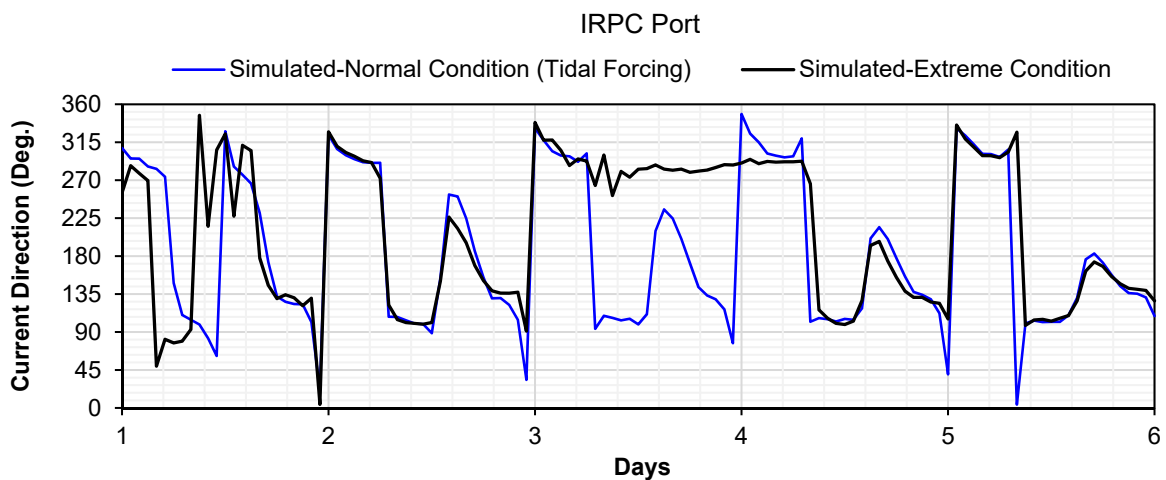


Fig. C.55 Current Direction at IRPC Port from 1st November to 6th November 1997 (+7UTC) – Extreme Condition

Appendix D

Static Moored Ship Motions Analysis Results

This appendix represents the analysis results of static moored ship motions as explanation in Chapter 6 with using MATLAB programing. The results include surge motion, sway motion and yaw motion, subjected to wind, wave and current due to tropical cyclone Linda at Sriracha Harbour Port (SRH) and BLCP Coal-Fired Power Plant Port (BLCP). The scenario of analysis includes the port operation condition as fully loaded and ballasted with variation of ship size and the stiffness of mooring rope.

Table D.1 to Table D.6 shows the moored ship motions for 50,000 DWT and 5,000 DWT ship at SRH Port and Table D.7 to Table D.12 shows the moored ship motions for 50,000 DWT and 5,000 DWT ship BLCP Port.

Table D.1 Static Moored Ship Motions Analysis Results for 50,000 DWT Ship at SRH Port
(EA = 3,000 kN)

No.	Surge U_x (m)	Sway U_y (m)	Yaw θ_z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	-0.204	-0.159	0.200	39.72	353.16	12.24	14.35	31.63	18.74
2	-0.179	-0.100	0.222	36.78	359.72	9.34	10.67	101.42	23.88
3	-0.165	-0.092	0.205	33.95	348.31	8.66	9.88	94.96	22.03
4	-0.096	-0.008	0.213	25.34	315.82	2.07	2.17	183.50	25.82
5	-0.101	-0.009	0.220	26.32	319.42	2.35	2.46	186.68	26.62
6	0.129	0.060	-0.146	24.80	227.78	7.34	8.14	67.00	16.39
7	0.061	0.036	-0.067	11.88	104.08	3.53	4.01	23.48	7.03
8	-0.125	-0.018	0.233	29.58	283.99	4.16	4.39	174.66	28.20
9	-0.132	-0.021	0.241	30.91	290.53	4.52	4.79	177.64	29.14
10	0.259	-0.162	-0.208	28.83	24.96	19.56	17.41	225.18	40.06
11	0.202	-0.155	-0.173	21.98	7.54	15.14	13.08	208.84	34.12
12	0.105	-0.216	-0.093	5.05	137.47	8.67	5.80	206.40	25.99
13	0.020	-0.227	-0.042	6.08	203.86	2.08	0.94	194.29	18.51
14	-0.048	-0.081	0.005	8.00	77.35	4.07	5.16	67.39	2.81
15	-0.053	-0.044	0.055	10.65	114.55	3.03	3.62	9.44	4.96
16	-0.046	-0.103	-0.011	7.58	64.48	4.33	5.69	93.94	5.88
Ballasted Condition									
1	0.341	-1.248	0.276	57.36	450.33	50.85	34.59	202.52	52.76
2	0.589	-0.912	-0.041	3.18	264.17	61.94	50.07	203.22	75.13
3	0.594	-0.961	-0.017	0.84	268.19	63.41	50.93	197.06	75.32
4	0.740	-0.449	-0.060	38.09	153.44	72.79	66.97	51.76	54.69
5	0.741	-0.433	-0.074	40.00	149.38	72.34	66.72	53.90	55.27
6	-0.499	0.698	0.151	15.68	163.10	47.92	38.84	199.92	71.84
7	-0.298	0.366	0.055	9.03	105.34	29.61	24.83	94.06	36.25
8	0.607	-0.181	-0.170	50.24	58.48	54.63	52.26	48.68	47.23
9	0.612	-0.179	-0.179	51.40	56.04	54.82	52.49	51.68	48.14
10	-0.524	-1.450	1.238	209.90	793.42	0.81	18.11	58.64	65.78
11	-0.475	-1.443	1.192	201.85	732.77	3.92	14.87	43.97	59.65
12	-0.191	-2.137	1.186	213.17	833.74	35.84	8.10	117.38	10.22
13	0.048	-2.502	1.030	199.52	765.88	55.93	23.60	227.26	34.99
14	-0.097	-0.316	0.143	33.66	78.92	2.47	6.53	32.37	0.04
15	0.132	-0.130	0.009	2.80	30.14	13.81	12.15	10.91	10.47
16	-0.179	-0.332	0.119	38.22	55.54	10.97	15.20	44.53	1.05

Table D.2 Static Moored Ship Motions Analysis Results for 50,000 DWT Ship at SRH Port
(EA = 6,000 kN)

No.	Surge U_x (m)	Sway U_y (m)	Yaw θ_z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	-0.102	-0.079	0.100	39.72	353.16	12.24	14.35	31.63	18.74
2	-0.089	-0.050	0.111	36.78	359.72	9.34	10.67	101.42	23.88
3	-0.083	-0.046	0.102	33.95	348.31	8.66	9.88	94.96	22.03
4	-0.048	-0.004	0.107	25.34	315.82	2.07	2.17	183.50	25.82
5	-0.051	-0.004	0.110	26.32	319.42	2.35	2.46	186.68	26.62
6	0.065	0.030	-0.073	24.80	227.78	7.34	8.14	67.00	16.39
7	0.031	0.018	-0.033	11.88	104.08	3.53	4.01	23.48	7.03
8	-0.062	-0.009	0.116	29.58	283.99	4.16	4.39	174.66	28.20
9	-0.066	-0.010	0.121	30.91	290.53	4.52	4.79	177.64	29.14
10	0.129	-0.081	-0.104	28.83	24.96	19.56	17.41	225.18	40.06
11	0.101	-0.078	-0.086	21.98	7.54	15.14	13.08	208.84	34.12
12	0.053	-0.108	-0.046	5.05	137.47	8.67	5.80	206.40	25.99
13	0.010	-0.113	-0.021	6.08	203.86	2.08	0.94	194.29	18.51
14	-0.024	-0.041	0.002	8.00	77.35	4.07	5.16	67.39	2.81
15	-0.026	-0.022	0.027	10.65	114.55	3.03	3.62	9.44	4.96
16	-0.023	-0.051	-0.006	7.58	64.48	4.33	5.69	93.94	5.88
Ballasted Condition									
1	0.170	-0.624	0.138	57.36	450.33	50.85	34.59	202.52	52.76
2	0.295	-0.456	-0.021	3.18	264.17	61.94	50.07	203.22	75.13
3	0.297	-0.480	-0.008	0.84	268.19	63.41	50.93	197.06	75.32
4	0.370	-0.224	-0.030	38.09	153.44	72.79	66.97	51.76	54.69
5	0.370	-0.217	-0.037	40.00	149.38	72.34	66.72	53.90	55.27
6	-0.249	0.349	0.076	15.68	163.10	47.92	38.84	199.92	71.84
7	-0.149	0.183	0.028	9.03	105.34	29.61	24.83	94.06	36.25
8	0.303	-0.091	-0.085	50.24	58.48	54.63	52.26	48.68	47.23
9	0.306	-0.089	-0.089	51.40	56.04	54.82	52.49	51.68	48.14
10	-0.262	-0.725	0.619	209.90	793.42	0.81	18.11	58.64	65.78
11	-0.238	-0.721	0.596	201.85	732.77	3.92	14.87	43.97	59.65
12	-0.096	-1.068	0.593	213.17	833.74	35.84	8.10	117.38	10.22
13	0.024	-1.251	0.515	199.52	765.88	55.93	23.60	227.26	34.99
14	-0.048	-0.158	0.071	33.66	78.92	2.47	6.53	32.37	0.04
15	0.066	-0.065	0.004	2.80	30.14	13.81	12.15	10.91	10.47
16	-0.089	-0.166	0.059	38.22	55.54	10.97	15.20	44.53	1.05

Table D.3 Static Moored Ship Motions Analysis Results for 50,000 DWT Ship at SRH Port
(EA = 9,000 kN)

No.	Surge U_x (m)	Sway U_y (m)	Yaw θ_z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	-0.068	-0.053	0.067	39.72	353.16	12.24	14.35	31.63	18.74
2	-0.060	-0.033	0.074	36.78	359.72	9.34	10.67	101.42	23.88
3	-0.055	-0.031	0.068	33.95	348.31	8.66	9.88	94.96	22.03
4	-0.032	-0.003	0.071	25.34	315.82	2.07	2.17	183.50	25.82
5	-0.034	-0.003	0.073	26.32	319.42	2.35	2.46	186.68	26.62
6	0.043	0.020	-0.049	24.80	227.78	7.34	8.14	67.00	16.39
7	0.020	0.012	-0.022	11.88	104.08	3.53	4.01	23.48	7.03
8	-0.042	-0.006	0.078	29.58	283.99	4.16	4.39	174.66	28.20
9	-0.044	-0.007	0.080	30.91	290.53	4.52	4.79	177.64	29.14
10	0.086	-0.054	-0.069	28.83	24.96	19.56	17.41	225.18	40.06
11	0.067	-0.052	-0.058	21.98	7.54	15.14	13.08	208.84	34.12
12	0.035	-0.072	-0.031	5.05	137.47	8.67	5.80	206.40	25.99
13	0.007	-0.076	-0.014	6.08	203.86	2.08	0.94	194.29	18.51
14	-0.016	-0.027	0.002	8.00	77.35	4.07	5.16	67.39	2.81
15	-0.018	-0.015	0.018	10.65	114.55	3.03	3.62	9.44	4.96
16	-0.015	-0.034	-0.004	7.58	64.48	4.33	5.69	93.94	5.88
Ballasted Condition									
1	0.114	-0.416	0.092	57.36	450.33	50.85	34.59	202.52	52.76
2	0.196	-0.304	-0.014	3.18	264.17	61.94	50.07	203.22	75.13
3	0.198	-0.320	-0.006	0.84	268.19	63.41	50.93	197.06	75.32
4	0.247	-0.150	-0.020	38.09	153.44	72.79	66.97	51.76	54.69
5	0.247	-0.144	-0.025	40.00	149.38	72.34	66.72	53.90	55.27
6	-0.166	0.233	0.050	15.68	163.10	47.92	38.84	199.92	71.84
7	-0.099	0.122	0.018	9.03	105.34	29.61	24.83	94.06	36.25
8	0.202	-0.060	-0.057	50.24	58.48	54.63	52.26	48.68	47.23
9	0.204	-0.060	-0.060	51.40	56.04	54.82	52.49	51.68	48.14
10	-0.175	-0.483	0.413	209.90	793.42	0.81	18.11	58.64	65.78
11	-0.158	-0.481	0.397	201.85	732.77	3.92	14.87	43.97	59.65
12	-0.064	-0.712	0.395	213.17	833.74	35.84	8.10	117.38	10.22
13	0.016	-0.834	0.343	199.52	765.88	55.93	23.60	227.26	34.99
14	-0.032	-0.105	0.048	33.66	78.92	2.47	6.53	32.37	0.04
15	0.044	-0.043	0.003	2.80	30.14	13.81	12.15	10.91	10.47
16	-0.060	-0.111	0.040	38.22	55.54	10.97	15.20	44.53	1.05

Table D.4 Static Moored Ship Motions Analysis Results for 5,000 DWT Ship at SRH Port
(EA = 3,000 kN)

No.	Surge U_x (m)	Sway U_y (m)	Yaw θ_z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	-0.142	-0.225	-0.509	5.434	10.64	32.34	25.85	142.25	21.41
2	-0.137	-0.132	-0.572	0.450	36.88	31.44	27.63	136.57	20.48
3	-0.132	-0.127	-0.556	0.563	36.44	30.48	26.78	134.30	20.03
4	-0.123	0.038	-0.618	9.431	76.10	27.84	28.94	110.48	15.78
5	-0.124	0.039	-0.625	9.516	76.71	28.15	29.28	110.91	15.86
6	0.060	0.103	0.284	0.274	13.58	14.94	11.97	78.41	13.06
7	0.040	0.050	0.163	0.410	8.15	9.25	7.81	41.17	6.33
8	-0.103	0.052	-0.518	8.506	65.04	22.90	24.38	83.97	12.05
9	-0.106	0.052	-0.526	8.542	65.64	23.33	24.81	85.07	12.19
10	-0.382	-0.026	-0.971	6.839	67.84	71.85	71.11	156.39	7.57
11	-0.351	-0.032	-0.873	7.178	58.78	65.96	65.05	143.15	6.42
12	-0.412	-0.084	-1.060	8.965	67.31	79.06	76.63	191.02	11.76
13	-0.374	-0.127	-0.957	10.178	52.59	72.91	69.20	189.91	13.10
14	-0.030	-0.052	-0.038	3.546	9.03	5.75	4.23	17.06	1.25
15	-0.020	-0.048	-0.024	2.925	8.74	4.09	2.69	14.61	1.40
16	-0.018	-0.065	0.021	4.808	18.69	3.21	1.27	8.88	0.28
Ballasted Condition									
1	-0.149	-0.234	-0.451	8.42	0.59	33.43	26.48	148.88	18.54
2	-0.074	-0.175	-0.328	2.95	5.37	19.38	14.19	115.91	17.61
3	-0.071	-0.170	-0.321	2.69	5.81	18.73	13.68	113.68	17.37
4	-0.076	0.009	-0.420	6.59	53.92	18.48	18.74	89.37	12.64
5	-0.076	0.008	-0.420	6.59	53.90	18.50	18.75	89.50	12.67
6	0.022	0.168	0.156	3.13	10.41	8.49	3.50	80.70	14.39
7	0.030	0.076	0.138	1.20	2.13	8.02	5.78	49.59	7.68
8	-0.056	0.025	-0.326	6.10	45.68	13.59	14.32	64.82	9.28
9	-0.056	0.024	-0.329	6.09	45.78	13.75	14.46	65.42	9.35
10	-0.320	-0.136	-0.731	12.61	28.42	62.18	58.14	160.80	8.27
11	-0.307	-0.121	-0.693	12.04	27.70	59.39	55.79	149.96	6.99
12	-0.328	-0.238	-0.770	15.92	14.07	65.77	58.69	197.61	14.62
13	-0.284	-0.295	-0.670	16.89	3.72	58.32	49.54	196.25	17.51
14	-0.023	-0.036	-0.016	3.10	8.80	4.25	3.17	9.48	0.05
15	-0.009	-0.027	0.005	2.07	7.57	1.71	0.92	4.25	0.06
16	-0.011	-0.049	0.044	4.29	18.06	1.57	0.10	0.41	0.93

Table D.5 Static Moored Ship Motions Analysis Results for 5,000 DWT Ship at SRH Port
(EA = 6,000 kN)

No.	Surge U_x (m)	Sway U_y (m)	Yaw θ_z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	-0.071	-0.112	-0.254	5.43	10.64	32.34	25.85	142.25	21.41
2	-0.068	-0.066	-0.286	0.45	36.88	31.44	27.63	136.57	20.48
3	-0.066	-0.064	-0.278	0.56	36.44	30.48	26.78	134.30	20.03
4	-0.061	0.019	-0.309	9.43	76.10	27.84	28.94	110.48	15.78
5	-0.062	0.020	-0.312	9.52	76.71	28.15	29.28	110.91	15.86
6	0.030	0.051	0.142	0.27	13.58	14.94	11.97	78.41	13.06
7	0.020	0.025	0.081	0.41	8.15	9.25	7.81	41.17	6.33
8	-0.052	0.026	-0.259	8.51	65.04	22.90	24.38	83.97	12.05
9	-0.053	0.026	-0.263	8.54	65.64	23.33	24.81	85.07	12.19
10	-0.191	-0.013	-0.486	6.84	67.84	71.85	71.11	156.39	7.57
11	-0.176	-0.016	-0.436	7.18	58.78	65.96	65.05	143.15	6.42
12	-0.206	-0.042	-0.530	8.97	67.31	79.06	76.63	191.02	11.76
13	-0.187	-0.064	-0.479	10.18	52.59	72.91	69.20	189.91	13.10
14	-0.015	-0.026	-0.019	3.55	9.03	5.75	4.23	17.06	1.25
15	-0.010	-0.024	-0.012	2.93	8.74	4.09	2.69	14.61	1.40
16	-0.009	-0.033	0.011	4.81	18.69	3.21	1.27	8.88	0.28
Ballasted Condition									
1	-0.074	-0.117	-0.226	8.42	0.59	33.43	26.48	148.88	18.54
2	-0.037	-0.087	-0.164	2.95	5.37	19.38	14.19	115.91	17.61
3	-0.036	-0.085	-0.160	2.69	5.81	18.73	13.68	113.68	17.37
4	-0.038	0.004	-0.210	6.59	53.92	18.48	18.74	89.37	12.64
5	-0.038	0.004	-0.210	6.59	53.90	18.50	18.75	89.50	12.67
6	0.011	0.084	0.078	3.13	10.41	8.49	3.50	80.70	14.39
7	0.015	0.038	0.069	1.20	2.13	8.02	5.78	49.59	7.68
8	-0.028	0.012	-0.163	6.10	45.68	13.59	14.32	64.82	9.28
9	-0.028	0.012	-0.164	6.09	45.78	13.75	14.46	65.42	9.35
10	-0.160	-0.068	-0.365	12.61	28.42	62.18	58.14	160.80	8.27
11	-0.153	-0.061	-0.346	12.04	27.70	59.39	55.79	149.96	6.99
12	-0.164	-0.119	-0.385	15.92	14.07	65.77	58.69	197.61	14.62
13	-0.142	-0.148	-0.335	16.89	3.72	58.32	49.54	196.25	17.51
14	-0.012	-0.018	-0.008	3.10	8.80	4.25	3.17	9.48	0.05
15	-0.005	-0.013	0.002	2.07	7.57	1.71	0.92	4.25	0.06
16	-0.005	-0.025	0.022	4.29	18.06	1.57	0.10	0.41	0.93

Table D.6 Static Moored Ship Motions Analysis Results for 5,000 DWT Ship at SRH Port
(EA = 9,000 kN)

No.	Surge U_x (m)	Sway U_y (m)	Yaw θ_z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	-0.047	-0.075	-0.170	5.43	10.64	32.34	25.85	142.25	21.41
2	-0.046	-0.044	-0.191	0.45	36.88	31.44	27.63	136.57	20.48
3	-0.044	-0.042	-0.185	0.56	36.44	30.48	26.78	134.30	20.03
4	-0.041	0.013	-0.206	9.43	76.10	27.84	28.94	110.48	15.78
5	-0.041	0.013	-0.208	9.52	76.71	28.15	29.28	110.91	15.86
6	0.020	0.034	0.095	0.27	13.58	14.94	11.97	78.41	13.06
7	0.013	0.017	0.054	0.41	8.15	9.25	7.81	41.17	6.33
8	-0.034	0.017	-0.173	8.51	65.04	22.90	24.38	83.97	12.05
9	-0.035	0.017	-0.175	8.54	65.64	23.33	24.81	85.07	12.19
10	-0.127	-0.009	-0.324	6.84	67.84	71.85	71.11	156.39	7.57
11	-0.117	-0.011	-0.291	7.18	58.78	65.96	65.05	143.15	6.42
12	-0.137	-0.028	-0.353	8.97	67.31	79.06	76.63	191.02	11.76
13	-0.125	-0.042	-0.319	10.18	52.59	72.91	69.20	189.91	13.10
14	-0.010	-0.017	-0.013	3.55	9.03	5.75	4.23	17.06	1.25
15	-0.007	-0.016	-0.008	2.93	8.74	4.09	2.69	14.61	1.40
16	-0.006	-0.022	0.007	4.81	18.69	3.21	1.27	8.88	0.28
Ballasted Condition									
1	-0.050	-0.078	-0.150	8.42	0.59	33.43	26.48	148.88	18.54
2	-0.025	-0.058	-0.109	2.95	5.37	19.38	14.19	115.91	17.61
3	-0.024	-0.057	-0.107	2.69	5.81	18.73	13.68	113.68	17.37
4	-0.025	0.003	-0.140	6.59	53.92	18.48	18.74	89.37	12.64
5	-0.025	0.003	-0.140	6.59	53.90	18.50	18.75	89.50	12.67
6	0.007	0.056	0.052	3.13	10.41	8.49	3.50	80.70	14.39
7	0.010	0.025	0.046	1.20	2.13	8.02	5.78	49.59	7.68
8	-0.019	0.008	-0.109	6.10	45.68	13.59	14.32	64.82	9.28
9	-0.019	0.008	-0.110	6.09	45.78	13.75	14.46	65.42	9.35
10	-0.107	-0.045	-0.244	12.61	28.42	62.18	58.14	160.80	8.27
11	-0.102	-0.040	-0.231	12.04	27.70	59.39	55.79	149.96	6.99
12	-0.109	-0.079	-0.257	15.92	14.07	65.77	58.69	197.61	14.62
13	-0.095	-0.098	-0.223	16.89	3.72	58.32	49.54	196.25	17.51
14	-0.008	-0.012	-0.005	3.10	8.80	4.25	3.17	9.48	0.05
15	-0.003	-0.009	0.002	2.07	7.57	1.71	0.92	4.25	0.06
16	-0.004	-0.016	0.015	4.29	18.06	1.57	0.10	0.41	0.93

Table D.7 Static Moored Ship Motions Analysis Results for 50,000 DWT Ship at BLCP Port
(EA = 3,000 kN)

No.	Surge U _x (m)	Sway U _y (m)	Yaw θ _z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	1.467	-2.656	1.295	142.22	1,119.96	158.56	190.32	500.79	124.38
2	1.130	-1.941	1.066	109.97	859.83	125.34	146.96	336.34	84.67
3	0.973	-1.539	0.972	92.34	718.16	111.10	126.26	237.68	61.53
4	0.631	-1.405	0.630	82.61	608.28	65.93	85.97	253.92	60.54
5	0.173	-1.564	0.059	78.02	527.73	2.35	33.02	398.31	86.02
6	0.395	-1.756	0.309	92.72	644.96	26.04	60.78	402.61	89.56
7	0.398	-2.209	0.189	106.63	744.31	16.81	63.16	555.44	122.98
8	-0.342	-1.980	-0.664	78.51	481.10	84.46	25.75	645.68	133.59
9	2.002	-3.060	1.604	147.31	1,241.71	221.06	250.73	600.36	155.13
10	2.726	-2.814	2.617	165.20	1,427.60	331.40	336.67	335.16	105.66
11	2.575	-2.518	2.574	157.63	1,353.82	317.66	318.81	247.12	84.06
12	2.106	-2.373	2.008	137.55	1,184.20	253.01	262.02	314.72	92.91
13	1.216	-2.078	0.920	96.87	828.32	129.92	153.55	443.28	110.09
14	1.408	-1.344	1.361	80.18	721.57	173.26	173.13	144.89	48.30
15	1.554	-0.898	1.654	69.77	659.49	203.74	188.44	39.77	10.63
16	0.857	-0.480	0.891	35.65	348.06	112.08	103.32	18.18	6.90
Ballasted Condition									
1	-0.666	-0.715	-0.550	45.05	119.30	96.64	64.96	179.91	36.77
2	-0.711	-0.169	-0.543	19.70	7.55	93.29	74.12	65.43	6.13
3	-0.749	0.069	-0.552	9.11	39.08	93.98	79.93	16.58	7.47
4	-0.654	0.588	-0.435	16.37	130.94	73.30	73.95	95.32	36.59
5	-0.330	0.850	-0.150	31.98	164.21	27.46	41.34	169.66	51.73
6	-0.532	0.943	-0.308	34.43	197.60	52.05	63.90	179.07	56.74
7	-0.380	0.550	-0.202	16.27	112.45	38.70	44.19	111.71	36.01
8	0.291	0.792	0.396	31.76	115.80	52.76	26.79	216.90	53.05
9	-0.103	-2.735	-0.303	130.31	558.08	58.25	11.21	602.65	154.65
10	-0.870	-2.225	-0.905	112.30	396.64	149.45	76.03	540.76	128.04
11	-0.663	-1.647	-0.644	86.83	297.08	111.89	57.42	384.09	91.24
12	-0.459	-1.823	-0.451	96.47	339.05	87.11	33.11	385.85	97.18
13	0.001	-2.138	-0.073	108.49	402.91	32.29	19.28	398.58	111.58
14	-0.347	-1.777	-0.297	97.27	307.49	69.64	20.09	324.91	88.91
15	-0.538	-1.702	-0.408	98.53	277.07	91.03	39.99	298.72	81.33
16	-0.324	-1.267	-0.238	72.59	199.97	57.72	21.53	210.15	59.95

Table D.8 Static Moored Ship Motions Analysis Results for 50,000 DWT Ship at BLCP Port
(EA = 6,000 kN)

No.	Surge U _x (m)	Sway U _y (m)	Yaw θ _z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	0.734	-1.328	0.648	142.22	1,119.96	158.56	190.32	500.79	124.38
2	0.565	-0.970	0.533	109.97	859.83	125.34	146.96	336.34	84.67
3	0.486	-0.769	0.486	92.34	718.16	111.10	126.26	237.68	61.53
4	0.316	-0.703	0.315	82.61	608.28	65.93	85.97	253.92	60.54
5	0.086	-0.782	0.030	78.02	527.73	2.35	33.02	398.31	86.02
6	0.197	-0.878	0.155	92.72	644.96	26.04	60.78	402.61	89.56
7	0.199	-1.104	0.095	106.63	744.31	16.81	63.16	555.44	122.98
8	-0.171	-0.990	-0.332	78.51	481.10	84.46	25.75	645.68	133.59
9	1.001	-1.530	0.802	147.31	1,241.71	221.06	250.73	600.36	155.13
10	1.363	-1.407	1.308	165.20	1,427.60	331.40	336.67	335.16	105.66
11	1.288	-1.259	1.287	157.63	1,353.82	317.66	318.81	247.12	84.06
12	1.053	-1.186	1.004	137.55	1,184.20	253.01	262.02	314.72	92.91
13	0.608	-1.039	0.460	96.87	828.32	129.92	153.55	443.28	110.09
14	0.704	-0.672	0.680	80.18	721.57	173.26	173.13	144.89	48.30
15	0.777	-0.449	0.827	69.77	659.49	203.74	188.44	39.77	10.63
16	0.429	-0.240	0.445	35.65	348.06	112.08	103.32	18.18	6.90
Ballasted Condition									
1	-0.333	-0.357	-0.275	45.05	119.30	96.64	64.96	179.91	36.77
2	-0.356	-0.085	-0.272	19.70	7.55	93.29	74.12	65.43	6.13
3	-0.374	0.034	-0.276	9.11	39.08	93.98	79.93	16.58	7.47
4	-0.327	0.294	-0.218	16.37	130.94	73.30	73.95	95.32	36.59
5	-0.165	0.425	-0.075	31.98	164.21	27.46	41.34	169.66	51.73
6	-0.266	0.472	-0.154	34.43	197.60	52.05	63.90	179.07	56.74
7	-0.190	0.275	-0.101	16.27	112.45	38.70	44.19	111.71	36.01
8	0.145	0.396	0.198	31.76	115.80	52.76	26.79	216.90	53.05
9	-0.052	-1.368	-0.151	130.31	558.08	58.25	11.21	602.65	154.65
10	-0.435	-1.112	-0.452	112.30	396.64	149.45	76.03	540.76	128.04
11	-0.331	-0.823	-0.322	86.83	297.08	111.89	57.42	384.09	91.24
12	-0.230	-0.911	-0.225	96.47	339.05	87.11	33.11	385.85	97.18
13	0.000	-1.069	-0.036	108.49	402.91	32.29	19.28	398.58	111.58
14	-0.173	-0.889	-0.149	97.27	307.49	69.64	20.09	324.91	88.91
15	-0.269	-0.851	-0.204	98.53	277.07	91.03	39.99	298.72	81.33
16	-0.162	-0.634	-0.119	72.59	199.97	57.72	21.53	210.15	59.95

Table D.9 Static Moored Ship Motions Analysis Results for 50,000 DWT Ship at BLCP Port
(EA = 9,000 kN)

No.	Surge U _x (m)	Sway U _y (m)	Yaw θ _z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	0.489	-0.885	0.432	142.22	1,119.96	158.56	190.32	500.79	124.38
2	0.377	-0.647	0.355	109.97	859.83	125.34	146.96	336.34	84.67
3	0.324	-0.513	0.324	92.34	718.16	111.10	126.26	237.68	61.53
4	0.210	-0.468	0.210	82.61	608.28	65.93	85.97	253.92	60.54
5	0.058	-0.521	0.020	78.02	527.73	2.35	33.02	398.31	86.02
6	0.132	-0.585	0.103	92.72	644.96	26.04	60.78	402.61	89.56
7	0.133	-0.736	0.063	106.63	744.31	16.81	63.16	555.44	122.98
8	-0.114	-0.660	-0.221	78.51	481.10	84.46	25.75	645.68	133.59
9	0.667	-1.020	0.535	147.31	1,241.71	221.06	250.73	600.36	155.13
10	0.909	-0.938	0.872	165.20	1,427.60	331.40	336.67	335.16	105.66
11	0.858	-0.839	0.858	157.63	1,353.82	317.66	318.81	247.12	84.06
12	0.702	-0.791	0.669	137.55	1,184.20	253.01	262.02	314.72	92.91
13	0.405	-0.693	0.307	96.87	828.32	129.92	153.55	443.28	110.09
14	0.469	-0.448	0.454	80.18	721.57	173.26	173.13	144.89	48.30
15	0.518	-0.299	0.551	69.77	659.49	203.74	188.44	39.77	10.63
16	0.286	-0.160	0.297	35.65	348.06	112.08	103.32	18.18	6.90
Ballasted Condition									
1	-0.222	-0.238	-0.183	45.05	119.30	96.64	64.96	179.91	36.77
2	-0.237	-0.056	-0.181	19.70	7.55	93.29	74.12	65.43	6.13
3	-0.250	0.023	-0.184	9.11	39.08	93.98	79.93	16.58	7.47
4	-0.218	0.196	-0.145	16.37	130.94	73.30	73.95	95.32	36.59
5	-0.110	0.283	-0.050	31.98	164.21	27.46	41.34	169.66	51.73
6	-0.177	0.314	-0.103	34.43	197.60	52.05	63.90	179.07	56.74
7	-0.127	0.183	-0.067	16.27	112.45	38.70	44.19	111.71	36.01
8	0.097	0.264	0.132	31.76	115.80	52.76	26.79	216.90	53.05
9	-0.034	-0.912	-0.101	130.31	558.08	58.25	11.21	602.65	154.65
10	-0.290	-0.742	-0.302	112.30	396.64	149.45	76.03	540.76	128.04
11	-0.221	-0.549	-0.215	86.83	297.08	111.89	57.42	384.09	91.24
12	-0.153	-0.608	-0.150	96.47	339.05	87.11	33.11	385.85	97.18
13	0.000	-0.713	-0.024	108.49	402.91	32.29	19.28	398.58	111.58
14	-0.116	-0.592	-0.099	97.27	307.49	69.64	20.09	324.91	88.91
15	-0.179	-0.567	-0.136	98.53	277.07	91.03	39.99	298.72	81.33
16	-0.108	-0.422	-0.079	72.59	199.97	57.72	21.53	210.15	59.95

Table D.10 Static Moored Ship Motions Analysis Results for 5,000 DWT Ship at BLCP Port
(EA = 3,000 kN)

No.	Surge U_x (m)	Sway U_y (m)	Yaw θ_z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	-0.059	-0.201	0.106	15.932	118.44	6.53	19.62	41.99	1.82
2	0.129	-0.173	-0.560	23.218	123.60	5.53	17.03	204.33	40.08
3	0.218	-0.161	-0.884	41.992	239.50	4.83	16.18	282.87	60.33
4	0.396	-0.153	-1.472	77.133	440.95	7.66	12.29	426.47	99.17
5	0.440	-0.136	-1.529	83.747	459.89	12.86	4.77	427.29	104.95
6	0.583	-0.173	-2.070	112.483	618.65	13.85	8.48	571.83	140.29
7	0.443	-0.198	-1.548	82.385	430.16	16.26	9.28	445.44	108.31
8	0.364	-0.121	-1.127	64.873	321.06	19.35	3.77	310.90	82.12
9	-1.063	-0.105	3.675	216.793	1267.64	4.11	17.77	883.41	235.58
10	-0.629	-0.183	2.002	127.515	754.83	5.10	28.91	439.45	128.55
11	-0.370	-0.178	1.122	75.934	463.19	1.96	25.17	222.36	70.97
12	-0.362	-0.151	1.107	73.910	468.99	2.88	22.76	234.42	70.84
13	-0.401	-0.096	1.316	82.099	544.42	2.31	15.04	318.79	84.62
14	-0.110	0.011	0.258	18.273	94.55	9.72	8.25	68.61	21.09
15	-0.197	-0.082	0.471	36.464	228.66	9.83	20.89	92.10	33.93
16	-0.139	-0.045	0.346	25.702	163.46	7.01	13.08	74.76	24.98
Ballasted Condition									
1	0.000	-0.036	-0.122	2.36	45.01	5.45	10.58	61.65	5.92
2	0.040	-0.023	-0.247	10.60	121.84	5.13	8.35	96.15	14.08
3	0.055	-0.019	-0.299	13.73	152.07	5.37	8.07	111.49	17.32
4	0.106	0.003	-0.432	23.64	237.10	3.42	2.94	142.41	26.55
5	0.137	0.026	-0.463	28.45	267.33	0.33	3.94	139.17	29.98
6	0.151	0.024	-0.536	32.04	307.29	0.88	2.47	165.26	34.23
7	0.125	0.014	-0.449	26.51	254.05	0.65	1.39	140.93	28.76
8	0.150	0.044	-0.430	29.45	259.94	4.44	10.61	116.42	29.42
9	-0.230	-0.096	0.622	45.16	396.27	7.41	20.96	152.15	42.68
10	-0.172	-0.095	0.364	31.54	255.25	10.44	23.86	65.77	27.26
11	-0.108	-0.062	0.234	20.08	164.86	6.16	14.85	42.57	17.28
12	-0.122	-0.065	0.279	22.96	190.89	6.28	15.46	55.55	20.24
13	-0.156	-0.068	0.422	30.69	264.45	4.80	14.32	101.08	28.81
14	-0.103	-0.053	0.217	18.67	140.46	6.49	13.94	39.19	16.37
15	-0.134	-0.082	0.286	24.92	183.69	7.34	18.78	46.09	20.97
16	-0.107	-0.065	0.243	20.25	146.20	4.89	13.82	41.50	17.27

Table D.11 Static Moored Ship Motions Analysis Results for 5,000 DWT Ship at BLCP Port
(EA = 6,000 kN)

No.	Surge U_x (m)	Sway U_y (m)	Yaw θ_z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	-0.029	-0.100	0.053	15.93	118.44	6.53	19.62	41.99	1.82
2	0.064	-0.086	-0.280	23.22	123.60	5.53	17.03	204.33	40.08
3	0.109	-0.081	-0.442	41.99	239.50	4.83	16.18	282.87	60.33
4	0.198	-0.077	-0.736	77.13	440.95	7.66	12.29	426.47	99.17
5	0.220	-0.068	-0.764	83.75	459.89	12.86	4.77	427.29	104.95
6	0.292	-0.086	-1.035	112.48	618.65	13.85	8.48	571.83	140.29
7	0.222	-0.099	-0.774	82.38	430.16	16.26	9.28	445.44	108.31
8	0.182	-0.060	-0.564	64.87	321.06	19.35	3.77	310.90	82.12
9	-0.532	-0.053	1.837	216.79	1,267.64	4.11	17.77	883.41	235.58
10	-0.314	-0.091	1.001	127.52	754.83	5.10	28.91	439.45	128.55
11	-0.185	-0.089	0.561	75.93	463.19	1.96	25.17	222.36	70.97
12	-0.181	-0.075	0.554	73.91	468.99	2.88	22.76	234.42	70.84
13	-0.201	-0.048	0.658	82.10	544.42	2.31	15.04	318.79	84.62
14	-0.055	0.006	0.129	18.27	94.55	9.72	8.25	68.61	21.09
15	-0.098	-0.041	0.235	36.46	228.66	9.83	20.89	92.10	33.93
16	-0.069	-0.022	0.173	25.70	163.46	7.01	13.08	74.76	24.98
Ballasted Condition									
1	0.000	-0.018	-0.061	2.36	45.01	5.45	10.58	61.65	5.92
2	0.020	-0.011	-0.124	10.60	121.84	5.13	8.35	96.15	14.08
3	0.027	-0.010	-0.150	13.73	152.07	5.37	8.07	111.49	17.32
4	0.053	0.002	-0.216	23.64	237.10	3.42	2.94	142.41	26.55
5	0.068	0.013	-0.231	28.45	267.33	0.33	3.94	139.17	29.98
6	0.076	0.012	-0.268	32.04	307.29	0.88	2.47	165.26	34.23
7	0.063	0.007	-0.224	26.51	254.05	0.65	1.39	140.93	28.76
8	0.075	0.022	-0.215	29.45	259.94	4.44	10.61	116.42	29.42
9	-0.115	-0.048	0.311	45.16	396.27	7.41	20.96	152.15	42.68
10	-0.086	-0.048	0.182	31.54	255.25	10.44	23.86	65.77	27.26
11	-0.054	-0.031	0.117	20.08	164.86	6.16	14.85	42.57	17.28
12	-0.061	-0.033	0.140	22.96	190.89	6.28	15.46	55.55	20.24
13	-0.078	-0.034	0.211	30.69	264.45	4.80	14.32	101.08	28.81
14	-0.051	-0.027	0.108	18.67	140.46	6.49	13.94	39.19	16.37
15	-0.067	-0.041	0.143	24.92	183.69	7.34	18.78	46.09	20.97
16	-0.054	-0.032	0.122	20.25	146.20	4.89	13.82	41.50	17.27

Table D.12 Static Moored Ship Motions Analysis Results for 5,000 DWT Ship at BLCP Port
(EA = 9,000 kN)

No.	Surge U_x (m)	Sway U_y (m)	Yaw θ_z (Deg.)	Mooring Force Line 1 (kN)	Mooring Force Line 2 (kN)	Mooring Force Line 3 (kN)	Mooring Force Line 4 (kN)	Mooring Force Line 5 (kN)	Mooring Force Line 6 (kN)
Fully Loaded Condition									
1	-0.020	-0.067	0.035	15.93	118.44	6.53	19.62	41.99	1.82
2	0.043	-0.058	-0.187	23.22	123.60	5.53	17.03	204.33	40.08
3	0.073	-0.054	-0.295	41.99	239.50	4.83	16.18	282.87	60.33
4	0.132	-0.051	-0.491	77.13	440.95	7.66	12.29	426.47	99.17
5	0.147	-0.045	-0.510	83.75	459.89	12.86	4.77	427.29	104.95
6	0.194	-0.058	-0.690	112.48	618.65	13.85	8.48	571.83	140.29
7	0.148	-0.066	-0.516	82.38	430.16	16.26	9.28	445.44	108.31
8	0.121	-0.040	-0.376	64.87	321.06	19.35	3.77	310.90	82.12
9	-0.354	-0.035	1.225	216.79	1,267.64	4.11	17.77	883.41	235.58
10	-0.210	-0.061	0.667	127.52	754.83	5.10	28.91	439.45	128.55
11	-0.123	-0.059	0.374	75.93	463.19	1.96	25.17	222.36	70.97
12	-0.121	-0.050	0.369	73.91	468.99	2.88	22.76	234.42	70.84
13	-0.134	-0.032	0.439	82.10	544.42	2.31	15.04	318.79	84.62
14	-0.037	0.004	0.086	18.27	94.55	9.72	8.25	68.61	21.09
15	-0.066	-0.027	0.157	36.46	228.66	9.83	20.89	92.10	33.93
16	-0.046	-0.015	0.115	25.70	163.46	7.01	13.08	74.76	24.98
Ballasted Condition									
1	0.000	-0.012	-0.041	2.36	45.01	5.45	10.58	61.65	5.92
2	0.013	-0.008	-0.082	10.60	121.84	5.13	8.35	96.15	14.08
3	0.018	-0.006	-0.100	13.73	152.07	5.37	8.07	111.49	17.32
4	0.035	0.001	-0.144	23.64	237.10	3.42	2.94	142.41	26.55
5	0.046	0.009	-0.154	28.45	267.33	0.33	3.94	139.17	29.98
6	0.050	0.008	-0.179	32.04	307.29	0.88	2.47	165.26	34.23
7	0.042	0.005	-0.150	26.51	254.05	0.65	1.39	140.93	28.76
8	0.050	0.015	-0.143	29.45	259.94	4.44	10.61	116.42	29.42
9	-0.077	-0.032	0.207	45.16	396.27	7.41	20.96	152.15	42.68
10	-0.057	-0.032	0.121	31.54	255.25	10.44	23.86	65.77	27.26
11	-0.036	-0.021	0.078	20.08	164.86	6.16	14.85	42.57	17.28
12	-0.041	-0.022	0.093	22.96	190.89	6.28	15.46	55.55	20.24
13	-0.052	-0.023	0.141	30.69	264.45	4.80	14.32	101.08	28.81
14	-0.034	-0.018	0.072	18.67	140.46	6.49	13.94	39.19	16.37
15	-0.045	-0.027	0.095	24.92	183.69	7.34	18.78	46.09	20.97
16	-0.036	-0.022	0.081	20.25	146.20	4.89	13.82	41.50	17.27

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