INVITED ARTICLE

Impacts of Typhoon Vae and Linda on wind waves in the Upper Gulf of Thailand and East Coast

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Abstract

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The Upper Gulf of Thailand and east coast are the locations of the 3 important deepsea ports of Thailand, namely Bangkok port, Laem Chabang port and Map Ta Phut port which needed wind wave data for designs of port structures and navigation of cargo vessels and container ships to and from the ports.

In the past, most wave data in the Gulf of Thailand were computed from wind data using the method proposed by Silvester and Vongvisessomjai (1970). Recently, Pornpinatepong *et al.* (1999) used the WAM Model to predict wind waves in the Gulf of Thailand and Andaman Sea using waves initially from satellites ERS-2 and TOPEX and later from 9 oceanographic buoys in the Gulf of Thailand and 2 buoys in the Andaman Sea for model calibration.

This study presents wind waves in 6 years (1997-2002) from the WAM Model at Petchaburi and Sichang buoys in the Upper Gulf of Thailand as well as Rayong and Ko Chang buoys on the east coast. Since the big waves in the study area are generated by strong winds of cyclones, emphasis is placed to the wind waves generated during the passage of cyclones Vae in 1952 formerly provided by Vongvisessomjai (1994b) and new data of Linda in 1997. Cyclonic waves are second in size to the tsunami waves in the Andaman Sea on December 26, 2004.

Key words : cyclone, deepsea port, disaster, oceanographic buoy, wind wave

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บทคัดย่อ

สุภัทท์ วงศ์วิเศษสมใจ
อิทธิพลของพายุโซนร้อนต่อคลื่นลมในอ่าวไทยตอนบนและชายฝั่งตะวันออก
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อ่าวไทยตอนบนและชายฝั่งตะวันออก เป็นที่ตั้งของท่าเรือน้ำลึกทั้งสามท่าของประเทศไทย ได้แก่ ท่าเรือกรุงเทพ ท่าเรือแหลมฉบัง และท่าเรือมาบตาพุด ซึ่งต้องใช้ข้อมูลคลื่นลมในการออกแบบโครงสร้างท่าเรือต่าง ๆ และใช้ในการเดินเรือสินค้าเข้าและออกจากท่าเรือ

ในอดีตข้อมูลคลื่นในอ่าวไทยคำนวณจากข้อมูลลมโดยใช้วิธีที่เสนอโดย Silvester และ Vongvisessomjai (1970) ในปัจจุบัน พรพิเนตพงศ์ และคณะ (1999) ใช้แบบจำลองคลื่น (The WAM Model) ในการพยากรณ์คลื่นในอ่าวไทยและทะเลอันดามันแล้วนำมาสอบเทียบกับข้อมูลคลื่นในเบื้องต้นจากดาวเทียม ERS-2 และ TOPEX และต่อมาจากทุ่นสมุทรศาสตร์ 9 ทุ่น ในอ่าวไทย และ 2 ทุ่น จากทะเลอันดามัน

การศึกษานี้จะใช้ข้อมูลคลื่น 6 ปี (1997-2002) จากแบบจำลองคลื่น (The WAM Model) ที่ทุ่นเพชรบุรีและสีชังในอ่าวไทยตอนบน และทุ่นระยอง และเกาะช้างจากชายฝั่งตะวันออก เนื่องจากคลื่นขนาดใหญ่ในบริเวณที่ศึกษาเกิดจากลมที่มีความเร็วสูงมากช่วงที่มีพายุโซนร้อนพัดผ่าน เช่น ใต้ฝุ่นเว้ ในปี ค.ศ. 1952 ซึ่งเสนอโดย Vongvisessomjai(1994b) และลินดาในปี ค.ศ. 1997 การศึกษานี้จึงเน้นถึงคลื่นที่เกิดจากพายุโซนร้อนนี้ ซึ่งมีขนาดใหญ่รองจากคลื่นสึนามิที่เกิดในทะเลอันดามันเมื่อวันที่ 26 ธันวาคม ค.ศ. 2004

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The 3 important deepsea ports of Thailand, namely Bangkok port, Laem Chabang port and Map Ta Phut port, are located in the Upper Gulf of Thailand and the east coast as shown in Figure 1 and needed wind wave data for design of the port structures.

Five cyclone disasters in Thailand due to strong winds and surges have occurred since the mid 20th century among which the first 3 were reported by Vongvisessomjai (1994 b). These were (i) in 1952 when typhoon Vae attacked the Upper Gulf; (ii) in 1962 when typhoon Harriet caused disaster at Laem Talumpuk of Nakorn Si Thammarat province due to its devastating winds and surges causing 800 deads; (iii) in 1970 when cyclone Ruth attacked Ko Samui and coastline of Surat Thani and Chumphon; (iv) new data in 1989 when typhoon Gay caused disaster at Patiew and Tha Sae of Chumphon province due to strong winds and surges, with 580 deads, mostly fishermen, 620 boats sunk, 40,000 houses destroyed causing about 11 billion baht damage; and (v) new data in 1997, when typhoon Linda attacked Thupsake of Prachuap Khiri Khan province resulting in 30 deads, 102 missing and more than 400,000 rai of agricultural land destroyed. This paper presents the characteristics of these cyclones.

Cyclones over Thailand

In summer, air over sea-surface near the equator which is overheated will become lighter and rise, creating a low pressure center defined as cyclone. The outer cooler air blows towards the center in counterclockwise direction over the northern hemisphere due to coriolis effect, and clockwise in the southern hemisphere. This results in a system of cloud which precipitates when it passes over a mountainous area and thus produces flood.

A tropical cyclone is characterized by four parameters, namely, its forward speed V_f, radius of the eye R, the minimum pressure at its center p_o and the maximum wind speed at the radius of

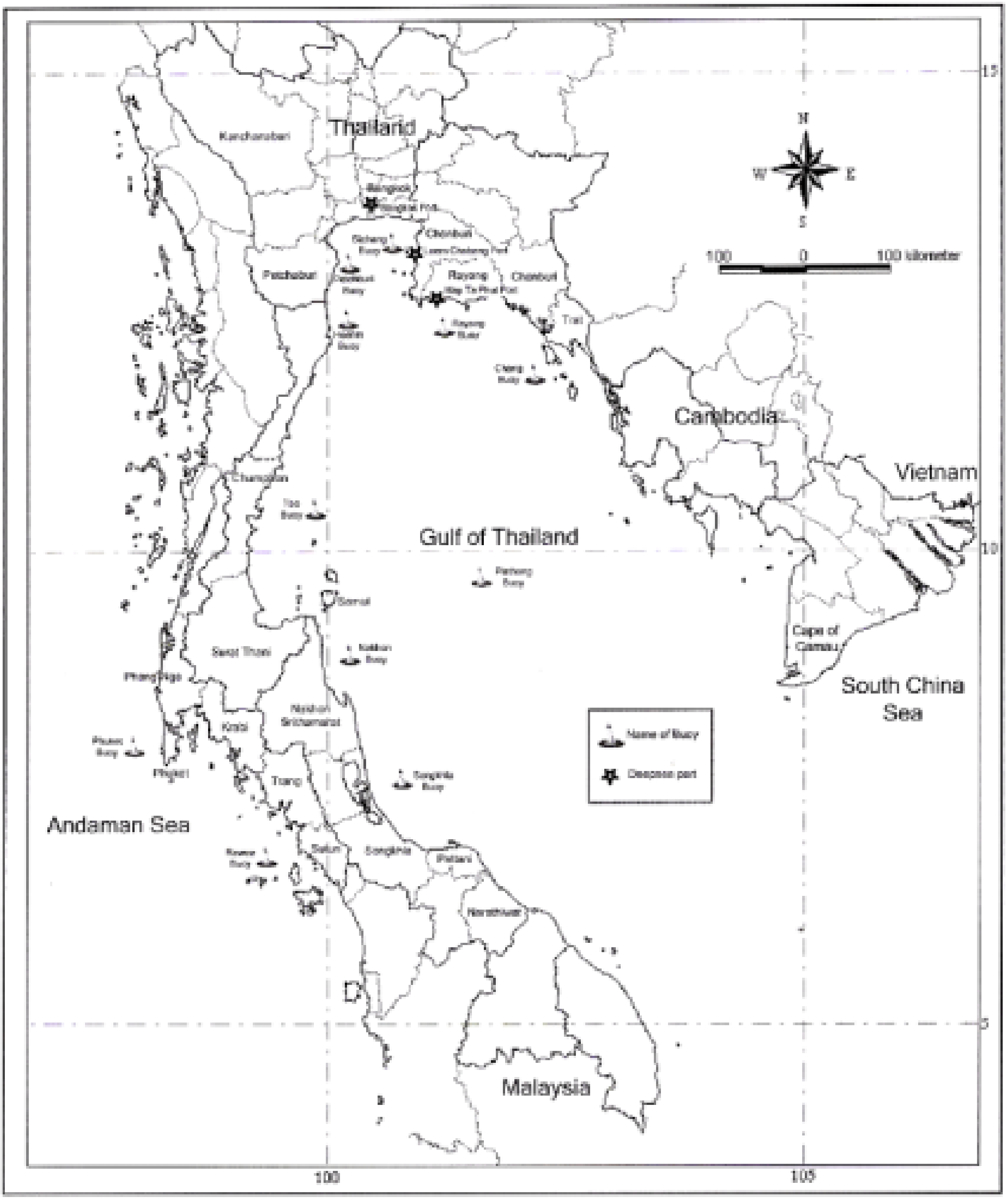

Figure 1. Location of 3 deepsea ports and oceanographic buoys operated by NRCT.

the eye U_{max}.

The pressure distribution of a cyclone p increases as a function of the radial distance r from its center p_O to the atmospheric pressure p_n, as proposed by Myers (1954) :

$$p - p_o = (p_n - p_o)\ e\,x\,p\ (-R/r) \text{ for } o < r < \quad (1)$$

The wind velocity distribution of a cyclone U varies as a function of the radial distance r, as proposed by Jelesnianski (1965) is given below.

$$U = U_{max}\ (r/R) \quad \text{for} \quad r \le R \quad (2)$$

$$U = U_{max}\ (R/r) \quad \text{for} \quad r > R \quad (3)$$

where U_{max} = the maximum sustained wind in a cyclone;
R = the radius of maximum sustained speed;
r = distance between center of the cyclone and the point where U is desired.

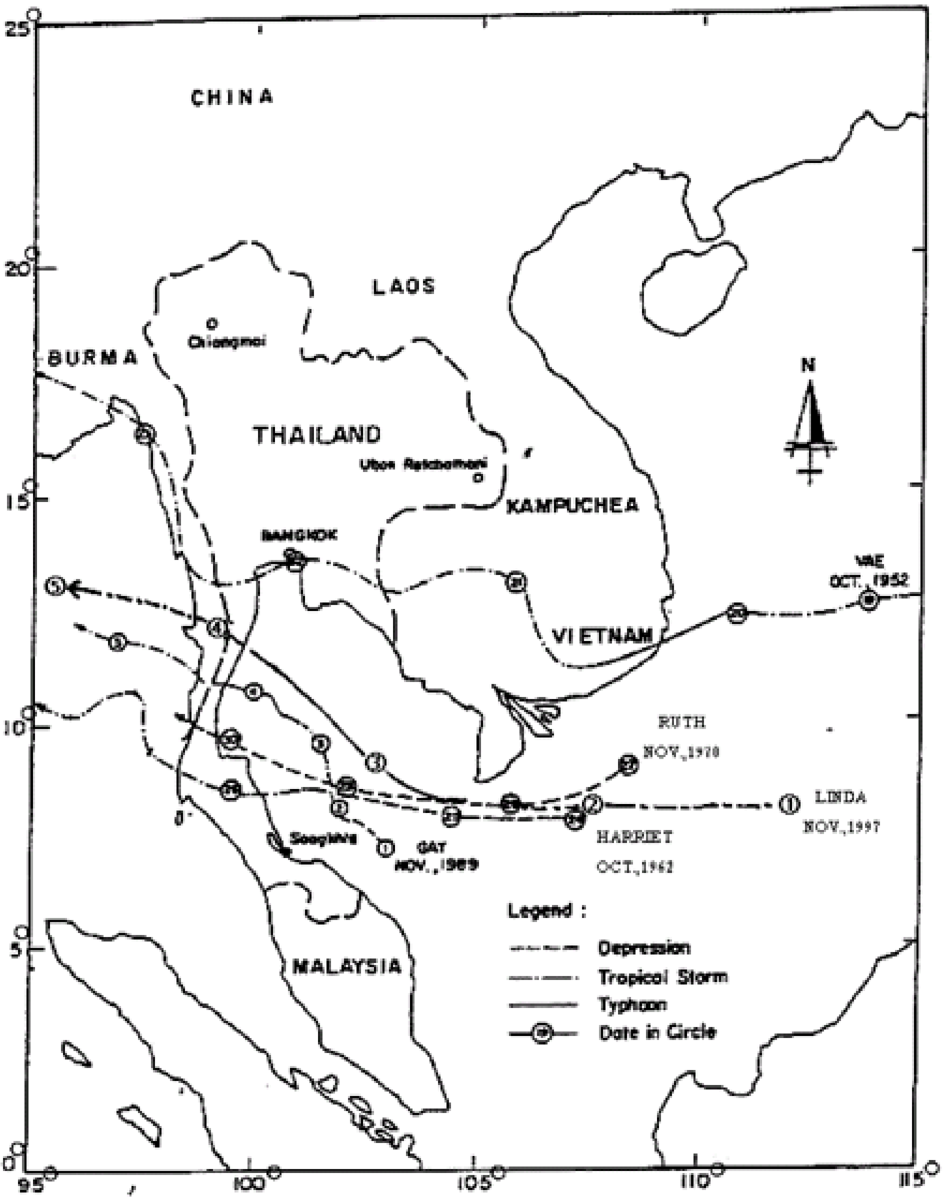

Figure 2. Tracks of 5 most disastrous cyclones over Thailand

Tracks of 5 disastrous cyclones over the South China Sea affecting Thailand are shown in Figure 2. Characteristics of the first three cyclones affecting Thailand as provided by Vongvisessomjai (1994b) are shown in Figure 3 for their variations of pressure and wind speed versus radial distance r. These cyclones can be seen clearly from weather satellite in form of huge clouds. These clouds caused heavy rainfall and floods, while strong winds caused destruction of houses and ships.

1. Cyclone in the Upper Gulf of Thailand

Vongvisessomjai (1994b) reported on cyclonic waves and surges generated by typhoon Vae at Ao Phai near to Laem Chabang port. The limited fetch length of the Upper Gulf of Thailand resulted in quite small values of extreme surge of 1.17 m and significant wave height of 2.3 m and period of 5.9 s. However, when typhoons Harriet and Gay attacked southern shorelines, which are open sea, the resulting surges and waves were much larger and caused much more damage and many more casualties. These disasters can be alleviated from known characteristics of cyclones and through proper warning. Figure 2 shows tracks of 5 most disastrous cyclones over Thailand.

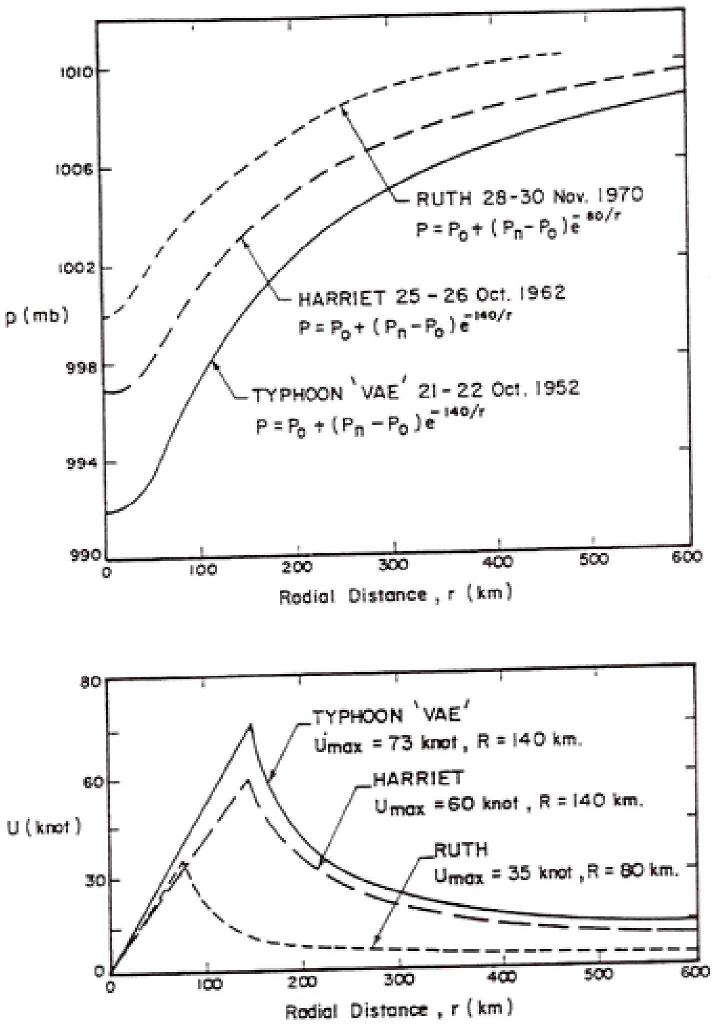

Figure 3. Radial distributions of pressures and wind velocity of typhoons Vae, Harriet and Ruth.

Typhoon Vae was the most severe one for the Upper Gulf of Thailand, therefore, it was considered to be the Probable Maximum Cyclone (PMC) here.

(i) Cyclonic Surge Analysis

The PMC and the 250 year cyclones, determined from historical data and shown in Table 1, are plotted in Figure 4, assuming that the Central Pressure Index (CPI) of the minimum central pressure (p_o) values of storms belong to a normally distribution population. This permits the extrapolation of the CPI to theoretically high recurrence interval so as to get inherent parameters adopted for PMC and the 250 year cyclone. It can be seen in Table 1 and Figure 2 that severe typhoon Vae (1952); Harriet (1962); Ruth (1970); Gay (1989) and Linda (1997) occurred once every 8-10 or 9 years, which is the recurrence interval of El Nino. (Trenberth, 1992).

Illustrated in Figures 5 and 6 respectively are the designed PMC wind field and typical

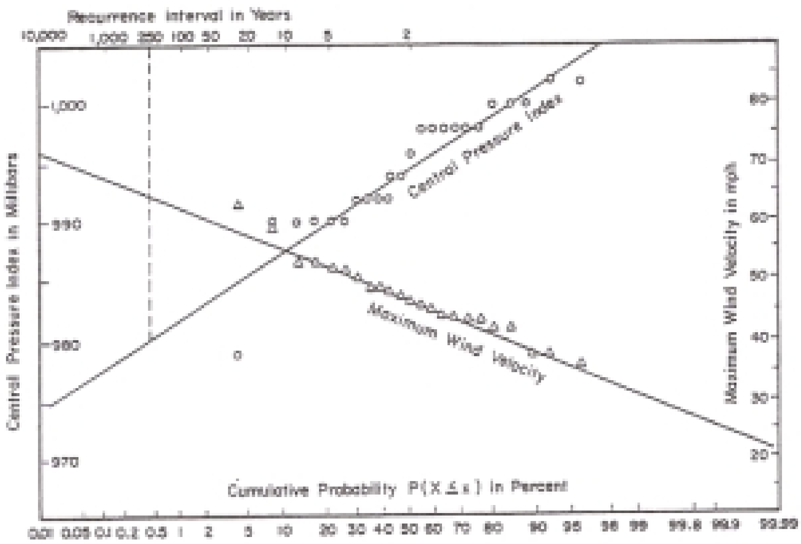

Figure 4. Recurrence intervals of cyclone characteristics for the Gulf of Thailand.

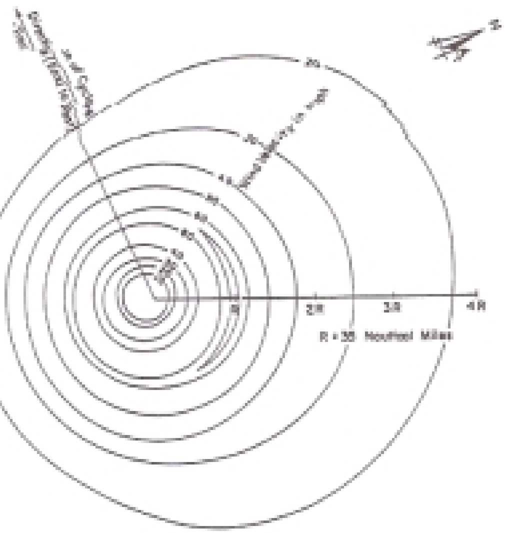

Figure 5. Wind field of the probable maximum cyclone for the Gulf of Thailand.

Table 1. Historical typhoon (cyclone) characteristics from Vongvisessomjai (1994b).

No.	Year, Month, Date	Name	CPI or p_o (m bars)	Max. Velocity U_{max} (mph)	Forward Speed, V_f (mph)	Radius, R (nautical miles)
1	1952 Oct 21-22	VAE	992	84	14.97	76
2	Oct 24-25	TRIX	998	44	17.27	60
3	1960 Oct 03-04	-	992	52	3.45	8.4
4	1962 Oct 25-26	HARRIET	997	69	18.45	76
5	1966 Jun 17-18	-	-	-	12.67	-
6	Oct 25-26	-	990	48	9.21	49
7	1967 Jun 17-18	-	978	62	12.67	140
8	Oct 05-06	-	996	49	11.52	16
9	Oct 09-10	-	998	44	17.27	90
10	Nov 10-11	-	-	-	12.67	-
11	1968 Sep 05-06	BESS	992	44	2.30	115
12	Oct 21-22	HESTER	998	46	11.52	10
13	1967 Jun 24-25	-	998	46	6.91	7.5
14	Sep 20-21	-	992	51	12.67	57
15	Nov 10-11	-	1000	45	16.12	10
16	1970 Sep 20-21	-	994	52	13.82	20
17	Oct 25-26	KATE	1000	27	13.82	314
18	Nov 29-30	RUTH	1000	42	11.52	43
19	1972 Jun 03-04	NAMIE	990	48	6.91	123
20	Sep 06-07	-	990	49	4.61	16
21	Sep 18-19	-	-	-	-	-
22	Dec 04-05	SALLY	994	50	5.76	5
23	1973 Nov 12-13	-	1002	38	5.76	4
24	Nov 17-18	THELMA	998	45	5.76	39
25	1974 Oct 09-10	-	1002	34	6.91	15
26	Nov 05-06	-	998	45	13.82	60
A	1989 Nov. 01-04	GAY	989	116	12.00	-
B	1997 Nov. 01-05	LINDA	976	64	30.00	-

four-hourly values of the wind field over the Gulf. Plotted in Figure 7 are the magnitudes and directions of wind that would be observed at different radial distances from the centers of the PMC and of the 250 year cyclone, for a span of 46 hours. The surge computation is then performed on an IMB-370 computer using the derived PMC data. The surge hydrography thus obtained is shown in Figure 8.

(ii) Cyclonic Waves

The observed seasonal waves are found to be insignificant in height and period. However, short-duration waves generated by cyclones, known as "cyclonic waves" are important aspects of cyclones occurring in the nearshore zone and in the immediate neighborhood of coastal front structures. They can be prominently superposed on the surge levels. Quantitative estimates of the waves associated with cyclones are forecasted and included here.

A procedure for present computation of cyclone waves has been developed (Day, 1977). Two design cyclones, the PMC and the 250-year cyclone as used for the surge computation, are

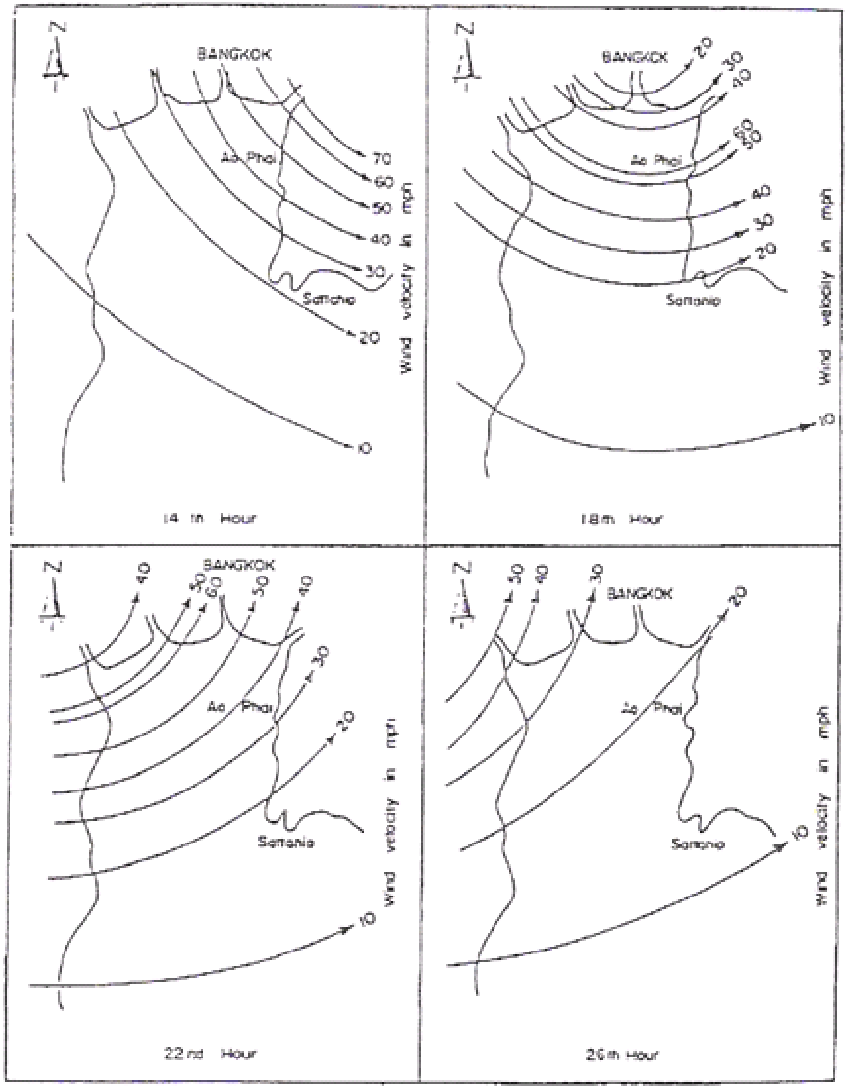

Figure 6. Probable maximum cyclone (PMC) wind field over the Gulf of Thailand.

adopted. The results are shown in Figure 9, in which the starting time of computation is taken to be that when the iso-velocity line of zero wind velocity touches the shoreline at the west side of the Gulf. The distance of the cyclone center from Ao Phai shown in this same figure indicates that the cyclone center is nearest to Ao Phai at about the 18th hour. At this time, the cyclonic waves would be the most severe; this would be particularly so if the track of the cyclone is about 35 nautical miles north of Ao Phai. The severest cyclonic wave characteristics were found to be 2.3 m in height and 5.9 s in period at PMC condition. For the condition of the 250-year cyclone, the severest cyclonic wave characteristics were found to be 1.9 m and 5.1s . No cyclonic waves have been actually recorded to permit comparisons. However, this cyclonic wave model has been successfully applied to tropical cyclones in Hong Kong and Taiwan (Day,1977), and the computed magnitudes obtained above are within this expectation.

Due to the limited fetch length of the Upper

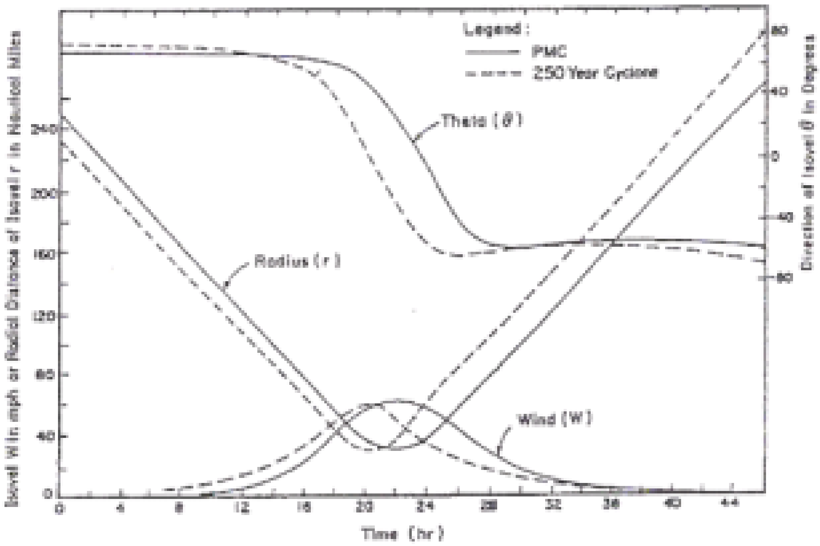

Figure 7. Probable maximum cyclone (PMC) and 250-year cyclone characteristics as would be observed at Ao Phai.

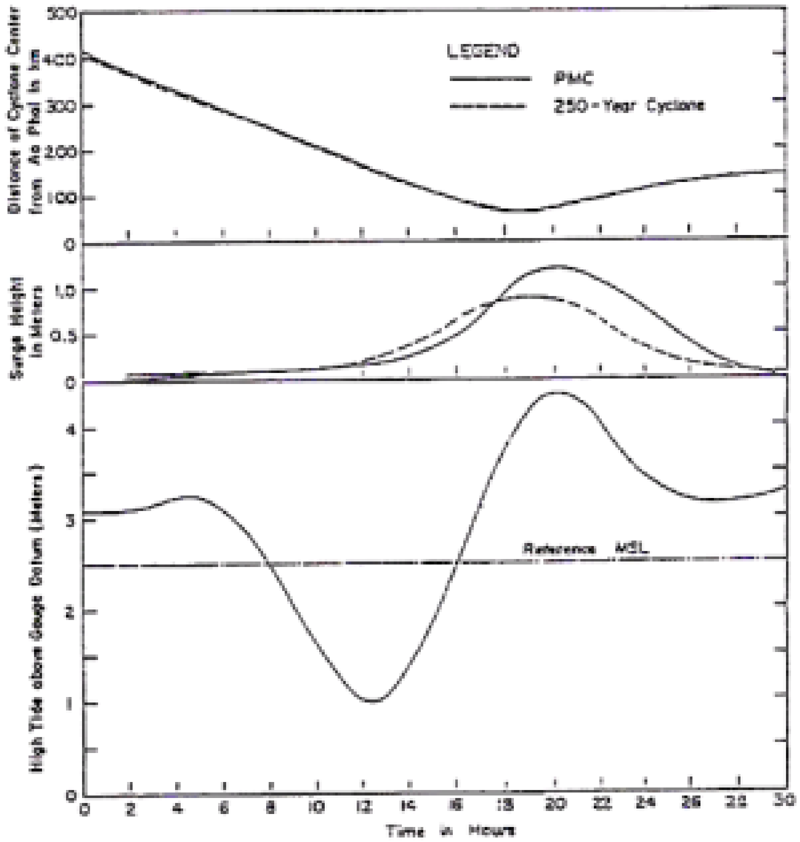

Figure 8. Probable maximum cyclonic surge (PMC and 250-year) and high tide at Ao Phai.

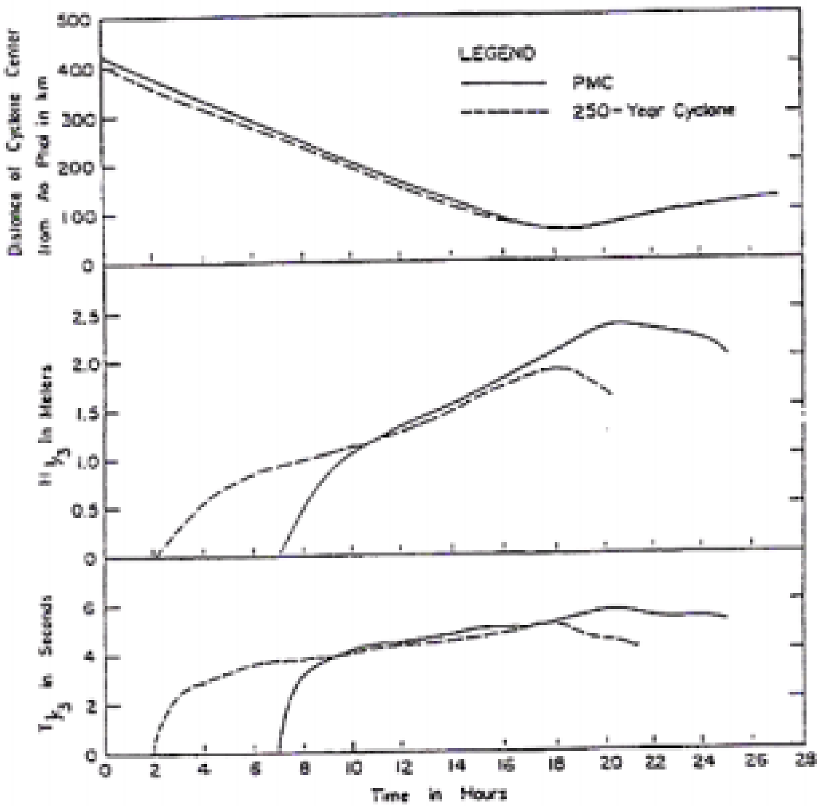

Figure 9. Probable maximum cyclonic wave (PMC and 250-year) at Ao Phai.

Gulf of Thailand, which has a surface area of 100 km. x 100 km., quite small values of extreme surges of 1.2 m and 0.9 m were obtained for PMC and 250 year cyclones respectively, while their corresponding significant waves are 2.3 m, 5.9 s and 1.9 m, 5.1 s at Ao Phai. It is to be noted that NEDECO (1972) in the study of the deepsea port of Laem Chabang estimated the design wave height of 2.3 m for a return period of 50 years and 2.5 m for a return period of 500 years.

2. Cyclone in the East Coast

Pornpinatepong *et al.* (1999) used the WAM Model in predicting wind waves in the Gulf of Thailand and Andaman Sea under a joint project of Thai and US Government agencies with financial support from Thai Research Fund from 1996-1999. Wave data used in calibrating the wave model were taken initially from satellites ERS-2 and TOPEX and later from 9 buoys in the Gulf of Thailand and 2 buoys in the Andaman Sea operated by the National Research Council of Thailand (NRCT) as shown in Figure 1. The WAM Model, which was the third generation of the WAM group (1988), was originally developed over 10 years by the Max Planck Institute for Meteorology in Germany. This wave model has been used to forecast ocean wave height in conjunction with an input forecast wind data, 110-km resolution, provided by the Master Environmental Library (MEL), US Department of Defense. The model developed from this project has been used operationally at the Weather Forecast Department of the Royal Thai Navy. The forecast data are shown daily on the Royal Thai Navy Website (Wirattipong, Ekmahachai *et al.*, 1999).

The most important results of the WAM Model are the wind waves generated by typhoon Linda, which was formed on October 26, 1997 as the tropical disturbance within an area of convect-

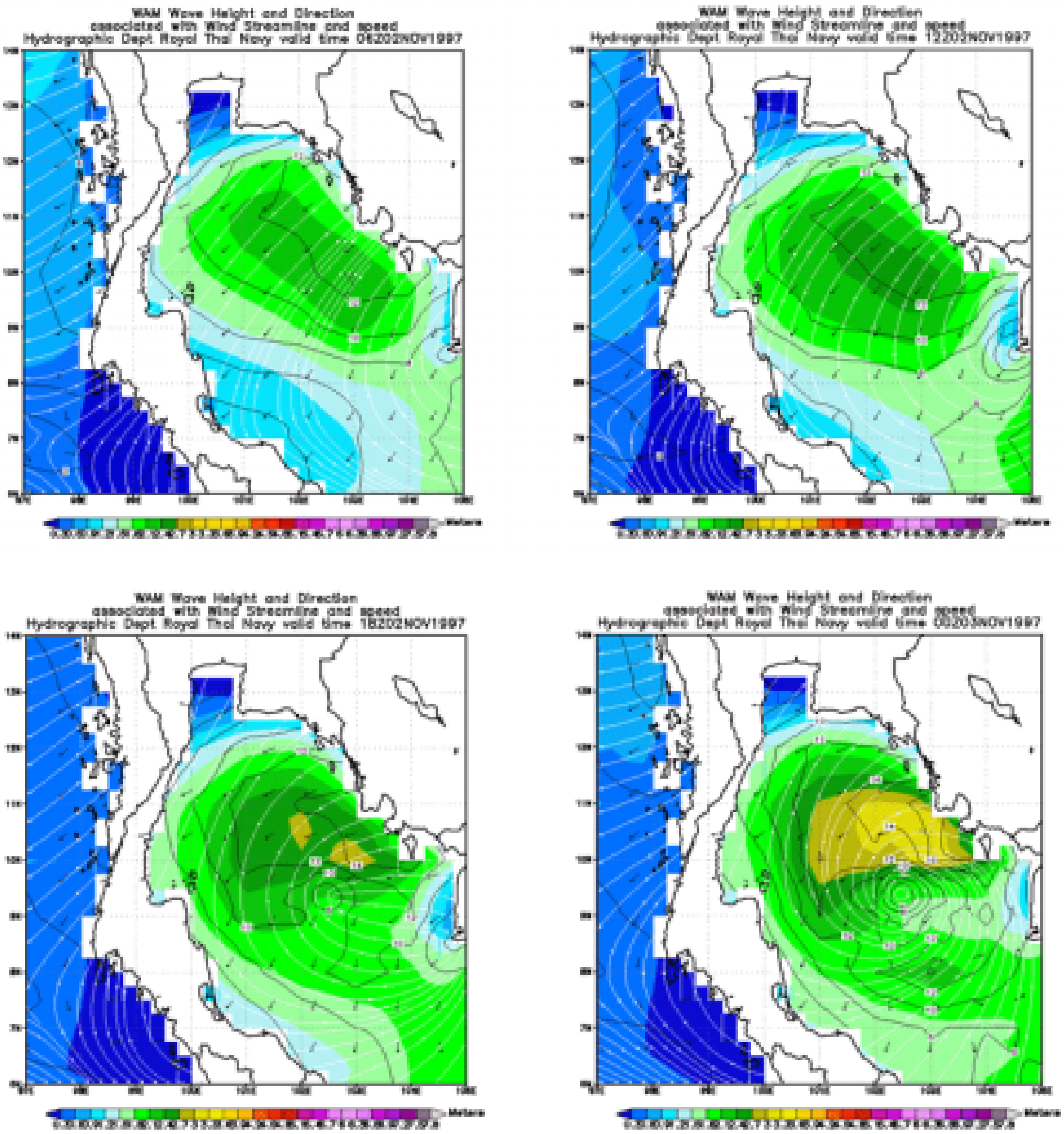

Figure 10. Six-hourly waves on November 2, 1997.
(Color figure can be viewed in the electronic version)

ion east of the Philippine islands near latitude 10°N and longitude 130°E , and then moved westward under the subtropical ridge to the north. When entering the South China Sea, it transformed into a tropical storm and moved westward to the southern tip of Cape Camau of Vietnam at 00Z on November 2 with the intensity of 55 knots (28 m/s) as shown in Figure 2. It approached the Gulf of Thailand around 00Z on November 3 with typhoon intensity and turned northwestward following steering from the subtropical ridge. Its strength weakened as it encountered mountains (Prachuap Khiri Khan province). After crossing over the Andaman Sea, it reconsolidated and became a typhoon once again at 00Z on November 6. Six hourly waves on November 2 and 3, 1997 are shown in Figures 10 and 11 respectively. The wave heights increase at 0.3 m (1 foot) internal

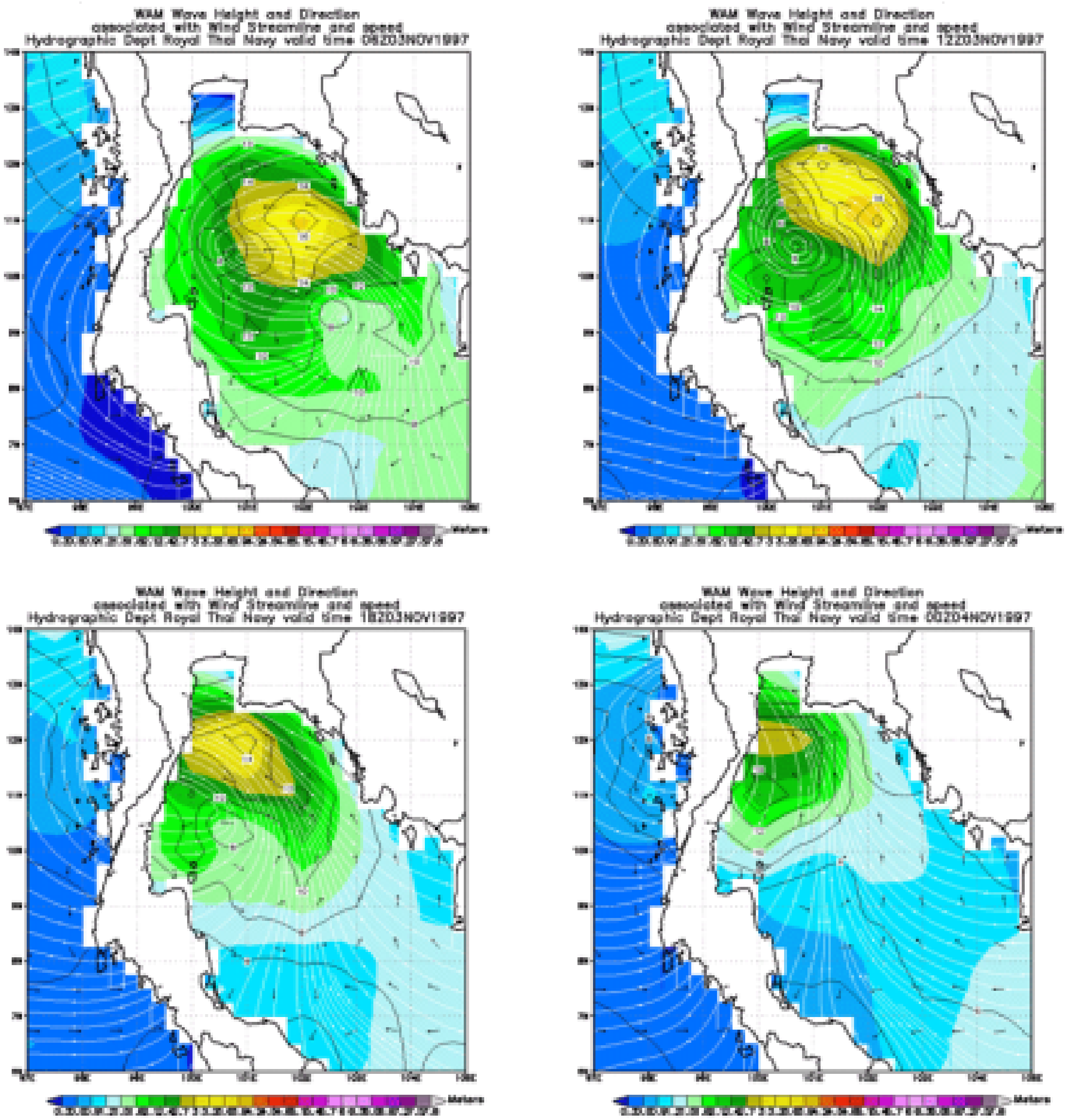

Figure 11. Six-hourly waves on November 3, 1997.
(Color figure can be viewed in the electronic version)

using blue colours from 0.3-1.5 m, green colours from 1.5-2.7 m, and yellow colours from 2.7-3.9 m. The black arrows show wave directions and the white arrows show directions of cyclonic winds which rotate counterclockwise around the center of cyclone. It can be seen that very big waves are located at the eye of the cyclone near to its center due to its maximum wind speed here. Figure 12 shows three-hourly waves of oceanographic buoys at Ko Chang with the maximum wave height of 2.2 m at noon on November 3, at Rayong with the maximum wave height of 2.5 m and at Huahin with the maximum wave height of 2.7 m around midnight on November 3, 1997. Note that the maximum wave heights at the eye of cyclone shown in Figures 10 and 11 are about 4.0 m, which are bigger than those waves recorded at the three buoys shown in Figure 12.

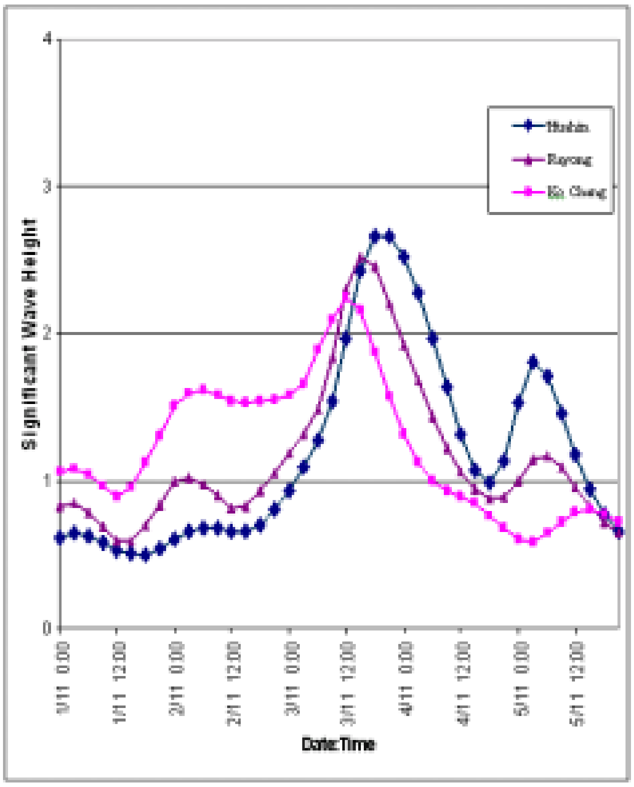

Figure 12. Three-hourly waves of buoys at Ko Chang , Rayong and Huahin November 1-5, 1997.

The increased fetch length of the east coast but still limited by the existence of its shoreline resulted in an increase of wave height of 2.5 m at Rayong and 2.7 m at Huahin while the maximum significant wave height at the eye of the cyclone is about 4.0 m. It is to be noted that in the study of the deepsea port at Map Ta Phut, JICA (1983) estimated the design wave height of 3.67 m for a return period of 50 years and 3.85 m for a return period of 100 years.

When typhoon Harriet (1962) and Gay (1989) attacked the southern shorelines, which are open sea, with unlimited fetch length, the resulting surges and waves at the southern shorelines were much larger and caused much more damage and many more casualties.

Wind Waves in the Upper Gulf of Thailand and the East Coast

Wind waves in the Upper Gulf of Thailand and the east coast for 6 years (1997-2002) were used in this study. These waves were kindly provided by the Royal Thai Navy using the WAM Model for weather forecast of waves in the Upper Gulf of Thailand and the Andaman Sea. These waves were mostly quite small, less than 0.5 m in the Upper Gulf of Thailand, while those on the east coast were moderate, about 1.0 m, which were much smaller than cyclonic waves presented before.

Wave roses of Petchaburi buoy as tabulated in Table 2 are plotted in Figure 13a. During the northeast monsoon, most of these waves were from NE (12%), NNE (11%), and ENE (5%), while during the southwest monsoon, most of these waves were from WSW (15%), W (12%) and SW (9%); 98.5% of these waves were smaller than 0.5 m and 1.5% were from 0.5-1.0 m.

The wave rose of Sichang buoy as tabulated

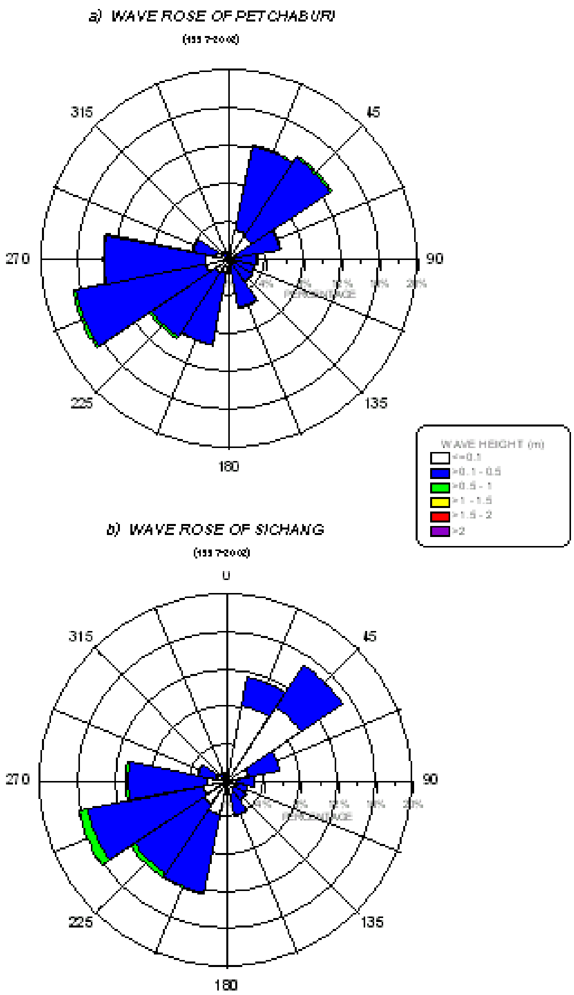

Figure 13. Wave roses of Petchaburi and Sichang from 1997-2002.

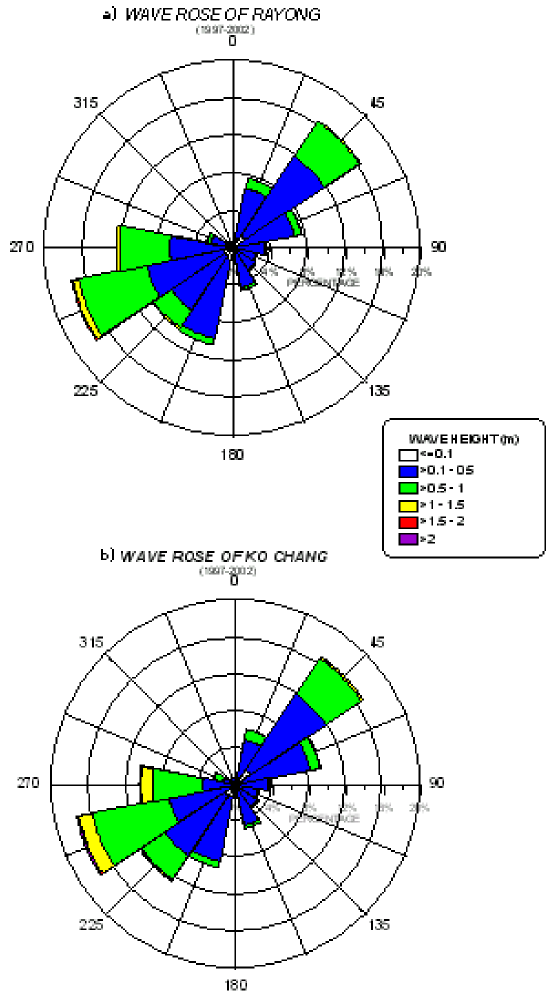

Figure 14. Wave roses of Rayong and Ko Chang from 1997-2002.

(Color figure can be viewed in the electronic version)

in Table 3 is plotted in Figure 13b. During the northeast monsoon most of these waves were from NE (13%), NNE (10%) and ENE (5%), while during the southwest monsoon most of these waves were from WSW (14%), SW (11%) and SSW (11%); 98.0% of these waves were smaller than 0.5 m and 2.0% were from 0.5-1.0 m.

The wave rose of Rayong buoy as tabulated in Table 4 is plotted in Figure 14a. During the northeast monsoon most of these waves were from NE (15%), NNE (7%) and ENE (7%) while during the southwest monsoon most of these waves were from WSW (16%), W (11%) and SW (9%); 77.1% of these waves were smaller than 0.5 m and 21.4% were from 0.5-1.0 m.

The wave rose of Ko Chang buoy as tabulated in Table 5 is plotted in Figure 14b. During the northeast monsoon most of these waves were from NE (15%), ENE (9%) and NNE (6%), while during the southwest monsoon, most of these waves were from WSW (16%), SW (12%) and W (10%) ; 71.8% of these waves were smaller than 0.5 m and 24.6% were from 0.5-1.0 m.

Table 2. Wave occurrence by WAM model at Petchaburi from 1 August 1997 - 31 December 2002.

Wave Height (m)

Direction	Wave Height of Occurrences (Hours)											Total(Hours)	Percentage
	0.1-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	5.0->		
N	1,305	6	0	0	0	0	0	0	0	0	0	1,311	2.76
NNE	5,157	54	3	0	0	0	0	0	0	0	0	5,214	10.98
NE	5,427	111	3	0	0	0	0	0	0	0	0	5,541	11.67
ENE	2,313	45	3	0	0	0	0	0	0	0	0	2,361	4.97
E	1,233	30	12	0	0	0	0	0	0	0	0	1,275	2.68
ESE	1,140	12	3	12	0	0	0	0	0	0	0	1,167	2.46
SE	1,239	6	0	3	0	0	0	0	0	0	0	1,248	2.63
SSE	2,190	48	0	0	0	0	0	0	0	0	0	2,238	4.71
S	3,672	54	0	0	0	0	0	0	0	0	0	3,726	7.84
SSW	3,903	21	0	0	0	0	0	0	0	0	0	3,924	8.26
SW	4,176	117	0	0	0	0	0	0	0	0	0	4,293	9.04
WSW	7,020	141	0	0	0	0	0	0	0	0	0	7,161	15.08
W	5,628	33	0	0	0	0	0	0	0	0	0	5,661	11.92
WNW	1,650	6	0	0	0	0	0	0	0	0	0	1,656	3.49
NW	378	0	0	0	0	0	0	0	0	0	0	378	0.80
NNW	342	0	0	0	0	0	0	0	0	0	0	342	0.72
Total(Hours)	46,773	684	24	15	0	0	0	0	0	0	0	47,496	
Percentage	98.48	1.44	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	

Wave Period (second)

Direction	Wave Period of Occurrences (Hours)											Total(Hours)	Percentage
	0.1-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	5.0-6.0	6.0-7.0	7.0-8.0	8.0-9.0	9.0-10.0	10.0->		
N	0	222	411	519	159	0	0	0	0	0	0	1,311	2.76
NNE	0	504	1,791	2,058	822	39	0	0	0	0	0	5,214	10.98
NE	0	228	1,896	2,304	1,041	66	6	0	0	0	0	5,541	11.67
ENE	0	39	597	1,197	501	27	0	0	0	0	0	2,361	4.97
E	0	24	339	663	228	18	3	0	0	0	0	1,275	2.68
ESE	0	15	411	567	162	0	12	0	0	0	0	1,167	2.46
SE	0	33	462	684	66	0	3	0	0	0	0	1,248	2.63
SSE	0	135	873	1,110	120	0	0	0	0	0	0	2,238	4.71
S	0	231	1,860	1,428	204	3	0	0	0	0	0	3,726	7.84
SSW	0	198	2,076	1,476	165	9	0	0	0	0	0	3,924	8.26
SW	0	141	2,532	1,371	240	9	0	0	0	0	0	4,293	9.04
WSW	0	114	4,479	2,301	255	12	0	0	0	0	0	7,161	15.08
W	0	84	3,459	1,893	213	12	0	0	0	0	0	5,661	11.92
WNW	0	18	885	591	153	9	0	0	0	0	0	1,656	3.49
NW	0	3	165	162	42	6	0	0	0	0	0	378	0.80
NNW	0	12	123	168	36	3	0	0	0	0	0	342	0.72
Total(Hours)	0	2,001	22,359	18,492	4,407	213	24	0	0	0	0	47,496	
Percentage	0.00	4.21	47.08	38.93	9.28	0.45	0.05	0.00	0.00	0.00	0.00	100.00	

Table 3. Wave occurrence by WAM model at Sichang from 1 August 1997 - 31 December 2002.

Wave Height (m)

Direction	Wave Height of Occurrences (Hours)											Total(Hours)	Percentage
	0.1-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	5.0->		
N	1,104	0	0	0	0	0	0	0	0	0	0	1,104	2.32
NNE	4,800	9	0	0	0	0	0	0	0	0	0	4,809	10.12
NE	6,312	6	3	0	0	0	0	0	0	0	0	6,321	13.31
ENE	2,439	6	0	0	0	0	0	0	0	0	0	2,445	5.15
E	1,239	9	0	0	0	0	0	0	0	0	0	1,248	2.63
ESE	954	12	9	0	0	0	0	0	0	0	0	975	2.05
SE	1,056	6	3	0	0	0	0	0	0	0	0	1,065	2.24
SSE	1,599	27	0	0	0	0	0	0	0	0	0	1,626	3.42
S	3,780	21	0	0	0	0	0	0	0	0	0	3,801	8.00
SSW	5,208	48	0	0	0	0	0	0	0	0	0	5,256	11.07
SW	5,055	213	0	0	0	0	0	0	0	0	0	5,268	11.09
WSW	6,450	405	9	0	0	0	0	0	0	0	0	6,864	14.45
W	4,485	123	0	0	0	0	0	0	0	0	0	4,608	9.70
WNW	1,314	27	0	0	0	0	0	0	0	0	0	1,341	2.82
NW	411	3	0	0	0	0	0	0	0	0	0	414	0.87
NNW	354	0	0	0	0	0	0	0	0	0	0	354	0.75
Total(Hours)	46,560	915	24	0	0	0	0	0	0	0	0	47,499	
Percentage	98.02	1.93	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	

Wave Period (second)

Direction	Wave Period of Occurrences (Hours)											Total(Hours)	Percentage
	0.1-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	5.0-6.0	6.0-7.0	7.0-8.0	8.0-9.0	9.0-10.0	10.0->		
N	0	90	321	513	168	12	0	0	0	0	0	1,104	2.32
NNE	0	564	1,131	1,998	990	126	0	0	0	0	0	4,809	10.12
NE	0	501	1,551	2,610	1,443	210	6	0	0	0	0	6,321	13.31
ENE	0	60	798	1,134	414	39	0	0	0	0	0	2,445	5.15
E	0	39	411	588	195	15	0	0	0	0	0	1,248	2.63
ESE	0	66	399	402	93	9	6	0	0	0	0	975	2.05
SE	0	81	501	408	72	0	3	0	0	0	0	1,065	2.24
SSE	0	147	888	555	36	0	0	0	0	0	0	1,626	3.42
S	0	471	2,295	984	51	0	0	0	0	0	0	3,801	8.00
SSW	0	483	3,267	1,461	42	3	0	0	0	0	0	5,256	11.07
SW	0	252	3,201	1,686	105	24	0	0	0	0	0	5,268	11.09
WSW	0	162	3,603	2,925	135	39	0	0	0	0	0	6,864	14.45
W	0	96	2,553	1,887	72	0	0	0	0	0	0	4,608	9.70
WNW	0	18	873	396	54	0	0	0	0	0	0	1,341	2.82
NW	0	3	252	135	24	0	0	0	0	0	0	414	0.87
NNW	0	9	189	144	12	0	0	0	0	0	0	354	0.75
Total(Hours)	0	3,042	22,233	17,826	3,906	477	15	0	0	0	0	47,499	
Percentage	0.00	6.40	46.81	37.53	8.22	1.00	0.03	0.00	0.00	0.00	0.00	100.00	

Table 4. Wave occurrence by WAM model at Rayong from 1 August 1997 - 31 December 2002.

Wave Height (m)

Direction	Wave Height of Occurrences (Hours)											Total(Hours)	Percentage
	0.1-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	5.0->		
N	639	24	0	0	0	0	0	0	0	0	0	663	1.40
NNE	2,781	474	3	0	0	0	0	0	0	0	0	3,258	6.86
NE	5,010	1,902	54	0	0	0	0	0	0	0	0	6,966	14.67
ENE	2,835	333	21	0	0	0	0	0	0	0	0	3,189	6.72
E	1,452	87	6	3	3	0	0	0	0	0	0	1,551	3.27
ESE	1,068	33	6	0	3	3	0	0	0	0	0	1,113	2.34
SE	1,179	57	3	6	3	0	0	0	0	0	0	1,248	2.63
SSE	1,809	144	0	0	0	0	0	0	0	0	0	1,953	4.11
S	3,732	180	12	0	0	0	0	0	0	0	0	3,924	8.26
SSW	4,170	303	0	0	0	0	0	0	0	0	0	4,473	9.42
SW	3,375	957	63	15	0	0	0	0	0	0	0	4,410	9.29
WSW	3,987	3,159	261	60	0	0	0	0	0	0	0	7,467	15.72
W	2,868	2,295	171	0	0	0	0	0	0	0	0	5,334	11.23
WNW	1,032	192	30	0	0	0	0	0	0	0	0	1,254	2.64
NW	348	12	0	0	0	0	0	0	0	0	0	360	0.76
NNW	309	15	0	0	0	0	0	0	0	0	0	324	0.68
Total(Hours)	36,594	10,167	630	84	9	3	0	0	0	0	0	47,487	
Percentage	77.06	21.41	1.33	0.18	0.02	0.01	0.00	0.00	0.00	0.00	0.00	100.00	

Wave Period (second)

Direction	Wave Period of Occurrences (Hours)											Total(Hours)	Percentage
	0.1-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	5.0-6.0	6.0-7.0	7.0-8.0	8.0-9.0	9.0-10.0	10.0->		
N	0	114	279	252	18	0	0	0	0	0	0	663	1.40
NNE	0	501	1,935	720	102	0	0	0	0	0	0	3,258	6.86
NE	0	612	4,137	2,049	165	3	0	0	0	0	0	6,966	14.67
ENE	0	93	1,236	1,614	243	3	0	0	0	0	0	3,189	6.72
E	0	39	537	837	135	3	0	0	0	0	0	1,551	3.27
ESE	0	48	420	570	66	3	6	0	0	0	0	1,113	2.34
SE	0	78	531	561	69	6	3	0	0	0	0	1,248	2.63
SSE	0	90	915	891	57	0	0	0	0	0	0	1,953	4.11
S	0	426	2,232	1,224	42	0	0	0	0	0	0	3,924	8.26
SSW	0	456	2,772	1,215	30	0	0	0	0	0	0	4,473	9.42
SW	0	237	2,706	1,350	99	18	0	0	0	0	0	4,410	9.29
WSW	0	207	3,924	2,988	294	54	0	0	0	0	0	7,467	15.72
W	0	102	2,853	2,205	174	0	0	0	0	0	0	5,334	11.23
WNW	0	15	726	426	87	0	0	0	0	0	0	1,254	2.64
NW	0	0	192	135	33	0	0	0	0	0	0	360	0.76
NNW	0	12	129	162	21	0	0	0	0	0	0	324	0.68
Total(Hours)	0	3,030	25,524	17,199	1,635	90	9	0	0	0	0	47,487	
Percentage	0.00	6.38	53.75	36.22	3.44	0.19	0.02	0.00	0.00	0.00	0.00	100.00	

Table 5. Wave occurrence by WAM model at Ko Chang from 1 August 1997 - 31 December 2002.

Wave Height (m)

Direction	Wave Height of Occurrences (Hours)											Total(Hours)	Percentage
	0.1-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	5.0->		
N	627	27	0	0	0	0	0	0	0	0	0	654	1.38
NNE	2,151	501	3	0	0	0	0	0	0	0	0	2,655	5.59
NE	5,103	2,031	96	15	0	0	0	0	0	0	0	7,245	15.26
ENE	3,576	468	18	15	0	0	0	0	0	0	0	4,077	8.59
E	1,548	78	3	3	0	0	0	0	0	0	0	1,632	3.44
ESE	1,086	42	6	6	9	0	0	0	0	0	0	1,149	2.42
SE	1,251	81	0	0	0	0	0	0	0	0	0	1,332	2.81
SSE	1,956	162	0	0	0	0	0	0	0	0	0	2,118	4.46
S	3,078	117	0	0	0	0	0	0	0	0	0	3,195	6.73
SSW	3,702	309	6	0	0	0	0	0	0	0	0	4,017	8.46
SW	4,029	1,320	78	24	12	0	0	0	0	0	0	5,463	11.51
WSW	3,204	3,684	651	57	60	0	0	0	0	0	0	7,656	16.13
W	1,557	2,376	549	75	0	0	0	0	0	0	0	4,557	9.60
WNW	639	420	12	12	0	0	0	0	0	0	0	1,083	2.28
NW	261	24	0	0	0	0	0	0	0	0	0	285	0.60
NNW	339	21	0	0	0	0	0	0	0	0	0	360	0.76
Total(Hours)	34,107	11,661	1,422	207	81	0	0	0	0	0	0	47,478	
Percentage	71.84	24.56	3.00	0.44	0.17	0.00	0.00	0.00	0.00	0.00	0.00	100.00	

Wave Period (second)

Direction	Wave Period of Occurrences (Hours)											Total(Hours)	Percentage
	0.1-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	5.0-6.0	6.0-7.0	7.0-8.0	8.0-9.0	9.0-10.0	10.0->		
N	0	42	351	243	18	0	0	0	0	0	0	654	1.38
NNE	0	384	1,554	651	54	12	0	0	0	0	0	2,655	5.59
NE	0	861	4,722	1,590	72	0	0	0	0	0	0	7,245	15.26
ENE	0	222	2,109	1,614	123	9	0	0	0	0	0	4,077	8.59
E	0	87	699	783	63	0	0	0	0	0	0	1,632	3.44
ESE	0	72	480	549	30	18	0	0	0	0	0	1,149	2.42
SE	0	93	582	630	27	0	0	0	0	0	0	1,332	2.81
SSE	0	150	1,122	810	36	0	0	0	0	0	0	2,118	4.46
S	0	432	1,920	804	39	0	0	0	0	0	0	3,195	6.73
SSW	0	621	2,508	852	36	0	0	0	0	0	0	4,017	8.46
SW	0	486	3,447	1,401	102	27	0	0	0	0	0	5,463	11.51
WSW	0	210	3,276	3,387	681	72	30	0	0	0	0	7,656	16.13
W	0	72	1,635	2,232	567	51	0	0	0	0	0	4,557	9.60
WNW	0	15	456	564	42	6	0	0	0	0	0	1,083	2.28
NW	0	12	123	135	15	0	0	0	0	0	0	285	0.60
NNW	0	27	195	126	12	0	0	0	0	0	0	360	0.76
Total(Hours)	0	3,786	25,179	16,371	1,917	195	30	0	0	0	0	47,478	
Percentage	0.00	7.97	53.03	34.48	4.04	0.41	0.06	0.00	0.00	0.00	0.00	100.00	

Conclusion

Cyclone disasters in Thailand could be grouped into two, namely, disasters due to strong winds and those due to heavy rainfall over high mountains causing severe floods and landslides (Vongvisesomjai, 1994a). In the past, these disasters caused high casualties and damage due to unknown characteristics and the lack of warning of cyclones; their pressure and wind velocity distributions are presented in Eqs. 1-3. These cyclones could be clearly seen from weather satellites so that their movement could be easily monitored and warning could be made several days before their attacks.

Strong winds of cyclones generated big waves which had tremendous destructive powers to cause high casualties and damages. Cyclonic waves are the second biggest next to the tsunami waves in the Andaman Sea on December 26, 2004 (Vongvisessomjai and Suppataratarn ,2005).

The Upper Gulf of Thailand with a limited fetch length of about 100 km in the north/south direction and about 100 km wide in the east/west direction, resulted in a limited maximum wave height of 2.3 or 2.5 m generated by Typhoon Vae (1952), as indicated by Vongvisessomjai (1994b), while the east coast, with longer fetch length but still limited by the existence of its shoreline, resulted an increase of maximum wave height to 4 m generated by Typhoon Linda (1997) as indicated of the new results of the WAM Model.

The southern shorelines, with unlimited fetch length on the east by cyclones approaching from the South China Sea, would produce maximum wave height larger than 6 m generated by Typhoon Harriet in 1962 and 11 m generated by Typhoon Gay in 1989, resulting in more casualties and damages. These cyclones prevailed only for a short period of a few days to a week while the two monsoonal winds prevailed for a longer period of half a year each. The waves generated by the monsoonal winds in the Upper Gulf of Thailand had a height of about 0.5 m and on the east coast a height of about 1.0 m, which are much smaller than the cyclonic waves.

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