Appendix 6-3

Wave Analysis at the Masinloc Site

1. Outline

1.1 Object

As a part of the feasibility study on the coal-fired thermal power project in the Republic of the Philippines, the design wave and calmness in port at the Masinloc site are analyzed by a large computer.

1.2 Materials

The materials used are shown below:

(1)	Philippine Island Pilot	1983 (The Maritime Safety Agency)
(2)	Wave Height Rose	
(3)	Tropical Cyclone Summaries	1948 - 1978 (PAGASA)
(4)	Tropical Cyclone Report	1981 - 1988 (PAGASA)
(5)	Meteorological Data at Iba Station	1981 - 1985 (PAGASA)
(6)	Map of the South China Sea	1/1,000,000
(7)	Sea Chart (Masinloc)	1/25,000

1.3 Outline of the Site

(1) Wave Characteristics of the western sea area of the Philippine Island.

According to the Philippine Island Pilot and Wave Height Rose, the wave characteristics of the South China Sea are as follows:

(Winter)

Because the South China Sea extends widely from northeast to southwest and the seasonal northeast winds are strong and continuous, wind wave height of 1.5 m or more have a probability of from 20% to 50% in winter.

The swells of 3.7 m or more have a probability of 5% to 10% in the South China Sea.

The prevailing wave direction is northeast. Wave heights of 4.75 m or more have a 3.8% probability. The high-wave period is twelve seconds or more, similar to a swell.

(Spring)

Prevailing wind waves come from the south or southwest in the southern half of the South China Sea, and form the northeast in the northern half. In the extreme north of the South China Sea and the Taiwan Straits, wave heights of 1.5 m or more have a 20% to 30% probability in this season.

In this sea area, the probability of high swells is 5% in this season. The direction of the swells is about the same as that of wind waves.

The probability of waves having a height of 4.75 m or more is about 0.7%.

(Summer)

In the central part of the South China Sea, the probability of wind waves having a height of 1.5 m or more increases to 30% or more, and prevailing wind waves come from the south or southwest.

The probability of high swells reaches about 10% in the South China Sea, and prevailing swells come from the south or southwest.

The typhoon season in the Northern Hemisphere continues from May to December, and the most powerful storms arise in August and September. For the past ten years, twenty tropical low pressures on an average passed through between Luzon and Taiwan each August and September. The low pressures have exerted great influence on the South China Sea.

Low pressure areas generated in the Pacific Ocean develop into typhoons more frequently than in the South China Sea. In the storm area there are violent wind waves, and storm swells spreading from the area are frequently high and conspicuous in areas a long distance from the storm.

The probability of the swells having a height of 4.75 m or more is about 0.6%, and the period of high waves is from eight to thirteen seconds.

(Autumn)

There are two kinds of wind waves in the South China Sea. Prevailing wind waves come from the south or southwest in the southern half of the South China Sea, and from the northeast in the northern half. The probability of wave heights of 1.5 m or more is about 1% in the southern part of the sea, and it increases to 80% in the Taiwan Straits.

High swells occur at northwestern part with a 10% to 20% probability in this season. In this sea area, the directions of prevailing sweels close to that of the wind waves.

The probability of wave heights of 4.75 m or more is 3.1%.

(2) Topographical characteristics

The project site is located in the small bay on the west coast of the Luzon Island. The bay opens widely to the South China Sea at its western part and there are shallows with water depth of 2 m to 3 m by coral reef in the bay.

1.4 Method of Analysis

The design wave means the maximum wave for designing the marine facilities of a power station. Both waves, the swells coming from northeast by the seasonal winds in winter and the wind waves coming from southwest by typhoons and tropical low pressures, can be identified as high waves in the South China Sea. Since the bay opens to the west and the waves from west or southwest by typhoons only seem to exert a large influence on plant facilities, the design wave will be calculated based on typhoon data. The calmness in the port is related to the working rate and days for berthing and unloading coal. The calmness will be calculated by the ordinary wind data recorded for five years at Iba station near the site.

2. Design Wave

2.1 Calculating Procedure of the Design Wave

The calculating procedure of the design wave is shown in Fig. 2.1.

At first, observing the records of typhoons for the past 29 years (1960 to 1988), the typhoons will be selected that appear to affect this site.

Next, the distribution of wind velocities is estimated based on the track, the central atmospheric pressure and the size of the selected typhoons. The development of wind waves and their movement are estimated by the numerical calculation of B. W. Wilson's significant wave method. The estimated waves are deep water waves at the off-shore of the site. The probability wave for a 50-year return period is calculated by Petruaskas Aagaard's method using the most significant wave height among those generated by each typhoon.

The probability wave at the off-shore are influenced by the sea bottom and land before they reach the project site. They are transformed by diffraction, shoaling and wave breaking. Such wave transformation will be calculated by the numerial calculation of Karlsson and the wave breaking model of Goda.

Waves at the project site include not only components of deep water wave but also those generated between the bay mouth and the project site. These waves generated in the bay are estimated by the significant wave method of B. W. Wilson using a wind velocity that corresponds to the probability wave for a 50-year return period.

The design wave is obtained by synthesizing the energy of both kinds of waves at the project site.

2.2 Typhoons

Sixteen typhoons have been selected that have the maximum size among those that cross the Luzon island or linger on the west coast of the island after 1960 (for 29 years) referring to the materials about typhoons, Tropical Cyclone Summaries (1948 - 1978) and Tropical Cyclone Reports (1981 - 1988).

Table 2-1 shows a list of the selected typhoons.

Figure 2-2 illustrates the track of the selected typhoons.

The data after 1981 contain central atmospheric pressures and tracks of typhoons, maximum wind velocities with these time, position and atmospheric pressure. The distance between the typhoon's center and the position of maximum wind velocity been calculated using these data to show the typhoon's size.

The data prior to 1980 contain tracks of typhoons, maximum wind velocities with these time, position, and atmospheric pressure. The atmospheric pressure at the typhoon's center is estimated by these data. In this case, the distance between the typhoon's center and the position of maximum wind velocity is set to 100 km. This is the average value for the typhoons after the year 1981.

2.3 Deepwater Waves

The grid method is applied to the numerical calculation of B. W. Wilson's method in a computer. The grid method is shown in Fig. 2-3 where the area for analysis is 1,000 km in the east and west direction, and 1,300 km in the north and south direction, including the Luzon island. The area is divided into grids at an interval of 10 km. A typhoon is made to pass through the area, determining its center position, central atmospheric pressure, and the radius in which occurs the maximum wind velocity.

The atmospheric pressure distribution of the typhoon is calculated by Myers' formula as shown below.

$$P(r) = P_c + \Delta P \exp(-r_0 / r)$$

Here, Pc is the central atmospheric pressure, ΔP is the depth of the central atmospheric pressure, r is the distance from the center of a typhoon and r_0 is the distance between the center of a typhoon and the position of the maximum wind velocity.

The wind velocity distribution is calculated as the synthesized force of a gradient wind velocity and a typhoon moving velocity as shown below.

$$U = C_1 \; F(r) \sqrt{1 + M^2 - M(\sin\theta - \sqrt{3}\cos\theta)}$$

$$F(r) = \sqrt{\frac{\Delta P}{\rho a} \frac{r_0}{r} \exp\left(-\frac{r_0}{r}\right) + \left(\frac{f}{2} r\right)^2} - \frac{f}{2} r$$

$$\beta = \tan^{-1}\left(\frac{\sqrt{3} + 2M\cos\theta}{1 - 2M\sin\theta}\right)$$

$$M = V / F(r_0)$$

Here, C_1 is a constant having the average value of 0.7, ρ_a is the density of air, f is the coefficient of Coriolis, ω is the angular velocity of the rotation of the earth, and φ is the latitude where the angular velocity is measured. ($f = 2\omega\sin\varphi$)

Using the calculated wind velocity distribution, a significant wave height H1/3 and a significant wave period T1/3 are determined. In the numerical calculation, the differential equation of B. W. Wilson is used as shown below.

$$gH_{1/3}/U^2 = 0.30A\left[1 - \{1 + 0.004/A)(gF/U^2)^{1/2}\}^{-2}\right]$$

$$gT_{1/3}/2\pi U = 1.37B\left[1 - \{1 + 0.008/B)(gF/U^2)^{1/3}\}^{-5}\right]$$

$$A = \tanh\{0.578\,(gh/U^2)^{3/4}\}$$

$$B = \tanh\{0.520\,(gh/U^2)^{3/8}\}$$

Here, F is the fetch length and U is the wind velocity, h is the water depth.

The above analysis is performed at an interval of ten minutes to calculate the significant wave height, the significant wave period and the distribution of wave directions. From the results of the analysis, the maximum value of significant wave heights is extracted for each wave direction of the deepwater waves at the off-shore of the site. Simultaneously, a significant wave period and a wind velocity are also extracted (Table 2-2).

2.4 Probability Wave

For the five directions (SW, WSW, W, WNW, NW) that will have an influence on the sea area of the project site, the significant wave height and the significant wave period of deepwater waves having return periods of 100, 50, 40, 30, 20, 10 and 5 years are calculated using the maximum waves of typhoons (Table 2-2).

The probability wave is calculated by using the method of Petruaskas Aagaard, an extreme statistical theory. In this method it is assumed that the probability of nonexceedance of wave heights depends either on the Gumbel distribution or on the Weibull distribution. The form of distribution is determined by the method of least squares. A significant wave period and a wind velocity of a probability wave are calculated from the relationship with the wave height.

Gumbel distribution

$$^{P}[H < x\,m,\ N] = \exp\left[-\exp\left(-\frac{x-B}{A}\right)\right]$$

Weibull distribution

$$^{P}[H < x\,m,\ N] = 1 - \exp\left[-\left(\frac{x-B}{A}\right)^{K}\right]$$

$$K = 0.75 \sim 2.0$$

The calculated probability waves are shown in Table 2-3 and Fig. 2-4.

The probability wave for a 50-year return period has the significant wave height of from 7.4 m (NW) to 10.2 m (SW), and the significant wave period of from 10 to 13 seconds. Considering our experience in Japan, the probability wave for a 50-year return period is assumed to be the design deepwater wave.

2.5 Transformation of Waves

Although the design deepwater wave has been calculated at the offshore of the bay mouth, it is influenced by shielding, diffraction, shoaling, etc. caused by the neighboring terrain or changes in the water depth, until it comes to the project site (outlet, pier and revetment of the power plant). The transformation of wave is calculated by Karlsson's energy transfer equation.

$$\frac{\delta}{\delta x}(SUx)+\frac{\delta}{\delta y}(SUy)+\frac{\delta}{\delta \theta}(SU\theta)=0$$

Where S is a directional spectrum density, and Ux, Uy, and U_θ are given with the following equations.

$$Ux=Cg\ \cos\theta$$

$$Uy=Cg\ \sin\theta$$

$$U\theta=\frac{Cg}{C}\left(\frac{\delta c}{\delta x}\sin\theta-\frac{\delta c}{\delta y}\cos\theta\right)$$

Where C is a phase velocity and Cg is a group velocity of waves.

As the directional spectrum of wave, the Bretschneider-Mitsuyasu type is used.

$$S(f,\theta)=S(f)\cdot G(f,\theta)$$

Here, S (f) is a frequency spectrum, and G (f, θ) is a directional spreading function given with the following formula. f is the freuqency and θ is the angle of deviation from the principle direction of the wave train.

$$S(f)=0.257(H_{1/3})^2(T_{1/3})^{-4}(f)^{-5}\exp\{-1.03\ (T_{1/3}\ f)^{-4}\}$$

$$G(f,\theta)=Go\ \cos^{2s}\left(\frac{\theta}{2}\right)$$

$$Go=\left\{\int_{-\pi/2}^{\pi/2}\cos^{2s}\left(\frac{\theta}{2}\right)d\theta\right\}^{-1}$$

S in the above formula is a parameter showing the degree of directional concentration of a wave and is given with the following formula.

$$S = \begin{cases} S_{max}\ (f/f_P)^{5}, & f \leq f_P \\ S_{max}\ (f/f_P)^{-2.5}, & f > f_P \end{cases}$$

$$f_P = 1/(1.05T_{1/3})$$

$$S_{max} = 10 \text{ (wind wave)}$$

If the height of deepwater waves is $H0'$, the wave length is L_0, the slope of the bottom of the sea is $\tan\beta$, and the depth of the water is h, then the attenuation of wave height is calculated using the following simple formula by Goda.

$$H_{1/3} = \begin{cases} K_sH_0' & (h/L_0 \geqq 0.2) \\ \min\{(\beta_0H_0' + \beta_1h),\ \beta_{max}H_0',\ K_sH_0'\} & (h/L_0 < 0.2) \end{cases}$$

where $\beta_0 = 0.028(H_0'/L_0)^{-0.38}\exp[20(\tan\theta)^{1.5}]$

$\beta_1 = 0.52\exp[4.2\tan\theta]$

$\beta_{max} = \max\{0.92,\ 0.32(H_0'/L_0)^{-0.29}\exp[2.4\tan\theta]\}$

The shoaling coefficient K_s is obtained from Fig. A min{ } and max{ } show the minimum value and maximum value in { } respectively. $\tan\theta$ represents the slope of sea bottom.

Similarly, the formula of approximate calculation of the maximum wave H_{max} is shown below.

$$H_{max} = \begin{cases} 1.8K_sH_0' & (h/L_0 \geqq 0.2) \\ \min\{(\beta_0^*H_0' + \beta_1^*h),\ \beta_{max}^*H_0',\ 1.8K_sH_0'\} & (h/L_0 < 0.2) \end{cases}$$

where $\beta_0^* = 0.052(H_0'/L_0)^{-0.38}\exp[20(\tan\theta)^{1.5}]$

$\beta_1^* = 0.63\exp[3.8\tan\theta]$

$\beta_{max}^* = \max\{1.65,\ 0.53(H_0'/L_0)^{-0.29}\exp[2.4\tan\theta]\}$

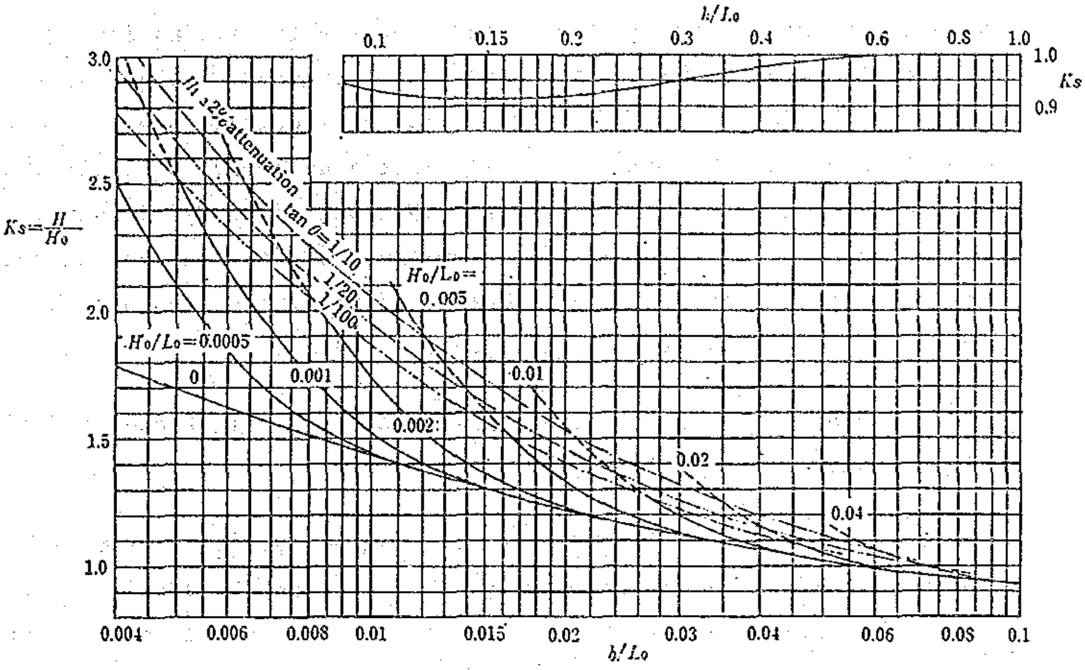

Fig. A Calculation Diagrams of Shoaling Coefficient[17)]

This method, as shown in Fig. 2-5, set the area of analysis at 9 km x 6 km including the project site, and the area is divided into grids with an interval of 50 m. A design deepwater wave (Table 2-3) is given to the deepwater edge of the area to calculated one by one from the off-shore to the coast. By calculating as above, a significant wave height and a wave direction are obtained on the grid points of the calculating area. The sea bottom level written in the sea chart is used for calculation, and the depth of water is calculated based on the mean high water level (datum level + 1.3 m).

The distribution of calculated significant wave height and wave direction is shown in Fig. 2-6.

The design deepwater wave (height of 7.4 m to 10.2 m) at the off-shore loses most of its energy by the wave breaking on the shoal inside the bay. The height decreases to 2.1 m at the outlet, and to 1.5 m at the jetty.

2.6 Wind Waves in the Bay

When a typhoon comes, it is impossible to neglect wave generation in the bay. Waves generated in the bay are calculated in the previously mentioned five directions (SW, WSW, W, SNW, NW) by using B. W. Wilson's method. The wind velocity distribution, as the outer force, is calculated using the wind corresponding to the probability wave for the 50-year return period in each wave direction, which is shown in Table 2-3.

The wind wave height is 1.0 m or less in the neighborhood of the project site.

2.7 Design Wave

The components of the deepwater wave and the wave generated in the bay are synthesized by energy combination at each grid point.

$$(\text{Combined wave}) = [(\text{Component of the deepwater wave})^2 + (\text{wave generated in the bay})^2]^{1/2}$$

The distribution of the significant wave heights of the synthesized waves are shown in Fig. 2-7.

The maximum significant wave height is shown in Table 2-4 for each wave direction at the project site.

The maximum height of the synthesized wave is 2.3 m at the outlet, and 1.8 m at the jetty. Considering the importance of the facilities and the suppositions of calculation, a required allowance is added. The design wave is set at 3 m at the outlet, and 2 m at the jetty and the revetment of the power plant.

3. Calmness in Port

3.1 Calculating Procedure for Calmness in Port

The calculating procedure for calmness in the port is shown in Fig. 3-1.

At the outset, the materials regarding winds (1981 to 1985) at the Iba station are arranged to enable understanding the wave characteristics at the site. The data at Iba should be converted into the wind velocity on the sea (at the height of 10 m).

Next, deepwater waves are estimated by S.M.B. method based on the wind data and fetch length (distance to the beach) from the off-shore point of the site.

The wave transformation that occurs when deepwater waves reach the position for determining calmness, is calculated by the same method as is used for the design wave.

The waves at the project site, include not only the components of deepwater waves, but also waves generated between the bay mouth and the project site. These waves generated in the bay are estimated by using S.M.B. significant wave method based on the wind data and the fetch length (distance to the beach) from the center of the position where the calmness in the port is calculated. Waves generated in the bay, are little influence by the terrain of the sea bottom, because they have a short fetch length and a short period. Therefore, their diffraction, shoaling, and wave breaking can be neglected.

Waves at the position for calmness calculation are obtained from the energy synthesis of both the above-mentioned waves.

The conditions that enable coal vessels to berth and unload are a wave height of less than 0.7 m and a wind velocity of less than 13 m/s in front of the jetty, and the calmness that is the frequency of satisfying such kinds of wave and wind is calculated.

3.2 Ordinary Winds

The data of wind speeds and wind directions for every three hours for five years from 1981 to 1985 at Iba are used for the calculation below.

Iba station is located at 37 km south from the site as shown in Fig. 1-1. The distribution of wind speeds and directions is shown in Fig. 3-2, and the frequency of wind velocity in Table 3-1.

The wind meter is set 30 ft (9.15 m) above ground surface, that is 13.75 m above sea level at Iba station. The neighboring terrain is flat and there are no obstacles to prevent winds. The beach is about 300 m southwest of the station.

In general, land has a larger friction than sea, so that the wind from sea tends to diminish its velocity on land depending on the terrain, wind direction, etc. The ratio of wind velocities at 10 m above the beach to 10 m above sea is calculated by following formula:

$$U \text{ (on sea)} = U \text{ (beach)}/0.9$$

The formula is contained in "Shore Protection, Planning and Design" of U.S. Army Coastal Engineering Research Center.

The difference between the height of the wind meter (9.15 m) and the defined height of the wind on sea (10 m) can be neglected, because it is very small.

3.3 Deepwater Waves

Deepwater waves are estimated by S.M.B significant wave method mentioned above.

The fetch length (distance to the beach) is measured at intervals of four degree referring to Fig. 3-3. The effective fetch length in each direction is determined by Saville's method.

$$F = \sum_i f_i \cos\theta_i \Big/ \sum_i \cos\theta_i$$

where F is the effective fetch length in the direction, fi is the distance to the beach with the angle of θi toward the direction.

The calculated, effective fetch length is shown in Table 3-2.

The deepwater waves are estimated with wind data at intervals of three hours.

The distributions of significant wave heights and significant wave periods are shown in Table 3-3. The deepwater wave height of 0.3 m or less is 75%, and 1.0 m or less is 93% (average value for five years).

3.4 Transformation of Waves

Deepwater waves are transformed by diffraction, shoaling, and wave breaking before they reach the jetty. To calculate such transformation of waves, Karlson's energy transfer equation and the simple formula by Goda are applied, the same as for the design wave.

Here, the transformation of waves is calculated in three cases of significant wave heights (0.5, 1.0, and 2.0 m); and in six cases of wave directions (SSW, SW, WSW, W, WNW, NW). 18 cases are considered as representative. Then, the relationship between the height of deepwater waves and the wave height at the jetty is determined. By using this relationship, the wave height is calculated for each wind data at the jetty.

The results of calculating the wave transformation are shown in Table 3-4 and Figure 3-4.

The deepwater wave heights of 0.5, 1.0, and 2.0 m are reduced to 0.44, 0.85, and 1.24 m or less at the pier.

3.5 Wind Waves in the Bay

Wind waves in the bay are estimated by S.M.B. significant wave method in the same way as for deepwater waves. They are calculated for each wind data.

The fetch length for each direction is the distance from the jetty to the beach around the bay, referring to Fig. 3-5. The effective fetch length for each direction is determined by Saville's method as shown in Table 3-5.

Table 3-6 shows the frequency of calculated wind waves in the bay. The wind waves in the bay have a height of 0.3 m or less with a probability of 97%.

3.6 Calmness in the Port

A composed wave at the jetty is made by energy synthesis of a component of deepwater wave and a wave generated in the bay.

$$(\text{Combined wave at jetty}) = [(\text{Component of deepwter wave})^2 + (\text{Wind wave in bay})^2]^{1/2}$$

The distribution of calculated wave height at jetty is shown in Table 3-7. The combined wave height of 0.3 m or less is 87%, and 0.7 m or less is 96%.

Table 3-9 shows the calmness in the port, that is the probability of nonexceedence for two kinds of critical conditions of winds and waves (Table 3-8).

The calmness in the port is 96% as the average value for five years, under the condition that a wave height is less than 0.7 m and a wind velocity is less than 13 m/s. The calmness seems to diminish to 71%

and 74% in June and August, respectively, but it never drops to a value of less than 85% for two months or more.

According to the analysis, it is considered that this port can provide sufficient calmness for berthing and unloading.

Wave Analysis at Masinloc Site

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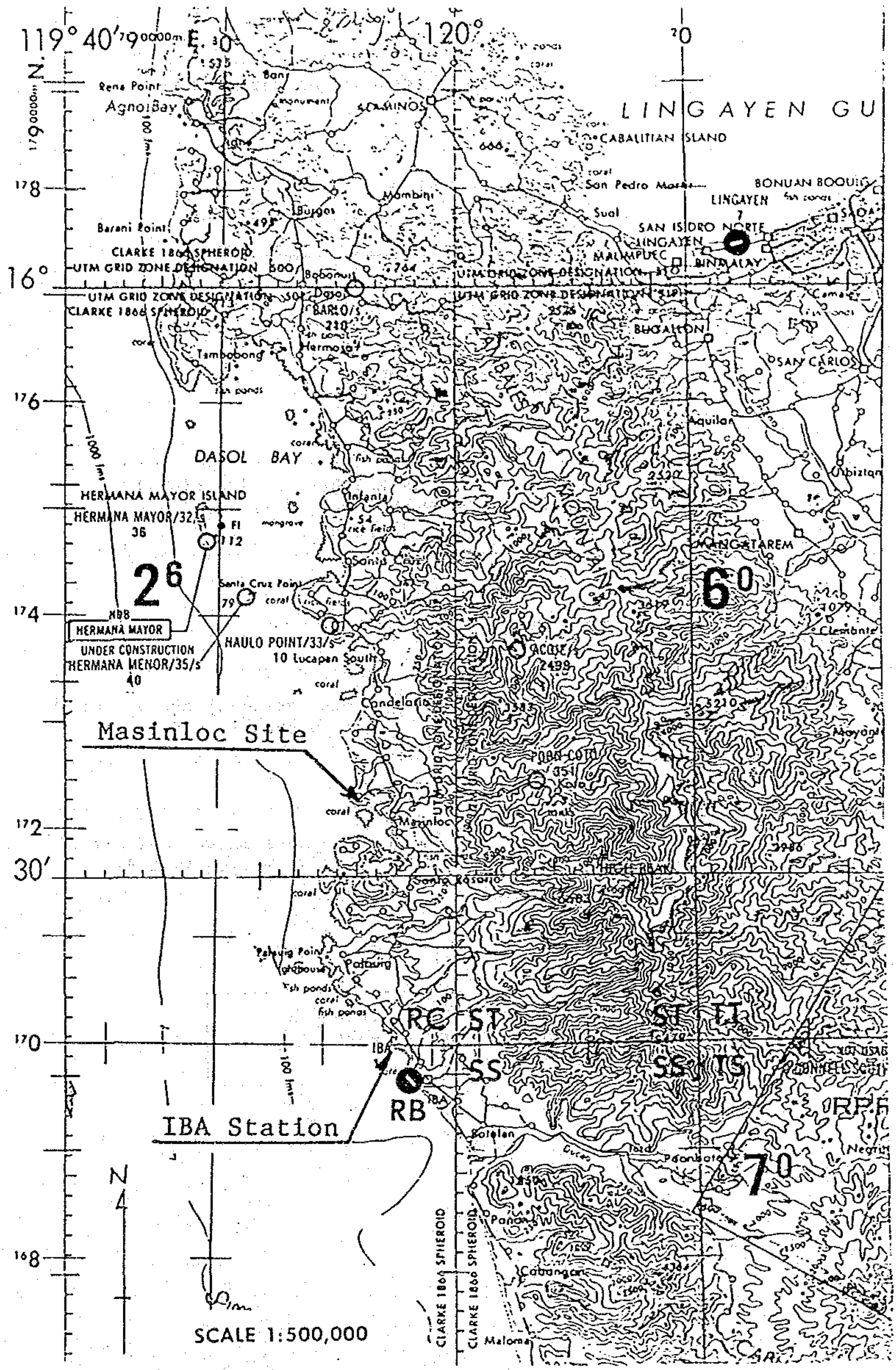
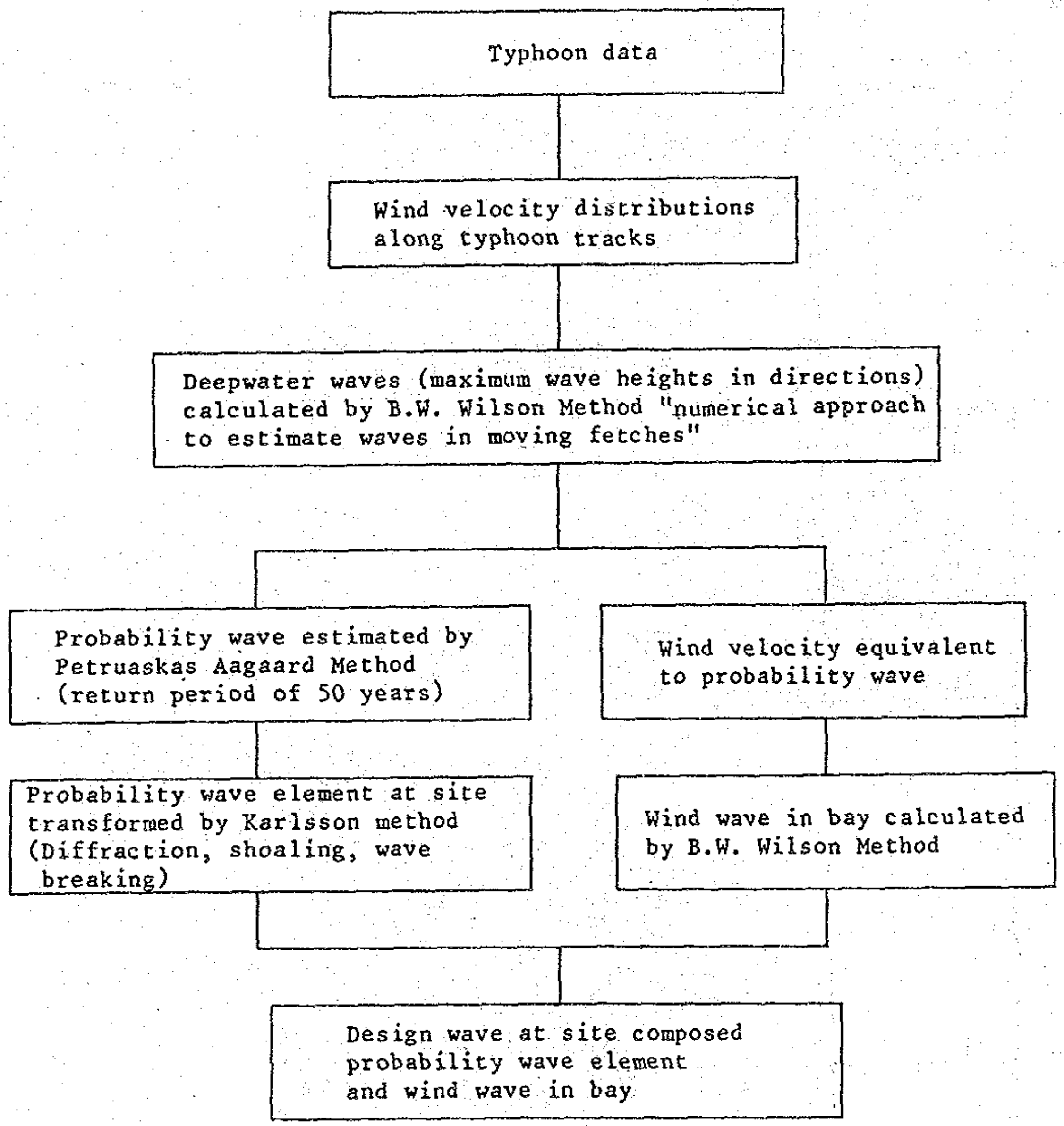


Fig. 1-1 Topographic Map

Fig. 2-1 Calculation Method for Design Wave



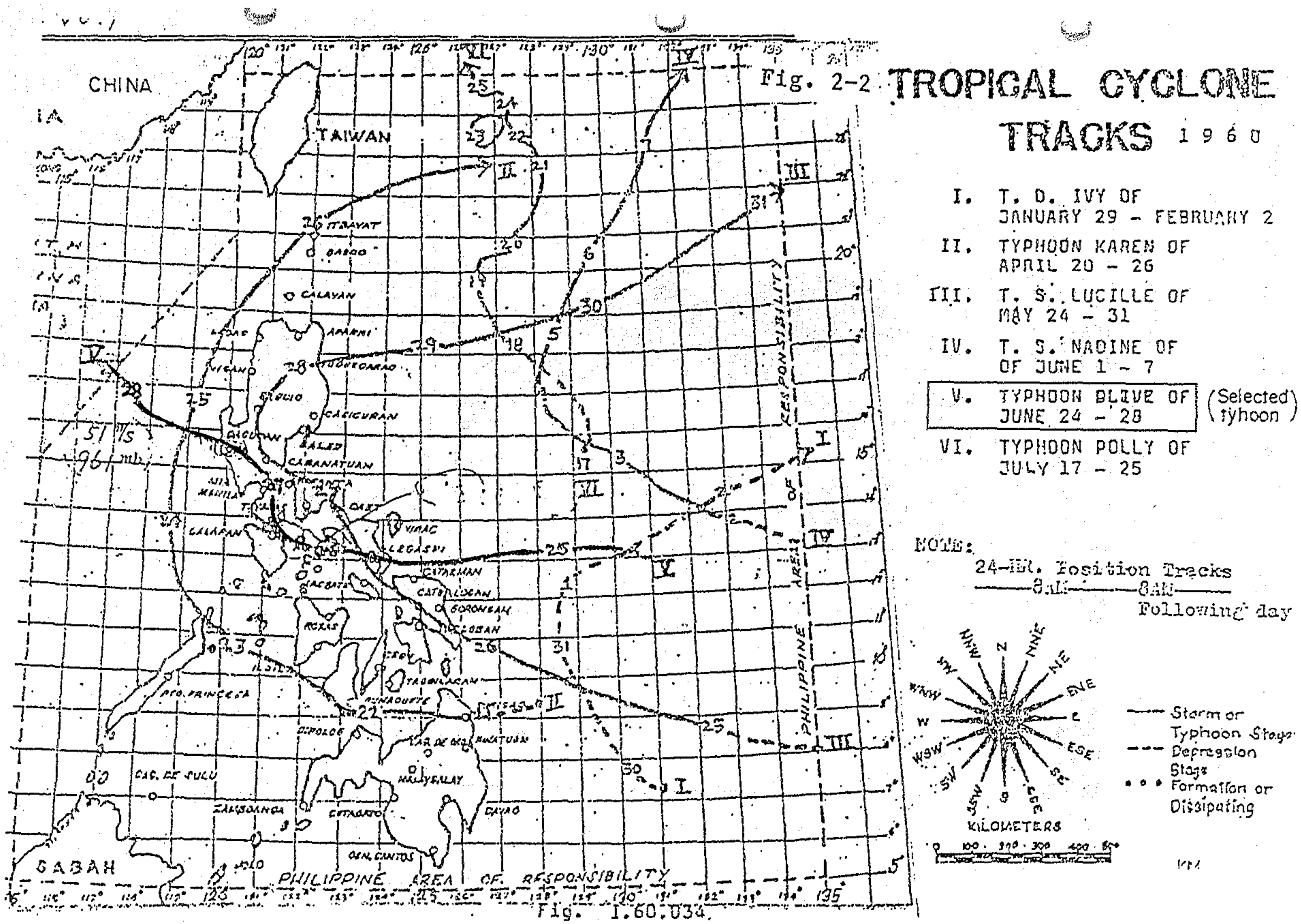


Fig. 2-2 Typhoons Tracks

Fig. 2-3 Calculation Area for Deepwater Waves

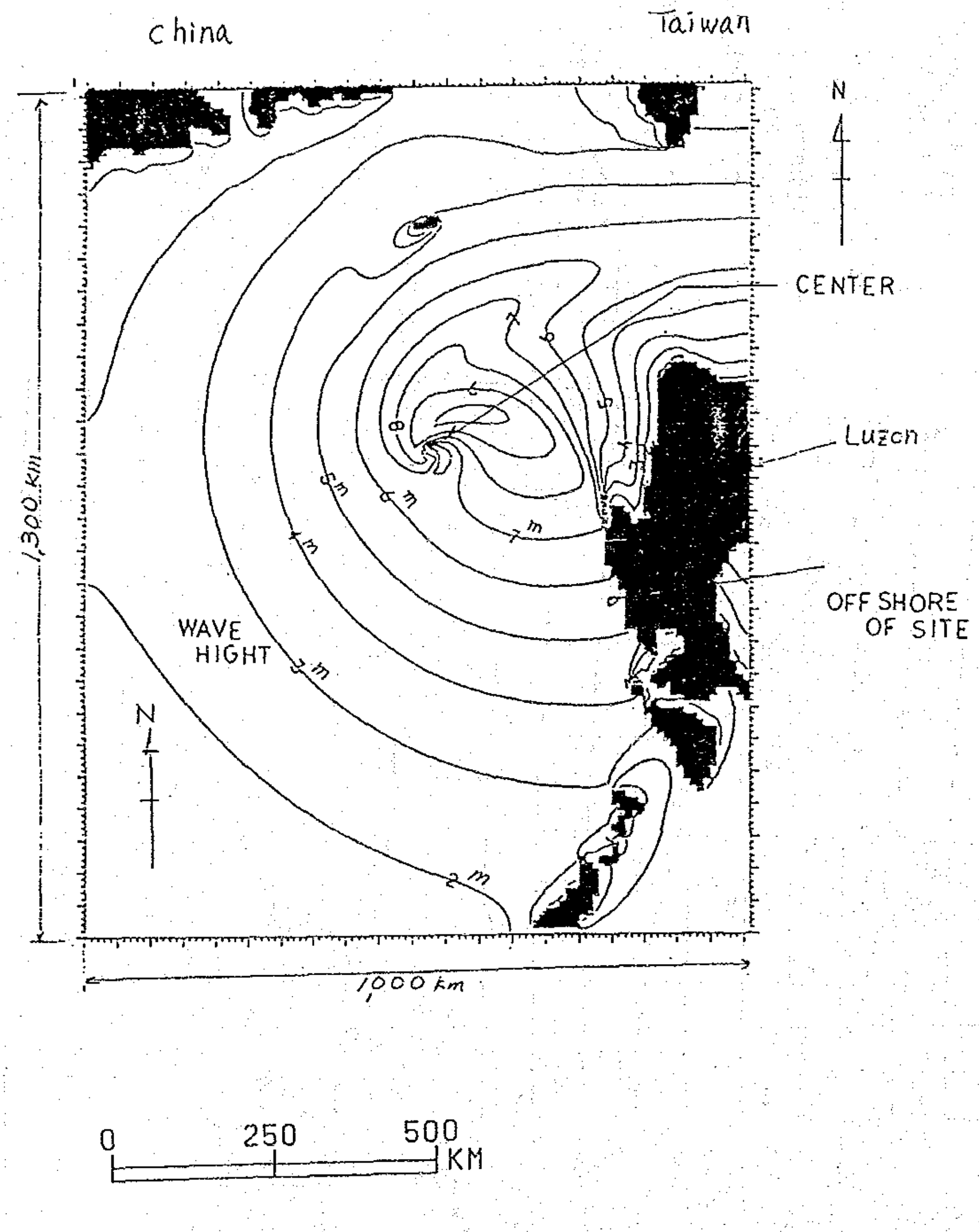


Fig. 2-4 Probability Wave [SW]

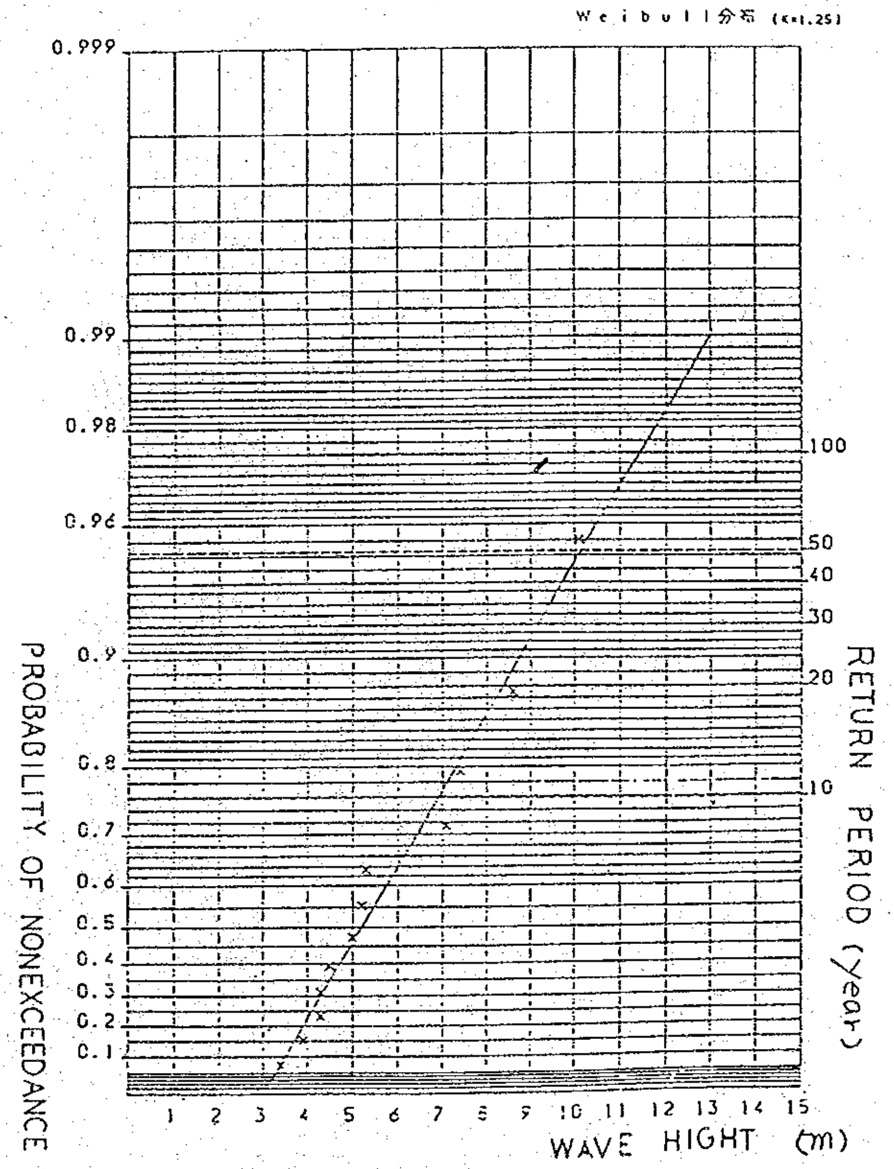


Fig. 2-5 Calculation Area for Transformation of Deepwater Waves

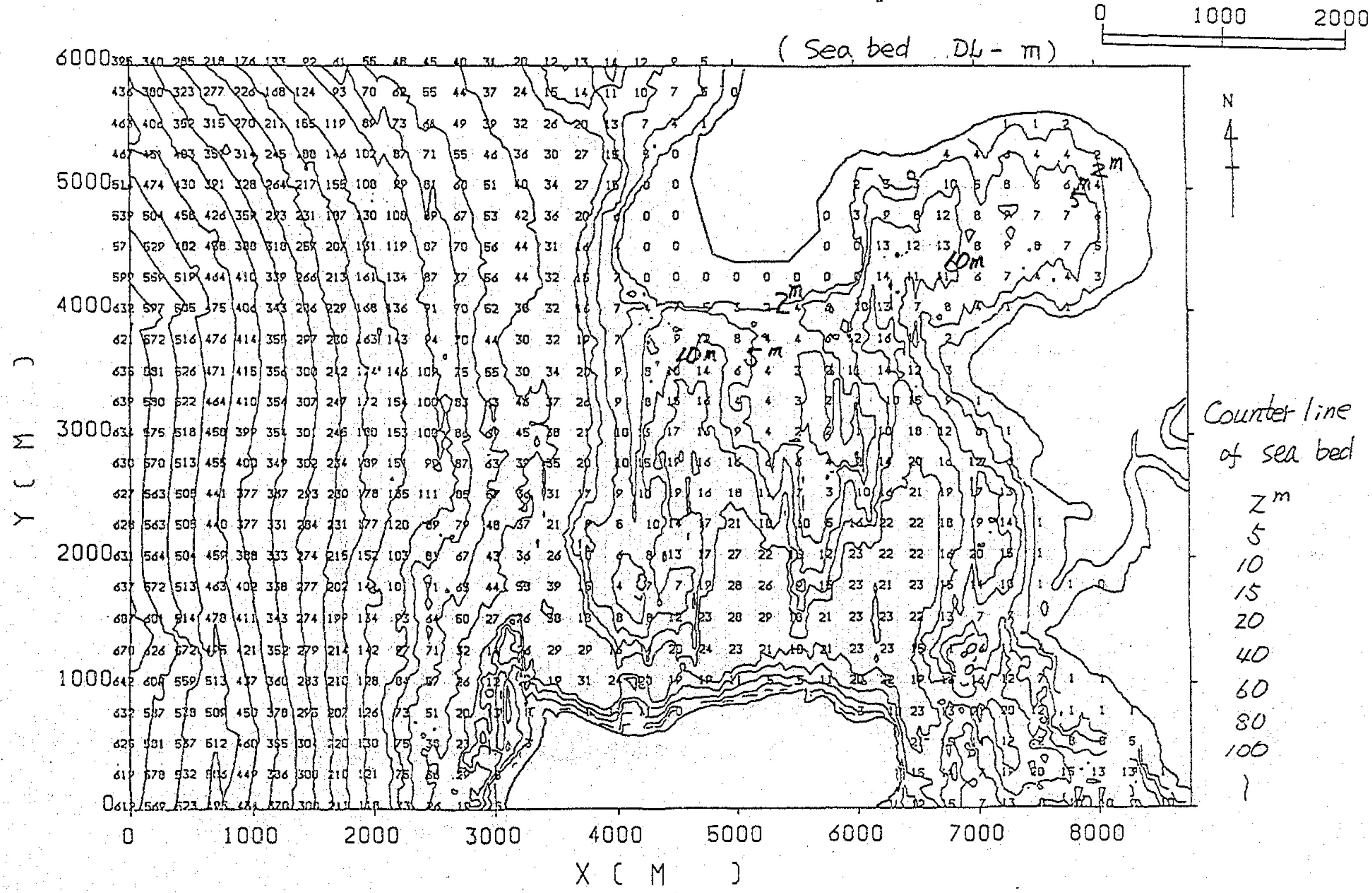


Fig. 2-6 Calculation Result on Transformation of Deepwater Waves

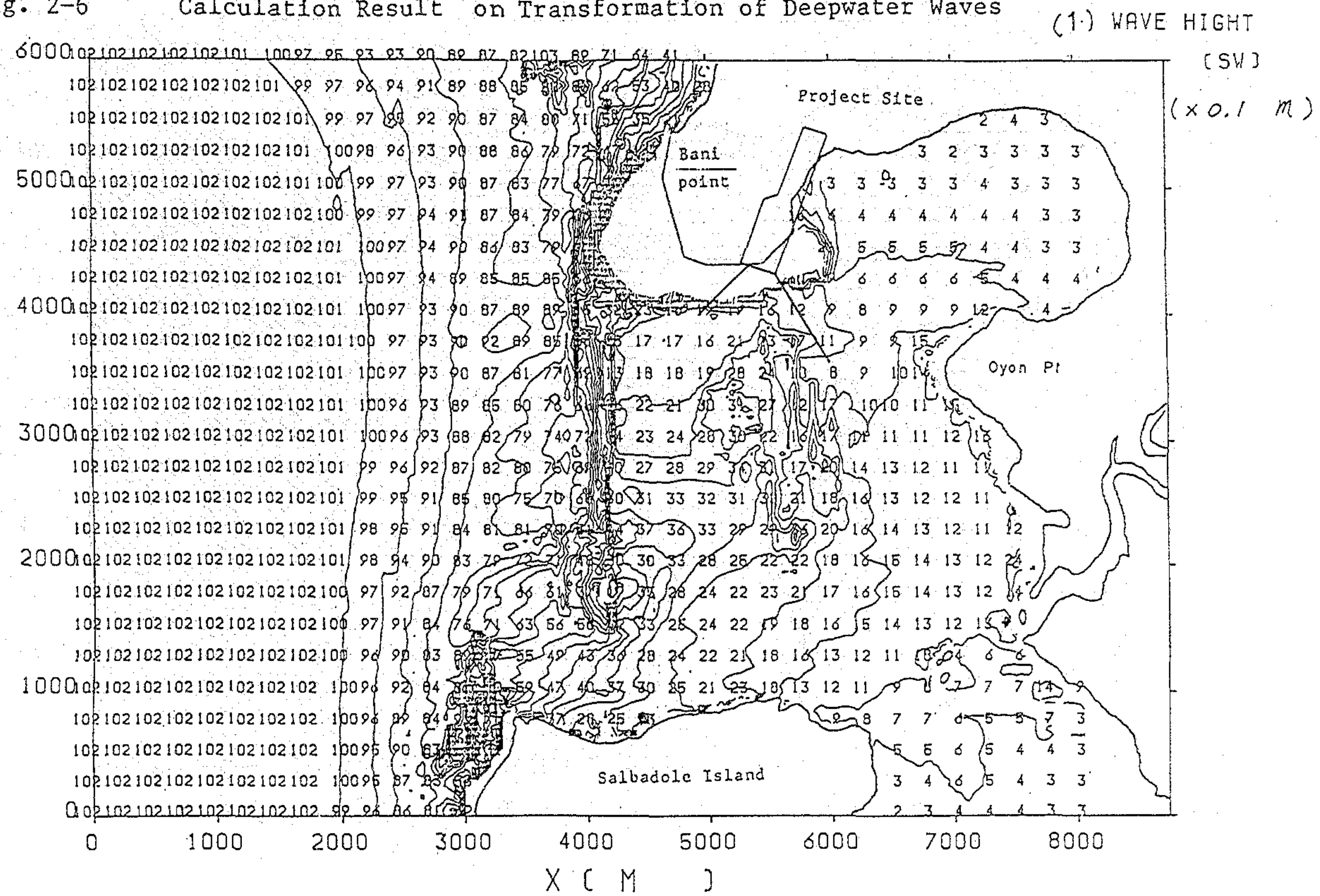


Fig. 2-6 Calculation Result on Transformation of Deepwater Waves (2) WAVE DIRECTION

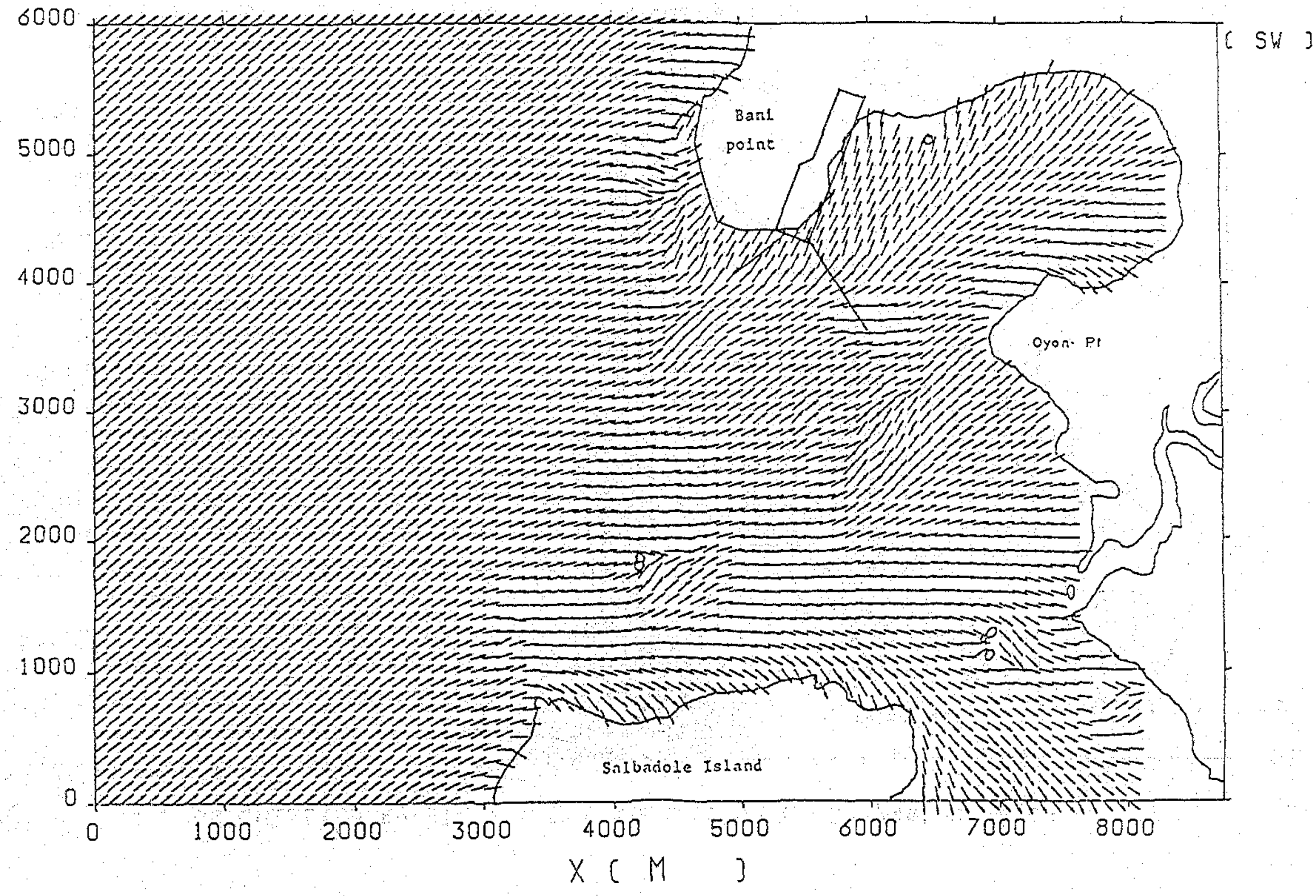


Fig. 2-7 Calculation Result on Waves Combined Deepwater Waves with Wind Waves in Bay

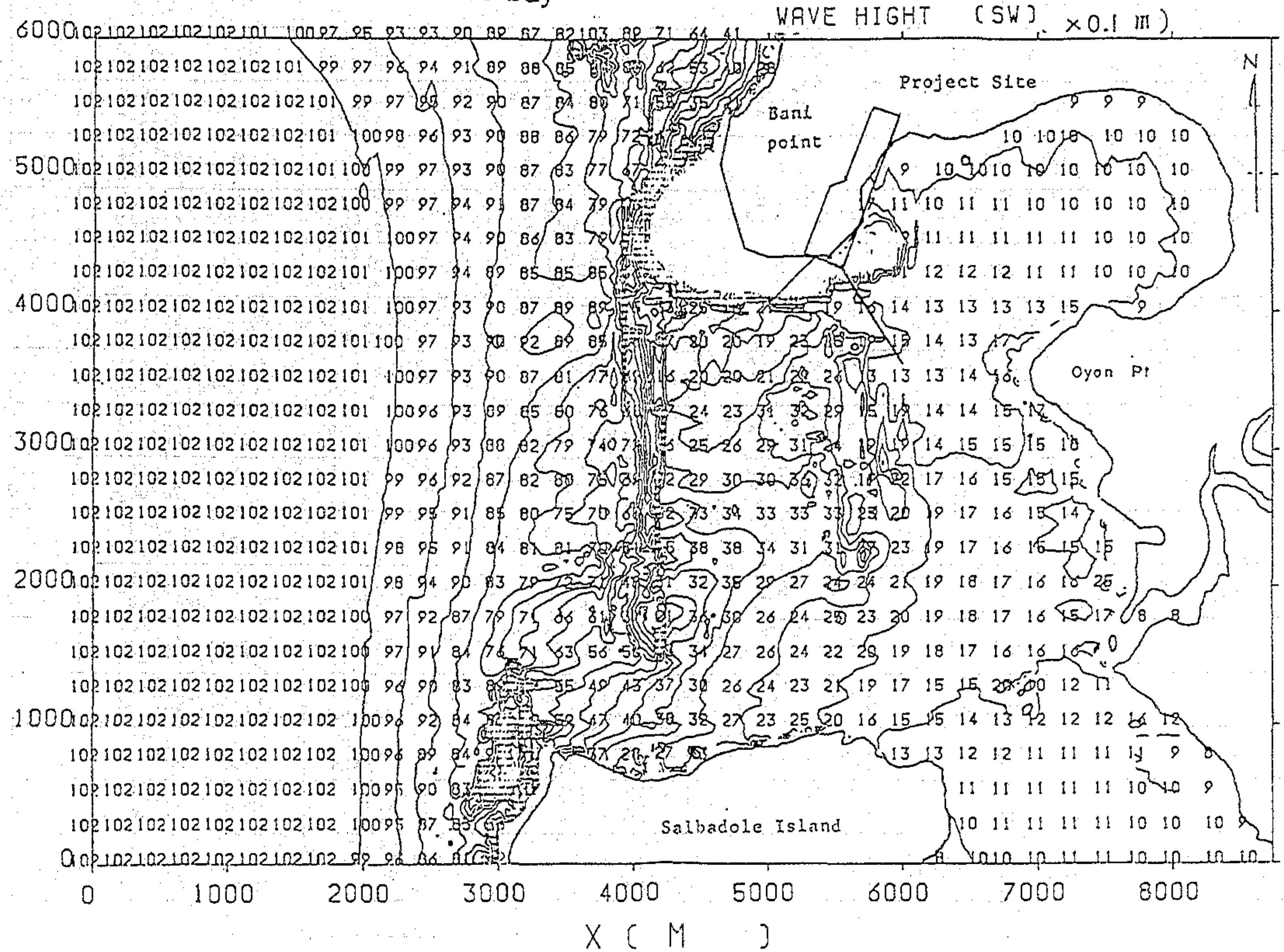


Table 2-1 Table of Typhoons

case	Names of Typhoon and Date of Occurrences	Max.Wind (m/s) observed Place and Date	Min.SLP (m/s) observed Place and Date	Radius (km) of Typhoon as Max.Wind	Min.SLP (mb) at center
1	Olive of June 24-28 1960	51m/s at Legaspi on June 26	961.2mb at Aurora,Quezon, 30km dist. from center on June 26	100km	958.4
2	Luding(Carmen) of Aug. 10-14 1963	43m/s at Virae,Catanduan ces on Aug. 13	967.8mb at Virac,Catanduanes 5 km di dist. from center on Aug. 13	100km	968.0
3	Dading (Winnie) of June 26-30 1964	35m/s at Infanta,Quezon on June 29	974.0mb at Infanta,Quezon 10km dist. from center on June 29	100km	974.0
4	Klaring(Irma) of May 11-22 1966	54m/s at Tacloban on May 15	967.0mb at Borongan,Samar 30km dist. from center on May 15	100km	964.6
5	nameless of Nov. 18-23 1966	37m/s at Infanta,Quezon on Nov. 20	974.6mb at Virac 0km dist. from center on Nov. 19	100km	975.0
6	Welming(Emma) of Nov. 1-5 1967	51m/s at Masbate on Nov. 3	970.6mb at Daet,Camarinos Norte 20km dist. from center on Nov. 4	100km	970.0
7	Sening of Oct. 10-15 1970	76m/s at Virac,Catanduan ces on Oct. 13	950.7mb at Virac Radar 50km dist. from center on Oct. 13	100km	938.5
8	Yoling of Nov. 17-20 1970	56m/s at MIA on Nov. 19	954.8mb at Infanta 40km dist. from center on Nov. 19	100km	940.0
9	Konsing(Cora) of June 23-25 1972	57m/s at Legaspi on Jan. 25	970.7mb at Legaspi 0km dist. from center on June 25	100km	971.0
10	Narsing(Ruth) of Oct. 12-16 1973	50m/s at Casiguran on Oct. 16	971.8mb at Baler 150km dist. from center on Oct. 15	100km	909.0
11	Bidang(Irma) of Nov. 24-29 1974	39m/s at Caguio City radar on Nov. 28	981.0mb at Cabanatuan 0km dist. from center on Nov. 27	100km	981.0
12	Yaning of Oct. 7-14 1978	40m/s at Virao radar	985.3mb at Port Abea 20km dist. from center on Oct.	100km	984.6
13	Norming of Aug.19-Sep.4 1982			70km - 100km	960.0
14	Bebeng of July 12-16 1983	46m/s at MIA on July 15	983.0mb at MIA 20km dist. from center on July 15	70km - 100km	975.0
15	Ising of Aug. 12-20 1987	45m/s at Baguio on Aug.	993.9mb at Munoz 110km dist. from center on Aug. 19	70km - 100km	970.0
16	Unsang of Oct. 21-26 1988		and Date	70km - 100km	950.0

Table 2-2 Maximum Deepwater Waves by Typhoons

case	Names of Typhoon and Date of Occurrences	N	NNW	NW	WNW	W	WSW	SW	SSW	S
1	Olive of June 24-28 1960	3.2 5.9 26.3	4.0 6.8 25.4	5.3 8.2 24.0	6.2 9.4 22.2	6.6 10.0 22.7	6.8 10.3 26.0	7.1 10.5 28.8	7.1 10.5 28.4	
2	Luding of Aug. 10-14 1963		1.4 4.4 12.5	2.6 6.2 16.0	3.3 7.1 18.4	3.8 7.6 20.5	4.2 8.0 20.7	4.3 8.1 20.0	4.1 8.1 17.8	
3	Dading of June 26-30 1964	3.3 6.1 21.8	3.4 6.4 23.3	2.8 6.1 19.9						5.8 9.1 24.4
4	Klaring of May 11-22 1966	1.4 4.0 15.2				7.7 11.1 25.3	8.2 11.4 26.5	8.6 11.6 28.3	8.6 11.6 28.3	8.7 11.6 28.4
5	nameless Nov. 18-23 1966		2.4 5.7 17.1	3.8 7.4 20.2	4.4 8.1 20.5	4.6 8.4 20.9	5.0 8.7 19.9	5.2 8.9 17.8	5.3 9.0 17.6	5.4 9.1 19.6
6	Welming of Nov. 1-5 1967		3.6 6.8 22.6	4.2 7.4 16.5	5.0 8.5 9.0			4.5 8.7 14.2	5.8 9.3 26.9	6.0 9.4 25.5
7	Sening of Oct. 10-15 1970	3.7 6.2 31.1	3.6 6.3 26.9							
8	Yoling of NOV. 17-20 1970	4.1 6.6 30.7	4.2 6.7 29.9							
9	Konsing of June 23-25 1972		3.1 6.3 20.8	3.9 7.3 19.9	4.2 7.9 18.0	4.4 8.2 18.1	4.5 8.3 21.0	5.0 8.7 25.5	5.2 8.9 23.8	4.7 8.6 18.0
10	Narsing of Oct. 12-16 1973		2.0 4.6 23.1	7.9 10.3 33.6	9.0 11.3 34.9	9.5 11.6 35.8	9.7 11.8 37.2	10.1 12.0 37.4	10.2 12.2 35.3	10.1 12.2 33.7
11	Bidang of Nov. 24-29 1974			1.9 5.4 14.2	4.0 7.7 18.5	4.3 8.0 16.4	4.3 8.1 15.5	4.3 8.2 17.1	4.6 8.4 21.7	4.8 8.6 22.0
12	Yaning of Oct. 7-14 1978			3.0 6.7 17.2	3.6 7.5 16.7	3.8 7.7 15.3	3.8 7.8 14.6	3.9 7.8 16.3	4.1 8.0 19.6	4.4 8.3 20.5
13	Norming of Aug.19-Sep. 4 1982	0.3 2.1 4.6					7.4 10.4 28.7	7.4 10.3 29.3	5.9 9.0 29.9	5.0 8.5 25.9
14	Bebeng of July 12-16 1983	2.4 5.3 20.4	2.4 5.3 20.2			0.1 0.7 0.7			4.2 8.0 21.5	1.9 5.3 7.0
15	Ising of Aug. 12-20 1987		0.1 0.8 1.5	1.1 4.4 8.3	2.4 6.4 14.1	3.2 7.2 17.5	3.3 7.3 17.7	3.4 7.3 18.5	3.6 7.5 20.7	3.8 7.7 19.6
16	Unsang of Oct. 21-26 1988		2.0 5.2 15.0	3.2 6.9 20.0	4.1 7.7 22.7	4.5 8.1 24.1	5.0 8.5 26.3	5.3 8.9 24.8	5.3 8.9 24.6	4.5 8.5 17.0

H1/3 / T1/3 / Wind Speed

Table 2-3 Probable Maximum Deepwater Waves

Return Period (years)	Items	Wave Direction				
		SW	WSW	W	WNW	NW
100	$H_{1/3}$(m)	11.4	11.1	10.9	10.0	8.6
	$T_{1/3}$(m)	13.3	13.2	14.6	12.1	11.1
	Wind SPD(m/s)	40.3	39.1	39.3	34.2	35.4
50	$H_{1/3}$(m)	10.2	9.9	9.5	8.2	7.4
	$T_{1/3}$(m)	12.4	12.3	13.1	10.8	10.1
	Wind SPD(m/s)	36.4	35.3	24.8	29.4	31.4
40	$H_{1/3}$(m)	9.7	9.4	9.0	7.7	7.0
	$T_{1/3}$(m)	12.1	12.0	12.6	10.4	9.7
	Wind SPD(m/s)	35.1	34.1	33.3	27.9	30.0
30	$H_{1/3}$(m)	9.2	8.9	8.4	7.0	6.4
	$T_{1/3}$(m)	11.7	11.5	12.0	9.9	9.3
	Wind SPD(m/s)	33.5	32.5	31.4	26.1	28.3
20	$H_{1/3}$(m)	8.4	8.1	7.6	6.1	5.7
	$T_{1/3}$(m)	11.1	10.9	11.1	9.3	8.7
	Wind SPD(m/s)	31.0	30.1	28.7	23.7	25.8
10	$H_{1/3}$(m)	6.9	6.6	6.0	4.8	4.3
	$T_{1/3}$(m)	10.1	9.9	9.4	8.3	7.5
	Wind SPD(m/s)	26.6	25.9	23.8	19.9	21.5
5	$H_{1/3}$(m)	5.3	5.0	4.3	3.6	2.9
	$T_{1/3}$(m)	8.9	8.6	7.5	7.4	6.4
	Wind SPD(m/s)	21.8	21.1	18.1	16.8	16.9

$T_{1/3}$ and Wind SPD correspond with $H_{1/3}$.

Table 2-4 Maximum Wave Height at Project Site

Project site	Sort	SW	WSW	W	WNW	NW
Cooling water outlet	Deepwater wave Windwave in bay Combined wave	2.1m 0.2m 2.3m	2.0m 0.2m 2.2m	1.9m 0.1m 2.0m	1.9m 0.1m 2.0m	1.8m 0.2m 2.0m
Coal unloading jetty	Deepwater wave Windwave in bay Combined wave	1.5m 0.3m 1.8m	1.4m 0.3m 1.7m	1.3m 0.1m 1.4m	1.4m 0.1m 1.5m	1.3m 0.2m 1.5m

Fig. 3-1 Calculation Method for Calmness

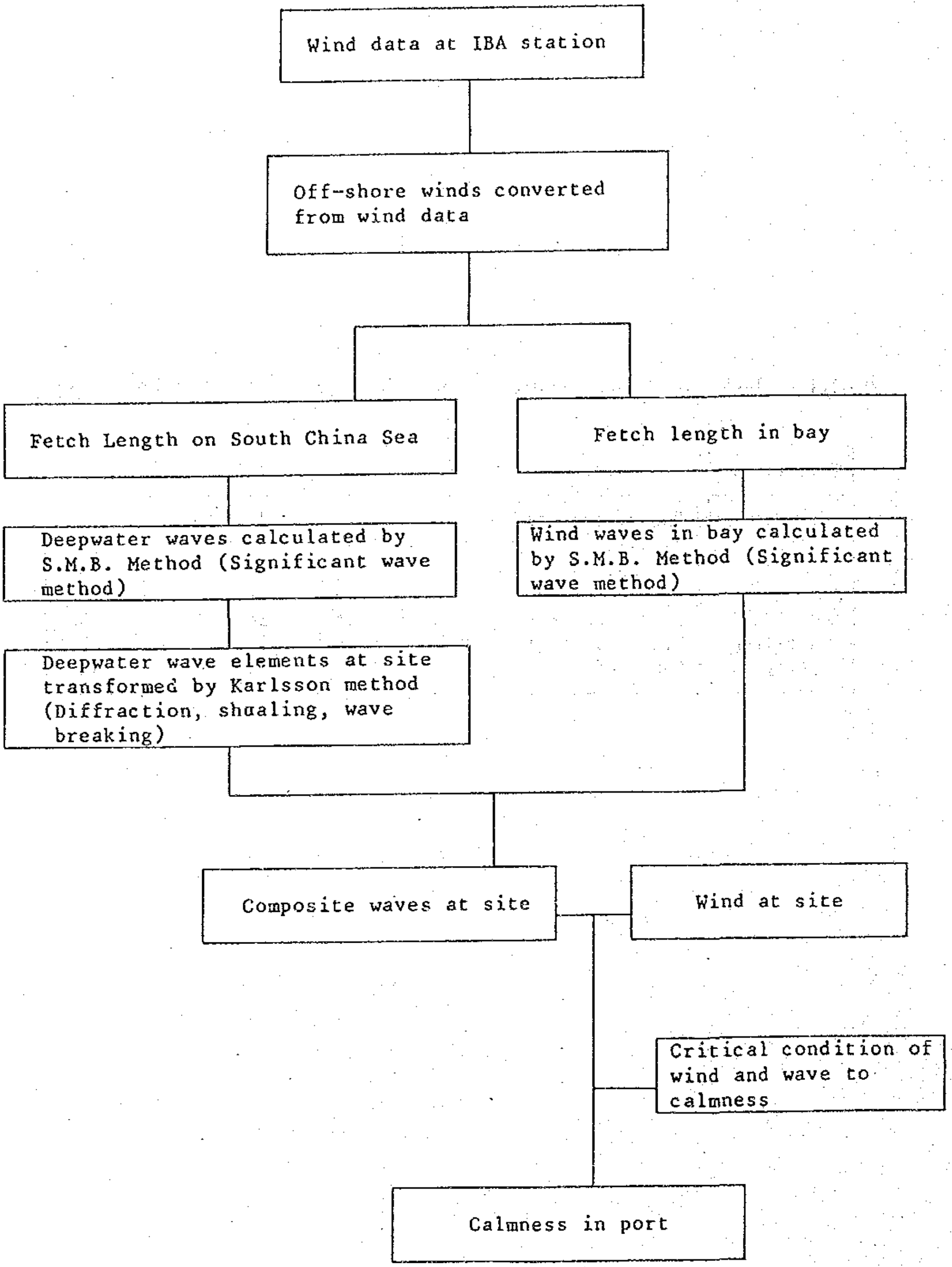


Fig. 3-2 Distribution of Wind Velocities and Directions at IBA Station

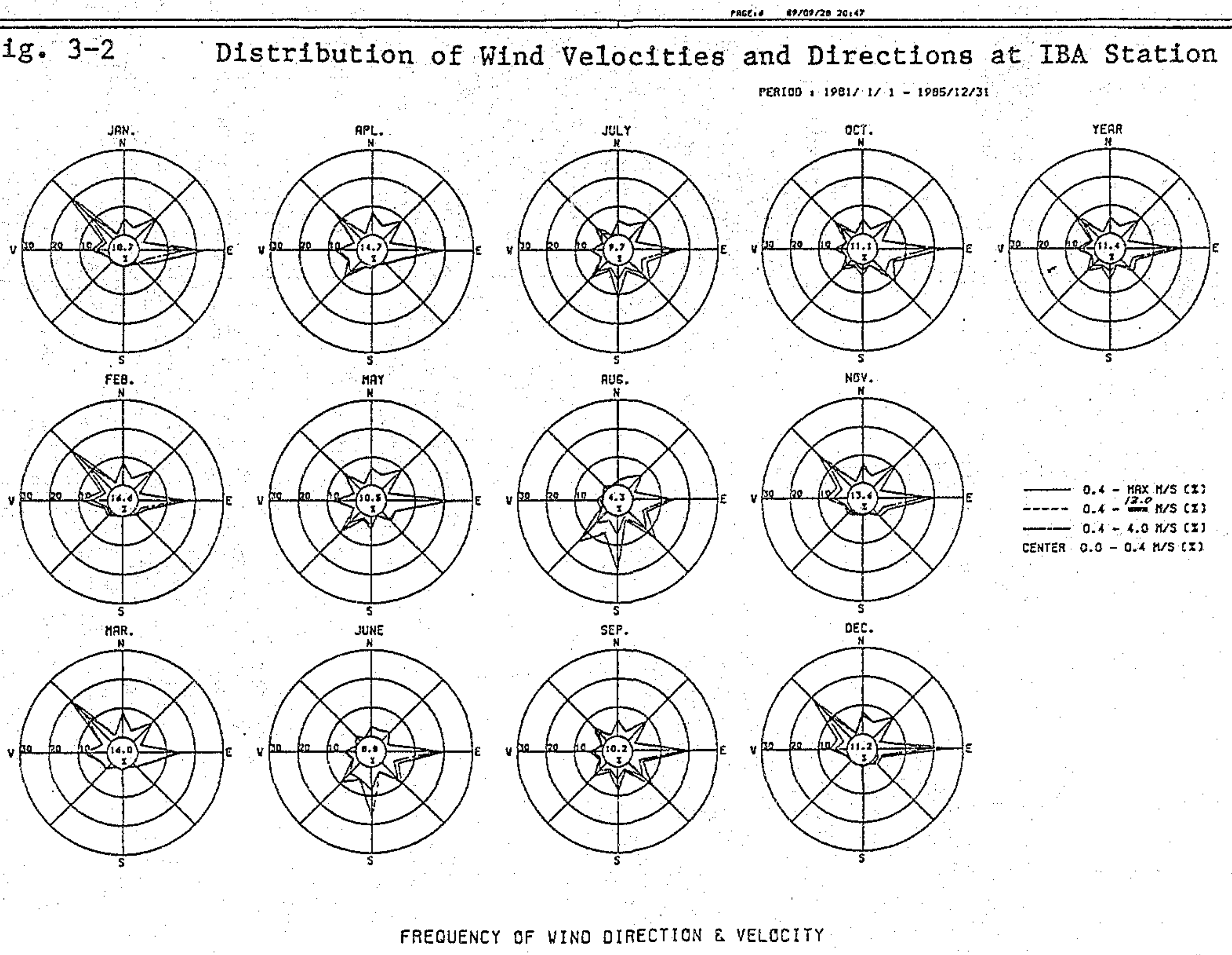


Fig. 3-3 Fetch Length to Deepwater Wave

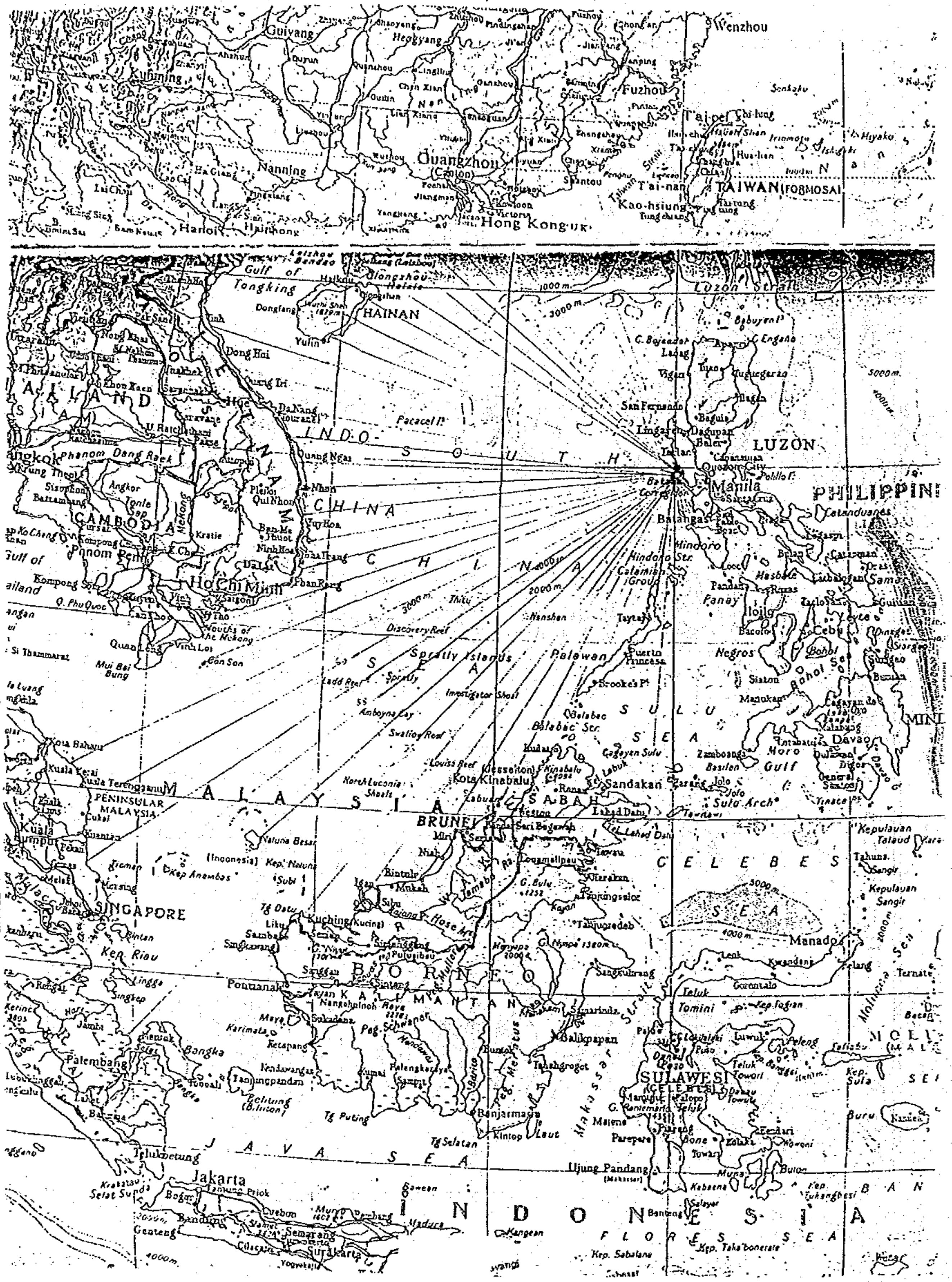


Fig. 3-4 Calculation Result on Transformation of Deepwater Wave

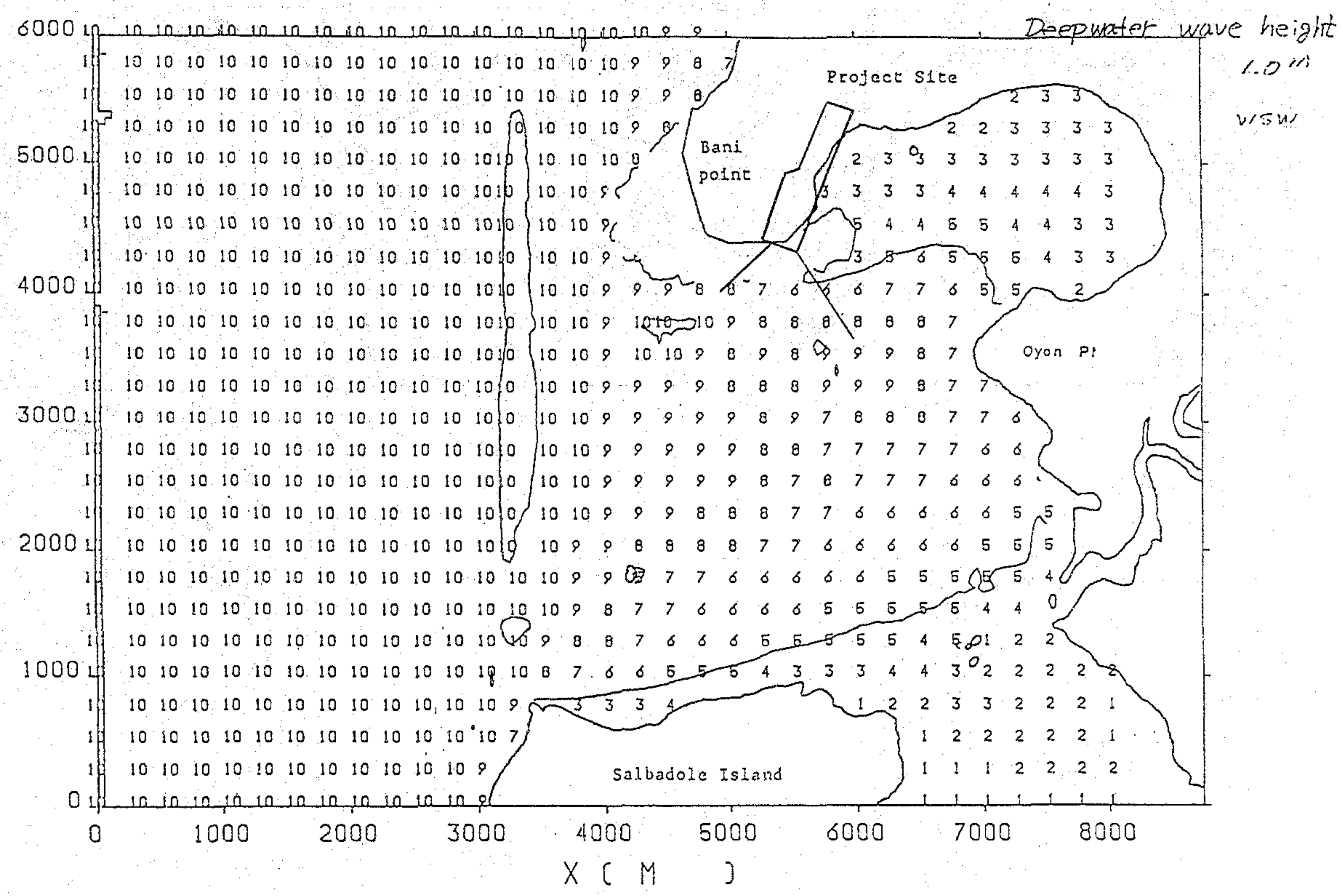
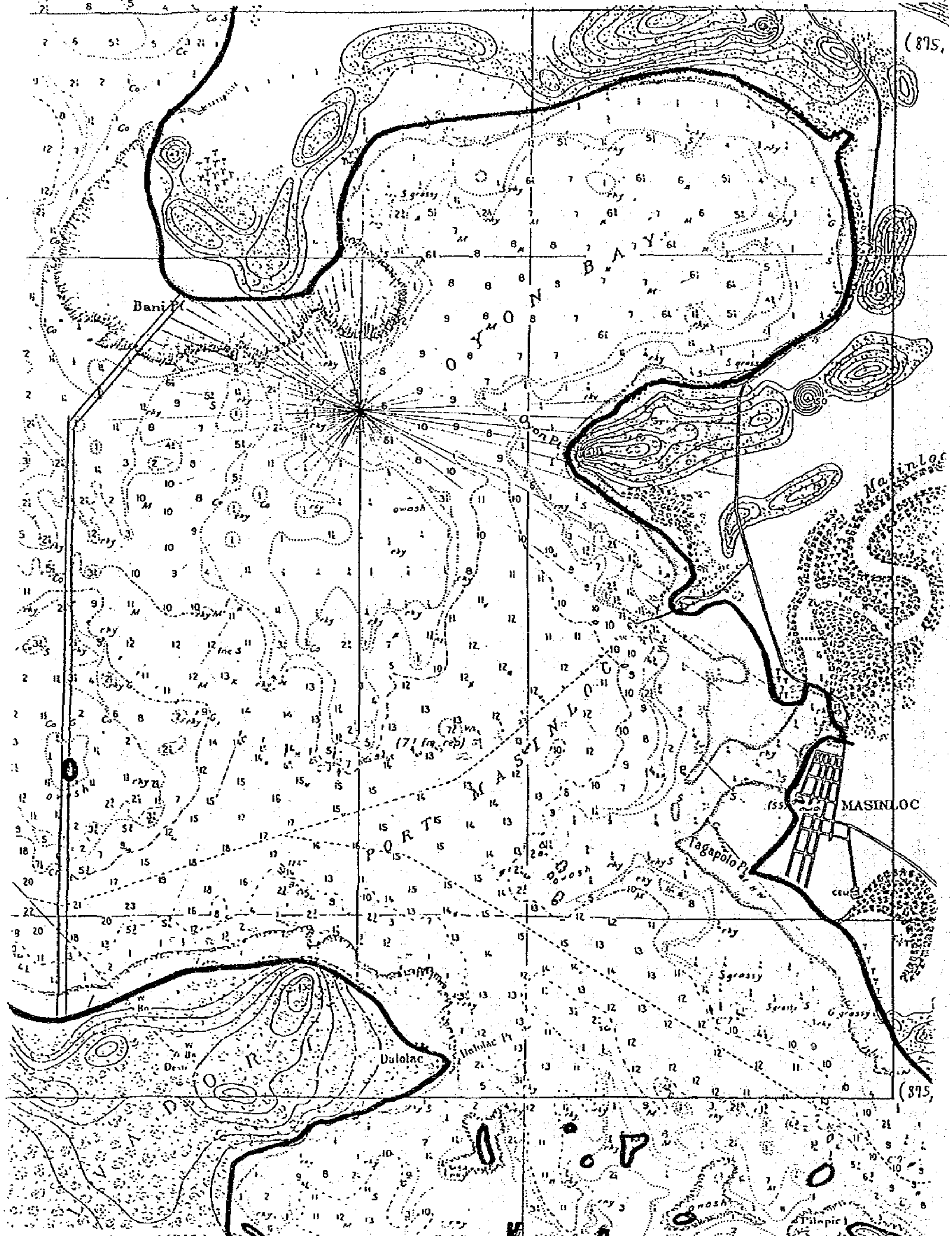


Fig. 3-5 Fetch Length to Berthing Basin



－5 吹送距離（桟橋）

Table 3-1 Distribution of Wind Velocities and Directions at IBA Station

DATA PERIOD : 1981/ 1/ 1 - 1985/12/31

	LT0.4	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0.0 - 0.4 M/S	1450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1450
(%)	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.42
0.4 - 2.0 M/S	0	523	278	784	135	1504	282	289	42	174	69	241	101	268	84	604	59	5437
(%)	0.0	4.1	2.2	6.2	1.1	11.8	2.2	2.3	0.3	1.4	0.5	1.9	0.8	2.1	0.7	4.8	0.5	42.82
2.0 - 4.0 M/S	0	192	135	339	41	650	141	253	32	170	70	176	58	290	61	419	25	3052
(%)	0.0	1.5	1.1	2.7	0.3	5.1	1.1	2.0	0.3	1.3	0.6	1.4	0.5	2.3	0.5	3.3	0.2	24.04
4.0 - 8.0 M/S	0	63	21	47	6	357	161	201	30	279	74	239	45	199	97	539	24	2382
(%)	0.0	0.5	0.2	0.4	0.0	2.8	1.3	1.6	0.2	2.2	0.6	1.9	0.4	1.6	0.8	4.2	0.2	18.76
8.0 - 13.0 M/S	0	3	1	1	1	20	13	36	15	109	27	69	6	15	1	16	0	333
(%)	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.3	0.1	0.9	0.2	0.5	0.0	0.1	0.0	0.1	0.0	2.62
13.0 - 17.0 M/S	0	0	0	0	0	1	0	5	1	7	4	3	0	3	0	1	0	25
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.20
17.0 - MAX M/S	0	0	1	1	0	1	3	6	0	0	1	0	0	1	0	5	0	19
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.15
T O T A L	1450	781	436	1172	183	2533	600	790	120	739	245	728	210	776	243	1584	108	12698
(%)	11.4	6.2	3.4	9.2	1.4	19.9	4.7	6.2	0.9	5.8	1.9	5.7	1.7	6.1	1.9	12.5	0.9	100.00

Table 3-2 Effective Fetch Length to Deepwater Wave

Wave Direction	N	NNE	NE	ENE	E	ESE	SE	SSE
Effective Fetch(km)	332	56	1	0	3	31	904	1202

Wave Direction	S	SSW	SW	WSW	W	WNW	NW	NNW
Effective Fetch(km)	1617	2039	1580	1702	1528	1289	1047	661

Table 3-3 Distribution of Wave Heights and Periods (Deepwater Waves)

DATA PERIOD : 1981/ 1/ 1 - 1985/12/31

Wave Heights	LT0.40	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0.0 - 0.3 M	1450	665	413	1171	183	2498	421	419	61	269	103	315	122	406	110	793	73	9472
(%)	11.4	5.2	3.3	9.2	1.4	19.7	3.3	3.3	0.5	2.1	0.8	2.5	1.0	3.2	0.9	6.2	0.6	74.59
0.3 - 0.5 M	0	50	12	0	0	32	112	121	12	70	34	98	34	149	35	223	11	993
(%)	0.0	0.4	0.1	0.0	0.0	0.3	0.9	1.0	0.1	0.6	0.3	0.8	0.3	1.2	0.3	1.8	0.1	7.82
0.5 - 0.7 M	0	32	7	0	0	2	36	86	9	71	25	102	26	107	49	258	10	820
(%)	0.0	0.3	0.1	0.0	0.0	0.0	0.3	0.7	0.1	0.6	0.2	0.8	0.2	0.8	0.4	2.0	0.1	6.46
0.7 - 1.0 M	0	18	2	0	0	0	22	60	9	98	16	70	13	58	31	179	4	580
(%)	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.5	0.1	0.8	0.1	0.6	0.1	0.5	0.2	1.4	0.0	4.57
1.0 - 2.0 M	0	16	1	0	0	0	6	68	13	115	35	71	9	37	17	109	10	507
(%)	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.5	0.1	0.9	0.3	0.6	0.1	0.3	0.1	0.9	0.1	3.99
2.0 - 4.0 M	0	0	0	0	0	0	0	24	13	103	24	63	4	13	1	13	0	258
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.8	0.2	0.5	0.0	0.1	0.0	0.1	0.0	2.03
4.0 - MAX M	0	0	1	1	0	1	3	12	3	13	8	9	2	6	0	9	0	68
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.54
T O T A L	1450	781	436	1172	183	2533	600	790	120	739	245	728	210	776	243	1584	108	12698
(%)	11.4	6.2	3.4	9.2	1.4	19.9	4.7	6.2	0.9	5.8	1.9	5.7	1.7	6.1	1.9	12.5	0.9	100.00

DATA PERIOD : 1981/ 1/ 1 - 1985/12/31

Periods	LT0.40	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0.0 - 4.0 SEC	1450	758	434	1171	183	2532	596	626	82	410	160	515	182	662	194	1274	94	11323
(%)	11.4	6.0	3.4	9.2	1.4	19.9	4.7	4.9	0.6	3.2	1.3	4.1	1.4	5.2	1.5	10.0	0.7	89.17
4.0 - 6.0 SEC	0	23	1	1	0	0	1	117	22	205	38	133	21	92	48	288	14	1004
(%)	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.9	0.2	1.6	0.3	1.0	0.2	0.7	0.4	2.3	0.1	7.91
6.0 - 8.0 SEC	0	0	0	0	0	1	1	34	12	93	34	60	5	14	1	13	0	268
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.7	0.3	0.5	0.0	0.1	0.0	0.1	0.0	2.11
8.0 - 10.0 SEC	0	0	0	0	0	0	0	6	4	30	8	18	2	5	0	4	0	77
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.61
10.0 - 12.0 SEC	0	0	0	0	0	0	0	4	0	1	4	2	0	2	0	0	0	13
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10
12.0 - 14.0 SEC	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	4	0	6
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05
14.0 - MAX SEC	0	0	1	0	0	0	2	2	0	0	0	0	0	1	0	1	0	7
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.06
T O T A L	1450	781	436	1172	183	2533	600	790	120	739	245	728	210	776	243	1584	108	12698
(%)	11.4	6.2	3.4	9.2	1.4	19.9	4.7	6.2	0.9	5.8	1.9	5.7	1.7	6.1	1.9	12.5	0.9	100.00

Table 3-4

Calculation Result on Transformation of Deepwater Wave

(1) Dimensions of deepwater waves calculated

case	Wave Height	Wave Period	Smax	Wave Direction
1	H1/3= 0.5 m	T1/3= 3.4 s	25	SSW, SW, WSW, W, WNW, NW
2	H1/3= 1.0 m	T1/3= 4.8 s	25	SSW, SW, WSW, W, WNW, NW
3	H1/3= 2.0 m	T1/3= 6.6 s	25	SSW, SW, WSW, W, WNW, NW

Smax ; parameter of angular concentration

(2) relation between deepwater wave and wave at jetty

Deep Water Wave	Pier	SSW	SW	WSW	W	WNW	NW
H0=0.5m T0=3.4s Smax=25	H1 H1/H0	0.24m 0.48	0.37m 0.74	0.44m 0.88	0.40m 0.80	0.29m 0.58	0.20m 0.40
H0=1.0m T0=4.8s Smax=25	H1 H1/H0	0.49m 0.49	0.70m 0.70	0.83m 0.83	0.76m 0.76	0.56m 0.56	0.39m 0.39
H0=2.0m T0=6.6s Smax=25	H1 H1/H0	0.93m 0.47	1.13m 0.57	1.24m 0.62	1.19m 0.60	1.00m 0.50	0.77m 0.39

H0 ; Significant wave height of deep water wave
T0 ; Significant wave period of deep water wave
H1 ; Significant wave height at the pier (x=6000m, y=3750m, h=16+1.3m)

Following rates are set up as an estimation.

N-SSE	S	NNW
0.0	0.22	0.22
0.0	0.28	0.22
0.0	0.37	0.28

Table 3-5 Effective Fetch Length to Berthing Basin

Wave Direction	N	NNE	NE	ENE	E	ESE	SE	SSE
Effective Fetch(km)	1.315	1.831	2.212	2.106	2.110	2.544	3.130	3.672

Wave Direction	S	SSW	SW	WSW	W	WNW	NW	NNW
Effective Fetch(km)	3.679	3.053	2.423	1.951	1.492	1.185	0.974	1.031

Table 3-6 Distribution of Wave Heights (Wind waves in bay)

DATA PERIOD : 1981/ 1/ 1 - 1985/12/31.

	LTO.40	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0.0 - 0.3 M	1450	781	434	1170	182	2522	584	737	101	597	213	656	205	765	243	1575	108	12323
(%)	11.4	6.2	3.4	9.2	1.4	19.9	4.6	5.8	0.8	4.7	1.7	5.2	1.6	6.0	1.9	12.4	0.9	97.05
0.3 - 0.5 M	0	0	1	1	1	10	13	41	15	115	26	69	5	10	0	4	0	311
(%)	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.1	0.9	0.2	0.5	0.0	0.1	0.0	0.0	0.0	2.45
0.5 - 0.7 M	0	0	0	0	0	0	0	5	4	26	5	3	0	0	0	4	0	47
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.37
0.7 - 1.0 M	0	0	0	0	0	0	0	4	0	1	1	0	0	0	0	1	0	7
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.06
1.0 - 2.0 M	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	4
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03
2.0 - 4.0 M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.0 - MAX M	0	0	1	1	0	1	2	0	0	0	0	0	0	1	0	0	0	6
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05
T O T A L	1450	781	436	1172	183	2533	600	790	120	739	245	728	210	776	243	1584	108	12698
(%)	11.4	6.2	3.4	9.2	1.4	19.9	4.7	6.2	0.9	5.8	1.9	5.7	1.7	6.1	1.9	12.5	0.9	100.00

Table 3-7 Distribution of Wave Heights

(Wave combined deepwater wave with wind wave in bay)

DATA PERIOD : 1981/ 1/ 1 - 1985/12/31

	LTO.40	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0.0 - 0.3 M	1450	781	434	1170	182	2522	584	737	101	410	139	400	122	540	145	1274	103	11094
(%)	11.4	6.2	3.4	9.2	1.4	19.9	4.6	5.8	0.8	3.2	1.1	3.2	1.0	4.3	1.1	10.0	0.8	87.37
0.3 - 0.5 M	0	0	1	1	1	10	13	41	15	185	32	113	37	122	49	237	5	862
(%)	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.1	1.5	0.3	0.9	0.3	1.0	0.4	1.9	0.0	6.79
0.5 - 0.7 M	0	0	0	0	0	0	0	5	4	20	27	72	23	39	31	51	0	272
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.6	0.2	0.3	0.2	0.4	0.0	2.14
0.7 - 1.0 M	0	0	0	0	0	0	0	4	0	38	15	63	13	50	17	11	0	211
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.5	0.1	0.4	0.1	0.1	0.0	1.66
1.0 - 2.0 M	0	0	0	0	0	0	1	3	0	85	26	64	13	17	1	6	0	216
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.2	0.5	0.1	0.1	0.0	0.0	0.0	1.70
2.0 - 4.0 M	0	0	0	0	0	0	0	0	0	1	5	16	2	7	0	3	0	34
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.27
4.0 - MAX M	0	0	1	1	0	1	2	0	0	0	1	0	0	1	0	2	0	9
(%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.07
T O T A L	1450	781	436	1172	183	2533	600	790	120	739	245	728	210	776	243	1584	108	12698
(%)	11.4	6.2	3.4	9.2	1.4	19.9	4.7	6.2	0.9	5.8	1.9	5.7	1.7	6.1	1.9	12.5	0.9	100.00

Table 3-8

Critical Conditions of Wind and Wave to Calmness

Case	Critical conditions of wind and wave to calmness
1	Wind velocity 13m/s less than & Wave hight 0.5m less than
2	Wind velocity 13m/s less than & Wave hight 0.7m less than
3	Wind velocity 13m/s less than & Wave hight 1.0m less than

Table 3-9 Calmness in Berthing Basin

Case 1

WIND-VEL : 0.0 <= M/S < 13.0
WAVE-H1/3 : 0.0 <= M < 0.5

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1981	236	224	242	240	208	240	246	248	240	248	218	154	2744
	212	190	242	239	208	230	219	166	209	230	189	142	2476
(%)	89.8	84.8	100.0	99.6	100.0	95.8	89.0	66.9	87.1	92.7	86.7	92.2	90.2
1982	250	224	248	240	216	216	232	248	236	208	120	116	2554
	250	224	248	240	216	216	230	246	236	208	120	116	2550
(%)	100.0	100.0	100.0	100.0	100.0	100.0	99.1	99.2	100.0	100.0	100.0	100.0	99.8
1983	124	112	124	120	124	120	128	124	120	124	188	248	1656
	124	112	124	120	124	120	128	124	120	124	188	248	1656
(%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1984	240	232	248	232	248	224	240	248	240	248	240	240	2880
	235	222	241	220	229	197	228	180	232	232	231	230	2677
(%)	97.9	95.7	97.2	94.8	92.3	87.9	95.0	72.6	96.7	93.5	96.2	95.8	93.0
1985	248	216	248	240	248	192	248	248	240	248	240	248	2864
	242	208	237	224	231	131	221	197	215	223	236	230	2595
(%)	97.6	96.3	95.6	93.3	93.1	68.2	89.1	79.4	89.6	89.9	98.3	92.7	90.6
TOTAL	1098	1008	1110	1072	1044	992	1094	1116	1076	1076	1006	1006	12698
	1063	956	1092	1043	1008	894	1026	913	1012	1017	964	966	11954
(%)	96.8	94.8	98.4	97.3	96.6	90.1	93.8	81.8	94.1	94.5	95.8	96.0	94.1

Case 2

WIND-VEL : 0.0 <= M/S < 13.0
WAVE-H1/3 : 0.0 <= M < 0.7

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1981	236	224	242	240	208	240	246	248	240	248	218	154	2744
	222	204	242	240	208	235	224	185	218	239	200	150	2567
(%)	94.1	91.1	100.0	100.0	100.0	97.9	91.1	74.6	90.8	96.4	91.7	97.4	93.5
1982	250	224	248	240	216	216	232	248	236	208	120	116	2554
	250	224	248	240	216	216	232	246	236	208	120	116	2552
(%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.2	100.0	100.0	100.0	100.0	99.9
1983	124	112	124	120	124	120	128	124	120	124	188	248	1656
	124	112	124	120	124	120	128	124	120	124	188	248	1656
(%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1984	240	232	248	232	248	224	240	248	240	248	240	240	2880
	240	228	246	228	240	204	232	187	236	236	237	236	2750
(%)	100.0	98.3	99.2	98.3	96.8	91.1	96.7	75.4	98.3	95.2	98.7	98.3	95.5
1985	248	216	248	240	248	192	248	248	240	248	240	248	2864
	248	216	243	234	240	137	225	211	225	230	240	244	2693
(%)	100.0	100.0	98.0	97.5	96.8	71.4	90.7	85.1	93.8	92.7	100.0	98.4	94.0
TOTAL	1098	1008	1110	1072	1044	992	1094	1116	1076	1076	1006	1006	12698
	1084	984	1103	1062	1028	912	1041	953	1035	1037	985	994	12218
(%)	98.7	97.6	99.4	99.1	98.5	91.9	95.2	85.4	96.2	96.4	97.9	98.8	96.2

(Appendix 7-1) Calculation Formula of Short-term Diffusion prediction (by Bosanquet-Sutton's formula)

1. Calculation of Coal Consumption

(1) Item (Example)

1) Generator Output Power : P_G (MW) P_G = 300

2) Plant Efficiency : p (%) p = 36.7
(Generator Output)

3) Coal Calorific Value : Hh (kcal/kg) Hh = 5,262
(Higher Calorific Value as Received)

(2) Calculation

1) Coal Consumption : Fcw (t/H)

$$\text{Wet Coal} : Fcw = \frac{P_G \times 860}{\dfrac{P}{100} \times Hh}$$

Fcw = 133.5

2. Calculation of Combustion Gas Volume

(1) Item

1) Coal

a) Carbon	: $[C_c]$ (%) (Dry)	$[C_c]$ =	64.82
b) Hydrogen	: $[h_c]$ (%) (Dry)	$[h_c]$ =	3.36
c) Oxygen	: $[O_c]$ (%) (Dry)	$[O_c]$ =	15.72
d) Total Sulfur	: $[S_c]$ (%) (Dry)	$[S_c]$ =	0.86
e) Nitrogen	: $[n_c]$ (%) (Dry)	$[n_c]$ =	1.34
f) Total Moisture	: W (%) (A.R.)	W =	19.39

2) Exhaust Gas O_2 : O_2 (%) O_2 = 5.1

(2) Calculation

1) Amount of Theoretical Combustion Air :

A_0 (Nm^3/kg - Fuel)

$$= \left\{ 8.89 \times [C] + 26.7 \left([h] - \frac{[O]}{8}\right) + 3.33 \times [S] \right\} \times \frac{100 - W}{100} \times \frac{1}{100}$$

A_0 = 4.96

2) Amount of Theoretical Combustion Gas :

G_0 (Nm^3/kg - Fuel)

$$= (0.79 \times A_0) + [\{1.867 \times [C] + 11.2 \times [h] + 0.8 \times [n] + 0.7 \times [S]\} \times \frac{100 - W}{100} + 1.244 \times W] \times \frac{1}{100}$$

G_0 = 5.45

3) Combustion Gas : G (Nm^3/kg - Fuel)

a) Wet : $G_w = G_0 + (m - 1) A_0$ — G_w = 7.05

b) Dry $G_d = G_w - \frac{0.224}{18}(9 \times h_c + W)$ — G_d = 6.43

3. Calculation of Discharge Gas Volume

(1) Item

1) Coal

a) Consumption : Fcw (t/H) — Fcw = 133.5

b) Consumption Gas: G (Nm^3/kg - Fuel)

i) Wet : G_w — G_w = 7.05

ii) Dry : G_d — G_d = 6.43

(2) Calculation

1) Discharge Gas at Boiler Outlet: Q_B (Nm^3/H)

a) Wet : $Q_{WB} = (FCW \times G_w) \times 10^3$ — $Q_{WB} = 941 \times 10^3$

b) Dry : $Q_{dB} = (FCW \times G_d) \times 10^3$ — $Q_{wd} = 858 \times 10^3$

4. Calculation of Effective Stack Height (Bosanquet's Equation)

(1) Item

1) Discharge Gas at Boiler Outlet : Q_{WB} (Nm^3/H) (wet) — $Q_{WB} = 941 \times 10^3$

2) Ambient Temperature : ta (℃) — ta = 28

3) Gas Temperature : tg (℃) — tg = 130

4) Stack Diameter : D (m) — D = 4

5) Wind Speed : U (m/s) — U = 5

6) Temperature Gradient of Atmosphere : $d\theta/dZ$(℃/m) — $d\theta/dZ$ = 0.0033

7) Actual Stack Height : H_0 (m) — H_0 = 120

(2) Calculation

1) Discharge Gas Volume :

$$Qt\ (m^3/s) = \frac{G_w\ (273 + ta)}{3{,}600 \times 273}$$

Qt = 288

2) Gas Speed :

$$Vg\ (m/s) = \frac{Q_w\ (273 + tg)}{3{,}600 \times 273 \times \frac{\pi D^2}{4}} \qquad Vg = 30.7$$

3) Inertia Height : Hm (m)

$$Hm = \frac{4.77}{1 + \frac{0.43 \times U}{Vg}} \times \frac{\sqrt{Qt \times Vg}}{U}$$

$$Hm = \frac{0.795\ \sqrt{Qt \times Vg}}{1 + \frac{2.58}{Vg}} \qquad Hm = 83.8$$

4) Buoyant Height : Ht (m)

$$Ht = 6.37 \times g \times \frac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \left(\ell n\ J^2 + \frac{2}{J} - 2 \right)$$

$$Ht = 2.01 \times 10^{-3} \times Qt\ (tg - 28) \times$$

$$\left(2.3\ \log J + \frac{1}{J} - 1\right) \qquad Ht = 148.0$$

$$J = \frac{U^2}{\sqrt{Qt \times Vg}} \left(0.43 \sqrt{\frac{(273 + ta)}{g(d\theta/dZ)}} - 0.28\ \frac{Vg\ (273 + ta)}{g\ (ta - ta)} \right) + 1$$

$$J = \frac{1}{\sqrt{Qt \cdot Vg}} \left(1{,}460 - \frac{296 \times Vg}{tg - 15} \right) + 1 \qquad J = 11.33$$

5) Effective Stack Height :

$$He\ (m) = Ho + 0.65\ (Hm + Ht) \qquad He = 270$$

5. Calculation of Volume of Discharged Smoke and Soot

(1) Item

1)	Coal Consumption	: Fcw (t/H)(Wet)	Fcw = 133.5
2)	Coal Sulfur	: [Sc] (%)(Dry)	[Sc] = 0.86
3)	Coal Ash	: [Ac] (%)(Dry)	[Ac] = 13.87
4)	Discharge Gas at Stack Outlet	: Q_{dB} (Nm^3/H)(Dry)	$Q_{dB} = 858 \times 10^3$
5)	Effective Stack Height	: He (m)	He = 270
6)	Exhaust Gas O_2	: O_2 (%)	O_2 = 5.1

7) Dust Concentration at Boiler Outlet

d'c (g/Nm^3) d'c = 18.1

$$d'c = \frac{Fcw \times [Ac] \times (1-0.2) \times 1.05}{\frac{Qd}{10^3}} \times 10$$

8) Efficiency of EP : EP (%) D = 99.0

(2) Calculation

1) Sox Discharge (Nm^3/H)

Boiler Outlet : $q' = 7 (Fcw \times [Sc])$ q' = 803

2) Sox Discharge Concentration :

$$qc\ (ppm) = \frac{q'}{Qd} \times 10^6$$ qc = 936

3) Nox Concentration : [NOx] (ppm at O_2 6%) [NOx] = 550

4) Dust Concentration : dc" (mg/Nm^3)

Ep Outlet : $dc'' = dc' \times \frac{100 - Ep}{100}$ dc" = 181

6. Diffusion Calculation (Sutton's Equation)

(1) Item

1)	Volume of Discharged Smoke and Soot	: $q (Nm^3/H)$	q = (SOx) 803
2)	Volume of Discharged Smoke and Soot	: $qt (m^3/s$ at 28℃)	qt = —
3)	Diffusion Parameter on Y Axis	: σy (m)	σy = —
4)	Diffusion Parameter on Z Axis	: σz (m)	σz = —
5)	Distance along X Axis	: X (km)	X = 10
6)	Distance along Y Axis	: Y (km)	Y = —
7)	Wind Speed	: U (m/s)	U = 5
8)	Ambient Temperature	: ta (℃)	ta = 28
9)	Effective Stack Height	: He (m)	He = 270

(2) Calculation

1) Ground Concentration :

$$C(x.y) = \frac{qt}{\pi \cdot \sigma y \cdot \sigma z \cdot U} \cdot \exp\left(\frac{y^2}{2 \cdot \sigma y^2}\right) \cdot \exp\left(-\frac{He^2}{2\sigma z^2}\right)$$

Where,

$$\sigma y^2 = \frac{Cy^2 \cdot x^{2-2}}{2}, \qquad \sigma z^2 = \frac{Cz^2 \cdot x^{2-n}}{2}$$

$$C(x) = \frac{2 \times qt \times K}{\pi \cdot Cy \cdot Cz \cdot U \cdot x^{2-n}} \times \exp\left(-\frac{He^2}{Cz^2 \cdot x^{2-n}}\right)$$

Where, ta = 28℃, Cy = Cz = 0.07, U = 5, n= 0.25

$$C(x) = (3 \text{ minutes value ppm}) = \frac{q \cdot K}{28.0 \cdot x^{1.75}} \cdot \exp\left(-\frac{He^2}{871 \cdot x^{1.75}}\right)$$

Where, Correction Factor from 3 minutes to 60 minutes K = 0.15 (K = 1, at 3 minutes value)

$K = km \times K_L$

km: meade Correction Factor (0.61)

K_L: Lowry Correction Factor (0.25)

$km = T^{-0.17}$

C(x) (Hourly Value ppm)

$$= \frac{q}{186.7 \cdot x^{1.75}} \exp\left(-\frac{He^2}{871 \cdot x^{1.75}}\right) \qquad C(x) = 0.02165$$

2) Maximum Ground Concentration

$$C_{max}\ (ppm) = \frac{2 \times qt \times K}{\pi \cdot e \cdot U \cdot He^2} \times \frac{Cz}{Cy} \times 10^6$$

Where, Cy = Cz = 0.07

ta = 28

U = 5

K = 0.15

$$C_{(max)}\ (\text{Hourly Value ppm}) = 1.72 \times \frac{q}{He^2} \qquad C_{max} = 0.02370$$

3) Maximum Ground Concentration Distance : X_{max} (km)

$$X_{max} = \left(\frac{He}{Cz}\right)^{\frac{n}{2-n}} \times 10^{-3}$$

Where, $C_z = 0.07$

$n = 0.25$

$X_{max} = 20.8 \times He^{1.149} \times 10^{-3}$ $X_{max} = 12.5$

(Appendix 7-2) Calculation Results of Short-term Diffusion Prediction.
(by Bosanquet-Sutton's Formula)

1. Ground Level Concentration and Downwind Distance.

The following table shows the calculation results on the ground level concentration at every 1 km downwind distance from the plume centerline which is referring to "Figure 7.4-2 Ground Level Concentration Curve (Hourly Average)" on page 7-41.

Table Ground Level Concentration (Hourly Value)

Distance (km)	SOx (ppm)		NOx (ppm)		Dust (mg/m3)	
	1 unit operation	2 units operation	1 unit operation	2 units operation	1 unit operation	2 units operation
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0.00029	0	0.00018	0	0.00005	0
5	0.00216	0.00011	0.00134	0.00007	0.00037	0.00002
6	0.00616	0.00090	0.00384	0.00056	0.00108	0.00015
7	0.01113	0.00302	0.00693	0.00188	0.00194	0.00052
8	0.01571	0.00647	0.00978	0.00402	0.00275	0.00113
9	0.01926	0.01064	0.01199	0.00662	0.00337	0.00186
10	0.02165	0.01485	0.01348	0.00925	0.00379	0.00260
11	0.02303	0.01862	0.01434	0.01159	0.00403	0.00326
12	0.02362	0.02171	0.01471	0.01352	0.00413	0.00380
13	0.02365	0.02407	0.01473	0.01498	0.00414	0.00421
14	0.02329	0.02573	0.01450	0.01602	0.00407	0.00450
15	0.02268	0.02680	0.01412	0.01668	0.00397	0.00469
16	0.02190	0.02738	0.01363	0.01705	0.00383	0.00479
17	0.02104	0.02757	0.01310	0.01717	0.00368	0.00482
18	0.02013	0.02746	0.01253	0.01710	0.00352	0.00480
19	0.01921	0.02714	0.01196	0.01689	0.00336	0.00475
20	0.01831	0.02664	0.01140	0.01659	0.0032	0.00466

2. Ground Level Concentration and Wind Speed, Actual Stack Height.

The following figures show the relation on NOx and Dust ground level concentration against wind speed and actual stack height which are referring to the "Figure 7.3-6 SOx Ground Concentration and Wind Speed, Actual Stack Height" on page 7-23.

Fig. NO_X Ground Concentration and Wind Speed, Actual Stack Height

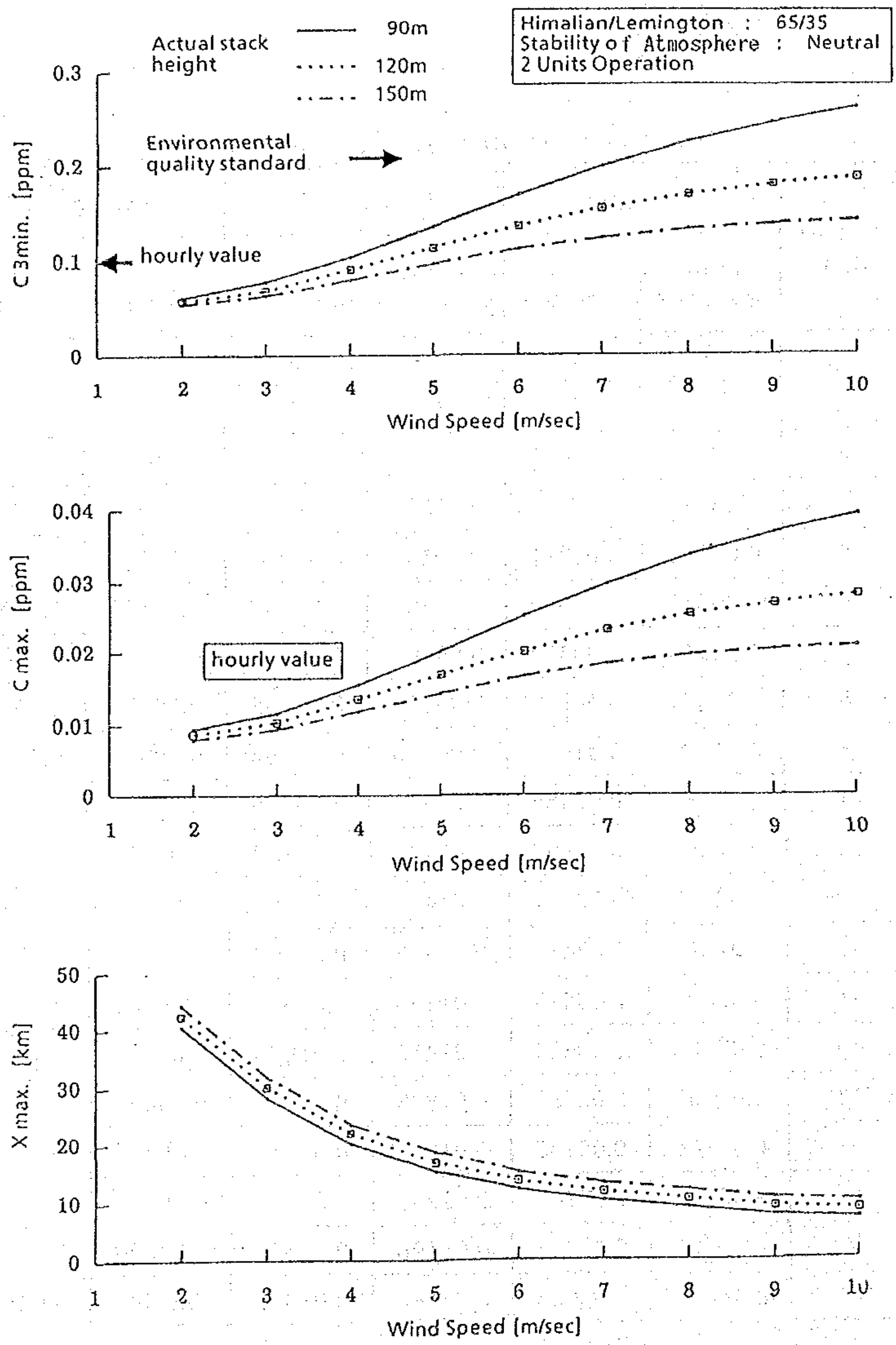
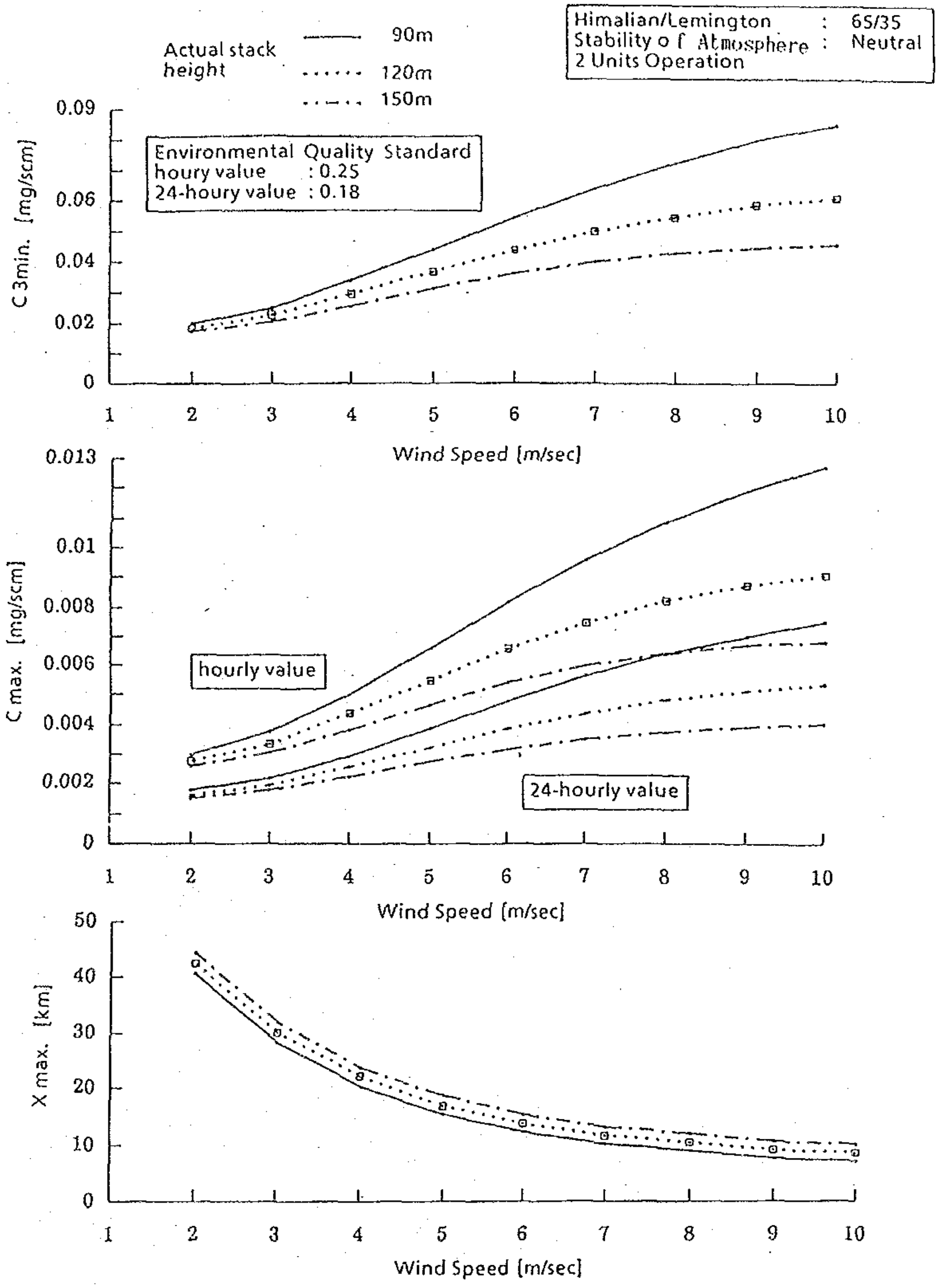


Fig. Dust Ground Concentration and Wind Speed, Actual Stack Height



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