A MODEL OF LONGSHORE SEDIMENT TRANSPORT ESTIMATION FOR KRUENG ACEH URGENT FLOOD CONTROL PROJECT IN INDONESIA

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By

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A Thesis Submitted to the School of Graduate Studies
in Partial Fulfilment of the Requirements for
the Degree of Master of Engineering

FACULTY OF ENGINEERING AND APPLIED SCIENCE
MEMORIAL UNIVERSITY OF NEWFOUNDLAND

APRIL, 1994

ST JOHN'S NEWFOUNDLAND CANADA

ISBN 0-315-91602-8

To :

My mother Ny. Siti Nasroh

My wife Nurlela

My son Adhi Wibowo

My daughter Ratna Pratiwi

Abstract

The objective of this study is to find a suitable model for predicting longshore sediment transport rate for Krueng Aceh Urgent Flood Control Project in Indonesia. Black Box approach was used in the study by employing the U. S. Army CERC-formula. To employ the CERC-formula, wave properties i. e., wave height, wave period and wave direction are required as data input. For longshore sediment transport estimation, a K-value of 0.39 was used since $H_{1/3}$ and $T_{1/3}$ were used in the study. Estimated longshore sediment transport was, then, compared to actual sediment trapped at the jetty which is in the study site. To estimate the volume of sediment trapped during periods of study, three cross sectional surveys were conducted. The first survey was in May 1992, second was in May 1993, and the last one was in August 1993.

Three procedures in estimating wave properties were tried. First, wind speed and direction at the study site(Alue Naga station) were estimated using wind data of another station(Blang Bintang station) employing vector regression analysis. Since the vector correlation coefficients were found to be very low, the procedure was not continued. Second, linear regression was used to estimate monthly average wind speeds at Alue Naga using data of Blang Bintang. Using monthly average wind speed data, the correlation coefficient of these stations was quite good. The procedure was continued to predict wave data from estimated wind speed. Third, the available wave data of a previous period were used, since the wind climate of this period and the period of study are almost identical.

The study revealed that using wave properties from hindcasting yield over estimated longshore sediment transport. While, using wave properties from available data yield estimated longshore sediment transport which is close to those observed.

Acknowledgements

The author would like to express sincere gratitude to Dr. Gary Sabin for his intensive guidance, advice, support and encouragement during the preparation until the completion of this thesis.

Acknowledgement is also extended to the Government of Indonesia, the Canadian International Development Agency(CIDA) for providing financial support, and Memorial University of Newfoundland which makes this research possible.

Further, the author would like to thank Dr. Leonard Lye, P. Eng. for his role as the Project Leader of the CIDA/DPU Professional Development Project, Memorial University of Newfoundland, and for his advice on data analysis.

I would like also to thank to Dr. James Sharp who provided me some reading materials related to my thesis.

Finally, special thanks to my wife Nurlela, my son Adhi Wibowo and my daughter Ratna Pratiwi for their moral support and their patience during my study in Canada.

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List of Symbols

A_j	:the area of section j of the first survey
A_j'	:the area of section j of the second survey
C	:a constant
D_{90}	:the sediment size for which 90% of the sample is smaller in size
E	:the wave energy
E_b	:the wave energy at the breaker line
F	:the fetch
H	:the wave height
H_b	:the wave height at the breaker line
H_i	:the height of incoming wave
H_o	:the wave height at deep water
H_p	:the mean of one-p^{th} wave height data
H_r	:the wave height of rank-r in the ordered wave height data
$H_s = H_{1/3}$	:the significant wave height
$\hat{H}$	:a specific wave height
H_{rms}	:root-mean-square of wave height data
H_1	:the mean of wave height data
I_{ls}	:the immersed weight of longshore sediment transport
K	:the coefficient of proportionality
K•	:the modified coefficient of proportionality
K_e	:the coefficient of wave energy reduction
K_f	:the coefficient of wave energy reduction due to friction
L	:the wave lengtn

L_b	:the wave length at the breaker line
L_o	:the wave length at deep water
L_j	:the distance between sections j and (j+1) in sediment volume calculation
N	:the total number of wave height data in statistical analysis of wave height
P_{ls}	:the longshore component of wave energy evaluated at the breaker line
$P(H > \hat{H})$	:the probability of $H > \hat{H}$ in statistical analysis of wave height
Q_s	:the rate of longshore sediment transport in force unit per unit of time
Q_s'	:the rate of longshore sediment transport in mass unit per unit of time
Q_v	:the rate of longshore sediment transport in volume unit per unit of time
Q_{v^*}	:modification of the rate of longshore sediment transport in volume unit
R	:rotation matrix in vector regression analysis
R_e	:Reynolds number
R_T	:the wind speed correction factor due to temperature difference
R_{vw}	:Court's correlation coefficient of vectors **V** and **W**
S	:slope in the direction of sediment movement
S_{xy}	:longshore component of radiation stress
T	:the wave period
T_p	:the period of the peak wave
$T_{1/3}$	:the significant wave period
U	:corrected wind speed
U_a	:adjusted wind speed
U_b	:sea current velocity
U_f	:the fastest mile wind speed
U_t	:the wind speed of duration t
$\bar{U}$	:advection velocity
U(z)	:the wind speed at elevation z
U(10)	:the wind speed at 10 m elevation
$U_{3,600}$	:the wind speed of duration one-hour
U_*	:friction velocity

V	:the volume change of sediment within inter survey
$\overline{V}$	:vector **V**
$\overline{W}$	:vector **W**
a	:stretching factor in vector regression analysis
a'	:solid content of one unit volume of sediment
b	:the thickness of moving sediment
d	:the base level used in sediment volume calculation
c	:the wave celerity(=velocity)
c_g	:the wave group velocity
c_o	:the wave velocity at deep water
c_{gb}	:the wave group velocity at the breaker line
c_{gi}	:the wave group velocity of incoming wave
e_i	:the elevation of point i of cross section data
f	:the sea bottom friction factor
$f(x_{old})$	:function x evaluated at x_{old}
$f'(x_{old})$	:the first derivative of function x evaluated at x_{old}
g	:the gravitational acceleration
h	:the water depth
k	:sediment grain roughness
k_e	:Kamphuis sand grain roughness
k_o	:the wave number at deep water
l_i	:the distance between points i and (i+1) of cross section data
m	:the beach slope
m_D	:the scale effect due to scaling sediment size
$m_{\rho s}$	:the scale effect due to scaling sediment density
n	:the ratio of wave group velocity to wave phase velocity
n_s	:the number of sample in wave statistics
p	:any values less or equal than one
r	:the rank of data

r_{vw}	:Durst's correlation coefficient of vectors **V** and **W**
t	:time duration
$\overline{u}$	:vector of translation in vector regression analysis
x_b	:the width of surf zone
x_{new}, x_{old}	:the values of x in the iteration process of Newton's method
z	:the vertical distance refer to a certain datum
α_o	:the angle of wave direction to the normal of the shoreline at deep water
α_b	:the angle of wave direction to the normal of the shoreline at the breaker line
ζ_b	:wave amplitude at the sea bottom
η	:sediment porosity
η_g	:geometrical factor
κ	:the ratio of the wave height to water depth at the breaker line
ν	:the kinematic viscosity
ξ_b	:the surf similarity parameter
ρ	:the sea water density
ρ_s	:the sediment density
ϕ	:a function

Chapter 1

Introduction

1.1. Background

It is common in engineering practices that any solution of a problem can create other problems, or may need measures to maintain the objective of the solution. In the Krueng Aceh Urgent Flood Control Project(KAUFCP), which is located in Aceh Province, in Indonesia, one important construction work is a floodway canal(see Figure 1.1 and 1.2). It has a total length of about 11 km., and runs northward to the Malacca Strait. The floodway canal's function is to convey excess water, which is diverted to the sea. At about 4 km. upstream of the floodway outlet, a barrage was built to protect the surrounding area from salt intrusion.

As the main purpose of KAUFCP is for flood protection, the performance of the floodway canal, to meet its function, is essential. During design stage of the project, a river mouth study included the proposed outlet of the floodway canal. This was carried out by Pacific Consultants International(PCI), Japan, but no detailed study about

Figure 1.1. A Map of Indonesia

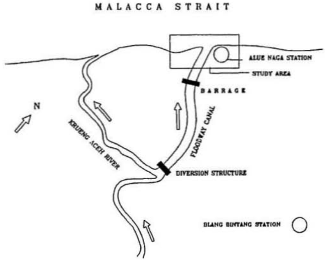

Figure 1.2. The Lay Out of Study Area

coastal preservation(PCI[1], 1982) was included. The study suggested to conduct a further investigation involving an additional survey. This second study about the Floodway Estuary(PCI[2], 1982) concluded that no special treatment is required to maintain the floodway canal's normal performance.

Later, after the floodway canal was completed, there was a sand bar formation just at the outlet of the floodway canal. The presence of the sand bar caused flow-capacity reduction. Based on such a situation, an additional coastal survey and study was conducted. This study(PCI, 1991) concluded that to avoid clogging at the outlet of floodway by sand bars, it is urgently required that a jetty be constructed. The jetty construction was completed in 1992, and the clogging problem seems, for the time being, solved.

1.2. Objective of the Thesis

After the completion of the jetty construction, there are alternating changes of sedimentation and erosion in the updrift and downdrift of the jetty. Since the existing Krueng Aceh river mouth turns to the right(East), it is expected that dominant sediment transport should move to the East as well.

In the long term, sediment deposition will be enough to alter the morphology in the study area. This may create problems such as another floodway canal outlet being clogged and eroded in the downdrift of the jetty.

To know such phenomena, periodic cross sectional surveys at the study area will provide a good indication. Since automatic instruments for measuring the sea bottom are still not available, such a survey usually employs conventional survey equipment. For measuring of the sea bottom a procedure called "wading" is commonly used. However, this procedure is only possible if the water is not to deep, sea current is not too strong and also the waves are not too high. Therefore, if another method of prediction is available, it will be beneficial.

This study is devoted to find a model to predict the sediment transport rate using wind or wave data. The model employs the CERC-formula which requires wave data as input. To have wave data, three different procedures were tried and compared. Estimated longshore sediment transport was, then, compared to actual sediment trapped at the jetty which is in the study site. To estimate the volume of sediment trapped during periods of study, three cross sectional surveys were conducted. The first survey was in May 1992, second was in May 1993, and the last one was in August 1993.

In this study, the comparison of the theories with field data is based on the assumption that all transported sediment are captured by the jetty. The jetty was designed so that the depth of water at the end of the jetty is too deep for the wave orbital motion to initiate the sediment movement at the sea bottom(see PCI, 1991).

1.3 Available Data

Climatological records of 10 years of the Blang Bintang climatological station are available. The data are daily data which consists of:

1). Average temperature in °C

2). Maximum temperature in °C

3). Rainfall intensity in mm

4). Solar radiation in %

5). Average barometric pressure in mb

6). Average wind velocity in knots, and its associated direction

7). Maximum wind velocity in knots, and its associated direction

8). Relative humidity in %

Some wind direction data are tabulated in compass direction like S for South, W for West, SE for South East etc., while the others are recorded in degrees measured clockwise from the North.

From Alue Naga station, which was temporarily set up, one year of records of maximum daily wind velocity, average daily wind velocity and their associated direction, and half-daily wave height and period are available. The data of wind started on July 1st, 1990, and ended on June 30st, 1991, and the data of waves from June 1st, 1990 to May 31st, 1991.

The data of sand grain size distribution for this area are available. The data were obtained from 309 samples of 500-1,000 grams each, taken along the coast of the study area. Each sample was analyzed to find out the diameter size distribution in term of D25, D50, and D75.

The changes of sediment volume in the updrift and downdrift of the jetty was measured two times, the first was in the period of May 1992 to May 1993, and the second was from May 1993 to August 1993. The measurement was conducted using 14 cross sections, 7 sections in the updrift and the other 7 sections in the downdrift. The distance between two sections is in the range of 44 meters to 70 meters. Along each section, the points of measurement are at a distance of about 10 meters. The cross sectional survey was carried out using a level, staff gauges and measuring tapes.

Chapter 2

Description of the Study Area

2.1. Location of the Study Area

The study area is located 15 kilometres North-East of the capital city of Aceh Province. It is a lowland part of Krueng Aceh river basin, and covers a length of about 1 kilometre updrift and downdrift of the jetty construction.

There are two jetties, one jetty was built as a continuation of the left bank of floodway canal, while the other one was constructed of the right bank of the canal. Both of them run through the sea perpendicular to the coastline, parallel to the canal direction, and end at 110 meters from the coastline. The width of the jetties, at their foundation is 30 meters, and 4 meters at their top.

Alue Naga climatological station, which was set up temporarily is located at the adjacent of floodway outlet. It recorded 1 year data for supporting the study of floodway canal preservation.

Blang Bintang climatological station which is owned by the Central Government of Indonesia, is located at about 25 kilometres South-East of the former station, and it is a permanent station. Therefore, in the future, the availability of data from this station will be guaranteed.

Generally, the study area is a flat land interrupted by some reliefs in the Eastern part of Krueng Aceh River. Adjacent to the outlet, there is a village and quite a large fish pond.

2.2 Climate

In the study area, rainfall takes place almost all year long, so it can be said that there is no clear separation between dry and wet seasons. A period of heavy rainfall takes place between October and January, and the peak is between April and May. The variation of annual rainfall is in the range of 1,500 to 3,000 mm with a high value at the mountainous area. The number of raindays is from 90 to 110 days.

The mean annual temperature measured at sea level is 26.2 °C with a monthly variation of less than 2.5 °C, and the mean annual relative humidity is in the range of 74% to 84%. The average monthly variation of relative humidity is 9%. At the Blang Bintang climatological station, the mean annual wind velocity is 2.8 m/s, and the mean of maximum wind velocity is 9.6 m/s. The variation of climate during one year is shown in Table 2.1.

Table 2.1. The Climate in the Study Area

Month	Rainfall (mm)	Raindays (day)	Temperature (°C)	Relative Humidity (%)	Sun shine Duration (%)
JAN	159	8	24.5	82	52
FEB	113	6	25.0	81	59
MAR	132	8	25.1	82	55
APR	149	10	25.5	82	54
MAY	128	9	25.7	80	55
JUN	79	6	26.3	74	53
JUL	60	6	26.0	73	56
AUG	93	7	26.4	71	53
SEP	135	9	25.9	74	47
OCT	174	11	25.2	80	42
NOV	210	12	24.6	84	43
DEC	208	11	24.3	85	45

2.3 Geomorphology

Along the Krueng Aceh River starting at 45 kilometres measured from its estuary, the Krueng Aceh River alluvial plain was formed. It has an average width of about 16 kilometres. The plain mainly consists of sands and clays with minor gravel formed in layers as a result of geological sedimentation. Between those layers, there is a thin layer of volcanic tuffs and ashes. The alluvial plain which has a fan-shape was created in the Quartennary and recent sediments

The Alue Naga beach, where the study is focused, is a part of the northmost tip of the Krueng Aceh River plain. The area lies as a part of the north boundary of the plain. The beach mainly consists of fine sands.

Chapter 3

Literature Review

3.1. Models of Longshore Sediment Transport

Models of longshore sediment transport are used to estimate the quantity of sediment transported by wave action. By this estimation, the possible erosion or sedimentation of coastline as well as the failure of coastal structures can be predicted before they happen. However, such predictions are not that easy because of the nature of the wave properties employed in the predicting formula which vary over time and space.

Generally, models of longshore sediment transport can be categorized into two groups, a physical model and a black box model. Since the 1970s, the study of longshore sediment transport by the physical model approach has been more intensive. The reason for this emphasis was to address the lack of available physical models since most models used the black box approach. In 1977, NSTS(The Nearshore Sediment Transport Study) Programme in the United States was established with the task to manage the research activities(see R. J. Seymor and D. B. Duane, 1978). This programme was intended to determine how longshore sediment transport is influenced by factors, such as, tidal current, wind stress, the change of beach contours, on-offshore transport. However, there is still no great success because of the difficulties to link those factors to longshore sediment transport. Even in the laboratory flume, with a very accurate measuring device, the prediction of longshore sediment transport is also not satisfying.

Considering the fact that no satisfactory physical model has yet to be developed, many researchers still use black box models. The concept of a black box model is to relate the input and the output without considering the process in the model. In longshore sediment transport study, the input is a forcing function which are waves and current, and the output is a response function which is the transported sediment.

3.2. Black Box Model Developed by Kamphuis and Readshaw

In modelling longshore sediment transport, the same as other models, the factors that most likely govern the process should be known first. Kamphuis and Readshaw(1978) suggest that longshore sediment transport rate is generally a function of sea water properties, wave properties and beach shape properties including sediments. This function is mathematically expressed as:

$$Q_s' = f(\mu, \rho, g, H, T, \alpha, \rho_s, D, t, \eta_s) \tag{3.1}$$

Dimensional analysis of this function leads to the following relationship:

$$\frac{Q_s'}{\rho H_b^{2.5} g^{0.5} \sin 2\alpha_b} = m_{\rho_s} m_D \phi \left(Re, \frac{H}{L_o}, \frac{t}{T}, \eta_g\right) \tag{3.2}$$

where, Q_s' :sediment transport rate in mass unit(kg/s),

ρ :the sea water density(kg/m^3),

H_b :the wave height at the breaker line(m),

g :the gravitational acceleration(m/s^2),

α_b :the angle of wave direction to the normal of shore line at the breaker line(^{0}),

$m_{\rho s}$:the scale effect due to scaling sediment density(non dim.),

m_D :the scale effect due to scaling sediment size(non dim.),

ϕ :a function,

Re :Reynolds number(non dim.),

$$Re = \frac{\pi H^2}{\nu T} \tag{3.3}$$

ν :the kinematic viscosity(m^2/s),

t :time(s),

T :the wave period(s),

η_g :geometrical factor(non dim.).

From the experiment in the laboratory flume, Kamphuis and Readshaw provided some conclusions:

1. The breaker type which is determined by the length of beach step, the energy dissipation rate, and beach shape each has a strong relationship with longshore sediment transport.
2. The CERC(Coastal Engineering Research Center) formula developed in the United States is good for the breaking waves which are plunging or surging types. For other type of breaking waves, they suggest to consider the value of surf similarity parameter, ξ_b.

Galvin(1968) developed a good prediction for the type of breaking waves by looking at the value of $H_o/L_o\, m^2$, where H_o is the wave height at deep water, L_o is the wave length at deep water and m is the beach slope. The type for breaking waves for different value of $H_o/L_o\, m^2$ is provided in Table 3.1

Table 3.1. The Types of Breaking Waves.

$H_o/L_o\, m^2$	Type of Breaking Waves
< 0.1	surging-collapsing
≥ 0.1 and < 7	plunging
≥ 7	spilling

The surf similarity parameter, ξ_b is defined as:

$$\xi_b = \frac{m}{\sqrt{\frac{H_b}{L_o}}} \tag{3.4}$$

where, m :the beach slope which depends on the beach profile(non dim.),

H_b :the wave height at the breaker line(m),

L_o :the wave length at deep water(m).

3.3. CERC Formula

The approach used by this formula is a black box model approach. The estimation of longshore sediment transport rate is performed by relating such transport to the longshore component of the wave energy evaluated at the breaker line. Such a relationship is given as:

$$Q_s = K \; P_{l_s} \tag{3.5}$$

where, Q_s :the rate of longshore sediment transport(Newton/s),

K :the coefficient of proportionality(non dim.),

P_{ls} :the longshore component of wave energy evaluated at the breaker line(Newton/s).

A detailed discussion of this equation is given in Chapter 4.

3.4. The Results of Previous Studies

Many studies of longshore sediment transport were conducted either in the laboratory flume or in the field. In the laboratory, there have been experiments to deal with quantifying littoral transport rate. By evaluating the concentration of dyed sand injected at a given point at different time and space, an estimate of the transport rate can be obtained. The techniques of sand tagging was introduced by several researchers, Teleki(1966), Yasso(1966), and Ingle(1966). Farinato and Kraus(1981) developed a spectrofluorometric by which sand tracer concentration can be measured.

Komar and Inman(1970) introduced a method called the spatial integration method which is employed to estimate the advection velocity of sediment. The procedure is to inject sand tracer across the beach at a fixed position, then, after a period of time, a grid sampling is conducted at the down drift of the injection point. At each point of sampling, the concentration of sand tracer is counted. By looking at the spatial distribution of sand tracer concentration, the average advection velocity, $\overline{U}$, can be obtained. The sediment transport rate in unit of volume, then, may be obtained as:

$$Q_v = \overline{U} \cdot x_b \cdot b \tag{3.6}$$

where, Q_v :longshore sediment transport rate in unit of volume(m^3/s),

$\bar{U}$:advection velocity of moving(m/s),

x_b :the width of surf zone(the zone between breaker line and shore line) (m),

b :the thickness of moving sediment(m).

Knoth and Nummedal(1977) used the techniques called time integration method for obtaining advection velocity, $\bar{U}$. This method is similar with the previous one, it also employs sand tracer injection at a given point. The injection is performed several times. At another fixed point down drift of the injection point, the time when the peak concentration passed is recorded. The advection velocity, $\bar{U}$, is the average velocity of the peak concentration passed. Sometimes, however, one sand tracer injection gives more than one peak concentration which causes an evaluation problem.

To avoid this problem, many studies evaluate the rate of longshore sediment transport by looking at the volume change over time of sediment trapped at coastal structures. These structures may be jetties, breakwaters or others.

Watts(1953) evaluated the sediment trapped by a jetty on the east coast of Florida. Longshore sediment transport was estimated based on the quantity of sediment pumped from a bypassing plant at that area. Wave heights and wave periods were recorded at 4-hour intervals from a wave gauge 10 miles from the study area, and this was considered as the wave properties of deep water. The wave direction at the breaker line was observed by eyesight 3.5 miles north of the study area. For a certain period of time, the relation between longshore sediment transport, Q_s(data from bypassing plant) and the longshore component of energy, P_{ls} can be obtained.

Caldwell(1956) studied erosion rate at the down drift of a jetty at a California beach. Twenty one cross sections with a distance of 500 ft. between sections was measured within a 2-3 months period. The change of volume was computed by the measured change of cross sections. Wave properties data was recorded by wave gauge erected 6 miles from the study area. The data of wave direction at the breaker line was obtained by hindcasting from the deep water data.

R. G. Dean *et. al.*(1982) studied the accumulation of sediment at the up drift of a break water at Santa Barbara, California. Sixty three cross sections were set up, and they were measured 10 times during 18 months of observation. Eight of measurement data were used in analysis, and this provides 7 inter survey results. The survey was conducted using an electronic device, as well as for wave properties recording. The estimations of wave properties at breaker line were evaluated using linear shoaling theory. In this study, they used two relationship; first, longshore sediment transport, Q_s is related to the longshore component of the wave energy; second, longshore sediment transport, Q_s is related to the longshore component of the radiation stress, S_{xy}, which is given as:

$$S_{xy} = E\, n \sin \alpha \cos \alpha \tag{3.7}$$

where, S_{xy} :longshore component of radiation stress(Newton),

E :the wave energy(Newton),

$$E = \frac{\rho g H^2}{8} \tag{3.8}$$

H :the wave height(m),

n :the ratio of wave group velocity to the wave phase velocity(non dimensional),

$$n = \frac{1}{2}\left(1 + \frac{\frac{4\pi h}{L}}{\sinh\frac{4\pi h}{L}}\right) \tag{3.9}$$

h :the water depth(m),

L :the wave length(m),

g :the gravitational acceleration(m/s^2).

J. W. Armon and S. B. McCann(1977) developed a model to predict longshore sediment transport using hourly wind data. The data consist of 9 months of data for 10 years. The study area was located at Malpeque Bay in Prince Edward Island. The wave properties were predicted employing the equation developed by CERC-US Army(US Army CERC, 1973). During major storms, the difference between predicted wave height and recorded wave height is within 0.4 m, and the predicted wave period was almost the same as the recorded data. The wave direction was taken the same as the wind direction. By using this predicted data, longshore sediment transport rate, then, can be estimated.

In this study, Armon and McCann did not compare the predicted sediment transport to the actual one, since there was no sediment transport measurement.

3.5. Summary of Previous Studies

Most studies on longshore sediment transport are devoted to obtain the factor of proportionality, K(see Equation 3.5), after which the CERC-formula can be used to predict the sediment transport rate. However, to obtain a value for K, an initial estimate of the sediment transport rate must be known. The previous studies used many different methods to find such an estimate and the resulting K-values are shown in Table 3.2.

Although the accuracy of the CERC formula is still questionable, the application of this formula is still popular. The argument for this is the simplicity of this method, and that no other method gives a better result. However, some studies revealed that this formula should be used carefully. For example the beach factor(Kamphuis and Readshaw, 1978), and the type of wave data strongly influence the result.

Dean *et. al.*(1982) in addition to obtaining the K-value, he also obtained K_*-value which is given as:

$$K_* = I_{ls} / S_{xy} \tag{3.10}$$

where, K_* :the modified coefficient of proportionality(1/s),

I_{ls} :the immersed weight of longshore sediment transport(Newton/s),

S_{xy} :the longshore component of radiation stress(Newton), The values of K from previous studies were compiled by P. D. Komar(1991) and it can be seen in Table 3.2

Table 3.2. The value of K obtained from previous studies.

Study by	Location of study	D_{50} (mm)	No. of data sets	K
Watts(1953)	Florida	0.40	4	0.89
Caldwell(1956)	California	0.40	6	0.63
Moore & Cole(1960)	Alaska	1.00	1	0.18
	Mexico	0.60	8	0.82
Komar & Inman(1970)	California	0.18	4	0.77
	Michigan	?	8	0.42
Knoth & Nummedal(1977)	Carolina	0.18	5	0.62
Inman et. al.(1980)	California	0.20	2	0.69
Duane & James(1980)	California	0.20	1	0.81
Bruno et. al.(1981)	California	0.20	7	0.80
Dean et. al.(1982)	California	0.22	7	1.15
Dean et. al.(1982)	Virginia	0.30	3	1.00

If all data are plotted in Q_s-P_{ls} graph, the best fit of the line that represents all points is for a K-value of 0.77. In fact, the data of K-values range from 0.18 to 1.15. Bruno et. al.(1981) evaluated his data and deduced the relation between K-value and D_{50}, where D_{50} is the sediment size for which 50 % of the sample is smaller in size. K-values listed in Table 3.2. were obtained using the root-mean-square wave height. If significant wave height is used, the K-values become half of those values listed.

Chapter 4

Theoretical Background

4.1. Longshore Sediment Transport

One approach to quantify longshore sediment transport is introduced by relating such transport to longshore component of wave energy. This approach is based on physical phenomena of wave trains when they approach the beach(see Bruno *et. al.*,1981). When waves approach the beach, their period is theoretically constant but both their height and length change due to shoaling and or refraction. Their height increases while their length decreases. In other words, their wave steepness(i.e., the ratio of wave height to wave length) grows until it reaches a limiting value when the waves break. When the waves break, they exert energy and this energy causes sediment transport.

There have been studies to relate longshore sediment transport rate with wave energy flux over 1 m length of shore line. The coefficient of proportionality K is used for such relation, and this is mathematically expressed as:

$$I_{ls} = K \cdot P_{ls} \tag{4.1}$$

where I_{ls} = immersed-weight transport rate which is another definition of Q_s as shown in Equation 3.5, and it is defined as:

$$I_{ls} = (\rho_s - \rho) \cdot g \cdot a' \cdot Q_v \tag{4.2}$$

ρ_s :the density of sand(kg/m^3),

ρ :the density of sea water(kg/m^3),

g :the gravity acceleration(m/s^2),

a' :the factor of porosity where a'. Q_v represents the volume of solid(non dim.),

Q_v :the volume of transported sand included pore volume(m^3/s),

K :the coefficient of proportionality(non dim.),

P_{ls} :the longshore component of wave energy(Newton/s).

To calculate the value of I_{ls} in Equation(4.1), the values of K and P_{ls} should be known first. The actual volume of sand Q_v may be calculated by using Equation(4.2).

4.2. Longshore Component of Wave Energy

Longshore component of wave energy P_{ls} may be calculated according to *the Shore Protection Manual(1984)* as follows:

$$P_{ls} = \frac{\rho g}{16} \cdot H_b^2 \cdot c_{gb} \cdot \sin 2\alpha_b \tag{4.3}$$

where H_b :wave height at the breaker line(m),

c_{gb} :wave group celerity(m/s),

α_b :wave direction measured from the normal of shore line(^{0}).

The subscript b means that these variables(H, c_g, α) are evaluated at the breaker line. The wave height at the breaker line can be the significant wave height, the average wave height or the root mean square wave height. Equation(4.3) can also be written in terms of the wave energy evaluated at the breaker line, E_b, as:

$$P_{ls} = E_b \cdot c_{gb} \cdot \cos \alpha_b \cdot \sin \alpha_b \tag{4.4}$$

The total wave energy E_b is defined, based on small amplitude wave theory, as:

$$E_b = \frac{\rho g}{8} \cdot H_b^2 \tag{4.5}$$

Substituting Equation(4.5) into Equation(4.4) actually gives the same equation as in Equation(4.3). Taking into account the energy losses due to bottom friction and percolation(Ippen, 1966), Equation(4.4) may be modified as follows:

$$P_{ls} = K_e^2 \cdot (E \cdot c_g \cdot \cos \alpha)_l \cdot \sin \alpha_b \tag{4.6}$$

where K_e :the energy reduction coefficient(non dim.),

The subscript i refers to wave properties at the offshore site. In fact, the bottom surface is covered by mud or other fine particles, so the contribution of percolation in energy reduction can be neglected(T.L. Walton, Jr. and J. R. Weggel, 1982). If this assumption is adopted, then, the energy reduction coefficient K_e is governed by bottom friction alone. Therefore, K_e may be replaced by the energy reduction coefficient due to friction K_f. Accordingly, Equation(4.4) may be changed as:

$$P_{ls} = K_f^2 \cdot (E \cdot c_g \cdot \cos\alpha)_i \cdot \sin\alpha_b \tag{4.7}$$

Bretschneider and Reid(1954) developed an equation to calculate K_f as a function of the wave properties in deep water(H_o, α_o, k_o), water depth h, bottom slope m, and friction coefficient f. Such an equation is expressed as:

$$K_f = \left[1 + \left(\frac{f \cdot H_o}{m \cdot h}\right) (\cos\alpha_o)^{1/2}\, 0.12\, (k_o \cdot h)^{-1/4}\right]^{-1} \tag{4.8}$$

where K_f :the energy reduction coefficient due to friction(non dim.),

f :friction coefficient(non dim.),

H_o :the wave height in deep water(m),

m :the beach slope(non dim.),

h :water depth(m),

k_o :$2\pi/L_o$ = the wave number in deep water(m^{-1})

L_o :the wave length in deep water(m).

Energy reduction coefficient K_f(non dim.) as expressed in Equation(4.8) is the result of a numerical integration from deep water to a depth of h. Since longshore component of wave energy P_{ls} used in Equation(4.7) is evaluated at the breaker line, so the depth h in Equation(4.8) is the depth at the breaker line as well. Therefore, for the purpose of longshore component of wave energy calculation, Equation(4.8) may be specifically defined by using the depth at the breaker line h_b instead of h.

Singamsetti and Wind(1980) reviewed various equations for the breaking wave and found that the ratio of the breaking wave height to the breaking depth can be related in the following expression:

$$\kappa = H_b / h_b \tag{4.9}$$

$$\kappa = 1.16 \, [\, m \, (H_o/L_o)^{-1/2} \,]^{0.22} \tag{4.10}$$

If data of wave height, wave period and beach slope are available, then, the value of κ can be calculated by using Equation(4.9). Furthermore, the breaking depth h_b can be calculated if the breaking height H_b is known.

T. L. Walton, Jr. and J. R. Weggel(1991) derived an approach to calculate the breaking height H_b by using the following equation:

$$H_b = \left[\left(\frac{\kappa}{g} \right)^{1/2} \cdot K_f^2 \cdot H_i^2 \cdot C_{gi} \cdot \cos \alpha_i \right]^{0.4} \tag{4.11}$$

where H_b :the wave height at the breaker line(m),

κ :the ratio of the wave height to water depth at the breaker line(non dim.),

g :the gravitational acceleration(m/s^2),

K_f :the energy reduction coefficient due to friction(non dim.),

H_i :the height of incoming wave(m),

c_{gi} :the group celerity of incoming wave(m/s).

4.3. Friction Factor

The friction factor, f, contributes to wave damping, so it causes a decrease in wave height. Since longshore sediment transport is proportional to the square of the wave height, the greater the f-value yields a greater reduction in longshore sediment transport.

Many studies have been devoted to evaluate the value of f. Those studies suggest that the friction factor, f, is determined by relative roughness and Reynolds number, Re. For a rough turbulent boundary layer, the friction factor, f, is not influenced by Reynolds number. In other words, it is governed solely by relative roughness.

Since in nature, the wave boundary layer is always rough turbulence(I.G. Johnson, 1966), the discussion will be focused only on the friction factor under rough turbulence or on relative roughness.

Relative roughness is defined as the ratio of maximum amplitude(water excursion) at the sea bottom, ζ_b, to sediment grain roughness. From small amplitude wave theory, the maximum amplitude at the sea bottom, ζ_b, is expressed as:

$$\zeta_b = -\frac{H}{2\sinh\frac{2\pi h}{L}} \tag{4.12}$$

where ζ_b :maximum amplitude at the sea bottom at the absence of friction, f (m),

H :wave height(m),

h :water depth(m),

L :wave length(m).

Sediment grain size roughness, k, may be defined as Nikuradse sand grain roughness, and it may be obtained from the following equation,

$$\frac{U_b}{U_*} = 5.75 \log \frac{30\,z}{k}, \tag{4.13}$$

$$U_* = \sqrt{g\,h\,S}$$

where, U_b :current velocity(m/s),

U_* :friction velocity(m/s),

g :the gravitational acceleration(m/s^2),

h :water depth(m),

S :the slope in the direction of sediment movement(non dim.),

z :the vertical distance measured from the sea bottom(m),

k :sediment grain roughness(m).

For a flat bottom, J. W. Kamphuis(1975) defined sand grain roughness, k_e, given as:

$$k_e \approx 2\,D_{90} \tag{4.14}$$

where, D_{90} is the sediment size for which 90% of the sample is smaller in size. To find the friction factor, f, using sand grain roughness, k_e, Kamphuis suggested using the following equation:

$$f \approx 0.1\left[\frac{k_e}{\zeta_b}\right]^{3/4}, \qquad for\ \frac{k_e}{\zeta_b} > 0.02 \tag{4.15}$$

and

$$\frac{1}{2\sqrt{f}} + \ln\frac{1}{2\sqrt{f}} = -0.35 - \frac{4}{3}\ln\frac{k_e}{\zeta_b}, \qquad for\ \frac{k_e}{\zeta_b} < 0.02 \tag{4.16}$$

where, f :friction factor(non dim.),

k_e :Kamphuis sand grain roughness(m),

ζ_b :maximum amplitude at the bottom(m).

4.4. Theories of Wind Wave Generation

When wind blows over a body of water, there is interaction between these two fluids. Such an interaction causes instability in the interface; furthermore, water waves may be generated by this process. There have been three theories dealing with wind wave generation:

4.4.1. Theory of Resonance

A thin air layer above the interface is called the boundary layer. Because of the nature of this layer, the air moving over the interface is in a turbulent state which, then, generates pressure pulses acting on the surface of the water. These pressure pulses, containing various frequencies, will cause water waves to propagate under a certain speed(celerity). If the wind speed is not equal to the wave celerity, there will be water wave damping. On the other hand, if their speed is the same, there will be amplification of water waves. This theory was introduced by Phillips(1957).

4.4.2. Theory of Shear Flow Velocity

Miles(1957) described his theory based on modified vertical wind velocity distribution in the boundary layer. If initially a small wave appears on the water, the wind speed is greater over the crest than over the trough, so the pressure over wave crest is smaller than over trough. The pressure pushes the waves in the direction of wind, and it gives energy to the wave. This process increases the elevation difference between the wave crest and trough. In other words, the wave height increases over time. At a certain level of wave generation as explained by this theory, the interaction between them becomes non-linear.

4.4.3. Theory of Fully Arisen Wave

Some of the energy supplied by wind is dissipated in the form of wave breaking. Consider a wave with a certain frequency. The equilibrium state is achieved when energy supply is equal to energy dissipation. When this state is reached, additional energy supply will be transferred to a lower frequency wave, and this process continues successively. Therefore, the equilibrium state moves from a higher frequency to a lower frequency wave.

4.5. Prediction of Wind Generated Waves in Deep Water

Two conditions are applied in predicting wind wave generation i.e., fetch-limited and duration-limited wave generation. In the first condition, the wind blows a long enough time to fully develop the wave, but it is limited by available space(fetch); while, in the second condition, the fetch is long enough for a fully developed wave, but it is limited by duration. Therefore, in both situations, the wave is not fully developed.

Under such conditions, Hasselman *et. al.*, 1976, introduced simple parametric models for predicting wave height and period as follows,

$$\mathbf{H_s = 1.616 \cdot 10^{-2}\ U_a\ F^{1/2}} \qquad \mathbf{(4.17)}$$

$$\mathbf{T_p = 6.238 \cdot 10^{-1}\ (U_a\ F)^{1/3}} \qquad \mathbf{(4.18)}$$

$$\mathbf{t = 8.93 \cdot 10^{-1}\ (F^2/U_a)^{1/3}} \qquad \mathbf{(4.19)}$$

When a fully developed wave is achieved, Equations(4.17), (4.18) and (4.19) cannot be used. Instead, fully developed wave formulas are employed, and they are given as:

$$H_s = 2.482 \, . \, 10^{-2} \, U_a^2 \tag{4.20}$$

$$T_p = 8.30 \, . \, 10^{-1} \, U_a \tag{4.21}$$

$$t = 2.027 \, U_a \tag{4.22}$$

where, H_s :significant wave height(m),

T_p :the period of peak wave(s),

T_p is approximated as $1/0.95 \, T_{1/3}$,

F :the fetch(km),

t :the duration(hr),

U_a :adjusted wind speed(m/s).

Wind speed data can not be used right away for wave prediction. It needs corrections due to elevation, extreme velocity, stability, location effects and drag force.

a. Correction due to elevation

The standard elevation of wind speed measurement is at the 10 m level. The equations for wave prediction are also based on such standard of measurements. Therefore, if the elevation of measurement is other than standard, a correction should be employed; it is given as:

$$U(10) = U(z)\,(10/z)^{1/7} \tag{4.23}$$

where, U(10) :wind speed at 10 m level(m/s),

U(z) :wind speed at elevation z(m/s),

z :elevation of measured wind(m).

b. Correction due to extreme velocity

During a 24 hour period(1-day), if there is an extreme velocity, it is usually only in a short period i.e., less than 2 minutes(US Army Engineer, 1959). Therefore, for wave prediction, if such data is used without any correction, the result will be an overestimate. To deal with this extreme data, a procedure of wind speed adjustment should be applied.

The extreme wind speed which is also termed as fastest mile wind speed may be converted to a certain period of average wind speed such as 10, 25, 50 minutes. The duration of fastest mile wind speed can be obtained as:

$$t = 1{,}609/U_f \tag{4.24}$$

where, t :the time required to travel 1 mile(s),

U_f :the fastest mile wind speed(m/s).

To find wind average velocity, Simiu and Scanlan(1978), developed an equation of the ratio of wind speed at any duration, U_t, to the one-hour duration wind speed, $U_{3,600}$; such an equation is expressed as:

$$U_t/U_{3,600} = 1.277 + 0.296 \tanh(0.9 \log_{10} (45/t)) \quad (4.25)$$

$$\text{for } 1 < t < 3{,}600 \text{ s}$$

$$U_t/U_{3,600} = - 0.15 \log_{10} t + 1.5334 \quad (4.26)$$

$$\text{for } 3{,}600 < t < 36{,}000 \text{ s}$$

c. Correction due to stability

The stability of a boundary layer of air and sea is determined by the temperature difference between those fluids given as $\Delta T = T_a - T_s$, where T_a and T_s(in ^{0}C) are the air and sea temperature respectively. In the event that ΔT is zero, the boundary layer is in a neutral stability, and no correction of wind speed is required. If ΔT is negative, the boundary layer is unstable, and the wind speed is more effective in generating waves. If ΔT is positive, the boundary layer is stable and in this case the wind is less effective in wave generation.

If ΔT is not zero, the wind speed correction is given as:

$$U = R_T\, U(10) \quad (4.27)$$

where, U :corrected wind speed(m/s),

R_T :correction factor(non dim.),

$U(10)$:wind speed at 10 m level(m/s).

A graph to find the correction factor R_T was developed by Resio and Vincent(1977) as shown in Figure 4.1

d. Correction due to location effects

This correction is used when wind data is not available over water. It is employed because there is a difference of friction when the wind travels over land and water. Resio and Vincent(1977) found the relationship between over water and over land wind speed as given in a graph as shown in Figure 4.2

e. Correction due to wind-stress factors

The wave growth formulas are expressed in terms of wind stress factor U_a. After appropriate windspeed conversions(a - d) are made, the windspeed is converted to a wind stress factor given as,

$$U_a = 0.71\ U^{1.23} \tag{4.28}$$

where, U_a :adjusted wind speed(m/s),

U :wind speed before adjustment(m/s).

The wind stress factor accounts for the non-linear relationship between windstress and wind speed. These approximations are made to reduce biases in wind data(*Shore Protection Manual*, 1984).

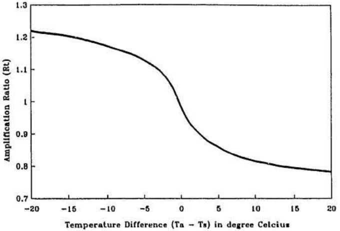

Figure 4.1. Amplification Ratio (R_t)

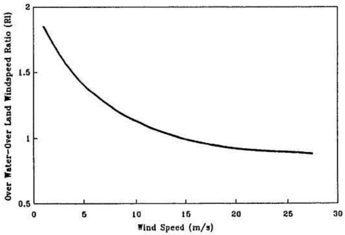

Figure 4.2. Over Water-Over Land Windspeed Ratio (R_l) (Resio & Vincent, 1977)

4.6. Vector Regression Analysis

One way to estimate a random variable from other variable(s) is by developing a model of the relationship between them. Such a model may be obtained by a procedure which is called regression analysis.

If a regression analysis is employed to relate one variable to other variables, then, a multivariate regression may be appropriate. This type of regression should fulfil a condition that those variables should be independent each other. Sometimes, such a condition can not be fulfilled, so other methods should be used.

A vector has two variables which are magnitude and direction. Most likely, the magnitude and direction of the vector representing winds are not independent. To relate two vectors, there is a method called vector regression. This regression may be used to estimate one vector from the other. Thus, they may be different in time, space or both.

Once an equation has, by regression, been established, one might want to know how good is that equation for estimation. This may be assessed by looking at the correlation coefficient or the error of the estimation to the observed data.

4.6.1. Vector regression equation

The general situation of two vectors V and W, in two dimensions, is illustrated in Figure 4.4. Each vector has its own coordinate system, so each has an x-component and y-component.

It can be said that vector V is the same as vector W, if W is rotated by an angle θ, stretched by a factor a and translated by a vector **u**(see F. Mc. Keena, 1986). This operation, in general, is written as:

$$\vec{V} = a R \vec{W} + \vec{u} \tag{4.29}$$

where, $\vec{V}$ = vector V,

$\vec{W}$ = vector W,

a = stretching factor,

R = rotation matrix,

$\vec{u}$ = vector of translation.

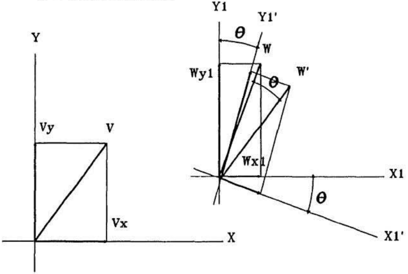

Figure 4.3. Vector Rotation and Translation

In two dimensions, the rotation matrix, R, is defined as :

$$R = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \tag{4.30}$$

For convenience, assume

$$A = aR = \begin{bmatrix} a\cos\theta & a\sin\theta \\ -a\sin\theta & a\cos\theta \end{bmatrix} = \begin{bmatrix} \alpha & \beta \\ -\beta & \alpha \end{bmatrix} \tag{4.31}$$

where α and β are $\mathbf{a.cos\theta}$ and $\mathbf{a.sin\theta}$ respectively.

Substituting matrix A into equation(4.29) gives the following matrix equation:

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} \alpha & \beta \\ -\beta & \alpha \end{bmatrix} \begin{bmatrix} W_x \\ W_y \end{bmatrix} + \begin{bmatrix} u_x \\ u_y \end{bmatrix} \tag{4.32}$$

or

$$\mathbf{V_x = u_x + \alpha\, W_x + \beta\, W_y} \tag{4.33}$$

$$\mathbf{V_y = u_y - \beta\, W_x + \alpha\, W_y} \tag{4.34}$$

If two sets of vectors V and W are available, for a constant value of u_x, u_y, α and β, the total squared error(SE) of these vectors is expressed as:

$$SE = \sum\left[(V_x - (u_x + \alpha W_x + \beta W_y))^2 + (V_y - (u_y - \beta W_x + \alpha W_y))^2 \right] \tag{4.35}$$

Minimizing the total SE can be performed by equating derivatives of SE with respect to

u_x, u_y, α, β equal to zero as follows,

$$\frac{\partial SE}{\partial u_x}=0$$

$$\sum V_x = n u_x + \sum \alpha W_x + \sum \beta W_y \tag{4.36}$$

$$\frac{\partial SE}{\partial u_y}=0$$

$$\sum V_y = n u_y - \sum \beta W_x + \sum \alpha W_y \tag{4.37}$$

$$\frac{\partial SE}{\partial \alpha}=0$$

$$\sum (V_x W_x + V_y W_y) = u_x \sum W_x + u_y \sum W_y + \alpha \sum (W_x^2 + W_y^2) \tag{4.38}$$

$$\frac{\partial SE}{\partial \beta}=0$$

$$\sum (V_x W_y - V_y W_x) = u_x \sum W_y - u_y \sum W_x + \beta \sum (W_x^2 + W_y^2) \tag{4.39}$$

Rewriting equation(4.36), (4.37), (4.38) and (4.39) in a form of matrix equation, leads to the following expression:

$$\begin{bmatrix} n & 0 & \sum W_x & \sum W_Y \\ 0 & n & \sum W_y & -\sum W_x \\ \sum W_x & \sum W_y & \sum (W_x^2+W_y^2) & 0 \\ \sum W_y & -\sum W_x & 0 & \sum (W_x^2+W_y^2) \end{bmatrix} \begin{bmatrix} u_x \\ u_y \\ \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} \sum V_x \\ \sum V_y \\ \sum (V_x W_x + V_y W_y) \\ \sum (V_x W_y - V_y W_x) \end{bmatrix} \tag{4.40}$$

Matrix equation(4.40) can be simplified as:

$$\begin{pmatrix} n & 0 & r & s \\ 0 & n & s & -r \\ r & s & t & 0 \\ s & -r & 0 & t \end{pmatrix} \begin{pmatrix} u_x \\ u_y \\ \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} \tag{4.41}$$

where, n = sample size,

$r = \sum W_x$,

$s = \sum W_y$,

$t = \sum (W_x^2 + W_y^2)$,

$a_1 = \sum V_x$,

$a_2 = \sum V_y$,

$a_3 = \sum (V_x W_x + V_y W_y)$,

$a_4 = \sum (V_x W_y - V_y W_x)$.

To find the constants u_x, u_y, α, β, in equation(4.35) can be solved by matrix operations. The results are :

$$u_x = \frac{a_1 t - (r a_3 + s a_4)}{nt - r^2 - s^2} \tag{4.42}$$

$$u_y = \frac{a_2 t + (ra_4 - sa_3)}{nt - r^2 - s^2} \tag{4.43}$$

$$\alpha = \frac{na_3 - (ra_1 + sa_2)}{nt - r^2 - s^2} \tag{4.44}$$

$$\beta = \frac{na_4 + (ra_2 - sa_1)}{nt - r^2 - s^2} \tag{4.45}$$

If equations(4.42), (4.43), (4.44), (4.45) are expanded to their original terms, then, they are rewritten as:

$$u_x = \frac{(\sum V_x)(\sum (W_x^2 + W_y^2)) - \left[(\sum W_x)(\sum (V_x W_x + V_y W_y)) + (\sum W_y)(\sum (V_x W_y - V_y W_x))\right]}{n\sum (W_x^2 + W_y^2) - (\sum W_x)^2 - (\sum W_y)^2} \tag{4.46}$$

$$u_y = \frac{(\sum V_y)(\sum (W_x^2 + W_y^2)) + \left[(\sum W_x)(\sum (V_x W_y - V_y W_x)) - (\sum W_y)(\sum (V_x W_x + V_y W_y))\right]}{n\sum (W_x^2 + W_y^2) - (\sum W_x)^2 - (\sum W_y)^2} \tag{4.47}$$

$$\alpha = \frac{n\sum (V_x W_x + V_y Wy) - (\sum W_x \sum V_x + \sum W_y \sum V_y)}{n\sum (W_x^2 + W_y^2) - (\sum W_x)^2 - (\sum W_y)^2} \tag{4.48}$$

$$\beta = \frac{n\sum (V_x W_y - V_y Wx) + (\sum W_x \sum V_y - \sum W_y \sum V_x)}{n\sum (W_x^2 + W_y^2) - (\sum W_x)^2 - (\sum W_y)^2} \tag{4.49}$$

4.6.2. Vector correlation coefficient

The relationship between two sets of vectors, whether it is good or not, can be judged by looking at their correlation coefficient. The closer the correlation coefficient to one is an indication that they have a strong relationship.

There are two ways of expressing a vector correlation coefficient. One was developed by C. S. Durst(1954) and the other was introduced by Arnold Court(1958).

Durst's correlation coefficient, r, was developed by neglecting the rotation factor. It is easy to calculate, and it provides a good indication. Durst's r is expressed as:

$$r_{VW}^2 = \frac{(\sum v_x w_x + \sum v_y w_y)^2}{(\sum v_x^2 + \sum v_y^2)\,(\sum w_x^2 + \sum w_y^2)} \tag{4.50}$$

where, r_{VW} = Durst's correlation coefficient of vector V and W,

$v_x = V_x - \overline{V_x}$

$v_y = V_y - \overline{V_y}$

$w_x = W_x - \overline{W_x}$

$w_y = W_y - \overline{W_y}$

To have a better indication of the vector relationship, one may use Court's correlation coefficient, R. It was developed by taking into account the rotation factor. However, it is more difficult to calculate this correlation coefficient. This correlation coefficient is expressed as:

$$R_{VW}^2 = \frac{s_{v_x}^2(r_{v_x w_x}^2 + r_{v_x w_y}^2 - 2r_{v_x w_x} r_{v_x w_y} r_{w_x w_y}) + s_{v_y}^2(r_{v_y w_x}^2 + r_{v_y w_y}^2 - 2r_{v_y w_x} r_{v_y w_y} r_{w_x w_y})}{(s_{v_x}^2 + s_{v_y}^2)(1 - r_{w_x w_y}^2)} \tag{4.51}$$

where, R_{vw} = Court's correlation coefficient of vector V and W,

$r_{v_x w_x}$ = correlation coefficient of v_x and w_x,

$r_{v_x w_y}$ = correlation coefficient of v_x and w_y,

$r_{v_y w_x}$ = correlation coefficient of v_y and w_x,

$r_{v_y w_y}$ = correlation coefficient of v_y and w_y,

$r_{w_x w_y}$ = correlation coefficient of w_x and w_y,

v_x, v_y, w_x, and w_y are the same as in equation(4.50).

4.7. Statistics of Waves

The waves generated in the sea have different wave properties(height, period and direction). If interaction among them is combined with refraction, reflection, damping, etc., then the variation of wave properties will become more complicated.

In engineering practice, it can be said that all planning and design related with coastal and ocean structures depend on representative wave properties. As the variation of wave direction is more certain, the discussion will be devoted to the variation of wave height and period.

4.7.1. Wave Height Distribution

The probability of a wave height, H, greater than a specific wave height, $\hat{H}$ in a wave height distribution is equal to the number of waves of height H greater than $\hat{H}$ divided by total number of waves. This is mathematically expressed as:

$$P(H>\hat{H}) = \frac{n_s}{N}, \qquad \text{for } N \rightarrow \infty \tag{4.52}$$

where, $P(H>\hat{H})$:the probability of $H>\hat{H}$,

n_s :number of $H>\hat{H}$,

N :total number of wave height data.

If the wave height is ranked from the highest order to the lowest order, the average value of pN highest data is defined as H_p which is expressed as:

$$H_p = \frac{\sum_{r=1}^{[pN]} H_r}{[pN]} \tag{4.53}$$

where, p :any positive values less or equal to one,

H_p :the mean of pN highest wave height(m),

r :the rank of data,

H_r :the wave height of rank r(m),

N :total number of wave data,

[pN] :the integer part of the number pN.

Based on the definition expressed in Equation(4.53), $H_{1/3}$ is an important wave height used in design. Munk(1944) defined $H_{1/3}$ as the significant wave height, H_s. The mean value of wave data is defined as H_1, and it is given as:

$$H_1 = \frac{\sum_{r=1}^{N} H_r}{N} \tag{4.54}$$

where, H_1 :the mean of wave height(m),

r :the rank of data,

H_r :the wave height of rank r(m),

N :total number of data.

Another important wave height is H_{rms}, which is given as:

$$H_{rms} = \sqrt{\frac{1}{N}\sum_{r=1}^{N} H_r^2} \tag{4.56}$$

where, H_{rms} :root mean square of wave height(m),

r :the rank of data,

N :total number of data.

The distribution of the probability of H greater than any given value of $\hat{H}$, is closely approximated by a Rayleigh distribution, and this is given as:

$$P(H>\hat{H}) = e^{-(\frac{\hat{H}}{H_{rms}})^2} \tag{4.57}$$

where, H :wave height(m),

$\hat{H}$:a specific wave height(m),

H_{rms} :root mean square wave height(m).

Using this distribution, the relationship between H_p and H_{rms} can mathematically be defined(see R. G. Dean and R. A. Dalrymple, 1991), and it leads to the following result,

$$\frac{H_p}{H_{rms}} = \sqrt{\ln\frac{1}{p}} + \frac{\sqrt{\pi}}{2p}\, erfc\left(\sqrt{\ln\frac{1}{p}}\right) \tag{4.58}$$

where, H_p :the mean of the pN highest wave height(m),

erfc :error function, where erfc(x) is defined as:

$$erfc(x) = \frac{2}{\sqrt{\pi}}\int_x^{\infty} \exp(-t^2)\,dt$$

From Equation(4.58), important wave heights can be found as:

$$H_{1/3} = 1.80\ H_{rms} \tag{4.59}$$

$$H_1 = 0.886\ H_{rms} \tag{4.60}$$

4.7.2. Significant Wave Period

The significant wave period may be obtained from observed data. It is likely equal to the mean of 10 to 15 successive prominent waves. It has also a value close to the average period of all waves whose crests are greater than the sea water level and whose troughs are lower than the sea water level(see Shore Protection Manual, 1984).

Chapter 5

Methodology

5.1. Quantification of Longshore Sediment Transport Rate

The most common way to estimate the longshore sediment transport quantity over a period of time is by evaluating the sediment trapped or eroded at coastal structures. In this study, two jetties, which are available in the study area, are used. Since the jetties used are relatively new structures, the change of shoreline due to sedimentation or erosion is still small. Therefore, the efficiency of trapping sediment of such structure can be expected to be reliable enough.

To measure the sediment trapped, three cross sectional surveys were performed. Each survey covers 12 cross sections, 6 cross sections are at the left side of the left jetty, and another 6 cross sections are at the right side of the right jetty(see Figure 5.1). Roughly, the distance between two successive jetties is expected to be 50 m. The actual distance, however, is in the range of 41.5 m up to 69.5 m. To locate the position of these sections, the control point of each section is linked, by a polygon, to the available

Bench Marks(BM) where their elevation and coordinates are known. Each section consists of several points. The distance between two successive points is about 10 to 20 m depending on the surface configuration. At each point, the elevation was measured referring to the BM. The elevation of each point was measured by using a level. Positioning of each section was performed by measuring the bearing angle between this section to the reference BM. To do this job, a theodolite was used. The distance between two successive points was measured using a measuring tape.

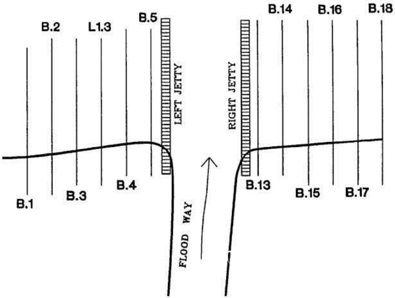

Figure 5.1. The Plan of Cross Sectional Survey

During the survey, one surveyor and four rod men were employed. Measurement of point elevation in the water was done by wading procedure. To keep the points in a straight line, the surveyor guided the rod man in placing the staff gauge. The time of the survey was selected during the low tide period and when the waves were not too high, so the error due to environmental conditions could be minimised. For the purpose of the study, the furthest section from the jetty was selected as the location where the section is relatively stable. In other words, there is no significant change in cross sectional area of this section.

To estimate the change of cross sectional area, the cross sectional area of each survey should be known first. The area of each section is calculated referring to a particular base level. The base level was chosen in a such, so that all points are above this level. The calculation of cross sectional area employs the following equation,

$$A_j = \left(\frac{e_1+e_2}{2} - d\right) \cdot l_1 + \left(\frac{e_2+e_3}{2} - d\right) \cdot l_2 + \cdots$$

$$\cdots\cdots + \left(\frac{e_{n-1}+e_n}{2} - d\right) \cdot l_{n-1} \qquad (5.1)$$

where, A_j : the cross sectional area of section $j(m^2)$,

e_i : the elevation of point $i(m)$,

d : the base level(m),

l_i : the distance between point i and point (i+1) (m).

Once cross sectional area data of each section for each survey obtained namely A_j, A_j', and A_j'', the change of cross sectional area of each inter survey of each section can be found as (A_j'-A_j) and (A_j''-A_j'). The notation of A_j' and A_j'' represent the cross sectional area of the second and the third surveys respectively.

The volume change of each inter survey period may be obtained as:

$$V = \left[\frac{A_1' - A_1 + A_2' - A_2}{2}\right] \cdot L_1 + \left[\frac{A_2' - A_2 + A_3' - A_3}{2}\right] \cdot L_2 + \dots\dots\dots$$

$$\dots\dots\dots\dots + \left[\frac{A_{n-1}' - A_{n-1} + A_n' - A_n}{2}\right] \cdot L_{n-1} \qquad (5.2)$$

where, V : the volume change within inter survey(m^3),

A_j : the area of section j of the first survey(m^2),

A_j' : the area of section j of the second survey(m^2),

L_j : the distance between section j and section (j+1) (m).

Since three surveys were conducted, two volume changes are available in this study.

5.2. Longshore Transport Energy Calculation

Longshore transport energy can be obtained if wave data are available. Such data includes wave height, period, and direction. For the purpose of the study, wave data in the period May 4th, 1992 to August 18th, 1993 are needed. This period coincides with the period of cross sectional survey. Unfortunately, the available wave data were obtained within the period of June 1st, 1990 to May 31st, 1991. To overcome such a shortage of data, wave hindcasting was conducted using wind speed data.

In the period July 1st, 1990 to June 30th, 1991, wind data are available. It consists of daily wind speed and wind direction. This data were recorded by a temporary meteorological station named Alue Naga station. At about 25 kms. south east of Alue Naga station, there is a permanent climatological station named Blang Bintang station. The climatological data of Blang Bintang station includes wind data which have been collected for about 10 years. The wind data of this station during the period of cross sectional survey are also available. Therefore, if the wind data of Alue Naga station can be estimated using the data of Blang Bintang station, and the wave data can be obtained using the estimated wind data then the estimated longshore transport energy of the study area can also be calculated. Three procedures in obtaining longshore transport energy have been tried as follows.

5.2.1. The Application of Vector Regression

In this procedure, wind data at Alue Naga station are estimated from Blang Bintang data applying vector regression analysis. The advantage of using vector regression is that the wind speed and wind direction can be obtained simultaneously. The flow chart of this procedure can be seen in Figure 5.2. The first step is the development of a regression equation employing wind data in the period when the data are available in both stations. The second step is checking the reliability of the model(the regression

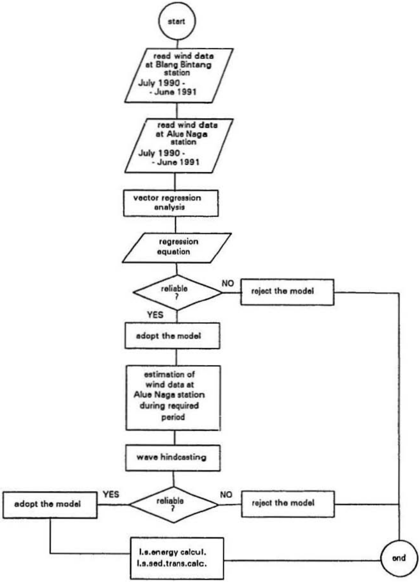

Figure 5.2. Flow Chart of An Application of Vector Regression

equation).The reliability of the model is assessed by looking at the correlation coefficient. Generally, if the correlation coefficient is greater than 0.90 the model is considered reliable. If the model is reliable, then, it is adopted; otherwise, the model is rejected. The third step is applied only if the model is good enough for prediction. In this step, the model is used for generating wind data during the required period. After wind data is obtained, this data can be used for wave data hindcasting. Finally, the longshore energy transport calculation can be performed employing estimated wave data.

5.2.2. The Application of Linear Regression

In this procedure, the first step is estimation of wind speed and direction which are treated separately. The disadvantage of this procedure is that the direction of the estimated wind speed is not known. However, the wind direction usually has a seasonal pattern. By looking at statistical data of wind direction, the distribution of wind direction may be obtained. The procedure of linear regression is almost the same as the procedure in 5.2.1. The only difference is that, in this procedure, linear regression is used instead of vector regression. When the model is reliable, which means the error does not give significant effect, the wave data of required period can be obtained using the model. The next step is estimating wave direction based on seasonal pattern of relationship between wind and wave direction. After wave data including direction are obtained, the next step deals with longshore transport energy calculation.

5.2.3. The Wave Data Similarity

In this procedure, the data of wind direction at Blang Bintang during the periods 1990-1991 and 1992-1993 are compared. By looking at the distribution of wind direction during these periods, it was found that the distribution of wind direction in both periods are almost identical. Considering this situation, it is reasonable to assume that the distribution of wind direction at Alue Naga station during periods 1990-1991 and 1992-1993 are also identical. Furthermore, the wave data within the period 1992-1993 is also assumed to have the same distribution as in 1990-1991. Applying these assumptions, the estimated longshore energy transport during the study period can be obtained directly using the wave data of the period 1990-1991.

The results and discussions of the application of procedures 5.2.1, 5.2.2, and 5.2.3 will be given in Chapter 6.

5.3. Computer Programmes Used in The Study

In this study, computer programmes written in QBasic were developed for longshore transport energy calculation. Generally, the programmes consist of inputs, processes and outputs. The data inputs include wave height, wave period, beach slope and bottom friction factor. The processes include calculations of wave properties at the deep water and at the breaker line, calculations of longshore transport energy and longshore sediment transport. If the processes include longshore sediment transport calculation, additional data are required, i.e., sediment specific gravity, sea water density, sediment porosity. The outputs are the results of the calculations, i.e., total longshore transport energy, total longshore sediment transport. The data input like wave height and period may be adopted from available wave data or generated by wave hindcasting. The data of wave direction may be obtained by statistical analysis of the relationship between wind direction and wave direction in the study area.

The first objective of data input processing is calculation of longshore transport energy which, then, can be used to calculate longshore sediment transport. Since longshore transport energy is evaluated using wave properties at the breaker line(see Chapter 4), these wave properties should be determined first. To performed this calculation, the wave properties at the deep water(data input) are required. The calculation procedures adopt linear wave theory, and the steps are as follows,

Step 1.Calculation of Wave Length and Celerity at Deep Water

If the wave period at the deep water is known, the wave length and celerity at the deep water may be calculated using the following equations,

$$L_o = \frac{gT^2}{2\pi} = 1.561310\,T^2 \tag{5.3}$$

$$C_o = \frac{gT}{2\pi} = 1.561310\,T \tag{5.4}$$

where, L_o : the wave length at the deep water(m),

T : the wave period(s),

c_o : the wave celerity at the deep water(m/s),

g : the gravitational acceleration(m/s^2),

$g = 9.81\ m/s^2$

$\pi = 3.141593$

Step 2.Calculation of Wave Height, Celerity and Direction at The Breaker Line

To calculate wave properties at the breaker line, the condition of critical wave steepness is applied. For shallow water, Hamada(1951) suggested that the critical wave steepness is well defined as:

$$\frac{H}{L} = 0.142 \tanh\left(\frac{2\pi h}{L}\right) \tag{5.5}$$

where, H : the wave height at shallow water(m),

L : the wave length at shallow water(m),

h : the water depth at shallow water(m).

When the waves propagate from the deep water to shallow water, wave properties translation takes place which is called shoaling. In this process, the wave height increases until it reaches a critical wave steepness. The wave height at any depth in shallow water can be defined as:

$$H = H_o\sqrt{\frac{1}{2n} \cdot \frac{C_o}{C}} \tag{5.6}$$

where, H : the wave height at the shallow water(m),

H_o : the wave height at the deep water(m),

n : the ratio of wave group celerity to wave celerity, and it is given as:

$$n = \frac{1}{2}\left[1 + \frac{4\pi h}{L} \cdot \frac{1}{\sinh\left(\frac{4\pi h}{L}\right)}\right] \tag{5.7}$$

h : the water depth at shallow water(m),

L : the wave length at shallow water(m),

c_o : the wave celerity at the deep water(m/s) as expressed in equation(5.4),

c : the wave celerity at shallow water(m/s), and it is expressed as:

$$c = \frac{gT}{2\pi}\tanh\left(\frac{2\pi h}{L}\right) \tag{5.8}$$

Combining equations(5.6), (5.7), (5.8) and (5.5) leads to the following equation:

$$\frac{\sqrt{c_o}.H_o}{L} / \sqrt{\left(1 + \frac{4\pi h/L}{\sinh(4\pi h/L)}\right) . \frac{gT}{2\pi}\tanh\left(\frac{2\pi h}{L}\right)}$$

$$= 0.142\tanh\left(\frac{2\pi h}{L}\right) \tag{5.9}$$

From linear wave theory, L/L_o may be expressed as:

$$\frac{L}{L_o} = \tanh\left(\frac{2\pi h}{L}\right) \tag{5.10}$$

or

$$\frac{2\pi h}{L} = \tanh^{-1}\left(\frac{L}{L_o}\right) \tag{5.11}$$

Substituting equation(5.11) into (5.9) and replacing L/L_o with x, yields the following equation,

$$\frac{H_o}{0.142L_o} = x^2\sqrt{x\left(1+\frac{2\tanh^{-1}(x)}{\sinh(2\tanh^{-1}(x))}\right)} \tag{5.12}$$

Some definitions involving hyperbolic function are given as follows,

$$\tanh^{-1}(x) = \frac{1}{2}\ln\left(\frac{1+x}{1-x}\right) \tag{5.13}$$

$$\sinh(\tanh^{-1}(x)) = \frac{x}{\sqrt{1-x^2}} \tag{5.14}$$

$$\cosh(\tanh^{-1}(x)) = \frac{1}{\sqrt{1-x^2}} \tag{5.15}$$

$$\sinh(2\tanh^{-1}(x)) = 2\sinh(\tanh^{-1}(x))\cosh(\tanh^{-1}(x))$$

$$= \frac{2x}{1-x^2} \tag{5.16}$$

Substituting equations(5.13) and (5.16) into equation(5.12), leads to the following expression,

$$\left(\frac{H_o}{0.142L_o}\right)^2 = x^5 + \ln\left(\frac{1+x}{1-x}\right) \cdot \frac{x^4(1-x^2)}{2} \tag{5.17}$$

Since H_o and L_o are known from the input data, equation(5.17) can be solved and the value of x of any values of H_o and L_o can also be determined. The easiest way to solve this equation is by employing Newton's method which is expressed as,

$$x_{new} = x_{old} - \frac{(f(x_{old}) - u)}{f'(x_{old})} \tag{5.18}$$

where, x_{new} : the new value of x in the iteration process,

x_{old} : the old value of x in the iteration process,

$f(x_{old})$: the value of the right side of equation(5.17) evaluated at x_{old},

$f'(x_{old})$: the value of the first derivative of the right side of equation(5.17) evaluated at x_{old}, u : the value of the left side of equation(5.17).

The first derivative of the right side of equation(5.17) is obtained as,

$$f'(x) = 6x^4 + (2x^3 - 3x^5) . \ln\left(\frac{1+x}{1-x}\right) \tag{5.19}$$

The process of iteration in finding the x-value should be started by giving an initial value of x. In the computer program, the initial value of x is taken as,

$$x = \left(\frac{H_o}{0.142 L_o}\right)^{\frac{2}{5}} \tag{5.20}$$

Since the critical wave steepness is applied in the calculation of x, a condition must be met which results from(5.17) and (5.5) and the fact that $|\tanh(x)| \leq 1$, namely,

$$\frac{H_o}{0.142 L_o} \leq 1 \tag{5.21}$$

This condition is based on equation(5.12) where at the right side of the equation has always the value of less than one. If this condition is violated, the computer program will not work. Once an x-value is obtained, the calculation is continued by step 3.

Step 3. Calculation of Longshore Transport Energy

The wave length at the shallow water can be obtained using the following expression,

$$L = L_o \cdot x \tag{5.22}$$

where, L : the wave length at shallow water(m),

L_o : the wave length at the deep water(m),

x : the x-value of equation(5.13).

The wave length, L, obtained from equation(5.22) is actually the wave length at the breaker line. The water depth, h, at the breaker line can be obtained as a function of x as,

$$h = \frac{L}{4\pi} . \ln\left(\frac{1+x}{1-x}\right) \tag{5.23}$$

The wave direction at the breaker line may be obtained employing Snell's law given as,

$$\frac{c_o}{\sin \alpha_o} = \frac{c_b}{\sin \alpha_b} \tag{5.24}$$

where, c_o : the wave celerity at the deep water(m/s) and it can be obtained from equation(5.4),

α_o : the wave direction at the deep water(^{o}),

α_b : the wave direction at the breaker line(^{o}),

c_b : the wave celerity at the breaker line(m/s) and it is given as,

$$c_b = \frac{gT}{2\pi}.x \tag{5.25}$$

Combining equations(5.25), (5.24) and (5.4) leads to the expression of α_b as,

$$\alpha_b = \sin^{-1}(x.\sin\alpha_o) \tag{5.26}$$

The value of c_{gb} for longshore transport energy calculation may be obtained by the following equation,

$$c_{gb} = n \cdot c_b \tag{5.27}$$

where, c_{gb} : the wave group celerity evaluated at the breaker line(m/s),

n : the ratio of wave group celerity to wave celerity given in equation(5.7),

c_b : the wave celerity at the breaker line(m/s); it can be obtained using equation(5.25).

Calculation of the wave height at the breaker line, H_b, can be performed by employing equations(4.10) and (4.11) in Chapter 4. The calculations employ the value of sea bottom friction factor, f, which in this study was taken to be equal to 0.015. Horikawa(1978) recommended the value of f in the range of 0.01 to 0.02. After the values of α_b, c_{gb}, and H_b are obtained, the longshore transport energy may be calculated using equation(4.3) in Chapter 4.

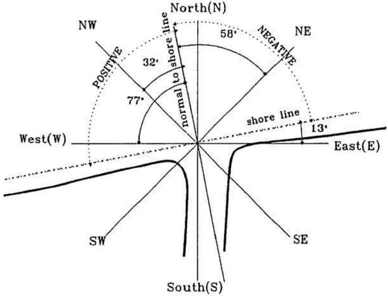

Figure 5.3. The Position of Shore Line with Respect to Dominant Wave Directions

For the wave direction to the left of normal line(see Figure 5.3), longshore transport energy is given a positive sign, otherwise it is given a negative sign. In other words, if longshore transport energy moves to the right, the sign is positive, and the negative sign is given for the opposite direction.

Step 4.Calculation Longshore Sediment Transport

After longshore transport energy is obtained, the step can be continued to find longshore sediment transport. Combining equations(4.1) and (4.2) leads to the following expression,

$$Q_v = \frac{K}{(\rho_s - \rho).g.a'}.P_{ls} \tag{5.28}$$

To calculate longshore sediment transport in unit of volume per unit of time, additional data are required, i. e., sediment specific gravity(ρ_s), sea water density(ρ), and porosity(η). In this study, the values of these parameters are taken as follows,

Sediment specific gravity(ρ_s)	: 2,650 kg/m^3,
Sea water density(ρ)	: 1,025 kg/m^3,
Porosity(η)	: 0.4

These values were also used by U. S. Army CERC(1973). The value of porosity of 0.4 gives a' the value of 0.6(=1-0.4), where a' represents the solid content of one unit volume of sediment. If significant wave height data is used for calculating the longshore transport energy, P_{ls}, the value of K is 0.39 (see U. S. Army CERC, 1973). Using these values, the equation of longshore sediment transport may be written as,

$$Q_{v'} = C \cdot P_{ls} \tag{5.29}$$

where, Q_{v*} : longshore sediment transport(m^3/year),

P_{ls} : longshore transport energy(N/s),

C : a constant = 1,290(m^3.s/N.year).

Note that the units of Q_v in equation(5.28) are unit volume per second. To obtain transport rate per year as indicated in equation(5.29), equation(5.28) was multiplied by the total number of seconds per year(=365x24x60x60).

A computer program listing for the longshore transport energy calculation including the longshore sediment transport is provided in Appendix C.

Chapter 6

Results and Discussions

6.1. Quantity of Longshore Sediment Transport

As mentioned in Chapter 5, during the study, three cross sectional surveys were conducted i.e., May 4th 1992, May 25th 1993, and August 18th 1993. From these surveys, two volume changes could be evaluated. The method used for the calculations of the volume change can be seen in Chapter 5. Calculation of cross sectional area refers to the base level of -6 m, where all survey points are above this level. Table 6.1. shows the calculated area, in m^2, of each section for the three surveys. The changes of cross sectional area are plotted in graphs as shown in Figure 6.1. and Figure 6.2. Figure 6.1. shows the change of the cross sectional area of the left jetty, and Figure 6.2. shows the change of the right one. In general, at the left jetty, the cross sectional area increased during the period of study; while at the right jetty it decreased. This suggests that during the study period, the net longshore sediment transport was positive. At the left jetty, sediment accumulated, while at the right jetty, the sediment eroded. Looking at the area

Table 6.1. Cross Sectional Area During Three Periods of Survey

Section no.	month		
	May 4th, 1992	May 25th, 1992	Aug 18th, 1992
The Left Jetty			
B.1	773.7265	798.6920	879.5485
B.2	791.3525	844.3325	980.1868
B.3	810.2658	902.4555	1,041.6930
L1.3	867.2771	942.8585	1,079.4434
B.4	1,001.4601	1,078.3856	1,152.4338
B.5	902.7342	1,212.4357	1,263.5738
The Right Jetty			
B.13	917.6748	1,079.8730	1,073.7028
B.14	1,024.2703	1,055.8899	1,076.3915
B.15	1,044.1573	1,012.5588	963.6441
B.16	1,050.4712	978.3104	906.8505
B.17	1,081.2738	1,033.0848	897.6602
B.18	1,095.4484	1,049.1540	948.3287

changes close to the jetties i.e., B.5 for the left jetty and B.13 for the right jetty(see Figure 5.1), it can be seen that for both jetties, sediment deposition took place. The reason for this is that the sediment which is close to the jetty is difficult to erode, even in the erosion region, because of the "protection" of the jetty against wave attack. When the waves propagate to the left direction, erosion takes place at the left jetty and sedimentation at the right jetty. In the opposite direction of wave propagation, erosion occurs at the right jetty and sedimentation at the left jetty. The net sedimentation or erosion is the difference between total sedimentation and erosion.

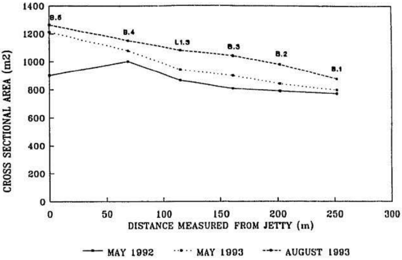

Figure 6.1. The Changes of Cross Sectional Area of The Left Jetty

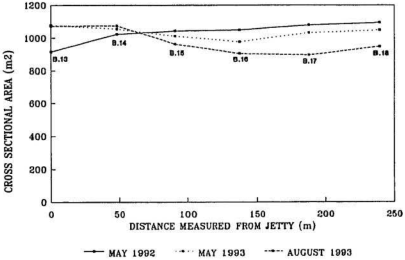

Figure 6.2. The Changes of Cross Sectional Area of The Right Jetty

The quantity of longshore sediment transport of each inter survey may be estimated from the area changes. This can be seen in Table 6.2 and Table 6.3. As mentioned in the previous chapter, the selection the furthest sections, i.e., B.1 for the left jetty and B.18 for the right jetty, are by the assumption that these sections are in an

Table 6.2. Total Volume Change of May 4th, 1992 to May 26th, 1993

Section no.	Distance (m)	The Change of Area (m2)	The Change of Volume (m3)
Bs.I	0.00	0.00	0.00
B.1	44.56	24.97	556.21
B.2	50.00	52.98	1,948.64
B.3	41.50	92.19	3,012.27
L1.3	45.00	75.58	3,774.85
B.4	46.00	76.93	3,507.66
B.5	69.50	309.70	13,435.29
Total Volume Change			26,234.91
B.13	0.00	162.20	0.00
B.14	48.00	31.62	4,651.63
B.15	43.00	(31.60)	0.45
B.16	46.00	(72.16)	(2,386.46)
B.17	51.00	(48.19)	(3,068.92)
B.18	51.00	(46.29)	(2,409.33)
Bs.II	1,246.18	0.00	(28,845.66)
Total Volume Change			(32,058.29)

Notes: Figures in brackets indicate negative values

equilibrium state; no cross sectional area changes take place in these sections. However, during the study period, it was found that these cross sectional areas did change. In order the volume of sediment transport during each inter survey can be obtained, the equilibrium sections should be known. To find the volume change of these sections, a method of extrapolation is used. The results of such extrapolation are estimated equilibrium sections Bs.I of the left jetty and Bs.II of the right jetty. The contribution of

Table 6.3. Total Volume Change of May 26th, 1993 to August 18th, 1993

Section no.	Distance (m)	The Change of Area (m2)	The Change of Volume (m3)
Bs.I	0.00	0.00	0.00
B.1	73.51	80.86	2,971.84
B.2	50.00	135.85	5,417.77
B.3	41.50	139.24	5,708.15
L1.3	45.00	136.58	6,206.00
B.4	46.00	74.05	4,844.56
B.5	69.50	51.14	4,350.22
Total Volume Change			29,498.55
B.13	0.00	(6.17)	0.00
B.14	48.00	20.50	343.95
B.15	43.00	(48.91)	(610.88)
B.16	46.00	(71.46)	(2,768.61)
B.17	51.00	(135.42)	(5,275.55)
B.18	51.00	(100.83)	(6,024.37)
Bs.II	148.62	0.00	(7,492.24)
Total Volume Change			(21,827.70)

Notes: Figures in bracket indicate negative values

section Bs.II of the right jetty to the total volume change is very significant about 90% during the first inter survey(Table 6.2) and 30% during the second inter survey(Table 6.3). While for the left jetty, estimated section Bs.I is less significant in contributing to the total volume change, i.e., about 2% during the first inter survey and about 10%

during the second one.

Theoretically, the total volume change of each inter survey of the left jetty and right jetty should be the same, assuming that the jetties are very efficient in trapping sediment. The results show that they are not the same. Since the evaluation of total volume change of the right jetty involves a very significant uncertainties, the error of such uncertainties will cause a significant change to the results. Therefore, in this study, the volume change at the left jetty is used for longshore sediment transport evaluation.

6.2. Vector Regression Approach

The method used is given in Chapter 5. For the purpose of the development of vector regression equation, the data from July 1st, 1990 to June 30th, 1991 of daily

Table 6.4. Vector Correlation Coefficients of Alue Naga and Blang Bintang stations

Data	Corr. coeff, r
Total	0.342785
July 1990	0.203511
August 1990	0.486099
September 1990	0.471815
October 1990	0.415054
November 1990	0.547547
January 1991	0.259412
February 1991	0.693012
March 1991	0.281864
April 1991	0.547930
May 1991	0.350497
June 1991	0.272307

Note: Data of December 1990 of Bl. Bintang st. is not available average wind velocity and direction of Blang Bintang and Alue Naga station are used. Calculations of vector correlation coefficients were performed for total data and monthly data. To do this calculation, Court's method was employed(see Chapter 4). The results of such calculations are given in Table 6.4. An inspection of the results, reveals that generally all data have a very low correlation coefficient, r, which ranges from 0.20 to 0.69. This suggests that those stations are not correlated. To show how this prediction was performed, the data in the month of February 1990 was analyzed, since in this month, the correlation coefficient is the highest. The results can be seen in Table 6.5. Figures 6.3 and 6.4 show the comparison of estimated wind speed and direction and observed ones at Alue Naga station. The standard error of estimate obtained was about 41% of the mean of daily average data. Because of such an unsatisfying result of estimation, this procedure was not continued.

6.3. Linear Regression Approach

As mentioned in Chapter 5, the procedure of linear regression is the same as the vector regression approach. The estimation of wind speed and direction are treated separately. The calculation of the correlation coefficient, r, was performed for total and monthly data, and the results are given in Table 6.6. Again the same as with the vector regression approach, the results showed very low correlation coefficients. This suggests that if daily average wind velocity data is used, the two stations have no correlation. Evaluation on a weekly average was also conducted. The graphs showing the comparison of weekly average wind speed at Alue Naga and Blang Bintang stations during the period

Table 6.5. The Comparison of Estimated and Actual Data of Wind Speed and Direction at Alue Naga Station as The Result of Vector Regression

FEB'91 date	AVR.VEL m/s	estAVEL m/s	DIR degree	estDIR degree	Vx m/s	estVx m/s	Vy m/s	estVy m/s
1	4.3	3.972846	22.5	32.161879	3.972682	2.114798	1.645539	3.363203
2	4.5	3.735928	22.5	52.704916	4.157458	2.972026	1.722075	2.263674
3	3.8	4.057815	22.5	29.075249	3.510742	1.971927	1.454197	3.546458
4	2.6	3.745762	22.5	56.261301	2.402087	3.114897	0.994977	2.080419
5	2.9	3.839631	22.5	38.696934	2.679251	2.400541	1.109782	2.996693
6	4.0	3.756063	22.5	58.029106	3.695518	3.186333	1.530734	1.988792
7	4.0	2.047184	22.5	(82.460043)	3.695518	2.029483	1.530734	(0.268626)
8	4.2	1.698648	22.5	(82.361331)	3.880294	1.683574	1.607270	(0.225793)
9	2.9	7.623945	22.5	(82.811937)	2.679251	7.564027	1.109782	(0.953958)
10	2.9	7.043028	22.5	(82.801282)	2.679251	6.987512	1.109782	(0.882569)
11	3.4	8.038585	22.5	79.946835	3.141190	7.915162	1.301124	1.403231
12	4.7	10.25876	22.5	73.559791	4.342234	9.839338	1.798612	2.903379
13	4.7	7.833958	22.5	80.741783	4.342234	7.731907	1.798612	1.260359
14	3.5	7.238342	22.5	(69.011961)	3.233578	6.758115	1.339392	(2.592579)
15	3.6	4.013874	22.5	30.602231	3.325966	2.043363	1.377660	3.454831
16	2.9	3.745762	22.5	56.261301	2.679251	3.114897	1.109782	2.080419
17	3.2	1.58247	22.5	(82.318765)	2.956415	1.568271	1.224587	(0.211516)
18	3.9	2.97663	22.5	(82.610258)	3.603130	2.951907	1.492465	(0.382848)
19	3.5	0.653134	22.5	(81.433091)	3.233578	0.645847	1.339392	(0.097294)
20	4.1	3.839631	22.5	38.696934	3.787906	2.400541	1.569002	2.996693
21	4.9	6.741174	45.0	58.895395	3.464823	5.771965	3.464823	3.482505
22	4.7	4.502795	45.0	18.120478	3.323402	1.400442	3.323402	4.279477
23	6.0	7.166314	45.0	(6.522639)	4.242641	(0.814063)	4.242641	7.119927
24	5.6	4.851122	45.0	12.418821	3.959798	1.043264	3.959798	4.737614
25	5.3	3.839631	45.0	38.696934	3.747666	2.400541	3.747666	2.996693
26	4.9	3.972846	45.0	32.161879	3.464823	2.114798	3.464823	3.363203
27	3.8	4.260814	45.0	23.312281	2.687006	1.686184	2.687006	3.912968
28	4.5	3.832376	45.0	64.956278	3.181981	3.472076	3.181981	1.622282

Note : Figures in bracket indicate negative values

Standard Error of Wind Vel. Estimate = **2.316899**

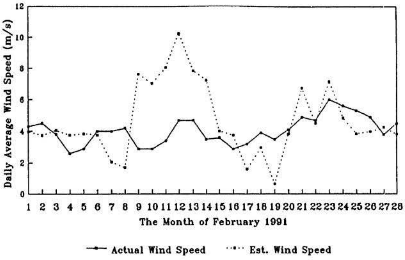

Figure 6.3. The Comparison of Estimated and Actual Wind Speed Data at Alue Naga Station

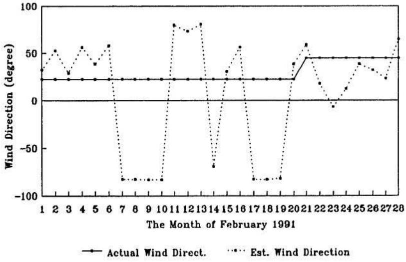

Figure 6.4. The Comparison of Estimated and Actual Wind Direction Data at Alue Naga Station

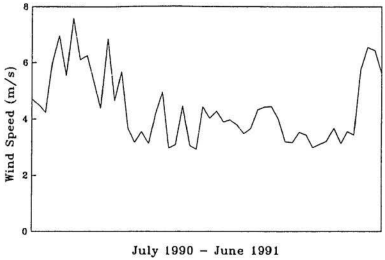

Figure 6.5. The Distribution of Weekly Average Wind Speed at Alue Naga Station

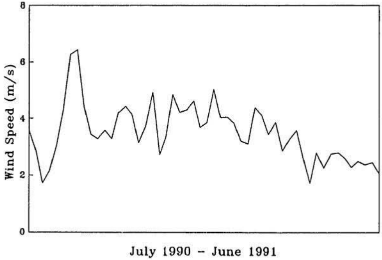

Figure 6.6. The Distribution of Weekly Average Wind Speed at Blang Bintang Station

of July 1990 to June 1991 can be seen in Figure 6.5 and Figure 6.6. By inspection, it is quite obvious that there is no correlation between those two data. Therefore, for weekly average data, further evaluation was not performed.

Table 6.6. Linear Correlation Coefficients of Alue Naga and Blang Bintang stations

Data	Corr. coeff, r
Total	0.342786
July 1990	0.018330
August 1990	0.256926
September 1990	0.004690
October 1990	0.179366
November 1990	0.242889
January 1991	0.486871
February 1991	0.627636
March 1991	0.340038
April 1991	0.422832
May 1991	0.182800
June 1991	0.238523

Notes: Data of December 1990 of Bl. Bintang st. is not available

The next trial was to compare monthly average wind speed data of both stations. This comparison can be seen in Figure 6.7 and Figure 6.8. The graphs show that there is some visible correlation, so their correlation coefficients were evaluated. If both data are plotted in a X-Y graph, where the X-axis represents the monthly average of wind speed at Blang Bintang, and the Y-axis represents the Alue Naga station, visually, two distinct relations can be seen in Figure 6.9; the first relation is in the period of October to May, and the second relation is in the period of June to September. If correlation coefficients are calculated for each of these periods, then this gives the correlation

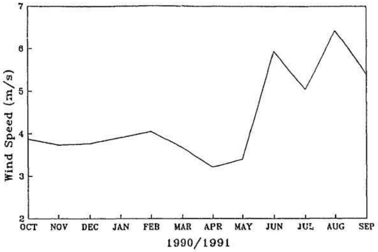

Figure 6.7. The Distribution of Monthly Average Wind Speed at Alue Naga Station in The Period of 1990-1991

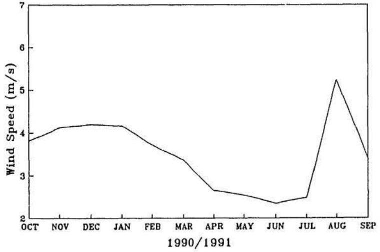

Figure 6.8. The Distributi.n of Monthly Average Wind Speed at Blang Bintang Station in The Period of 1990-1991

coefficient of 0.97 for the period of October to May, and for the other period, the correlation coefficient is 0.69. The results of this calculation are given in Table 6.7.

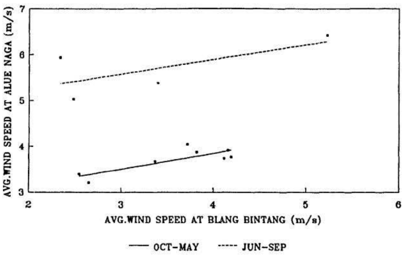

Figure 6.9. A Correlation of Average Wind Speed at Alue Naga and Blang Bintang Station in The Period of 1990-1991

Since the results show quite a good prediction, the regression equation was adopted for longshore transport energy calculation. These regression equations are given as,

Est.AN = 0.342075 . BB + 2.479067 for the period of Oct.-May (6.1)

Est.AN = 0.317475 . BB + 4.625153 for the period of June-Sept (6.2)

where, Est.AN : estimated average monthly wind speed at Alue Naga station(m/s),

BB : the data of average monthly wind speed at Blang Bintang station(m/s).

After the estimated monthly average data at Alue Naga were obtained, they were used for prediction of wave properties at the same location(the study area). This wave hindcasting was done by employing equations(4.20) and (4.21) in Chapter 4, with the

Table 6.7. The Results of Regression Analysis

Month	AN	estAN	BB	Sq. Error
Oct	3.874194	3.786677	3.822581	0.007659
Nov	3.736667	3.888417	4.120000	0.023028
Dec	3.767742	3.914679	4.196774	0.021591
Jan	3.909677	3.903645	4.164516	0.000036
Feb	4.046429	3.752075	3.721429	0.086644
Mar	3.670000	3.630720	3.366667	0.001543
Apr	3.210000	3.385566	2.650000	0.030823
May	3.396774	3.349703	2.545161	0.002216
Mean Square Error		0.021693		
Standard Error		0.147284		
Correlation Coeff., r		0.968555		
Jun	5.933333	5.369104	2.343333	0.318355
Jul	5.032258	5.413721	2.483871	0.145514
Aug	6.419355	6.284218	5.225806	0.018262
Sep	5.386667	5.704570	3.400000	0.101062
Mean Square Error		0.145798		
Standard Error		0.381835		
Correlation Coeff., r		0.690882		

assumption that fully developed waves occurred. The wave direction data of each month was estimated as having the same distribution as in the respective month of the period of 1990 and 1991. The reason for this will be discussed in the next section.

Computer programs for calculation longshore sediment transport by this approach

Table 6.8. The Program Output IA−1, IA−2, IB−1 and IB−2

No.	Output	E.l.s.t(m3)	Output	E.l.s.t(m3)
	IA−1		IB−1	
1	2 reg.eq	194,270.219	2 reg.eq	97,824.953
2	1 reg.eq.	2,843.655	1 reg.eq.	7,821.297
	IA−2		IB−2	
3	− s.e.e	125,014.445	− s.e.e	65,801.922
4	+ s.e.e	292,710.313	+ s.e.e	141,981.188

Remarks :

E.l.s.t : Estimated Longshore Sediment Transport

No.1 : 2 regression equations were used for prediction wind speed at Alue Naga

No.2 : 1 regression equation was used for prediction wind speed at Alue Naga

No.3 : 2 regression equations were deducted by their standard error of estimate(s.e.e)

No.4 : 2 regression equations were added by their standard error of estimate(s.e.e)

Table 6.9. The Program Output IA−3 and IB−3

Output IA−3			Output IB−3	
factor	E.l.s.t 1(m3)	E.l.s.t 2(m3)	E.l.s.t 1(m3)	E.l.s.t 2(m3)
0.50	(7)	2,736	919	1,378
0.55	(4)	4,916	2,023	2,476
0.60	(826)	8,395	3,783	4,227
0.65	4,778	13,735	6,484	6,916
0.70	13,102	21,665	10,497	10,909
0.75	25,121	33,116	16,290	16,675
0.80	42,056	49,250	24,453	24,800
0.85	65,414	71,504	35,712	36,006
0.90	97,028	101,624	50,951	51,173
0.95	139,105	141,712	71,234	71,359
1.00	194,270	194,270	97,825	97,825
1.05	265,626	262,253	132,220	132,058
1.10	356,799	349,117	176,169	175,798
1.15	472,006	458,879	231,702	231,069
1.20	616,109	596,171	301,164	300,202
1.25	794,685	766,307	387,243	385,874
1.30	1,014,093	975,344	493,003	491,135
1.35	1,281,542	1,230,152	621,922	619,444
1.40	1,605,171	1,538,484	777,921	774,705
1.45	1,994,127	1,909,057	965,409	961,307
1.50	2,458,644	2,351,618	1,189,320	1,184,159

Remarks :

E.l.s.t 1 : Estimated Longshore Sediment Transport if Esimated Wind Speed at Alue Naga in the months of June, July, August, and Sept. are multiplied by factors of 0.5 to 1.5

E.l.s.t 2 : Estimated Longshore Sediment Transport if Esimated Wind Speed at Alue Naga in all months are multiplied by factors of 0.5 to 1.5

are given in Appendix C. The computer program IA is for the longshore sediment transport calculation of the period of May 4th, 1992 to May 25th, 1993, while the computer program IB is for the period of May 26th, 1993 to August 18th, 1993. The output of computer programs IA and IB are presented in Table 6.8, 6.9, and 6.10. The

Table 6.10. The Program Output IA-4 and IB-4

Output IA-4		Output IB-4
Sea Water Dens.	E.l.s.t(m^3)	E.l.s.t(m^3)
1,021	193,512	97,443
1,022	193,702	97,539
1,023	193,891	97,634
1,024	194,081	97,730
1,025	194,270	97,825
1,026	194,460	97,920
1,027	194,649	98,016
1,028	194,839	98,111
1,029	195,028	98,207
Friction factor		
0.010	200,579	100,315
0.011	199,291	99,809
0.012	198,016	99,307
0.013	196,754	98,809
0.014	195,506	98,315
0.015	194,270	97,825
0.016	193,047	97,339
0.017	191,836	96,857
0.018	190,638	96,379
0.019	189,451	95,904

Note: E.l.s.t = estimated longshore sediment transport

output IA-1 and IB-1 shows the comparison of using 2 regression equations and 1 regression equation, i.e., equation(6.1) assuming that this equation is valid for entire period. If these outputs are compared to the measured sediment transport, i.e.,26,000 m^3

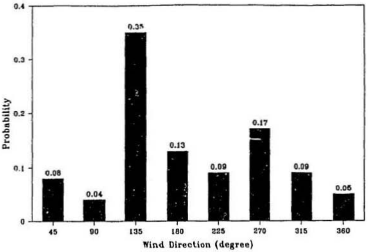

Figure 6.10. The Distribution of Wind Direction at Blang Bintang Station in The Period of 1990-1991

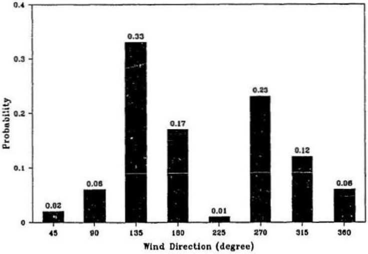

Figure 6.11. The Distribution of Wind Direction at Blang Bintang Station in The Period of 1992-1993

for the first period and 29,000 m^3 for the second period, then using 2 regression equations provides an overestimate, while using 1 regression gives an underestimate. The output IA-2 and IB-2 show the results if the standard error of estimate is deducted or added to the two regression equations. Even though the regression equations are reduced by their standard error of estimate, the results are still very high. The output IA-3 and IB-3 show the sensitivity of estimated wind speed data at Alue Naga in influencing the results. Since longshore sediment transport is proportional to almost the fifth power of the wind speed, it is obvious that a small error in its prediction will give quite a significant error in the calculation of the longshore sediment transport. The output IA-4 and IB-4 show how the change of the value of sea water density(ρ) and the friction factor(f) influence the results. It is clearly not significant. In this study, generally, within the period of October to May, the wave force contributes a significant amount of longshore sediment transport, even if it happens in a shorter time.

6.4. The Similarity of Wind Direction Approach

The distribution of wind direction at Blang Bintang station during periods of 1990-1991 and 1992-1993 is grouped into 8 directions. The results of grouping can be seen in Figures 6.10 and 6.11. These two distributions appear to be almost identical, and their correlation coefficient is 0.898. This is more obvious if they are plotted in one graph as shown in Figure 6.12. Since the distribution of wind direction at Blang Bintang station in periods 1990-1991 and 1992-1993 are almost identical, it is likely that at Alue Naga station, the distribution of wind direction will behave the same as at Blang Bintang station. Furthermore, in this study, wave direction, height, period at Alue Naga during these periods are also assumed the same. Based on this assumption, longshore sediment transport during the study period(1992-1993) was estimated using the available wave data of the period of 1990-1991. The available data consists of $H_{1/3}$, $T_{1/3}$, and the direction of deep water waves; these data were measured at 9:00 a. m. and 3:00 p. m. In this study,

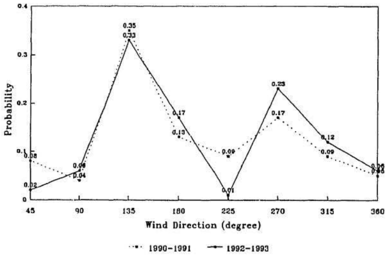

Figure 6.12. The Comparison of The Distribution of Wind Direction at Blang Bintang Station in The Period of 1990-1991 and 1992-1993

these data are assumed to represent the half-daily average data. The data measured at 9:00 a. m. is assumed representing the data of the period of 0:00 - 12:00 a. m., and the data measured at 3:00 p. m. for the period of 0:00 - 12:00 p. m. Since the equation used for the longshore sediment transport calculation as given in equation(5.28) is for the rate per year, this equation should be multiplied by a factor 12/(365 x 24) for the half daily rate. This factor depends on what duration is chosen. Computer programs of this calculation are given in Appendix C. The computer program IIA is for the longshore sediment transport calculation of the period of May 4th, 1992 to May 25th, 1993, while for the period of May 26th, 1993 to August 18th was calculated using the computer

Table 6.11. The Program Output IIA-1 to IIA-5 and IIB-1 to IIB-5

Computer Program IIA		Computer Program IIB	
Output	E.l.s.t(m^3)	Output	E.l.s.t(m^3)
IIA-1	29,232.668	IIB-1	31,054.092
IIA-2	39,269.469	IIB-2	31,054.092
IIA-3	29,498.576	IIB-3	31,054.092
IIA-4	23,780.850	IIB-4	22,535.840
IIA-5	26,553.219	IIB-5	27,160.357

Note : E.l.s.t = estimated longshore sediment transport

program IIB. The difference between these two programs is that the data input are taken from different time periods. The program output are given in Table 6.11. In this study, the computer program does not work if the condition of $H_o/0.142\ L_o < 1$ is not fulfilled(see 5.21). Some input data of the computer program IIA violates this condition, while no input data for the computer program IIB does. To overcome this problem for data which violate the condition, the $T_{1/3}$-value is replaced by a new $T_{1/3}$-value. This is based on the assumption that theoretically the data should fulfill the condition. Since it is violated, either $T_{1/3}$ or H_o must be wrong. Since observation of H_o is easier than $T_{1/3}$, it is reasonable to assume that possible error is for observed $T_{1/3}$. The replacement of $T_{1/3}$-value employs the following equation;

$$T > \sqrt{\frac{H_o}{0.22171}} \qquad (6.3)$$

where, T : the corrected wave period(m/s),

H_o : the wave height at the deep water(m), in this case it is significant wave height($H_{o\,1/3}$).

This expression is derived from equations(5.3) and (5.21) in Chapter 5. Since the required T should be greater than the value on the right side of expression(6.3), a small value is added to this term, in this study it is 0.015. Looking at the outputs of both computer programs, their performance is quite satisfying. The measured quantity of longshore sediment transport of 26,000 m^3 is estimated to be 29,000 m^3, and in the second period, the measured quantity of 29,000 m^3 is estimated to be 31,000 m^3. The computer program IIA is modified by not including the data that violates the condition. This gives the output of 39,000 m^3 which is further from the measured quantity compared to the output of IIA. The next trial was to correct the data that violates the condition by the average value of T of available data that do not violate the condition and have the same wave height. This program yields an estimated longshore sediment transport of 29,500 m^3. If the input data of the computer program IIA are replaced by monthly averages, no data violate the condition. This will give estimated sediment transport of 24,000 m^3 for the first period and 22,000 m^3 for the second period. The last trial in this study employs a monthly root mean square of wave height data and monthly average of wave period data. This leads to the results of 26,000 of the first period and 27,000 of the second period. In the computer program, the calculation of longshore sediment transport employs the value of the coefficient of proportionality, K, of 0.39. On the other hand, instead of calculating sediment transport, the K-value can also be computed. Table D in Appendix D shows the results of this calculation.

Chapter 7

Conclusions and Recommendation

7.1. Conclusions

Since the actual quantity of longshore sediment transport is estimated based on cross sectional survey results, the accuracy of such surveys is crucial. Possible inaccuracies may have originated from human error, instrument error and the error due to environmental influences. Attempts to minimize such errors were executed in this study. For example, to minimize the error due to environmental influence, the survey was conducted at the time when the tide was low and the waves were not too high. This means the available period for the survey is short which, in turn, minimizes human error due to tiredness. The calculated volume of sediment trapped or eroded at the jetties is also subject to uncertainty, since the extent of the cross sectional survey did not cover the equilibrium sections. However, since the pattern of cross sectional changes of each intersurvey can be seen(see Figure 6.1 and 6.2), the uncertainty may be minimized.

Another source of error comes from wind data. In this study, some of the available wind speed data were recorded as a whole number. Since longshore sediment transport is proportional to almost the fifth power of wind speed, rounding the data may yield significantly different results. Some data of direction are recorded in qualitative expressions, such as, N for North, NE for North East etc. In this study, such directional data were converted to qualitative expressions, such as, 0^0 for N, 45^0 for NE, etc., in order that quantification of longshore sediment transport could be performed. This implies that the actual directional data other than those are rounded to the nearest such direction, so this is another source of error. If wind data is used, the models employed in wave hindcasting may also contributes inaccuracy of estimated longshore sediment transport.

The results of this study as given in Chapter 6, suggest that using observed wave data provides a better result compared to using estimated wave data. Employing a value of the coefficient of proportionality, K, of 0.39 yields the estimated longshore sediment transport close to the observed data. When the monthly root-mean-square of $H_{1/3}$ and monthly average of $T_{1/3}$ of the available data were employed, the result is closest to the observed data. The advantage of using monthly root-mean-square of the data is that no data violates the condition as discussed in Chapter 6. Therefore, for estimation of longshore sediment transport in the study area, the use of monthly root-mean-square of $H_{1/3}$ and monthly average of $T_{1/3}$ of observed half-daily data is suggested. In summary, it can be said that estimation of longshore sediment transport is possible, and it gives quite good results.

7.2. Recommendations

To reduce uncertainty involved in the volume calculation, the cross sectional survey should include equilibrium sections. In the study, the jetties are assumed efficient in trapping sediment; this means no sediment passes by the jetties. From the literature, most of the volume of longshore sediment transport is in the surf zone which is the zone inbetween the shoreline and breaker line. During the survey, most of the breaking waves occurred at a distance from shoreline shorter than the length of the jetties; this suggests that the assumption of efficient trapping may be correct. Even if sediment bypassing occurred, the quantity may not be significant. To avoid such uncounted sediment, an evaluation of the volume change at the erosion side during the period of erosion(negative transport for the left jetty and positive transport for the right jetty) may answer the problem. Therefore, a shorter period of intersurvey would be a good practice, since it has a better chance to have only one direction of sediment movement. It is also possible that the sediment bypassing the first jetty may also bypass the second jetty. If this happens, the evaluation of longshore sediment transport quantity will be more complicated. However, such a situation is not likely to happen in this study, because the distance between the two jetties is quite far, i. e., about 300 m. The study of longshore sediment transport by evaluating sediment trapped at the coastal structures is better conducted just after the completion of such structures; at this time the shoreline advancement is still small which will minimize the possible sediment bypassing.

If wave hindcasting is used for estimation, the model used should be calibrated first. This can be done, if continous data of both wind and wave data over a period of time are available. Continous data may also be needed for estimating wind data of one station from another station.

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Appendix A

The Data of Cross Sectional Area and Beach Slope

Table A.1. The Data of Cross Sections B.1, B.2, B.3, Measured in May 1992

Section B1					Section B2					Section B3				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
B"	7.4780				B2"	7.8880				B3"	7.5000			
B1'	7.4370	7.4575	5.00	37.2875	B2'	7.9540	7.9210	10.00	79.2100	B3'	7.3940	7.4470	9.00	67.0230
a	7.8920	7.6645	9.00	68.9805	B2	7.6960	7.8250	8.00	62.6000	B3	7.6170	7.5055	7.50	56.2913
B1	7.9170	7.9045	9.00	71.1405	a	7.4610	7.5785	2.00	15.1570	a	7.5280	7.5725	4.20	31.8045
b	7.1540	7.5355	1.00	7.5355	b	5.9620	6.7115	12.00	80.5380	b	6.0830	6.8055	12.70	86.4299
c	6.0170	6.5855	10.00	65.8550	c	4.6120	5.2870	25.00	132.1750	c	4.4850	5.2840	25.00	132.1000
d	4.5430	5.2800	25.00	132.0000	d	4.1720	4.3920	25.00	109.8000	d	4.0990	4.2920	25.00	107.3000
e	4.1930	4.3680	25.00	109.2000	e	3.7630	3.9675	25.00	99.1875	e	3.8390	3.9690	25.00	99.2250
f	3.8080	4.0005	25.00	100.0125	f	3.4320	3.5975	25.00	89.9375	f	3.5350	3.6870	25.00	92.1750
g	3.3980	3.6030	25.00	90.0750	g	3.0670	3.2495	25.00	81.2375	g	3.3650	3.4500	25.00	86.2500
g'	2.9220	3.1600	29.00	91.6400	g'	2.8630	2.9650	14.00	41.5100	g'	3.2590	3.3120	15.60	51.6672
			163.00					171.00					174.00	
Section Area (in−m2)				773.7265					791.3525					810.2658

*) Refer to datum −6 m

Table A.2. The Data of Cross Sections L1.3, B.4, B.5, Measured in May 1992

Section L1.3					Section B4					Section B5				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
L1.3'	7.5290				B4'	7.6300				B5'	7.5040			
L1.3	8.0850	7.8070	14.00	109.2980	B4	7.6120	7.6210	16.00	121.9360	B5	7.7160	7.6100	13.00	98.9300
L1.3'	8.0080	8.0465	4.60	37.0139	a	7.6750	7.6435	11.20	85.6072	a	7.6550	7.6855	12.60	96.8373
a	7.7160	7.8620	2.20	17.2964	b	8.9930	8.3340	2.60	21.6684	b	8.9490	8.3020	3.00	24.9060
b	7.2330	7.4745	1.00	7.4745	B4'	9.0530	9.0230	1.00	9.0230	B5"	8.9150	8.9320	13.00	116.1160
c	6.3150	6.7740	14.20	96.1908	c	8.8090	8.9310	11.50	102.7065	1	5.2240	7.0695	6.70	47.3657
d	6.6280	6.4715	6.00	38.8290	d	6.1050	7.4570	5.00	37.2850	2	4.9740	5.0990	10.00	50.9900
e	5.6650	6.1465	5.00	30.7325	e	4.7340	5.4195	25.00	135.4875	3	4.8160	4.8950	10.00	48.9500
f	4.5650	5.1150	25.00	127.8750	f	4.4670	4.6005	25.00	115.0125	4	4.5110	4.6635	10.00	46.6350
g	4.2350	4.4000	25.00	110.0000	g	4.2680	4.3675	25.00	109.1875	5	4.3310	4.4210	10.00	44.2100
h	3.7550	3.9950	25.00	99.8750	h	4.0240	4.1460	25.00	103.6500	6	4.2610	4.2960	10.00	42.9600
i	3.3030	3.5290	25.00	88.2250	i	3.9070	3.9655	25.00	99.1375	7	3.9560	4.1085	10.00	41.0850
j	3.0950	3.1990	25.00	79.9750	i'	3.8330	3.8700	15.70	60.7590	8	3.6660	3.8110	10.00	38.1100
j'	3.0280	3.0615	8.00	24.4920						9	3.6510	3.6585	10.00	36.5850
										10	3.1760	3.4135	10.00	34.1350
										11	2.8360	3.0060	10.00	30.0600
										12	2.3960	2.6160	10.00	26.1600
										12'	0.8360	1.6160	48.70	78.6992
			180.00					188.00					207.00	
Section Area (in−m2)				867.2771					1,001.4601					902.7342

*) Refer to datum −6 m

Table A.3. The Data of Cross Sections B.13, B.14, B.15, Measured In May 1992

Section B13					Section B14					Section B15				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
B13"	8.8000				B14'	8.1500				B15"	8.5000			
B13	8.0940	8.4470	1[illegible].90	109.8110	B14	8.2510	8.2005	22.00	180.4110	B15	8.6090	8.5545	28.00	239.5260
a	7.9630	8.0285	2.00	16.0570	a	8.2650	8.2580	3.00	24.7740	a	8.5050	8.5570	4.00	34.2280
b	8.8040	8.3835	1.90	15.9287	b	8.8460	8.5555	1.70	14.5444	b	8.9130	8.7090	1.50	13.0635
B13'	8.7390	8.7715	12.40	108.7666	B14"	8.9170	8.8815	10.40	92.3676	B15'	9.0280	8.9705	9.00	80.7345
c	7.0770	7.9080	3.50	27.6780	c	9.0270	8.9720	4.20	37.6[illegible]74	c	7.2960	8.1620	4.00	32.6480
d	7.2360	7.1565	8.70	62.2616	d	7.0800	8.0535	10.80	86.9778	d	7.2520	7.2740	15.00	109.1100
e	6.3180	6.7770	6.00	40.6620	e	5.3780	6.2290	17.00	105.8930	e	5.0920	6.1720	20.00	123.4400
f	5.3410	5.8295	10.00	58.2950	f	4.2560	4.8170	25.00	120.4250	f	4.2870	4.6895	25.00	117.237[illegible]
g	4.8300	5.0855	10.00	50.8550	g	4.2160	4.2360	25.00	105.9000	g	4.3570	4.3220	25.00	108.0500
h	4.5290	4.6795	10.00	46.7950	h	4.3860	4.3010	25.00	107.5250	h	4.2670	4.3120	25.00	107.8000
i	4.2200	4.3745	10.00	43.7450	h'	4.3320	4.3590	33.90	147.7701	h'	4.2000	4.2335	18.50	78.3198
j	4.0620	4.1410	10.00	41.4100										
k	4.2600	4.1610	10.00	41.6100										
l	3.1500	3.7050	10.00	37.0500										
m	3.9150	3.5325	10.00	35.3250										
n	3.6500	3.7825	10.00	37.8250										
o	3.4000	3.5250	15.00	52.8750										
p	3.2900	3.3450	15.00	50.1750										
p'	3.1980	3.2440	12.50	40.5500										
			180.00					178.00					175.00	
Section Area (in−m2)				917.6748					1,024.2703					1,044.1573

*) Refer to datum −6 m

Table A.4. The Data of Cross Sections B.16, B.17, B.18, Measured In May 1992

Section B16					Section B17					Section B18				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
B16"	8.5000				B17"	8.5000				B18"	8.5000			
B16	8.6960	8.5980	41.00	352.5180	B17	8.9450	8.7225	44.00	383.7900	B18	9.0620	8.7810	46.00	403.9260
B16'	7.9780	8.3370	5.80	48.3546	B17'	8.9380	8.9415	8.70	77.7911	B18'	8.9640	9.0130	10.30	92.8339
a	7.1880	7.5830	5.00	37.9150	a	7.1040	8.0210	6.00	48.1260	a	7.2290	8.0965	5.00	40.4825
b	7.2220	7.2050	16.80	121.0440	b	7.1430	7.1235	15.00	106.8525	b	7.1080	7.1685	16.60	118.9971
c	5.4900	6.3560	19.00	120.7640	c	5.9160	6.5295	15.00	97.9425	c	5.7730	6.4405	21.00	135.2505
d	4.1120	4.8010	25.00	120.0250	d	4.1280	5.0220	25.00	125.5500	d	4.4390	5.1060	25.00	127.6500
e	4.2320	4.1720	25.00	104.3000	e	4.3830	4.2555	25.00	106.3875	e	4.1540	4.2965	25.00	107.4125
f	4.0620	4.1470	25.[illegible]0	103.6750	f	4.2630	4.3230	25.00	108.0750	f'	3.9040	4.0290	17.10	68.8959
f'	3.9910	4.0265	10.40	41.8756	f'	4.2320	4.2475	6.30	26.7593					
			173.00					170.00					166.00	
Section Area (in−m2)				1,050.4712					1,081.2738					1,095.4484

*) Refer to datum −6 m

Table A.5. The Data of Cross Sections B.1, B.2, B.3, Measured in May 1993

Section B1					Section B2					Section B3				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
a'	7.8850				a'	7.9390				a'	7.6030			
a	8.0740	7.9795	10.00	79.7950	a	8.0040	7.9715	7.00	55.8005	a	7.6030	7.6030	4.00	30.4120
b	8.3620	8.2180	9.60	78.8928	B2	8.2650	8.1345	10.00	81.3450	B3	7.9920	7.7975	11.30	88.1118
B1	7.7690	8.0655	2.40	19.3572	1	8.2110	8.2380	1.60	13.1808	1	8.2640	8.1280	14.00	113.7920
1	6.5180	7.1435	10.00	71.4350	2	7.3650	7.7880	8.40	65.4192	2	8.0040	8.1340	0.00	0.0000
2	5.5920	6.0550	10.00	60.5500	3	6.6880	7.0265	10.00	70.2650	3	7.1560	7.5800	10.00	75.8000
3	6.0980	5.8450	10.00	58.4500	4	5.6200	6.1540	10.00	61.5400	4	6.2680	6.7120	10.00	67.1200
4	6.8280	6.4630	10.00	64.6300	5	4.7330	5.1765	10.00	51.7650	5	5.0030	5.6355	10.00	56.3550
5	4.9220	5.8750	10.00	58.7500	6	4.9930	4.8630	10.00	48.6300	6	4.9930	4.9980	10.00	49.9800
6	4.4420	4.6820	10.00	46.8200	7	4.9130	4.9530	10.00	49.5300	7	4.8830	4.9380	10.00	49.3800
7	4.1370	4.2895	10.00	42.8950	8	4.8530	4.8830	10.00	48.8300	8	4.7980	4.8405	10.00	48.4050
8	3.8720	4.0045	10.00	40.0450	9	4.6680	4.7605	10.00	47.6050	9	4.7430	4.7705	10.00	47.7050
9	3.6220	3.7470	10.00	37.4700	10	4.2480	4.4580	10.00	44.5800	10	4.6430	4.6930	10.00	46.9300
10	3.3720	3.4970	10.00	34.9700	11	3.9730	4.1105	10.00	41.1050	11	4.2630	4.4530	10.00	44.5300
11	2.9720	3.1720	10.00	31.7200	12	3.6480	3.8105	10.00	38.1050	12	3.9230	4.0930	10.00	40.9300
11'	1.7320	2.3520	31.00	72.9120	13	3.2980	3.4730	10.00	34.7300	13	3.5630	3.7430	10.00	37.4300
					13'	2.1080	2.7030	34.00	91.9020	14	3.2630	3.4130	10.00	34.1300
										15	2.5220	2.8925	24.70	71.4448
			163.00					171.00					174.00	
Section Area (in−m2)				798.6920					844.3325					902.4555

*) Refer to datum −6 m

Table A.6. The Data of Cross Sections L1.3, b.4, B.5, Measured in May 1993

Section L1.3					Section B4					Section B5				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
L1.3'	7.7250				1'''	7.6200				a''	7.7000			
L1.3	8.0740	7.8995	14.00	110.5930	1''	7.6120	7.6160	15.00	114.2400	a'	7.7160	7.7080	26.00	200.4080
1	8.1710	8.1225	17.00	138.0825	1'	7.5490	7.5805	11.00	83.3855	a	8.9250	8.3205	4.00	33.2820
2	7.6250	7.8980	10.00	78.9800	1	8.9490	8.2490	4.00	32.9960	B5	8.9250	8.9250	13.50	120.4875
3	6.1880	6.9065	10.00	69.0650	2	8.8110	8.8800	13.00	115.4400	1	7.4050	8.1650	4.00	32.6600
4	5.9520	6.0700	10.00	60.7000	3	7.6470	8.2290	1.70	13.9693	2	7.2730	7.3390	15.00	110.0850
5	5.1070	5.5295	10.00	55.2950	4	6.9200	7.2835	10.00	72.8350	3	6.7830	7.0280	10.00	70.2800
6	5.0420	5.0745	10.00	50.7450	5	6.2970	6.6085	10.00	66.0850	4	6.3460	6.5645	10.00	65.6450
7	4.7820	4.9120	10.00	49.1200	6	5.6820	5.9895	10.00	59.8950	5	5.9360	6.1410	10.00	61.4100
8	4.7320	4.7570	10.00	47.5700	7	5.2870	5.4845	10.00	54.8450	6	5.5910	5.7635	10.00	57.6350
9	4.6320	4.6820	10.00	46.8200	8	5.0970	5.1920	10.00	51.9200	7	5.1610	5.3760	10.00	53.7600
10	4.4520	4.5420	10.00	45.4200	9	4.9070	5.0020	10.00	50.0200	8	4.9210	5.0410	10.00	50.4100
11	4.1020	4.2770	10.00	42.7700	10	4.8070	4.8570	10.00	48.5700	9	4.7260	4.8235	10.00	48.2350
12	3.5820	3.8420	10.00	38.4200	11	4.6670	4.7370	10.00	47.3700	10	4.4810	4.6035	10.00	46.0350
13	3.1820	3.3820	10.00	33.8200	12	4.5970	4.6320	10.00	46.3200	11	4.1710	4.3260	10.00	43.2600
13'	2.0220	2.6020	29.00	75.4580	13	4.5070	4.5520	10.00	45.5200	12	4.3310	4.2510	10.00	42.5100
					14	4.3270	4.4170	10.00	44.1700	13	4.4810	4.4060	10.00	44.0600
					15	4.0870	4.2070	10.00	42.0700	14	4.1210	4.3010	10.00	43.0100
					15'	3.5280	3.8075	23.30	88.7148	15	3.7310	3.9260	10.00	39.2600
										15'	3.1660	3.4485	14.50	50.0033
			180.00					188.00					207.00	
Section Area (in−m2)				942.8585					1,078.3856					1,212.4357

*) Refer to datum −6 m

Table A.7. The Data of Cross Sections B.13, B.14, B.15, Measured in May 1993

Section B13					Section B14					Section B15				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
1"	7.7000				1"	8.2000				a'	8.5000			
1'	7.7000	7.7000	16.00	123.2000	1'	8.0000	8.1000	24.00	194.4000	a	8.0100	8.2550	9.00	74.2950
1	8.8910	8.2955	3.00	24.8865	1	8.9340	8.4670	3.00	25.4010	b	7.7540	7.8820	9.50	74.8790
2	8.8710	8.8810	13.00	115.4530	2	8.9680	8.9510	13.20	118.1532	B15	6.9890	7.3715	9.50	70.0293
3	7.4880	8.1795	3.00	24.5385	3	6.6760	7.8220	4.00	31.2880	1	7.0130	7.0010	7.00	49.0070
4	6.1510	6.8195	16.00	109.1120	4	7.1380	6.9070	20.50	141.5935	2	6.7510	6.8820	9.70	66.7554
5	6.7200	6.4355	12.00	77.2260	5	6.2060	6.6720	10.00	66.7200	3	6.8750	6.8130	3.40	23.1642
6	6.3170	6.5185	10.00	65.1850	6	5.7810	5.9935	10.00	59.9350	4	7.3930	7.1340	17.30	123.4182
7	5.9190	6.1180	10.00	61.1800	7	5.3110	5.5460	10.00	55.4600	5	6.2550	6.8240	10.00	68.2400
8	5.8190	5.8690	10.00	58.6900	8	4.9960	5.1535	10.00	51.5350	6	5.6550	5.9550	10.00	59.5500
9	5.2590	5.5390	10.00	55.3900	9	4.7560	4.8760	10.00	48.7600	7	5.0750	5.3650	10.00	53.6500
10	4.8090	5.0340	10.00	50.3400	10	4.6810	4.7185	10.00	47.1850	8	4.5550	4.8150	10.00	48.1500
11	4.6290	4.7190	10.00	47.1900	11	4.3910	4.5360	10.00	45.3600	9	4.5550	4.5550	10.00	45.5500
12	4.6440	4.6365	10.00	46.3650	12	4.1610	4.2760	10.00	42.7600	10	4.2750	4.4150	10.00	44.1500
13	5.1140	4.8790	10.00	48.7900	12'	3.4870	3.8240	33.30	127.3392	11	4.2670	4.2710	31.00	132.4010
14	5.0590	5.0865	10.00	50.8650						11'	4.2620	4.2645	18.60	79.3197
15	4.6440	4.8515	10.00	48.5150										
15'	3.9380	4.2910	17.00	72.9470										
			180.00					178.00					175.00	
Section Area (in−m2)				1,079.8730					1,055.8899					1,012.5588

*) Refer to datum −6 m

Table A.8. The Data of Cross Sections B.16, B.17, B.18, Measured in May 1993

Section B16					Section B17					Section B18				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
a'	8.3530				a'	8.6500				a'	8.6000			
a	7.7740	8.0635	13.00	104.8255	a	7.9950	8.3225	27.00	224.7075	a	8.8160	8.7080	35.00	304.7800
b	7.9590	7.8665	7.00	55.0655	b	8.1390	8.0670	4.40	35.4948	b	8.7220	8.7690	4.20	36.8298
c	7.1490	7.5540	11.00	83.0940	c	7.2260	7.6825	5.60	43.0220	c	7.2370	7.9795	3.30	26.3324
B16	6.9720	7.0605	10.30	72.7232	B17	6.9920	7.1090	7.00	49.7630	B18	7.0760	7.1565	3.80	27.1947
1	6.0070	6.4895	15.00	97.3425	1	7.4770	7.2345	31.30	226.4399	1	7.5220	7.2990	27.60	201.4524
2	6.4920	6.2495	17.50	109.3663	2	5.0930	6.2850	23.00	144.5550	2	5.3690	6.4455	20.00	128.9100
3	6.0530	6.2725	10.00	62.7250	3	4.2780	4.6855	9.00	42.1695	3	4.6390	5.0040	10.00	50.0400
4	5.1200	5.5865	10.00	55.8650	4	4.3780	4.3280	10.00	43.2800	4	4.4490	4.5440	10.00	45.4400
5	4.5500	4.8350	10.00	48.3500	5	4.3780	4.3780	10.00	43.7800	5	4.4690	4.4590	10.00	44.5900
6	4.3500	4.4500	10.00	44.5000	6	4.4180	4.3980	10.00	43.9800	6	4.6090	4.5390	10.00	45.3900
7	4.2300	4.2900	10.00	42.9000	7	4.2480	4.3330	10.00	43.3300	7	4.5490	4.5790	10.00	45.7900
8	4.0620	4.1460	31.00	128.5260	8	4.1480	4.1980	10.00	41.9800	8	4.1140	4.3315	10.00	43.3150
8'	3.9630	4.0125	18.20	73.0275	9	3.8880	4.0180	10.00	40.1800	8'	4.0000	4.0570	12.10	49.0897
					9'	3.8180	3.8530	2.70	10.4031					
			173.00					170.00					166.00	
Section Area (in−m2)				978.3104					1,033.0848					1,049.1540

*) Refer to datum −6 m

Table A.9. The Data of Cross Sections B.1, B.2, B.3, Measured in August 1993

Section B1					Section B2					Section B3				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
a'	7.8200				B2'	7.9260				B3'	7.9800			
a	8.0370	7.9285	12.00	95.1420	B2	8.3790	8.1525	18.00	146.7450	B3	8.1020	8.0410	15.00	120.6150
B1	8.0060	8.0215	12.00	96.2580	a	8.1130	8.2460	26.50	218.5190	a	8.2310	8.1665	13.50	110.2478
b	8.1680	8.0870	10.00	80.8700	b	5.7506	6.9315	20.00	138.6300	b	7.9370	8.0840	1.00	8.0840
c	8.0100	8.0890	10.00	80.8900	c	5.0690	5.4095	10.00	54.0950	c	8.0960	8.0165	25.00	200.4125
d	5.4950	6.7525	10.00	67.5250	d	5.4540	5.2615	10.00	52.6150	d	5.5600	6.8280	20.00	136.5600
e	5.2460	5.3705	10.00	53.7050	e	5.2490	5.3515	10.00	53.5150	e	5.1410	5.3505	10.00	53.5050
f	5.0350	5.1405	10.00	51.4050	f	5.1440	5.1965	10.00	51.9650	f	5.4300	5.2855	10.00	52.8550
g	5.1100	5.0725	10.00	50.7250	g	4.9090	5.0265	10.00	50.2650	g	5.3320	5.3810	10.00	53.8100
h	5.0200	5.0650	10.00	50.6500	h	4.6890	4.7990	10.00	47.9900	h	5.1570	5.2445	10.00	52.4450
i	4.6700	4.8450	10.00	48.4500	i	4.2740	4.4815	10.00	44.8150	i	4.9600	5.0585	10.00	50.5850
j	4.3000	4.4850	10.00	44.8500	j	3.7490	4.0115	10.00	40.1150	j	4.6350	4.7975	10.00	47.9750
k	3.8700	4.0850	10.00	40.8500	j'	2.3580	3.0535	26.50	80.9178	k	4.1750	4.4050	10.00	44.0500
k'	2.1930	3.0315	39.00	118.2285						l	3.8850	4.0300	10.00	40.3000
										l'	3.3200	3.6025	19.50	70.2488
			163.00					171.00					174.00	
Section Area (in−m2)				879.5485					980.1868					1,041.6930

*) Refer to datum −6 m

Table A.10. The Data of Cross Sections L1.3, B.4, B.5, Measured in August 1993

Section L1.3					Section B4					Section B5				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
L1.3'	7.6000				a'	7.6300				B5'''	7.5040			
L1.3	8.0740	7.8370	14.00	109.7180	a	8.8990	8.2645	15.00	123.9675	B5"	7.7160	7.6100	26.00	197.8600
a	8.0200	8.0470	20.00	160.9400	B4	8.7810	8.8400	13.00	114.9200	B5'	9.0220	8.3690	4.00	33.4760
b	8.0110	8.0155	24.80	198.7844	b	8.0250	8.4030	14.30	120.1629	B5	9.4940	9.2580	12.00	111.0960
c	5.8330	6.9220	20.00	138.4400	c	7.8460	7.9355	21.70	172.2004	a	7.7320	8.6130	2.50	21.5325
d	5.0040	5.4185	10.00	54.1850	d	6.1520	6.9990	20.00	139.9800	b	7.6130	7.6725	29.50	226.3388
e	5.4030	5.2035	10.00	52.0350	e	5.0710	5.6115	10.00	56.1150	c	6.3140	6.9635	20.00	139.2700
f	5.3630	5.3830	10.00	53.8300	f	4.9080	4.9895	10.00	49.8950	d	5.5230	5.9185	10.00	59.1850
g	5.1730	5.2680	10.00	52.6800	g	5.3130	5.1105	10.00	51.1050	e	5.0430	5.2830	10.00	52.8300
h	5.0030	5.0880	10.00	50.8800	h	5.2380	5.2755	10.00	52.7550	f	4.7230	4.8830	10.00	48.8300
i	4.6530	4.8280	10.00	48.2800	i	5.0230	5.1305	10.00	51.3050	g	4.8930	4.8080	10.00	48.0800
j	4.3330	4.4930	10.00	44.9300	j	4.7130	4.8680	10.00	48.6800	h	5.1230	5.0080	10.00	50.0800
k	3.9130	4.1230	10.00	41.2300	k	4.3230	4.5180	10.00	45.1800	i	4.9830	5.0530	10.00	50.5300
k'	3.0220	3.4675	21.20	73.5110	l	3.9330	4.1280	10.00	41.2800	j	4.7730	4.8780	10.00	48.7800
					m	3.6030	3.7680	10.00	37.6800	k	4.5230	4.6480	10.00	46.4800
					m'	3.1410	3.3720	14.00	47.2080	l	4.2130	4.3680	10.00	43.6800
										m	3.7830	3.9980	10.00	39.9800
										m'	3.2240	3.5035	13.00	45.5455
			180.00					188.00					207.00	
Section Area (in−m2)				1,079.4434					1,152.4338					1,263.5738

*) Refer to datum −6 m

Table A.11. The Data of Cross Sections B.13, B.14, B.15, Measured in August 1993

Section B13					Section B14					Section B15				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
a"	7.6710				a"	8.2000				a'	8.5000			
a'	7.7160	7.6935	17.00	130.7895	a'	8.0000	8.1000	23.00	186.3000	a	7.6050	8.0525	15.00	120.7875
a	8.9460	8.3310	4.00	33.3240	a	8.9320	8.4660	3.00	25.3980	B15	7.4780	7.5415	13.20	99.5478
B13	8.9260	8.9360	11.50	102.7640	B14	8.8660	8.8990	10.00	88.9900	b	5.8970	6.6875	21.60	144.4500
b	7.6520	8.2890	3.20	26.5248	b	7.1500	8.0080	14.50	116.1160	c	5.4980	5.6975	10.00	56.9750
c	7.4510	7.5515	11.60	87.5974	c	6.0130	6.5815	10.00	65.8150	d	5.4000	5.4490	10.00	54.4900
d	6.3580	6.9045	10.00	69.0450	d	5.3580	5.6855	10.00	56.8550	e	5.2920	5.3460	10.00	53.4600
e	6.2530	6.3055	10.00	63.0550	e	5.3090	5.3335	10.00	53.3350	f	5.1440	5.2180	10.00	52.1800
f	5.3180	5.7855	10.00	57.8550	f	5.2380	5.2735	10.00	52.7350	g	5.0320	5.0880	10.00	50.8800
g	5.2770	5.2975	10.00	52.9750	g	5.1350	5.1865	10.00	51.8650	h	4.8170	4.9245	10.00	49.2450
h	5.1680	5.2225	10.00	52.2250	h	5.0780	5.1065	10.00	51.0650	i	4.7470	4.7820	10.00	47.8200
i	5.2270	5.1975	10.00	51.9750	i	5.0250	5.0515	10.00	50.5150	j	4.5020	4.6245	10.00	46.2450
j	4.9920	5.1095	10.00	51.0950	j	5.0410	5.0330	10.00	50.3300	k	4.2670	4.3845	10.00	43.8450
k	4.6470	4.8195	10.00	48.1950	k	4.9880	5.0145	10.00	50.1450	l	4.0620	4.1645	10.00	41.6450
l	4.5170	4.5820	10.00	45.8200	l	4.9580	4.9730	10.00	49.7300	m	4.0820	4.0720	10.00	40.7200
m	4.8870	4.7020	10.00	47.0200	m	4.6980	4.8280	10.00	48.2800	n	4.0220	4.0520	10.00	40.5200
n	4.9270	4.9070	10.00	49.0700	n	4.4810	4.5895	10.00	45.8950	n'	3.9910	4.0065	5.20	20.8338
o	4.6370	4.7820	10.00	47.8200	n'	4.3250	4.4030	7.50	33.0225					
o'	4.2690	4.4530	12.70	56.5531										
			180.00					178.00					175.00	
Section Area (in−m2)				1,073.7028					1,076.3915					963.6441

*) Refer to datum −6 m

Table A.12. The Data of Cross Sections B.16, B.17, B.18, Measured in August 1993

Section B16					Section B17					Section B18				
Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)	Point	Depth *)	Avg. Depth	Dist. (m)	Area (m2)
a'	8.4000				a'	8.6500				a'	8.6000			
a	8.0450	8.2225	11.00	90.4475	a	7.9810	8.3155	19.00	157.9945	a	8.1360	8.3680	29.00	242.6720
B16	8.0630	8.0540	12.00	96.6480	B17	8.2620	8.1215	10.00	81.2150	B18	8.6990	8.4175	10.00	84.1750
b	5.6430	6.8530	20.00	137.0600	b	7.5350	7.8985	1.80	14.2173	b	8.6500	8.6745	1.60	13.8792
c	5.3100	5.4765	10.00	54.7650	c	6.4030	6.9690	20.00	139.3800	c	7.6480	8.1490	1.60	13.0384
d	5.2380	5.2740	10.00	52.7400	d	5.1220	5.7625	10.00	57.6250	d	6.5450	7.0965	10.00	70.9650
e	5.2080	5.2230	10.00	52.2300	e	5.1770	5.1495	10.00	51.4950	e	5.5440	6.0445	10.00	60.4450
f	5.0330	5.1205	10.00	51.2050	f	5.0020	5.0895	10.00	50.8950	f	5.0840	5.3140	10.00	53.1400
g	4.7940	4.9135	10.00	49.1350	g	4.6500	4.8260	10.00	48.2600	g	5.2460	5.1650	10.00	51.6500
h	4.5280	4.6610	10.00	46.6100	h	4.3820	4.5160	10.00	45.1600	h	5.1410	5.1935	10.00	51.9350
i	4.3780	4.4530	10.00	44.5300	i	4.3680	4.3750	10.00	43.7500	i	4.8960	5.0185	10.00	50.1850
j	4.1280	4.2530	10.00	42.5300	j	3.8670	4.1175	10.00	41.1750	j	4.5760	4.7360	10.00	47.3600
k	3.9180	4.0230	10.00	40.2300	k	3.6680	3.7675	10.00	37.6750	k	4.3460	4.4619	10.00	44.6100
l	3.8180	3.8680	10.00	38.6800	l	3.5420	3.6050	10.00	36.0500	l	4.0760	4.2110	10.00	42.1100
l'	3.5180	3.6680	30.00	110.0400	m	3.2920	3.4170	10.00	34.1700	m	3.6760	3.8760	10.00	38.7600
					m'	2.8120	3.0520	19.20	58.5984	n	3.6360	3.6560	10.00	36.5600
										o	3.2860	3.4610	10.00	34.6100
										o'	3.1530	3.2195	3.80	12.2341
			173.00					170.00					166.00	
Section Area (in−m2)				906.8505					897.6602					948.3287

*) Refer to datum −6 m

Table A.13. The Data of Beach Slope

Crs.Sec.No	May 1992	May 1993	Aug.1993
Left Jetty			
B1	0.034145	0.043609	0.026750
B2	0.023160	0.041495	0.043640
B3	0.021744	0.035390	0.042110
L1.3	0.020560	0.041575	0.040980
B4	0.017616	0.029667	0.038573
B5	0.025709	0.025338	0.034818
Average	0.023822	0.036179	0.037812
Right Jetty			
B13	0.028114	0.022219	0.022910
B14	0.025691	0.037212	0.031785
B15	0.011000	0.032544	0.024407
B16	0.028213	0.033444	0.035375
B17	0.027057	0.025174	0.035358
B18	0.030551	0.027528	0.036350
Average	0.025104	0.029687	0.031031

Appendix B

The Data of Wind Speed and Direction of Blang Bintang Station

The Data of Wind Speed and Direction of Alue Naga Station

The Data of Significant Wave Height and Period of Alue Naga Station

Table B.1. Average Wind Speed Data of Blang Bintang Station in The Period of January 1990 to June 1990

	January 1990			February 1990			March 1990			April 1990			May 1990			June 1990	
Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)
1	5.0	130.0	1	6.0	120.0	1	6.0	150.0	1	6.0	150.0	1	4.0	270.0	1	5.0	260.0
2	6.0	150.0	2	7.0	130.0	2	8.0	60.0	2	8.0	40.0	2	6.0	170.0	2	6.0	270.0
3	6.0	150.0	3	6.0	180.0	3	8.0	50.0	3	6.0	150.0	3	5.0	170.0	3	5.0	270.0
4	6.0	160.0	4	8.0	90.0	4	10.0	50.0	4	5.0	130.0	4	6.0	150.0	4	6.0	290.0
5	6.0	120.0	5	7.0	90.0	5	8.0	60.0	5	6.0	120.0	5	5.0	150.0	5	10.0	290.0
6	10.0	160.0	6	10.0	70.0	6	8.0	60.0	6	8.0	130.0	6	5.0	160.0	6	8.0	270.0
7	6.0	170.0	7	6.0	150.0	7	5.0	150.0	7	7.0	180.0	7	5.0	160.0	7	7.0	270.0
8	6.0	150.0	8	8.0	150.0	8	5.0	150.0	8	8.0	130.0	8	5.0	160.0	8	5.0	270.0
9	5.0	170.0	9	8.0	160.0	9	5.0	140.0	9	5.0	190.0	9	6.0	60.0	9	6.0	250.0
10	7.0	150.0	10	8.0	160.0	10	4.0	150.0	10	7.0	360.0	10	5.0	160.0	10	8.0	170.0
11	7.0	130.0	11	6.0	140.0	11	4.0	140.0	11	4.0	50.0	11	4.0	120.0	11	5.0	240.0
12	4.0	250.0	12	7.0	150.0	12	10.0	40.0	12	6.0	160.0	12	4.0	160.0	12	6.0	170.0
13	6.0	170.0	13	8.0	150.0	13	7.0	180.0	13	5.0	150.0	13	5.0	170.0	13	5.0	270.0
14	6.0	150.0	14	6.0	120.0	14	5.0	150.0	14	5.0	130.0	14	5.0	150.0	14	6.0	250.0
15	5.0	190.0	15	6.0	140.0	15	8.0	170.0	15	5.0	160.0	15	6.0	270.0	15	5.0	290.0
16	5.0	140.0	16	5.0	170.0	16	6.0	170.0	16	5.0	170.0	16	6.0	270.0	16	5.0	260.0
17	4.0	150.0	17	5.0	170.0	17	5.0	70.0	17	6.0	30.0	17	4.0	150.0	17	8.0	260.0
18	5.0	80.0	18	5.0	140.0	18	6.0	90.0	18	6.0	170.0	18	5.0	270.0	18	10.0	270.0
19	5.0	130.0	19	6.0	120.0	19	8.0	170.0	19	5.0	160.0	19	6.0	260.0	19	8.0	260.0
20	5.0	20.0	20	7.0	160.0	20	6.0	150.0	20	5.0	290.0	20	6.0	250.0	20	8.0	260.0
21	6.0	200.0	21	6.0	150.0	21	6.0	150.0	21	6.0	270.0	21	5.0	270.0	21	7.0	270.0
22	6.0	130.0	22	7.0	140.0	22	5.0	160.0	22	6.0	290.0	22	5.0	270.0	22	8.0	270.0
23	5.0	170.0	23	8.0	120.0	23	5.0	160.0	23	6.0	280.0	23	5.0	150.0	23	7.0	270.0
24	6.0	150.0	24	6.0	140.0	24	6.0	70.0	24	5.0	250.0	24	6.0	270.0	24	8.0	260.0
25	8.0	150.0	25	7.0	60.0	25	5.0	140.0	25	5.0	240.0	25	4.0	270.0	25	7.0	270.0
26	7.0	150.0	26	5.0	110.0	26	6.0	150.0	26	5.0	140.0	26	5.0	250.0	26	6.0	290.0
27	8.0	110.0	27	8.0	120.0	27	6.0	170.0	27	7.0	50.0	27	5.0	260.0	27	8.0	290.0
28	8.0	150.0	28	5.0	60.0	28	5.0	170.0	28	6.0	90.0	28	5.0	260.0	28	6.0	
29	8.0	150.0				29	5.0	160.0	29	5.0	140.0	29	6.0	180.0	29	6.0	
30	8.0	60.0				30	5.0	130.0	30	6.0	270.0	30	7.0	290.0	30	6.0	
31	10.0	170.0				31	6.0	150.0				31	8.0	290.0			

Table B.2. Average Wind Speed Data of Blang Bintang Station in The Period of July 1990 to December 1990

July 1990			August 1990			September 1990			October 1990			November 1990			December 1990		
Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)
1	2.0	315.0	1	2.0	315.0	1	4.0	270.0	1	5.0	270.0	1	4.4	135.0	1		
2	4.0	270.0	2	5.0	270.0	2	2.0	90.0	2	5.0	315.0	2	4.6	135.0	2		
3	4.0	270.0	3	5.0	270.0	3	2.0	90.0	3	4.0	225.0	3	7.0	135.0	3		
4	5.0	270.0	4	4.0	270.0	4	5.0	225.0	4	5.5	225.0	4	7.4	135.0	4		
5	3.0	180.0	5	5.0	270.0	5	5.0	225.0	5	3.0	225.0	5	4.3	135.0	5		
6	4.0	180.0	6	3.0	225.0	6	4.0	135.0	6	4.0	45.0	6	5.4	135.0	6		
7	3.0	270.0	7	3.0	270.0	7	3.0	135.0	7	2.0	45.0	7	5.0	135.0	7		
8	3.0	315.0	8	5.0	270.0	8	3.0	135.0	8	4.0	135.0	8	4.3	135.0	8		
9	3.0	315.0	9	2.0	270.0	9	4.0	180.0	9	4.0	180.0	9	3.7	135.0	9		
10	5.0	270.0	10	4.0	135.0	10	2.0	315.0	10	9.0	180.0	10	4.3	135.0	10		
11	5.0	270.0	11	6.0	225.0	11	2.0	315.0	11	2.0	225.0	11	3.2	135.0	11		
12	2.0	270.0	12	6.0	180.0	12	3.0	315.0	12	8.0	315.0	12	2.0	135.0	12		
13	1.0	270.0	13	6.0	180.0	13	4.0	225.0	13	2.0	225.0	13	2.4	45.0	13		
14	1.0	270.0	14	4.0	225.0	14	4.0	225.0	14	5.0	315.0	14	2.1	45.0	14		
15	2.0	180.0	15	3.0	270.0	15	4.0	315.0	15	5.0	315.0	15	3.0	135.0	15		
16	3.0	270.0	16	6.0	225.0	16	3.0	270.0	16	3.0	315.0	16	4.8	135.0	16		
17	2.0	270.0	17	10.0	225.0	17	3.0	270.0	17	6.0	270.0	17	0.9	135.0	17		
18	1.0	270.0	18	9.0	225.0	18	7.0	225.0	18	2.0	315.0	18	2.0	135.0	18		
19	2.0	270.0	19	8.0	180.0	19	3.0	225.0	19	4.0	360.0	19	1.4	135.0	19		
20	1.0	270.0	20	8.0	225.0	20	2.0	270.0	20	4.0	360.0	20	1.5	135.0	20		
21	1.0	270.0	21	7.0	180.0	21	4.0	270.0	21	3.0	135.0	21	4.0	90.0	21		
22	2.0	270.0	22	6.0	225.0	22	3.0	315.0	22	6.0	360.0	22	2.9	135.0	22		
23	1.0	270.0	23	6.0	135.0	23	6.0	315.0	23	2.0	135.0	23	5.0	90.0	23		
24	1.0	270.0	24	4.0	135.0	24	3.0	315.0	24	5.0	270.0	24	6.1	135.0	24		
25	4.0	270.0	25	6.0	135.0	25	6.0	315.0	25	1.0	315.0	25	4.3	135.0	25		
26	4.0	270.0	26	5.0	135.0	26	2.0	270.0	26	3.0	180.0	26	4.0	135.0	26		
27	1.0	270.0	27	4.0	135.0	27	2.0	270.0	27	2.0	315.0	27	6.0	90.0	27		
28	2.0	270.0	28	4.0	225.0	28	2.0	315.0	28	4.0	135.0	28	5.3	135.0	28		
29	1.0	270.0	29	4.0	225.0	29	2.0	225.0	29	4.0	135.0	29	5.6	135.0	29		
30	2.0	270.0	30	6.0	225.0	30	3.0	225.0	30	1.0	45.0	30	5.5	135.0	30		
31	2.0	270.0	31	4.0	225.0				31	1.0	45.0				31		

Note : Data of the month of December is not available

Table B.3. Average Wind Speed Data of Blang Bintang Station in The Period of January 1991 to June 1991

January 1991			February 1991			March 1991			April 1991			May 1991			June 1991		
Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)
1	3.2	135.0	1	4.4	135.0	1	3.0	180.0	1	3.0	180.0	1	1.8	360.0	1	3.1	135.0
2	3.6	135.0	2	3.2	135.0	2	4.0	360.0	2	5.0	90.0	2	2.0	135.0	2	1.7	270.0
3	2.8	135.0	3	4.6	135.0	3	2.0	360.0	3	6.0	135.0	3	3.0	135.0	3	3.6	45.0
4	4.0	180.0	4	3.0	135.0	4	3.0	135.0	4	3.0	135.0	4	2.0	360.0	4	3.1	45.0
5	4.5	135.0	5	4.0	135.0	5	4.0	45.0	5	2.0	135.0	5	2.0	270.0	5	2.3	135.0
6	5.9	135.0	6	2.9	135.0	6	3.0	45.0	6	2.0	360.0	6	3.0	270.0	6	2.3	45.0
7	3.7	135.0	7	2.8	180.0	7	4.0	135.0	7	4.0	135.0	7	3.0	135.0	7	3.6	45.0
8	5.1	180.0	8	3.1	180.0	8	4.0	45.0	8	3.0	180.0	8	2.1	135.0	8	2.4	45.0
9	6.4	135.0	9	2.0	360.0	9	4.0	45.0	9	2.0	315.0	9	3.2	135.0	9	2.1	135.0
10	4.3	135.0	10	1.5	360.0	10	5.0	90.0	10	3.0	315.0	10	3.0	180.0	10	3.2	225.0
11	5.3	135.0	11	2.9	45.0	11	5.0	45.0	11	2.0	135.0	11	2.9	135.0	11	1.5	225.0
12	4.5	90.0	12	5.0	45.0	12	3.0	360.0	12	2.0	135.0	12	2.0	270.0	12	1.9	225.0
13	2.7	180.0	13	2.7	45.0	13	3.0	360.0	13	4.0	315.0	13	3.0	315.0	13	3.3	180.0
14	3.8	155.0	14	2.1	315.0	14	3.0	360.0	14	2.0	135.0	14	3.0	135.0	14	1.9	135.0
15	3.2	180.0	15	4.5	135.0	15	3.0	135.0	15	1.0	360.0	15	2.2	180.0	15	2.1	225.0
16	6.4	90.0	16	3.0	135.0	16	5.0	360.0	16	2.0	180.0	16	3.0	180.0	16	2.7	270.0
17	5.4	135.0	17	3.2	180.0	17	3.0	360.0	17	1.0	360.0	17	3.3	180.0	17	2.9	270.0
18	3.4	135.0	18	2.0	180.0	18	3.0	360.0	18	3.0	360.0	18	1.7	135.0	18	1.9	135.0
19	3.2	135.0	19	4.0	180.0	19	4.0	135.0	19	2.0	360.0	19	3.3	135.0	19	2.4	135.0
20	5.3	135.0	20	4.0	135.0	20	3.0	135.0	20	1.0	360.0	20	2.0	135.0	20	2.5	315.0
21	2.9	135.0	21	3.6	90.0	21	2.0	135.0	21	2.0	315.0	21	2.8	135.0	21	1.5	225.0
22	4.7	135.0	22	5.4	135.0	22	2.0	135.0	22	3.0	270.0	22	3.0	180.0	22	3.8	180.0
23	4.9	180.0	23	8.5	135.0	23	3.0	360.0	23	3.0	180.0	23	4.0	135.0	23	2.1	135.0
24	4.2	135.0	24	5.9	135.0	24	2.0	180.0	24	2.0	270.0	24	2.0	135.0	24	3.0	315.0
25	3.8	135.0	25	4.0	135.0	25	4.0	45.0	25	3.0	135.0	25	1.8	135.0	25	3.4	45.0
26	2.5	135.0	26	4.4	135.0	26	3.0	135.0	26	3.0	270.0	26	2.6	135.0	26	1.4	45.0
27	3.1	135.0	27	5.0	135.0	27	3.0	180.0	27	3.5	270.0	27	2.5	135.0	27	1.7	135.0
28	2.9	180.0	28	2.5	135.0	28	3.0	180.0	28	2.0	360.0	28	2.0	135.0	28	0.8	45.0
29	4.4	135.0				29	4.0	45.0	29	2.0	360.0	29	1.7	45.0	29	2.4	315.0
30	4.7	45.0				30	4.0	45.0	30	3.0	315.0	30	3.0	180.0	30	1.7	135.0
31	4.2	180.0				31	3.0	180.0				31	2.0	180.0			

Table B.4. Average Wind Speed Data of Blang Bintang Station in The Period of July 1991 to December 1991

July 1991			August 1991			September 1991			October 1991			November 1991			December 1991		
Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)
1	2.0	135.0	1	3.0	270.0	1	3.0	180.0	1	4.0	45.0	1	4.0	180.0	1	2.0	360.0
2	2.0	135.0	2	3.0	360.0	2	0.1	180.0	2	4.0	45.0	2	1.5	135.0	2	3.0	135.0
3	1.2	180.0	3	2.5	270.0	3	3.0	270.0	3	4.0	45.0	3	4.0	135.0	3	4.0	315.0
4	3.0	135.0	4	3.0	360.0	4	3.0	135.0	4	3.0	45.0	4	3.5	135.0	4	4.0	315.0
5	2.5	135.0	5	2.0	180.0	5	2.0	180.0	5	4.0	360.0	5	5.0	135.0	5	5.9	90.0
6	2.7	225.0	6	2.7	180.0	6	7.0	225.0	6	5.0	180.0	6	4.0	270.0	6	5.0	135.0
7	1.4	225.0	7	2.0	135.0	7	4.0	270.0	7	3.0	315.0	7	4.0	315.0	7	6.0	135.0
8	1.7	225.0	8	2.0	270.0	8	6.0	225.0	8	2.0	135.0	8	3.0	135.0	8	5.0	315.0
9	7.3	135.0	9	1.3	135.0	9	3.0	135.0	9	5.0	225.0	9	4.0	315.0	9	5.0	315.0
10	1.7	270.0	10	0.1	360.0	10	1.0	180.0	10	5.0	225.0	10	4.5	135.0	10	5.0	135.0
11	1.7	315.0	11	1.0	270.0	11	2.0	135.0	11	2.0	270.0	11	3.5	135.0	11	5.0	135.0
12	2.6	225.0	12	2.2	180.0	12	3.0	270.0	12	4.0	135.0	12	4.0	135.0	12	5.2	135.0
13	1.4	225.0	13	2.5	180.0	13	3.0	315.0	13	3.0	270.0	13	8.0	135.0	13	4.0	135.0
14	3.4	135.0	14	2.7	225.0	14	4.0	135.0	14	2.0	135.0	14	6.0	135.0	14	5.7	135.0
15	3.0	270.0	15	3.6	180.0	15	5.0	180.0	15	2.0	135.0	15	6.0	135.0	15	5.0	135.0
16	3.5	180.0	16	6.0	180.0	16	5.0	315.0	16	4.0	315.0	16	4.5	135.0	16	6.0	315.0
17	2.3	180.0	17	5.0	270.0	17	5.0	315.0	17	4.0	225.0	17	4.0	180.0	17	7.0	135.0
18	3.5	315.0	18	4.0	135.0	18	3.0	135.0	18	0.1	270.0	18	3.0	135.0	18	5.0	90.0
19	3.4	135.0	19	5.5	180.0	19	3.0	270.0	19	4.0	270.0	19	6.0	90.0	19	5.0	225.0
20	3.3	180.0	20	3.5	180.0	20	3.0	180.0	20	2.0	180.0	20	2.0	45.0	20	7.0	135.0
21	4.2	225.0	21	3.0	360.0	21	4.0	180.0	21	3.0	180.0	21	2.0	135.0	21	4.0	135.0
22	4.0	270.0	22	3.0	135.0	22	2.0	135.0	22	4.0	315.0	22	4.0	225.0	22	5.0	135.0
23	4.5	270.0	23	2.0	135.0	23	5.0	225.0	23	4.0	315.0	23	4.5	135.0	23	3.0	180.0
24	4.7	270.0	24	5.4	135.0	24	4.0	180.0	24	2.0	180.0	24	5.0	135.0	24	5.0	90.0
25	2.6	225.0	25	5.0	270.0	25	4.0	135.0	25	3.0	270.0	25	4.0	90.0	25	3.0	135.0
26	1.8	225.0	26	4.0	270.0	26	2.0	135.0	26	5.0	225.0	26	4.5	135.0	26	4.2	180.0
27	3.4	270.0	27	3.6	270.0	27	0.1	225.0	27	1.0	180.0	27	5.0	270.0	27	0.3	270.0
28	1.2	45.0	28	3.0	270.0	28	2.0	180.0	28	3.0	270.0	28	2.0	45.0	28	2.0	315.0
29	2.0	315.0	29	3.0	270.0	29	8.0	225.0	29	3.0	135.0	29	1.5	135.0	29	2.6	270.0
30	2.0	135.0	30	3.0	270.0	30	4.0	225.0	30	6.0	135.0	30	4.0	360.0	30	4.0	180.0
31	1.7	315.0							31	7.0	90.0				31	4.0	135.0

Table B.5. Average Wind Speed Data of Blang Bintang Station in The Period of January 1992 to June 1992

January 1992			February 1992			March 1992			April 1992			May 1992			June 1992		
Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)
1	4.0	135.0	1	3.6	180.0	1	2.0	90.0	1	3.0	360.0	1	2.0	135.0	1	3.0	180.0
2	4.0	135.0	2	5.3	135.0	2	5.0	135.0	2	3.0	225.0	2	3.0	135.0	2	2.0	315.0
3	5.0	135.0	3	6.4	135.0	3	4.0	180.0	3	4.0	135.0	3	2.0	135.0	3	2.0	135.0
4	4.0	135.0	4	4.1	135.0	4	3.0	360.0	4	4.0	180.0	4	2.0	270.0	4	3.0	135.0
5	3.0	135.0	5	5.4	90.0	5	4.0	135.0	5	3.0	315.0	5	2.0	180.0	5	3.0	180.0
6	3.6	180.0	6	3.8	135.0	6	6.0	360.0	6	5.0	180.0	6	1.0	360.0	6	2.0	135.0
7	5.0	135.0	7	3.3	180.0	7	4.0	135.0	7	3.0	360.0	7	2.0	360.0	7	3.0	360.0
8	4.0	135.0	8	2.8	45.0	8	3.0	180.0	8	3.0	315.0	8	3.0	135.0	8	3.0	360.0
9	5.6	135.0	9	2.9	135.0	9	3.0	135.0	9	3.0	360.0	9	3.0	135.0	9	2.0	135.0
10	5.0	135.0	10	3.8	135.0	10	4.0	135.0	10	2.0	315.0	10	3.0	135.0	10	2.0	270.0
11	5.3	180.0	11	4.2	180.0	11	6.0	135.0	11	2.0	180.0	11	3.0	135.0	11	4.0	270.0
12	6.0	180.0	12	2.6	45.0	12	6.0	135.0	12	3.0	315.0	12	3.0	135.0	12	2.0	180.0
13	7.0	135.0	13	3.8	45.0	13	5.0	135.0	13	3.0	90.0	13	4.0	135.0	13	3.0	135.0
14	6.0	135.0	14	3.4	360.0	14	6.0	90.0	14	4.0	360.0	14	2.0	270.0	14	2.0	135.0
15	5.0	135.0	15	3.2	360.0	15	5.0	90.0	15	3.0	315.0	15	4.0	270.0	15	1.0	180.0
16	6.0	225.0	16	3.0	360.0	16	4.5	135.0	16	3.0	315.0	16	2.0	360.0	16	3.0	180.0
17	6.8	180.0	17	3.0	135.0	17	5.0	90.0	17	4.0	270.0	17	3.0	315.0	17	4.0	180.0
18	5.8	135.0	18	3.0	180.0	18	6.0	90.0	18	3.0	360.0	18	3.0	225.0	18	2.0	270.0
19	4.0	135.0	19	4.0	180.0	19	5.0	90.0	19	3.6	135.0	19	3.0	360.0	19	2.0	270.0
20	6.0	135.0	20	3.0	135.0	20	6.0	135.0	20	2.0	135.0	20	4.0	135.0	20	2.0	315.0
21	6.0	135.0	21	4.2	360.0	21	4.0	135.0	21	3.0	315.0	21	2.0	315.0	21	2.0	315.0
22	4.0	135.0	22	4.6	180.0	22	6.0	135.0	22	3.0	270.0	22	3.0	135.0	22	2.0	270.0
23	4.4	135.0	23	7.0	135.0	23	5.0	90.0	23	3.0	180.0	23	3.0	180.0	23	4.0	180.0
24	7.0	180.0	24	7.0	135.0	24	3.0	135.0	24	4.0	45.0	24	2.0	180.0	24	3.0	270.0
25	5.0	135.0	25	4.0	135.0	25	4.0	45.0	25	5.0	45.0	25	3.0	180.0	25	2.0	180.0
26	5.0	135.0	26	6.1	135.0	26	5.0	360.0	26	3.0	135.0	26	3.0	180.0	26	4.0	270.0
27	4.2	135.0	27	4.4	135.0	27	4.0	135.0	27	3.0	135.0	27	3.0	180.0	27	4.0	270.0
28	5.0	135.0	28	4.2	135.0	28	5.0	135.0	28	3.0	135.0	28	3.0	180.0	28	2.0	270.0
29	5.0	180.0	29	8.0	135.0	29	3.5	135.0	29	3.0	135.0	29	2.0	90.0	29	3.0	180.0
30	4.0	180.0				30	4.0	90.0	30	4.0	135.0	30	3.0	315.0	30	3.0	180.0
31	4.0	135.0				31	4.0	180.0				31	4.0	270.0			

Table B.6. Average Wind Speed Data of Blang Bintang Station In The Period of July 1992 to December 1992

July 1992			August 1992			September 1992			October 1992			November 1992			December 1992		
Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)
1	3.0	315.0	1	4.0	135.0	1	4.0	180.0	1	2.0	135.0	1	3.0	315.0	1	6.0	180.0
2	2.0	270.0	2	3.0	180.0	2	4.0	315.0	2	2.0	135.0	2	2.0	270.0	2	5.0	135.0
3	3.0	270.0	3	2.0	135.0	3	4.0	180.0	3	3.0	315.0	3	3.0	270.0	3	5.0	135.0
4	3.0	360.0	4	2.0	180.0	4	5.0	315.0	4	4.0	270.0	4	2.0	270.0	4	5.0	90.0
5	2.0	270.0	5	5.0	360.0	5	4.0	180.0	5	2.0	270.0	5	3.0	270.0	5	5.0	135.0
6	3.0	270.0	6	4.0	360.0	6	1.0	180.0	6	2.0	180.0	6	3.0	270.0	6	4.0	135.0
7	3.0	315.0	7	3.0	315.0	7	7.0	360.0	7	2.0	360.0	7	5.0	315.0	7	3.0	135.0
8	2.0	315.0	8	2.0	180.0	8	4.0	270.0	8	2.0	180.0	8	2.0	315.0	8	4.0	135.0
9	4.0	270.0	9	3.0	270.0	9	3.0	270.0	9	2.0	270.0	9	4.0	270.0	9	4.0	135.0
10	3.0	270.0	10	2.0	315.0	10	3.0	270.0	10	2.0	270.0	10	3.0	270.0	10	5.0	135.0
11	2.0	225.0	11	3.0	315.0	11	3.0	135.0	11	3.0	270.0	11	2.0	225.0	11	4.0	135.0
12	3.0	180.0	12	3.0	270.0	12	3.0	270.0	12	4.0	270.0	12	3.0	180.0	12	4.0	135.0
13	3.0	315.0	13	4.0	270.0	13	4.0	270.0	13	2.0	270.0	13	3.0	315.0	13	3.0	135.0
14	3.0	180.0	14	4.0	270.0	14	3.0	315.0	14	3.0	225.0	14	3.0	180.0	14	4.0	135.0
15	3.0	270.0	15	6.0	270.0	15	4.0	315.0	15	2.0	180.0	15	3.0	270.0	15	5.0	135.0
16	4.0	315.0	16	4.0	270.0	16	3.0	180.0	16	3.0	180.0	16	4.0	315.0	16	7.0	135.0
17	3.0	270.0	17	4.0	270.0	17	3.0	315.0	17	2.0	130.0	17	3.0	270.0	17	6.0	135.0
18	4.0	270.0	18	2.0	270.0	18	3.0	270.0	18	2.0	270.0	18	4.0	270.0	18	5.0	90.0
19	5.0	315.0	19	5.0	270.0	19	4.0	270.0	19	2.0	45.0	19	5.0	315.0	19	5.0	135.0
20	4.0	270.0	20	5.0	270.0	20	3.0	270.0	20	2.0	90.0	20	4.0	270.0	20	5.0	135.0
21	4.0	270.0	21	3.0	270.0	21	3.0	135.0	21	2.0	135.0	21	4.0	270.0	21	4.0	135.0
22	3.0	270.0	22	3.0	270.0	22	3.0	135.0	22	3.0	180.0	22	3.0	270.0	22	4.0	135.0
23	4.0	225.0	23	6.0	270.0	23	3.0	135.0	23	5.0	270.0	23	3.0	270.0	23	3.0	135.0
24	4.0	180.0	24	5.0	270.0	24	2.0	315.0	24	2.0	270.0	24	4.0	180.0	24	3.0	135.0
25	4.0	180.0	25	5.0	270.0	25	2.0	135.0	25	2.0	180.0	25	4.0	180.0	25	3.0	135.0
26	5.0	270.0	26	4.0	270.0	26	1.0	360.0	26	2.0	270.0	26	5.0	270.0	26	4.0	135.0
27	5.0	270.0	27	3.0	315.0	27	2.0	180.0	27	3.0	315.0	27	5.0	270.0	27	2.0	90.0
28	4.0	315.0	28	4.0	270.0	28	3.0	135.0	28	2.0	180.0	28	4.0	315.0	28	3.0	135.0
29	2.0	315.0	29	6.0	270.0	29	3.0	360.0	29	3.0	270.0	29	2.0	315.0	29	3.0	135.0
30	2.0	315.0	30	2.0	180.0	30	3.0	360.0	30	3.0	270.0	30	2.0	315.0	30	3.0	135.0
31	2.0	180.0	31	3.0	180.0				31	3.0	270.0				31	6.0	135.0

Table B.7. Average Wind Speed Data of Blang Bintang Station in The Period of January 1993 to June 1993

January 1993			February 1993			March 1993			April 1993			May 1993			June 1993		
Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)
1	5.0	90.0	1	6.0	180.0	1	6.0	135.0	1	3.7	120.0	1	4.0	120.0	1	5.0	300.0
2	6.0	135.0	2	6.0	135.0	2	5.0	90.0	2	2.2	360.0	2	3.0	150.0	2	4.0	260.0
3	5.0	135.0	3	7.0	90.0	3	4.0	135.0	3	2.5	170.0	3	4.0	150.0	3	4.0	240.0
4	5.0	135.0	4	5.0	135.0	4	6.0	90.0	4	2.7	150.0	4	4.0	150.0	4	4.0	170.0
5	4.0	135.0	5	5.0	90.0	5	4.0	135.0	5	2.8	150.0	5	4.0	150.0	5	4.0	230.0
6	5.0	135.0	6	5.0	135.0	6	5.0	135.0	6	3.4	330.0	6	2.0	150.0	6	5.0	300.0
7	6.0	135.0	7	6.0	90.0	7	4.0	90.0	7	3.4	360.0	7	2.0	180.0	7	4.0	170.0
8	7.0	90.0	8	6.0	135.0	8	5.0	135.0	8	2.8	100.0	8	2.0	180.0	8	3.0	120.0
9	6.0	90.0	9	5.0	135.0	9	4.0	135.0	9	2.6	120.0	9	3.0	350.0	9	4.0	300.0
10	6.0	135.0	10	5.0	135.0	10	5.0	135.0	10	4.3	150.0	10	3.0	150.0	10	5.0	180.0
11	6.0	135.0	11	3.0	135.0	11	4.0	135.0	11	2.6	120.0	11	3.0	340.0	11	6.0	300.0
12	5.0	90.0	12	4.0	135.0	12	3.0	135.0	12	2.6	180.0	12	2.0	160.0	12	6.0	180.0
13	4.0	90.0	13	3.0	135.0	13	4.0	135.0	13	3.1	120.0	13	2.0	170.0	13	5.0	270.0
14	3.0	135.0	14	5.0	135.0	14	2.0	135.0	14	4.3	140.0	14	3.0	250.0	14	4.0	290.0
15	5.0	360.0	15	3.0	180.0	15	2.0	180.0	15	2.6	150.0	15	2.0	330.0	15	4.0	160.0
16	4.0	135.0	16	3.0	180.0	16	2.0	180.0	16	3.9	120.0	16	2.0	360.0	16	3.0	310.0
17	4.0	90.0	17	4.0	90.0	17	3.0	90.0	17	2.9	120.0	17	2.0	120.0	17	5.0	290.0
18	3.0	135.0	18	2.0	45.0	18	3.0	135.0	18	3.8	270.0	18	4.0	300.0	18	5.0	300.0
19	5.0	135.0	19	4.0	90.0	19	2.0	360.0	19	1.7	180.0	19	3.0	180.0	19	5.0	280.0
20	5.0	135.0	20	4.0	45.0	20	3.0	135.0	20	2.4	130.0	20	3.0	330.0	20	5.0	290.0
21	1.0	180.0	21	4.0	135.0	21	3.0	180.0	21	2.7	100.0	21	3.0	180.0	21	3.0	330.0
22	4.0	135.0	22	4.0	90.0	22	5.0	90.0	22	3.8	150.0	22	3.0	180.0	22	6.0	270.0
23	4.0	315.0	23	6.0	135.0	23	4.0	90.0	23	3	180.0	23	2.0	160.0	23	6.0	300.0
24	3.0	135.0	24	5.0	135.0	24	4.0	135.0	24	4	120.0	24	2.0	320.0	24	5.0	270.0
25	3.0	135.0	25	5.0	135.0	25	2.0	135.0	25	2	120.0	25	3.0	160.0	25	1.0	300.0
26	4.0	135.0	26	4.0	135.0	26	3.0	270.0	26	1.8	150.0	26	3.0	180.0	26	4.0	300.0
27	3.0	45.0	27	4.0	135.0	27	4.0	45.0	27	2.3	290.0	27	3.0	300.0	27	5.0	290.0
28	3.0	45.0	28	4.0	135.0	28	5.0	45.0	28	2.5	340.0	28	3.0	300.0	28	6.0	300.0
29	5.0	360.0				29	5.0	135.0	29	2.5	330.0	29	3.0	320.0	29	5.0	150.0
30	6.0	135.0				30	2.0	270.0	30	2.4	350.0	30	2.0	300.0	30	10.0	230.0
31	5.0	90.0				31	3.0	270.0				31	2.0	330.0			

Table B.8. Average Wind Speed Data of Blang Bintang Station in The Period of July 1993 to December 1993

July 1993			August 1993			September 1993			October 1993			November 1993			December 1993		
Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)
1	4.0	270.0	1	4.0	270.0												
2	3.0	40.0	2	3.0	130.0												
3	3.0	360.0	3	2.0	160.0												
4	4.0	290.0	4	4.0	330.0												
5	5.0	280.0	5	3.0	160.0												
6	6.0	200.0	6	3.0	220.0												
7	6.0	150.0	7	2.0	150.0												
8	5.0	300.0	8	3.0	270.0												
9	5.0	270.0	9	3.0	290.0												
10	5.0	270.0	10	5.0	240.0												
11	6.0	270.0	11	4.0	240.0												
12	4.0	60.0	12	6.0	260.0												
13	3.0	120.0	13	4.0	180.0												
14	5.0	30.0	14	4.0	360.0												
15	5.0	160.0	15	3.0	180.0												
16	3.0	360.0	16	5.0	270.0												
17	4.0	180.0	17	4.0	360.0												
18	6.0	150.0	18	4.0	150.0												
19	6.0	170.0	19	5.0	300.0												
20	6.0	190.0	20	6.0	330.0												
21	4.0	180.0	21	6.0	270.0												
22	6.0	250.0	22	3.0	180.0												
23	7.0	270.0	23	2.0	300.0												
24	5.0	270.0	24	4.0	270.0												
25	6.0	270.0	25	3.0	260.0												
26	6.0	270.0															
27	5.0	240.0															
28	7.0	270.0															
29	5.0	270.0															
30	6.0	270.0															
31	5.0	240.0															

Note : The available data is up to August 25, 1993

Table B.9. Average Wind Speed Data of Alue Naga Station in The Period of July 1990 to December 1990

July 1990			August 1990			September 1990			October 1990			November 1990			December 1990		
Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)
1	5.5	67.5	1	7.8	22.5	1	8	67.5	1	5.4	67.5	1	2.9	67.5	1	3.1	247.5
2	6.1	67.5	2	7	22.5	2	5.8	67.5	2	6.3	67.5	2	2.4	67.5	2	3.8	247.5
3	4.3	67.5	3	7.2	22.5	3	5.9	67.5	3	5.2	67.5	3	3.3	67.5	3	4.6	247.5
4	5.4	67.5	4	6.7	22.5	4	5.9	67.5	4	7.2	67.5	4	3.2	67.5	4	5	247.5
5	4.4	67.5	5	4.6	22.5	5	4.2	67.5	5	6.6	67.5	5	2.9	67.5	5	4.5	247.5
6	4.7	67.5	6	6.9	22.5	6	4.3	67.5	6	3.5	67.5	6	2.8	112.5	6	4.2	247.5
7	2.5	67.5	7	6.5	22.5	7	5.1	67.5	7	4.2	67.5	7	3.9	112.5	7	5	247.5
8	3.8	67.5	8	4.6	22.5	8	6	67.5	8	5.4	67.5	8	5.3	112.5	8	4	247.5
9	3.3	67.5	9	4.8	22.5	9	5.7	67.5	9	2.7	67.5	9	5.3	112.5	9	3.3	247.5
10	5.6	67.5	10	5.6	22.5	10	5	67.5	10	4.5	67.5	10	6.1	112.5	10	4.2	247.5
11	6	67.5	11	5.7	22.5	11	4.2	22.5	11	3	90	11	5.6	22.5	11	3.5	225
12	4.4	67.5	12	5.8	22.5	12	3.2	22.5	12	2.4	90	12	5.2	22.5	12	2.5	225
13	3.5	67.5	13	6.1	22.5	13	3.1	22.5	13	3.4	90	13	5	22.5	13	2.7	225
14	4.8	67.5	14	7.4	22.5	14	3.6	22.5	14	2.8	90	14	5	22.5	14	2.6	225
15	2.4	67.5	15	8.2	22.5	15	5.8	22.5	15	2.9	90	15	4.8	22.5	15	2.6	225
16	3.7	67.5	16	8.8	22.5	16	8	22.5	16	3	90	16	5.8	22.5	16	3.4	225
17	4.6	67.5	17	8.9	22.5	17	8.6	22.5	17	3.7	90	17	3.2	22.5	17	2.8	225
18	6.1	67.5	18	7.9	22.5	18	8	22.5	18	3	90	18	2.3	22.5	18	2.4	225
19	4.2	67.5	19	6.9	22.5	19	5.3	22.5	19	3.5	90	19	2.5	22.5	19	2	225
20	4.2	67.5	20	7	22.5	20	5.5	22.5	20	3.3	90	20	3.4	22.5	20	2.4	225
21	4.4	22.5	21	6.1	22.5	21	6.5	22.5	21	3.7	202.5	21	4.4	202.5	21	3.9	247.5
22	6.4	22.5	22	6.8	22.5	22	6	22.5	22	4.3	202.5	22	3	202.5	22	3.6	247.5
23	6	22.5	23	5.1	22.5	23	3.9	22.5	23	3.5	202.5	23	2.8	202.5	23	4.3	247.5
24	4.6	22.5	24	5.6	22.5	24	5	67.5	24	3.1	202.5	24	2.4	202.5	24	5	247.5
25	4.2	22.5	25	5.2	22.5	25	3.5	67.5	25	3	202.5	25	4.1	202.5	25	3.9	247.5
26	6.7	22.5	26	5	22.5	26	5.5	67.5	26	4.3	202.5	26	3.8	202.5	26	4.6	247.5
27	6.7	22.5	27	6.4	22.5	27	5.2	45	27	2.9	202.5	27	2.8	202.5	27	3.9	247.5
28	7.5	22.5	28	5.9	22.5	28	4.3	45	28	3.3	202.5	28	2.3	202.5	28	4.7	247.5
29	5.9	22.5	29	5.9	22.5	29	5.1	45	29	2.9	202.5	29	2.4	202.5	29	4.5	247.5
30	7.2	22.5	30	6	22.5	30	5.4	45	30	2.6	202.5	30	3.2	202.5	30	5.3	247.5
31	6.9	22.5	31	6.6	22.5				31	4.5	202.5				31	4.5	247.5

Table B.10. Average Wind Speed Data of Alue Naga Station in The Period of January 1991 to June 1991

January 1991			February 1991			March 1991			April 1991			May 1991			June 1991		
Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)	Date	WindSpeed (m/s)	WindDirect (degree)
1	4.3	225	1	4.3	22.5	1	2.9	22.5	1	2.5	45	1	3.8	337.5	1	3.9	67.5
2	4.3	225	2	4.5	22.5	2	3.9	22.5	2	3.9	45	2	3	337.5	2	4.3	67.5
3	2.3	225	3	3.8	22.5	3	4.6	22.5	3	4.9	45	3	3.3	337.5	3	5.4	67.5
4	4	225	4	2.6	22.5	4	3.7	22.5	4	4	45	4	3.3	360	4	4.2	67.5
5	3.5	225	5	2.9	22.5	5	3.1	22.5	5	3.3	45	5	3.8	360	5	4.5	67.5
6	4.4	225	6	4	22.5	6	4.7	22.5	6	2.5	45	6	5	360	6	7	67.5
7	4.4	225	7	4	22.5	7	5.2	22.5	7	3.5	45	7	3.6	22.5	7	7.8	67.5
8	4.2	225	8	4.2	22.5	8	4.9	22.5	8	3.3	45	8	2.8	22.5	8	4.5	67.5
9	4.2	225	9	2.9	22.5	9	4.8	22.5	9	4.4	45	9	3.2	22.5	9	6.7	67.5
10	3.6	225	10	2.9	22.5	10	4.3	22.5	10	3.9	45	10	3.5	22.5	10	7.5	67.5
11	4.5	225	11	3.4	22.5	11	4.4	22.5	11	3.5	22.5	11	3.9	22.5	11	6.9	22.5
12	4.6	225	12	4.7	22.5	12	4.3	22.5	12	2.9	22.5	12	3.6	22.5	12	5.2	22.5
13	3.6	225	13	4.7	22.5	13	3.2	22.5	13	3.2	22.5	13	2.9	22.5	13	6.8	22.5
14	3.2	225	14	3.5	22.5	14	3	22.5	14	2.7	22.5	14	3	22.5	14	6.9	22.5
15	4.7	225	15	3.6	22.5	15	3.9	22.5	15	3.7	22.5	15	3.5	22.5	15	4.9	22.5
16	4.2	225	16	2.9	22.5	16	4.8	22.5	16	2.8	22.5	16	3.7	22.5	16	7.5	45
17	4.4	225	17	3.2	22.5	17	3.4	22.5	17	3.1	22.5	17	3.3	22.5	17	6.4	45
18	3.3	225	18	3.9	22.5	18	2.9	22.5	18	2.5	22.5	18	3.1	22.5	18	5.3	45
19	3.9	225	19	3.5	22.5	19	3.1	22.5	19	3.6	22.5	19	2.4	22.5	19	6.8	45
20	4.2	225	20	4.1	22.5	20	3.3	22.5	20	2.6	22.5	20	4.8	22.5	20	7.2	45
21	2.9	225	21	4.9	45	21	2.6	22.5	21	2.6	247.5	21	2.9	270	21	5.9	22.5
22	4.6	225	22	4.7	45	22	3.4	22.5	22	2.4	247.5	22	3.8	270	22	6.1	22.5
23	4.6	225	23	6	45	23	3.6	22.5	23	2.3	247.5	23	4.3	270	23	7.2	22.5
24	3.8	225	24	5.6	45	24	3.4	22.5	24	2.4	247.5	24	2.9	270	24	7	22.5
25	4.5	225	25	5.3	45	25	2.5	22.5	25	4.3	247.5	25	3	270	25	6.5	22.5
26	3.2	225	26	4.9	45	26	3.7	22.5	26	3.3	247.5	26	3.1	270	26	7.1	22.5
27	3.4	225	27	3.8	45	27	3.5	22.5	27	3.7	247.5	27	4.5	270	27	6	22.5
28	3.8	225	28	4.5	45	28	2.4	22.5	28	3.2	247.5	28	3	270	28	4.9	22.5
29	3.1	225				29	4.2	22.5	29	2.8	247.5	29	2.2	270	29	3.7	22.5
30	4.5	225				30	2.4	22.5	30	2.5	247.5	30	2.9	270	30	3.9	22.5
31	3	225										31	3.2	270			

Table B.11. The Data of Significant Wave Height and Period of Alue Naga Station in The Period of June 1990 to September 1990

	June 1990						July 1990						August 1990						September 1990					
	time 09:00			time 15:00			time 09:00			time 15:00			time 09:00			time 15:00			time 09:00			time 15:00		
Date	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.
1	0.49	3.50	W	0.26	3.00	W	0.22	2.70	NW	0.46	2.40	NW	0.52	2.20	NW	0.40	2.50	NW	0.36	2.70	NW	0.73	2.70	NW
2	0.89	3.30		0.70	3.10		0.24	2.50		–	–		0.39	2.40		0.89	2.10		0.29	3.10		0.79	2.70	
3	0.50	2.90		0.90	2.70		–	–		–	–		0.33	2.50		1.05	2.40		–	–		0.82	2.70	
4	0.70	3.00		0.50	2.50		0.78	2.70		–	–		0.33	2.50		1.02	2.60		–	–		0.74	2.60	
5	0.50	3.10		0.60	2.60		0.34	2.80		0.66	2.60		0.34	2.30		1.02	2.20		0.25	3.30		0.71	2.70	
6	0.70	2.80		0.60	2.90		0.23	3.10		0.74	2.30		0.30	2.60		1.00	2.20		0.24	2.50		0.79	2.80	
7	–	–	–	0.50	2.80	–	0.26	2.90		0.85	2.90		0.25	2.70		1.04	2.40		0.35	2.60		0.50	2.30	
8	0.40	3.00		0.30	2.80		0.33	2.80		0.72	2.80		0.29	2.50		0.57	2.60		0.20	3.00		0.28	2.80	
9	0.29	2.60		0.49	2.80		0.28	2.50		0.43	2.60		0.32	2.60		0.57	3.20		0.16	2.90		0.23	2.30	
10	0.36	3.30		0.50	2.80		0.29	2.70		0.71	2.30		0.36	3.00		0.39	2.20		0.26	2.60		0.24	2.80	
11	0.46	3.30		0.71	2.90		0.41	2.30		0.68	2.50		0.25	2.70		0.41	2.50		0.24	2.60		0.29	2.30	
12	0.55	3.50		0.43	2.90		0.24	3.30		–	–		0.70	2.80		0.49	2.50		0.24	2.90		0.23	2.70	
13	0.80	3.00		–	–	–	0.27	2.60		0.30	2.30		0.78	2.60		0.40	3.00		0.19	3.10		0.25	2.80	
14	0.79	2.80		0.41	2.60		0.63	2.40		0.44	2.60		0.50	2.60		0.36	2.60		0.25	2.80		0.27	2.70	
15	0.76	3.50		0.43	2.70		0.71	2.90		0.40	2.40		0.38	2.60		0.28	2.70		–	–		–	–	
16	0.76	3.40		0.47	2.70		0.81	2.90		0.36	2.50		0.28	2.70		0.76	2.70		–	–		–	–	
17	0.58	3.30		0.43	2.30		0.68	2.90		0.32	2.60		0.46	2.70		0.82	2.70		–	–		–	–	
18	0.31	2.90		0.31	2.90		0.28	2.70		0.80	2.40		0.37	2.80		0.73	2.60		–	–		–	–	
19	0.45	2.80		0.84	2.60		0.41	2.30		0.74	2.20		0.35	2.30		0.81	2.60		–	–		–	–	
20	0.51	2.80		0.53	2.70		0.27	2.90		0.71	2.70		0.39	3.00		0.61	2.90		–	–		–	–	
21	–	–		0.35	2.90		0.38	2.30		0.38	2.30		0.34	3.00		0.74	2.80		–	–		–	–	
22	0.47	2.50	NW	0.51	2.80	NW	0.33	2.20		0.50	2.60		0.46	3.20		0.51	3.20		–	–		–	–	
23	0.50	2.60		0.41	2.80		0.30	2.60		0.32	2.40		0.22	2.60		0.26	2.80		–	–		–	–	
24	0.52	2.90		0.49	2.90		0.49	2.60		0.44	2.10		0.23	3.20		–	–		0.71	2.70		0.80	2.80	
25	0.36	2.50		0.82	3.10		0.56	2.70		0.44	2.50		0.17	2.70		0.28	2.80		0.32	2.60		0.82	2.60	
26	0.50	2.60		0.56	2.70		0.49	2.50		0.48	2.20		0.15	3.60		0.24	2.90		0.24	2.40		0.86	2.50	
27	0.67	2.70		0.46	2.50		0.47	2.30		0.35	2.30		0.22	2.90		0.24	2.40		0.19	2.50		0.89	2.40	
28	0.80	2.50		0.34	2.60		0.74	2.40		0.43	2.10		0.52	2.70		0.26	2.30		0.29	2.50		0.90	2.30	
29	0.77	2.90		0.32	2.50		0.71	2.50		0.40	2.20		0.29	2.90		0.31	2.50		0.89	2.80		0.89	2.30	
30	0.30	3.10		0.36	2.30		0.61	2.50		0.42	2.30		0.34	2.70		0.44	2.50		0.26	2.30		0.24	2.70	
31							0.39	2.20		0.35	2.10		0.36	2.90		0.51	2.50							

Table B.12. The Data of Significant Wave Height and Period of Alue Naga Station in The Period of October 1990 to January 1991

	October 1990						November 1990						December 1990						January 1991					
	time 09:00			time 15:00			time 09:00			time 15:00			time 09:00			time 15:00			time 09:00			time 15:00		
Date	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.
1	0.20	3.30	NW	0.23	2.30	NW	0.24	2.30	NW	0.52	2.40	NW	0.16	2.60	NE	0.26	2.40	NE	0.61	2.50	NE	0.36	2.30	NE
2	0.17	2.60		0.28	2.70		0.28	2.70		0.43	2.50		0.30	2.20		0.25	2.50		0.63	2.50		0.34	2.40	
3	0.24	2.50		0.29	2.50		0.31	2.70		0.62	2.40		–	–		–	–		0.90	2.60		0.90	2.10	
4	0.30	2.40		0.36	2.50		0.21	2.60		0.40	2.20		–	–		–	–		0.24	2.70		0.20	2.50	
5	0.29	2.40		0.45	2.40		0.30	2.20		0.68	2.30		–	–		–	–		0.19	2.90		0.24	2.40	
6	0.31	2.90		0.45	2.70		0.22	2.40		0.21	2.50		–	–		–	–		0.23	2.50		0.34	2.40	
7	0.39	2.90		0.78	2.50		0.89	2.70		0.26	2.40		–	–		–	–		0.15	2.70		–	–	
8	0.84	2.90		0.78	2.70		0.88	3.10		0.14	2.40		–	–		–	–		0.36	2.70		0.36	2.40	
9	0.22	2.80		0.90	2.70		0.84	2.70		–	–		–	–		0.26	2.40		0.16	2.40		0.31	2.40	
10	0.24	3.10		0.40	2.70		–	–		–	–		0.84	2.20		0.25	2.50		0.22	3.40		0.88	2.20	
11	0.22	3.10		0.88	3.30		–	–		–	–		0.38	2.60		0.33	2.80		0.83	2.60		0.85	2.10	
12	0.23	3.10		0.90	2.90		–	–		–	–		–	–		–	–		0.66	2.80		0.42	2.60	
13	0.88	3.00		0.86	2.70		–	–		–	–		–	–		–	–		0.15	3.00		0.23	2.30	
14	0.16	3.00		0.16	2.50		–	–		–	–		–	–		–	–		0.12	2.70		0.22	2.60	
15	0.16	3.10		0.17	2.40		–	–		–	–		–	–		–	–		0.22	2.50		0.43	2.70	
16	0.12	3.10		0.16	2.70		–	–		–	–		–	–		–	–		0.31	2.50		0.54	2.40	
17	0.13	3.00		0.15	2.60		–	–		–	–		0.29	2.30		0.24	2.60		0.71	2.50		0.53	2.40	
18	0.19	2.90		0.21	3.10		–	–		–	–		0.26	2.60		0.23	2.50		0.71	2.50		0.61	2.50	
19	0.20	3.10		0.14	2.90		–	–		–	–		0.63	2.30		0.34	2.40		0.86	2.80		0.98	2.60	
20	0.21	3.10		0.56	2.50		0.14	3.10	NE	0.89	2.40	NE	0.42	2.40		0.90	2.30		0.17	2.50		0.97	2.40	
21	0.42	2.80		0.86	2.40		0.90	2.70		0.35	2.50		0.90	2.30		0.90	3.10		0.16	2.60		0.30	2.30	
22	0.18	3.10		0.87	2.00		0.90	3.00		0.25	2.60		0.89	2.50		0.34	2.30		0.16	2.80		0.33	1.90	
23	0.66	2.50		0.75	2.10		0.69	2.10		0.26	2.40		0.20	2.70		0.32	2.20		0.18	2.50		0.30	2.20	
24	0.87	2.60		0.14	2.20		0.71	2.50		0.37	2.40		0.23	2.90		0.31	2.40		0.20	2.60		0.30	2.10	
25	0.90	2.60		0.20	2.60		0.62	2.80		0.34	2.40		0.16	2.70		0.27	2.50		0.18	2.90		0.27	2.00	
26	0.90	2.70		0.15	2.60		0.80	2.50		0.35	2.40		0.14	2.70		0.29	2.30		0.94	3.00		–	–	
27	0.88	2.50		0.13	2.70		0.54	2.50		0.35	2.30		0.84	3.10		0.37	2.40		0.51	2.30		0.24	2.40	
28	0.17	2.70		0.61	2.20		0.70	2.60		0.45	2.80		0.50	2.60		0.83	2.50		0.19	2.70		0.18	2.60	
29	0.15	2.40		0.42	2.20		0.17	2.60		0.74	2.90		0.20	2.50		0.68	2.20		0.20	2.50		0.23	2.10	
30	0.20	2.60		0.83	2.20		0.14	2.90		0.66	2.70		0.24	2.20		0.29	2.40		0.23	2.60		0.18	2.00	
31	0.22	2.20		0.63	2.00								0.17	2.50		0.29	2.50		0.18	2.40		0.93	3.10	

Table B.13. The Data of Significant Wave Height and Period of Alue Naga Station in The Period of February 1991 to May 1991

	February 1991						March 1991						April 1991						May 1991					
	time 09:00			time 15:00			time 09:00			time 15:00			time 09:00			time 15:00			time 09:00			time 15:00		
Date	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.	H(1/3)	T(1/3)	direct.
1	0.90	2.50	NE	0.90	2.30	NE	0.21	2.49	NE	0.21	1.82	NE	0.22	1.38	NE	0.90	1.20	NE	–	–	NE	–	–	NW
2	0.89	3.10		0.35	2.60		0.23	2.24		0.26	1.26		0.19	1.92		0.90	1.35		–	–		–	–	
3	0.16	2.80		0.24	2.10		0.90	1.36		0.90	2.65		0.90	1.39		0.90	1.27		–	–		–	–	
4	0.14	2.80		0.24	2.50		0.90	1.62		0.90	1.80		0.90	1.81		0.90	0.97		–	–		–	–	
5	0.13	3.90		0.21	2.30		0.19	2.68		0.59	1.67		0.24	1.77		0.23	1.96		–	–		–	–	
6	0.17	3.40		0.23	2.20		0.19	2.72		0.27	1.85		0.22	2.12		0.23	1.42		–	–		–	–	
7	0.17	3.30		0.22	2.10		0.10	2.40		0.37	1.77		0.36	1.63		0.25	2.69		0.51	3.84		0.22	1.66	
8	0.53	3.20		0.97	3.10		0.15	4.01		0.61	1.36		0.90	1.60	NW	0.25	2.66	NW	0.90	1.59		0.27	1.45	NE
9	0.90	3.00		0.92	2.50		0.11	2.71		0.90	2.25		0.22	1.12		0.90	1.40		0.23	2.14		0.90	1.53	
10	0.94	2.60		0.75	2.20		0.90	1.52		0.90	1.26		0.23	2.02	NE	0.90	1.37	NE	0.26	1.97		0.81	1.29	
11	0.34	2.20		0.54	2.60		0.90	2.90		0.90	1.59		0.20	1.72		0.21	2.12		0.24	1.71		0.33	3.09	
12	0.18	2.20		0.14	2.40		0.20	1.77		0.86	1.43		0.24	2.02		0.34	1.83		0.23	3.97		0.21	1.70	
13	0.11	2.50		0.15	2.20		0.21	1.91		0.33	1.61		0.21	2.12		0.21	3.51		0.19	1.51		0.24	2.14	
14	0.22	2.30		0.16	2.50		0.21	1.75		0.29	1.65		0.21	4.06		0.30	2.07		0.17	2.11		0.23	1.55	
15	0.22	1.43		0.21	1.76		0.20	2.78		0.28	1.52		0.21	2.92		0.27	2.00		0.13	2.05		0.29	1.66	
16	0.16	2.16		0.20	2.79		0.19	1.76		0.33	1.00		–	–		–	–		0.20	2.14		0.89	1.27	
17	0.16	1.59		0.90	1.39		0.12	2.05		0.19	1.59		0.20	2.65		0.22	2.41		0.70	1.88		0.24	2.07	
18	0.90	2.76		0.90	1.20		0.19	1.50		0.23	1.71		0.15	3.41		0.24	2.69		0.38	3.14		0.23	1.79	
19	0.11	2.12		0.33	1.23		0.17	2.44		0.90	2.68		0.11	3.48		0.16	3.09		0.26	2.59		0.26	2.51	
20	0.10	1.49		0.23	1.35		0.90	3.79		0.20	2.07		0.13	2.44	NW	0.18	0.96	NW	0.20	2.70		0.29	1.73	NW
21	0.18	1.50		0.24	1.16		0.12	1.13		0.19	2.44		0.90	1.48		0.23	1.63		0.26	2.32		0.24	1.85	
22	0.28	2.00		0.48	1.47		0.21	1.42		0.16	2.05		0.90	1.43		0.28	1.80		0.90	1.67		0.26	1.63	
23	0.80	1.73		0.79	1.36		0.13	2.79		0.21	2.17		0.39	6.25		0.24	2.12		0.43	2.10		0.90	1.66	
24	0.87	2.25		0.68	1.67		0.90	4.26		0.90	2.29		0.23	1.82		0.81	1.51		0.20	4.21		0.27	1.44	
25	0.90	1.26		0.83	2.04		0.90	1.52		0.67	1.23		0.35	2.70		0.88	1.17		0.24	2.71		0.31	2.27	NE
26	0.25	2.09		0.28	1.51		0.18	3.79		0.89	1.20		0.58	3.16		0.77	1.84		0.20	2.01		0.24	1.19	NW
27	0.24	1.86		0.38	1.74		0.21	1.93		0.28	1.37		0.52	3.84		–	–		0.31	1.61		0.39	2.61	
28	0.25	2.01		0.32	1.18		0.23	2.35		0.27	2.12		–	–		–	–		0.30	2.19		0.32	2.10	
29							0.25	2.66		0.31	1.16		–	–		–	–		0.30	2.31		0.31	1.81	
30							0.21	2.09		0.28	1.49		–	–		–	–		0.38	2.03		0.52	1.98	NE
31							0.18	1.87		0.90	1.62								0.32	3.71		0.75	2.64	NW

Appendix C

The Computer Program for Calculating Longshore Sediment Transport using The Wind Data of Blang Bintang Station

The Computer Program for Calculating Longshore Sediment Transport using The Wave Data of Alue Naga Station

Notations Used in The Computer Program

M	$= m$	: the beach slope,
FR	$= f$	: friction factor of the sea bottom,
RHO	$= \rho$	: the density of sea water,
MO$		: string variable of the period in a month,
H0	$= H_{o\,1/3}$	: significant wave height at the deep water,
T	$= T_{1/3}$	: significant wave period,
A0	$= \alpha_o$	: wave direction at the deep water,
Q		: longshore sediment transport quantity,
COEFF		: correction factor applied for longshore sediment transport calculation refers to the length of period used in calculation,
WBB		: wind speed at Blang Bintang station,
WAN		: wind speed at Alue Naga station,
Ua		: adjusted wind speed due to drag factor,
L0	$= L_o$	: wave length at the deep water,
C0	$= c_o$	: wave celerity at the deep water,
K0	$= k_o$	: the wave number at the deep water,
K		: the value used for calculation of X-value using Newton's method where $K = U^2$ (see Chapter 4),
XOLD, XNEW		: X-value in iteration process where $X = L/L_o$ (see Chapter 4),
D	$= d_b$	: the water depth at the breaker line,
N	$= n$	: the ratio of wave group celerity to wave celerity.
C	$= c_b$	: the wave celerity at the breaker line,

CGI $= c_{gb}$: the wave group celerity at the breaker line,

KAPPA $= \kappa$: the ratio of wave height to the water depth at the breaker line,

KF $= K_f$: correction factor for calculating the wave height at the breaker line,

HI : the wave height at the breaker line before taking into account friction factor,

HB $= H_b$: the wave height at the breaker line,

ALPHA.B $= \alpha_b$: the wave direction at the breaker line,

PLS $= P_{ls}$: the longshore component of wave energy.

The Computer Program IA for Calculating Longshore Sediment Transport

The wind data of Blang Bintang of the period of May 4th, 1992 to May 25th, 1993 is used as data input.

```
DECLARE FUNCTION f! (x!)
DECLARE FUNCTION df! (x!)
CLS
OPEN "B:EF01-00.OUT" FOR OUTPUT AS #1
M = .03
FR = .015
RHO = 1025
DIM MO$(14), H0(14), T(14), A0(14), Q(14), COEFF(14), WBB(14)
FOR I = 1 TO 14
READ MO$(I), WBB(I), A0(I), COEFF(I)
NEXT I
FOR I = 1 TO 14
IF I >= 2 AND I <= 5 THEN WAN = .317475 * WBB(I) + 4.625153
IF I = 1 OR I > 5 THEN WAN = .342075 * WBB(I) + 2.479067
Ua = .71 * WAN ^ (1.23)
H0(I) = 2.482 * (10 ^ (-2)) * Ua ^ 2
T(I) = 8.3 * (10 ^ (-1)) * Ua
NEXT I
sumQ = 0
FOR I = 1 TO 14
L0 = 1.56131 * T(I) ^ 2
C0 = 1.56131 * T(I)
K0 = 2 * 3.14159 / L0
K = 4 * (3.14159) ^ 2 * H0(I) ^ 2 / ((.142) ^ 2 * (9.81) ^ 2 * T(I) ^ 4)
XOLD = (K) ^ (1 / 5)
D = 1
DO WHILE D > 10 ^ (-5)
      XNEW = XOLD - (f(XOLD) - K) / df(XOLD)
      D = ABS(XNEW - XOLD)
      XOLD = XNEW
LOOP
D = 1 / (6.28318) * XNEW * L0 * 1 / 2 * LOG((1 + XNEW) / (1 - XNEW))
N = 1 / 2 * (1 + (1 - XNEW ^ 2) / (2 * XNEW) * LOG((1 + XNEW) / (1 - XNEW)))
C = 1.56131 * T(I) * XNEW
CGI = N * C
KAPPA = 1.16 * (M * (H0(I) / L0) ^ (-1 / 2)) ^ (.22)
KF = (1 + ((FR * H0(I)) / (M * D)) * (COS((A0(I) / 180) * 3.14159)) ^ (1 / 2) * .12 * (K0
* D) ^ (-1 / 4)) ^ (-1)
```

```
HI = ((C0 / (2 * N * C)) ^ (1 / 2)) * H0(I)
SIN.AI = (C * SIN(3.14159 * A0(I) / 180)) / C0
COS.AI = (1 - SIN.AI ^ 2) ^ .5
ALPHA.B = ATN(SIN.AI / COS.AI)
HB = ((KAPPA / 9.81) ^ .5 * KF ^ 2 * HI ^ 2 * CGI * COS.AI) ^ .4
SELECT CASE A0(I)
CASE IS = 58
PLS = -RHO * 9.81 / 16 * HB ^ 2 * CGI * SIN(2 * ALPHA.B)
CASE IS = 32
PLS = RHO * 9.81 / 16 * HB ^ 2 * CGI * SIN(2 * ALPHA.B)
END SELECT
Q(I) = 1290 * PLS * COEFF(I)
PRINT MO$(I), USING "###,###.###"; Q(I)
PRINT #1, MO$(I), USING "Longshore Transport = ###,###.###"; Q(I)
sumQ = sumQ + Q(I)
NEXT I
PRINT USING "Estimated sediment trapped or eroded = ###,###.### m3"; sumQ
PRINT #1, ""
PRINT #1,"==================================="
PRINT #1, USING "Estimated sediment trapped or eroded = ###,###.### m3"; sumQ
END

DATA "May4-May31'92  ",2.741935,58,0.076712
DATA "June1-June30'92 ",2.633333,32,0.082192
DATA "July1-July31'92 ",3.258065,32,0.084932
DATA "Aug1-Aug31'92  ",3.677419,32,0.084932
DATA "Sep1-Sep30'92  ",3.233333,32,0.082192
DATA "Oct1-Oct31'92  ",2.516129,32,0.084932
DATA "Nov1-Nov19'92  ",3.266667,32,0.052055
DATA "Nov20-Nov30'92 ",3.266667,58,0.030137
DATA "Dec1-Dec31'92  ",4.258065,58,0.084932
DATA "Jan1-Jan31'93  ",4.516129,58,0.084932
DATA "Feb1-Feb28'93  ",4.535714,58,0.076712
DATA "Mar1-Mar31'93  ",3.741935,58,0.084932
DATA "Apr1-Apr30'93  ",2.910000,58,0.082192
DATA "May1-May25'93  ",2.774194,58,0.068493

FUNCTION df (x)
    df = 6 * x ^ 4 + (2 * x ^ 3 - 3 * x ^ 5) * LOG((1 + x) / (1 - x))
END FUNCTION

FUNCTION f (x)
    f = x ^ 5 + .5 * LOG((1 + x) / (1 - x)) * (1 - x ^ 2) * x ^ 4
END FUNCTION
```

The Program Output IA-1

The assumptions used are:

1) Sediment Spesific Gravity(ρ_s) = 2,650 kg/m^3
2) Sea water density(ρ) = 1,025 kg/m^3
3) a' = 0.6
4) Gravity acceleration(g) = 9.80 m/s^2

2 regression equations are used

May4-May31'92	Longshore Transport =	-971.892
June1-June30'92	Longshore Transport =	40,730.871
July1-July31'92	Longshore Transport =	52,413.941
Aug1-Aug31'92	Longshore Transport =	60,471.363
Sep1-Sep30'92	Longshore Transport =	50,291.789
Oct1-Oct31'92	Longshore Transport =	2,045.111
Nov1-Nov19'92	Longshore Transport =	1,976.609
Nov20-Nov30'92	Longshore Transport =	-523.116
Dec1-Dec31'92	Longshore Transport =	-2,565.935
Jan1-Jan31'93	Longshore Transport =	-2,940.985
Feb1-Feb28'93	Longshore Transport =	-2,683.663
Mar1-Mar31'93	Longshore Transport =	-1,934.890
Apr1-Apr30'93	Longshore Transport =	-1,153.847
May1-May25'93	Longshore Transport =	-885.141

==============================

Estimated sediment trapped or eroded = **194,270.219** m3

1 regression equation is used

May4-May31'92	Longshore Transport =	-971.892
June1-June30'92	Longshore Transport =	2,129.841
July1-July31'92	Longshore Transport =	3,208.807
Aug1-Aug31'92	Longshore Transport =	4,082.158
Sep1-Sep30'92	Longshore Transport =	3,060.598
Oct1-Oct31'92	Longshore Transport =	2,045.111
Nov1-Nov19'92	Longshore Transport =	1,976.609
Nov20-Nov30'92	Longshore Transport =	-523.116
Dec1-Dec31'92	Longshore Transport =	-2,565.935
Jan1-Jan31'93	Longshore Transport =	-2,940.985
Feb1-Feb28'93	Longshore Transport =	-2,683.663
Mar1-Mar31'93	Longshore Transport =	-1,934.890

Apr1-Apr30'93	Longshore Transport =	-1,153.847
May1-May25'93	Longshore Transport =	-885.141

==============================

Estimated sediment trapped or eroded = **2,843.655** m3

The Program Output IA-2

The assumptions used are:

1) Sediment Spesific Gravity(ρ_s) = 2,650 kg/m^3
2) Sea water density(ρ) = 1,025 kg/m^3
3) a' = 0.6
4) Gravity acceleration(g) = 9.80 m/s^2

Estimation of wind speed at Alue Naga uses 2(two) regression equations, and each equation is deducted by its standard error.

May4-May31'92	Longshore Transport =	-741.206
June1-June30'92	Longshore Transport =	26,081.277
July1-July31'92	Longshore Transport =	34,109.805
Aug1-Aug31'92	Longshore Transport =	39,757.551
Sep1-Sep30'92	Longshore Transport =	32,708.510
Oct1-Oct31'92	Longshore Transport =	1,549.720
Nov1-Nov19'92	Longshore Transport =	1,528.407
Nov20-Nov30'92	Longshore Transport =	-404.498
Dec1-Dec31'92	Longshore Transport =	-2,029.428
Jan1-Jan31'93	Longshore Transport =	-2,338.286
Feb1-Feb28'93	Longshore Transport =	-2,134.527
Mar1-Mar31'93	Longshore Transport =	-1,513.222
Apr1-Apr30'93	Longshore Transport =	-884.013
May1-May25'93	Longshore Transport =	-675.648

==============================

Estimated sediment trapped or eroded = **125,014.445** m3

Estimation of wind speed at Alue Naga uses 2(two) regression equations, and each equation is added by its standard error.

May4-May31'92	Longshore Transport =	-1,259.884
June1-June30'92	Longshore Transport =	61,720.559
July1-July31'92	Longshore Transport =	78,312.117
Aug1-Aug31'92	Longshore Transport =	89,546.641

Sep1-Sep30'92	Longshore Transport =	75,181.984
Oct1-Oct31'92	Longshore Transport =	2,666.739
Nov1-Nov19'92	Longshore Transport =	2,529.993
Nov20-Nov30'92	Longshore Transport =	-669.571
Dec1-Dec31'92	Longshore Transport =	-3,216.434
Jan1-Jan31'93	Longshore Transport =	-3,668.656
Feb1-Feb28'93	Longshore Transport =	-3,346.459
Mar1-Mar31'93	Longshore Transport =	-2,450.793
Apr1-Apr30'93	Longshore Transport =	-1,489.477
May1-May25'93	Longshore Transport =	-1,146.488

==============================

Estimated sediment trapped or eroded = **292,710.313** m3

The Program Output IA-3

Estimated wind speed at Alue Naga in months June, July, Aug., Sept., are multiplied by factors 0.5 up to 1.5

.5	Estimated sediment trapped or eroded =	-6,766 m3
.55	Estimated sediment trapped or eroded =	-4,478 m3
.6	Estimated sediment trapped or eroded =	-826 m3
.65	Estimated sediment trapped or eroded =	4,778 m3
.7	Estimated sediment trapped or eroded =	13,102 m3
.75	Estimated sediment trapped or eroded =	25,121 m3
.8	Estimated sediment trapped or eroded =	42,056 m3
.85	Estimated sediment trapped or eroded =	65,414 m3
.9	Estimated sediment trapped or eroded =	97,028 m3
.95	Estimated sediment trapped or eroded =	139,105 m3
1	Estimated sediment trapped or eroded =	194,270 m3
1.05	Estimated sediment trapped or eroded =	265,626 m3
1.1	Estimated sediment trapped or eroded =	356,799 m3
1.15	Estimated sediment trapped or eroded =	472,006 m3
1.2	Estimated sediment trapped or eroded =	616,109 m3
1.25	Estimated sediment trapped or eroded =	794,685 m3
1.3	Estimated sediment trapped or eroded =	1,014,093 m3
1.35	Estimated sediment trapped or eroded =	1,281,542 m3
1.4	Estimated sediment trapped or eroded =	1,605,171 m3
1.45	Estimated sediment trapped or eroded =	1,994,127 m3
1.5	Estimated sediment trapped or eroded =	2,458,644 m3

Estimated wind speed at Alue Naga in all months are multiplied by factors 0.5 up to 1.5

.5	Estimated sediment trapped or eroded =	2,736 m3
.55	Estimated sediment trapped or eroded =	4,916 m3
.6	Estimated sediment trapped or eroded =	8,395 m3
.65	Estimated sediment trapped or eroded =	13,735 m3
.7	Estimated sediment trapped or eroded =	21,665 m3
.75	Estimated sediment trapped or eroded =	33,116 m3
.8	Estimated sediment trapped or eroded =	49,250 m3
.85	Estimated sediment trapped or eroded =	71,504 m3
.9	Estimated sediment trapped or eroded =	101,624 m3
.95	Estimated sediment trapped or eroded =	141,712 m3
1	Estimated sediment trapped or eroded =	194,270 m3
1.05	Estimated sediment trapped or eroded =	262,253 m3
1.1	Estimated sediment trapped or eroded =	349,117 m3
1.15	Estimated sediment trapped or eroded =	458,879 m3
1.2	Estimated sediment trapped or eroded =	596,171 m3
1.25	Estimated sediment trapped or eroded =	766,307 m3
1.3	Estimated sediment trapped or eroded =	975,344 m3
1.35	Estimated sediment trapped or eroded =	1,230,152 m3
1.4	Estimated sediment trapped or eroded =	1,538,484 m3
1.45	Estimated sediment trapped or eroded =	1,909,057 m3
1.5	Estimated sediment trapped or eroded =	2,351,618 m3

The Program Output IA-4

For different value of sea water density(ρ), ranging from 1,021-1,029 kg/m^3

1021	Estimated sediment trapped or eroded =	193,512 m3
1022	Estimated sediment trapped or eroded =	193,702 m3
1023	Estimated sediment trapped or eroded =	193,891 m3
1024	Estimated sediment trapped or eroded =	194,081 m3
1025	Estimated sediment trapped or eroded =	194,270 m3
1026	Estimated sediment trapped or eroded =	194,460 m3
1027	Estimated sediment trapped or eroded =	194,649 m3
1028	Estimated sediment trapped or eroded =	194,839 m3
1029	Estimated sediment trapped or eroded =	195,028 m3

For different friction value(f) of sea bottom, ranging from 0.01-0.019

.01	Estimated sediment trapped or eroded =	200,579 m3
.011	Estimated sediment trapped or eroded =	199,291 m3
.012	Estimated sediment trapped or eroded =	198,016 m3
.013	Estimated sediment trapped or eroded =	196,754 m3
.014	Estimated sediment trapped or eroded =	195,506 m3
.015	Estimated sediment trapped or eroded =	194,270 m3
.016	Estimated sediment trapped or eroded =	193,047 m3
.017	Estimated sediment trapped or eroded =	191,836 m3
.018	Estimated sediment trapped or eroded =	190,638 m3
.019	Estimated sediment trapped or eroded =	189,451 m3

The Computer Program IB for Calculating Longshore Sediment Transport

The wind data of Blang Bintang of the period May 26th, 1993 to August 18th, 1993 is used as data input.

```
DECLARE FUNCTION f! (x!)
DECLARE FUNCTION df! (x!)
CLS
OPEN "B:EF03-00.OUT" FOR OUTPUT AS #1
M = .03
FR = .015
RHO = 1025
DIM MO$(4), H0(4), T(4), A0(4), Q(4), COEFF(4), WBB(4)
FOR I = 1 TO 4
READ MO$(I), WBB(I), A0(I), COEFF(I)
NEXT I
FOR I = 1 TO 4
IF I > 1 THEN WAN = .317475 * WBB(I) + 4.625153
IF I = 1 THEN WAN = .342075 * WBB(I) + 2.479067
Ua = .71 * WAN ^ (1.23)
H0(I) = 2.482 * (10 ^ (-2)) * Ua ^ 2
T(I) = 8.3 * (10 ^ (-1)) * Ua
NEXT I
sumQ = 0
FOR I = 1 TO 4
Lo = 1.56131 * T(I) ^ 2
C0 = 1.56131 * T(I)
K0 = 2 * 3.14159 / Lo
K = 4 * (3.14159) ^ 2 * H0(I) ^ 2 / ((.142) ^ 2 * (9.81) ^ 2 * T(I) ^ 4)
XOLD = (K) ^ (1 / 5)
D = 1
DO WHILE D > 10 ^ (-5)
      XNEW = XOLD - (f(XOLD) - K) / df(XOLD)
      D = ABS(XNEW - XOLD)
      XOLD = XNEW
LOOP

D = 1 / (6.28318) * XNEW * Lo * 1 / 2 * LOG((1 + XNEW) / (1 - XNEW))
N = 1 / 2 * (1 + (1 - XNEW ^ 2) / (2 * XNEW) * LOG((1 + XNEW) / (1 - XNEW)))
C = 1.56131 * T(I) * XNEW
CGI = N * C
KAPPA = 1.16 * (M * (H0(I) / Lo) ^ (-1 / 2)) ^ (.22)
KF = (1 + ((FR * H0(I)) / (M * D)) * (COS((A0(I) / 180) * 3.14159)) ^ (1 / 2) * .12 * (K0
```

```
* D) ^ (-1 / 4)) ^ (-1)
HI = ((C0 / (2 * N * C)) ^ (1 / 2)) * H0(I)
SIN.AI = (C * SIN(3.14159 * A0(I) / 180)) / C0
COS.AI = (1 - SIN.AI ^ 2) ^ .5
ALPHA.B = ATN(SIN.AI / COS.AI)
HB = ((KAPPA / 9.81) ^ .5 * KF ^ 2 * HI ^ 2 * CGI * COS.AI) ^ .4
SELECT CASE A0(I)
CASE IS = 58
PLS = RHO * 9.81 / 16 * HB ^ 2 * CGI * SIN(2 * ALPHA.B)
CASE IS = 32
PLS = -RHO * 9.81 / 16 * HB ^ 2 * CGI * SIN(2 * ALPHA.B)
END SELECT
Q(I) = 1290 * PLS * COEFF(I)
PRINT MO$(I), USING "###,###.###"; Q(I)
PRINT #1, MO$(I), USING "Longshore Transport = ###,###.###"; Q(I)
sumQ = sumQ + Q(I)
NEXT I
PRINT USING "Estimated sediment trapped or eroded = ###,###.### m3"; sumQ
PRINT #1, ""
PRINT #1,"===================================="
PRINT #1, USING "Estimated sediment trapped or eroded = ###,###.### m3"; sumQ
END

DATA "May26-May31'93  ",2.774194,32,0.016438
DATA "June1-June30'93 ",4.800000,58,0.082192
DATA "July1-July31'93 ",5.032258,58,0.084932
DATA "Aug1-Aug18'93   ",3.800000,58,0.049315

FUNCTION df (x)
      df = 6 * x ^ 4 + (2 * x ^ 3 - 3 * x ^ 5) * LOG((1 + x) / (1 - x))
END FUNCTION

FUNCTION f (x)
      f = x ^ 5 + .5 * LOG((1 + x) / (1 - x)) * (1 - x ^ 2) * x ^ 4
END FUNCTION
```

The Program Output IB-1

The assumptions used are:
1) Sediment Spesific Gravity(ρ_s) = 2,650 kg/m^3
2) Sea water density(ρ) = 1,025 kg/m^3
3) a' = 0.6
4) Gravity acceleration(g) = 9.80 m/s^2

2 regression equations are used

May26-May31'93	Longshore Transport =	-464.703
June1-June30'93	Longshore Transport =	38,620.539
July1-July31'93	Longshore Transport =	42,943.535
Aug1-Aug18'93	Longshore Transport =	16,725.582

================================

Estimated sediment trapped or eroded = **97,824.953** m3

1 regression equation is used

May26-May31'93	Longshore Transport =	-464.703
June1-June30'93	Longshore Transport =	3,295.642
July1-July31'93	Longshore Transport =	3,829.873
Aug1-Aug18'93	Longshore Transport =	1,160.485

================================

Estimated sediment trapped or eroded = **7,821.297** m3

The Program Output IB-2

The assumptions used are:
1) Sediment Spesific Gravity(ρ_S) = 2,650 kg/m^3
2) Sea water density(ρ) = 1,025 kg/m^3
3) a' = 0.6
4) Gravity acceleration(g) = 9.80 m/s^2

Estimation of wind speed at Alue Naga uses 2(two) regression equations, and each equation is deducted by its standard error.

May26-May31'93 Longshore Transport = -354.718

June1-June30'93	Longshore Transport =	26,036.955
July1-July31'93	Longshore Transport =	29,091.387
Aug1-Aug18'93	Longshore Transport =	11,028.298

==============================

Estimated sediment trapped or eroded = **65,801.922** m3

Estimation of wind speed at Alue Naga uses **2(two) regression equations, and each equation is added by its standard error.**

May26-May31'93	Longshore Transport =	-601.912
June1-June30'93	Longshore Transport =	55,940.633
July1-July31'93	Longshore Transport =	61,937.836
Aug1-Aug18'93	Longshore Transport =	24,704.617

==============================

Estimated sediment trapped or eroded = **141,981.188** m3

The Program Output IB-3

Estimated wind speed at Alue Naga in months June, July, Aug., Sept., are multiplied by factors 0.5 up to 1.5

.5	Estimated sediment trapped or eroded =	919 m3
.55	Estimated sediment trapped or eroded =	2,023 m3
.6	Estimated sediment trapped or eroded =	3,783 m3
.65	Estimated sediment trapped or eroded =	6,484 m3
.7	Estimated sediment trapped or eroded =	10,497 m3
.75	Estimated sediment trapped or eroded =	16,290 m3
.8	Estimated sediment trapped or eroded =	24,453 m3
.85	Estimated sediment trapped or eroded =	35,712 m3
.9	Estimated sediment trapped or eroded =	50,951 m3
.95	Estimated sediment trapped or eroded =	71,234 m3
1	Estimated sediment trapped or eroded =	97,825 m3
1.05	Estimated sediment trapped or eroded =	132,220 m3
1.1	Estimated sediment trapped or eroded =	176,169 m3
1.15	Estimated sediment trapped or eroded =	231,702 m3
1.2	Estimated sediment trapped or eroded =	301,164 m3
1.25	Estimated sediment trapped or eroded =	387,243 m3
1.3	Estimated sediment trapped or eroded =	493,003 m3
1.35	Estimated sediment trapped or eroded =	621,922 m3
1.4	Estimated sediment trapped or eroded =	777,921 m3
1.45	Estimated sediment trapped or eroded =	965,409 m3

1.5	Estimated sediment trapped or eroded =	1,189,320 m3

Estimated wind speed at Alue Naga in all months are multiplied by factors 0.5 up to 1.5

.5	Estimated sediment trapped or eroded =	1,378 m3
.55	Estimated sediment trapped or eroded =	2,476 m3
.6	Estimated sediment trapped or eroded =	4,227 m3
.65	Estimated sediment trapped or eroded =	6,916 m3
.7	Estimated sediment trapped or eroded =	10,909 m3
.75	Estimated sediment trapped or eroded =	16,675 m3
.8	Estimated sediment trapped or eroded =	24,800 m3
.85	Estimated sediment trapped or eroded =	36,006 m3
.9	Estimated sediment trapped or eroded =	51,173 m3
.95	Estimated sediment trapped or eroded =	71,359 m3
1	Estimated sediment trapped or eroded =	97,825 m3
1.05	Estimated sediment trapped or eroded =	132,058 m3
1.1	Estimated sediment trapped or eroded =	175,798 m3
1.15	Estimated sediment trapped or eroded =	231,069 m3
1.2	Estimated sediment trapped or eroded =	300,202 m3
1.25	Estimated sediment trapped or eroded =	385,874 m3
1.3	Estimated sediment trapped or eroded =	491,135 m3
1.35	Estimated sediment trapped or eroded =	619,444 m3
1.4	Estimated sediment trapped or eroded =	774,705 m3
1.45	Estimated sediment trapped or eroded =	961,307 m3
1.5	Estimated sediment trapped or eroded =	1,184,159 m3

The Program Output IB-4

For different value of sea water density(ρ), ranging from 1,021-1,029 kg/m^3

1021	Estimated sediment trapped or eroded =	97,443 m3
1022	Estimated sediment trapped or eroded =	97,539 m3
1023	Estimated sediment trapped or eroded =	97,634 m3
1024	Estimated sediment trapped or eroded =	97,730 m3
1025	Estimated sediment trapped or eroded =	97,825 m3
1026	Estimated sediment trapped or eroded =	97,920 m3
1027	Estimated sediment trapped or eroded =	98,016 m3
1028	Estimated sediment trapped or eroded =	98,111 m3
1029	Estimated sediment trapped or eroded =	98,207 m3

For different friction value(f) of sea bottom, ranging from 0.01-0.019

.01	Estimated sediment trapped or croded =	100,315 m3
.011	Estimated sediment trapped or eroded =	99,809 m3
.012	Estimated sediment trapped or eroded =	99,307 m3
.013	Estimated sediment trapped or eroded =	98,809 m3
.014	Estimated sediment trapped or eroded =	98,315 m3
.015	Estimated sediment trapped or eroded =	97,825 m3
.016	Estimated sediment trapped or eroded =	97,339 m3
.017	Estimated sediment trapped or eroded =	96,857 m3
.018	Estimated sediment trapped or eroded =	96,379 m3
.019	Estimated sediment trapped or eroded =	95,904 m3

The Computer Program IIA for Calculating Longshore Sediment Transport

The data of period May 4th, 1990 to May 25th, 1991 is used as data input

The data that violates the condition of $\frac{H_o}{0.142\,L_o} \geq 1$, T-value is corrected by

$$T = \sqrt{\frac{H_o}{0.22171}} + 0.015$$

```
DECLARE FUNCTION f! (x!)
DECLARE FUNCTION df! (x!)
CLS
OPEN "B:EF06-01.OUT" FOR OUTPUT AS #1
M = .03
FR = .015
RHO = 1025
DIM H0(700), T(700), A0(700)
FOR I = 1 TO 672
READ H0(I), T(I), A0(I)
IF (H0(I) / (.142 * 1.56131 * T(I) ^ 2)) >= 1 THEN T(I) = (H0(I) / .22171) ^ .5 + .015
NEXT I
sumQ = 0
FOR I = 1 TO 672
L0 = 1.56131 * T(I) ^ 2
C0 = 1.56131 * T(I)
K0 = 2 * 3.14159 / L0
K = 4 * (3.14159) ^ 2 * H0(I) ^ 2 / ((.142) ^ 2 * (9.81) ^ 2 * T(I) ^ 4)
XOLD = (K) ^ (1 / 5)
D = 1
DO WHILE D > 10 ^ (-5)
      XNEW = XOLD - (f(XOLD) - K) / df(XOLD)
      D = ABS(XNEW - XOLD)
      XOLD = XNEW
LOOP
D = 1 / (6.28318) * XNEW * L0 * 1 / 2 * LOG((1 + XNEW) / (1 - XNEW))
N = 1 / 2 * (1 + (1 - XNEW ^ 2) / (2 * XNEW) * LOG((1 + XNEW) / (1 - XNEW)))
C = 1.56131 * T(I) * XNEW
CGI = N * C
KAPPA = 1.16 * (M * (H0(I) / L0) ^ (-1 / 2)) ^ (.22)
KF = (1 + ((FR * H0(I)) / (M * D)) * (COS((A0(I) / 180) * 3.14159)) ^ (1 / 2) * .12 * (K0
* D) ^ (-1 / 4)) ^ (-1)
HI = ((C0 / (2 * N * C)) ^ (1 / 2)) * H0(I)
SIN.AI = (C * SIN(3.14159 * A0(I) / 180)) / C0
```

```
COS.AI = (1 - SIN.AI ^ 2) ^ .5
ALPHA.B = ATN(SIN.AI / COS.AI)
HB = ((KAPPA / 9.81) ^ .5 * KF ^ 2 * HI ^ 2 * CGI * COS.AI) ^ .4
SELECT CASE A0(I)
CASE IS = 58
PLS = -RHO * 9.81 / 16 * HB ^ 2 * CGI * SIN(2 * ALPHA.B)
CASE IS = 32
PLS = RHO * 9.81 / 16 * HB ^ 2 * CGI * SIN(2 * ALPHA.B)
CASE IS = 77
PLS = RHO * 9.81 / 16 * HB ^ 2 * CGI * SIN(2 * ALPHA.B)
END SELECT
Q = 1290 * PLS * 12 / (365 * 24)
sumQ = sumQ + Q
PRINT I, Q
NEXT I
PRINT USING "Estimated sediment trapped or eroded = ###,###.### m3"; sumQ
PRINT #1, USING "Estimated sediment trapped or eroded = ###,###.### m3"; sumQ
END

DATA .51,3.84,58,.22,1.66,32
DATA .9,1.59,58,.27,1.45,58
DATA .23,2.14,58,.9,1.53,58
DATA .26,1.97,58,.81,1.29,58
DATA .24,1.71,58,.33,3.09,58
DATA .23,3.97,58,.21,1.7,58
DATA .19,1.51,58,.24,2.14,58
DATA .17,2.11,58,.23,1.55,58
DATA .13,2.06,58,.29,1.66,58
DATA .2,2.14,58,.89,1.27,58
DATA .7,1.88,58,.24,2.07,58
DATA .38,3.14,58,.23,1.79,58
DATA .26,2.59,58,.26,2.51,58
DATA .2,2.7,58,.29,1.73,32
DATA .26,2.32,58,.24,1.85,32
DATA .9,1.67,58,.26,1.63,32
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DATA .2,4.21,58,.27,1.44,32
DATA .24,2.71,58,.31,2.27,58
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DATA .3,2.19,58,.32,2.1,32
DATA .3,2.31,58,.31,1.81,32
DATA .38,2.03,58,.52,1.98,58
DATA .32,3.71,58,.75,2.64,32
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DATA .3,2.8,77,.29,2.6,77
DATA .49,2.8,77,.36,3.3,77
DATA .5,2.8,77,.46,3.3,77
DATA .71,2.9,77,.55,3.5,77
DATA .43,2.9,77,.8,3,77
DATA .79,2.8,77,.41,2.6,77
DATA .76,3.5,77,.43,2.7,77
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DATA .78,2.7,32,.34,2.8,32
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DATA .74,2.3,32,.26,2.9,32
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DATA .68,2.9,32,.32,2.6,32
DATA .28,2.7,32,.8,2.4,32
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DATA .51,2.5,32,.36,2.7,32
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DATA .71,2.5,58,.53,2.4,58
DATA .77,2.5,58,.61,2.5,58
DATA .86,2.8,58,.98,2.6,58
DATA .17,2.5,58,.97,2.4,58
DATA .16,2.6,58,.3,2.3,58
DATA .16,2.8,58,.33,1.9,58
DATA .18,2.5,58,.3,2.2,58
DATA .2,2.6,58,.3,2.1,58
DATA .18,2.9,58,.27,2,58
DATA .94,3,58,.51,2.3,58
DATA .24,2.4,58,.19,2.7,58
DATA .18,2.6,58,.2,2.5,58
DATA .23,2.1,58,.23,2.6,58
DATA .18,2,58,.18,2.4,58
DATA .93,3.1,58,.9,2.5,58
DATA .9,2.3,58,.89,3.1,58
DATA .35,2.6,58,.16,2.8,58
DATA .24,2.1,58,.14,2.8,58
DATA .24,2.5,58,.13,3.9,58
DATA .21,2.3,58,.17,3.4,58
DATA .23,2.2,58,.17,3.3,58
DATA .22,2.1,58,.53,3.2,58
DATA .97,3.1,58,.9,3,58
DATA .92,2.5,58,.94,2.6,58
DATA .75,2.2,58,.34,2.2,58
DATA .54,2.6,58,.18,2.2,58
DATA .14,2.4,58,.11,2.5,58
```

```
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DATA .16,2.5,58,.22,1.43,58
DATA .21,1.76,58,.16,2.16,58
DATA .2,2.79,58,.16,1.59,58
DATA .9,1.39,58,.9,2.76,58
DATA .9,1.2,58,.11,2.12,58
DATA .33,1.23,58,.1,1.49,58
DATA .23,1.35,58,.18,1.5,58
DATA .24,1.16,58,.28,2,58
DATA .48,1.47,58,.8,1.73,58
DATA .79,1.36,58,.87,2.25,58
DATA .68,1.67,58,.9,1.26,58
DATA .83,2.04,58,.25,2.09,58
DATA .28,1.51,58,.24,1.86,58
DATA .38,1.74,58,.25,2.01,58
DATA .32,1.18,58,.21,2.49,58
DATA .21,1.82,58,.23,2.24,58
DATA .26,1.26,58,.9,1.36,58
DATA .9,2.65,58,.9,1.62,58
DATA .9,1.8,58,.19,2.68,58
DATA .59,1.67,58,.19,2.72,58
DATA .27,1.85,58,.1,2.4,58
DATA .37,1.77,58,.15,4.01,58
DATA .61,1.36,58,.11,2.71,58
DATA .9,2.25,58,.9,1.52,58
DATA .9,1.26,58,.9,2.9,58
DATA .9,1.59,58,.2,1.77,58
DATA .86,1.43,58,.21,1.91,58
DATA .33,1.61,58,.21,1.75,58
DATA .29,1.65,58,.2,2.78,58
DATA .28,1.52,58,.19,1.76,58
DATA .33,1,58,.12,2.05,58
DATA .19,1.59,58,.19,1.5,58
DATA .23,1.71,58,.17,2.44,58
DATA .9,2.68,58,.9,3.79,58
DATA .2,2.07,58,.12,1.13,58
DATA .19,2.44,58,.21,1.42,58
DATA .16,2.05,58,.13,2.79,58
DATA .21,2.17,58,.9,4.26,58
DATA .9,2.29,58,.9,1.52,58
DATA .67,1.23,58,.18,3.79,58
DATA .89,1.2,58,.21,1.93,58
DATA .28,1.37,58,.23,2.35,58
DATA .27,2.12,58,.25,2.66,58
```

```
DATA .31,1.16,58,.21,2.08,58
DATA .28,1.49,58,.18,1.87,58
DATA .9,1.62,58,.22,1.38,58
DATA .9,1.2,58,.19,1.92,58
DATA .9,1.35,58,.9,1.39,58
DATA .9,1.27,58,.9,1.81,58
DATA .9,.97,58,.24,1.77,58
DATA .23,1.96,58,.22,2.12,58
DATA .23,1.42,58,.36,1.63,58
DATA .25,2.69,58,.9,1.6,32
DATA .25,2.66,32,.22,1.12,32
DATA .9,1.4,32,.23,2.02,58
DATA .9,1.37,58,.2,1.72,58
DATA .21,2.12,58,.24,2.02,58
DATA .34,1.83,58,.21,2.12,58
DATA .21,3.51,58,.21,4.06,58
DATA .3,2.07,58,.21,2.92,58
DATA .27,2,58,.2,2.65,58
DATA .22,2.41,58,.15,3.41,58
DATA .24,2.69,58,.11,3.48,58
DATA .16,3.09,58,.13,2.44,58
DATA .18,.96,32,.9,1.48,58
DATA .23,1.63,32,.9,1.43,58
DATA .28,1.8,32,.39,6.25,58
DATA .24,2.12,32,.23,1.82,58
DATA .81,1.51,32,.35,2.7,58
DATA .88,1.17,32,.58,3.16,58
DATA .77,1.84,32,.52,3.84,58
DATA .51,3.84,58,.22,1.66,32
DATA .9,1.59,58,.27,1.45,58
DATA .23,2.14,58,.9,1.53,58
DATA .26,1.97,58,.81,1.29,58
DATA .24,1.71,58,.33,3.09,58
DATA .23,3.97,58,.21,1.7,58
DATA .19,1.51,58,.24,2.14,58
DATA .17,2.11,58,.23,1.55,58
DATA .13,2.06,58,.29,1.66,58
DATA .2,2.14,58,.89,1.27,58
DATA .7,1.88,58,.24,2.07,58
DATA .38,3.14,58,.23,1.79,58
DATA .26,2.59,58,.26,2.51,58
DATA .2,2.7,58,.29,1.73,32
DATA .26,2.32,58,.24,1.85,32
DATA .9,1.67,58,.26,1.63,32
```

```
DATA .43,2.1,58,.9,1.66,32
DATA .2,4.21,58,.27,1.44,32
DATA .24,2.71,58,.31,2.27,58

FUNCTION df (x)
    df = 6 * x ^ 4 + (2 * x ^ 3 - 3 * x ^ 5) * LOG((1 + x) / (1 - x))
END FUNCTION

FUNCTION f (x)
    f = x ^ 5 + .5 * LOG((1 + x) / (1 - x)) * (1 - x ^ 2) * x ^ 4
END FUNCTION
```

The Program Output IIA-1

The data that violates the condition of $\frac{H_o}{0.142\ L_o} \geq 1$, T-value is corrected by

$$T = \sqrt{\frac{H_o}{0.22171}} + 0.015$$

Estimated sediment trapped or eroded = **29,232.668** m3

The Program Output IIA-2

The data that violates the condition of $\frac{H_o}{0.142\ L_o} \geq 1$ are not included in calculation

Estimated sediment trapped or eroded = **39,269.469** m3

The Program Output IIA-3

The data that violates the condition of $\frac{H_o}{0.142\ L_o} \geq 1$, T-value is corrected by the average value of available data which do not violate the condition and have the same wave height

Estimated sediment trapped or eroded = **29,498.576** m3

The Program Output IIA-4

The monthly average data of H_o and T are used

Estimated sediment trapped or eroded = **23,780.850** m3

The Program Output IIA-5

The data of root mean square of H_o and average of T are used

Estimated sediment trapped or eroded = **26,553.219** m3

The Computer Program IIB for Calculating Longshore Sediment Transport

The data of period May 26th, 1990 to Aug 18th, 1990 is used as data input

```
DECLARE FUNCTION f! (x!)
DECLARE FUNCTION df! (x!)
CLS
OPEN "B:EF05-01.OUT" FOR OUTPUT AS #1
M = .03
FR = .015
RHO = 1025
DIM H0(200), T(200), A0(200)
FOR I = 1 TO 162
READ H0(I), T(I), A0(I)
NEXT I
sumQ = 0
FOR I = 1 TO 162
L0 = 1.56131 * T(I) ^ 2
C0 = 1.56131 * T(I)
K0 = 2 * 3.14159 / L0
K = 4 * (3.14159) ^ 2 * H0(I) ^ 2 / ((.142) ^ 2 * (9.81) ^ 2 * T(I) ^ 4)
XOLD = (K) ^ (1 / 5)
D = 1
DO WHILE D > 10 ^ (-5)
      XNEW = XOLD - (f(XOLD) - K) / df(XOLD)
      D = ABS(XNEW - XOLD)
      XOLD = XNEW
LOOP
D = 1 / (6.28318) * XNEW * L0 * 1 / 2 * LOG((1 + XNEW) / (1 - XNEW))
N = 1 / 2 * (1 + (1 - XNEW ^ 2) / (2 * XNEW) * LOG((1 + XNEW) / (1 - XNEW)))
C = 1.56131 * T(I) * XNEW
CGI = N * C
KAPPA = 1.16 * (M * (H0(I) / L0) ^ (-1 / 2)) ^ (.22)
KF = (1 + ((FR * H0(I)) / (M * D)) * (COS((A0(I) / 180) * 3.14159)) ^ (1 / 2) * .12 * (K0
* D) ^ (-1 / 4)) ^ (-1)
HI = ((C0 / (2 * N * C)) ^ (1 / 2)) * H0(I)
SIN.AI = (C * SIN(3.14159 * A0(I) / 180)) / C0
COS.AI = (1 - SIN.AI ^ 2) ^ .5
ALPHA.B = ATN(SIN.AI / COS.AI)
HB = ((KAPPA / 9.81) ^ .5 * KF ^ 2 * HI ^ 2 * CGI * COS.AI) ^ .4
SELECT CASE A0(I)
CASE IS = 58
PLS = -RHO * 9.81 / 16 * HB ^ 2 * CGI * SIN(2 * ALPHA.B)
```

```
CASE IS = 32
PLS = RHO * 9.81 / 16 * HB ^ 2 * CGI * SIN(2 * ALPHA.B)
CASE IS = 77
PLS = RHO * 9.81 / 16 * HB ^ 2 * CGI * SIN(2 * ALPHA.B)
END SELECT
Q = 1290 * PLS * 12 / (365 * 24)
sumQ = sumQ + Q
PRINT I, Q
NEXT I
PRINT USING "Estimated sediment trapped or eroded = ###,###.### m3"; sumQ
PRINT #1, USING "Estimated sediment trapped or eroded = ###,###.### m3"; sumQ
END

DATA .2,2.01,58,.24,1.19,32
DATA .31,1.61,58,.39,2.61,58
DATA .3,2.19,58,.32,2.1,32
DATA .3,2.31,58,.31,1.81,32
DATA .38,2.03,58,.52,1.98,58
DATA .32,3.71,58,.75,2.64,32
DATA .49,3.5,77,.26,3,77
DATA .89,3.3,77,.7,3.1,77
DATA .5,2.9,77,.9,2.7,77
DATA .7,3,77,.5,2.5,77
DATA .5,3.1,77,.6,2.6,77
DATA .7,2.8,77,.6,2.9,77
DATA .5,2.8,77,0.4,3,77
DATA .3,2.8,77,.29,2.6,77
DATA .49,2.8,77,.36,3.3,77
DATA .5,2.8,77,.46,3.3,77
DATA .71,2.9,77,.55,3.5,77
DATA .43,2.9,77,.8,3,77
DATA .79,2.8,77,.41,2.6,77
DATA .76,3.5,77,.43,2.7,77
DATA .76,3.4,77,.47,2.7,77
DATA .58,3.3,77,0.43,2.3,77
DATA .31,2.9,77,0.31,2.9,77
DATA .45,2.8,77,.84,2.6,77
DATA .51,2.8,77,0.53,2.7,77
DATA .35,2.9,77,.47,2.5,32
DATA .51,2.8,32,.5,2.6,32
DATA .41,2.8,32,.52,2.9,32
DATA .49,2.9,32,.36,2.5,32
DATA .82,3.1,32,.5,2.6,32
DATA .56,2.7,32,.67,2.7,32
```

```
DATA .46,2.5,32,.8,2.5,32
DATA .34,2.6,32,0.77,2.9,32
DATA .32,2.5,32,.3,3.1,32
DATA .36,2.3,32,0.22,2.7,32
DATA .46,2.4,32,.24,2.5,32
DATA .78,2.7,32,.34,2.8,32
DATA .66,2.6,32,.23,3.1,32
DATA .74,2.3,32,.26,2.9,32
DATA .85,2.9,32,.33,2.8 32
DATA .72,2.8,32,.28,2.5,32
DATA .43,2.6,32,.29,2.7,32
DATA .71,2.3,32,.41,2.3,32
DATA .68,2.5,32,.24,3.3,32
DATA .27,2.6,32,.3,2.3,32
DATA .63,2.4,32,.44,2.6,32
DATA .71,2.9,32,.4,2.4,32
DATA .81,2.9,32,.36,2.5,32
DATA .68,2.9,32,.32,2.6,32
DATA .28,2.7,32,.8,2.4,32
DATA .41,2.3,32,.74,2.2,32
DATA .27,2.9,32,.71,2.7,32
DATA .38,2.3,32,.38,2.3,32
DATA .33,2.2,32,.5,2.6,32
DATA .3,2.6,32,.32,2.4,32
DATA .49,2.6,32,.44,2.1,32
DATA .56,2.7,32,.44,2.5,32
DATA .49,2.5,32,.48,2.2,32
DATA .47,2.3,32,.35,2.3,32
DATA .74,2.4,32,.43,2.1,32
DATA .71,2.5,32,.4,2.2,32
DATA .61,2.5,32,.42,2.3,32
DATA .39,2.2,32,.35,2.1,32
DATA .52,2.2,32,.4,2.5,32
DATA .39,2.4,32,.89,2.1,32
DATA .33,2.5,32,1.05,2.4,32
DATA .33,2.5,32,1.02,2.6,32
DATA .34,2.3,32,1.02,2.2,32
DATA .3,2.6,32,1,2.2,32
DATA .25,2.7,32,1.04,2.4,32
DATA .29,2.5,32,.57,2.6,32
DATA .32,2.6,32,.57,3.2,32
DATA .36,3,32,.39,2.2,32
DATA .25,2.7,32,.41,2.5,32
DATA .7,2.8,32,.49,2.5,32
```

```
DATA .78,2.6,32,.4,3,32
DATA .5,2.6,32,.36,2.6,32
DATA .38,2.6,32,.28,2.7,32
DATA .28,2.7,32,.76,2.7,32
DATA .46,2.7,32,.82,2.7,32
DATA .37,2.8,32,.73,2.6,32

FUNCTION df (x)
    df = 6 * x ^ 4 + (2 * x ^ 3 - 3 * x ^ 5) * LOG((1 + x) / (1 - x))
END FUNCTION

FUNCTION f (x)
    f = x ^ 5 + .5 * LOG((1 + x) / (1 - x)) * (1 - x ^ 2) * x ^ 4
END FUNCTION
```

The Program Output IIB-1

Actual half daily data is used, and no data violates the condition of $\frac{H_o}{0.142\ L_o} \geq 1$

Estimated sediment trapped or eroded = **31,054.092** m3

The Program Output IIB-2

The data that violates the condition of $\frac{H_o}{0.142\ L_o} \geq 1$ are not included in calculation

Estimated sediment trapped or eroded = **31,054.092** m3

The Program Output IIB-3

The data that violates the condition of $\frac{H_o}{0.142\ L_o} \geq 1$, T-value is corrected by the average value of available data which do not violate the condition and have the same wave height

Estimated sediment trapped or eroded = **31,054.092** m3

The Program Output IIB-4

The mothly average data of H_o and T are used

Estimated sediment trapped or eroded = **22,535.840** m3

The Program Output IIB-5

The data of root mean square of H_o and average of T of each month are used

Estimated sediment trapped or eroded = **27,160.357** m3

Appendix D

The Comparison of Actual Data and Estimated Data of Net Longshore Sediment Transport and K-value of Different Calculation Approach

Table D. The Comparison of Actual Data and Estimated Data of Net Longshore Sediment Transport and K-value of Different Calculation Approach

descr.	period May'92 May'93	K	period May'93 Aug'93	K
1	**26,000**		**29,000**	
2	194,270	0.053	97,824	0.118
3	29,232	0.351	31,054	0.372
4	39,269	0.261	31,054	0.372
5	29,498	0.348	31,054	0.372
6	26,553	0.386	27,160	0.425
7	23,780	0.432	22,535	0.517

description 1:

Survey result of accumulated sediment at the jetty

description 2:

Significant Wave Height and Period ($H_{1/3}$ and $T_{1/3}$) in deep water at Alue Naga are estimated from predicted wind at Alue Naga.

description 3:

Significant Wave Height and Period ($H_{1/3}$ and $T_{1/3}$) in deep water at Alue Naga in period 1992-1993 are assumed the same as in period 1990-1991, since they have the same distribution of wind direction. The T-value of the data having Ho/0.142 Lo $\geq$ 1 is corrected by $T=(Ho/0.22171)^{1/2} + 0.015$.

description 4:

Significant Wave Height and Period ($H_{1/3}$ and $T_{1/3}$) in deep water at Alue Naga in period 1992-1993 are assumed the same as in period 1990-1991, since they have the same distribution of wind direction. The data having Ho/0.142 Lo $\geq$ 1 are not included in calculation.

description 5:

Significant Wave Height and Period ($H_{1/3}$ and $T_{1/3}$) in deep water at Alue Naga in period 1992-1993 are assumed the same as in period 1990-1991, since they have the same distribution of wind direction. The T-value of the data having Ho/0.142 Lo $\geq$ 1 is corrected by the average value of the available data.

description 6:

Significant Wave Height and Period ($H_{1/3}$ and $T_{1/3}$) in deep water at Alue Naga in period 1992-1993 are assumed the same as in period 1990-1991, since they have the same distribution of wind direction. The $H_{1/3\,rms}$ and $T_{1/3\,avg}$ are used in calculation.

description 7:

Significant Wave Height and Period ($H_{1/3}$ and $T_{1/3}$) in deep water at Alue Naga in period 1992-1993 are assumed the same as in period 1990-1991, since they have the same distribution of wind direction. The $H_{1/3\,avg}$ and $T_{1/3\,avg}$ are used in calculation.