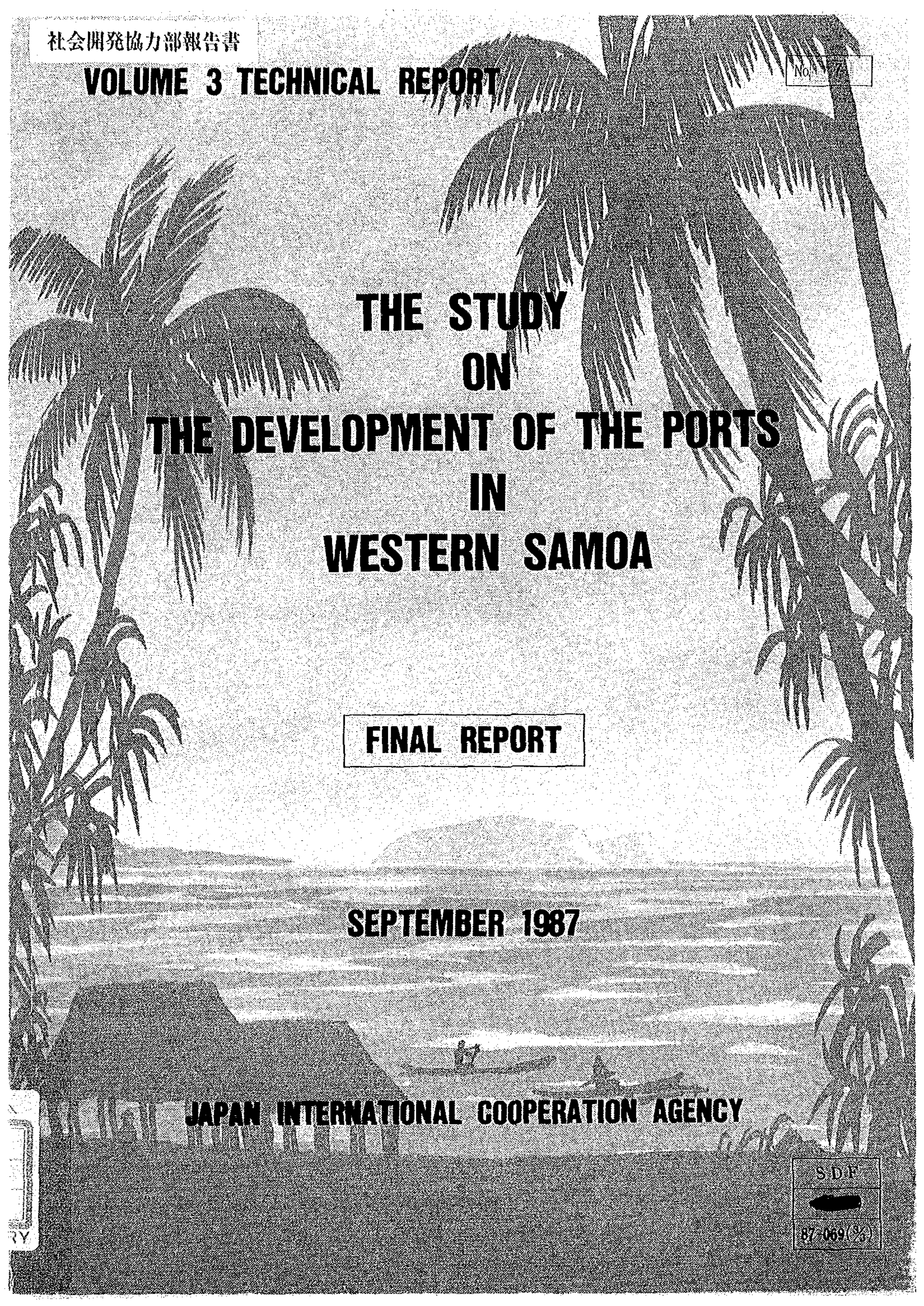

社会開発協力部報告書

VOLUME 3 TECHNICAL REPORT

No.

THE STUDY ON THE DEVELOPMENT OF THE PORTS IN WESTERN SAMOA

FINAL REPORT

SEPTEMBER 1987

JAPAN INTERNATIONAL COOPERATION AGENCY

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(As of March, 1987)

Abbreviations

bd ft	board feet
BP	Burns Philip
CD	Customs Department
CFS	Container Freight Station
CIF	Cost, Insurance and Freight
DED	Department of Economic Development
EIRR	Economic Internal Rate of Return
FCL	Full Container Load
FIRR	Financial Internal Rate of Return
FOB	Free on Board
GDP	Gross Domestic Product
GRT	Gross Registered Tonnage
JIS	Japanese Industrial Standard
LCL	Less than Full Container Load
LOA	Length Over All
MH	Morris Hedstrom
MOT	Ministry of Transport
MS	Maintenance Shop
NZ	New Zealand
PFL	Pacific Forum Line
PWD	Public Works Department
Ro/Ro	Roll on/Roll off
SMB	Sverdrup, Munk, Bretschneider
SSS	Samoa Shipping Services
TEU	Twenty Foot Equivalent Unit
US$	United States Dollar
WESTEC	Western Samoa Trust Estates Corporation
WSSC	Western Samoa Shipping Corporation
WS$	Western Samoa Dollar (or Tala)
¥	Yen

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CHAPTER 6 PRELIMINARY DESIGN OF THE MAIN FACILITIES FOR THE FIRST STAGE PLAN

CHAPTER 7 CONSTRUCTION PLAN AND COST ESTIMATION

CHAPTER 1
GENERAL NATURAL CONDITIONS

Chapter 1 General Natural Conditions

1-1 Geographical and Topographical Features

1. Western Samoa consists of two large islands, Upolu Island (approximately 1,110 sq km) and Savai'i Island (approximately 1,980 sq km), and the small adjacent islets of Aalima, Manono, Mu'utele (Vini), Nu'lulu, Namu'a and Fanuatapu. The islands are located between 13° and 15° S latitude and 168° and 173° W longitude, just east of the International Date Line. The capital is Apia on Upolu Island where local time is 11 hours behind GMT. The islands are about 3,700 km southwest of Hawaii and 2,900 km north-northeast of Auckland. The country's closest neighbours are American Samoa, Tonga, Waillis and Tokelau (Fig. 1.1.1, Fig. 1.1.2).

2. Fig. 1.1.3 and Fig. 1.1.4 show the bathymetric features in the Southwest Pacific. There is a structural boundary named the Marshall Line or the Andestite Line which follows the Tonga-Kermadec Trench from New Zealand and swings west around Fiji past the New Hebrides and the Solomon Islands. The boundary is considered to be the northeast boundary of the Australian plate. Entirely different island structures and rocks lie on opposite sides of the boundary.

3. West of the boundary lie island-arc structures, with fold mountains and plutonic intrusions typical of continental margins. Close to the boundary, island arcs are fronted by deep trenches, volcanoes occasionally erupt, and fold movements are still occurring along seismically active belts.

4. East of the boundary the islands are scattered in a more random fashion in broad linear chains, very little evidence of fold movements is known, and there are no continental rocks. Seismic activity is associated only with volcanicity, the products of which arise from a parent alkaline basaltic magma.

5. Samoa is classified in the group of arcuate and strewn islands, lying northeast of the Andesite Line. The Samoan Islands are situated in a unique position, directly in line with, but striking at right angles to,

the main reach of the Tonga Trench, and on the opposite side of the trench from the Andesite Line.

6. The general structure of Western Samoa is that of an old volcanic terrain, deeply weathered and eroded so that little or none of the original form remains, with a thick series of younger lava flows and cones rising over and largely burying the older rocks.

1-2 Meteorological Conditions

7. The climate of Western Samoa is tropical and oceanic and has distinct rainy and dry seasons. The dry season is from May to August and the rainy season is from December to March. Table 1.2.1 shows the climatic data from 1931 to 1961 which was observed at the Meteorological Office in Apia, 13°48'S latitude, 171°47'W longitude, at the north tip of the Mulinuu Peninsula.

1) Temperature

8. Table 1.2.2 shows monthly mean max. and min. temperatures for the past 10 years. The monthly mean max. ranges from 29°C to 31°C and the mean min. ranges from 21°C to 24°C.

2) Precipitation

9. The south and southeast windward area of the islands receives from 5,000mm to 7,000mm of rain annually. On the leeward side, the islands receive from 2,500 to 3,000mm of rain. There is however a marked dry season, from May to August. The average rainfall at Apia is about 2,900mm a year. There is a great 200% difference in the volume of rainfall between dry years and wet years. Table 1.2.3 and Table 1.2.4 show the number of rain days per month and the total monthly rainfall.

3) Wind

10. Long term records of winds are available at Apia. Table 1.2.5 shows the annual occurrence frequency of wind speed and direction and Table 1.2.6

shows the annual occurrence frequency of wind direction from 1951 to 1971. The occurrence frequency of winds 6.5m/sec or less is more than 87 percent and that of storm winds more than 25m/sec is 0.05 percent. The east and southeast winds dominate throughout the year. However, the direction of heavy storm winds, more than 20m/sec., is mainly northwest.

4) Hurricanes

11. Table 1.2.7 shows the record of hurricanes which affected Western Samoa. The dominant wind direction is northwest, and winds continue for a long period of time.

1-3 Oceanographical Conditions

1) Waves

12. Western Samoa has no data station equipped with a wave recording gauge. Apia Harbour is well protected during the season of the southeast trades, from May to October. Between the months of November to March, northerly waves and swells enter the harbour through the wide entrance. Regarding surge, it is reported that along with the northeast waves from November to March, surge occurs almost throughout the season due to the long wave components of the waves penetrating from the outer sea.*[1]

2) Tide

13. Tidal data have been recorded at the Tide Station located at the inner part of Apia Harbour. The mean high water interval at Apia Port is 6hrs 27 min..

Apia Harbour has the following tide table:

Highest Astronomical Tide	(HAT)	+ 1.2m
Mean High Water Spring	(MHWS)	+ 1.0m
Mean High Water Neap	(MHWN)	+ 0.8m
Mean Sea Level	(MSL)	+ 0.5m

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*1 Report on Siltation Problem and Desirability of Relocation of Apia Harbour, ESCAP, 1983

Mean Low Water Neap	(MLWN)	+ 0.2m
Mean Low Water Spring	(MLWS)	± 0.0m (Chart Datum)
Lowest Astronomical Tide	(LAT)	- 0.2m

The tide table of Asau Harbour is as follows:

Mean High Water Spring	(MHWS)	+ 1.2m
Mean High Water Neap	(MHWN)	+ 1.1m
Mean Sea Level	(MSL)	+ 0.7m
Mean Low Water Neap	(MLWN)	+ 0.4m
Mean Low Water Spring	(MLWS)	+ 0.2m
Chart Datum	(CD)	± 0.0m

3) Current

14. Fig. 1.3.1 shows the predominant currents in the South Pacific. Western Samoa is located in the band of the south sub-tropical current. The current's speed around the Samoa Islands is relatively constant in the range of 9 to 11 miles per day (16.7 to 20.3km per day) throughout the year. The direction of the current is westward.

1-4 Earthquakes

15. Western Samoa lies at the vertex of two vigorous systems of seismic activities, one extending southwestward through Tonga Island to New Zealand, the other in a more westerly direction through Fiji to the New Hebrides. The two systems are formed by the contact of the Indian and Pacific structural plates. Table 1.4.1 shows the record of earthquakes that affected Samoa.

16. Fig. 1.4.1 shows seismicity in the region of Fiji-Tonga-Samoa-New Hebrides. Western Samoa is located in a range of seismicity of 10^{16} to 10^{17} ergs km^{-2} $year^{-1}$. That figure is equivalent to the seismicity in the southeast area of New Zealand's north island. In that area a seismic coefficient of 0.15 is used for the design of buildings.

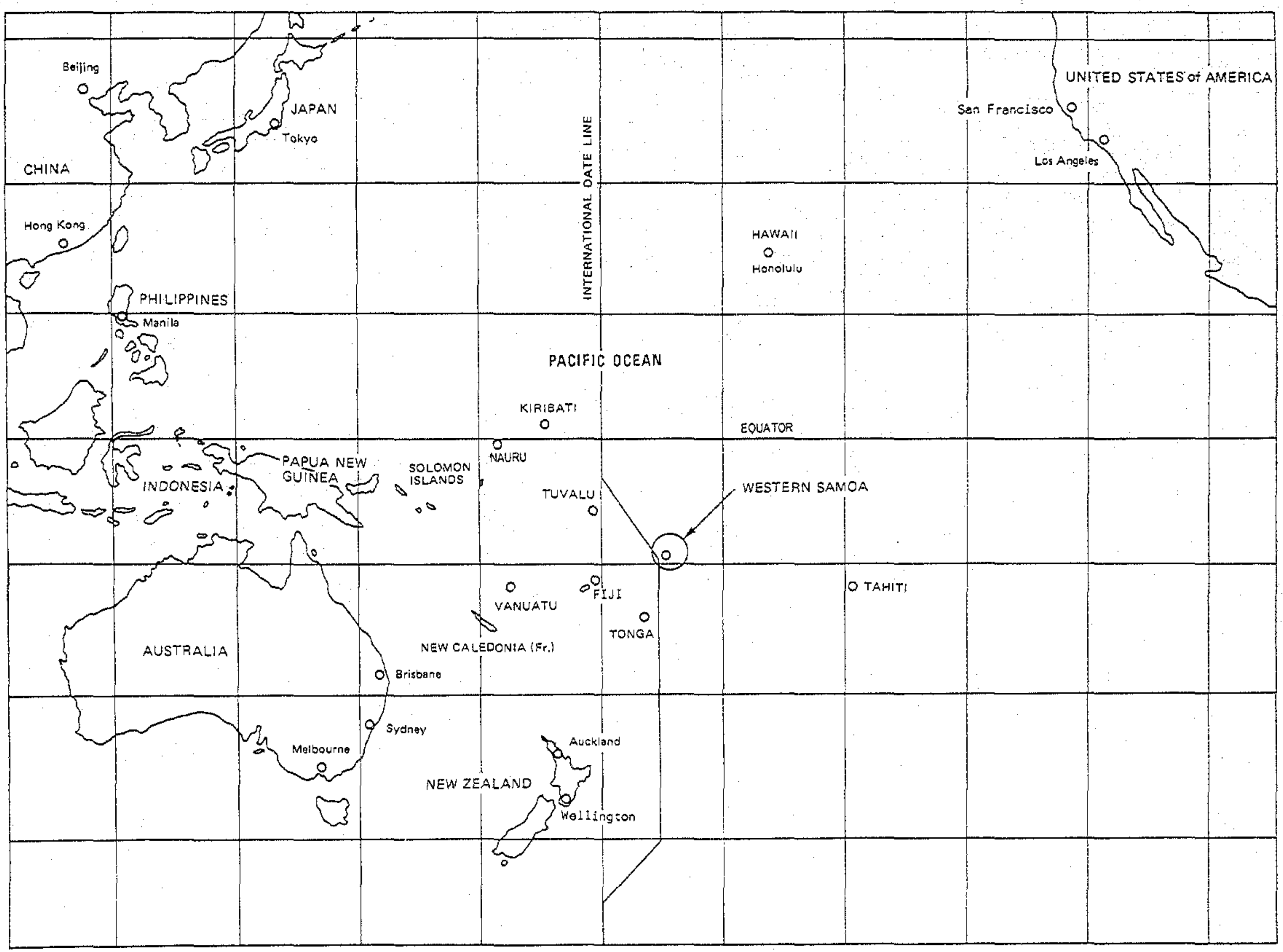


Fig. 1.1.1 Location of Western Samoa

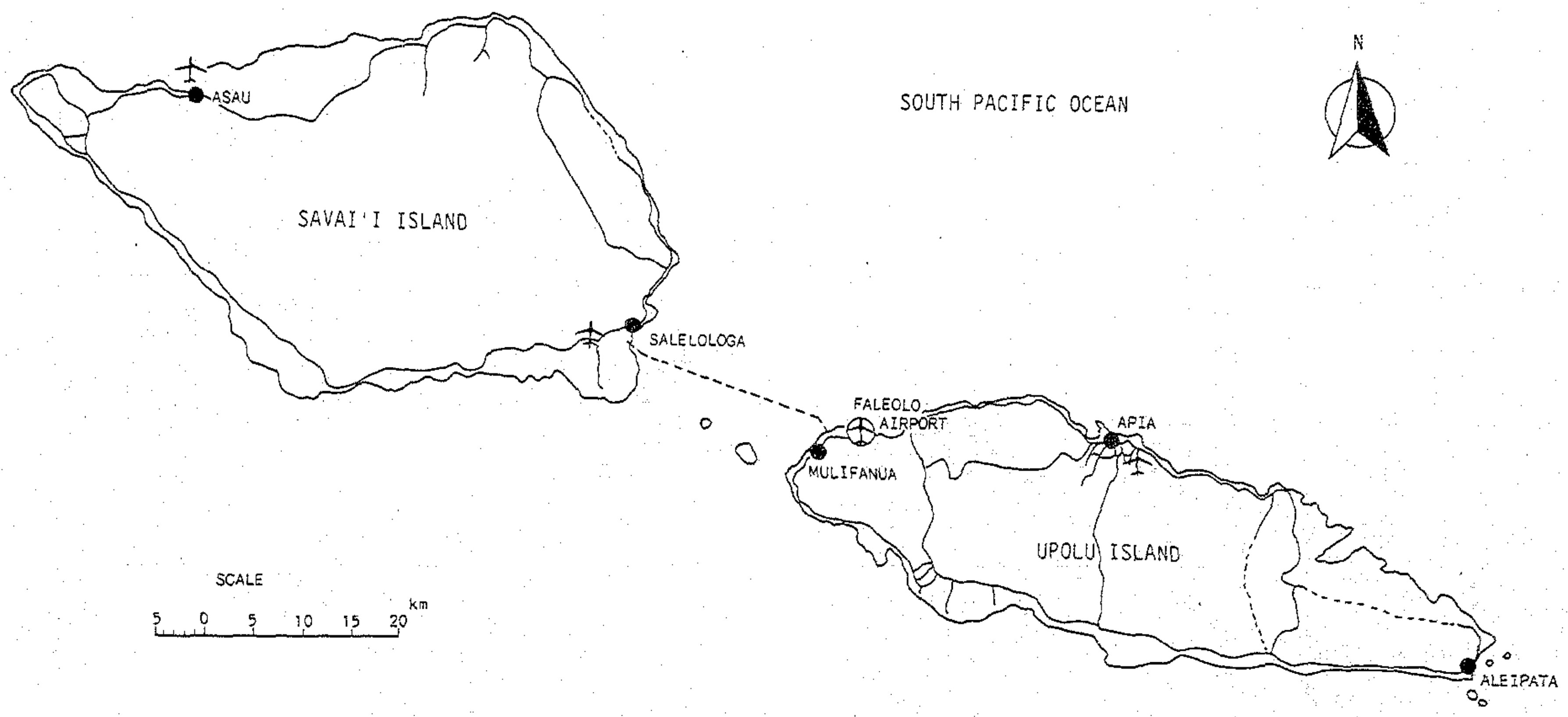


Fig. 1.1.2 Upolu Island and Savai'i Island

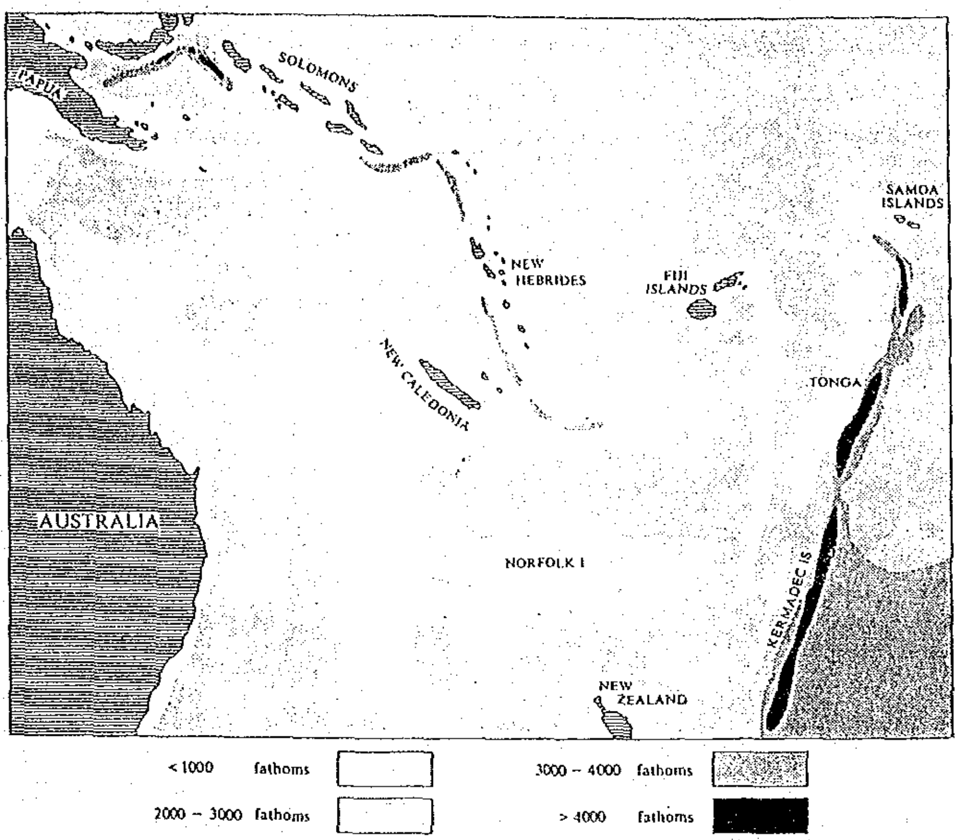


Fig. 1.1.3 General Bathymetric Features of the Southwest Pacific

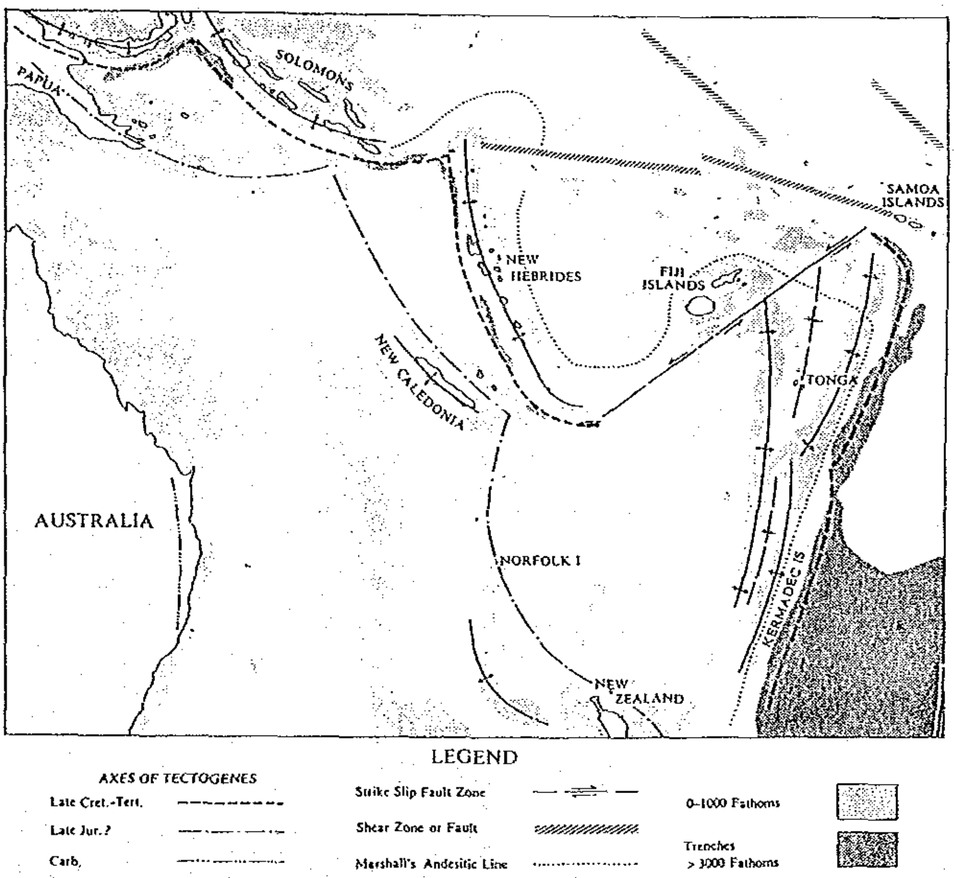


Fig. 1.1.4 Structural Interpretation of Bathymetric Features

Source: The Geology and Hydrology of WESTERN SAMOA

Table 1.2.1 Climatic Table

APIA, SAMOA. Lat. 13°48′S., Long. 171°46′W. *Height above Mean Sea Level, 6 ft.* (1m8).
compiled from 8 to 31 Years' Observations, 1931 to 1961.

Month	Pressure at M.S.L.	Air temperature				Relative humidity		Mean cloud amount		Rain	
	Mean	Mean daily max.	Mean daily min.	Mean highest in each month	Mean lower in each month	0600	1200	0900	1500	Average fall	No. of days with 1 mm or more
	mb.	°C.	°C.	°C.	°C.	%	%	OKTAS		mm.	
January	1008	30	24	32	22	89	78	6	6	424	20
February	1008	30	24	31	23	89	78	6	6	364	19
March	1009	30	24	31	32	89	77	5	6	352	18
April	1010	30	24	32	22	89	76	5	5	214	15
May	1011	30	24	31	21	89	76	5	5	186	13
June	1011	30	23	31	21	88	74	4	5	130	10
July	1012	29	23	31	20	86	72	4	4	115	10
August	1012	29	23	31	20	86	73	4	4	111	10
September	1012	29	23	31	21	87	74	4	5	147	11
October	1011	30	23	31	21	87	75	5	5	221	14
November	1009	30	23	31	22	88	76	5	6	279	15
December	1008	30	24	31	22	89	77	6	6	385	19
Means	1010	30	23	32*	19**	88	75	5	5	–	–
Totals	–	–	–	–	–	–	–	–	–	2928	174
Extreme Values	–	–	–	34†	18††	–	–	–	–	–	–
No. of years' observations	30	30				18		20	17	31	23

Month	Wind direction 0900: Percentage of observation from									Wind direction 1500: Percentage of observation from									Mean wind speed		No. of days with wind speed 27 knots, or more	No. of days with visibility less than 1 mile
	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm	0900	1500		
																			Knots		*	*
January	7	8	26	7	4	2	5	6	35	12	13	30	9	4	3	4	12	13	5	7	+	+
February	7	6	24	6	2	2	6	7	40	10	15	25	11	4	3	8	14	10	5	8	+	+
March	8	9	33	9	3	1	5	6	26	9	12	37	10	4	4	4	11	9	4	7	0	0
April	4	2	41	13	2	0	2	2	34	4	11	48	14	4	1	3	7	8	5	8	0	+
May	1	2	43	20	2	0	2	1	29	4	5	53	22	2	1	2	5	6	5	9	0	0
June	1	3	47	18	2	1	1	1	26	3	4	61	21	2	1	1	2	5	5	10	0	0
July	2	3	50	17	3	0	1	0	24	2	6	57	22	3	1	0	3	6	6	10	+	0
August	1	1	63	17	1	0	0	1	16	1	4	58	26	2	2	2	2	3	8	12	0	+
September	4	5	55	19	1	1	1	1	13	4	8	55	25	2	2	1	1	2	8	10	0	+
October	5	3	57	13	1	0	1	2	18	4	5	56	22	2	2	2	2	5	8	10	0	0
November	10	10	44	9	4	1	1	3	18	6	11	42	16	5	4	2	6	8	5	9	0	0
December	8	6	38	12	4	2	5	2	23	10	12	38	16	4	2	3	4	11	6	8	+	+
Means	5	5	43	13	2	1	3	3	25	6	9	47	18	3	2	3	6	7	6	9	–	–
Totals	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
Extreme Values	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
No. of years' observations	10																		8		11	

* Ma * Mean of highest each year.
** Mean of lowest each year.

† Highest recorded temperature.
†† Lowest recorded temperature.

Standard of time; 165°E.
+ Indicates less than 0.5.

Source: Meteorological Office.

Table 1.2.2 Monthly Mean Max. and Min. Temperatures

(°C)

		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1977	Mean Max.	30.6	30.6	29.9	30.9	30.3	29.9	29.1	29.2	29.6	30.0	30.2	30.6	30.1°C
	Mean Min.	23.3	24.0	23.5	23.1	22.7	22.5	22.2	22.2	22.6	23.6	23.7	23.8	23.1°C
1978	Mean Max.	29.6	30.7	29.6	30.3	30.3	30.0	29.7	29.4	30.0	30.0	29.8	30.6	30.0°C
	Mean Min.	24.1	24.1	23.8	23.4	23.4	22.9	22.1	22.7	22.5	23.2	22.9	23.7	23.2°C
1979	Mean Max.	30.3	30.7	30.6	30.9	30.7	30.5	29.8	30.1	30.3	30.3	30.1	30.1	30.4°C
	Mean Min.	24.0	23.7	23.6	23.0	23.1	23.9	22.5	22.2	23.2	23.3	23.2	23.3	23.3°C
1980	Mean Max.	30.7	31.0	30.9	31.0	30.0	30.3	29.7	29.8	29.7	29.7	30.5	30.6	30.3°C
	Mean Min.	23.7	24.1	24.3	24.0	23.4	23.2	23.0	23.1	23.5	23.4	23.6	23.7	23.6°C
1981	Mean Max.	30.6	30.7	30.4	-	-	-	29.5	29.9	30.2	29.8	30.5	30.2	30.2°C
	Mean Min.	24.1	22.6	23.6	-	-	-	21.5	23.1	23.3	23.6	23.4	23.9	23.2°C
1982	Mean Max.	30.1	29.7	31.4	31.2	31.0	32.2	30.3	29.5	29.9	30.8	30.2	30.7	30.6°C
	Mean Min.	23.9	23.4	24.3	24.2	23.5	23.0	22.8	23.0	22.9	23.1	23.4	22.9	23.4°C
1983	Mean Max.	30.7	31.9	31.0	31.0	31.0	30.3	29.7	29.5	30.1	30.7	30.9	30.2	30.6°C
	Mean Min.	24.2	24.9	24.4	23.0	23.7	23.0	22.2	21.6	23.3	23.5	23.4	23.9	23.4°C
1984	Mean Max.	30.3	30.6	30.2	30.9	31.2	30.0	29.5	29.6	29.8	30.2	30.4	29.5	30.2°C
	Mean Min.	23.5	23.9	24.3	24.1	23.4	23.3	22.2	22.4	22.7	23.0	23.4	23.7	23.3°C
1985	Mean Max.	29.9	30.4	30.9	31.0	30.3	30.1	29.6	30.0	30.2	30.4	30.6	30.8	30.3°C
	Mean Min.	23.5	23.9	23.8	23.4	23.6	23.0	22.5	22.9	22.6	23.2	23.1	24.1	23.3°C
1986	Mean Max.	30.1	30.4	30.0	30.5	30.4	30.2	29.3	29.2	29.8	30.3	30.3	30.7	30.1°C
	Mean Min.	24.1	24.0	23.8	23.9	23.3	23.1	22.8	22.3	23.3	22.9	23.6	24.3	23.4°C

Source: Apia Meteorological Office

Table 1.2.3 Number of Rain Days Per Month

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1971	30	24	26	23	14	16	11	17	21	24	20	25	251
1972	24	24	19	24	13	13	11	11	21	18	15	21	214
1973	21	23	21	19	14	14	17	20	25	26	28	28	256
1974	25	24	25	22	15	18	16	7	15	19	21	20	256
1975	26	19	22	19	22	20	16	14	24	25	16	27	227
1976	27	23	23	19	17	17	25	10	4	13	21	21	251
1977	19	21	23	15	15	11	9	8	9	15	20	17	220
1978	30	18	28	17	19	15	4	17	12	22	24	22	182
1979	25	24	20	17	17	20	13	8	13	18	12	19	228
1980	24	19	25	17	18	18	13	18	26	24	19	18	239
1981	22	21	24	-	-	-	10	18	18	22	22	26	183
1982	27	24	25	12	15	9	12	18	9	11	14	8	184
1983	19	13	16	11	15	12	8	6	12	17	11	24	164
1984	21	22	25	21	14	14	10	13	12	14	14	24	204
1985	22	27	22	23	18	18	13	18	10	13	15	18	217
1986	22	17	22	28	19	14	18	9	19	14	11	22	215
1987	22	-	-	-	-	-	-	-	-	-	-	-	-
Mean	24	21	23	19	14	14	13	13	15	18	17	21	218

Source: Apia Meteorological Office

Table 1.2.4 Total Monthly Rainfall

(mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1977	366.9	261.9	454.9	61.9	97.9	85.6	59.4	44.1	57.1	132.7	149.5	134.0	1,905.9
1978	959.7	197.1	640.9	100.5	141.6	125.7	130.0	267.7	70.1	281.6	513.3	412.9	3,841.1
1979	209.3	270.4	332.0	100.3	244.3	119.9	208.7	51.7	236.2	348.9	247.8	391.6	2,761.1
1980	372.2	310.2	464.4	302.7	216.1	161.2	162.4	161.9	593.1	488.0	208.8	180.1	3,621.1
1981	259.3	361.3	634.9	-	-	-	67.5	75.2	198.6	350.3	438.2	596.6	2,981.9
1982	481.1	947.1	132.6	33.9	289.3	51.5	71.6	276.3	63.1	100.9	125.4	63.1	2,635.9
1983	228.5	141.1	256.5	130.9	75.8	113.8	14.5	105.2	23.6	82.6	202.4	573.7	1,948.6
1984	274.1	260.2	277.0	131.0	59.4	301.2	90.5	158.3	191.5	159.2	674.0	619.9	3,196.3
1985	440.1	379.1	354.8	240.4	288.6	141.7	96.6	84.5	71.3	86.4	65.8	145.4	2,394.7
1986	489.1	162.6	349.8	249.9	288.2	158.3	149.2	75.2	202.2	155.7	125.5	460.6	2,866.3
1987	508.8	-	-	-	-	-	-	-	-	-	-	-	-
Mean	417.2	329.1	389.8	150.2	189.0	139.8	105.0	130.0	170.7	218.6	275.1	357.8	2,872.3

Source: Apia Meteorological Office

Table 1.2.5 Annual Occurrence Frequency of Wind Speed and Direction - Period 1951 - 1970

Speed in Knots	N	NE	E	SE	S	SW	W	NW	Total
0 - 2									37.942
3 - 13	2.158	3.480	19.230	12.265	6.262	2.029	1.882	1.620	48.926
14 - 27	0.359	0.576	10.775	0.758	0.040	0.019	0.152	0.402	13.080
28 - 40	0.010	-	0.017	-	-	-	0.007	0.012	0.046
40 -	-	-	-	-	-	-	-	0.005	0.005
Total	2.527	4.056	30.022	13.023	6.302	2.048	2.041	2.039	100.000

Source: Apia Meteorological Office

Table 1.2.6 Annual Occurrence Frequency of Wind Direction at Apia 1951 - 1970

(%)

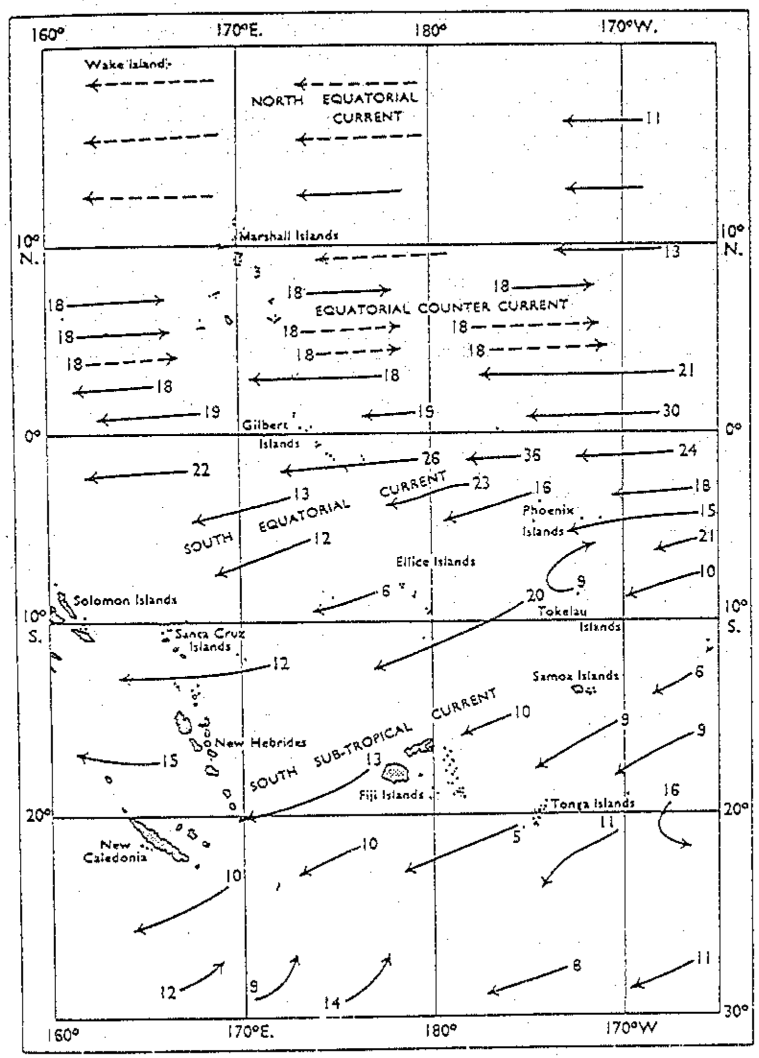
Month	N	NE	E	SE	S	SW	W	NW	CALM
Jan.	0.55	0.51	1.63	0.75	0.63	0.31	0.34	0.34	3.40
Feb.	0.43	0.35	1.32	0.60	0.55	0.31	0.42	0.46	2.95
Mar.	0.51	0.42	1.44	0.73	0.50	0.21	0.38	0.37	3.96
Apr.	0.15	0.31	1.67	0.82	0.31	0.15	0.17	0.23	4.38
May	0.09	0.28	2.47	1.15	0.40	0.07	0.04	0.05	3.99
June	0.05	0.19	3.28	1.34	0.44	0.05	0.05	0.02	2.76
July	0.04	0.20	3.21	1.67	0.69	0.11	0.04	0.04	2.56
Aug.	0.07	0.30	3.49	1.59	0.60	0.21	0.03	0.04	2.22
Sep.	0.03	0.30	3.56	1.34	0.37	0.07	0.03	0.02	2.54
Oct.	0.12	0.36	3.35	1.18	0.55	0.15	0.08	0.06	2.72
Nov.	0.21	0.40	2.60	0.95	0.54	0.13	0.17	0.15	3.12
Dec.	0.30	0.44	2.02	0.82	0.72	0.27	0.30	0.26	3.35
Total	2.55	4.06	30.04	13.07	6.30	2.04	2.05	2.05	37.95

Source : Apia Meteorological Office

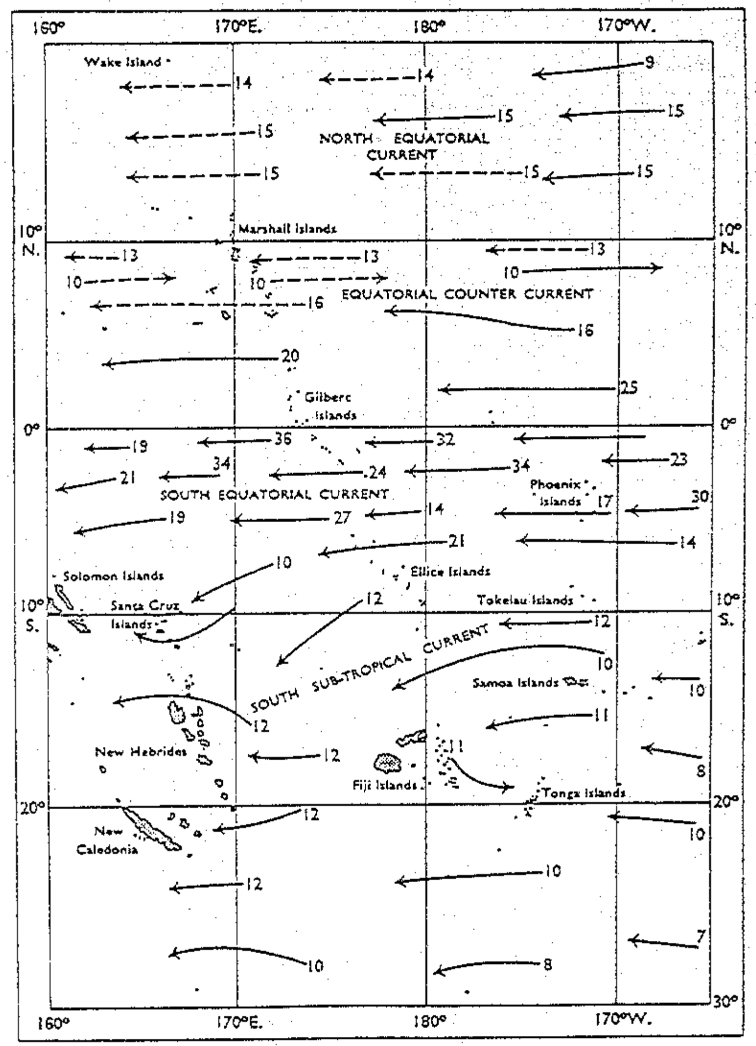
Table 1.2.7 Record of Hurricanes

Year	Month	Mean Wind Velocity (m/sec)	Time (hrs)	Wind Direction	Max Wind Velocity (m/sec)
1831 1888	Storm: Only basic records, no data for wind direction and velocity				
1889	3	30	24 (Same wind direction 8 hrs)	W - S -SE	-
1923	3	25	12	NE - NW	-
1926	1	30	2	NSE - S	-
1930	12	20	-	N	-
1946	12	23.6	-	-	-
1952	1	19.4	3	-	-
1957	12	14.4	24	ESE	38
1958	3	15	1	ENE	24
1959	2	9.8	24	N	21
1960	1	19	5	NW	26
1961	3	11.8	72	NW	26
1963	3	15	14	NW	21
1964	1	5	24	NE	19
1965	3	4.5	24	E	18
1966	1	30	9	S	41
1967	12	10.5	24	NE	21
1968	2	28.3	1.25	NW	39
1969	1	10.3	24	NNE	21.5
1970	2	11.5	24	NNE	22.5
1972	1	10.5	24	NE	26
1974	1	10.5	24	NNE	19
1975	1	9	48	SSE	26

Source: Apia Meteorological Office



December, January, February



March, April, May

Fig. 1.3.1 (1) Predominant Currents in the South Pacific (Speeds in Miles per Day)
(Broken Lines Indicated Few Observation)

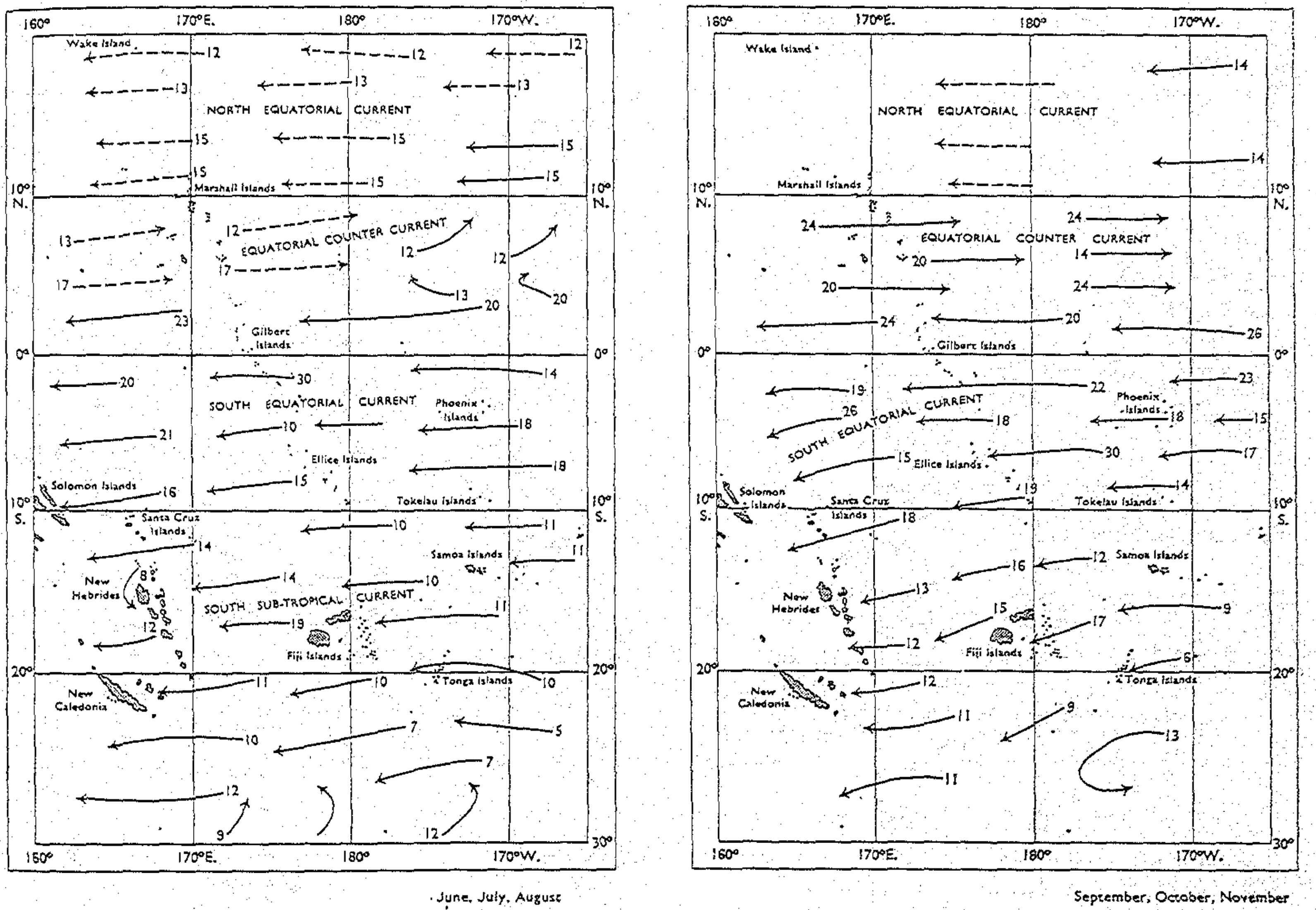


Fig. 1.3.1 (2) Predominant Currents in the South Pacific (Speeds in Miles per Day)
(Broken Lines Indicated Few Observation)

Table 1.4.1 List of Earthquakes Magnitude 4.7 and Over

Date	Month	Year	Time	Mag
16	June	1917	06:00	8.3
3	March	1956	00:06	6.5
28	January	1957	08:17	6.5
14	April	1957	19:19	7.0
31	March	1959	07:21	6.0
12	April	1959	20:55	6.5
10	March	1961	08:50	6.0
30	April	1961	23:40	6.25
8	October	1963	00:17	6.0
11	March	1968	08:27	6.0
10	April	1968	12:16	6.25
6	October	1968	08:48	6.0
9	October	1968	03:39	6.0
7	August	1972	09:25	6.0
7	September	1972	09:12	5.9
12	December	1972	16:23	6.0
16	March	1974	10:56	6.0
21	September	1974	08:29	6.0
9	December	1975	09:14	6.0
26	December	1975	15:56	6.4
11	February	1976	21:44	6.0
3	April	1977	07:15	6.0
17	July	1978	13:26	6.0
4	February	1979	02:10	5.4

Date	Month	Year	Time	Mag
15	April	1979	07:30	4.8
11	June	1979	17:24	4.9
14	June	1979	02:59	5.2
15	June	1979	03:34	5.1
18	September	1979	20:56	5.4
13	November	1979	14:44	5.5
27	December	1979	07:45	5.5
21	January	1980	02:39	5.1
3	February	1980	11:59	6.2
3	February	1980	19:02	4.8
19	February	1980	06:06	4.7
24	February	1980	15:19	4.8
8	March	1980	01:01	5.5
8	March	1980	01:14	5.1
2	May	1980	16:50	5.3
18	June	1980	10:50	5.9
2	July	1980	15:43	5.7
13	July	1980	22:14	5.4
25	July	1980	04:30	4.7
20	August	1980	04:45	4.8
31	August	1980	01:44	4.7
15	September	1980	23:31	5.3
17	September	1980	05:08	5.6
17	September	1980	05:37	5.4
9	October	1980	16:20	5.7

Source: Apia Meteorological Office

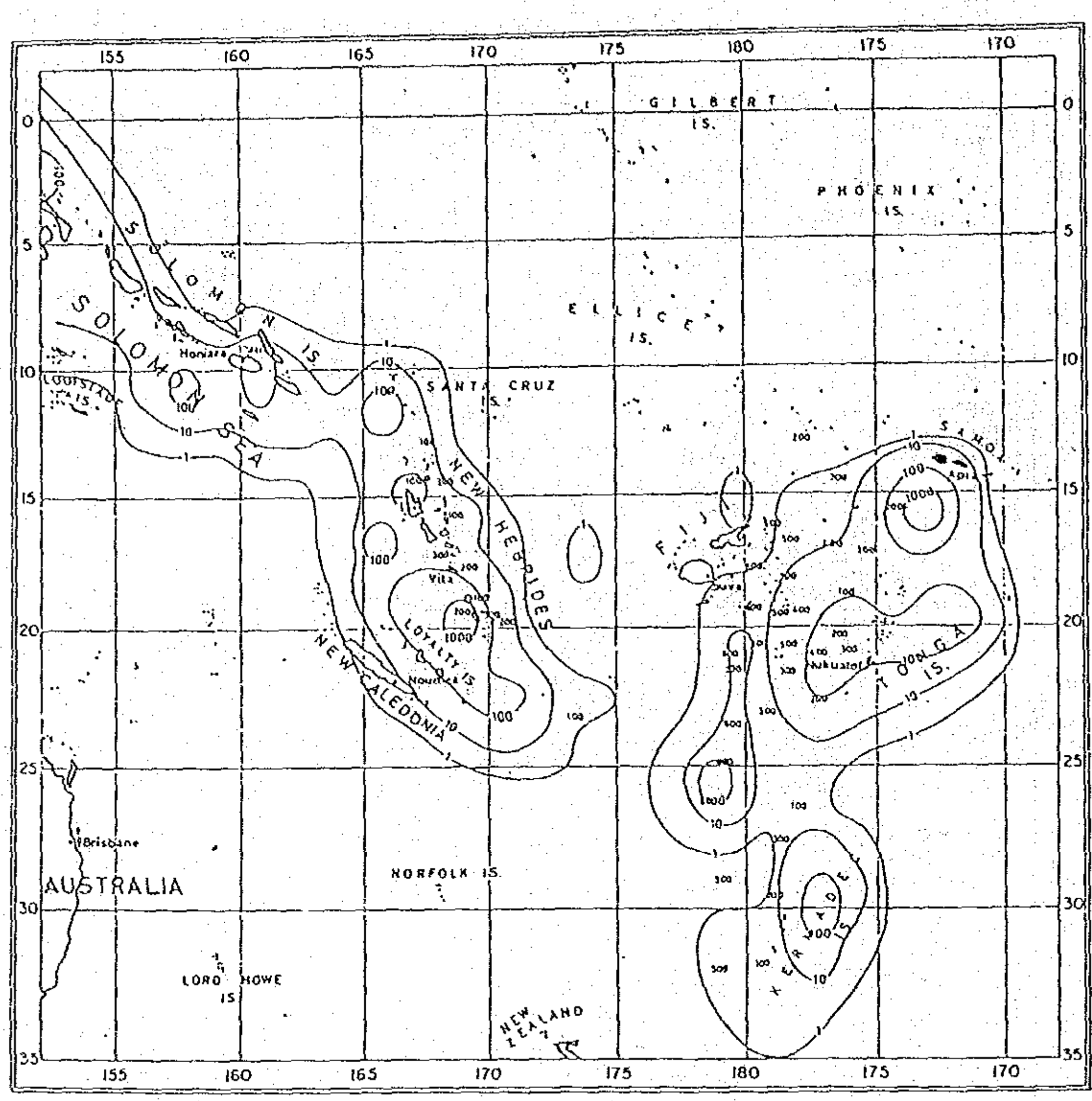


Fig. 1.4.1 Seismicity of Fiji-Tonga-Samoa-New Hebrides: (Seismicity contours are numbered in 10^{15} ergs km^{-2} $year^{-1}$.)

Source: Global Tectonics and Earthquake Risk

CHAPTER 2
NATURAL CONDITIONS SURROUNDING APIA HARBOUR

Chapter 2 Natural Conditions Surrounding Apia Harbour

2-1 Background of the Study and Study Items

1. Apia Harbour is located in the center of the north side of Upolu Island and is an inlet in the coastal reef between the western side of East Reef, which extends northward from pilot point (13°49'S, 171°45'W) and the eastern side of West Reef, which extends eastward from the Mulinuu Peninsula.

2. The harbour is open northward. Therefore it is reported that during the November to April hurricane season heavy swells enter the harbour and severe surging problems at the wharf may force vessels to leave the berth.[*1] A siltation problem in the harbour caused from floods of the Vaisigano River is also reported.

3. Field surveys were carried out to obtain data for analysis of wave and siltation problems and to determine the subsoil conditions for basic design of port facilities. The study items, methods and purposes are as follows.

Item	Purpose	Method/Equipment
Wave Investigation	Wave Conditions	Ultrasonic Wave Recorder
Sounding Survey	Siltation Conditions	Ultrasonic Echo Sounder
Current Observation	Siltation Conditions	Float
Bed Material Sampling	Siltation Conditions	Sampler, Soil Tests
Soil Investigation	Design Conditions	Boring, Soil Tests

A full analysis has been carried out based on the collected data.

*1 Report on Port Development Proposals for Apia, Western Samoa, Wilton & Bell Pty. Ltd., 1977.

2-2 Waves

1) Objectives and Results of the Analysis

4. The objectives of the wave analysis at Apia Harbour are divided broadly into two as follows:

1. Analysis of resonance phenomenon in the harbour
2. Improvement of the calmness in the harbour

The schematic flows of the analysis are shown in Fig. 2.2.1 and Fig. 2.2.2. The main flows are represented by bold lines.

5. The resonance phenomenon was analized mainly by spectrum analysis of actually recorded wave data, and by three other methods: moving average analysis, finite element analysis and simple model analysis for comfirmation of the results of the spectrum analysis.

6. All the analysis showed the same results. The results are summarized as follows.

① The dominant wave period of component waves is about 10 sec. at the mouth of the harbour and at the inner port of the harbour.

② A resonance phenomena of long period components occurs in the harbour.

③ The dominant periods of resonance are 60 sec. in the east-west directions and 600 sec. in the south-north directions.

④ The magnitude of the amplification of these long period components in the harbour is 1.5 to 3 times the values offshore.

⑤ The energy density of the amplified components in the harbour are rather small: about 1 percent of that of the dominant wave component offshore.

7. The analysis of the calmness in the harbour was carried out considering the occurrence probability of waves in the harbour based on the wave deformation calculation of ordinary waves.

8. The required calmness in the harbour will be obtained by constructicn of a 100m long breakwater at the northern harbour of the existing wharf.

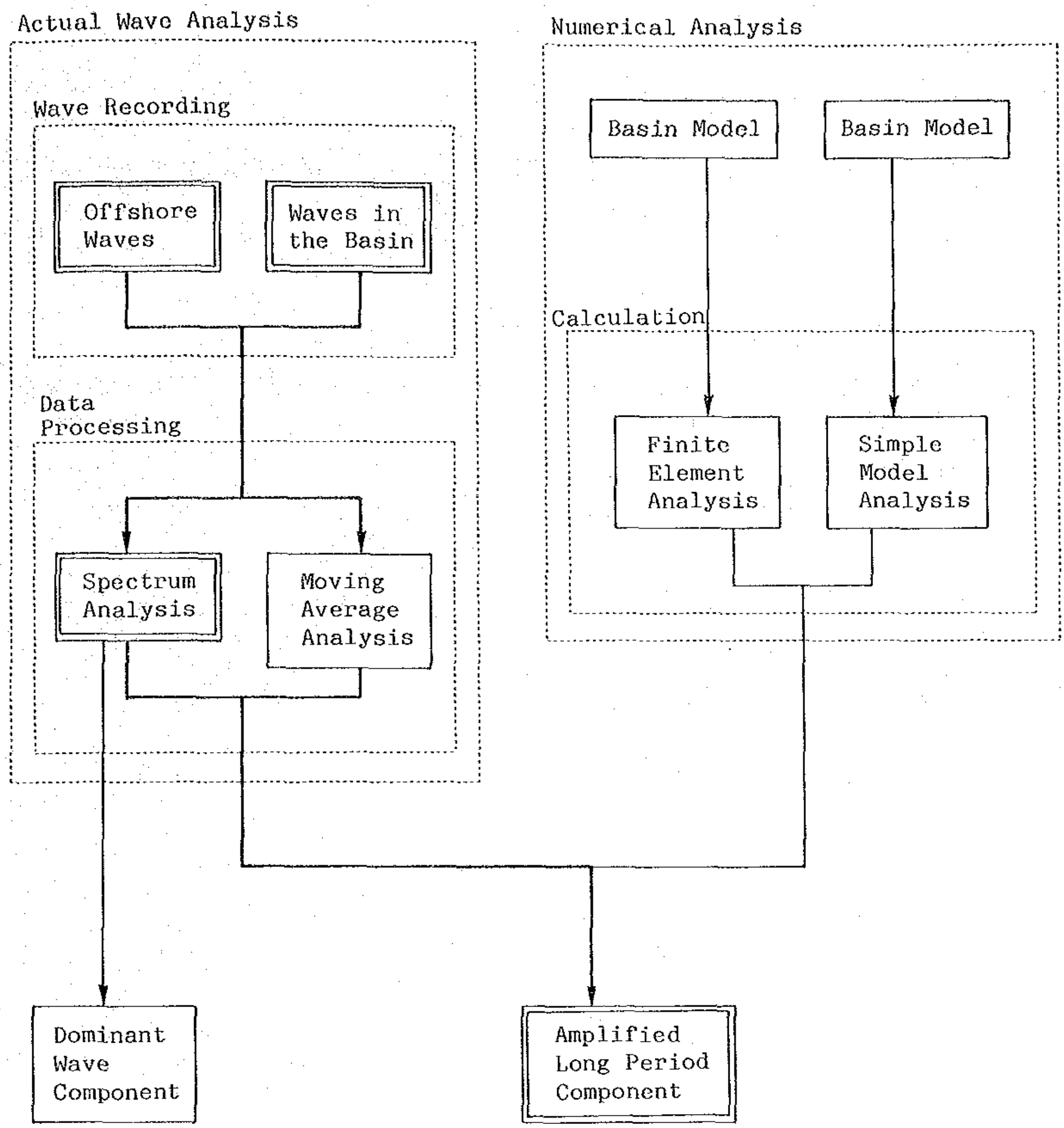


Fig. 2.2.1 Flow Chart of the Resonance Analysis

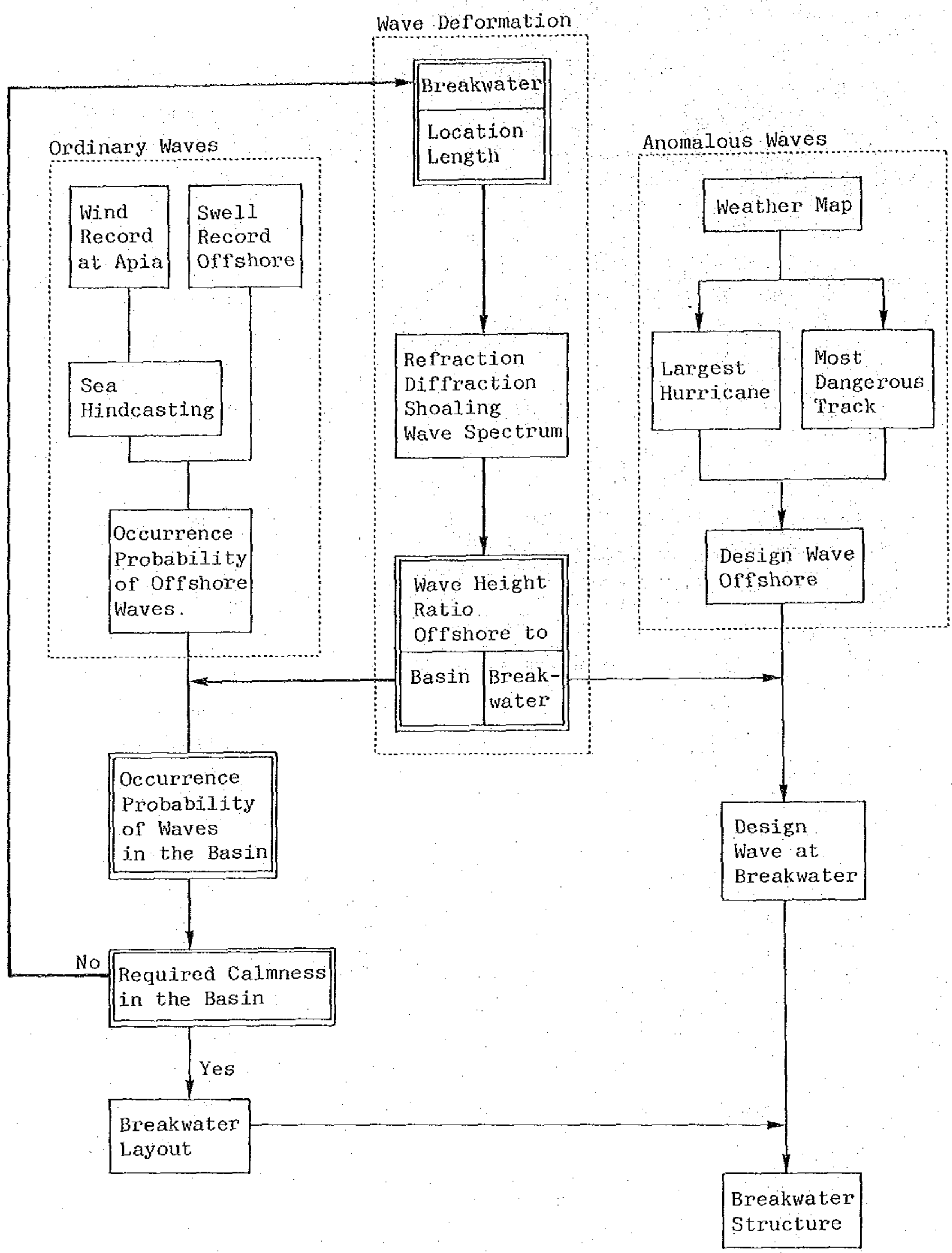


Fig. 2.2.2 Flow Chart of Improvement of the Calmness in the Harbour

9. The structural design of the breakwater is presented in Chapter 7 based on the design wave at the location of the breakwater as calculated by the anomalous wave analysis.

2) Resonance Analysis

(1) Former Study on Resonance in Apia Harbour

10. Apia Harbour is open to the north and during the southeastern trade wind season it is well protected from waves. However, during the November to April hurricane season big waves enter the harbour and force vessels to move away from the wharf or to wait for berthing in the basin. There is no statistical data on waves. However, waves of that magnitude are said to occur about 20 to 30 days per year. It is also reported that the cause of the waves is amplification of the long period component of waves penetrating into the port such as seiche or resonance.

11. The waves in Apia Harbour was extensively investigated in 1975 by Professor Raudkivi of the University of Auckland using the following three study methods.

① Recording of actual waves
② Hydraulic model test
③ Numerical model test

12. The report concluded as follows.

① Both the computer model and the hydraulic model results show that resonance conditions do occur in Apia Harbour.

② Serious resonance conditions are to be expected at a period of 50 - 60 seconds and at about 120 - 150 seconds. Other resonance conditions take place at about 200 and 600 seconds.

③ The breakwaters are very effective in reducing the wave height of short waves. However, for long period waves the situation is reversed.

Professor Raudkivi recommended that Apia Harbour should be resited in Vaiusu Bay.

13. Other reports regarding the waves have been issued and most of them confirm that Apia Harbour has difficulty with long period waves. These reports use many terms for long period waves which are amplified in the basin, such as swell, surge, seiche and resonance. In this report 'resonance' shall be used for the phenomenon of amplification of a free wave or oscillation of a system by a forced wave or oscillation of exactly equal period.

(2) Wave Recording

14. Wave recording was carried out from January 28, 1987 to March 17, 1987. Two or three ultrasonic wave recorders, model SSW-II Kyowa Shoko, were used for the recording of wave height and wave period.

15. Fig. 2.2.3 shows the location of the wave recording stations (S.T.). S.T. 1 was on the coral bank at the mouth of the harbour. Waves having a period of five sec. and more are already deformed by shoaling there, and therefore the offshore wave height was obtained by conversion of the wave data of S.T. 1. S.T. 2 was located in front of the west reclaimed land. S.T. 3 to S.T. 8 were located around the Main Wharf.

16. The recorders set on the sea bed transduce ultrasonic pulses (200 KHZ) at intervals of 0.5 sec. and sense reflected pulses from the water surface. The recorders measure the time between transducing and sensing and calculate the distance between the sea bed and the water surface. Continuous transducing of pulses measures wave height, and the measured wave signals are recorded on magnetic tapes.

17. The wave recoders transduces ultrasonic pulses for 1,024 sec. (2,048 pulses) continuously and calculates the singificant wave height (H 1/3)*[1] and significant wave period (T 1/3) *[2]automatically.

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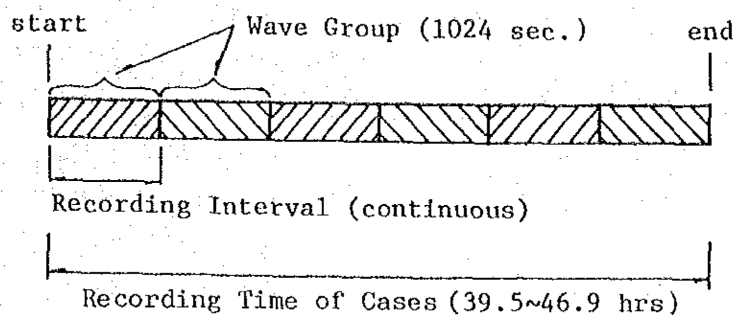
*1 The average height of the one-third highest waves of a given wave group.

*2 The average period generally taken as the period of one-third highest waves within a given group.

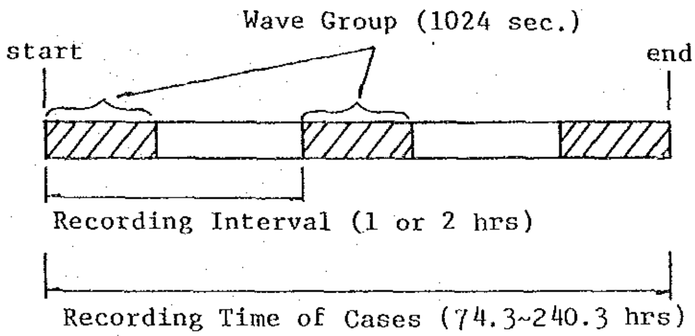
Cases 1 ~ 8

Continuous
Recording



Cases 9 ~ 11

Periodical
Recording



18. In this report, 'Case' means a combination of locations of wave recording stations. 'Wave Group' means a series of waves recorded during 1,024 sec. and 'Recording Interval' means the interval between wave groups as shown in the following figures.

19. The recording cases are as below. Six cases out of eleven cases were recorded by the combination of S.T. 1 and S.T. 4 for analysis on the amplification of the long period component of waves in front of the wharf.

Case No.	Location of Wave Recorder 1	2	3	4	5	6	7	8	Recording Time of Case (hrs)	Recording Interval
1	0			0					45.8	Continuously
2	0			0					43.2	do
3	0			0					46.9	do
4	0			0					46.9	do
5	0			0					46.6	do
6	0	0							43.5	do
7		0		0					43.2	do
8			0	0					39.5	do
9	0			0					240.3	2 hrs
10				0	0				74.3	1 hr
11					0	0	0	0	96.3	2 hrs

20. Fig. 2.2.4 shows samples of the results of the wave recording. Upper and middle figures show significant wave height (H 1/3) and significant wave period (T 1/3) at each S.T., and the lower figures show the wave height ratio among two S.T.; in these figures the larger wave's height is converted to 1.0.

21. Fig. 2.2.5 shows a wave refraction diagram of regular waves. The refraction coefficient at S.T. 1 is estimated to be Kr = 0.97 for waves of T = 10 sec. incident from N10°E. Fig. 2.2.6 shows a shoaling diagram of nonlinear waves. At S.T. 1, h/L is 0.128 for waves of T = 10 sec. At water depth h = 20m, the shoaling coefficient is Ks = 0.92. Therefore the wave height ratio at S.T. 1 is Kr x Ks = 0.89 to deep water wave height.

22. The approximate wave height ratios at each station to offshore waves are as follows based on the recorded wave data.

S.T. No.	1	2	3	4	5	6	7	8
Ratio to Offshore Waves	0.90	0.70	0.25	0.30	0.50	0.30	0.25	0.25

(3) Analysis of Resonance

23. In this section, the amplification of the long period component of waves in Apia Harbour is discussed.

(i) Spectrum Analysis

24. A spectrum analysis was conducted for the data obtained at S.T. 1 and S.T. 4. Five data which have an evident tendency of amplification of the long period component are selected among all the analyzed data. The recording time, H 1/3 and T 1/3 of these data are as follows.

Case	Wave Group No.	Recording Time (sec.)	S.T. 1 H 1/3 (m)	S.T. 1 T 1/3 (sec.)	S.T. 4 H 1/3 (m)	S.T. 4 T 1/3 (sec.)
5	20	1,024	0.98	12.2	0.37	13.7
9	11	1,024	1.68	9.4	0.50	10.3
9	47	1,024	1.11	8.9	0.25	11.7
5	11 - 14	4,096	1.06	12.7	0.29	11.8
5	20 - 23	4,096	0.95	12.0	0.31	13.5

25. Fig. 2.2.7 (1) - (5) shows samples of the power spectrum and wave height ratio. Of these figures, (1) to (3) shows the results of analysis for 1,024 sec. (for one Wave Group) and (4) and (5) show that of for 4,096 sec. (for four Wave Groups).

26. Fig. 2.2.7 (1) shows the spectrum with a stationary wave height (see Fig. 2.2.4(1)). The power spectrum shows that both peaks of S.T. 1 and S.T. 4 are in the range of $F = 8 \times 10^{-2}$ to 6.5×10^{-2} $sec.^{-1}$ (12.5 to 15 sec.), and they are almost equivalent to the significant wave period (T

1/3). S.T. 1 has only one peak, while S.T. 4 has a second peak at F = 1.6 x 10^{-2} sec. $^{-1}$ (about 60 sec.).

27. The wave height ratio shows amplification of the long period component in the harbour. The magnitude of amplification of the long period component in the harbour is about 2.5 at F = 1.6 x 10^{-2} sec.$^{-1}$ (60 sec.).

28. The energy density peak of S.T. 1 is 4 x 10^{4} cm^{2} sec. and the second energy density peak of S.T. 4 is 5 x 10^{2} cm^{2} sec. Therefore, the wave height ratio between the significant wave height at S.T. 1 and the wave height of the long period component at S.T. 4 is 0.11 ($\sqrt{5 \times 10^{2}/4 \times 10^{4}}$ The wave height of the amplified long period compoment is about 11cm (0.98m x 0.11)).

29. Fig. 2.2.7 (2) shows the spectrum for waves in the stage of growth (see Fig. 2.2.4(2)). The tendency of amplification of the low frequency component is the same as that shown in Fig. 2.2.7 (1). The wave height of the long period component at S.T. 4 is estimated as 12 percent of the significant wave height at S.T. 1. The wave height of the amplified long period component is estimated as about 20cm (1.68m x 0.12). The peak of the wave height ratio is about 2.4 at F = 1.6 x 10^{-2} sec.$^{-1}$ (60 sec.).

30. Fig. 2.2.7 (3) shows the spectrum for waves which are decreasing (see Fig. 2.2.4 (2)). The energy density shows that there is a low frequency zone where the energy density is amplified in the harbour. The frequency of the zone is 1 x 10^{-3} to 3 x 10^{-3} sec.$^{-1}$ (33 sec. to 100 sec.). Three peaks of low frequency wave height ratio are shown at frequencies of 3 x 10^{-2}, 1.6 x 10^{-2} and 1.0 x 10^{-2} sec.$^{-1}$ (33, 60, and 100 sec.), and the magnitudes of amplification are 2.0, 2.2 and 1.7 respectively.

31. Fig. 2.2.7 (4) and (5) are the results of a continuous 4,098 sec. analysis to analyze the amplificatin in the zone lower than F =10^{-2} sec.$^{-1}$ (100 sec.).

32. In these figures, amplification of low frequency components in the range of 6.5×10^{-3} to 1.7×10^{-3} $sec.^{-1}$ (about 150 to 600 sec.) are shown. However, the amplification rate of wave height is 1.2 to 1.4. It is rather lower than the rate of amplification in the frequency range 1×10^{-2} to 3×10^{-2} $sec.^{-1}$ (100 sec. to 30 sec.).

(ii) Moving Average Analysis

33. Fig. 2.2.8 (1) to (3) show actual wave profiles and wave profiles processed by the moving average method. This method makes low frequency waves visible by using a high-pass filter which neglect the high frequency component and accentuates the low frequency component.

34. Fig. 2.2.8 (1) is the result of the process for the data of Fig. 2.2.7 (1). At S.T. 1, no low frequency wave profile is shown. On the other hand, at S.T. 4 a small fluctuation in the period of about 60 sec. is shown. However, the wave height of the long period component is less than 10 cm. In this case the significant wave height (H 1/3) at S.T. 4 is 0.98m. Therefore the amplified 60 sec. component in the basin is about 10% of the significant wave height (H 1/3) at S.T. 1. The result of this analysis is equivalent to that of the spectrum analysis.

35. Fig. 2.2.8 (2), which employs the same data of Fig. 2.2.7 (2), shows no distinct tendency of amplification in the basin. Fig. 2.2.8 (3) shows long period fluctuations around the main wharf. At S.T. 8, distinct long period fluctuations in the period of about 1 min. are shown. However, the amplitude is less than 10cm.

(iii) Finite Element Method Analysis

36. Numerical analysis by finite element method analysis was conducted to analyse the amplification of the long period component in the harbour. Fig. 2.2.9 shows the triangle components used for calculation and symbols show the location of the grids where amplification was calculated. The calculation conditions include the conditions of wave refraction, reflection and diffraction. Fig. 2.2.8 shows the result of the calculation.

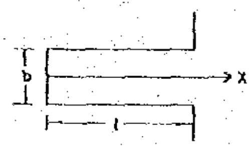
37. Fig. 2.2.11 shows amplification at four points in the harbour. A dominant amplification is shown in the period of 60 sec. at the inner part of the harbour. However, no amplification is shown at the mouth of the harbour. There is another peak at about 630 sec. including the point at the mouth of the harbour, and a small peak at about 300 sec.

(iv) Simple Model Analysis

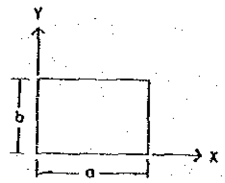
38. Both the results of the analysis of actual wave data and the computer model show that reasonance does occur in Apia Harbour. The mechanism of resonance is discussed below.

39. The natural period of a rectangular basin with one open end is calculated by equation (1) and that of a closed basin is calculated by equation (2) if the water depth is constant.

$$To = \frac{4l \times \alpha}{(2m - 1)\sqrt{gh}} \qquad (1)$$



$$Tc = \frac{2}{\sqrt{(gh)}\sqrt{\frac{m^2}{a^2} + \frac{n^2}{b^2}}} \qquad (2)$$



Where

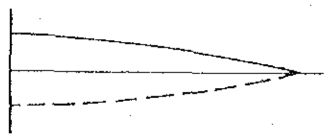
l : length of the basin with one open end
a : width of the closed basin on the X axis
b : length of the closed basin on the Y axis
m : number of nodes on the X axis
n : number of nodes on the Y axis
α : revision coefficient
h : water depth in the basin
g : acceleration of gravity

$$\alpha = \left\{ 1 + \frac{2b}{\pi \ell} \left(0.9228 - \ln \frac{\pi b}{4\ell} \right) \right\}^{1/2}$$

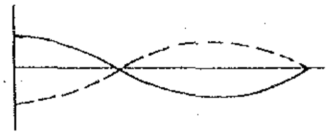
40. Apia Harbour can be assumed to be a rectangular basin with one open end in the north - south direction. Under the condition of 1 = 1500m, b = 600m and h = 15m, the natural periods are obtained as follows by equation (1).

α = 1.237

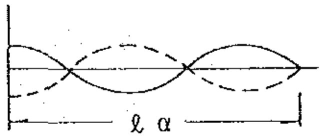
m = 1 To 1 = 612 sec.



m = 2 To 2 = 204 sec.

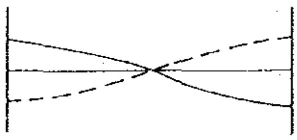


m = 3 To 3 = 122 sec.

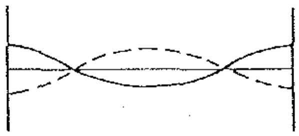


41. On the other hand, Apia Harbour can be assumed to be a closed basin between the wharf and the western reclaimed area in the east - west direction. Under the condition of a = 600m, n = 0 and h = 10m, the natural periods are obtained as follows by equation (2).

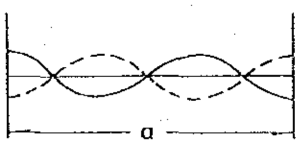
m = 1 Tc 1 = 121 sec.



m = 2 Tc 2 = 61 sec.



m = 3 Tc 3 = 40 sec.



(4) Resonance at Apia Port

42. Apia Port has some natural oscillation periods as shown in the results of the spectrum analysis. However, from the results of the spectrum analysis, the finite element method and the simple model mentioned above it is concluded that the dominant natural oscillation period is about 60 sec. and 600 sec.

43. The four methods of analysis above confirm that resonance phenomena in Apia Harbour may occur. However, even under the condition of resonance, the energy density of the amplified long period component is only about 1/100 of that of the significant offshore wave as shown in the wave spectrum, i.e. the energy of the amplified long period component is small.

44. Former reports mainly discussed the resonance phenomenon without analysis of actual waves. However, the wave problem in Apia Harbour should be discussed including incidental waves. Generally speaking, the port area and especially the berthing area should be well protected from incidental waves. Improvement of the port layout of Apia Harbour is discussed in the subsequent section.

3) Calmness in Apia Harbour

(1) Ordinary Waves

45. Normal waves can be calculated by the S.M.B. method which is one method of wave hindcasting for constant wind areas. The wave height and wave period are calculated by the relation between wind speed and wind duration or wind speed and fetch.

46. Table 2.2.1 shows the wind data for a period of three months including the period of the field survey from January 18, 1987 to March 18, 1987. The wind data were recorded at Apia Observatory. Table 2.2.2 shows wave occurrence by direction and wave height and Table 2.2.3 shows wave occurrence by direction based on the above data. Fig. 2.2.12 and 2.2.13 show the wind rose and the directional distribution of waves respectively. The calculation of waves was done in the WNW-N-ESE directions and waves in the W-S-SE directions are indicated as zero.

47. The results of the wave hindcasting closely correspond with recorded wave data during strong winds. However, the results underestimate the wave height during weak winds because swells can travel a long distance in the Pacific and reach Apia Harbour. During the survey, swells were sometimes observed when there was no wind or when the wind direction was against the wave direction.

48. Seas and swells are considered separately. In this report seas and swells are defined as follows.

Seas : Waves caused by wind at the place and time of observation.
Swells: Wind-generated waves that have travelled out of their generated area.

49. Table 2.2.4 shows the wind data for a period of 3 years from February 1984 to January 1987. Table 2.2.5 and Table 2.2.6 show the occurrence of seas based on that data. Fig. 2.2.14 and Fig. 2.2.15 show the wind rose and the directional distribution of seas.

50. "Seas and Swell Charts" published by the U.S. Navy are used for the estimation of swells. Fig. 2.2.16 shows the directional distribution of swells.

51. Table 2.2.5 indicate that the probability of NW-ENE seas is 12.6 percent i.e. 46 days per year. Fig. 2.2.17 shows the relation between the height of seas and the number of exceedance days. The probability of NW-NE swells is 11.0%, i.e. 40 days per year based on Fig. 2.2.16. Fig. 2.2.18 shows the relation between the height of swells and the number of exceedance days.

(2) Anomalous Waves

52. Fig. 2.2.19 shows the number of hurricanes that crossed each 5-degree area in the 30 seasons from November 1938 to April 1969. The total number of hurricanes that crossed the Samoa Area, 10 - 15 deg. S. latitude and 170 -175 deg. W. longitude, is 25. The number is rather small and it is one-third of that in the New Caledonia area. 16 of the hurricanes crossed the area in the months of November, December and January, and the others in February, March and April. Most of hurricanes which crossed the Samoa Area were in the early stage of growth and 70 percent of them ran southeastward to southward.

53. The largest hurricane disaster at Apia Harbour occurred on March 16, 1889, and seven warships were trapped. There is no wave data for Apia Harbour. In order to determine the design wave, the Wilson Method which can estimate wave height and period of moving wind areas was used.

54. Two hurricanes were chosen for the estimation of anomalous waves. One is the hurricane in 1944 (Hurricane A), which is one of largest hurricanes for which the weather map is available, and the other is the hurricane in 1941 (Hurricane B), whose track is most dangerous to Apia Harbour. Fig. 2.2.20 shows the track of Hurricane B. The weather map of Hurricane A was imposed on the track of Hurricane B for the estimation of the most dangerous hurricane which could occur.

55. Fig. 2.2.19 shows the process of growth of the waves. Fig. 2.2.22 to 2.2.24 show wind direction, wave height and wave period at the peak of wave height offshore from Apia. The design wave conditions offshore from Apia Harbour can be determined as follows:

H = 7.0m T = 10 sec.

(3) Wave Deformation

56. Apia Harbour has no structure sheltering the wharf from incident waves. In this subsection, the sheltering of Apia Harbour against incident waves is discussed.

57. The calculation is done using irregular waves and considers refraction, diffraction, shoaling and directional wave spectrum.

58. Refraction is the process whereby waves progress into the coastline obliquely and the wave direction is changed to a line normal to the contour lines.

59. Diffraction is the phenomenon by which energy is transmitted laterally along a wave crest when a part of a wave train is interrupted by a barrier, such as a breakwater. The effect of diffraction is manifested by propagation of waves into the sheltered region within the barrier's geometric shadow.

60. The shoaling coefficient is the ratio of the wave height in water of any depth to its height in deep water without the effects of refraction, friction and percolation.

61. The directional spectrum represents the distribution of wave energy.

(4) Degree of sheltering

62. In order to obtain the required calmness for consistent cargo handling, the wave height in front of the wharf has to be less than 45 percent of the present height. In this subsection, some port layouts are

discussed from the viewpoint of calmness in the harbour.

63. Fig. 2.2.27 (1) to (4) show the degree of sheltering of each port layout. Case A is the plan with expansion of the existing wharf and reclamation. Case B is the plan with a 112.5m long breakwater jutting out from the existing breakwater to the west. Case C also provides a 112.5m breakwater shifted 75m to north and Case C' is a variation of Case C with a 75m long breakwater.

64. The comparison of the degree of sheltering in front of the existing wharf for each layout is as follows:

Case	Present Condition	A	B	C	C'
Degree of Sheltering (percentage to offshore waves)	28.3	12.8	7.8	9.2	18.6

65. In Case A, calmness is not sufficient and the water area in front of the expanded wharf is still rough. Case B is more calm than Case C. The relation between breakwater length and wave height in Case C is as follows:

Breakwater Length (m)	0 (Present Condition)	112.5 (Case C)	100	75 (Case C')
Ratio to Offshore (%)	28.3	9.2	12.3	18.6
Ratio to Present (%)	100	33	43	66

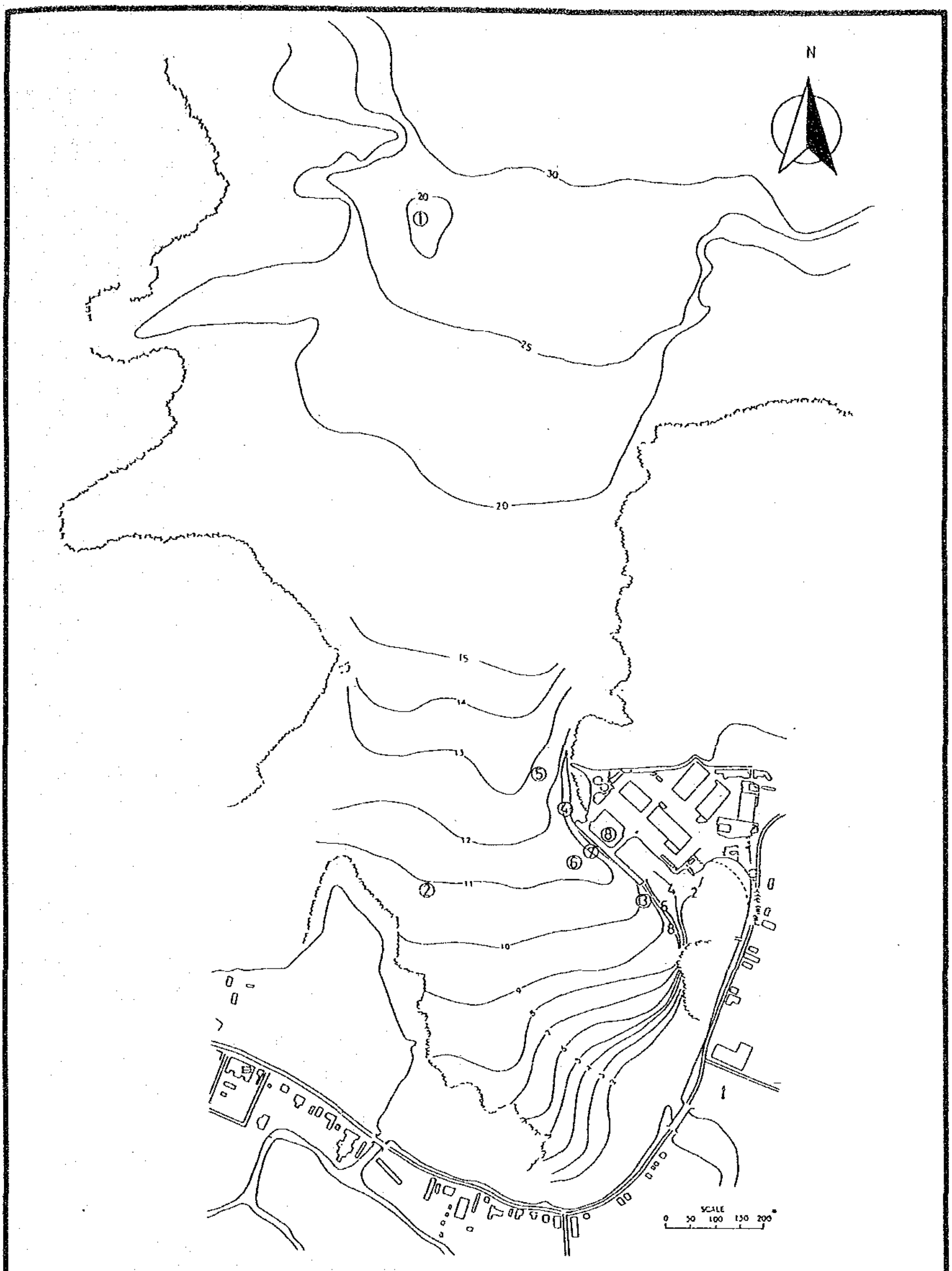
66. In the modified Case C with a 100m long breakwater, the wave height in front of the existing wharf is reduced to the required value.

67. The wave height ratio at the breakwater is about 60 percent of that offshore. The dimensions of the design wave is as follows:

H = 4.2m (7.0m x 0.6)

T = 10 sec.

These values are used for the design of the breakwater in Chapter 6.



Note : Figures with circle denote
locations of wave recorder

Fig. 2.2.3 Locations of Wave Recorder

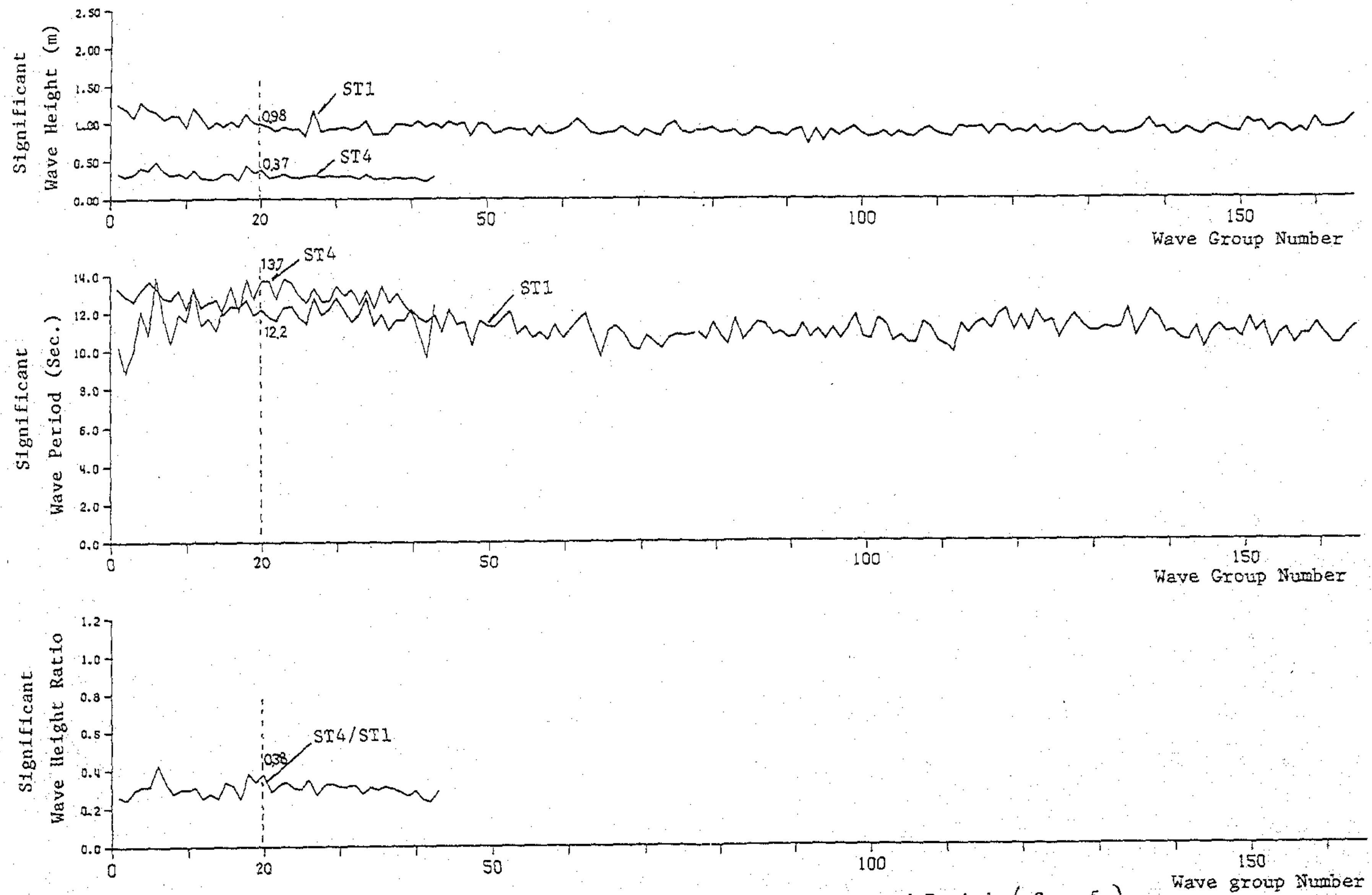


Fig. 2.2.4 (1) Significant Wave Height and Period (Case 5)
(1987. 2. 13. 18:00~)
(Continuous Recording)

Bold Line : S.T.1
Fine Line : S.T.4

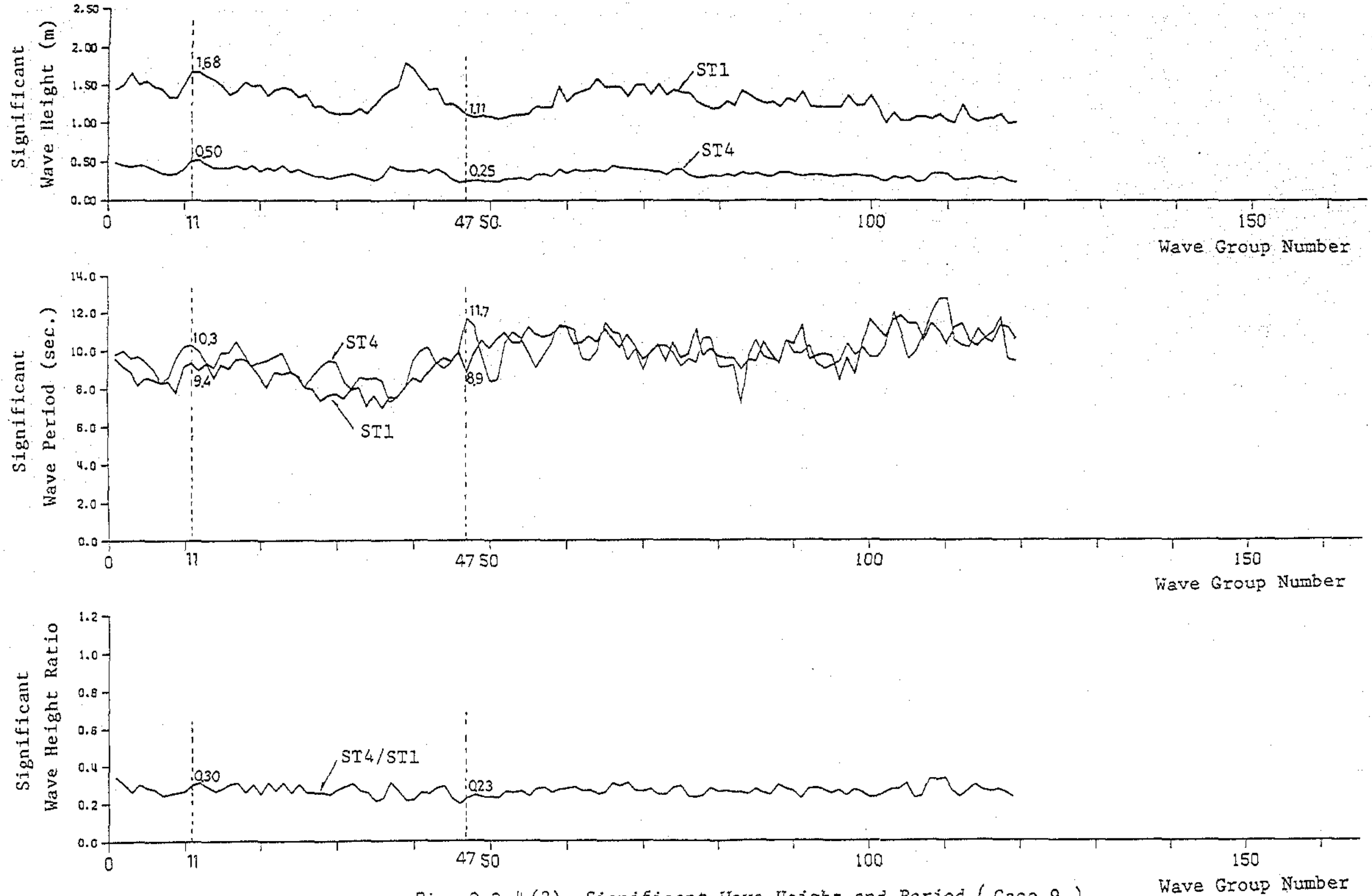


Fig. 2.2.4 (2) Significant Wave Height and Period (Case 9)
(1987. 2. 25. 18:00~)
(2 hrs intervals)

Bold Line : S.T.1
Fine Line : S.T.4

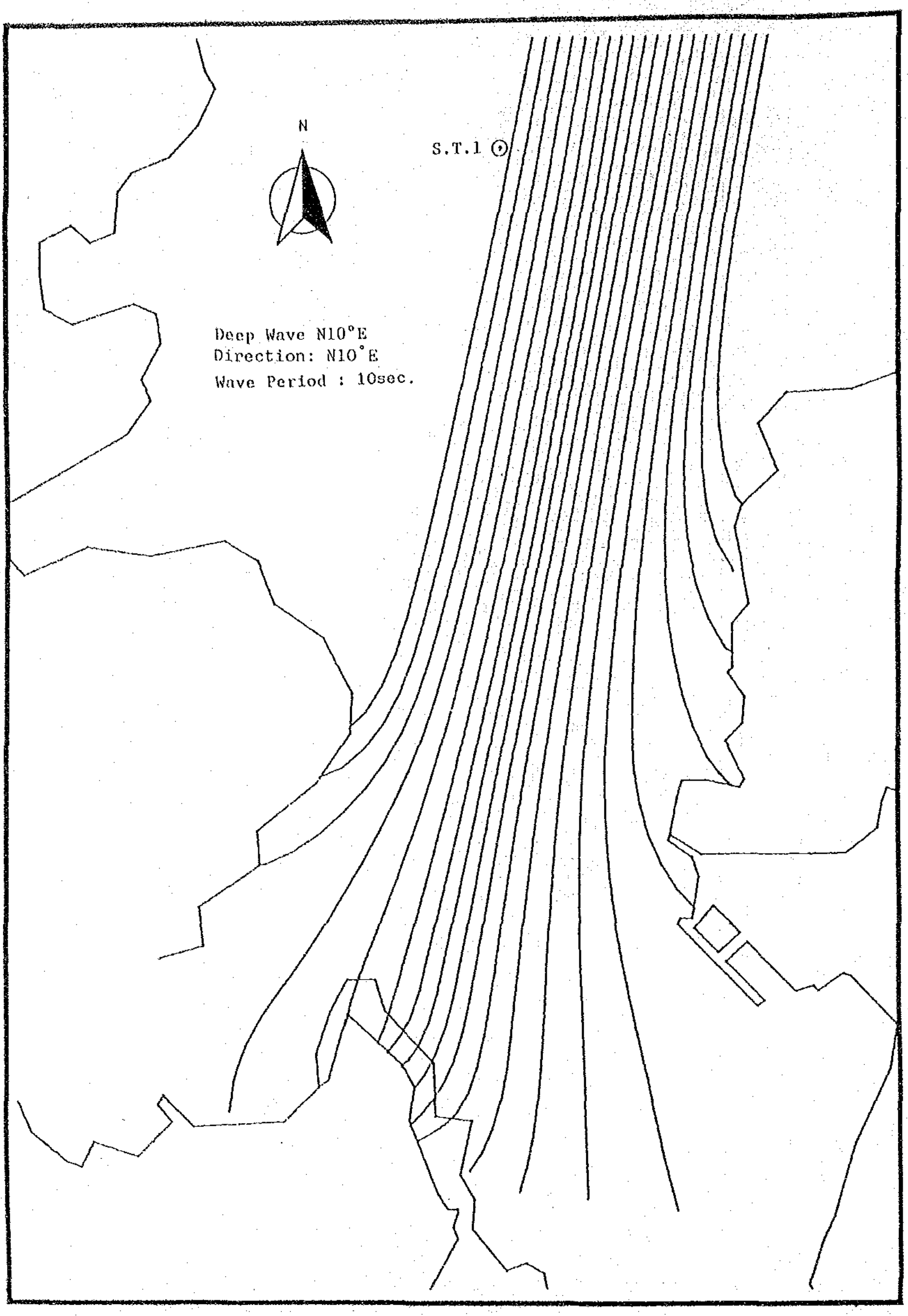


Fig. 2.2.5 Wave Refraction Diagram

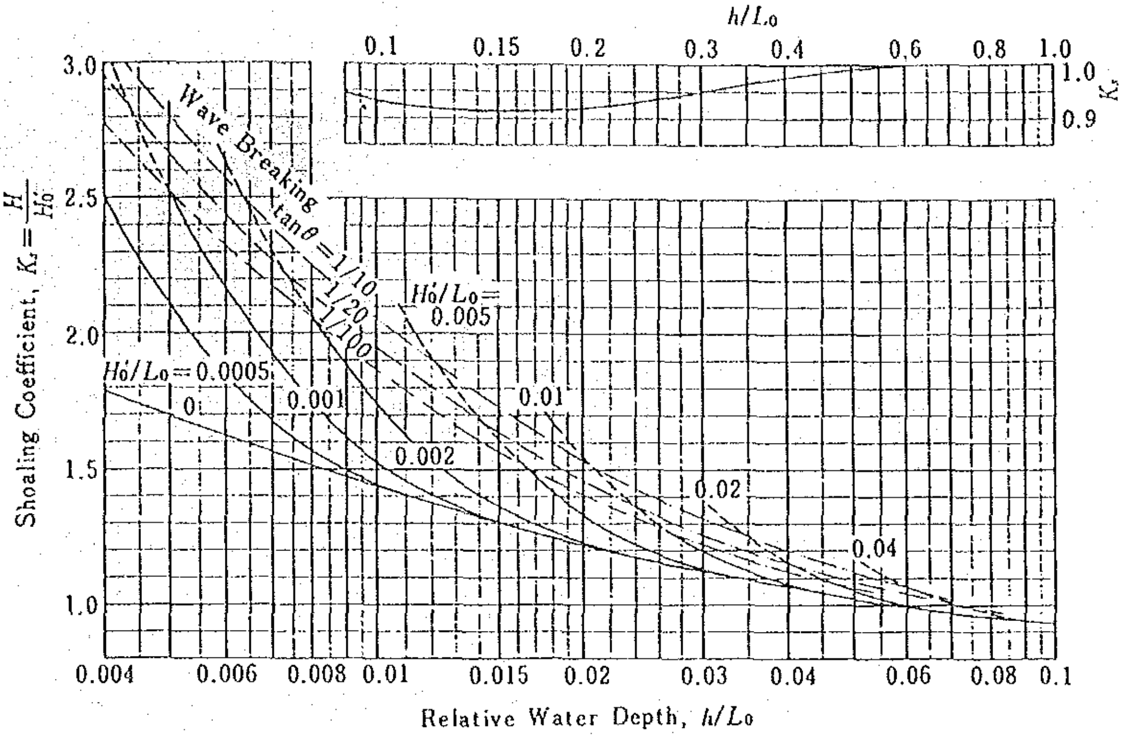


Fig. 2.2.6 Diagram of Nonlinear Wave Shoaling

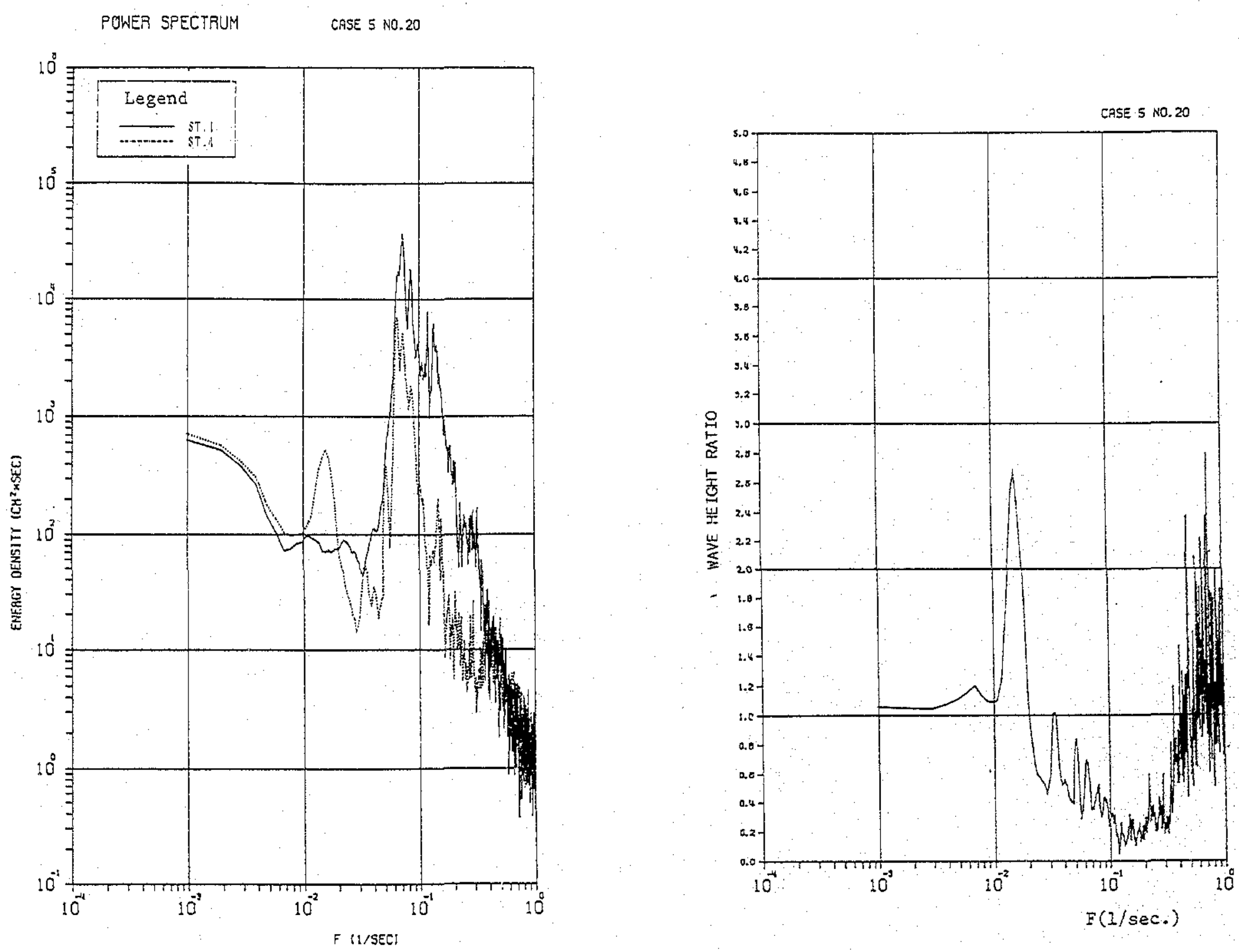


Fig. 2.2.7(1) Spectrum of Waves (Case 5, Wave Group No.20, 1,024 sec.)

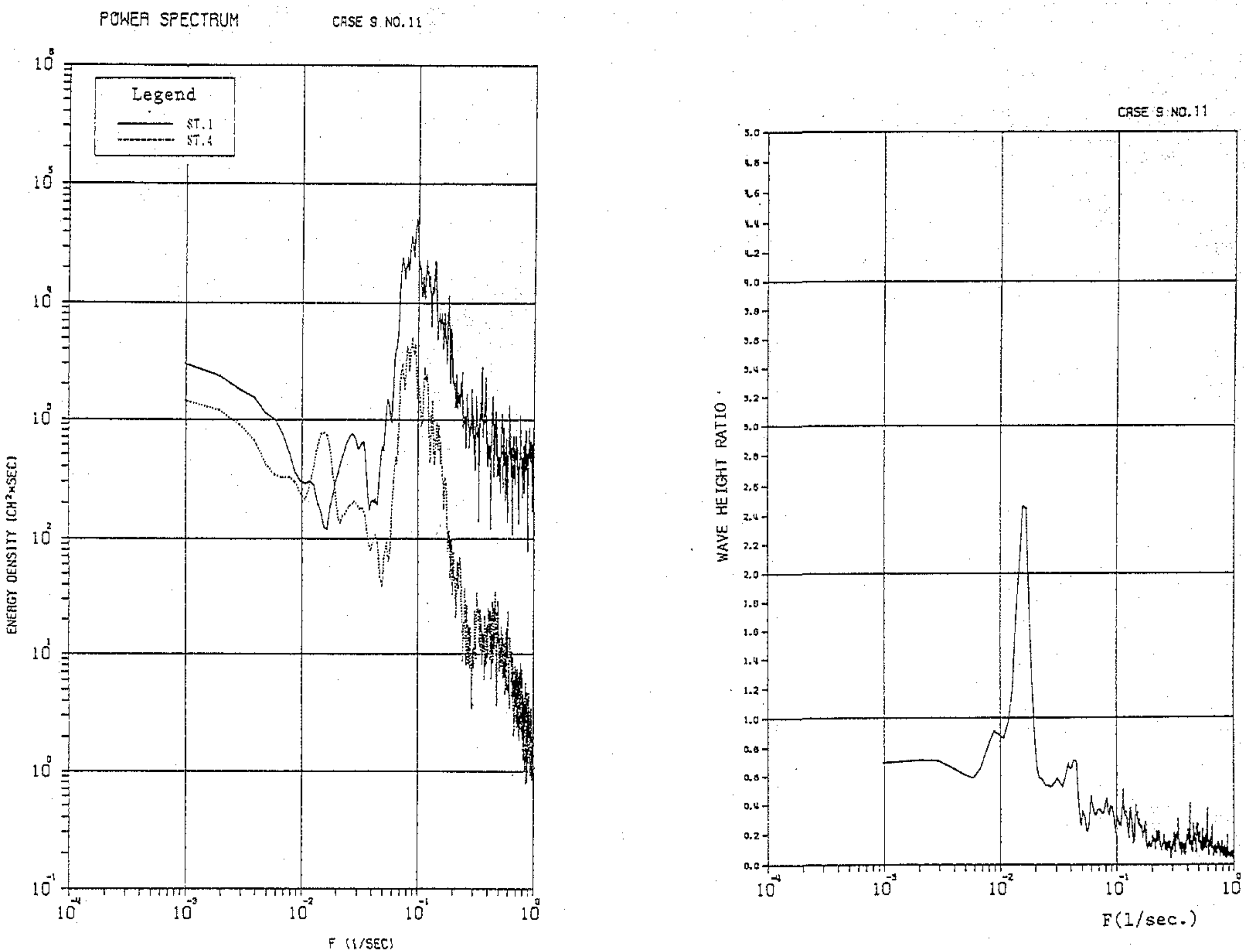
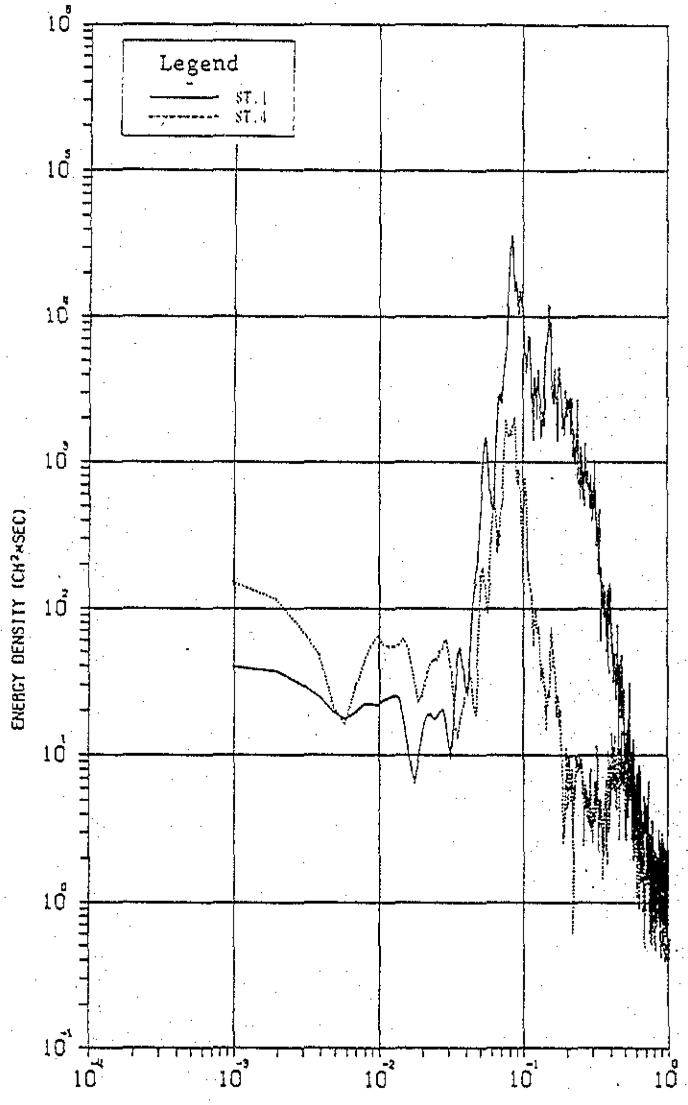


Fig. 2.2.7(2) Spectrum of Waves (Case 9, Wave Group No.11, 1,024 sec.)



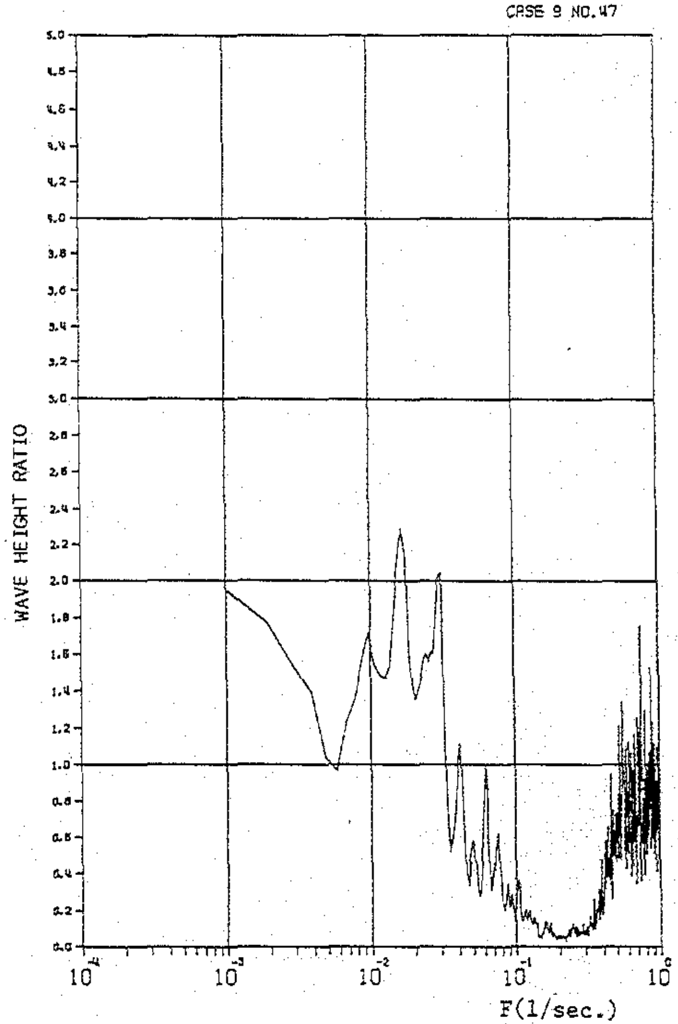


Fig. 2.2.7(3) Spectrum of Waves (Case 9, Wave Group No.47, 1,024 sec.)

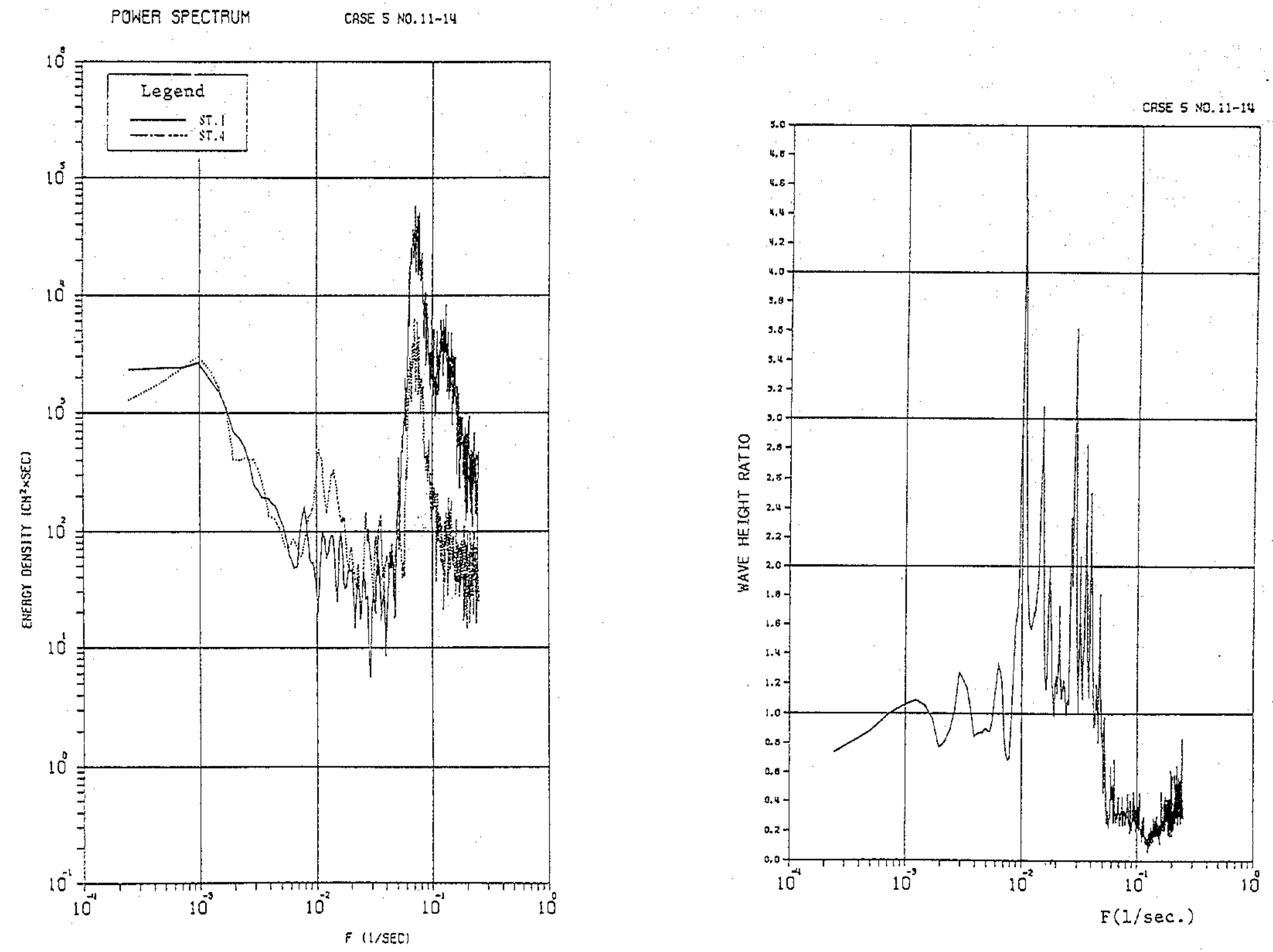
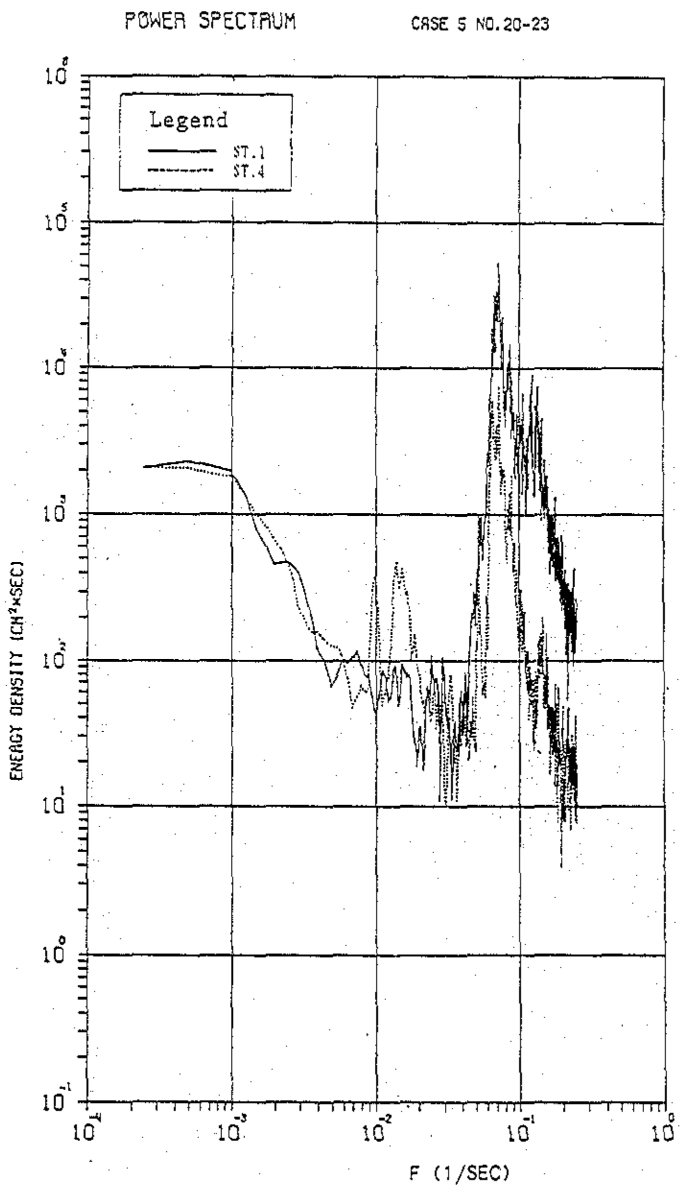


Fig. 2.2.7(4) Spectrum of Waves (Case 5, Wave Group No.11-14, 4,096 sec.)



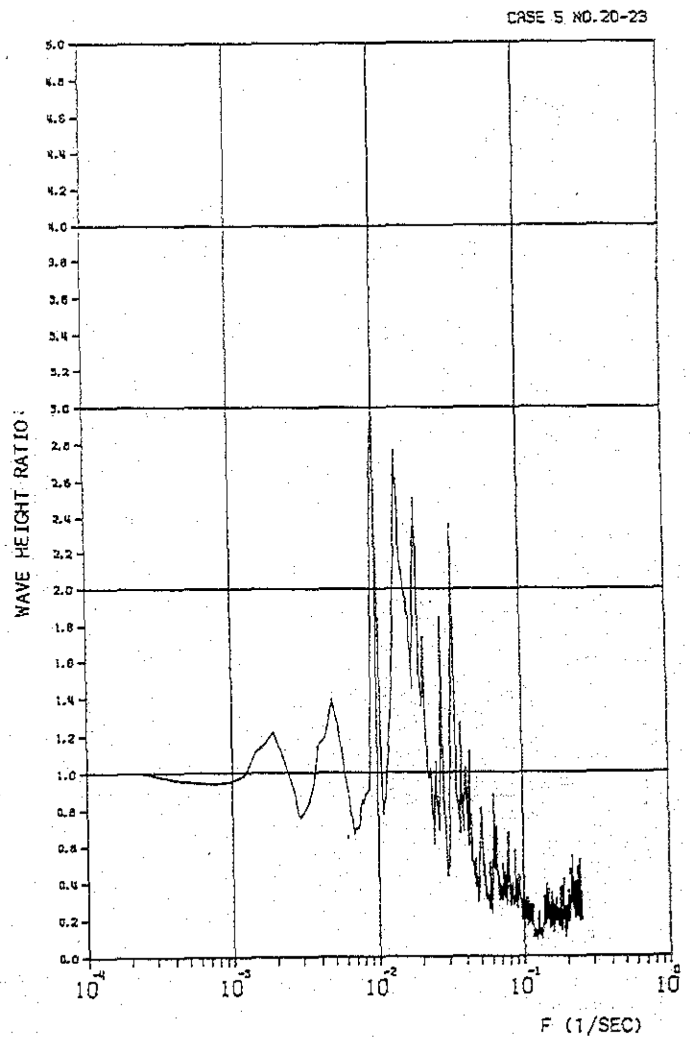
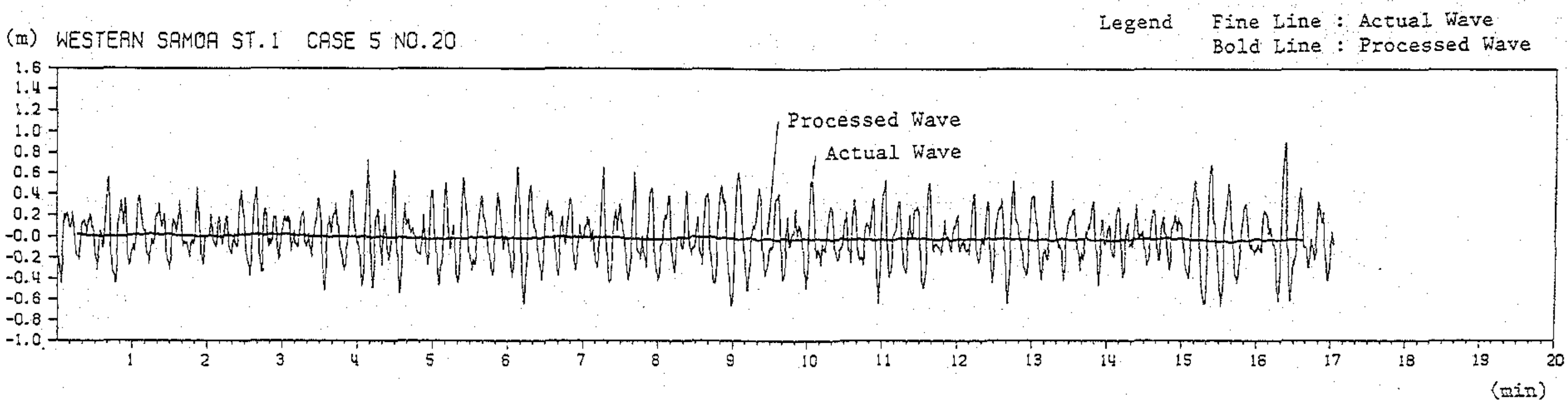


Fig. 2.2.7(5) Spectrum to Waves (Case 5, Wave Group No.20~23, 4,096 sec.)



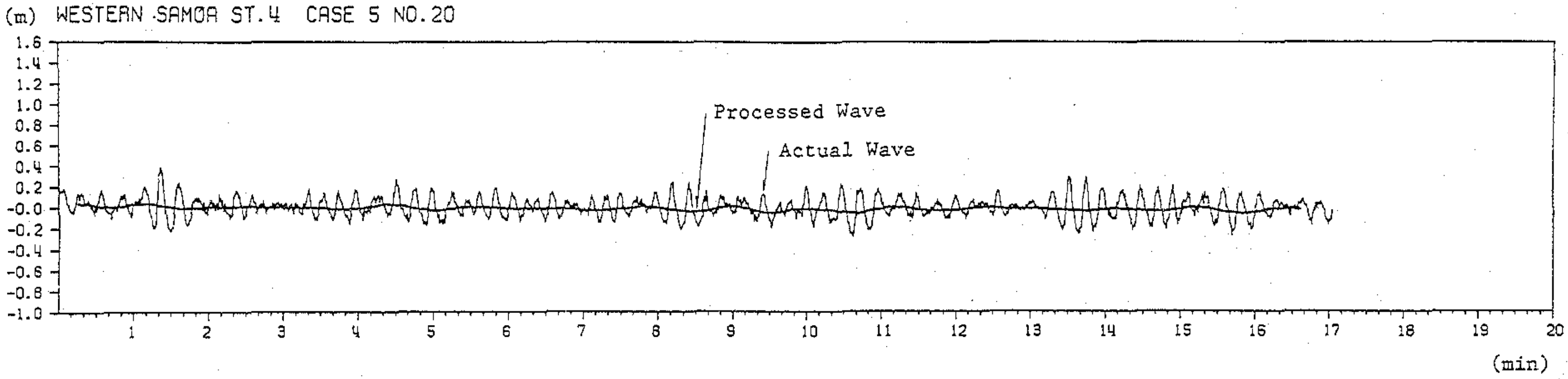
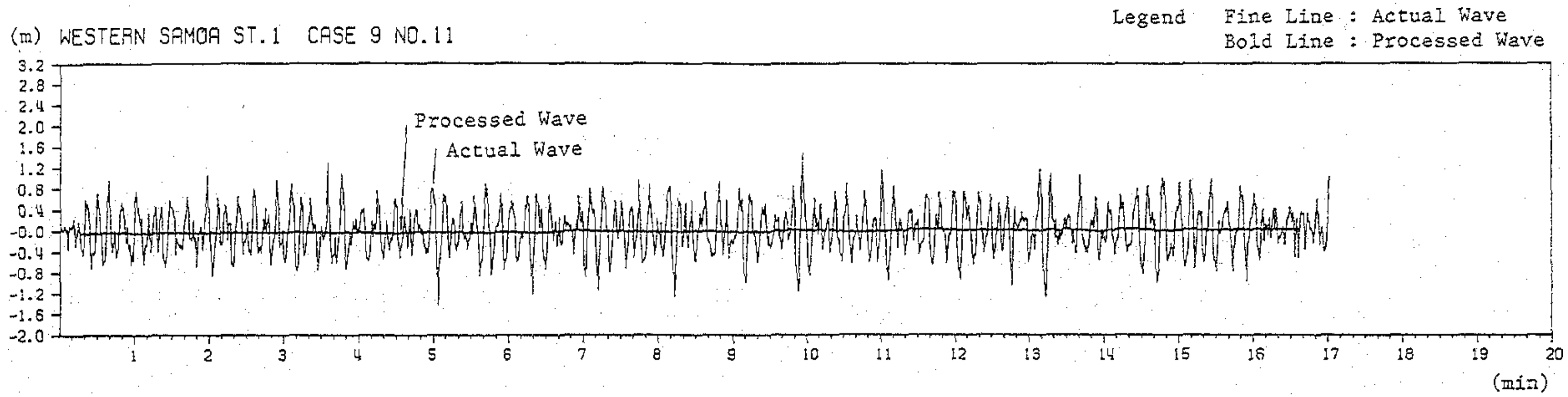


Fig. 2.2.8 (1) Wave Record (Case 5, Wave Group No.20, 1,024 sec.)



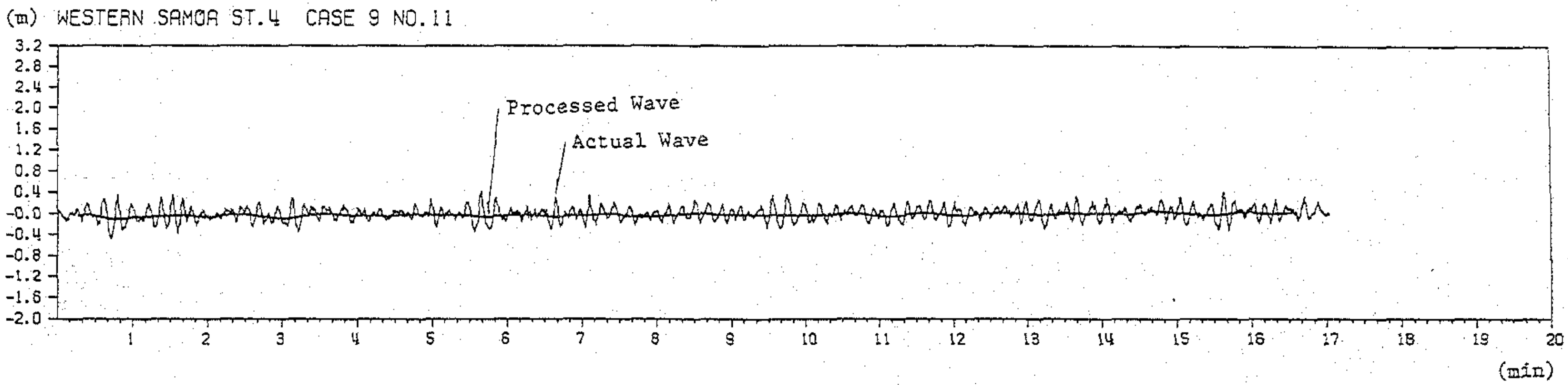


Fig. 2.2.8(2) Wave Record (Case 9, Wave Group No.11, 1,024 sec.)

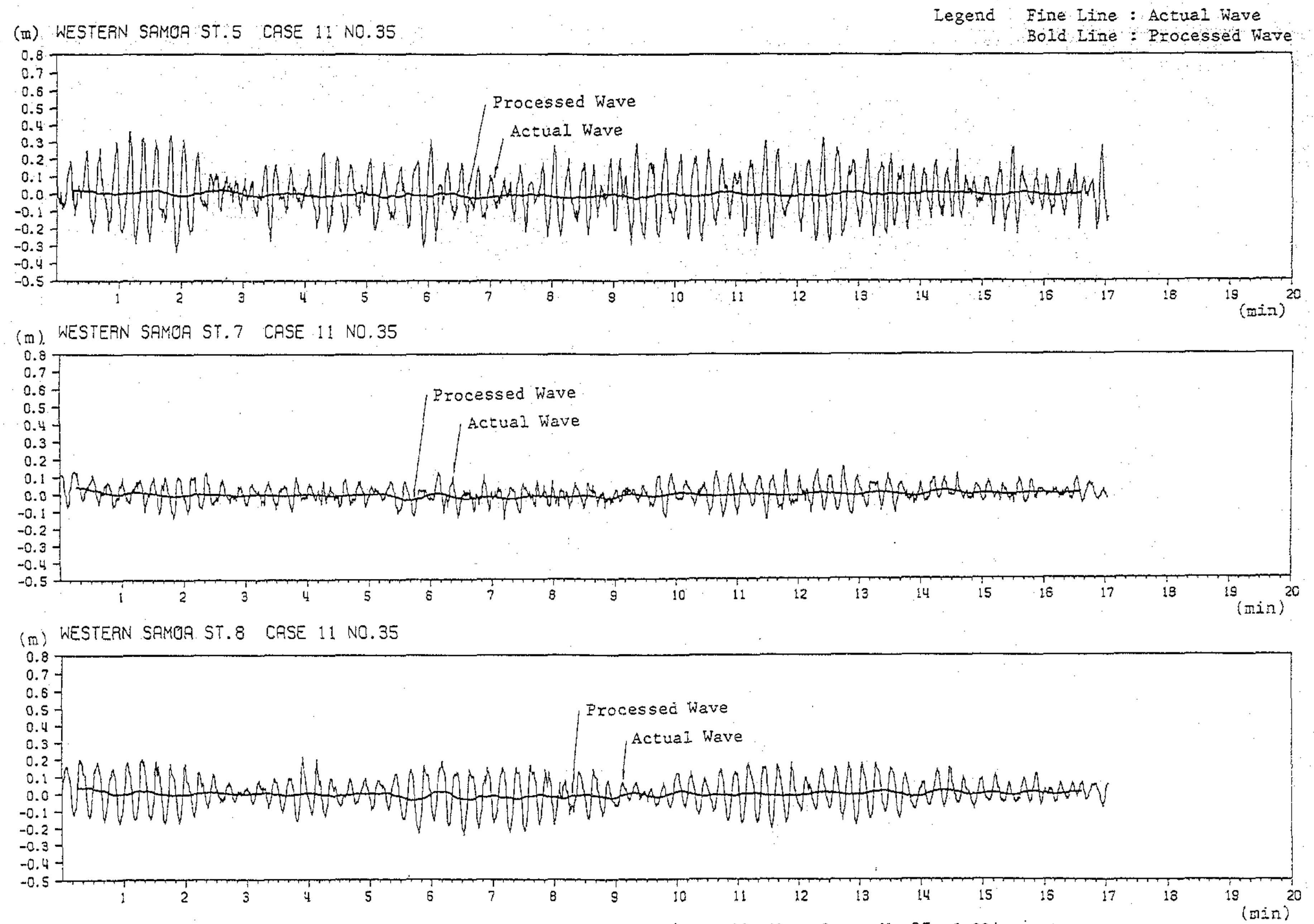
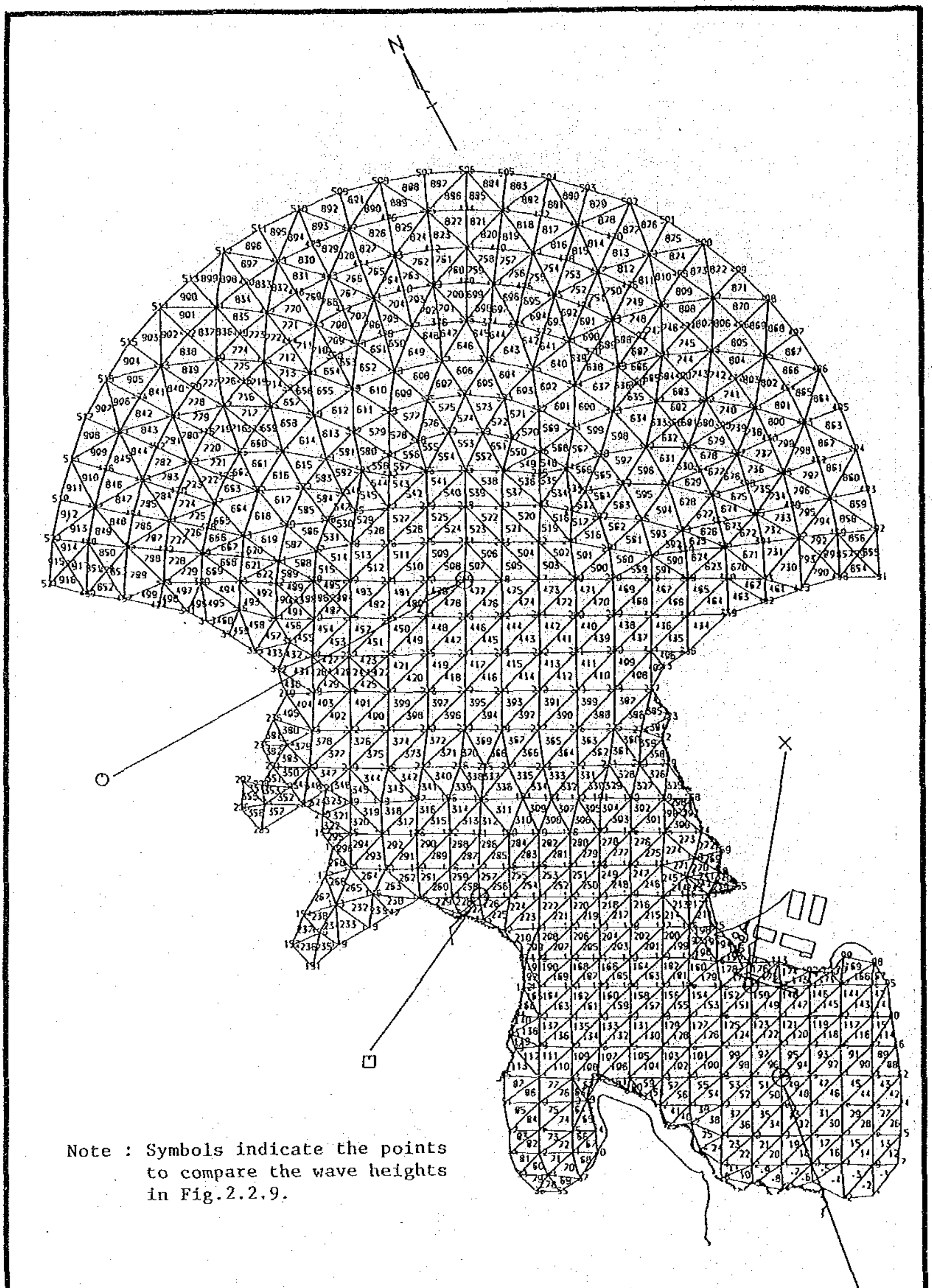


Fig. 2.2.8(3) Wave Record (Case 11, Wave Group No.35, 1,024 sec.)



Note : Symbols indicate the points to compare the wave heights in Fig.2.2.9.

Fig. 2.2.9 Triangle Components of FEM

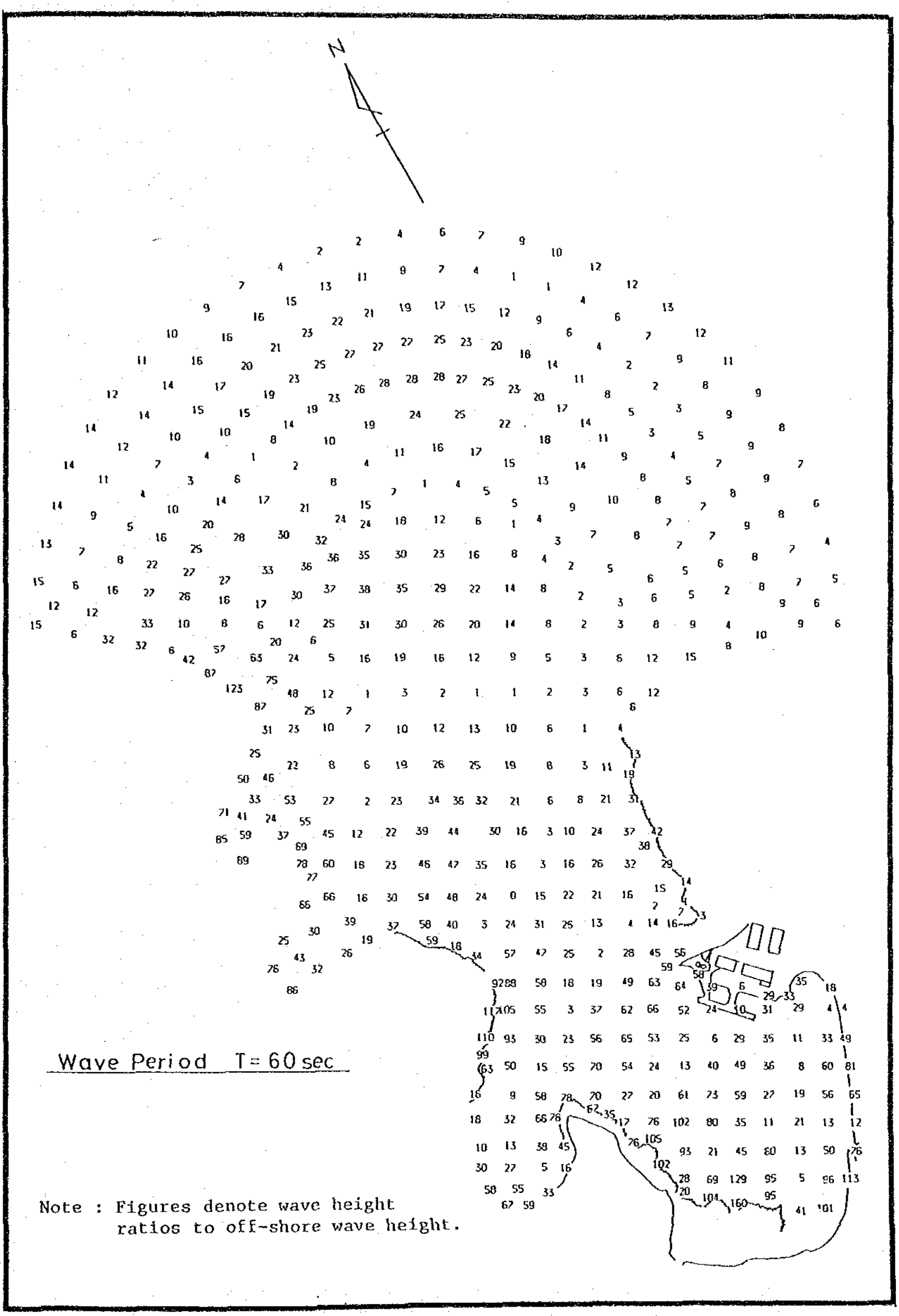


Fig. 2.2.10 (1) Results of FEM Analysis

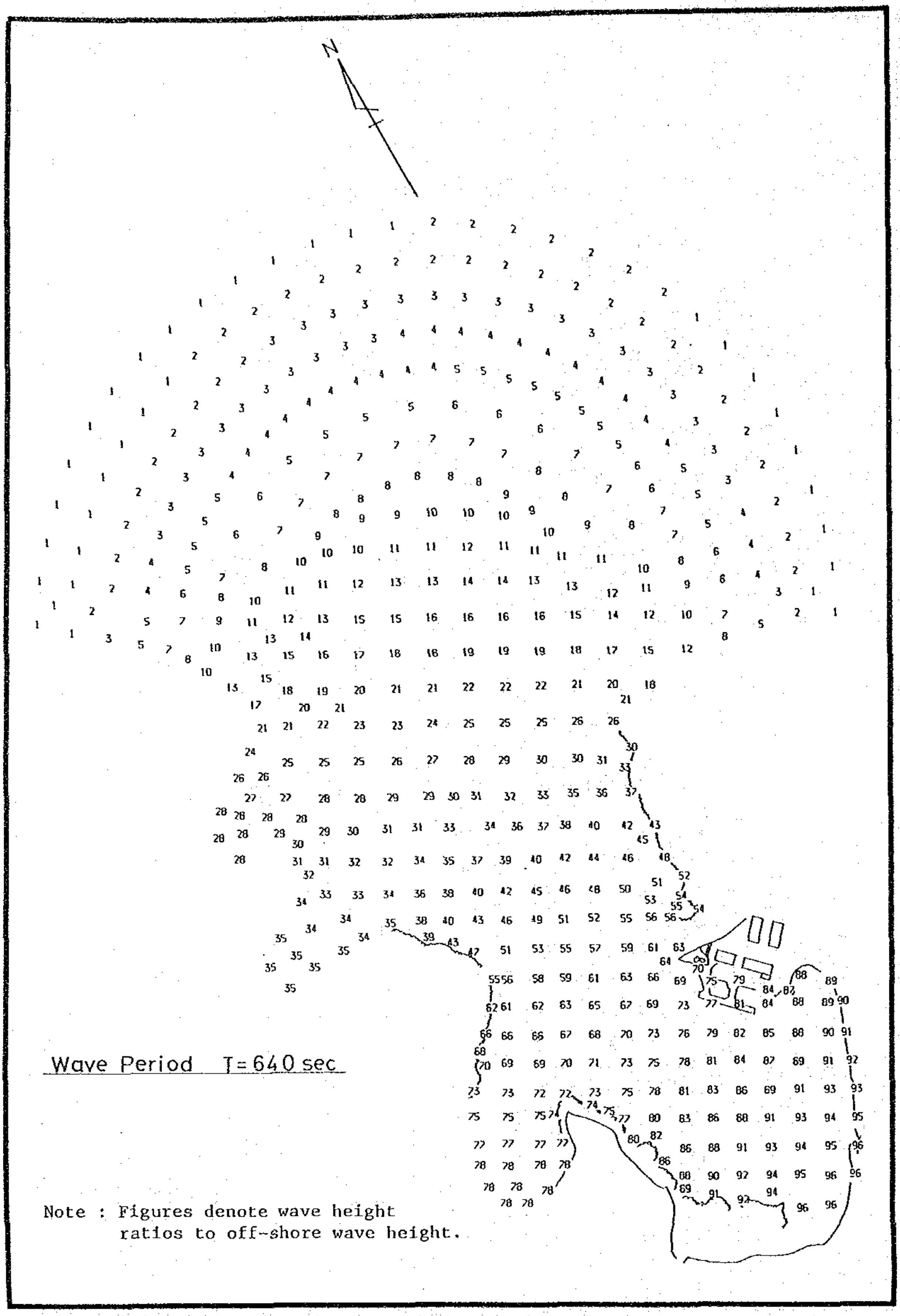


Fig. 2.2.10 (2) Results of FEM Analysis

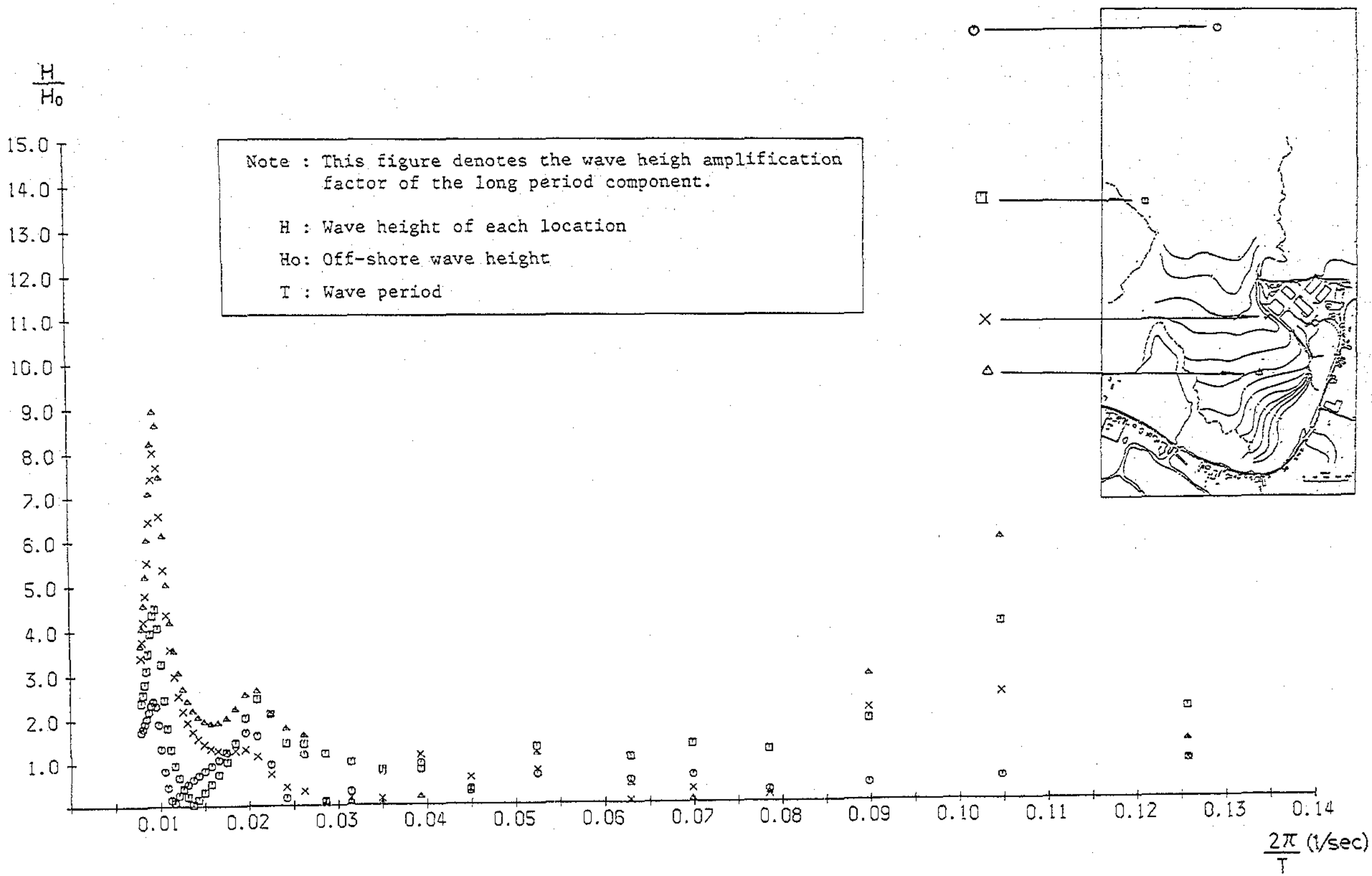


Fig. 2.2.11 Amplification of the Long Period Component

Table 2.2.1 Wind Occurrence by Direction and Speed. (Observed Jan. Feb. Mar. 1987)

W.DIRECTION / WI.SPEED (M/S)	CALM	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	N	TOTAL
	560	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	562
CALM	51.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52.0
	0	8	11	14	43	19	34	13	26	11	12	9	16	7	10	12	7	252
0.0 - 2.5	0.0	0.7	1.0	1.3	4.0	1.8	3.1	1.2	2.4	1.0	1.1	0.8	1.5	0.6	0.9	1.1	0.6	23.3
	0	1	5	12	40	14	12	2	2	2	0	5	12	13	14	5	1	140
2.5 - 5.0	0.0	0.1	0.5	1.1	3.7	1.3	1.1	0.2	0.2	0.2	0.0	0.5	1.1	1.2	1.3	0.5	0.1	13.0
	0	1	1	5	27	7	0	1	2	0	0	1	4	8	9	3	1	70
5.0 - 7.5	0.0	0.1	0.1	0.5	2.5	0.6	0.0	0.1	0.2	0.0	0.0	0.1	0.4	0.7	0.8	0.3	0.1	6.5
	0	1	1	3	19	3	0	1	0	0	0	0	1	5	6	1	1	42
7.5 -10.0	0.0	0.1	0.1	0.3	1.8	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.5	0.6	0.1	0.1	3.9
	0	0	0	0	3	0	0	0	0	0	0	0	0	3	1	1	0	8
10.0 -12.5	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.0	0.7
	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2
12.5 -15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.2
	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
15.0 -20.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	3
20.0 -	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3
	560	11	18	34	136	43	46	17	30	14	12	15	33	37	41	23	10	1080
TOTAL	51.9	1.0	1.7	3.1	12.6	4.0	4.3	1.6	2.8	1.3	1.1	1.4	3.1	3.4	3.8	2.1	0.9	100.0

Table 2.2.2 Wave Occurrence by Direction and Height

(Hindcasted by Wind Data Jan. Feb. Mar. 1987)

W.DIRECTION / W.HEIGHT (M)	CALM	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	S	TOTAL
CALM	729 67.5	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	729 67.5
0.00 – 0.49	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	15 1.4	20 1.9	16 1.5	7 0.6	9 0.8	13 1.2	22 2.0	63 5.8	29 2.7	0 0.0	0 0.0	0 0.0	194 18.0
0.50 – 0.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	10 0.9	10 0.9	5 0.5	2 0.2	1 0.1	4 0.4	8 0.7	39 3.6	9 0.8	0 0.0	0 0.0	0 0.0	88 8.1
1.00 – 1.49	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	6 0.6	3 0.3	0 0.0	1 0.1	1 0.1	1 0.1	2 0.2	15 1.4	4 0.4	0 0.0	0 0.0	0 0.0	33 3.1
1.50 – 1.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	2 0.2	5 0.5	1 0.1	0 0.0	0 0.0	0 0.0	2 0.2	11 1.0	1 0.1	0 0.0	0 0.0	0 0.0	22 2.0
2.00 – 2.49	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	2 0.2	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	3 0.3	0 0.0	0 0.0	0 0.0	0 0.0	5 0.5
2.50 – 2.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	2 0.2	2 0.2	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	2 0.2	0 0.0	0 0.0	0 0.0	0 0.0	6 0.6
3.00 – 3.49	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.1	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.1
3.50 – 3.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0
4.00 – 4.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0
5.00 –	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.1	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.1	0 0.0	0 0.0	0 0.0	0 0.0	2 0.2
TOTAL	729 67.5	0 0.0	0 0.0	0 0.0	0 0.0	37 3.4	41 3.0	23 2.1	10 0.9	11 1.0	18 1.7	34 3.1	134 12.4	43 4.0	0 0.0	0 0.0	0 0.0	1080 100.0

Table 2.2.3 Wave Occurrence by Period and Height

(Hindcasted by Wind Jan. Feb. Mar. 1987)

W.PERIOD (S) / W.HEIGHT (M)	CALM	0- 1	1- 2	2- 3	3- 4	4- 5	5- 6	6- 7	7- 8	8- 9	9-10	10-	TOTAL
CALM	729	0	0	0	0	0	0	0	0	0	0	0	729
	67.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.5
0.00 - 0.49	0	82	68	42	2	0	0	0	0	0	0	0	194
	0.0	7.6	6.3	3.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0
0.50 - 0.99	0	0	0	31	54	3	0	0	0	0	0	0	88
	0.0	0.0	0.0	2.9	5.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	8.1
1.00 - 1.49	0	0	0	0	16	17	0	0	0	0	0	0	33
	0.0	0.0	0.0	0.0	1.5	1.6	0.0	0.0	0.0	0.0	0.0	0.0	3.1
1.50 - 1.99	0	0	0	0	1	12	9	0	0	0	0	0	22
	0.0	0.0	0.0	0.0	0.1	1.1	0.8	0.0	0.0	0.0	0.0	0.0	2.0
2.00 - 2.49	0	0	0	0	0	0	5	0	0	0	0	0	5
	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.5
2.50 - 2.99	0	0	0	0	0	0	2	4	0	0	0	0	6
	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.0	0.0	0.0	0.0	0.6
3.00 - 3.49	0	0	0	0	0	0	0	1	0	0	0	0	1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1
3.50 - 3.99	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.00 - 4.99	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.00 -	0	0	0	0	0	0	0	0	0	1	1	0	2
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.2
TOTAL	729	82	68	73	73	32	16	5	0	1	1	0	1080
	67.5	7.6	6.3	6.8	6.8	3.0	1.5	0.5	0.0	0.1	0.1	0.0	100.0

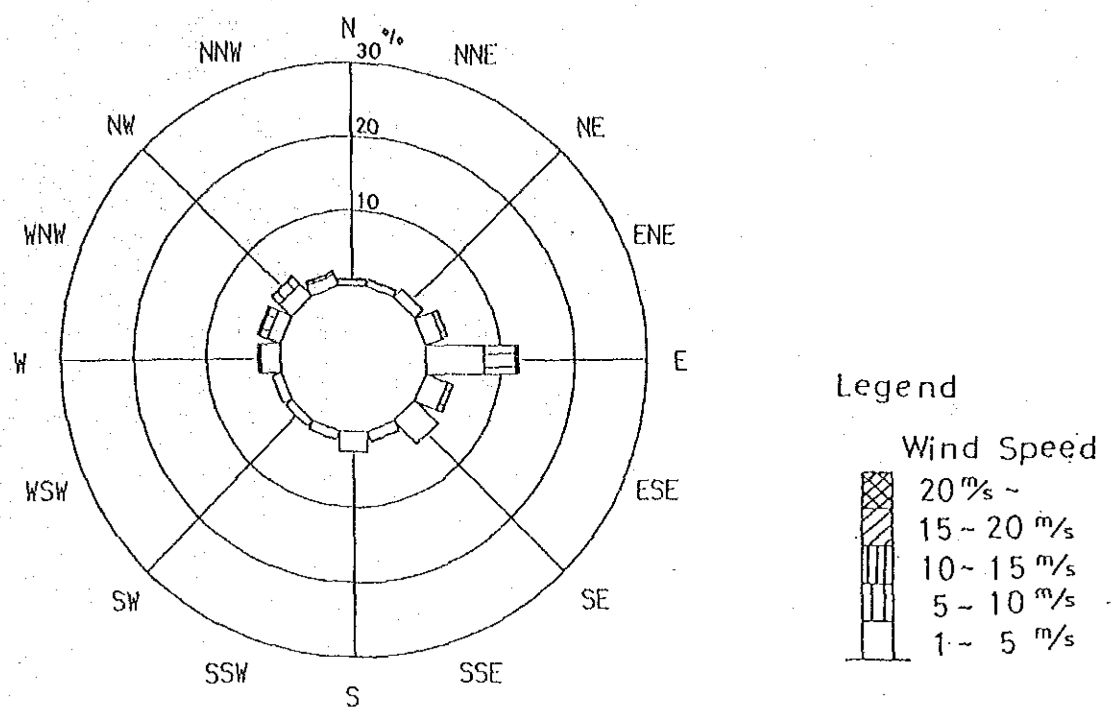


Fig. 2.2.12 Wind Rose
(Observed, Jan. Feb. Mar. 1987)

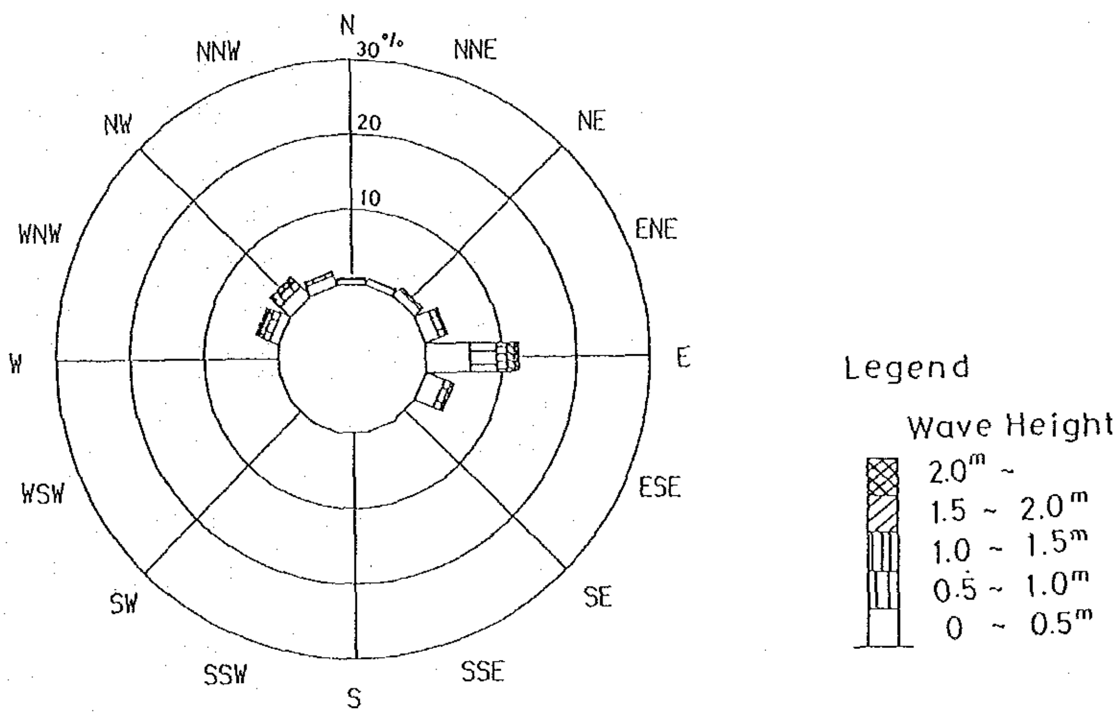


Fig. 2.2.13 Directional Distribution of Waves
(Hindcasted by Wind Data Jan. Feb. Mar. 1987)

Table 2.2.4 Wind Occurrence by Direction and Speed

(Observed Feb. 1984~Jan. 1987)

W.DIRECTION / WI.SPEED (M/S)	CALM	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	N	TOTAL
CALM	4639	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4642
	35.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.3
0.0 - 2.5	1	105	132	168	441	421	484	311	710	234	53	50	91	78	100	91	121	3591
	0.0	0.8	1.0	1.3	3.4	3.2	3.7	2.4	5.4	1.8	0.4	0.4	0.7	0.6	0.8	0.7	0.9	27.3
2.5 - 5.0	0	44	74	176	745	370	137	52	43	16	7	27	65	62	86	52	51	2007
	0.0	0.3	0.6	1.3	5.7	2.8	1.0	0.4	0.3	0.1	0.1	0.2	0.5	0.5	0.7	0.4	0.4	15.3
5.0 - 7.5	0	10	33	111	781	244	28	7	6	3	2	6	29	33	61	21	17	1392
	0.0	0.1	0.3	0.8	5.9	1.9	0.2	0.1	0.0	0.0	0.0	0.0	0.2	0.3	0.5	0.2	0.1	10.6
7.5 -10.0	0	8	11	85	735	131	5	3	2	1	0	3	12	23	30	10	8	1067
	0.0	0.1	0.1	0.6	5.6	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.1	0.1	8.1
10.0 -12.5	0	2	3	27	293	47	2	0	2	2	0	0	7	5	11	6	1	408
	0.0	0.0	0.0	0.2	2.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	3.1
12.5 -15.0	0	0	1	0	19	2	0	0	0	0	0	0	2	2	4	0	0	30
	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
15.0 -20.0	0	0	0	1	6	0	1	0	0	0	0	0	3	0	3	0	0	14
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
20.0 -	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	4640	170	254	569	3021	1215	657	373	763	256	62	86	210	203	295	180	198	13152
	35.3	1.3	1.9	4.3	23.0	9.2	5.0	2.8	5.8	1.9	0.5	0.7	1.6	1.5	2.2	1.4	1.5	100.0

Table 2.2.5 Wave Occurrence by Direction and Height

(Hindcasted by Wind Data Feb. 1984 ~ Jan. 1987)

W.DIRECTION W.HEIGHT (M)	CALM	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	S	TOTAL
CALM	7050 53.6	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	7050 53.6
0.00 - 0.49	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	126 1.0	165 1.3	133 1.0	160 1.2	143 1.1	185 1.4	285 2.2	832 6.3	627 4.8	0 0.0	0 0.0	0 0.0	2656 20.2
0.50 - 0.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	38 0.3	55 0.4	33 0.3	25 0.2	17 0.1	40 0.3	139 1.1	778 5.9	291 2.2	0 0.0	0 0.0	0 0.0	1416 10.8
1.00 - 1.49	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	20 0.2	26 0.2	6 0.0	11 0.1	6 0.0	14 0.1	63 0.5	560 4.3	148 1.1	0 0.0	0 0.0	0 0.0	854 6.5
1.50 - 1.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	14 0.1	28 0.2	5 0.0	1 0.0	3 0.0	10 0.1	49 0.4	379 2.9	78 0.6	0 0.0	0 0.0	0 0.0	567 4.3
2.00 - 2.49	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	3 0.0	12 0.1	4 0.0	0 0.0	0 0.0	4 0.0	20 0.2	259 2.0	49 0.4	0 0.0	0 0.0	0 0.0	351 2.7
2.50 - 2.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.0	4 0.0	0 0.0	0 0.0	0 0.0	0 0.0	4 0.0	129 1.0	16 0.1	0 0.0	0 0.0	0 0.0	154 1.2
3.00 - 3.49	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.0	2 0.0	0 0.0	0 0.0	0 0.0	1 0.0	6 0.0	56 0.4	6 0.0	0 0.0	0 0.0	0 0.0	72 0.5
3.50 - 3.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	2 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.0	23 0.2	0 0.0	0 0.0	0 0.0	0 0.0	26 0.2
4.00 - 4.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	5 0.0	0 0.0	0 0.0	0 0.0	0 0.0	6 0.0
5.00 -	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0
TOTAL	7050 53.6	0 0.0	0 0.0	0 0.0	0 0.0	203 1.5	295 2.2	181 1.4	197 1.5	169 1.3	254 1.9	567 4.3	3021 23.0	1215 9.2	0 0.0	0 0.0	0 0.0	13152 100.0

Table 2.2.6 Wave Occurrence by Period and Height

(Hindcasted by Wind Data Feb. 1984 ~ Jan. 1987)

W.PERIOD (S) / W.HEIGHT (M)	CALM	0- 1	1- 2	2- 3	3- 4	4- 5	5- 6	6- 7	7- 8	8- 9	9-10	10-	TOTAL
CALM	7050 53.6	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	7050 53.6
0.00 - 0.49	0 0.0	964 7.3	927 7.0	754 5.7	11 0.1	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	2656 20.2
0.50 - 0.99	0 0.0	0 0.0	0 0.0	536 4.1	789 6.0	91 0.7	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1416 10.8
1.00 - 1.49	0 0.0	0 0.0	0 0.0	0 0.0	305 2.3	493 3.7	56 0.4	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	854 6.5
1.50 - 1.99	0 0.0	0 0.0	0 0.0	0 0.0	8 0.1	316 2.4	231 1.8	12 0.1	0 0.0	0 0.0	0 0.0	0 0.0	567 4.3
2.00 - 2.49	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	16 0.1	263 2.0	69 0.5	3 0.0	0 0.0	0 0.0	0 0.0	351 2.7
2.50 - 2.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	2 0.0	28 0.2	109 0.8	15 0.1	0 0.0	0 0.0	0 0.0	154 1.2
3.00 - 3.49	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	1 0.0	50 0.4	19 0.1	2 0.0	0 0.0	0 0.0	72 0.5
3.50 - 3.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	2 0.0	17 0.1	7 0.1	0 0.0	0 0.0	26 0.2
4.00 - 4.99	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	3 0.0	3 0.0	0 0.0	0 0.0	6 0.0
5.00 -	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0
TOTAL	7050 53.6	964 7.3	927 7.0	1290 9.8	1113 8.5	918 7.0	579 4.4	242 1.8	57 0.4	12 0.1	0 0.0	0 0.0	13152 100.0

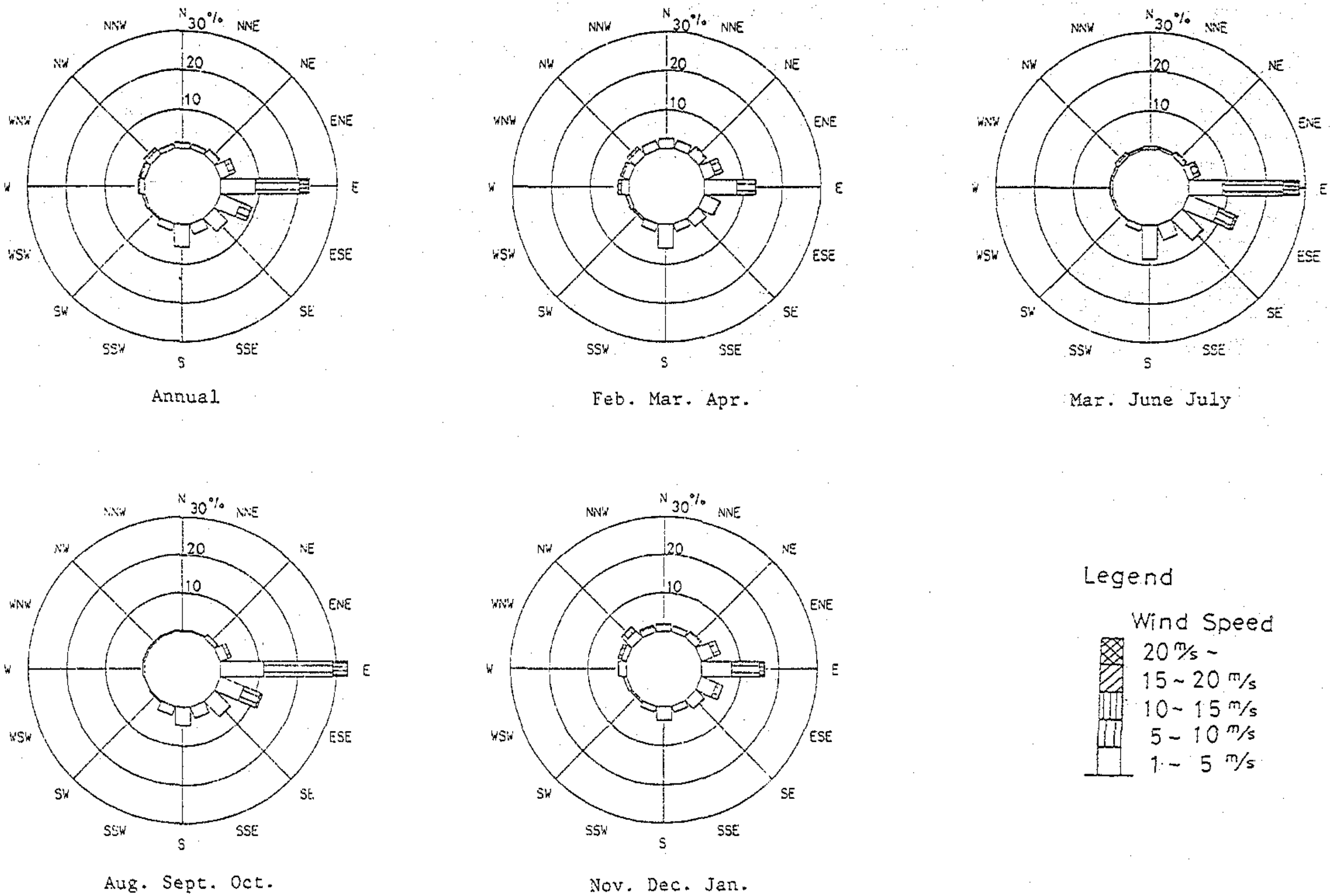


Fig. 2.2.14 Wind Rose (Observed, Feb. 1984 ~ Jan. 1987)

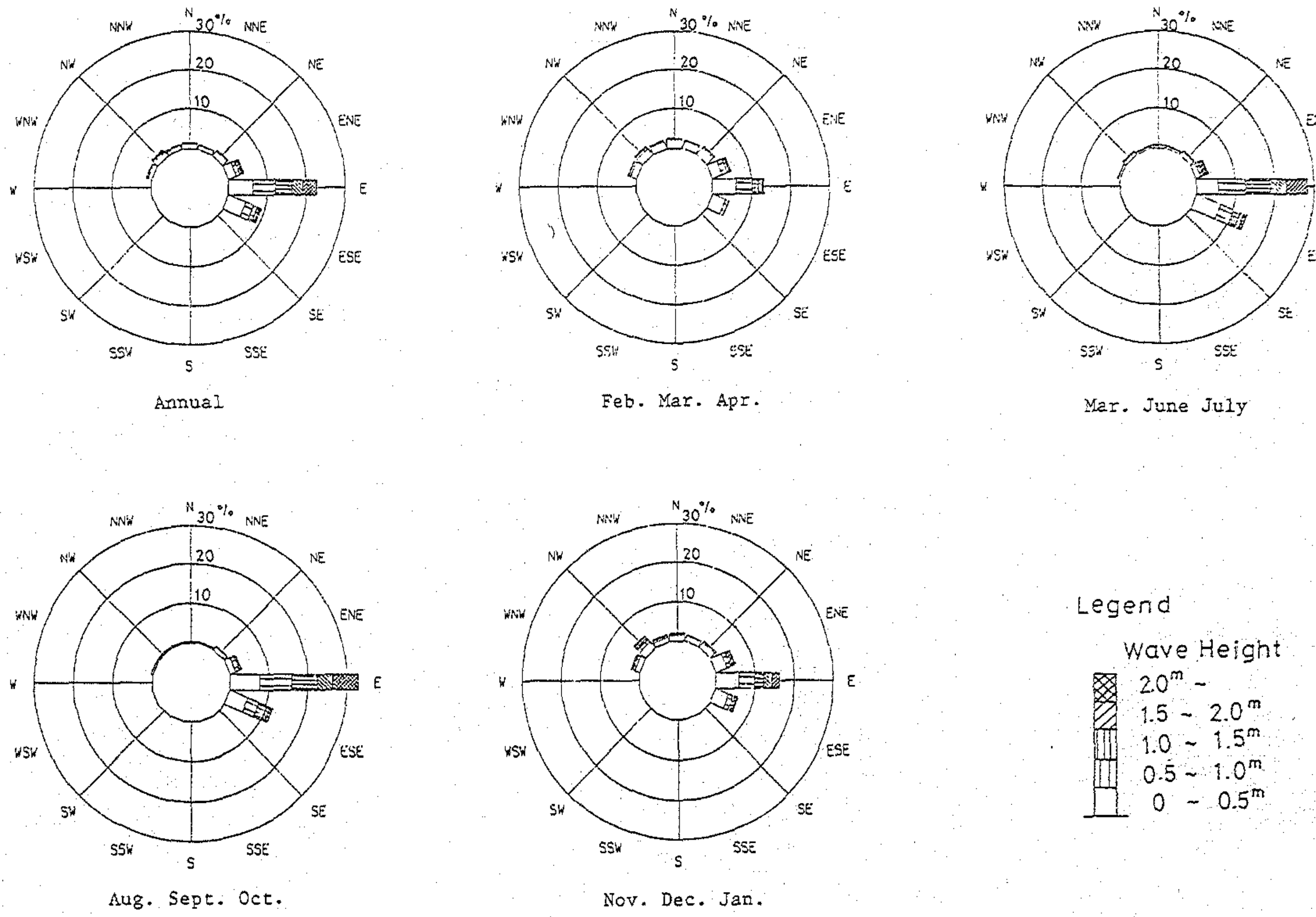


Fig. 2.2.15 Directional Distribution of Waves
(Hindcasted by Wind Data, Feb. 1984 ~ Jan. 1987)

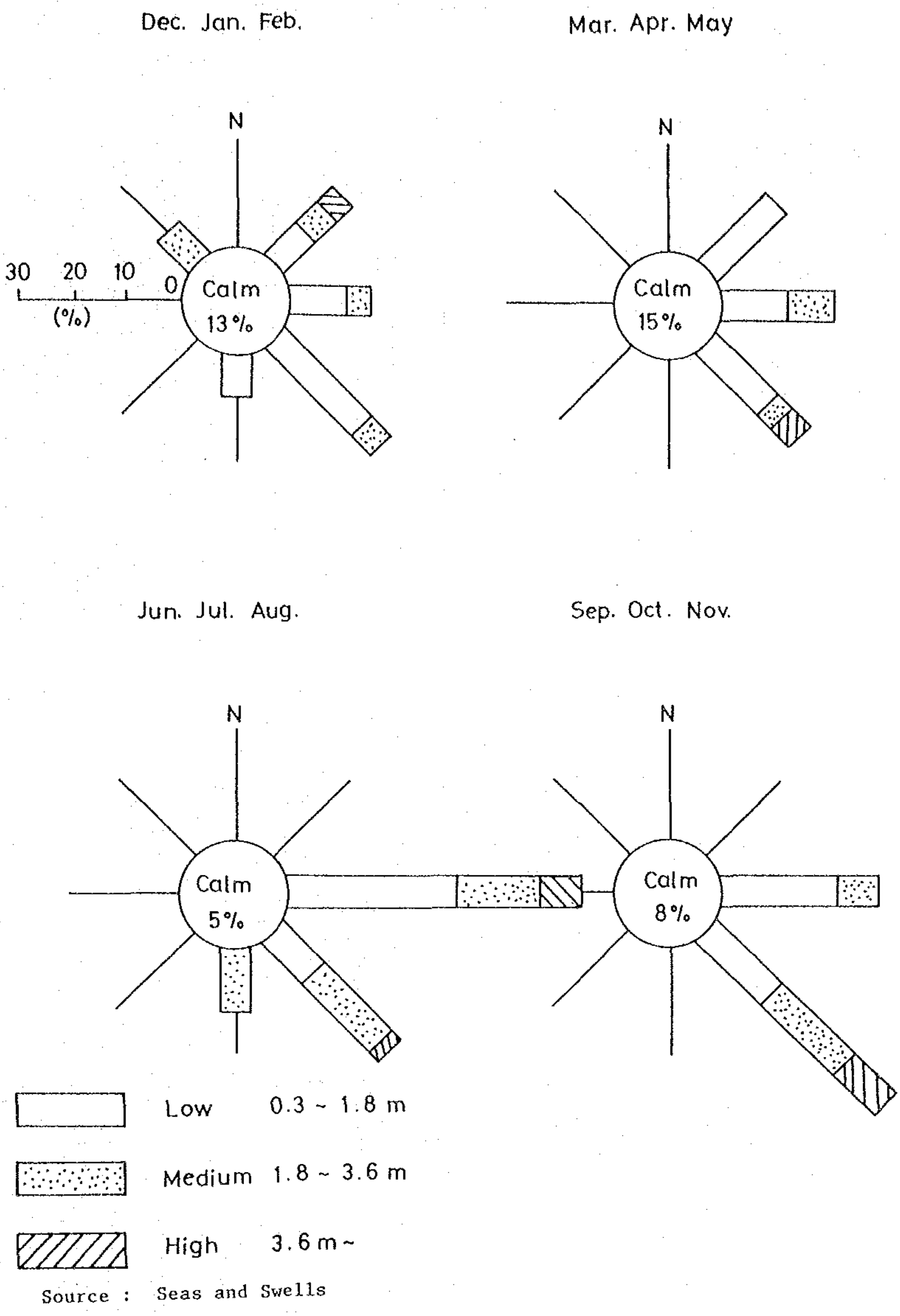


Fig. 2.2.16 Directional Distribution of Swells

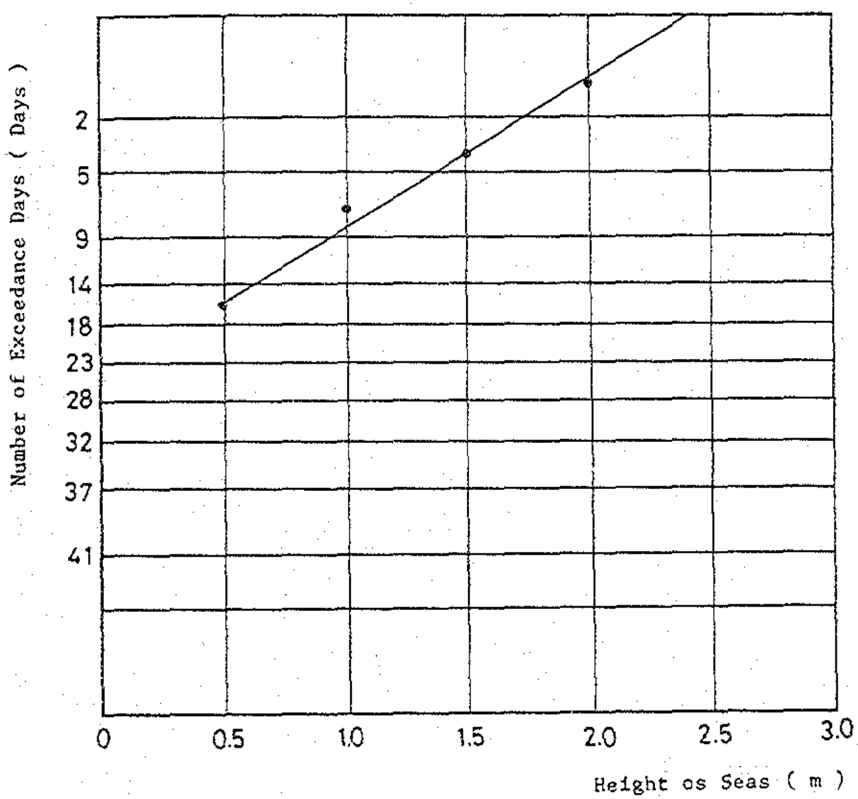


Fig. 2.2.17 Probability of Exceedance - Height of Seas

(Direction, NW - ENE)

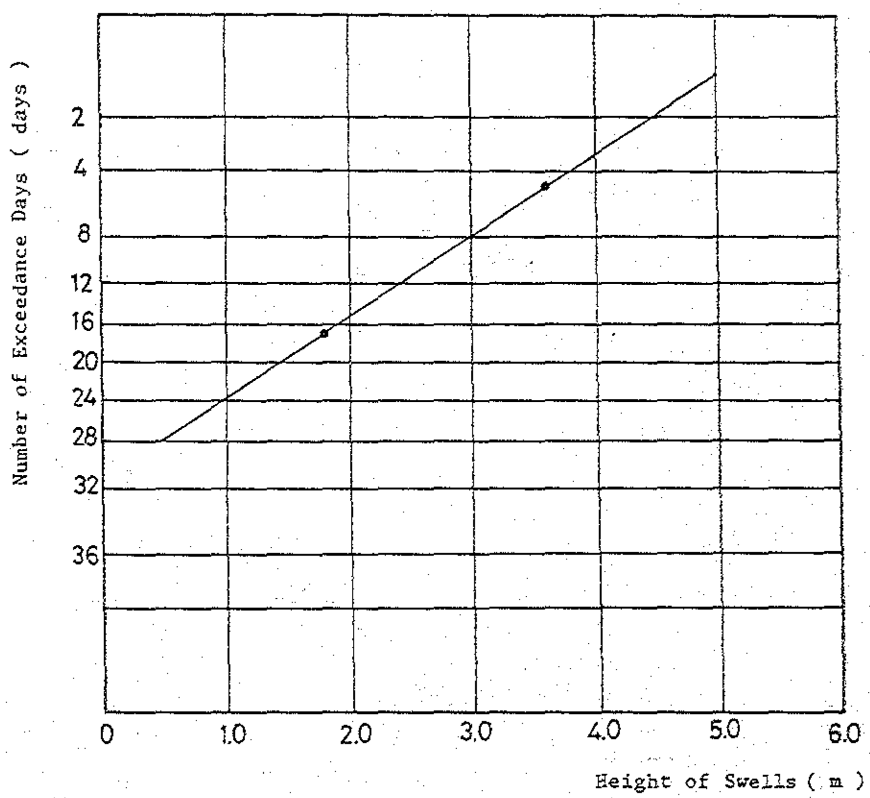


Fig. 2.2.18 Probability of Exceedance - Height of Swells

(Direction NW - NE)

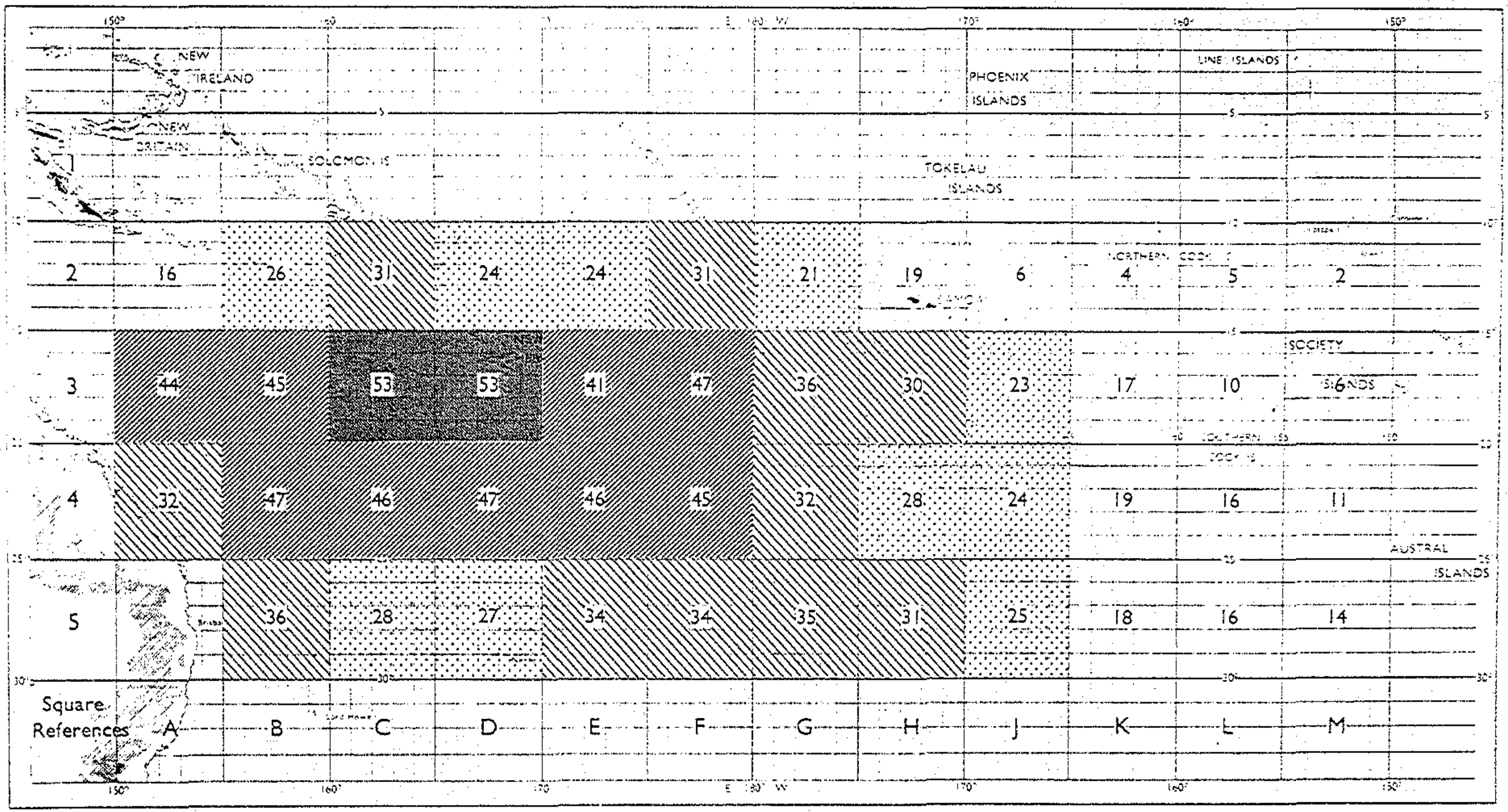
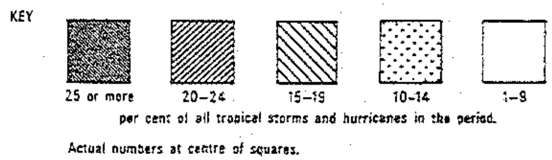


Fig. 2.2.19 (1) Number of cyclones that crossed each 5-degree square in the 30 "seasons" November 1939 to April 1969



Source : Tropical Storms and Hurricanes in the Southwest Pacific

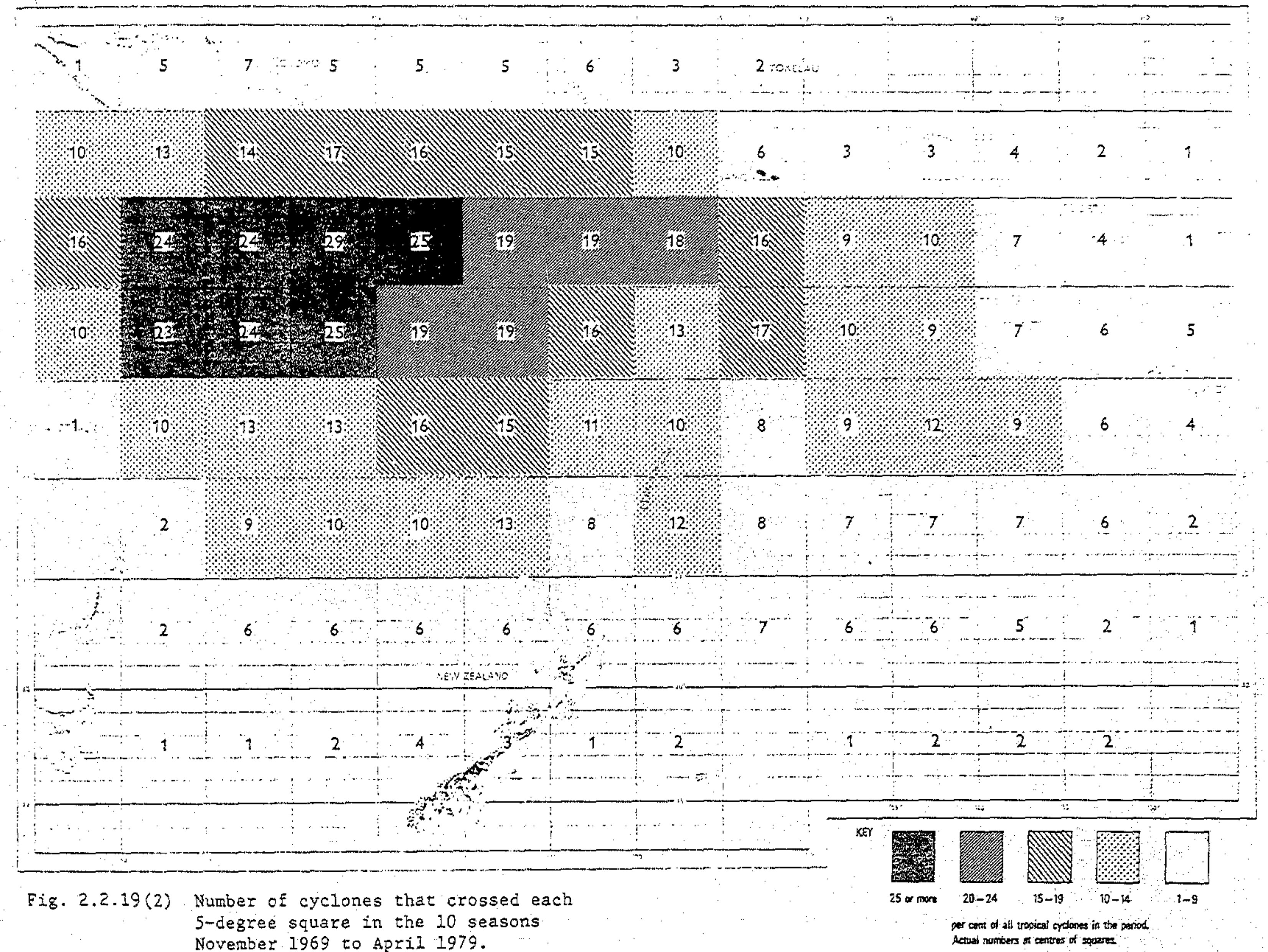


Fig. 2.2.19(2) Number of cyclones that crossed each 5-degree square in the 10 seasons November 1969 to April 1979.

Source : Tropical Cyclones in the Southwest Pacific

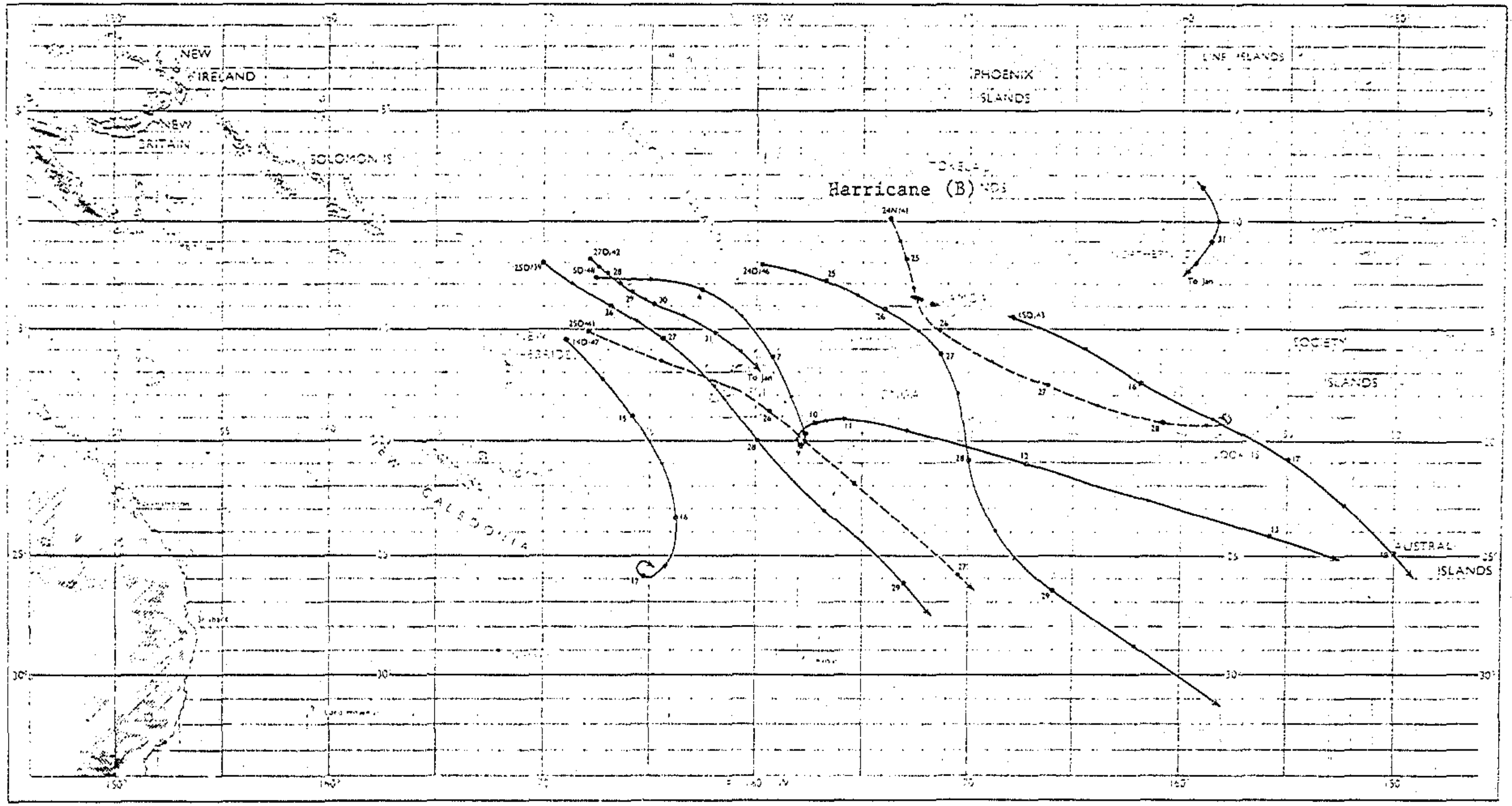
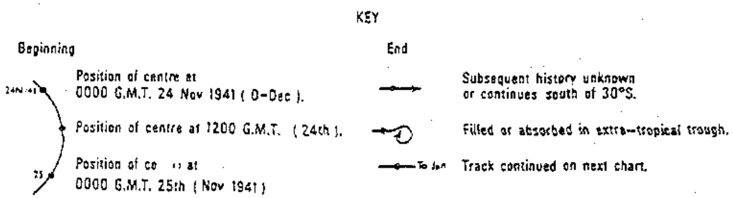


Fig. 2.2.20 Track of Hurricane (B)



Source : Tropical Storms and Hurricanes in the Southwest Pacific.

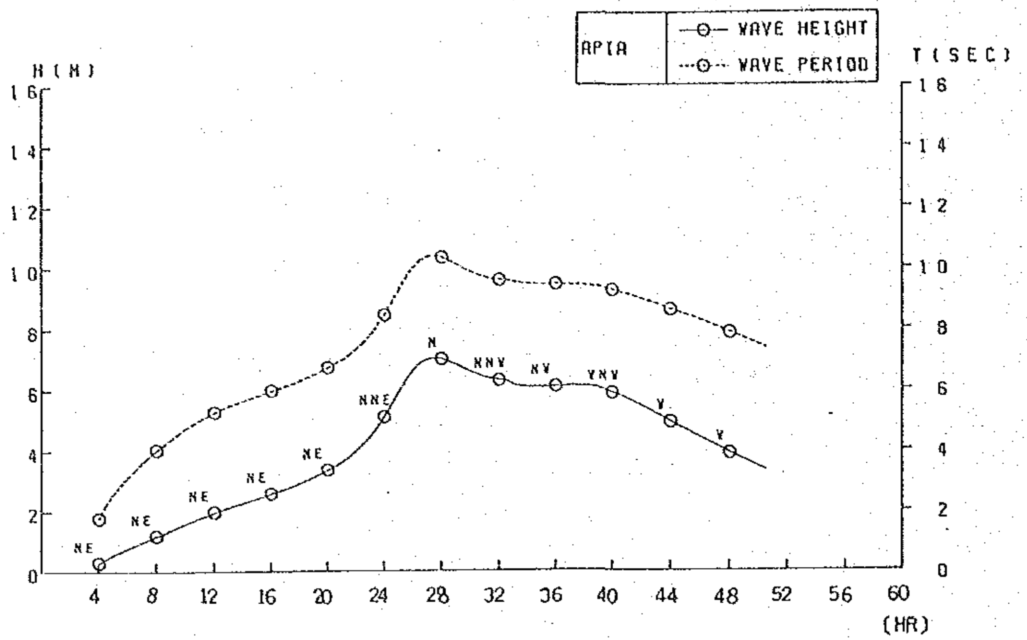


Fig. 2.2.21 Growth Process of Virtual Hurricane

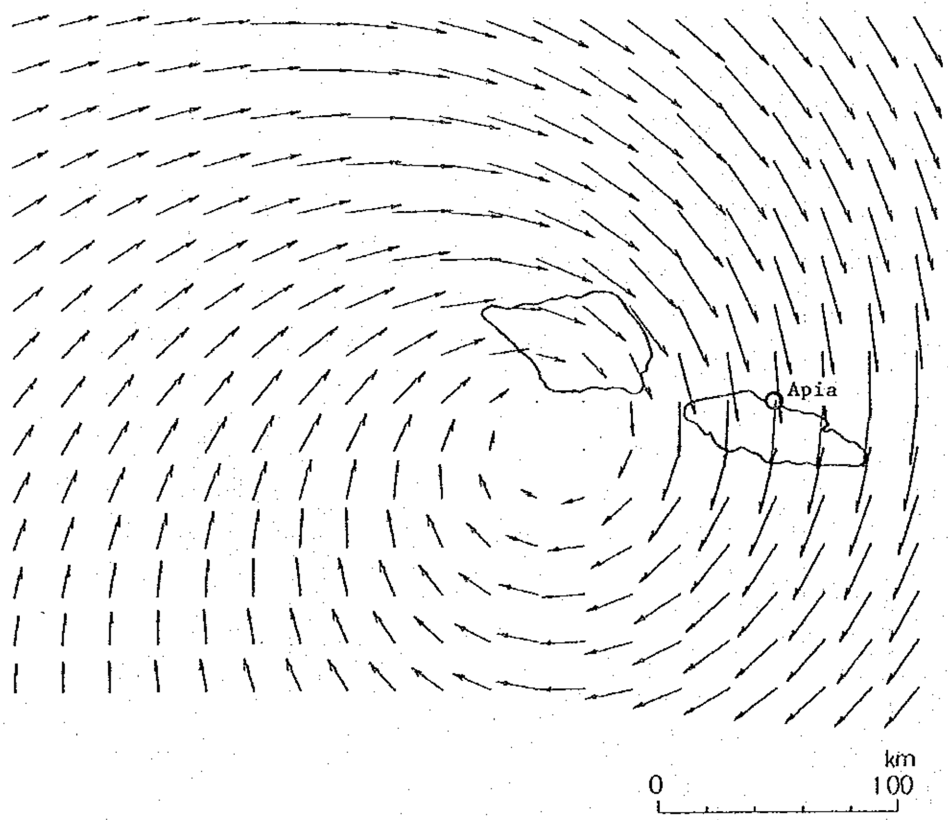


Fig. 2.2.22 Wave Direction of Virtual Hurricane

1.9	2.0	2.2	2.4	2.6	2.8	3.0	3.3	3.6	3.8	4.1	4.4	4.7	4.9	5.1	5.3	5.4	5.3	5.2	5.1
1.6	2.0	2.2	2.4	2.6	2.8	3.0	3.3	3.5	3.6	4.1	4.5	4.8	5.1	5.3	5.5	5.6	5.6	5.5	5.3
1.6	2.0	2.2	2.3	2.5	2.7	3.0	3.2	3.5	3.8	4.1	4.4	4.6	5.2	5.5	5.7	5.9	5.9	5.8	5.6
1.6	2.0	2.2	2.4	2.5	2.7	3.0	3.2	3.4	3.7	3.9	4.3	4.7	5.1	5.6	5.9	6.1	6.2	6.0	5.8
1.6	2.0	2.2	2.3	2.5	2.7	3.0	3.2	3.4	3.6	3.8	4.0	4.3	4.9	5.5	6.1	6.3	6.4	6.2	5.9
1.7	1.9	2.0	2.2	2.4	2.6	2.8	3.0	3.3	3.5	3.7	3.6	3.6	4.4	5.4	6.1	6.5	6.6	6.4	6.0
1.6	1.7	1.8	2.0	2.1	2.3	2.4	2.6	2.7	2.8	3.1	2.9	2.7	3.9	5.3	6.3	6.7	6.6	6.5	5.0
1.5	1.6	1.7	1.9	2.0	2.2	2.3	2.5	2.5	2.2	1.1	0.5	0.8	3.4	5.4	6.5	6.9	6.6	6.3	2.1
1.6	1.7	1.9	2.0	2.2	2.3	2.5	2.8	3.0	3.2	1.5	0.3	0.3	4.3	6.0	6.9	7.0	6.6	5.3	2.1
1.5	1.6	1.8	1.9	2.0	2.2	2.4	2.6	3.0	3.3	3.7	5.5	6.1	5.7	6.5	6.6	6.6	5.7	4.2	2.1
1.4	1.5	1.6	1.7	1.9	2.0	2.2	2.5	2.9	3.3	4.0	5.0	5.9	6.2	6.3	6.2	5.6	4.6	3.5	2.0
1.3	1.4	1.5	1.6	1.7	1.8	2.0	2.3	2.7	3.2	3.8	4.4	5.0	5.3	5.3	5.1	4.6	3.9	3.0	1.9
1.2	1.3	1.3	1.4	1.5	1.6	1.8	2.0	2.3	2.8	3.4	3.9	4.2	4.4	4.4	4.2	3.9	3.4	2.8	1.9
1.0	1.1	1.2	1.2	1.3	1.4	1.4	1.6	1.8	2.2	2.7	3.4	3.7	3.6	3.8	3.7	3.4	3.0	2.5	1.6
0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	3.3	3.4	3.4	3.3	3.1	2.8	2.4	1.7

Apia

km
0 100

Fig. 2.2.23 Wave Height of Virtual Hurricane

5.3	5.5	5.7	5.9	6.1	6.4	6.6	6.9	7.2	7.4	7.7	8.0	8.3	8.5	8.6	9.0	9.1	9.1	9.1	9.0
5.2	5.4	5.6	5.9	6.1	6.3	6.6	6.6	7.1	7.4	7.7	8.0	8.3	8.6	8.9	9.1	9.3	9.3	9.3	9.2
5.2	5.4	5.6	5.8	6.1	6.3	6.5	6.7	7.0	7.2	7.6	7.9	8.3	8.6	9.0	9.3	9.5	9.5	9.5	9.4
5.3	5.5	5.7	5.9	6.2	6.4	6.6	6.8	7.0	7.1	7.4	7.7	8.1	8.5	9.0	9.3	9.6	9.7	9.7	9.5
5.4	5.6	5.8	6.0	6.2	6.5	6.7	7.0	7.2	7.3	7.4	7.4	7.6	8.2	8.9	9.4	9.7	9.9	9.8	9.6
5.1	5.3	5.5	5.7	5.9	6.2	6.4	6.7	7.1	7.4	7.6	7.1	6.9	7.7	8.7	9.5	9.9	10.0	10.0	9.6
4.6	4.8	5.0	5.1	5.3	5.5	5.7	5.9	6.1	6.3	6.9	6.3	5.7	7.1	8.6	9.6	10.1	10.2	10.1	6.4
4.6	4.7	4.9	5.1	5.3	5.5	5.7	5.9	6.0	5.5	3.5	1.9	2.8	6.6	8.8	9.9	10.3	10.3	9.8	4.6
5.0	5.2	5.4	5.6	5.8	6.0	6.3	6.7	7.0	7.4	4.0	1.0	1.0	7.6	9.5	10.2	10.4	10.0	8.6	4.8
4.9	5.0	5.2	5.4	5.6	5.8	6.1	6.5	6.9	7.4	7.9	9.1	9.6	9.3	10.1	10.3	10.0	9.1	7.3	4.8
4.7	4.8	5.0	5.1	5.3	5.5	5.8	6.2	6.7	7.3	7.9	8.7	9.4	9.7	9.8	9.6	8.9	7.9	6.5	4.7
4.4	4.6	4.7	4.8	5.0	5.2	5.4	5.8	6.4	7.0	7.6	8.0	8.5	8.8	8.8	8.5	7.9	7.1	6.1	4.7
4.2	4.3	4.4	4.5	4.6	4.8	5.0	5.3	5.8	6.4	7.1	7.6	7.8	7.9	7.9	7.6	7.2	6.6	5.8	4.6
3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.6	4.9	5.4	6.1	7.0	7.3	7.4	7.3	7.1	6.8	6.3	5.8	4.5
3.3	3.4	3.5	3.5	3.6	3.6	3.7	3.7	3.8	3.8	3.9	4.0	7.0	7.0	6.9	6.7	6.4	6.0	5.4	4.4

Apia

km
0 100

Fig. 2.2.24 Wave Period of Virtual Hurricane

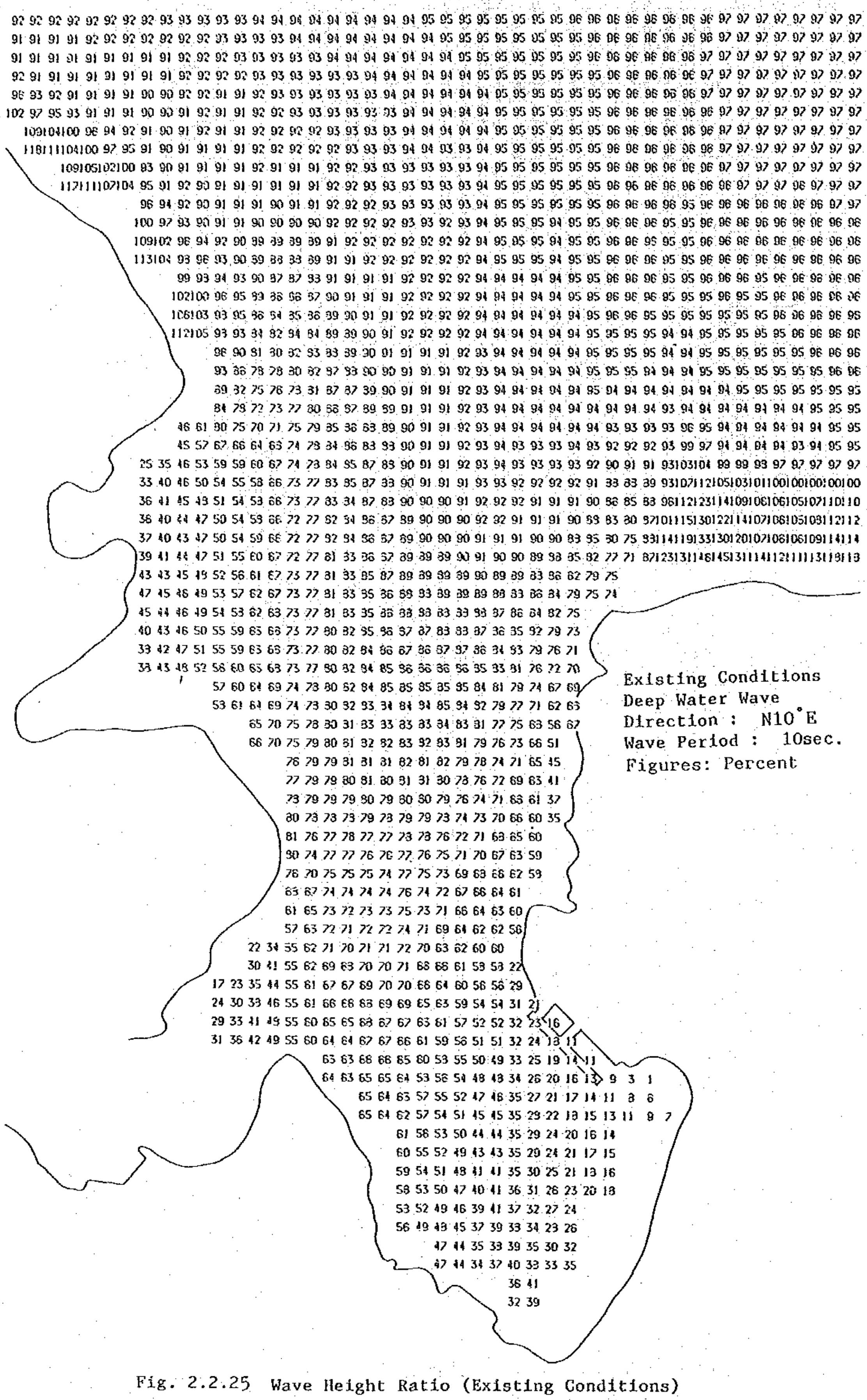


Fig. 2.2.25 Wave Height Ratio (Existing Conditions)

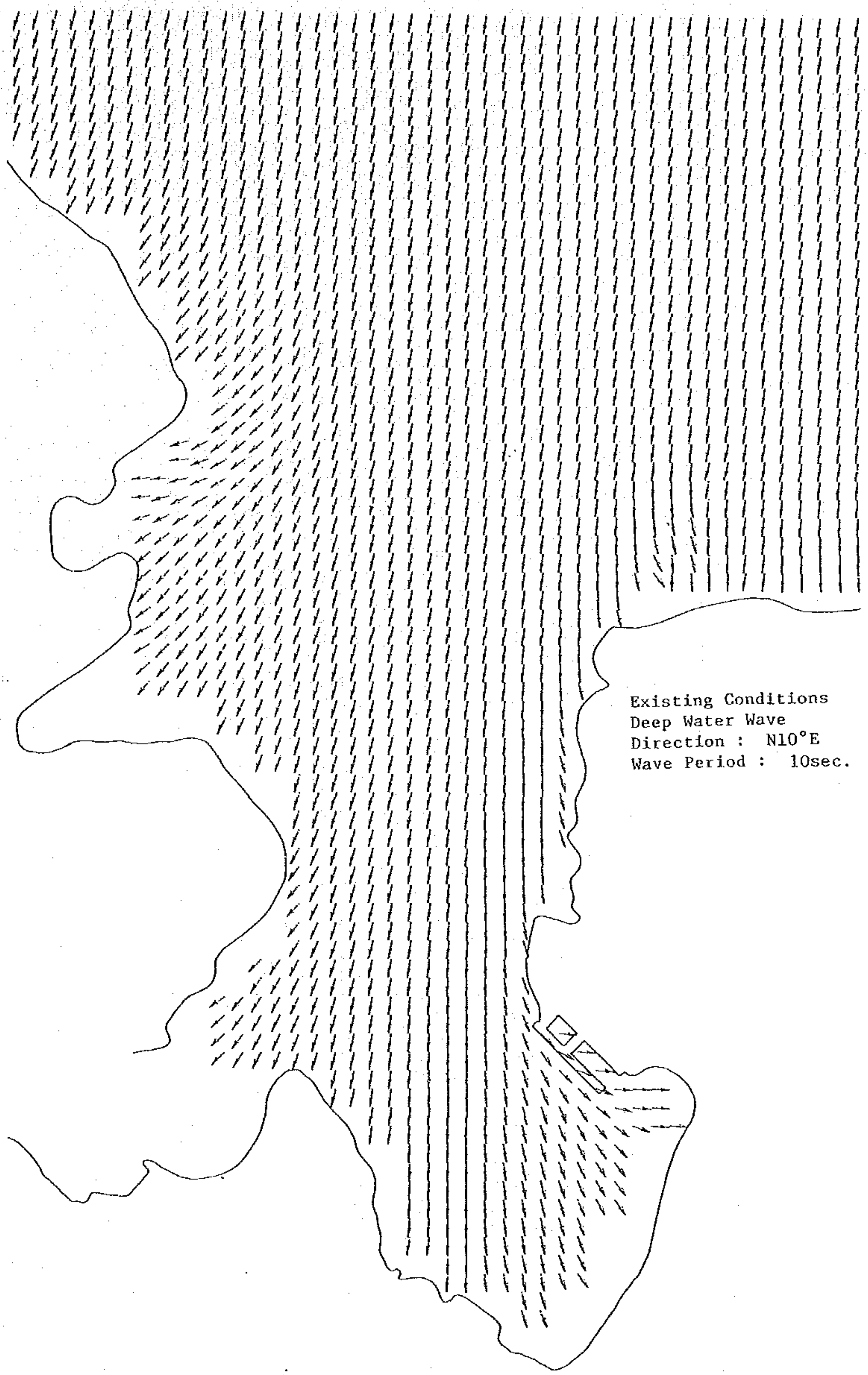


Fig. 2.2.26 Change of Wave Direction (Existing Conditions)

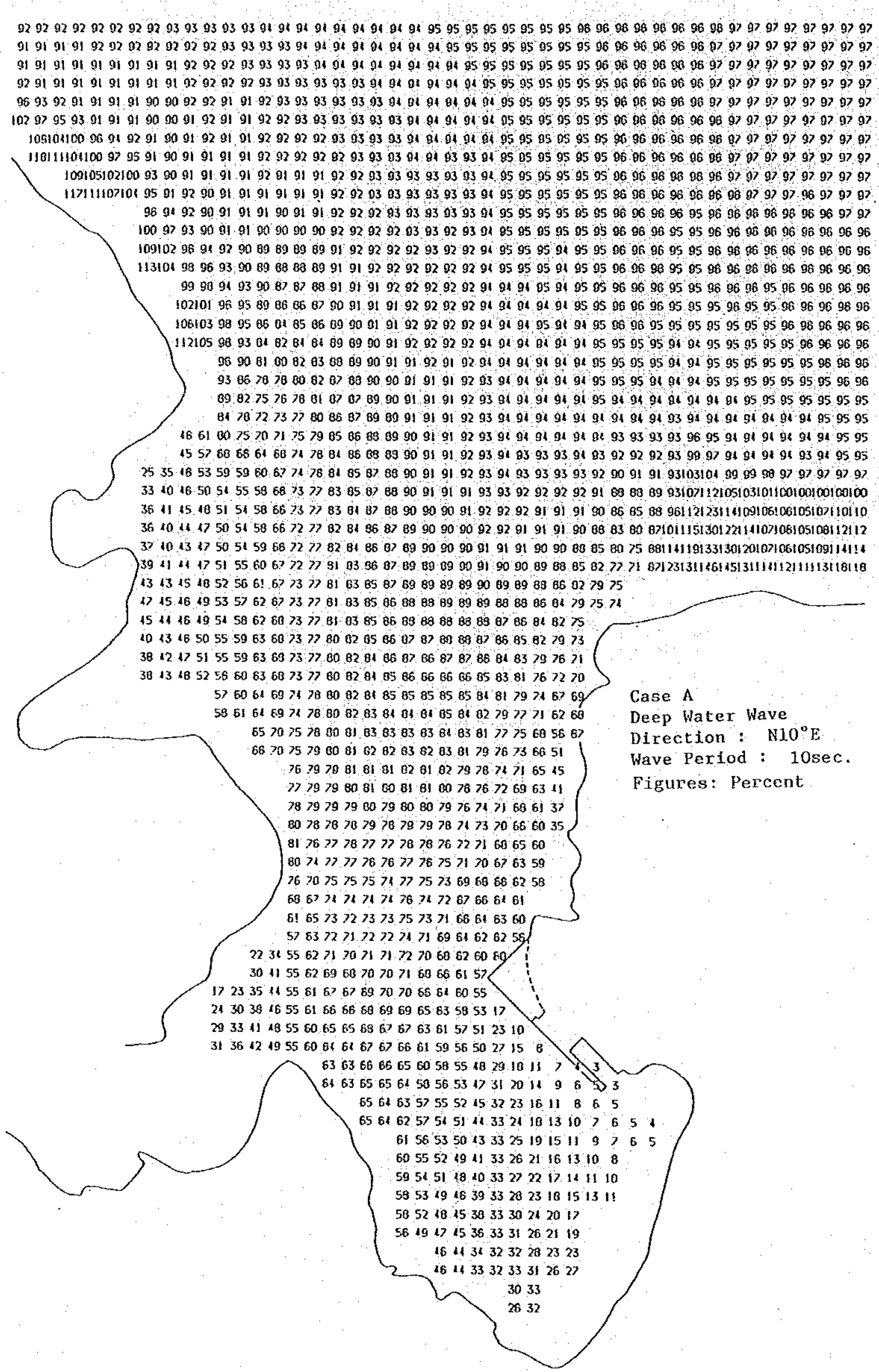


Fig. 2.2.27(1) Wave Height Ratio (Case A)

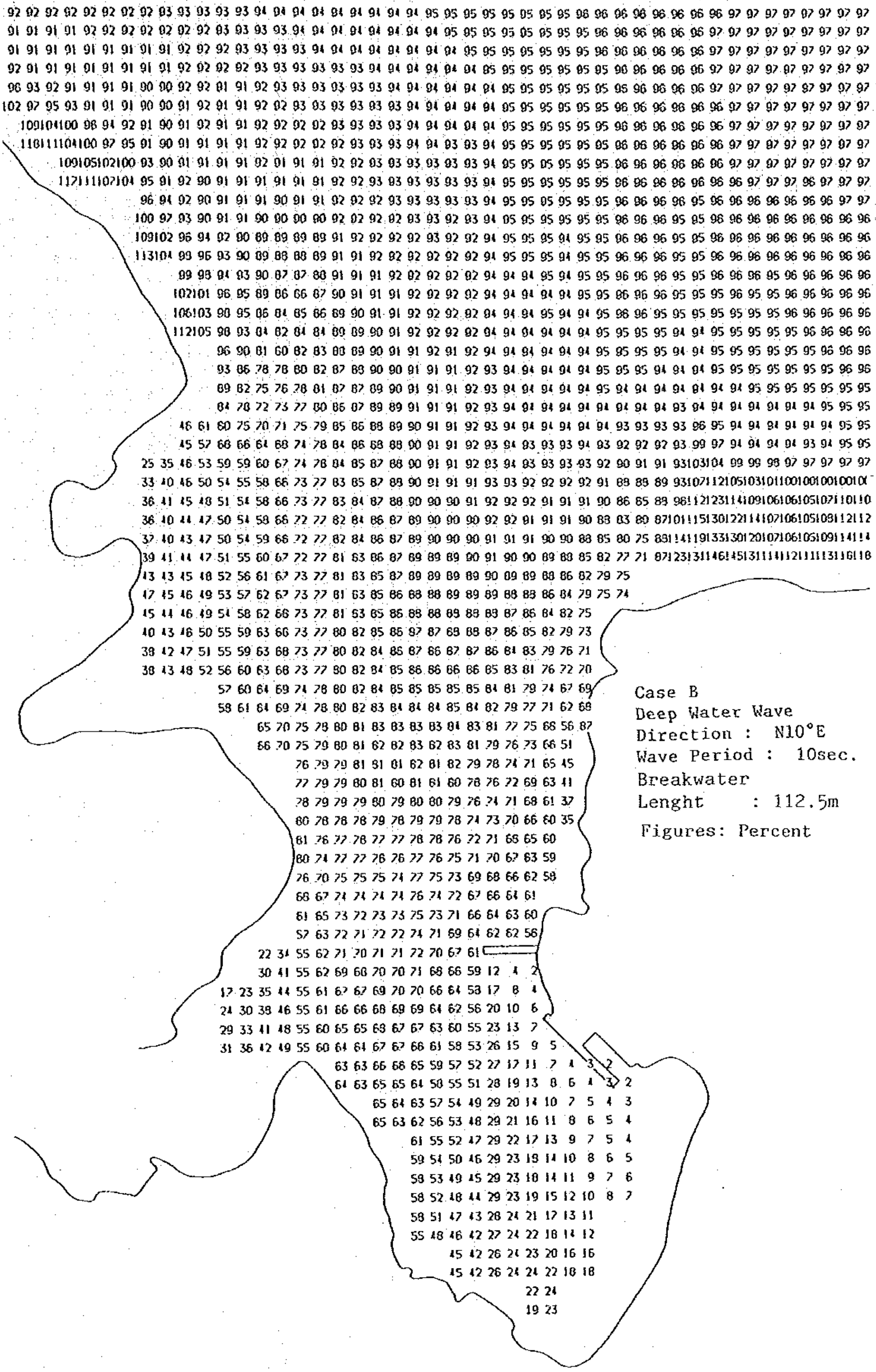


Fig. 2.2.27(2) Wave Height Ratio (Case B)

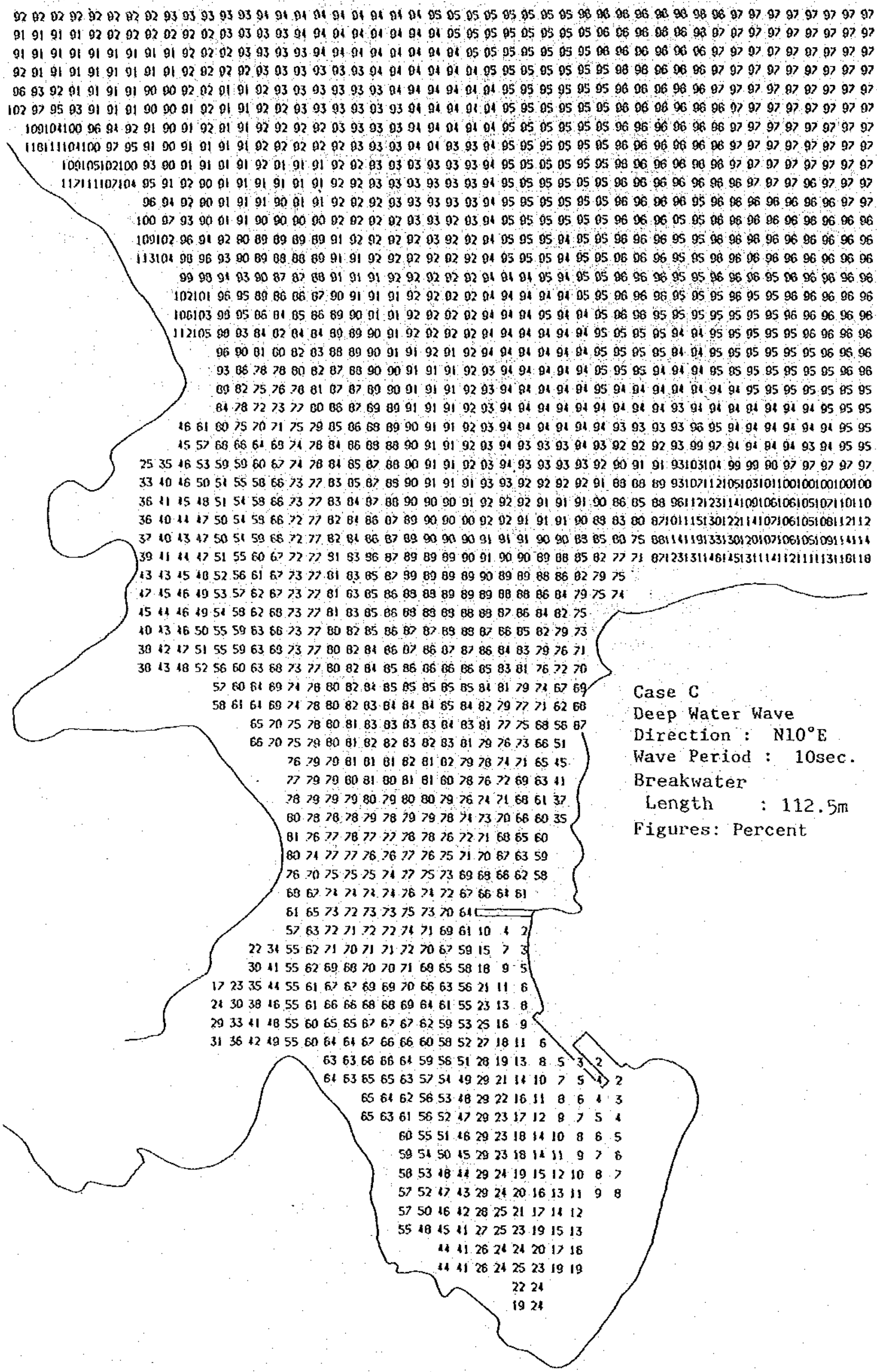


Fig. 2.2.27(3) Wave Height Ratio (Case C)

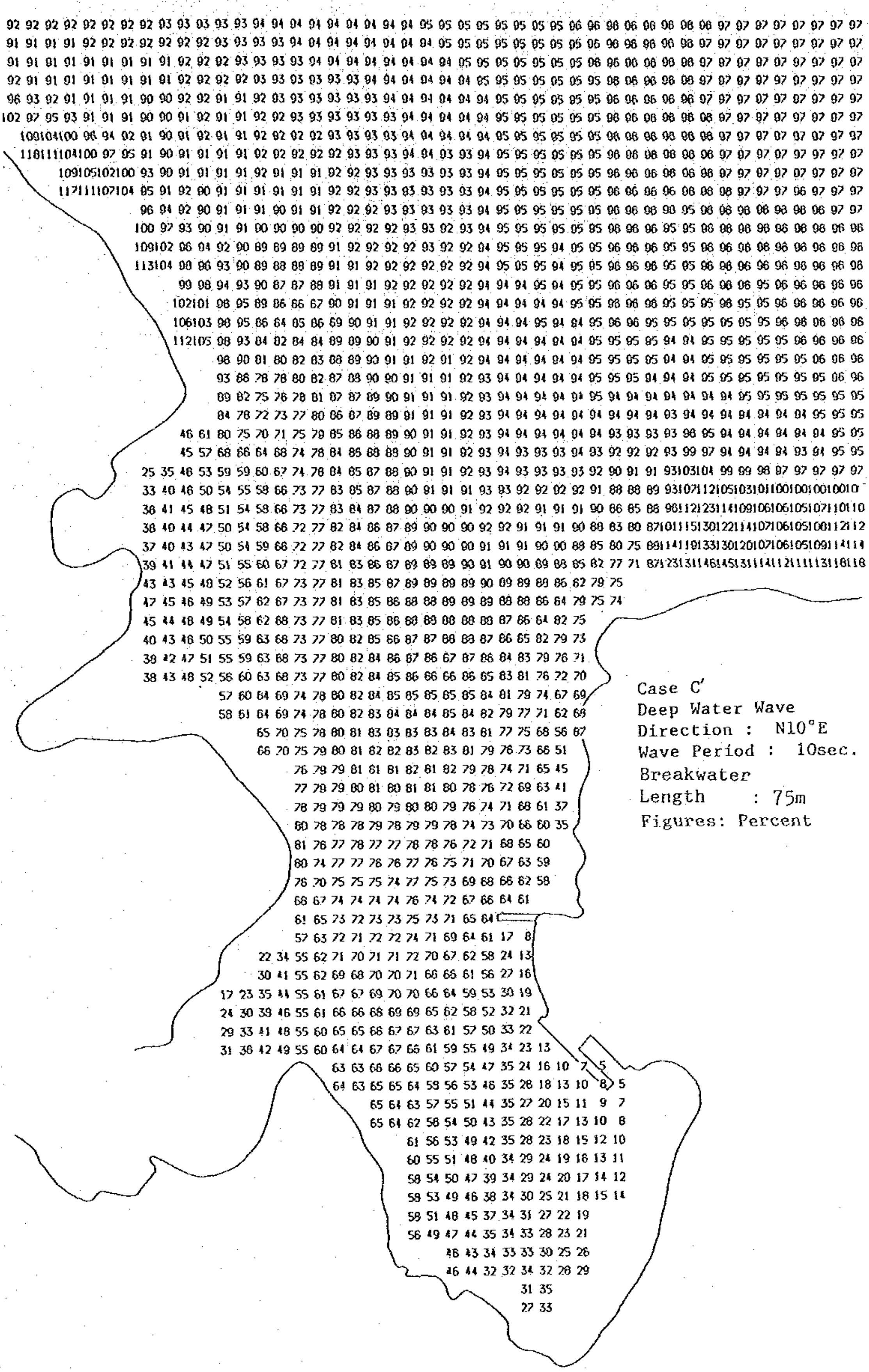


Fig. 2.2.27(4) Wave Height Ratio (Case C′)