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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 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.*

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 |

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

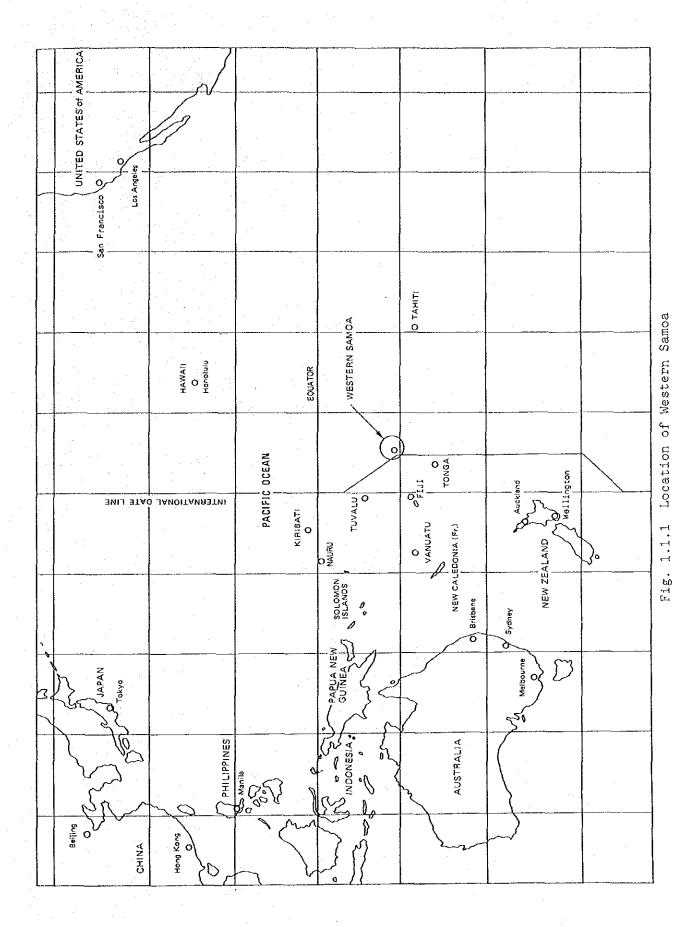
| Mean Low Water Neap | (MLWN) | |
|--------------------------|--------------|---------------------|
| Mean Low Water Spring | (MLWS) | + 0.0m (Chart Datum |
| Lowest Astronomical Tide | (LAT) | - 0,2m |
| The tide table of Asau H | arbour is as | follows: |
| Mean High Water Spring | (MHWS) | + 1.2m |
| 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) | <u>+</u> 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.



-5-

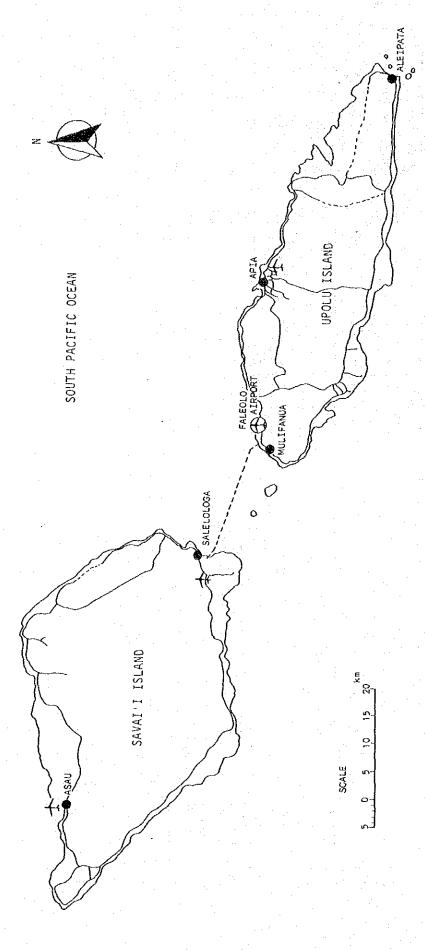


Fig. 1.1.2 Upolu Island and Savai'i Island

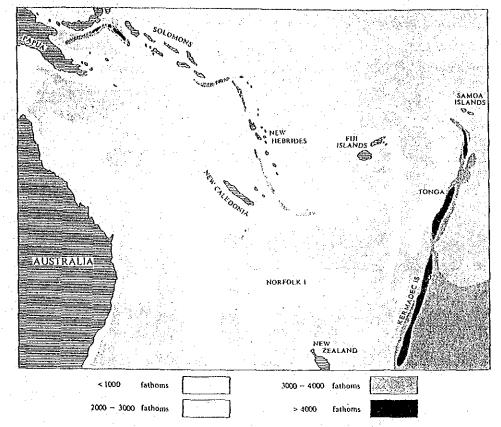


Fig. 1.1.3 General Bathymetric Features of the Southwest Pacific

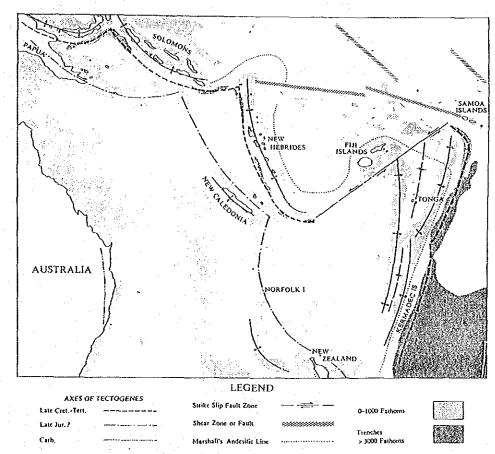


Fig. 1.1.4 Structural Interpretation of Bathymetric Features
Source: The Geology and Hydrology of WESTERN SAMOA

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.

| | લસ્પા જ | or more No. of days with visibility less t I mile | | | * | + | | | 0 0 | | O + | | | | | 1 | | | 11 | - |
|---|-------------------------|---|--------------------------------|---------------------|--------------------|---------|------------|----------------|-----------------|----------|--------------|---------------|------------|------------|----------|----------|--------|----------------|---|----|
| | 27 knots. | paods p | No. of days with wind speed | | | + | | | | - - | + 0 | | | <u> </u> | | المالية. | | |) | |
| | | Mean wind speed | | 1200 | Knots | | | | <u>.</u> و د | | | 10 | | | | | 1 | 1 | ∞ | |
| | | ≱≱₿ | | 0060 | 72 | | 2 | 2 | יט ע | | φ <u></u> | | | <u> </u> | | ٥ | | 1 | <u>, </u> | - |
| | | | | Çalın | | 2 | 2 0 | · ∞ | φv | | φ 10 | G | <u>ن</u> د | , oo | = | 7 | - (. | 1 | | |
| | | | E | MΝ | | 77 | 7 - | 4.1 | ν, c | ١ [| ю <i>1</i> 4 | | 7 | ۰ • | 4 | ٥ | . 1. | 1 | | |
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| | | | observation from | W.2 | | m c | ם מ | | . | | H (1 | 7 | ٧. | 4 (| 7 | 7 | 1 | ı | | |
| | | 1500 | əsqo | .s | | 4 4 | 4 4 | r .4. | 40 | ١ | w 0 | 7 | 7 | ^ ` | t | m | 1 | 1 | | |
| 1 | | ·.· | Percentage of | 3.8 | | ο, | 7 6 | 4.4 | 22 | 1 | 22 22 | 25 | 22 | 9 | ရ | 18 | 1 | 1 | | |
| | | ٠. | centa | а | | 30 | 7 6 | 4 | 53 | 7 | 57. | 55 | 56 | 4 0 | ς, | 47 | 1 | 1 | | } |
| Ì | 도 | | Per | N.E. | | 13 | 2 5 | 4 [| S A | | ο 4 | ∞ | Ś | Ξ ; | 2 | ٥ | 1 | 1 | Ì | |
| | Wind direction | | | .N | | 17 | 3 0 | 4 | 4 4 | | 7 - | 4 | 4 | 9 9 | 3 | 9 | 1 | 1 | 01 | |
| | nd di | | | Calm | | 35 | ξ 5 γ | 3.4 | 29 | 3 | 24 | 13 | 82 | 8 6 | 52 | 25 | i i | 1 | - | |
| , | W | | E | .W.И | | vo t | - v |) (A | ٦. | | 0 - | 7 | ~ | m (| 7 | ന | 1 | 1 | | |
| Ì | | . 12 | m fro | .W. | | 1/3 / | Ø 4 | r (4 | 7 - | 4 | - 0 | - | н | i • | n | 'n | 1 . | 1 | | |
| | | | rvatic | .w.s | | (4) | ~1 - | ۰ 0 | 0 - | 1 | 00 | . +-1 | 0 | ⊣ (| 7 | | 1. | 1 : | | |
| | | 0060 | asqo | .s | | 4 (| 71 0 | . 4 | ، 2 | 3 | m H | . | | 4 , | 4 | 7 | 1 | 1 | | |
| ł | | | Percentage of observation from | S.E. | | r ' | <u>د</u> ه | 7 2 | 20 | | 17 | 13 | 23 | 0, (| ? | | | 1 | | |
| | | | cent | E. | | 26 | 24 | 41 | 54 | } | 50 | 55 | 57 | 4 6 | χ | 4 | 1 | 1 | | |
| | | | Per | N.E. | | ∞ , | 00 | ۲. ٦ | 64.6 | n | m – | S | m | <u>۹</u> ۲ | ٥ | ٧, | 1 | 1 | | |
| 1 | | | _ | 'N | | F 1 | · 0 | 0 4 | -4 - | 7 | ~ - | 4 | ا ر | 0 9 | χ. | l/1 | 1 | ١ | <u>} </u> | 1 |
| | ű | 10 W | m i diiw | No. of days more | | 20 | <u></u> | 15 | 13 | 3 | 2 2 | 11 | 4 | ٠ <u>٠</u> | 5 | 1 | 174 | ! | 23 | |
| | Rain | | पिद्दा शुक्राः | θVΑ | m m | 424 | 364 | 232 | 186 | OCT | 115 | 147 | 221 | 279 | 385 | 1 | 2928 | - | 31 | - |
| | an ud unt | | 905 | 1 | FAS | 9 | φ · ų | o vi | , V) , V | ^ | ব ব | v) | 'n | 9 | စ | Ŋ | 1 | ŧ | 17 | |
| | Mean cloud amount | | 006 | 0 | OK | ِ ۾ | φ 4 | ט יט | ٠, د | 4 | 4 4 | 4 | 8 | in i | و | S | . 1 | 1 : | 70 | |
| | tive | | 200 | ī | 89 | 78 | 78 | 76 | 76 | 4 | 22 5 | 4 | 75 | 76 | 77 | 75 | 1 | i | 38 | |
| | Relative humidity | | 009 | 0 | 25 | 68 | 68 | 8 6 | 8 | 8 | 88 8 | 8 | 8 | 88 | €. | 88 | 1 | 1 | <u> </u> | |
| | | ųjuot | in each m | Меап ючет | ပ | 22 | 3 23 | 7 7 | 21 | 17 | 20 02 | 2 2 | 73 | 22 | 22 | 19** | 1 | 1811 | | |
| | Air peratu | циош | dasa ni 3 | Меап һівћез | ပ္ပဲ | 32 | 3 | 32. | 3.13 | 7 | 3 3 | 33 | 31 | 5 | 31 | 32* | 1 | 341 | 30 | |
| 1 | Air temperature | , | uim | Mean daily | ပ္ | 74 | 4 5 | 1 4 | 24 | 3 | 3 33 | 13 | 33 | ಣ . | 24 | 23 | 1 | 1 | | 1 |
| ` | | Mean daily max. | | | ن | | 9 S | | | 3 | 29 | | | | 30 | 30 | 1 | 1, | <u> </u> | 1 |
| | £ | Sure at A C 1 | 7.5.7 | Mean | mp. | 1008 | 1008 | 1010 | 1011 | 1701 | 1012 | 1012 | 1101 | 1009 | 1008 | 1010 | 1. | 1 | 30 | |
| | | | Month | | | January | February | waren April | May | June | July | September | October | November | December | Means | Totals | Extreme Values | No. of years' observations | |
| ١ | | | | | * ; . . | | | - | | | | | | | | · | | | · . | -4 |

^{*} Ma * Mean of highest each year. † Hig ** Mean of lowest each year. †† Lo

[†] Highest recorded temperature. Standar

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

Table 1.2.2 Monthly Mean Max. and Min. Temperatures

(°C) Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec. Mean Mean 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 Max. 1977 Mean 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 Min. Mean 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 Max. 1978 Mean 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 Min. Mean 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 Max. 1979 Mean 24.0|23.7|23.6|23.0|23.1|23.9|22.5|22.2|23.2|23.3|23.2|23.3|23.2°C Min. Mean 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 Max. 1980 Mean 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 Min. Mean 30.6 30.7 30.4 29.5|29.9|30.2|29.8|30.5|30.2|30.2°C Max. 1981 Mean 24.1 22.6 23.6 21.5 | 23.1 | 23.3 | 23.6 | 23.4 | 23.9 | 23.2°C Min. Mean 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 Max. 1982 Mean 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 Min. Mean 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 Max. 1983 Mean 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 Min. Mean 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 Max. 1984 Mean 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 Min. Mean 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 Max. 1985 Mean 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 Min. Mean 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 Max. 1986 Mean 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 Min.

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 | | | | | _ | - | | ر آهن . | _ | | | - |
| Mean | 24 | 21 | 23 | 19 | 14 | 14 | 13 | 13 | 15 | 18 | 17 | 21 | 218 |

Table 1.2.4 Total Monthly Rainfall

| | | | 11111 | 4. | | in to | | | 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1 | | | <u> </u> | (mm) | |
|-----|------|-------|-------|----------|-------|--------------|-------|---------|--|-------|-------|----------|----------|---------|
| 1 | | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Total |
| 1 | 1.00 | | | <u> </u> | | | | 1 12 12 | | | | | 73 S. 11 | |
| - | 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 |
| l | 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 |
| 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 |
| Ì | | | | | | | | | | | | | | 2,981.9 |
| į | 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 |
| ĺ | 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 |
| ĺ | 1984 | 274.1 | 260.2 | 277.0 | 131.0 | 59.4 | 301.2 | | | | | | | 3,196.3 |
| 1 | | | | | | 288.6 | | | | | | | | 2,394.7 |
| Į | 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 |
| . [| | 508.8 | | - | | - | | | : | | _ | | | |
| 1 | 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 |

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

| Speed in Knots | N | NE | Е | 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 |

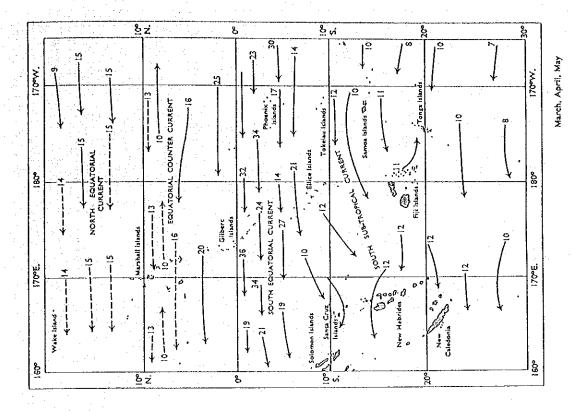
Table 1.2.6 Annual Occurrence Frequency of Wind Direction at Apia 1951 - 1970

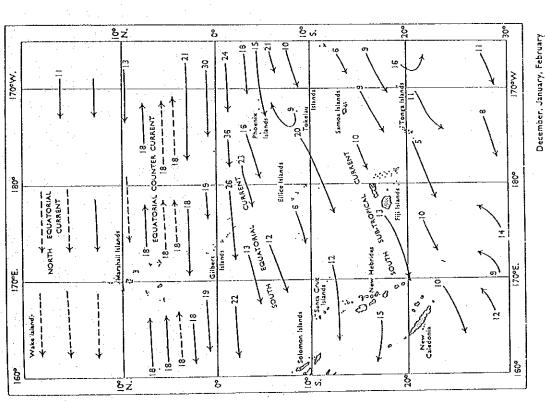
(%)

| Month | N | NE | Е | 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 |

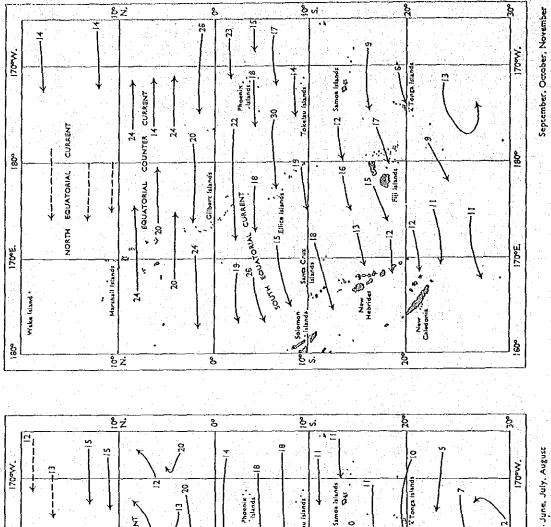
Table 1.2.7 Record of Hurricanes

| | | | Table | 1.2.7 Record of | Harrada | |
|----|----------------|----------|----------------------------------|------------------|-------------------|---|
| | Year | Month | Mean Wind Velocity (m/sec) | Time (hrs) | Wind Direction | Max Wind Velocity (m/sec) |
| | 1831 1888 | Storm | : Only basic | records, no data | | ion and velocity |
| ı | 1889 | 3 | 30 | 24 | W - S -SE | - |
| 1 | | | | (Same wind | | |
| | | | | direction 8 hrs) | | |
| 1 | 1923 | 3 | 25 | 12 | NE - NW | - |
| - | 1926 | 1 | 30 | 2 | NSE - S | iga a a a a a a a a a a a a a a a a a a |
| - | 1930 | 12 | .20 | | N | - |
| | 1946 | 12 | 23.6 | _ | | |
| - | 1952 | 1 | 19.4 | 3 | - | - 20 |
| - | 1957 | 12 | 14.4 | 24 | ESE | 38 24 |
| | 1958 | 3 | 15 | $\frac{1}{2}$ | ENE | |
| - | 1959 | 2 | 9.8 | 24 | N | 21 26 |
| -[| 1960 | 1 | 19 | 5 72 | NW | 26 26 |
| | 1961 | 3 | 11.8 | 12 | WW WW | 20 21 |
| | 1963 | 3 | 15 | 14 24 | NE | 19 |
| 1 | 1964 | 1 | 5 | 24 | E E | 18 |
| 1 | 1965 | 3 1 | 4.5 | 9 | S | 41 |
| 1 | 1966 | 12 | 30 10 5 | 24 | NE. | 21 |
| 1 | 1967 | 2 | 10.5 | 1.25 | NW | 39 |
| 1 | 1968 | 1 | 28.3 | 24 | NNE | 21.5 |
| 1 | 1969 | 2 | 10.3 | 24 | NNE | 22.5 |
| 1 | 1970 | 1 | 11.5 10.5 | 24 | NE | 26 |
| | 1972 1974 | $1 \\ 1$ | 10.5 | 24 | NNE | 19 |
| | 1975 | 1 | 9 | 48 | SSE | 26 |
| L | 1717 | L | <u> </u> | 1 | | |





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



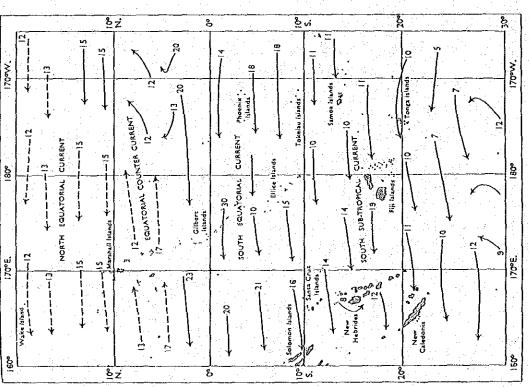


Fig. 1.3.1 (2) Predominant Currents in the South Pacific (Speeds in Miles per Day) (Broken Lines Indicated Few Observation)

September, October, November

Table 1.4.1 List of Earthquakes Magnitude 4.7 and Over

| | حبية والتناب والمناب | | - | , | | | | | | |
|------|--|----------|----------|------------------|----|------|-----------|------|-------|-----|
| Date | Month | Year | Time | Mag | | Date | Month | Year | Time | Mag |
| 16 | June | 1917 | 06:00 | 8.3 | ٠. | 15 | April | 1979 | 07:30 | 4.8 |
| 3 | March | 1956 | 00:06 | 6.5 | | 11 | June | 1979 | 17:24 | 4.9 |
| 28 | January | 1957 | 08:17 | 6.5 | | 14 | June | 1979 | 02:59 | 5.2 |
| 14 | April | 1957 | 19:19 | 7.0 | | 15 | June | 1979 | 03:34 | 5.1 |
| 31 | March | 1959 | 07:21 | 6.0 | | 18 | September | 1979 | 20:56 | 5.4 |
| 12 | April | 1959 | 20:55 | 6.5 | | 13 | November | 1979 | 14:44 | 5.5 |
| 10 | March | 1961 | 08:50 | 6.0 | | 27 | December | 1979 | 07:45 | 5.5 |
| 30 | April | 1961 | 23:40 | 6.25 | | 21 | January | 1980 | 02:39 | 5.1 |
| 8 | October | 1963 | 00:17 | 6.0 | | 3 | February | 1980 | 11:59 | 6.2 |
| 11 | March | 1968 | 08:27 | 6.0 | | 3 | February | 1980 | 19:02 | 4.8 |
| 10 | April | 1968 | 12:16 | 6.25 | | 19 | February | 1980 | 06:06 | 4.7 |
| 6 | October | 1968 | 08:48 | 6.0 | | 24 | February | 1980 | 15:19 | 4.8 |
| 9 | October | 1968 | 03:39 | 6.0 | | 8 | March | 1980 | 01:01 | 5.5 |
| 7 | August | 1972 | 09:25 | 6.0 | | 8 | March | 1980 | 01:14 | 5.1 |
| 7 | September | 1972 | 09:12 | 5.9 | | 2 | May | 1980 | 16:50 | 5.3 |
| 12 | December | 1972 | 16:23 | 6.0 | | 18 | June | 1980 | 10:50 | 5.9 |
| 16 | March | 1974 | 10:56 | 6.0 | | 2 | July | 1980 | 15:43 | 5.7 |
| 21 | September | 1974 | 08:29 | 6.0 | | 13 | July | 1980 | 22:14 | 5.4 |
| 9 | December | 1975 | 09:14 | 6.0 | | 25 | July | 1980 | 04:30 | 4.7 |
| 26 | December | 1975 | 15:56 | 6.4 | | 20 | August | 1980 | 04:45 | 4.8 |
| 11 | February | 1976 | 21:44 | 6.0 | | 31 | August | 1980 | 01:44 | 4.7 |
| 3 | April | 1977 | 07:15 | 6.0 | | 15 | September | 1980 | 23:31 | 5.3 |
| 17 | July | 1978 | 13:26 | 6.0 | | 17 | September | 1980 | 05:08 | 5.6 |
| 4 | February | 1979 | 02:10 | 5.4 | | 17 | September | 1980 | 05:37 | 5.4 |
| | | <u> </u> | <u> </u> | | 1 | 9 | October | 1980 | 16:20 | 5.7 |

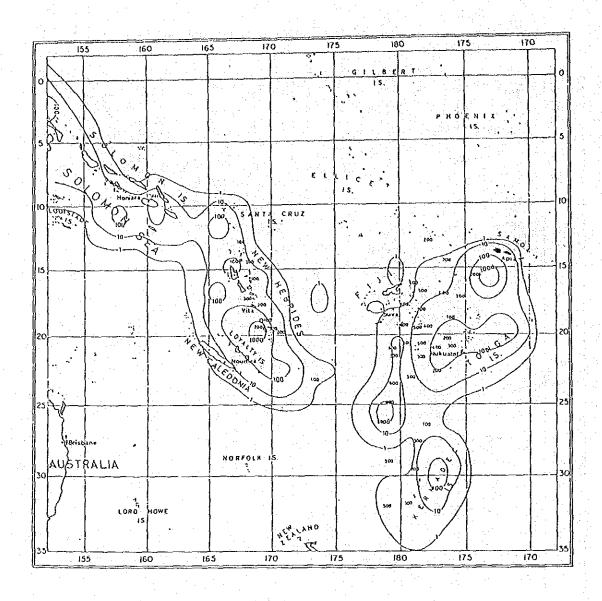


Fig. 1.4.1 Seismicity of Fiji-Tonga-Samoa-New Hebrides: (Seismicity contours are numbered in $10^{15}~{\rm ergs~km}^{-2}~{\rm year}^{-1}$.)

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. 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.

| Purpose | Method/Equipment | | | | |
|----------------------|--|--|--|--|--|
| Wave Conditions | Ultrasonic Wave Recorder | | | | |
| Siltation Conditions | Ultrasonic Echo Sounder | | | | |
| Siltation Conditions | Float | | | | |
| Siltation Conditions | Sampler, Soil Tests | | | | |
| Design Conditions | Boring, Soil Tests | | | | |
| | Wave Conditions Siltation Conditions Siltation Conditions Siltation Conditions | | | | |

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 construction of a 100m long breakwater at the northern harbour of the existing wharf.

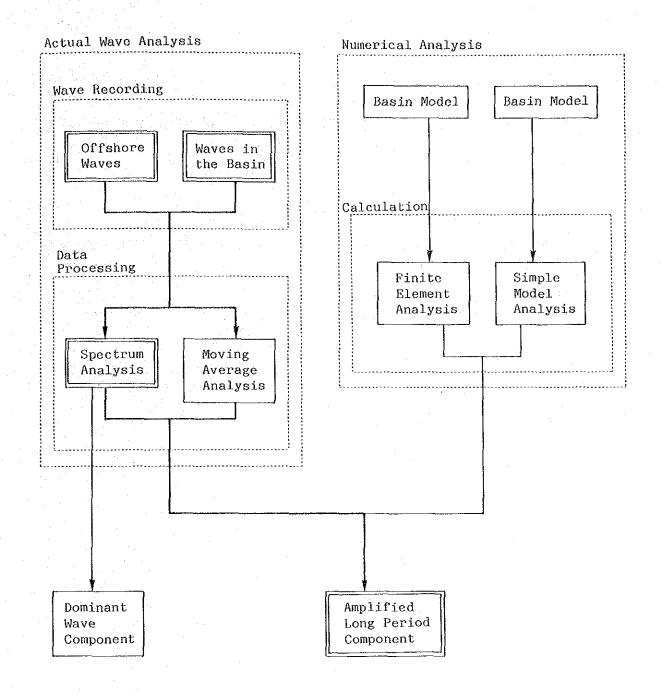


Fig. 2.2.1 Flow Chart of the Resonance Analysis

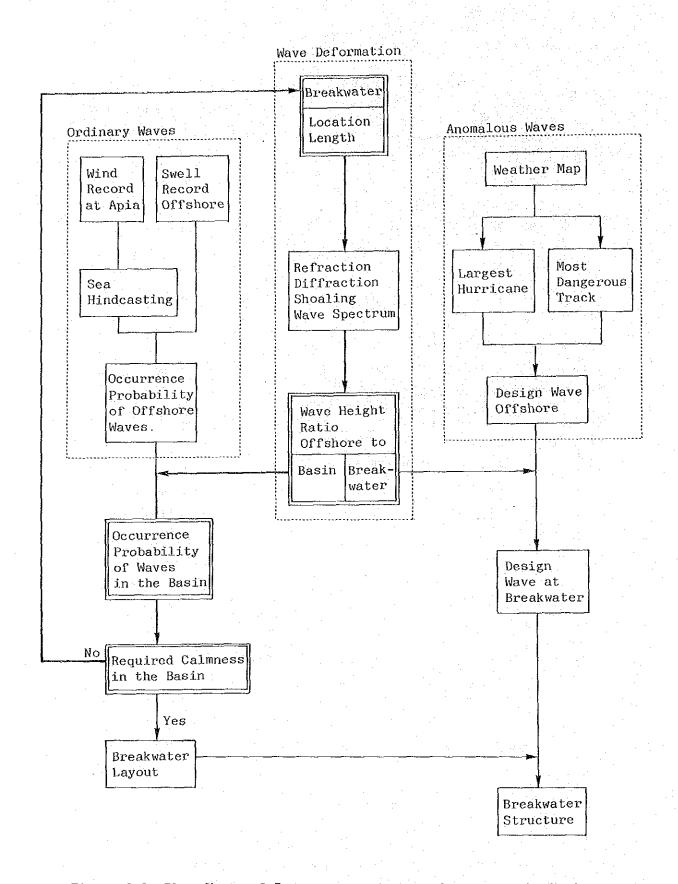


Fig. 2.2.2 Flow Chart of Improvement of the Calmness in the Harbour

- 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 Raudkíví 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.

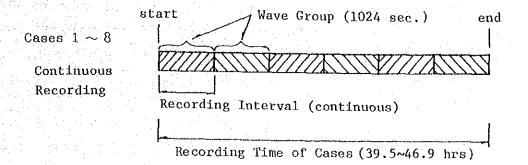
13. Other reports regarding the waves have been issued and most of them confirm that Apia Harbour has difficulty with long period waves. These reports use many terms for long period waves which are amplified in the basin, such as swell, surge, seiche and resonance. In this report 'resonance' shall be 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.

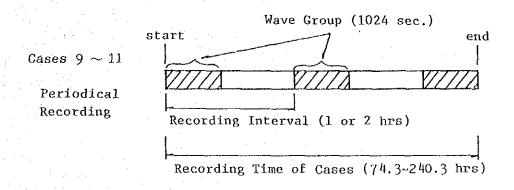
(2) Wave Recording

- 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.

^{*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.





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.

| | | نسنس | | | | |
|------|------|------|-------|---------------|----------------|--------------|
| Case | Loc | atio | on of | Wave Recorder | Recording Time | Recording |
| No. | 1 | 2. | 3 4 | 5 6 7 8 | of Case (hrs) | 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 | o | | 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 $Kr \times Ks = 0.89$ 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 | 11 | 5 | 6 | 7 | 8 |
|----------------|------|------|------|------|---------------------------------------|------|------|------|
| Ratio to | 0.00 | 0.50 | | | · · · · · · · · · · · · · · · · · · · | | | |
| 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.

| | Wave | | S.T | . 1 | S.T | . 4 |
|------|-----------|----------------|-------|--------|-------|--------|
| Case | Group No. | Recording Time | Н 1/3 | T 1/3 | Н 1/3 | T 1/3 |
| | | (sec.) | (m) | (sec.) | (m) | (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 x 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 $F = 1.6 \times 10^{-2}$ 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 $F = 1.6 \times 10^{-2} \text{ sec.}^{-1}$ (60 sec.).
- 28. The energy density peak of S.T. 1 is 4×10^4 cm² sec. and the second energy density peak of S.T. 4 is 5×10^2 cm² 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 $0.11 \cdot (\sqrt{5} \times 10^2/4 \times 10^4)$. The wave height of the amplified long period component is about 11cm (0.98m \times 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 $F = 1.6 \times 10^{-2} \text{ sec.}^{-1}$ (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 1×10^{-3} to 3×10^{-3} sec. ⁻¹ (33 sec. to 100 sec.). Three peaks of low frequency wave height ratio are shown at frequencies of 3×10^{-2} , 1.6×10^{-2} and 1.0×10^{-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 x 10^{-2} to 3 x 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

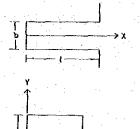
36. Numerical analysis by finite element method analysis was conducted to analyse the amplification of the long period component in the harbour. Fig. 2.2.9 shows the triangle components used for calculation and symbols show the location of the grids where amplification was calculated. The calculation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

$$To = \frac{h1 \times \alpha}{(2m-1)\sqrt{gh}}$$
 (1)



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

Where

1: 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

a: revision coefficient

h : water depth in the basin

g: acceleration of gravity

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

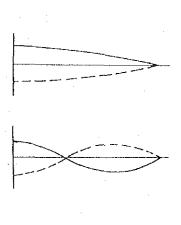
40. Apia Harbour can be assumed to be a rectangular basin with one open end in the north - south direction. Under the condition of 1 = 1500m, b = 600m and h = 15m, the natural periods are obtained as follows by equation (1).

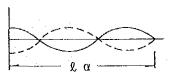
$$\alpha = 1.237$$

m = 1 To 1 = 612 sec.

m = 2 To 2 = 204 sec.

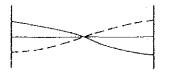
m = 3 To 3 = 122 sec.





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).

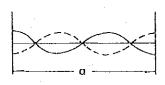
$$m = 1$$
 Tc 1 = 121 sec.



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:

| | Present | A | В | C. | C |
|--------------------------------|-----------|------|-----|---------|------|
| Case | Condition | | | <u></u> | |
| Degree of Sheltering | 28.3 | 12.8 | 7.8 | 9.2 | 18.6 |
| (percentage to offshore waves) | 20.3 | 16.0 | 7.0 | | |

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:

| | Present (Condition) | (Case C) | | (Case C') |
|----------------------|---------------------|----------|------|-----------|
| | "Condition | | | |
| | | | | |
| Ratio to Offshore (% |) 28.3 | 9.2 | 12.3 | 18.6 |
| Ratio to Present (% |) 100 | 33 | 413 | 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:

$$H = 4.2m (7.0m \times 0.6)$$

T = 10 sec.

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

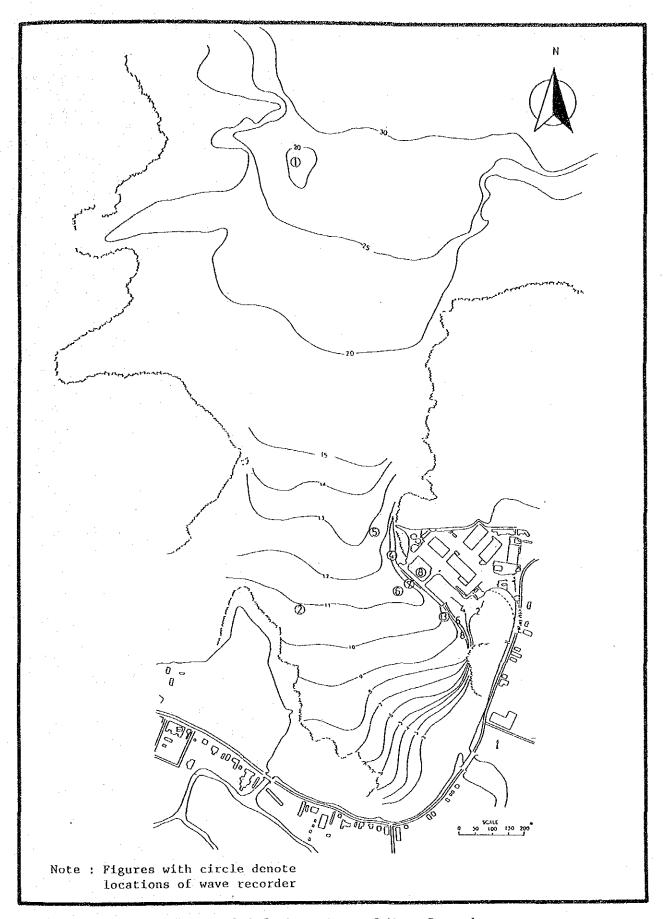
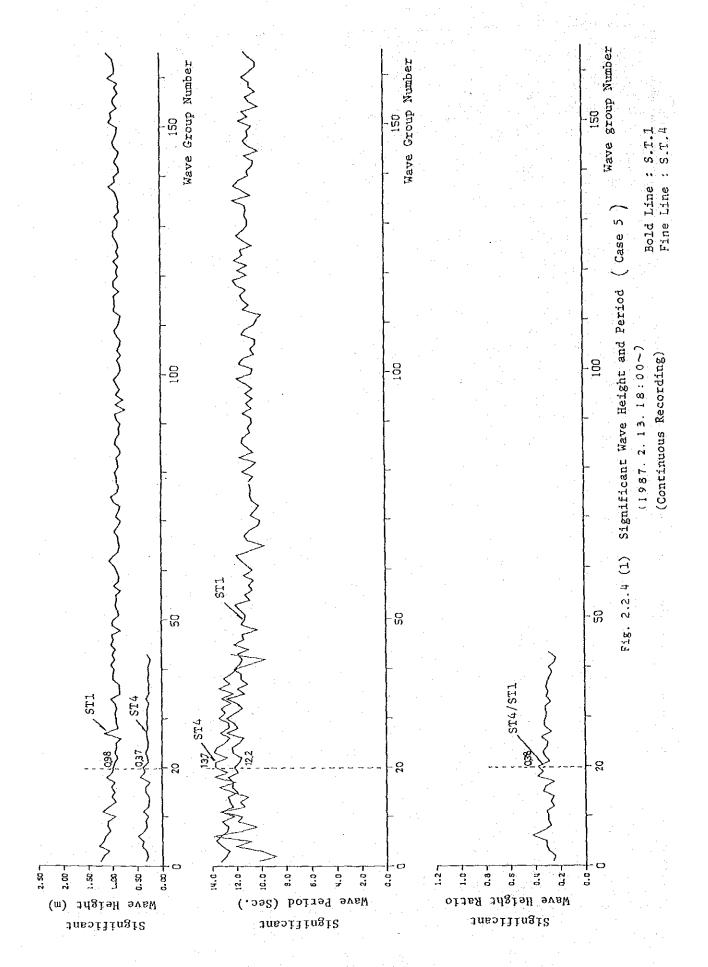
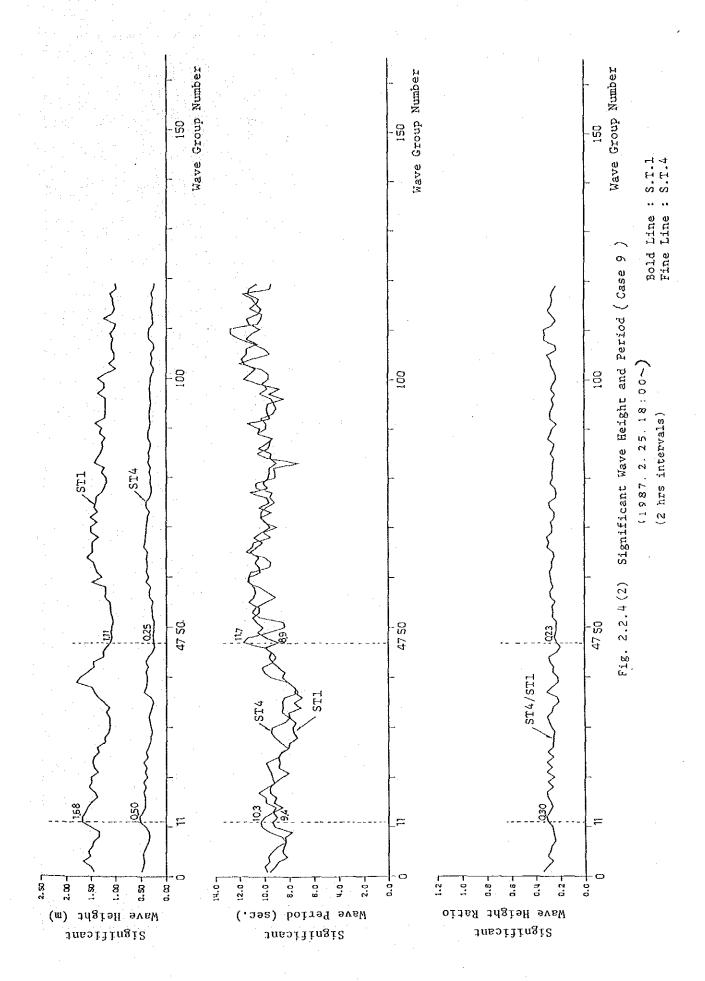


Fig. 2.2.3 Locations of Wave Recorder





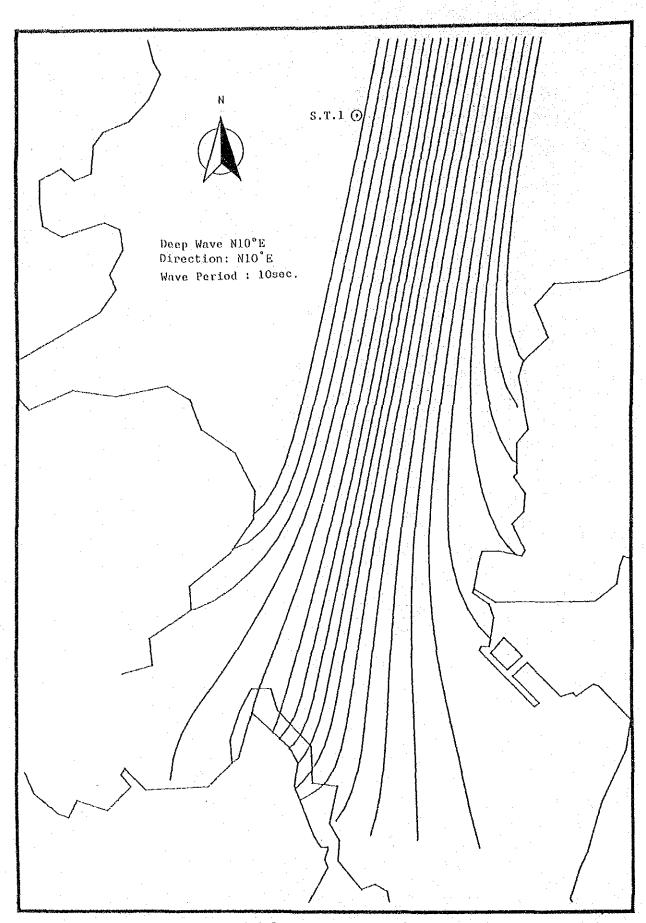


Fig. 2.2.5 Wave Refraction Diagram

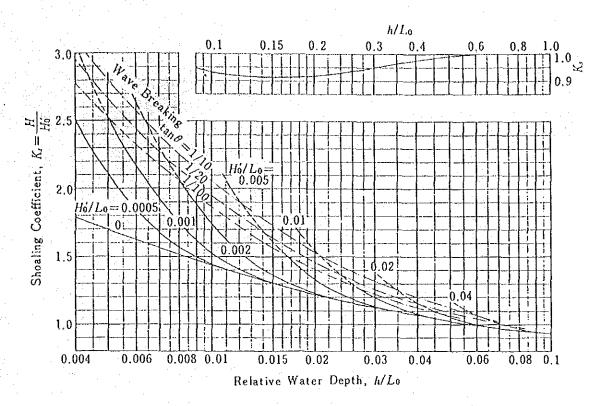
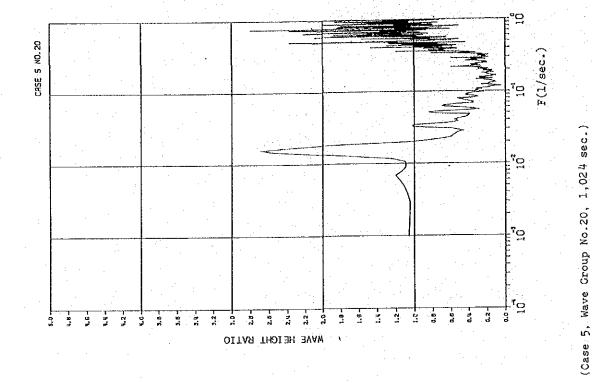
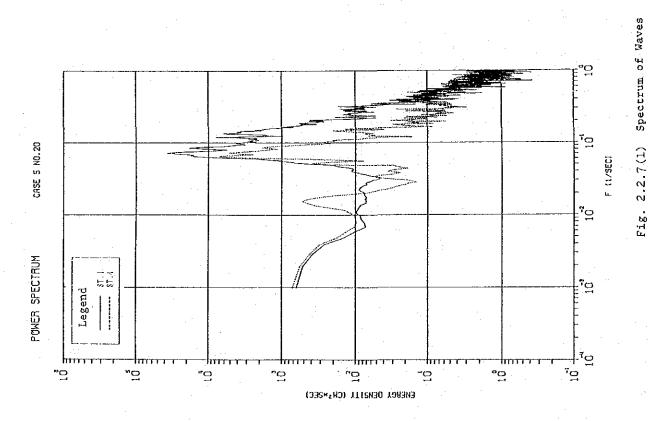
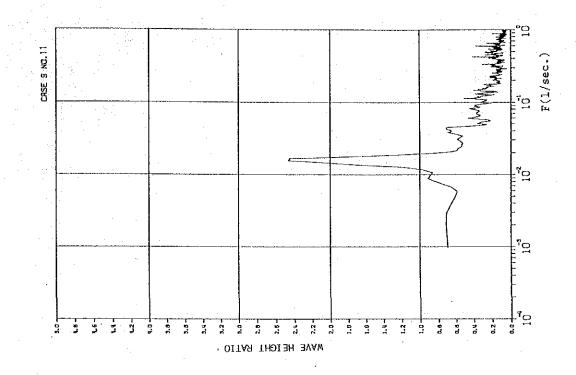
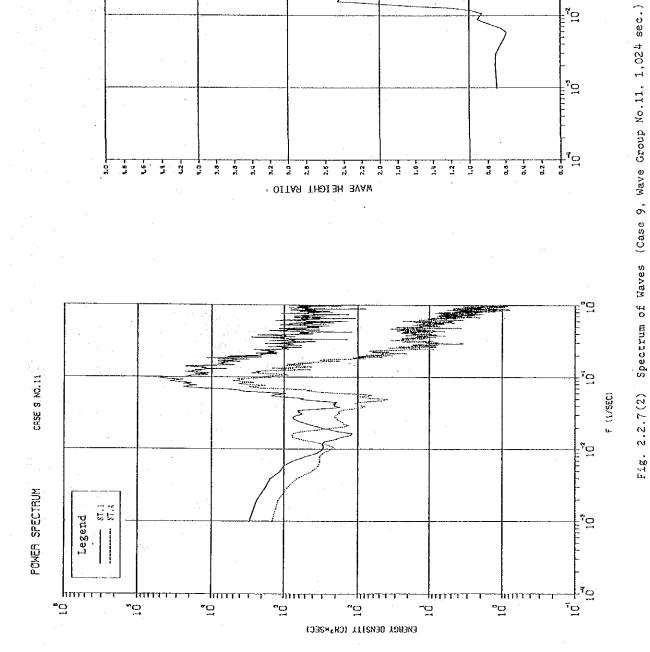


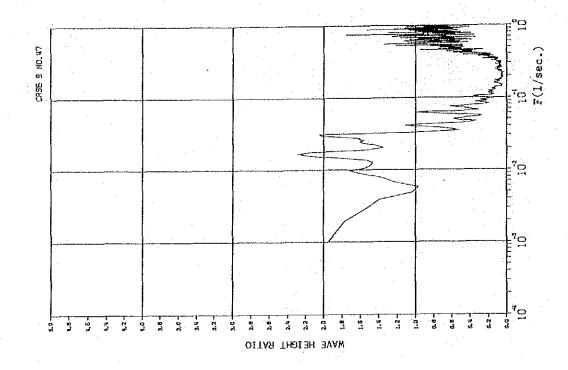
Fig. 2.2.6 Diagram of Nonlinear Wave Shoaling

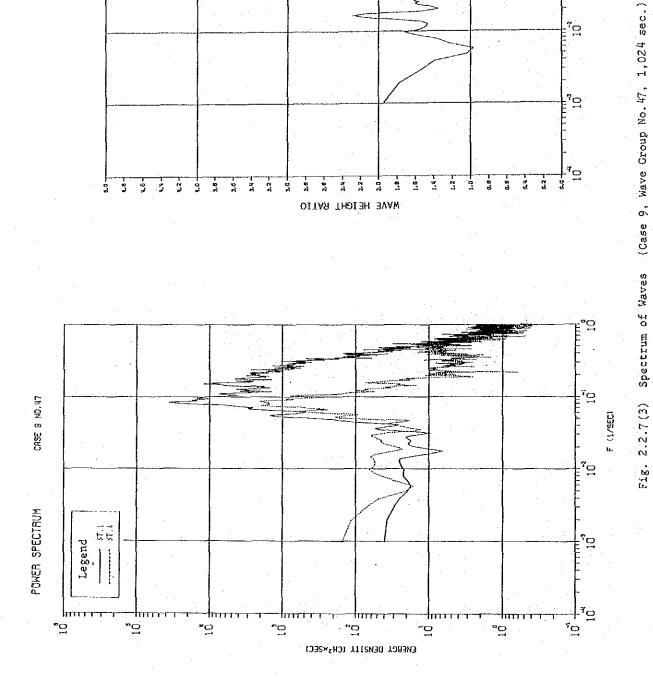


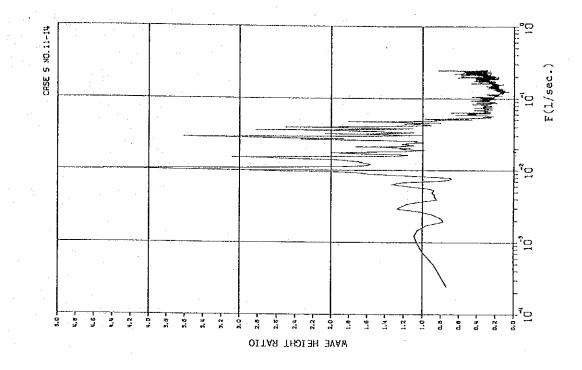


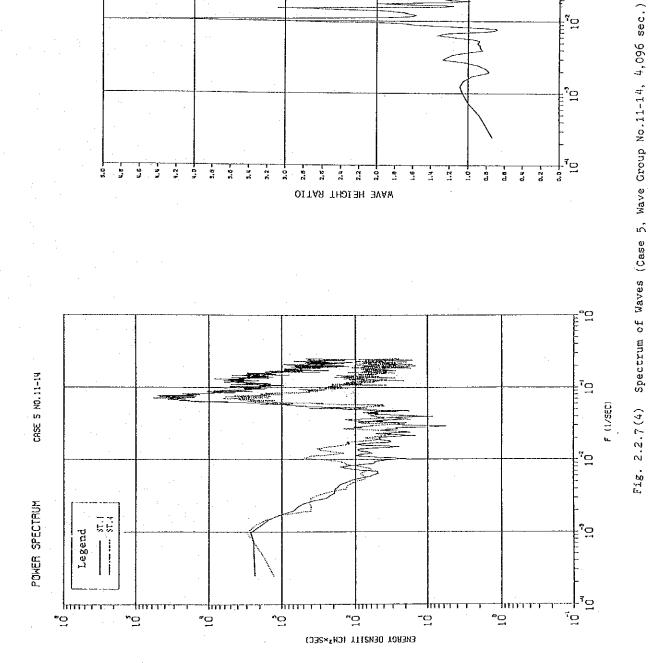


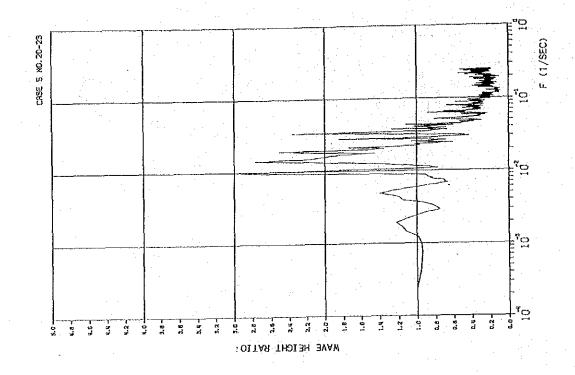


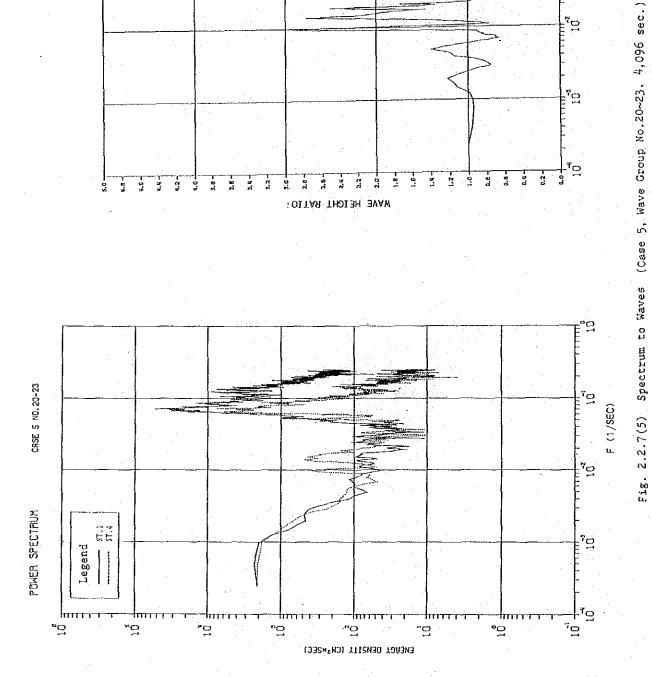












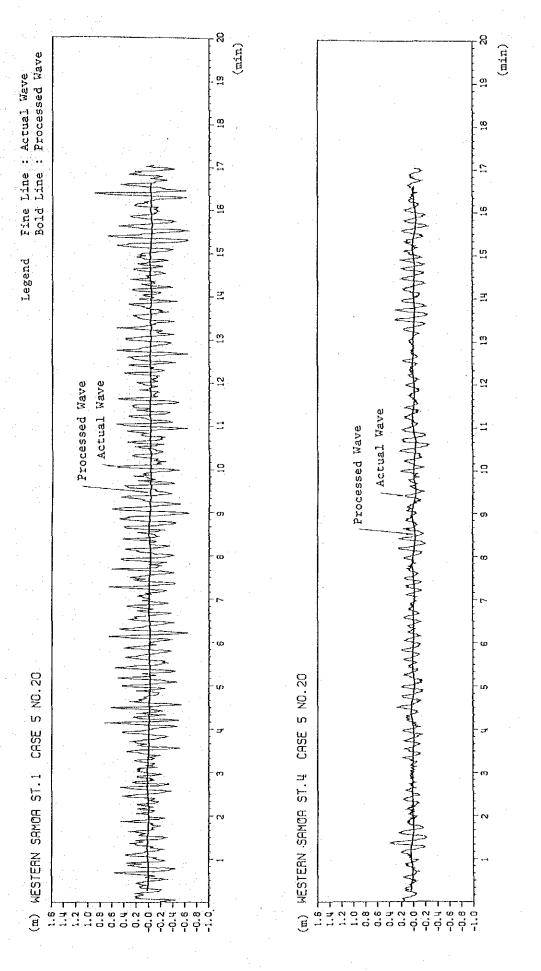
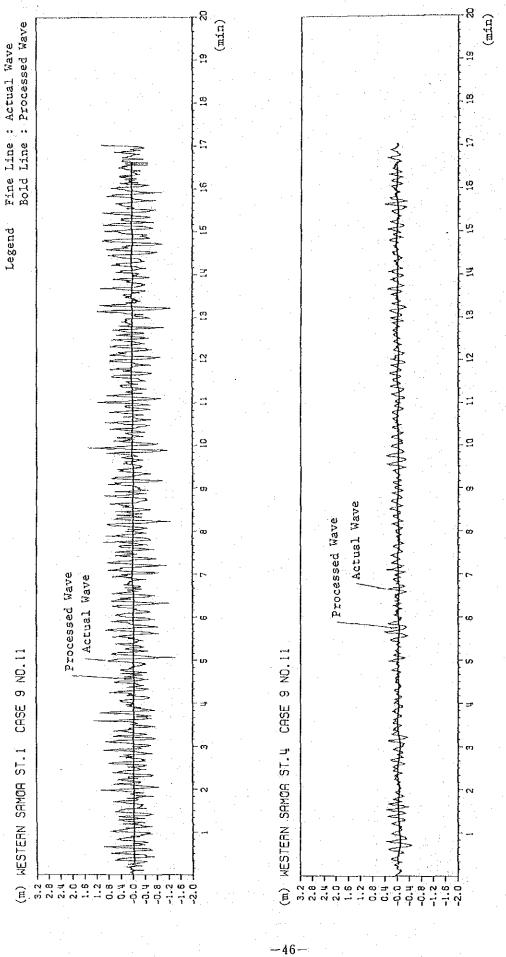
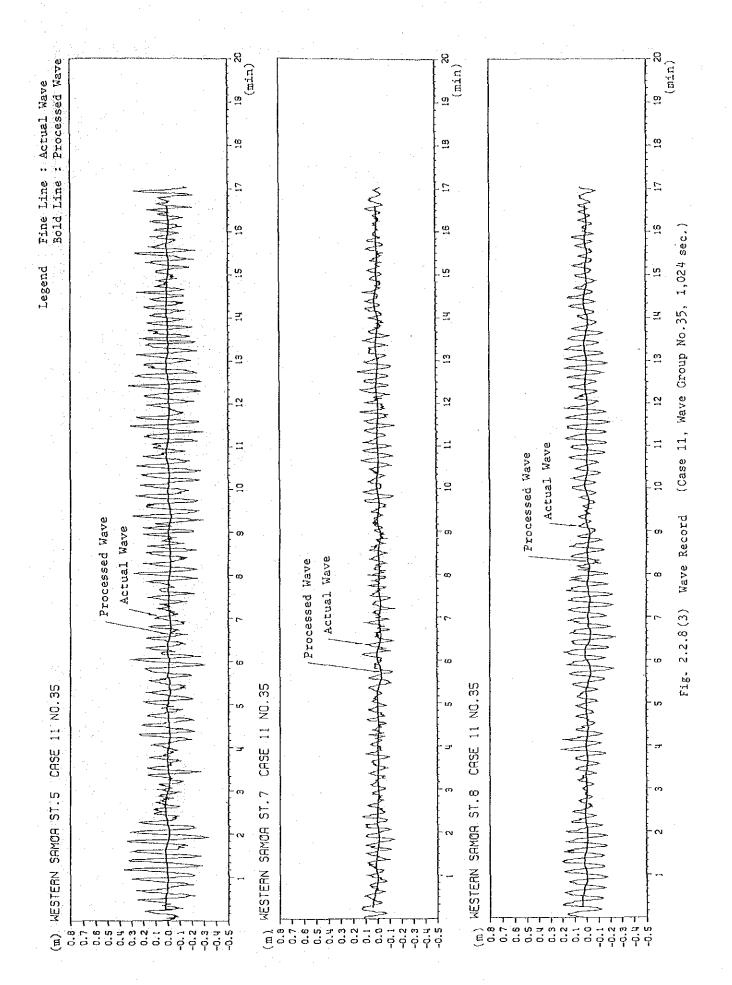


Fig. 2.2.8(1) Wave Record (Case 5, Wave Group No.20, 1,024 sec.)



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



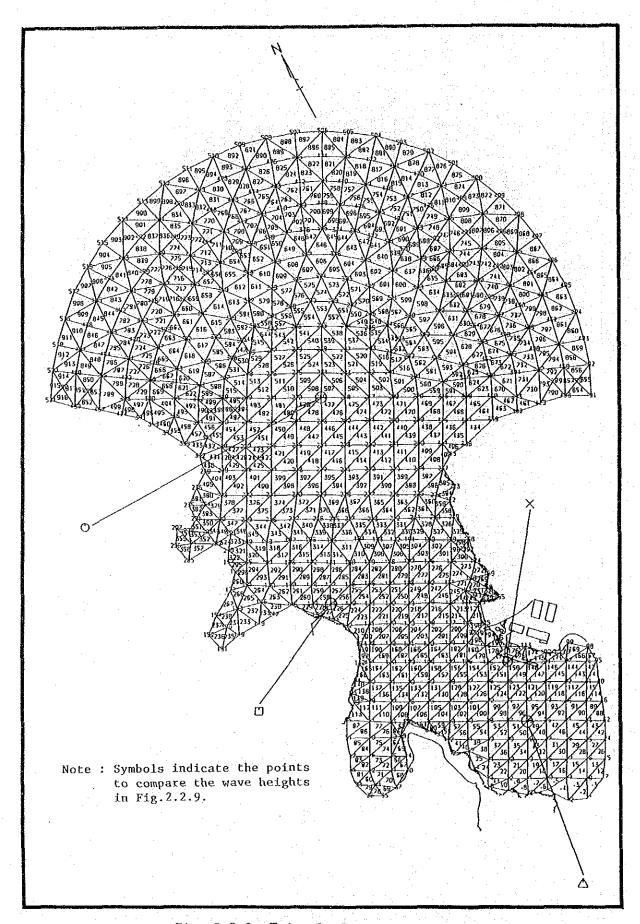


Fig. 2.2.9 Triangle Components of FEM

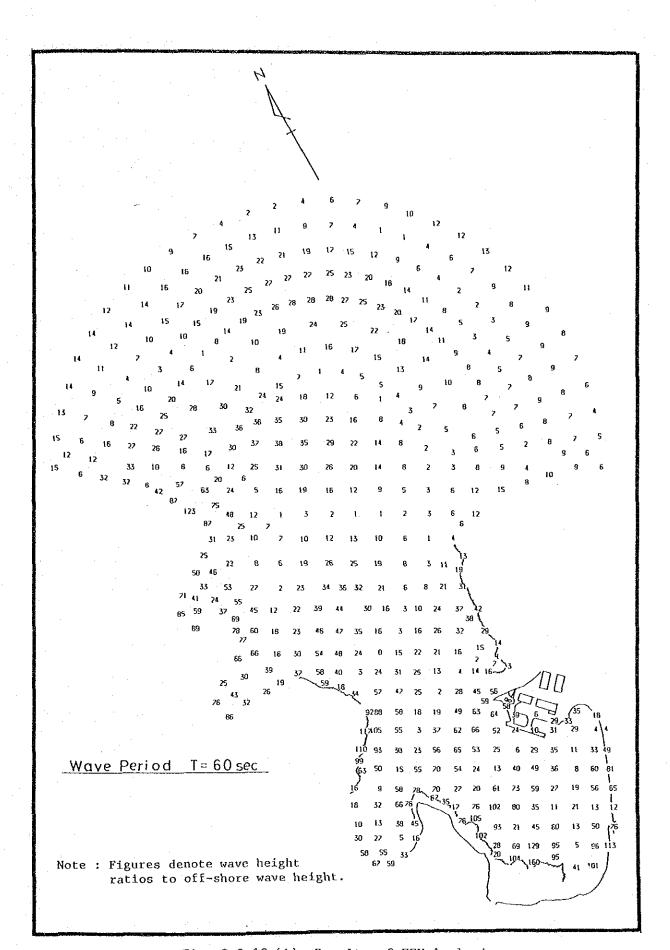


Fig. 2.2.10 (1) Results of FEM Analysis

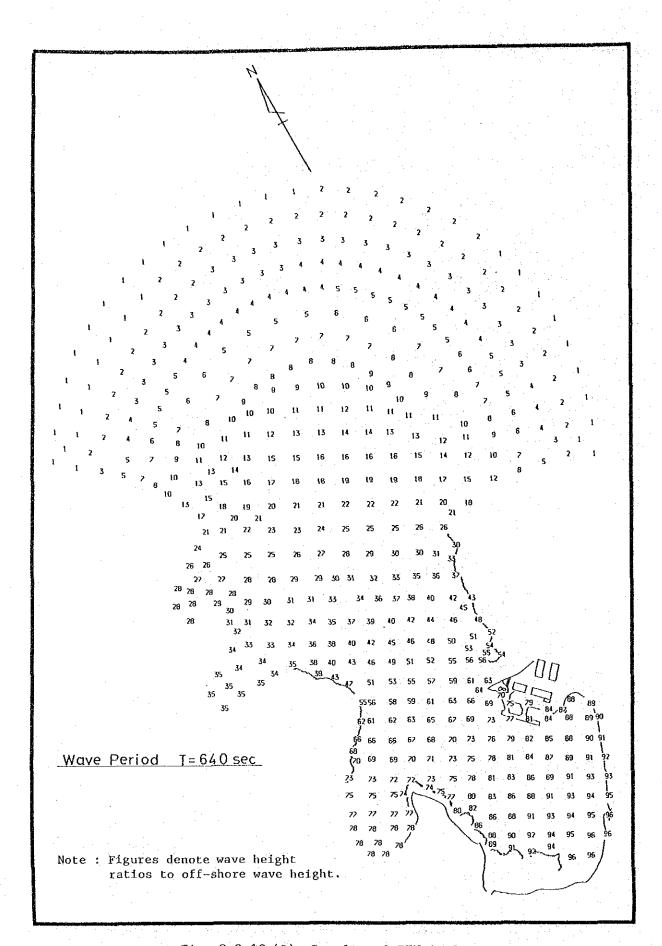


Fig. 2.2.10 (2) Results of FEM Analysis

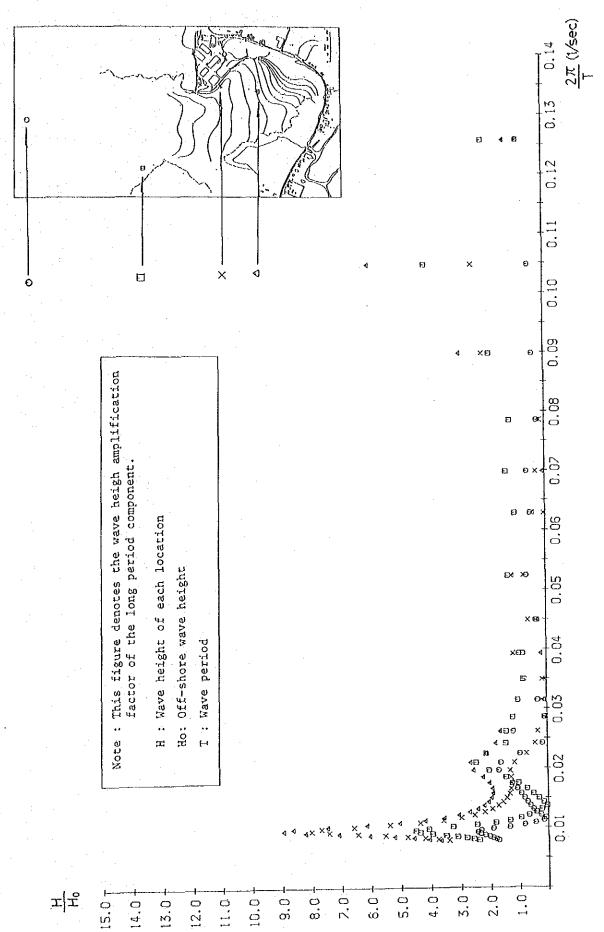


Fig. 2.2.11 Amplification of the Long Period Component

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

| W.DIRECTION | CALN | N E | S S | EN E | ហ | 383 | S | ខ្ល | ιΩ | SSW | N.S | HS.M | 2: | MNN | Z. | NNN | z | TOTAL |
|----------------|-------------|--------|--------|----------|-----------|-------|------|------|------|----------|-----------|------------|-------------|-------|-------------------|------|-------|-------------|
| WI.SPEED (N/S) | | | | | | | | | | | | | | | | | | |
| CALM | 560 51.9 | 0.0 | 0.0 | 0.0 | 00.0 | 0.0 | 0.0 | 0.0 | 00. | 00. | 0.0 | 0.0 | 0.0 | 000 | 00. | 00 | 00, | 562 52.0 |
| 0.0 1 2.5 | 0.0 | 0.18 | 1.0 | 14 | 43 | 1.0 | 34. | 13 | 26 | 11 1.0 | 12 1.1 | 9.0 | 4 5 5 | 7 0.0 | 10 | 2 | 2 0 0 | 252 |
| 2.5 - 5.0 | 0.0 | 0.1 | ດທຸ | 12 | 3.7 | 14 | 12 | 0.7 | 0 0 | 0.22 | 00. | 0 2 13 | 1.1 | 13 | 1,3 | ດ | 0 | 140 |
| 5.0 - 7.5 | 00. | . 0 | ٠. | ວ ທຸນ | 27.5 | 7.0.6 | 000 | 0.1 | 0.52 | 0.0 | 0.0 | 0 | 4 4. | 0.7 | σ. _Β . | 86 | 0.1 | 70 6.5 |
| 7.5 -10.0 | 00.0 | 0.11 | 0.1 | e e. | 19 1.8 | 0 | 00.0 | 0.1 | 0.0 | 0.0 | 00. | 0.0 | 0.1 | 0 ហ្គ | 9 0 | 0.11 | H 0 | 42 |
| 10.0 -12.5 | 00. | 00. | 00.0 | 00.0 | 0 n | 00.0 | 0.0 | 0.0 | 0.0 | 0.0 | 00. | 00.0 | 00. | 0 | ٠ ١ ١ | 0.1 | 0.0 | 0.13 |
| 12.5 -15.0 | 00 | 00 | 00 | 00 | 00. | 000 | 0.0 | 0.0 | 00. | 0.0 | 00 | 0.0 | 0.0 | 0.1 | 000 | ٠, ٥ | 00.0 | 0.2 |
| 15.0 -20.0 | 0.0 | 0.0 | 00. | 0.0 | ен. О | 00.0 | 0.0 | 00.0 | 000 | 0.0 | 0.0 | 00.0 | 0.0 | 0.0 | 00,0 | 000 | 0 0 | ਰ ਜ਼ ੦ |
| 20.0 | 0.0 | 000 | 0.0 | .00 | ٦ | 00 | 00 | 0.0 | 0.0 | н н О | 00. | 0.0 | 00 | 00.0 | н н, О | 000 | 0.0 | 0 |
| TOTAL | 560 | 11 | 1.8 | 3.1. | 136 | 4.0 | 4.3 | 17 | 30 | 1.3 | 12 1.1 | 2.1 4.1 | 33 133 | 37.8 | 41 3.8 | 23 | 10 | 1080 |
| | | | | | | | | | | | | | | | | | | |

Table 2.2.2 Wave Occurrence by Direction and Height

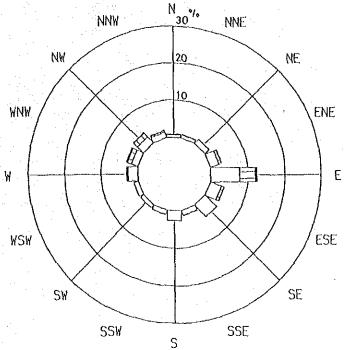
(Hindcasted by Wind Data Jan. Feb. Mar. 1987)

| | | | | | | . • | | | | | | | | | | | | ٠ |
|--------------|------|------|-------|------|------|-------|-----------|-----------|------|------------|--------|----------|----------|---------|------|------|------|--------------|
| W.DIRECTION | CALM | SSW | SH | MSM | * | NA | N. | NNN | z | N N | N N | EN EN | ĺυ | ESE | (V) | SSE | Ń | TOTAL |
| W.HEIGHT (N) | | | | | | | | | | | • | | | | | | | |
| כעדא | 729 | 0.0 | 00 | 0 0 | 0.0 | 00 | 0.0 | 000 | 00.0 | 0.0 | 00 | 00.0 | 0 0 | 0 0 | 00 | 00 | 000 | 729 |
| 0.00 - 0.49 | . 00 | 0.0 | 00.0 | 0.0 | 00.0 | 15 | 20 | 16 1 5 | 0.6 | 0 0 | 13 | 22 | 5.3 | 29.7 | 0.0 | 00 | 0.0 | 194 18.0 |
| 66.0 - 05.0 | 00.0 | 0.0 | 00 | 000 | 00.0 | 10 | 10 | 0 0 0 | 0.0 | ਜ ਜ ਼ 0 | 4 4 | 0.7 | 6 6 6 | 6 0 | 00 | 00 | 0.0 | 08.1 |
| 1.00 - 1.49 | 00.0 | 0.0 | 0 | 0.0 | 0.0 | 9.0 | o.0 | 00 | 0.1 | 0.1 | 0.1 | 0.22 | 1.4 | 4.0 | 0.0 | 00 | 0.0 | 3 1 3 |
| 1.50 - 1.99 | 0.0 | 00.0 | 0.0 | 00.0 | 000 | 0.73 | o | 0.1 | 00.0 | 00.0 | 0.0 | 0 7 7 | 11,0 | ਜਜ 0 | 000 | 0.0 | 0.0 | 22 2 2 2 . 0 |
| 2.00 - 2.49 | 00.0 | 0.0 | 00.00 | 0.0 | 0.0 | 0.2.2 | 00.0 | 0.0 | 0.0 | 0.0 | 0.0 | 00.0 | 0 0 | 0.0 | 0.0 | 00. | 0.0 | 0.5 |
| 2.50 - 2.99 | 0.0 | 00. | 0.0 | 0.0 | 0.0 | 0.2 | 0 2 2 | 0 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 9.0 |
| 3.00 - 3.49 | 0.0 | 0.0 | 0.0 | 90 | 00.0 | 00 | 000 | 0.1 | 00.0 | 0.0 | 0.0 | 00.0 | 00. | 0.0 | 0.0 | 0.0 | 00.0 | 0.1 |
| 3.50 - 3.99 | 00.0 | 00.0 | 00. | 0.0 | 00.0 | 00. | 00.0 | 0 0 | 0.0 | 0.0 | 00.0 | 0:0 | 00.0 | 0.0 | 000 | 0.0 | 000 | 00. |
| 4.00 - 4.99 | 0.0 | 00.0 | 00.0 | 0.0 | 00. | 0.0 | 0.0 | 0.0 | 0.0 | 00.0 | 0.0 | 00. | 00. | 00 | 00.0 | 00.0 | 00. | 0.00 |
| 5.00.5 | 00. | 0.0 | 0.0 | 00. | 0.0 | 0.0 | 1.0 | 0.0 | 00.0 | 0.0 | 00. | 00. | 0.1 | 0.0 | 00.0 | 00.0 | 0.0 | 0.22 |
| TOTAL | 729 | 00.0 | 00.0 | 00.0 | 0.0 | 37 | 41 3.0 | 23 | 10 | 11,10,10 | 18 | 3.1 | 134 | 43 | 0.0 | 0.0 | 0.0 | 1080 |

Table 2.2.3 Wave Occurrence by Period and Height

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

| W.PERIOD (S) | ני) כערוו | 5 1 | 1- 2 | 2- 3 | 31. | 4 - 5 | 9 1 10 | 2 -9 | 1 6 | 6 | 9-10 | 10- | TOTAL |
|--------------|-----------|------|-----------|---------|---------|-------|--------------|----------|------|------|------|-----|---------------|
| W.HEIGHT (M) | | | | | | | | | | | | | |
| CALM | 729 | 0.0 | 0 0 0 | 0.0 | 00.0 | 00. | 0.0 | 0.0 | 000 | 000 | 0.0 | 00 | 729 |
| 0.00 - 0.49 | 000 | 92 | | 3.6 | 0 77 | 00. | 00 | 0.0 | 00 | 00 | 00 | 0.0 | 194 |
| 0.50 - 0.99 | 00.0 | 0.0 | 00,0 | 31, 2.9 | 5.0 | e e | 0.0 | 0.0 | 00.0 | 0.0 | 00 | 0.0 | 9 9,1 |
| 1.00 - 1.49 | 00.0 | 00.0 | 00.0 | 0.00 | ። ብር | 17 | 000 | 00.0 | 000 | 00.0 | 00.0 | 00. | 3,13 |
| 1.50 - 1.99 | 0.0 | 00. | | 0.0 | 0.1 | 12 | 6.0 | 00.0 | 00.0 | 0.0 | 0.0 | 0.0 | 22 2.0 |
| 2.00 - 2,49 | 00.0 | 0 | 00. | 000 | 00,0 | 000 | 0.0 | 00 | 00 | 00.0 | 00 | 00 | 0 20 20 |
| 2.50 - 2.99 | 0.0 | 0.0 | 00. | 000 | 00.0 | 00.0 | 0 0 | 4 4 | 0.0 | 0.0 | 0.0 | 0.0 | 9,0 |
| 3.00 - 3.49 | 0.0 | 0 0 | 0.0 | 0 0 | 0.0 | 0.0 | 0.0 | 0.1 | 000 | 0.0 | 00 | 000 | 1.0 |
| 3.50 - 3.99 | 0.0 | 00 | 0.0 | 00.0 | 00. | 00. | 00.0 | 00 | 00 | 00.0 | 0.0 | 0.0 | 000 |
| 7.00 - 4.99 | 0.0 | 000 | 00. | 00 | 00. | 00.0 | 0.0 | 0.0 | 00.0 | 00.0 | 0.0 | 0.0 | 0.0 |
| 5.00 - | 0.0 | 0.0 | 0.0 | 00.0 | 0.0 | 00 | 0.0 | 00.0 | 0 0 | 1,0 | 0.1 | 00 | 0.2 |
| TOTAL | 729 | 9.7 | 68 6.3 | 73 | 73 | 32 | 16 1.5 | 0 5 S | 000 | o. | 0.1 | 0.0 | 1080 |



Legend

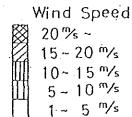


Fig. 2.2.12 Wind Rose
(Observed, Jan. Feb. Mar. 1987)

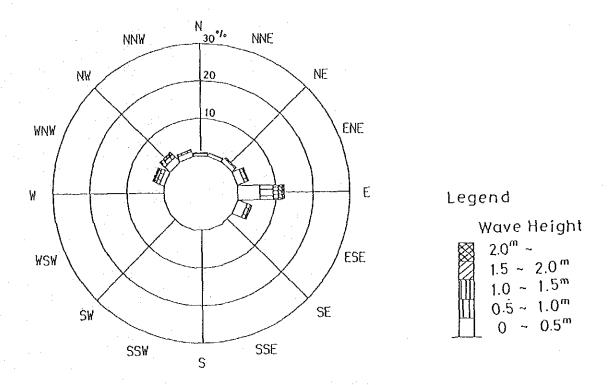


Fig. 2.2.13 Directional Distribution of Waves
(Hindcasted by Wind Data Jan. Feb. Mar. 1987)

Table 2.2.4 Wind Occurrence by Direction and Speed

(Observed Feb. 1984~Jan. 1987)

| TOTAL | | 4642 | 3591 | | | 3 1067 1 8.1 | | 0.30 | 0 0 14 | 0.0 | 8 13152 5 100.0 |
|-------------|----------------|--------------|------------|-------------|------------------|-----------------|---|------------|------------|------|--------------------|
| Z | : | 00 | 121 | 0 31 | 17.0 | 0 | 40. | 00. | 00 | , 0 | 1 9 8 5 |
| NNW | | 00 | 91 | 52 0.4 | 2100.2 | 10 | 90.0 | 0.0 | 00 | 00 | 180 |
| N | | 00. | 100 0.8 | 96 | 61 | 0.2 | 0.1 | 40 | 0 | 00. | 295 |
| FNE | | 000 | 78 0.6 | 0.5 | 0 0 0 0 | 0.2 | 0.0 | 0 70 | 00 | 00.0 | 203 |
| * | | 00. | 91.0 | 0 0 0 | 2.0 | 1.2 | 7 0.1 | 0.0 | ၈၀ | 0.0 | 210 |
| WSW | : | 00 | 50 | 27 | 900 | . e o | 0.00 | 00.0 | 000 | 00.0 | 96 |
| N.S. | | 00.0 | 53 | 0 1 7 | 0.0 | 000 | 00. | 00.0 | 000 | 00 | 0.5 |
| SSW | | 00. | 234 | 0.1 | 0 0 | 10.0 | 0.0 | 00.0 | 00.0 | 00. | 256 |
| w | | 00. | 710 | ტ. ი.ი. | 90.0 | 0.0 | 0.0 | 00.0 | 000 | 00. | 763 5.8 |
| SSE | | 00. | 311 | 32 0.4 | 0.1 | 0 0 | 00 | 000 | 000 | 000 | 373 2.8 |
| ល ម | | 00. | 484 | 137 | 28 | 0.03 | 0 0 | 00 | 0.0 | 000 | 5.0 |
| ES E | | 00. | 421 3.2 | 370 2.8 | 244 | 131 | 47 | 0.0 | 00.0 | 00.0 | 1215 |
| E) | | 000 | 4413.4 | 745 | 781 | 735 | 2 9 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 | 190.1 | 90.0 | 00 | 3021 |
| ы N O | | 00,0 | 168 1.3 | 176 | 11100.8 | 8 9.0 | 0.2 | 00. | , 0 | 00. | ი. გ. გ. |
| N E | | 00.0 | 132 | 74 | ი ი ი . | 0.1 | 0.0 | д O | 00. | 0.0 | 254 |
| NNE | | 00.0 | 105 0.8 | 44.0 | 10 | 0.1 | 0.0 | 00.0 | 00. | 000 | 170 |
| CALM | | 4639 35.3 | 10.0 | 00. | 00 | 00 | 00 | 00 | 000 | 00. | 4640 |
| W.DIRECTION | WI.SPEED (M/S) | CALM | 0.0 - 2.5 | 2.5 - 5.0 | 5.0 - 7.5 | 7.5 -10.0 | 10.0 -12.5 | 12.5 -15.0 | 15.0 -20.0 | 20.0 | TOTAL |

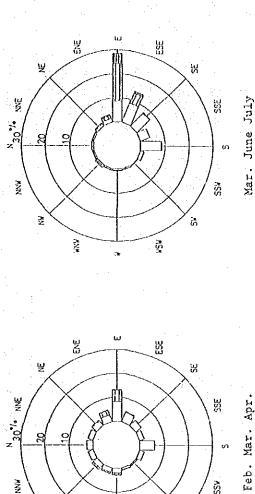
Table 2.2.5 Wave Occurrence by Direction and Height (Hindcasted by Wind Data Feb. 1984 $^{\circ}$ Jan. 1987)

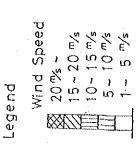
| ; J | | | | | | | | | | | | | |
|--------------|---------------|------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------|--------------|
| T0T | | 7050 | 2.656 | 1215 | 6.5 | 567 | 351 | 154 | 72 0.5 | 26 | 6.0 | 00 | 13152 |
| v | ٠ | 0.0 | 00 | 00 | 0.0 | 00 | 00. | 00 | 00, | 0,0 | 0.0 | 00 | 0 G |
| S S E | * | 00 | 0.0 | 000 | 000 | 0.0 | 00 | 000 | 00. | 00 | 0.0 | 00.0 | 0 0 |
| S Th | .* | 0.0 | 00 | 00 | 0.0 | 00.0 | 000 | 0 | 000 | 0.0 | 0.0 | 00. | p 0 |
| ក ស កា | | 00.0 | 627 | 2.2 | 148 | 78 | 64 | . 8 - | , 0 0 | 000 | 000 | 0 | 1215 |
| ឃ | | 0.0 | 833 | 778 5.9 | 5.40 4.3 | 379 | 259 | 129 | 56 | 2.5 | 50.0 | 000 | 3021 |
| n S M | | 0.0 | 285 | 139 | 63 | 5.0 6.7 | 2.0 | 7 0 0 | 90. | 0.0 | 00.0 | 0.0 | 567 |
| Z Z | | 00 | 1 8 5 4 5 5 | 40 | 14,0 | 0,10 | 9.0 | 00 | 0.0 | 0.0 | 0.0 | 00 | 455 |
| N N | | 0.0 | 1.1 | 0.1 | 90.0 | , a | 0.0 | 0.0 | 00 | 00.0 | 00 | 0.0 | 169 |
| z | | 0.0 | 160 | 25 0 25 | 11.0 | -0 | 000 | 0.0 | 0.0 | 00.0 | 00 | 00.0 | 197 |
| Z | | 0.0 | 133 | ₩₩ 6 | 90.0 | ٥٠ ٥. | 40.0 | 00.0 | 00,0 | 0.0 | 00.0 | 000 | 8 1 |
| 3 : | | 0.0 | 2. t | 55 | 0.28 | 0.2 | 12 | 70.0 | 0.0 | 2.0 | -0.0 | 000 | 295 |
| 3 2 3 | | 00. | 126 | 0.38 | 20 | 14.0 | m 0 · 0 | -0 | 0.0 | 0.0 | 000 | 0.0 | 203 |
| 23 | | 0,0 | 00.0 | 0.0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | ၁၀ ဘ | 00.0 | 0.0 | 0.0 |
| 3 S | | 00 | 00 | 00 | 00.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0,0 | 0.0 | 0.0 | 0.0 |
| S.W | | 00. | 00. | 20 | 0.0 | 0,0 | 0.0 | 00,0 | 00.0 | 0.0 | 0.0 | 0.0 | 000 |
| SSA | | 00 | 000 | 0,0 | 0 0 | 00 | 000 | 0.00 | 00 | 00.0 | 0 | 0 | 000 |
| CALM CALM | | 7050 | 00.0 | 00.0 | 0 0 | 0.0 | 00.0 | 90 | 0.0 | 0.0 | 000 | 90 9 | 7050 53.5 |
| W.DIRECTION | W. HEIGHT (M) | CALM | 65.0 - 00.0 | 66.0 - 02.0 | 1,00 - 1,49 | 1.50 - 1.99 | 2.00 - 2.49 | 2.50 - 2.99 | 3.00 - 3.49 | 3,50 - 3,99 | 4.00 - 4.99 | - 00.8 | TOTAL |

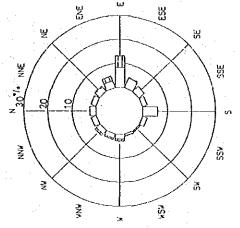
Table 2.2.6 Wave Occurrence by Period and Height

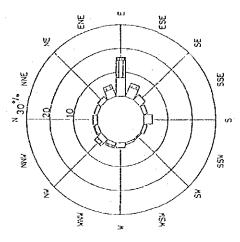
(Hindcasted by Wind Data Feb. 1984 v Jan. 1987)

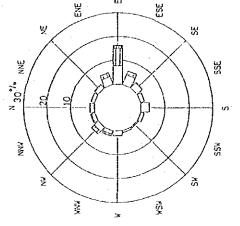
| W.PERIOO (S) | CALM | <u>0</u> | 1 - 2 | 5 - 3 | 3- 4 | 4- 5 | 2- 6 | 2 -9 | 7 8 | 6- | 9-10 | 10- | TOTAL |
|---------------|------|----------|-------|-------|-----------------------|-------------|------|------|------|-----|------|------|---|
| W. HEIGHT (M) | | | | | ٠ | | | | | | | | |
| CALM | 7050 | 0 0 | 0.0 | 0.0 | 0.0 | 000 | 000 | 0.0 | 000 | 00. | 00 | 0.0 | 7050 |
| 0.00 - 0.49 | 0.0 | 964 | 927 | 754 | 0.1 | 0.0 | 0.0 | 0.0 | 0 0 | 000 | 0.0 | 000 | 2656 |
| 66.0 - 03.0 | 0.0 | 000 | 0 0 | 536 | 789 | 91 | 0,0 | 0.0 | 000 | 00. | 00 | 00 | |
| 1.00 - 1.49 | 0.0 | 0.0 | 0.0 | 0.0 | 305 | 449 | 56 | 00 | 0.0 | 00 | 000 | 00. | 8 8 8 4 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 |
| 1.50 - 1.99 | 0.0 | 00.0 | 0.0 | 00. | ο ∞ ι . | 316 | • | 0.12 | 00,0 | 000 | 00. | 00 | 567 |
| 3-00 - 2-49 | 0.0 | 000 | 00 | 000 | 0 0 | 16 | | 69 | m 0 | 00 | 00 | 0.0 | |
| 2.50 - 2.99 | 0.0 | 00.0 | 00 | 0.0 | 00 | 0.0 | | 109 | 21.0 | 00 | 00 | 00.0 | |
| 67.8 - 00.8 | 00 | 00.0 | 0.0 | 00 | 000 | 0 | 0.0 | 50 | 19 | 0.0 | 00 | 00 | |
| 3.50 - 3.99 | 00.0 | 00 | 00 | 00 | 0.0 | 0.0 | | 0.0 | 17 | | 00 | 0.0 | |
| 66"7 - 00"7 | 0.0 | 00 | 00 | 0.0 | 0.0 | 0 | | 00 | ۳°. | | 000 | | |
| - 00°s | 0.0 | 0.00 | 00 | 0.0 | 0 | 00 | 00 | 00 | 0 0 | 0 0 | 00 | | 0.0 |
| 7 O T A L | 7050 | 964 | 927 | 1290 | 1113 | 9.18 0.0 | | 24.5 | 57.0 | | 00 | | |

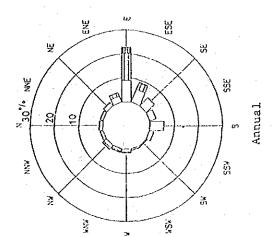












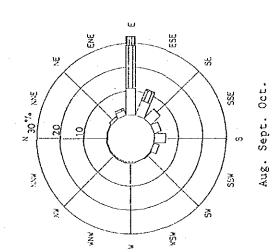
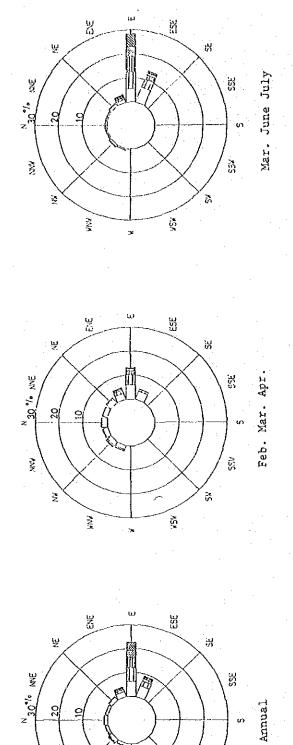
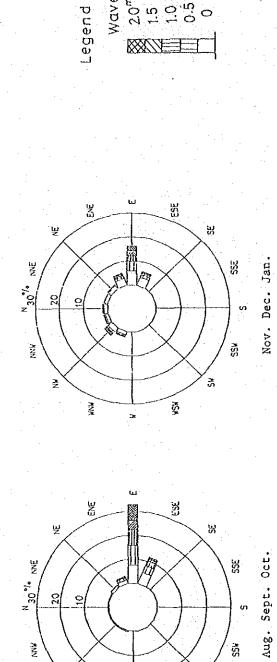


Fig. 2.2.14 Wind Rose (Observed, Feb. 1984 ~ Jan. 1987)

Nov. Dec. Jan.



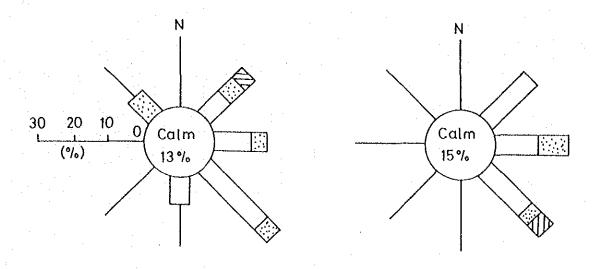
, N NS.





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Jun. Jul. Aug.

Sep. Oct. Nov.

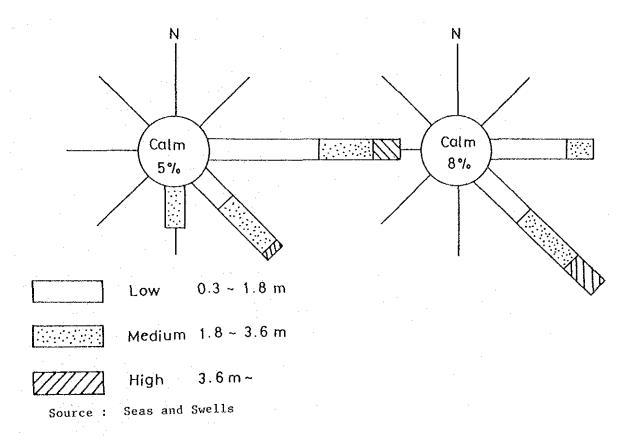
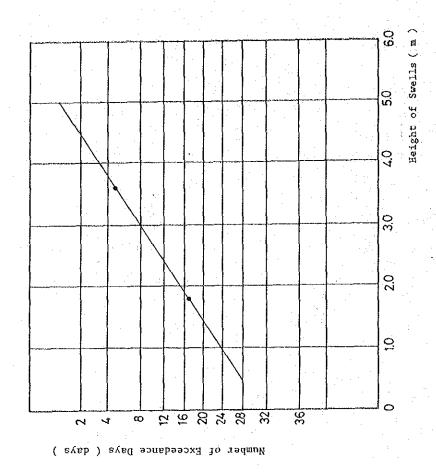
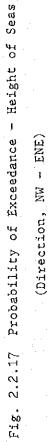
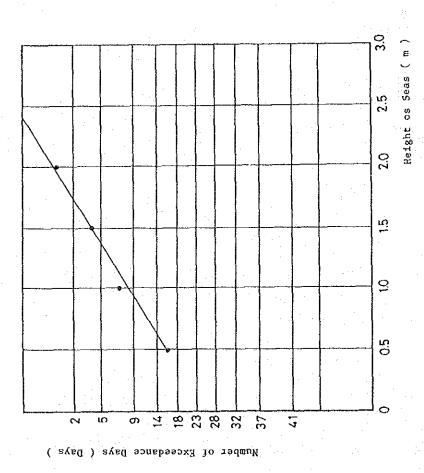


Fig. 2.2.16 Directional Distribution of Swells







Probability of Exceedance - Height of Swells

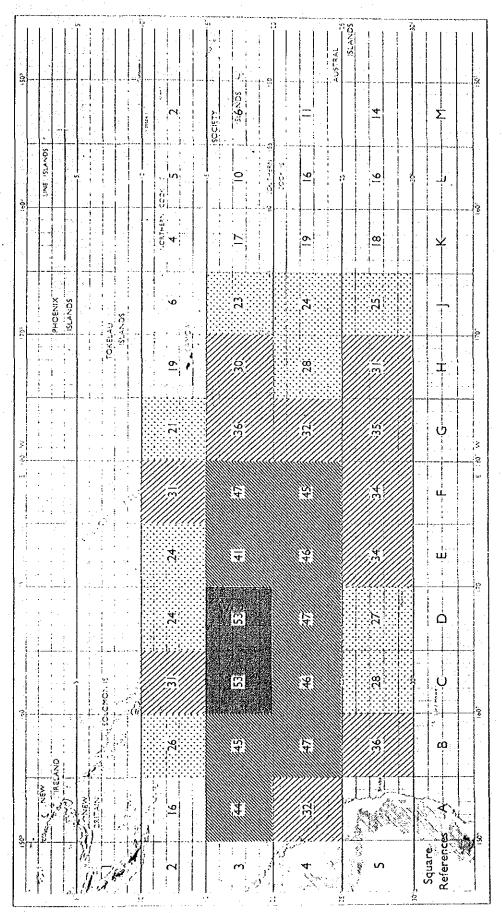


Fig. 2.2.19(1) Number of cyclones that crossed each 5-degree square in the 30 "seasons" November 1939 to April 1969

25 or more 20–24 15–15 10–14 1–9
per cent of all tradical storms and hurricanes in the period.
Actual numbers at centre of squares.

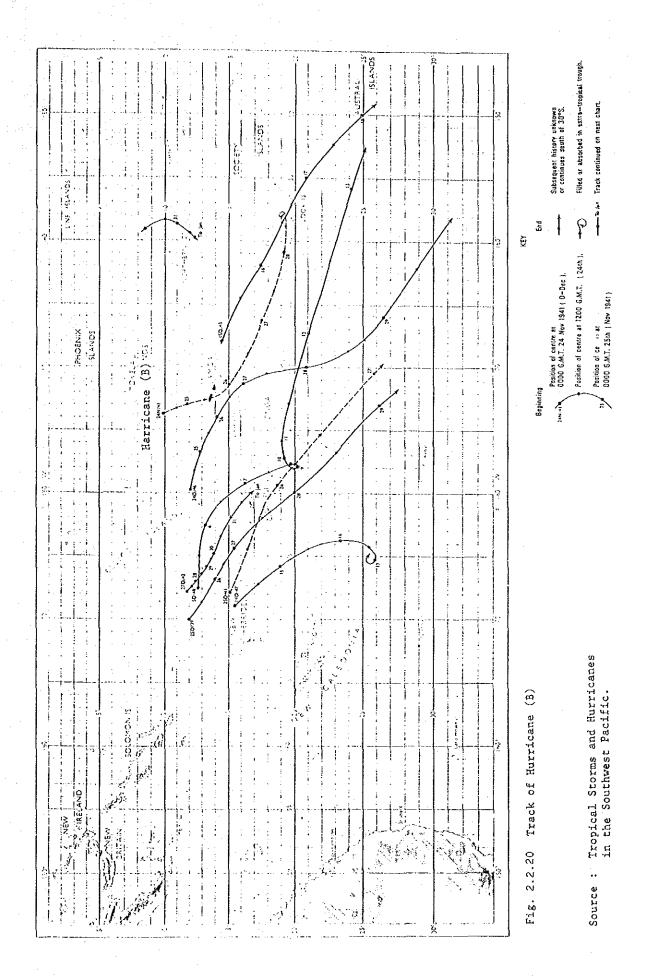
Source : Tropical Storms and Hurricanes in the Southwest Pacific

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

Source : Iropical Cyclones in the Southwest Pacific

per cent of all trapical cyclones in the period. Actual numbers of centres of squares.



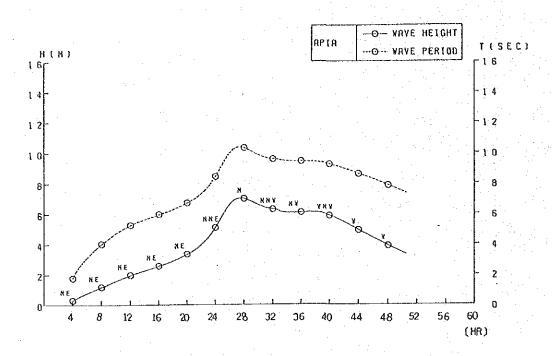


Fig. 2.2.21 Growth Process of Virtual Hurricane

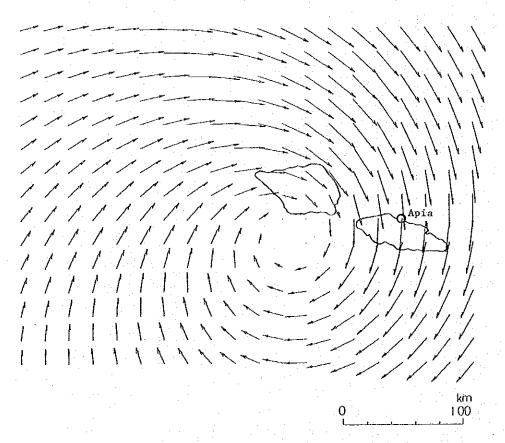


Fig. 2.2.22 Wave Direction of Virtual Hurricane

```
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 3.8 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 5.6 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
1.8 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 1.6 2.0 2.1 2.3 2.4 2.6 2.7 2.6 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 6.8 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 1.6 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 1.6 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 1.5 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
                                                                                km
                                                                                100
```

Fig. 2.2.23 Wave Height of Virtual Hurricane

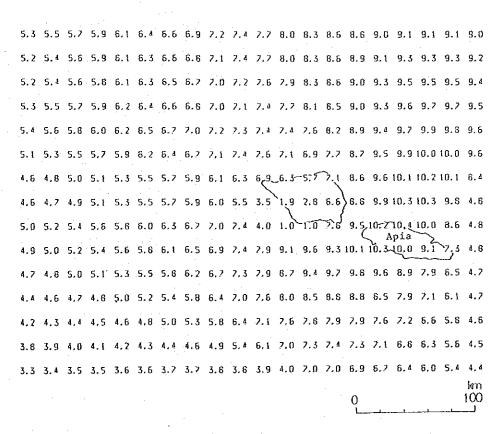


Fig. 2.2.24 Wave Period of Virtual Hurricane

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97 97 97 97 97 97 97 97 93 93 93 93 93 93 93 94 94 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 96 96 96 96 97 97 97 97 97 97 97 97 97
91 91 91 92 92 92 92 92 92 93 93 93 93 93 94 94 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 96 96 96 97 97 97 97 97 97 97 97
91 91 91 91 91 91 91 91 92 92 93 93 93 93 93 93 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 96 97 97 97 97 97 97 97 97 97
102 97 95 93 91 91 91 90 90 91 92 91 91 92 92 93 93 93 93 93 93 94 94 94 94 95 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97 97 97 97
  109104100 06 94 97 91 90 91 97 91 91 92 92 92 92 93 93 93 94 94 94 94 95 95 95 95 95 96 96 96 96 96 97 97 97 97 97 97 97 97 97
  116111104100 97 95 91 90 91 91 91 91 92 92 92 92 92 93 93 93 94 94 93 93 94 95 95 95 95 95 96 96 96 96 96 97 97 97 97 97 97 97 97 97 97
       109105102100 83 90 91 91 91 92 91 91 92 97 97 97 97 93 93 93 93 93 94 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97 97 97 97 97 97 97 97
       117111107104 95 01 97 90 91 91 91 91 91 91 92 97 93 93 93 93 93 94 95 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97
                 100 92 93 90 91 91 90 90 90 90 92 92 92 92 93 93 92 93 94 95 95 95 95 96 96 96 96 95 95 96 96 96 96 96 96 96 96
                 99 93 94 93 90 87 87 83 91 91 91 91 92 92 92 92 94 94 94 94 95 95 96 96 96 95 96 96 96 96 96 96 96 96 96 96
                      102100 96 95 93 36 56 37 90 91 91 91 92 92 92 92 94 94 94 94 94 95 95 96 96 95 95 96 96 95 95 96 96 96 96 96 96
                      106103 03 05 36 54 35 36 39 30 91 91 92 92 92 93 94 94 94 94 95 96 96 95 95 95 95 95 95 96 96 96 96 96
                      117105 93 93 34 82 34 84 89 39 90 91 92 92 92 92 94 94 94 94 94 95 95 95 95 94 94 95 95 95 95 95 96 96 96 96
                           96 90 91 30 32 93 33 39 30 01 91 91 91 92 93 94 94 94 94 95 95 95 95 94 94 95 95 95 95 95 95 96 96 96
                           93 36 28 28 30 82 92 93 90 90 91 91 92 93 94 94 94 94 95 95 95 94 94 94 95 95 95 95 95 95 95 96 96
                           69 32 75 76 73 31 87 87 87 90 91 91 91 92 93 94 94 94 94 95 94 94 94 94 94 94 94 95 95 95 95 95 95 95 95
                           46 61 90 75 70 71 75 79 85 86 88 89 90 91 91 92 93 94 94 94 94 94 93 93 93 93 93 96 95 94 94 94 94 94 94 94 95 95
                      45 57 67 66 64 65 74 78 34 96 83 93 90 91 91 92 93 94 93 93 94 93 92 92 92 93 99 97 94 94 94 94 93 94 95 95
                 25 35 46 53 59 59 60 67 74 73 84 85 87 83 90 91 91 92 93 94 93 93 93 97 90 91 91 93103104 99 99 93 97 97 97 97 97
                 33 40 46 50 54 55 58 66 73 77 83 85 87 33 90 91 91 93 93 92 97 92 92 91 38 83 39 931071121051031011001001001001
                 36 41 45 43 51 54 53 66 73 77 33 34 87 83 90 90 90 91 92 92 91 91 90 56 85 83 96112123114109106106105105107110110
                 36 40 44 47 50 54 53 66 72 27 52 34 36 52 39 90 90 90 92 92 91 91 90 53 83 30 57101115130122114107168105103112112
                 37 40 43 47 50 54 59 66 72 77 92 94 96 57 99 90 90 90 91 91 91 90 90 83 95 30 75 9314419133130120107108106109104114
                 39 41 44 47 51 55 60 67 72 77 81 33 36 57 89 39 39 90 91 90 90 89 98 95 82 72 71 87123131148145131114112111113119113
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                 40 43 46 50 55 59 65 66 73 77 80 82 85 86 37 87 83 83 87 36 85 92 79 73
                 33 42 47 51 55 59 63 68 73 22 80 82 84 86 87 86 87 97 86 84 93 29 26 21
                 33 43 48 52 58 60 63 68 73 77 50 82 94 85 96 56 86 96 95 93 81 26 22 20
                                                                                   Existing Conditions
                           57 60 61 69 74 73 80 52 84 85 85 85 85 85 84 81 79 74 67 69,
                                                                                   Deep Water Wave
                           53 61 61 69 74 73 30 32 33 34 84 31 85 34 32 78 77 71 62 63
                                                                                   Direction: N10°E
                                65 70 75 78 80 31 83 33 83 83 84 83 81 77 75 63 56 67
                                                                                   Wave Period: 10sec.
                                66 20 75 79 80 81 82 82 83 92 93 91 79 76 73 66 51
                                     76 29 79 31 31 31 82 81 82 79 78 74 71 65 45
                                                                                   Figures: Percent
                                     27 79 79 80 81 80 31 31 30 73 76 72 69 63 41
                                     23 79 79 79 80 79 80 30 79 76 24 71 83 61 32
                                     80 73 73 73 79 73 79 79 73 71 73 70 66 60 35
                                     81 76 77 78 77 77 73 73 76 72 71 63 65 60
                                     90 74 77 77 76 76 77 76 75 71 70 67 63 59
                                     76 70 75 75 75 74 77 75 73 69 68 66 62 59
                                     63 67 74 74 74 74 76 74 72 67 66 64 61
                                     61 65 23 22 23 23 25 23 21 66 64 63 60
                                     57 63 22 71 22 22 74 71 69 64 62 62 56
                                22 34 55 62 21 20 21 21 22 20 63 62 60 60
                                30 41 55 62 69 63 70 70 71 68 66 61 53 53 2
                           17 23 35 44 55 61 67 67 69 70 70 66 64 60 56 56 29
                           24 30 33 46 55 61 66 68 83 69 69 65 63 59 54 54 31 2
                           29 33 41 49 55 60 65 65 68 67 67 63 61 57 52 52 32 23 16
                           31 36 42 49 55 60 64 64 67 67 66 61 59 56 51 51 32 24 18 11
                                          63 63 66 66 65 60 53 55 50 49 33 25 19 14 11
                                          64 63 65 65 64 53 58 54 48 48 34 26 20 16 13 9 3 1
                                               65 64 63 57 55 52 47 48 35 27 21 17 14 11 8 8
                                               65 64 62 57 54 51 45 45 35 29 22 18 15 13 11 9
                                                    61 56 53 50 44 44 35 29 24 20 16 14
                                                    60 55 52 49 43 43 35 29 24 21 17 15
                                                    59 54 51 48 41 41 35 30 25 21 13 16
                                                    58 53 50 47 40 41 36 31 26 23 20 18
                                                    53 52 49 46 39 41 37 32 27 24
                                                    56 49 49 45 37 39 33 34 23 26
                                                         47 44 35 33 39 35 30 32
                                                         47 44 34 37 40 33 33 35
                                                                   36 41
                                                                   32 39
```

Fig. 2.2.25 Wave Height Ratio (Existing Conditions)

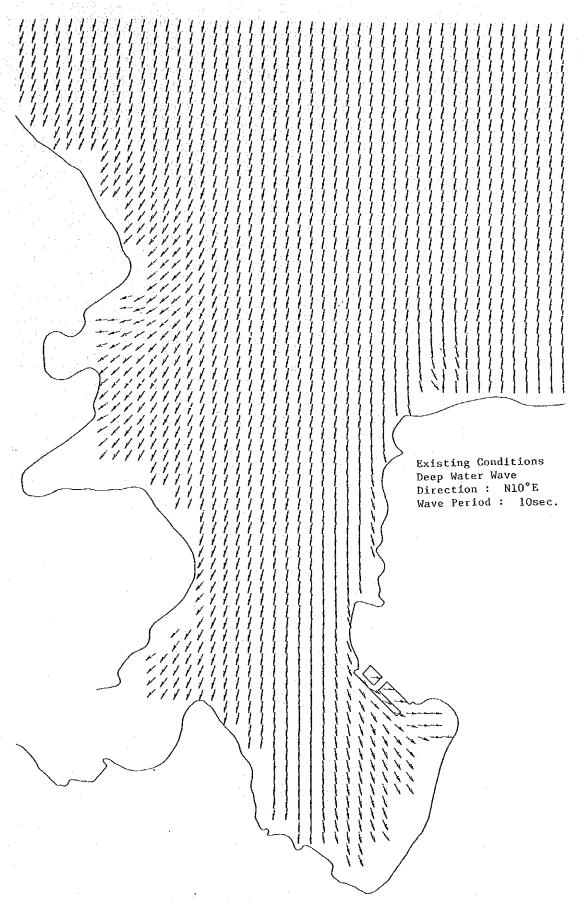


Fig. 2.2.26 Change of Wave Direction (Existing Conditions)

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91 91 91 92 92 92 92 92 92 92 93 93 93 93 93 94 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97 97 97 97 97 97 97
91 91 91 91 91 91 91 91 91 92 92 92 93 93 93 94 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97 97 97 97 97 97 97
92 91 91 91 91 91 91 91 91 92 92 92 92 93 93 93 93 93 93 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 96 97 97 97 97 97 97 97 97 97 97
96 93 97 91 91 91 90 90 92 92 91 91 92 93 93 93 93 93 93 94 94 94 94 94 95 95 95 95 95 96 96 96 96 96 97 97 97 97 97 97 97 97 97 97 97 97
102 97 95 93 91 91 91 90 90 91 92 91 91 92 92 93 93 93 93 93 93 94 94 94 94 94 95 95 95 95 95 96 96 96 96 96 96 96 97 97 97 97 97 97 97
  109104100 96 94 92 94 90 94 92 94 01 92 92 92 92 93 93 93 94 94 94 95 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97 97 97 97 97
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                  100 97 93 90 91 91 90 90 90 90 92 92 92 92 93 93 93 92 93 94 95 95 95 95 95 96 96 96 96 96 96 96 96 96 96 96 96
                 109102 96 94 97 90 89 89 89 89 91 92 92 92 92 92 92 92 93 95 95 95 95 95 96 96 96 96 96 96 96 96 96 96 96 96 96
                 99 90 94 93 90 87 87 88 91 91 91 92 92 92 92 92 94 94 94 95 94 95 95 96 96 96 95 95 96 96 96 95 96 96 96 96 96
                       102101 96 95 89 86 86 87 90 91 91 91 92 92 92 92 94 94 94 94 95 95 96 96 96 95 95 95 96 96 96 96 96 96 96 96 96
                      106103 98 95 86 04 85 86 89 90 01 91 92 92 92 92 94 94 95 95 95 96 96 95 95 95 95 95 95 96 98 96 96 96
                       112105 98 93 84 82 84 84 89 89 90 91 92 92 92 94 94 94 94 94 95 95 95 95 94 94 95 95 95 95 95 96 96 96 96
                             96 90 81 90 82 83 88 89 90 91 91 92 91 92 94 94 94 94 94 95 95 95 95 94 94 95 95 95 95 95 95 96 96 96 96
                            93 86 78 78 80 82 87 83 90 90 91 91 91 92 93 94 94 94 94 95 95 95 94 94 95 95 95 95 95 95 95 95 95 96 96
                             89 82 75 76 78 81 87 87 89 90 91 91 91 92 93 91 91 91 93 93 94 94 94 94 94 94 94 94 96 95 95 95 95 95 95
                            46 61 80 75 70 71 75 79 85 86 88 89 90 91 91 92 93 94 94 94 94 94 9 93 93 93 93 96 95 94 94 94 94 94 94 95 95
                       45 57 88 88 68 64 68 74 78 84 86 88 89 90 91 91 92 93 94 93 93 93 93 92 92 92 93 99 97 94 94 94 94 93 93 95 95
                  25 35 46 53 59 59 60 67 74 78 84 85 87 86 90 91 91 92 93 94 93 93 93 92 90 91 91 93103104 99 99 90 97 97 97 97
                  33 40 46 50 54 55 58 68 73 27 83 85 87 88 90 91 91 91 93 93 92 92 92 91 88 88 89 93 071 121051031011001001001001
                  36 41 45 48 51 54 58 66 23 22 83 84 82 88 90 90 91 92 92 92 91 91 91 90 86 85 88 961 21 2311 4109106106105107 (10110
                  36 40 44 47 50 54 58 66 72 77 82 84 86 87 89 90 90 92 92 91 91 90 88 83 80 8710111513012214107108105108112112
                  37 40 43 47 50 54 59 68 72 77 82 84 86 67 69 90 90 90 91 91 91 90 90 88 85 80 75 88114119133130120107106105109114114
                  139 41 44 47 51 55 60 67 72 77 91 83 96 87 89 89 69 90 91 90 90 89 88 85 82 77 71 8712313114614513111411211113118118
                  43 43 45 48 52 56 6! 67 73 77 81 63 85 87 89 89 89 89 90 89 89 88 86 82 79 75
                  47 45 46 49 53 57 62 67 23 77 81 83 85 86 88 88 89 89 89 88 88 86 84 79 75 74
                  45 44 46 49 54 58 62 60 73 77 81 83 85 86 88 88 88 88 87 86 84 82 75
                  40 43 46 50 55 59 63 68 23 72 80 82 85 86 87 82 88 88 87 86 85 82 29 73
                  38 42 47 51 55 59 63 69 73 77 80 82 84 86 87 86 87 88 84 83 79 76 71
                  38 43 48 52 56 60 63 68 73 77 60 82 81 85 86 86 86 86 85 83 81 76 72 70
                            57 60 64 69 74 78 80 82 84 85 85 85 85 84 81 79 74 67 69
                                                                                       Case A
                            58 61 64 69 74 78 80 82 83 84 84 84 85 84 82 79 77 71 62 69
                                                                                       Deep Water Wave
                                                                                       Direction: N10°E
                                 65 70 75 78 80 81 83 83 83 84 83 81 77 75 68 56 67
                                 66 70 75 79 60 81 62 82 83 82 83 81 79 76 73 66 51
                                                                                       Wave Period: 10sec.
                                      76 79 79 81 81 81 82 81 82 79 78 74 71 65 45
                                                                                       Figures: Percent
                                      27 79 79 80 81 60 81 81 00 78 76 72 69 63 41
                                      28 79 79 79 80 79 80 80 79 76 74 71 68 61 32
                                      80 78 78 78 79 78 79 79 78 74 73 70 66 60 35
                                      81 76 77 78 77 77 78 78 76 72 71 60 65 60
                                      80 74 77 77 76 76 77 76 75 71 70 67 63 59
                                      76 70 75 75 75 74 77 75 73 69 68 68 62 58
                                      68 67 24 24 24 24 26 24 22 62 66 64 61
                                      6! 65 73 72 73 73 75 73 71 66 61 63 60
                                      57 63 72 71 72 72 74 71 69 64 62 62 58
                                 22 34 55 62 71 70 71 71 72 70 68 62 60 89
                                 30 41 55 62 69 68 70 70 71 68 66 61 57
                            17 23 35 44 55 61 62 67 69 70 70 66 64 60 55
                           21 30 38 46 55 61 66 66 69 69 65 63 58 53 17
                           29 33 41 48 55 60 65 65 68 62 62 63 61 57 51 23 10
                           31 36 42 49 55 60 64 64 67 67 66 61 59 56 50 27 15 8
                                           63 63 66 66 65 60 58 55 48 29 18 11
                                            64 63 65 65 64 50 56 53 47 31 20 14 9 6
                                                 55 64 63 57 55 52 45 32 23 16 11 B 6
                                                65 64 62 57 54 51 44 33 24 18 13 10 7
                                                                                    6
                                                      61 56 53 50 43 33 25 19 15 11 9
                                                                                       6 5
                                                      60 55 52 49 41 33 26 21 16 13 10 8
                                                     59 54 51 48 40 33 22 22 17 14 11 10
                                                      58 53 49 46 39 33 28 23 18 15 13 11
                                                     58 52 48 45 38 33 30 24 20 17
                                                      56 49 47 45 36 33 31 26 21 19
                                                           16 44 34 32 32 28 23 23
                                                           46 44 33 32 33 31 26 22
                                                                      30 33
                                                                      26 32
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Fig. 2.2.27(1) Wave Height Ratio (Case A)

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92 92 92 92 92 92 92 92 93 93 93 93 93 94 94 94 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 96 96 96 96 97 97 97 97 97 97
92 91 91 91 91 91 91 91 92 92 92 92 93 93 93 93 93 93 93 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 96 97 97 97 97 97 97 97 97 97 97
96 93 92 91 91 91 90 90 92 92 91 91 92 93 93 93 93 93 93 93 94 94 94 94 95 95 95 95 95 95 96 96 96 97 97 97 97 97 97 97 97 97
102 97 95 93 91 91 91 90 90 91 92 91 91 92 92 93 93 93 93 93 93 94 94 94 95 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97 97 97 97 97
 118111101100 97 95 91 90 91 91 91 91 92 92 92 92 92 93 93 93 94 94 93 93 94 95 95 95 95 95 96 96 96 96 96 96 96 97 97 97 97 97 97 97
       109105102100 93 90 91 91 91 91 92 91 91 92 92 93 93 93 93 93 93 95 95 95 95 96 96 96 96 96 96 96 97 97 97 97 97 97 97
       117111107104 95 91 92 90 91 91 91 91 91 91 92 93 93 93 93 93 93 94 95 95 95 95 95 96 96 96 96 96 96 96 97 97 97 96 97 97 97
                  96 94 92 90 91 91 91 91 91 92 92 92 93 93 93 93 93 93 9 95 95 95 95 95 96 96 96 96 96 96 96 96 96 96 96 96 97 97
                 100 97 93 90 91 91 90 90 90 90 92 92 92 92 93 93 92 93 94 95 95 95 95 96 96 96 96 96 96 96 96 96 96 96 96 96
                 109102 96 94 92 90 69 69 69 69 69 91 92 92 92 92 93 92 92 94 95 95 95 96 96 96 96 96 95 95 96 96 96 96 96 96 96
                 107101 96 95 89 86 66 67 90 91 91 91 92 92 92 92 94 94 94 94 95 95 96 96 96 95 95 95 96 96 96 96 96 96
                      106103 90 95 06 84 85 86 89 90 91 91 92 92 92 92 94 94 94 95 94 94 95 98 96 95 95 95 95 95 95 95 96 96 96 96 96
                      112105 98 93 04 82 84 84 89 89 90 91 92 92 92 92 94 94 94 94 94 95 95 95 95 94 94 95 95 95 95 95 95 95 96 96 96
                            96 90 81 60 82 83 86 89 90 91 91 92 91 92 94 94 94 94 94 95 95 95 95 94 94 95 95 95 95 95 95 95 95 95 95 96 96
                            93 86 78 78 80 82 87 83 90 90 91 91 91 92 93 94 94 94 94 95 95 95 94 94 94 95 95 95 95 95 95 95 95 96 96
                            69 62 75 76 78 81 67 67 69 90 91 91 91 92 93 94 94 94 94 94 94 94 94 94 94 94 94 95 95 95 95 95 95 95
                            46 61 60 75 70 71 75 79 85 86 88 89 90 91 91 92 93 94 94 94 94 94 93 93 93 93 96 95 94 94 94 94 94 95 95 95
                       45 57 66 66 61 66 74 78 64 66 68 68 68 90 91 91 92 93 94 93 93 93 94 93 92 92 92 93 99 97 94 94 94 94 94 93 94 95 95
                  25 35 46 53 59 59 60 67 74 78 84 85 87 86 90 91 91 92 83 94 83 93 93 93 90 91 91 93103104 99 99 98 97 97 97 97
                  33 40 45 50 54 55 58 66 23 22 83 85 82 89 90 91 91 93 93 92 92 92 93 88 89 93 97 11210510310110010010010010
                  36, 41 45, 48, 51, 54, 58, 66, 73, 77, 83, 84, 87, 88, 90, 90, 90, 91, 92, 92, 91, 91, 90, 86, 65, 83, 981(2123114109106106105107110110
                  36 10 44 17 50 54 58 66 72 77 82 84 86 87 89 90 90 90 92 92 81 91 91 90 88 03 80 87101115130122114107106105109112112
                  37 40 43 47 50 54 59 66 72 77 82 84 86 87 89 90 90 91 91 91 90 90 88 85 80 75 83114119133130120107106105109114114
                  39 41 44 47 51 55 60 67 72 77 81 63 86 87 89 89 89 90 91 90 90 89 88 85 82 77 71 871231311461451311114112111113116118
                  13 13 15 18 52 56 61 62 73 77 81 83 85 82 89 89 89 89 90 09 89 88 86 82 79 75
                  17 45 46 49 53 57 62 67 73 77 81 63 85 86 88 89 89 89 88 88 86 84 79 75 74
                  15 14 16 19 51 58 62 66 73 77 81 63 65 86 88 88 88 89 88 89 87 86 61 82 75
                  40 43 46 50 55 59 63 66 73 77 80 82 85 86 97 87 68 88 87 86 85 82 79 73
                  38 42 47 51 55 59 63 68 73 77 80 82 84 85 87 86 87 86 81 83 79 76 71
                  38 13 48 52 56 60 63 68 23 77 80 82 84 85 86 86 86 86 85 83 81 76 72 70
                            52 60 64 69 24 28 80 82 84 85 85 85 85 84 81 79 74 67 69/
                                                                                   Case B
                            58 61 64 69 74 78 80 82 83 84 84 84 85 84 82 79 77 71 62 68
                                                                                   Deep Water Wave
                                 65 70 75 78 80 81 83 83 83 84 83 81 77 75 68 56 87
                                                                                    Direction: N10°E
                                 86 70 75 79 80 81 62 82 83 62 83 81 79 76 73 66 51
                                                                                    Wave Period: 10sec.
                                      76 79 79 81 81 81 82 81 82 79 78 74 71 65 45
                                                                                    Breakwater
                                      77 79 79 80 81 60 81 61 60 78 76 72 69 63 41
                                      28 29 29 29 80 29 80 80 29 26 24 21 68 61 32
                                                                                    Lenght
                                                                                                   : 112.5m
                                      80 28 28 28 29 28 29 29 28 24 23 20 66 60 35
                                                                                    Figures: Percent
                                      81 76 77 78 77 77 78 78 76 72 71 68 65 60
                                      80 74 77 77 76 76 77 76 75 71 70 67 63 59
                                      26 70 25 25 25 24 27 25 23 69 68 66 62 58
                                      68 67 74 74 74 74 76 74 72 67 66 64 61
                                      81 65 73 72 73 73 75 73 71 66 64 63 60
                                      57 63 72 71 72 72 74 71 69 64 62 62 56
                                 22 34 55 62 71 70 71 71 72 70 67 61
                                 30 41 55 62 69 68 20 70 71 68 66 59 12 4
                            17 23 35 44 55 61 62 67 69 70 70 66 64 58 17 8
                            24 30 38 46 55 61 66 66 68 69 69 64 62 56 20 10
                            29 33 41 48 55 60 65 65 68 67 67 63 60 55 23 13 7
                            31 36 42 49 55 60 64 64 67 67 66 61 58 53 26 15 9
                                           63 63 66 68 65 59 57 52 27 17 11 7
                                            64 63 65 65 64 58 55 51 28 19 13 8 6 4
                                                 65 64 63 57 54 49 29 20 14 10 7 5 4 3
                                                 65 63 62 56 53 48 29 21 16 11 8 6 5 4
                                                      61 55 52 47 29 22 17 13 9 7 5 4
                                                      59 54 50 46 29 23 18 14 10 8 6
                                                      58 53 49 45 29 23 18 14 11 9 7
                                                      58 52 48 44 29 23 19 15 12 10 8 2
                                                      58 51 47 43 28 24 21 12 13 11
                                                      55 48 46 42 27 24 22 18 14 12
                                                           45 42 26 24 23 20 16 16
                                                           45 42 26 24 24 22 18 18
                                                                     22.24
                                                                     19 23
```

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

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92 92 92 92 92 92 92 92 93 93 93 93 93 94 94 94 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97 97 97
91 91 91 91 92 92 92 92 92 92 92 93 93 93 93 94 94 94 94 94 94 94 95 95 95 95 95 95 95 96 96 96 96 96 98 97 97 97 97 97 97 97 97 97 97
91 91 91 91 91 91 91 91 92 92 93 93 93 93 93 94 94 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97 97 97 97
06 83 92 01 91 91 90 90 92 02 01 01 02 93 03 93 93 93 93 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 97 97 97 97 97 97 97 97 97 97 97 97
102 97 95 93 91 91 91 90 90 91 92 91 91 92 92 93 93 93 93 93 93 94 94 94 94 95 95 95 95 95 95 96 96 96 96 96 97 97 97 97 97 97 97 97 97
  100104100 96 94 92 91 90 91 92 91 91 92 92 92 92 93 93 93 94 94 94 94 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97 97 97
  118111101100 97 95 91 90 91 91 91 92 92 92 92 92 93 93 93 94 91 93 93 94 95 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97 97 97
       100105102100 93 90 01 91 01 91 92 01 91 92 92 83 93 93 93 93 94 95 05 05 05 95 96 96 96 96 98 97 97 97 97 97 97 97
       117111107104 95 91 92 90 91 91 91 91 91 91 92 92 93 93 93 93 93 94 95 95 95 95 95 96 96 96 96 96 96 96 97 97 97 97 97 97
                  100 92 93 90 01 91 90 90 90 90 92 92 92 92 93 93 93 93 94 95 95 95 95 95 96 96 96 95 95 96 96 96 96 96 96 96
                 99 98 91 93 90 87 87 88 91 91 91 92 92 92 92 92 94 94 94 94 95 95 96 96 96 95 95 96 96 96 96 96 96 96 96 96 96
                       102101 96 95 80 86 66 67 90 91 91 91 92 92 02 02 04 94 94 94 05 95 96 96 96 95 95 95 96 96 96 96 96 96
                      100103 99 95 86 81 85 86 89 90 91 91 92 92 92 92 94 94 94 95 96 96 95 95 95 95 95 95 95 96 96 96 96 96
                      112105 99 93 84 82 84 84 80 89 90 91 92 92 92 92 94 94 94 94 94 95 95 95 95 94 94 95 95 95 95 95 96 96 96 96 96
                            96 90 81 00 82 83 88 89 90 91 91 92 91 92 94 94 94 94 94 95 95 95 95 95 95 95 95 95 95 95 96 96 96
                            93 86 78 78 80 82 87 88 90 90 91 91 91 92 93 94 94 94 95 95 95 94 94 94 95 95 95 95 95 95 95 95 95 95 95 96 96
                            69 82 25 26 26 81 07 87 89 90 91 91 91 92 93 94 94 94 94 94 94 94 94 94 94 94 94 95 95 95 95 95 95 95
                            84 78 72 73 77 80 86 87 69 89 91 91 91 92 93 94 94 94 94 94 94 94 94 94 94 93 94 94 94 94 94 94 94 95 95 95
                       46 61 80 75 70 71 75 79 85 86 88 89 90 91 91 92 93 94 94 94 94 94 93 93 93 93 96 95 91 94 94 94 94 94 94 95 95
                       45 57 66 66 64 69 74 78 84 86 69 88 90 91 91 92 93 94 93 93 94 93 92 92 92 93 99 97 94 94 94 94 93 94 95 95
                  25 35 46 53 59 59 60 67 74 28 84 65 87 88 90 91 91 92 93 94 93 93 93 92 90 91 91 93103104 99 99 90 97 97 97 97 97
                  33 40 46 50 51 55 58 66 23 27 83 85 82 88 90 91 91 91 93 93 92 92 92 91 88 88 89 931021121051031001001001001001
                  36 41 45 48 51 54 58 66 23 27 63 64 97 68 90 90 90 91 92 92 92 91 91 91 90 86 65 68 96112123114109106106105102110110
                  36 40 44 47 50 54 59 66 72 77 82 84 86 67 89 90 90 90 92 92 91 91 90 88 83 80 87101115130122114107106105108112112
                  37 40 43 47 50 51 59 66 72 77 82 84 86 87 89 90 90 90 91 91 91 90 90 83 85 80 75 8811411913313012010710610510914114
                  39 41 44 47 51 55 60 67 72 77 91 63 96 87 89 89 89 90 91 90 90 69 68 85 82 77 71 8712313114614513111411211113116118
                  13 13 15 10 52 56 61 67 73 77 81 83 85 87 99 89 89 89 90 89 89 88 86 82 79 75
                  47 45 46 49 53 57 62 67 73 77 81 63 65 86 88 88 89 89 89 88 88 86 84 79 75 74
                  45 44 46 49 54 58 62 68 73 77 81 83 85 88 88 88 88 88 87 86 84 82 75
                  40 13 16 50 55 59 63 66 23 27 80 82 85 86 82 82 88 88 87 66 85 82 79 23
                  30 12 17 51 55 59 63 69 73 77 80 82 81 86 87 86 87 87 86 84 83 79 76 71
                  38 43 48 52 56 60 63 68 73 77 80 82 84 85 86 86 86 86 85 83 81 76 72 70
                            57 60 64 69 74 76 80 82 84 85 85 85 85 85 81 81 79 74 67 69
                                                                                      Case C
                            58 61 61 69 24 28 80 82 83 84 84 84 85 84 82 29 77 71 62 68
                                                                                      Deep Water Wave
                                 65 20 75 78 80 81 83 83 83 83 84 83 81 77 75 68 56 87
                                                                                      Direction: N10°E
                                 66 20 25 29 80 81 82 82 83 82 83 81 29 26 23 66 51
                                                                                      Wave Period: 10sec.
                                      76 79 79 81 81 81 82 81 82 79 78 74 71 65 45
                                      27 79 79 60 81 80 81 61 60 28 76 72 69 63 41
                                                                                      Breakwater
                                      28 29 29 29 80 29 80 80 29 26 24 21 68 61 32
                                                                                        Length
                                                                                                       : 112.5m
                                      60 78 78 78 79 78 79 79 78 71 73 70 66 60 35
                                                                                      Figures: Percent
                                      81 26 77 78 77 22 28 78 26 22 21 68 65 60
                                      80 24 27 27 26 26 27 26 25 21 20 62 63 59
                                      76 70 75 75 75 74 77 75 73 69 68 66 62 58
                                      69 62 71 71 71 71 76 71 72 67 66 61 61
                                      61 65 73 72 73 73 75 73 70 64 =
                                      57 63 72 71 72 72 74 71 69 61 10 4
                                 27 34 55 62 71 70 71 71 72 70 67 59 15 7
                                 30 41 55 62 69 68 70 70 71 68 65 58 18 9
                            17 23 35 44 55 61 67 67 69 69 70 66 63 56 21 11 6
                            24 30 38 46 55 61 66 66 68 68 69 64 61 55 23 13 8
                            29 33 41 48 55 60 65 65 67 67 67 62 59 53 25 16 9
                            31 36 42 49 55 60 64 64 67 66 66 60 58 52 27 18 11 6
                                           63 63 66 66 64 59 56 51 28 19 13 8 5
                                           64 53 55 65 63 57 54 49 29 21 14 10 7
                                                 65 64 62 56 53 48 29 22 16 11 8 6 4 3
                                                 65 63 61 56 52 42 29 23 17 12 Q
                                                      60 55 51 46 29 23 18 14 10 8 6 5
                                                      59 54 50 45 29 23 18 14 11 9 7
                                                      56 53 48 44 29 24 19 15 12 10 8
                                                      57 52 47 43 29 24 20 16 13 11 9
                                                      57 50 46 42 28 25 21 17 14 12
                                                      55 48 45 41 27 25 23 19 15 13
                                                           44 41 26 24 24 20 17 16
                                                           44 41 26 24 25 23 19 19
                                                                     72 24
                                                                     19 24
```

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

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92 92 92 92 92 92 92 92 93 93 93 93 93 94 94 94 94 94 94 94 94 95 95 95 95 95 96 96 96 96 96 96 96 96 96 97 97 97 97 97 97 97
91 91 91 92 92 92 92 92 92 92 93 93 93 93 94 94 94 94 94 94 94 95 95 95 95 95 95 95 96 96 96 96 96 96 96 97 97 97 97 97 97 97 97 97 97
91 91 91 91 91 91 91 91 92 92 93 93 93 94 94 94 94 94 94 95 95 95 95 95 96 96 96 96 96 96 96 97 97 97 97 97 97 97 97 97
92 91 91 91 91 91 91 91 92 92 92 92 93 93 93 93 93 93 94 94 94 94 94 94 95 95 95 95 95 95 95 96 96 96 96 96 97 97 97 97 97 97 97 97 97
96 93 92 91 91 91 90 90 92 92 91 91 92 93 93 93 93 93 93 94 94 94 94 94 94 95 95 95 95 95 95 96 96 96 96 97 97 97 97 97 97 97 97 97 97 97 97
100104100 06 94 02 91 90 01 92 91 91 92 92 92 92 93 93 93 94 04 94 05 95 95 95 95 95 96 96 98 98 98 98 97 97 07 07 97 97 97
  116111104100 97 95 91 90 91 91 91 91 92 92 92 92 93 93 94 94 93 93 94 95 95 95 96 96 96 96 96 96 96 97 97 97 97 97 97 97 97 97 97 97
        109105102100 93 90 91 01 91 91 92 91 91 91 92 92 93 93 93 93 93 93 93 95 95 95 95 95 96 96 96 96 96 96 97 97 97 97 97 97 97 97 97 97
        117111107104 85 91 92 90 91 91 91 91 91 91 92 92 93 93 83 93 93 93 94 95 95 95 95 95 96 96 96 96 96 98 97 97 97 96 97 97 97
                    96 94 92 90 91 91 90 91 91 92 92 93 93 93 93 93 93 94 95 95 95 95 95 96 96 96 98 98 96 96 96 98 98 98 98 98 98 97 97
                   100 92 93 90 91 91 00 90 90 92 92 92 92 93 93 93 92 93 94 95 95 95 95 96 96 96 95 95 96 96 98 98 98 98 98 98 98
                   109102 06 94 92 90 89 89 89 89 91 92 92 92 92 93 92 94 95 95 95 94 05 95 96 96 96 96 96 96 96 96 96 96 96 96 96
                   99 98 94 93 90 87 87 88 91 91 91 92 92 92 92 94 94 94 95 94 95 95 96 96 95 95 96 96 96 95 95 96 96 96 96 96 96
                         102101 98 95 89 86 66 67 90 91 91 91 92 92 92 94 94 94 94 94 95 95 96 96 95 95 95 96 95 95 96 96 96 96
                        106103 98 95 86 64 65 66 89 90 91 91 92 92 92 92 94 94 94 95 94 84 95 96 96 95 95 95 95 95 95 95 96 98 98 98 98
                         112103 08 93 84 82 84 89 89 80 00 01 92 92 92 92 94 94 94 94 94 95 95 95 95 94 94 95 95 95 95 95 96 96 96 96
                               98 90 81 80 82 83 88 89 90 91 91 92 91 92 94 94 94 94 94 95 95 85 85 84 94 95 95 95 95 95 95 86 96
                               93 86 78 78 80 82 87 88 90 90 91 91 91 92 93 94 04 94 94 95 95 95 94 94 94 95 95 95 95 95 95 95 95 95 95 95 95
                               89 82 75 78 78 81 87 87 89 90 91 91 91 92 93 94 94 94 94 94 94 94 94 94 94 94 95 95 95 95 95 95 95 95 95
                               46 61 80 25 20 21 25 20 85 86 88 89 90 91 91 92 93 94 94 94 94 94 93 93 93 93 96 95 94 94 94 94 94 94 95 95
                         45 57 68 66 64 68 74 78 84 85 68 89 90 91 91 92 93 94 93 93 94 93 92 92 92 93 99 97 94 94 94 94 93 94 95 95
                    25 35 46 53 59 59 60 67 74 76 84 65 87 88 90 91 91 92 93 94 93 93 93 93 92 90 91 91 93103104 99 99 98 97 97 97 97 97
                    33 40 46 50 54 55 58 66 73 77 63 65 67 88 60 91 91 91 93 93 92 92 92 91 88 88 69 9310711210510310110010010010
                    36 41 45 48 51 54 58 66 73 77 83 84 87 88 90 90 90 91 92 92 92 91 91 90 66 65 68 96112123114109106106105107110110
                    38 40 44 47 50 54 58 66 72 77 82 84 96 87 89 90 90 90 92 92 91 91 91 90 88 63 80 87(01)15130122114107106105100112112
                    37 40 43 47 50 54 59 68 72 77 82 84 86 67 89 90 90 90 91 91 91 90 90 88 85 80 75 88114119133130120107106105109114114
                    39 41 44 47 51 55 60 67 72 77 81 83 86 87 89 89 89 90 91 90 90 89 86 87 77 71 8712313114614513111411211113116118
                    43 43 45 49 52 56 61 67 73 77 81 83 85 87 89 89 89 89 90 09 89 89 86 62 79 75
                    47 45 46 49 53 57 62 67 73 77 81 63 85 86 88 88 89 89 89 88 88 86 64 79 75 74
                    45 44 48 49 54 58 62 68 73 77 81 83 85 86 88 88 88 88 87 87 86 64 82 75
                    40 43 46 50 55 59 63 68 73 77 80 82 85 66 87 87 88 83 87 86 65 82 79 73
                    38 42 47 51 55 59 63 68 73 77 80 82 84 86 67 86 67 87 86 84 83 79 76 71
                    38 43 48 52 56 60 63 68 73 77 80 82 84 85 86 66 66 86 65 83 81 76 72 70
                                                                                            Case C'
                               52 60 64 69 74 78 80 82 84 85 85 85 85 84 81 79 74 67 69
                                                                                            Deep Water Wave
                               58 61 64 69 74 78 60 82 83 84 84 85 84 82 79 77 71 62 69
                                                                                            Direction: N10°E
                                     65 70 75 78 80 81 83 83 83 84 83 61 77 75 68 56 67
                                                                                            Wave Period: 10sec.
                                     66 70 75 79 80 81 82 82 83 82 83 81 79 76 73 66 51
                                          76 79 79 81 81 81 82 81 82 79 78 74 71 65 45
                                                                                            Breakwater
                                          77 29 79 80 81 80 81 81 80 78 76 72 69 63 41
                                                                                            Length
                                                                                                             : 75m
                                          78 79 79 79 80 79 80 80 79 76 74 71 88 61 37
                                                                                             Figures: Percent
                                          80 78 78 78 79 78 79 79 78 74 73 70 66 60 35
                                          81 76 77 78 77 77 78 78 76 72 71 68 65 60
                                          80 74 77 77 78 76 77 76 75 71 70 67 63 59
                                          26 20 25 25 25 24 27 25 23 69 68 66 62 58
                                          68 67 74 74 74 74 76 74 72 67 68 64 61
                                          6! 65 73 72 73 73 75 73 71 65 61
                                          57 63 72 71 72 72 74 71 69 64 61 17 8
                                     22 31 55 62 71 70 71 71 72 70 67 62 58 24 13
                                    30 41 55 62 69 68 20 20 21 66 66 61 56 22 16
                               17 23 35 44 55 61 67 67 69 70 70 66 64 59 53 30 19
                               24 30 39 46 55 61 66 66 68 69 69 65 62 58 52 32 21
                               29 33 41 48 55 60 65 65 68 67 67 63 61 57 50 33 22
                               31 38 42 49 55 60 64 64 67 67 66 61 59 55 49 34 23 13
                                               63 63 66 66 65 60 57 54 47 35 24 16 10
                                                64 63 65 65 64 58 56 53 48 35 28 18 13 10
                                                                                      `8` 5
                                                     65 64 63 57 55 51 44 35 27 20 15 11 9 7
                                                     65 64 62 58 54 50 43 35 28 22 17 13 10 B
                                                          61 56 53 49 42 35 28 23 18 15 12 10
                                                          60 55 51 48 40 34 29 24 19 16 13 11
                                                          58 54 50 47 39 34 29 24 20 17 14 12
                                                          58 53 49 46 38 34 30 25 21 18 15 14
                                                          58 51 48 45 37 34 31 27 22 19
                                                           56 49 47 44 35 34 33 28 23 21
                                                                46 43 34 33 33 30 25 26
                                                                46 44 32 32 34 32 28 29
                                                                           31 35
                                                                           22 33
```

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