structure that stretches along the last 170 m of its eastern extension.

(7) The land elevation behind the protection structure is low; therefore, the dimensions of the structure must be sufficient to minimize wave overtopping.

4.2 Design Criteria

4.2.1 Design Wave Height and Period

The procedure for estimating the design wave height in front of the protection structure is as follows:

i) Determination of structure design cyclone
ii) Estimation of deepwater wave
iii) Calculation of waves in shoaling water (diffraction and refraction coefficients)
iv) Calculation of wave height in front of protection structure

The wave height for the foreshore protection structure was determined by the above procedures:

(1) Determination of Structure Design Cyclone

A list of South Pacific cyclone that occurred during the forty-three year period from 1939 through 1982 was obtained from the New Zealand Meteorological Service records. The cyclone that caused damage to Tonga were screened. Fig 4-1 shows the passing routes of these cyclones.

Judging from the barometric pressure within the area of the eye, the maximum wind velocity, the speed of travel, and the direction of travel, it can be assumed that Cyclone Issac which attacked Tonga in March 1982 created the maximum wave heights ever recorded along the Nuku'alofa coast. Therefore, the design wave height was estimated by assuming that Cyclone Issac was the strongest South Pacific cyclone in forty-three years.

(2) Wind Speed Distribution

The wind speed distribution of Cyclone Issac was calculated based on data recorded by the Fiji Meteorological Service (see Fig. 4-2). Fig. 4-4 shows the results of the calculated wind speed distribution.

As the Fiji Meteorological Service estimated the wind speed to be 148 km/hr (41 m/sec), and a ship that was only 24 km away from the cyclone's centre reported the wind speed to be 167 km/hr (46 m/sec), Issac's estimated wind speed at 1:00 on March 3 was 41 m/sec, and was 46 m/sec from 4:00 through 16:00 on March 3,1982.

In addition, the lowest barometric pressure reading at the Nuku'alofa coast was 976.4 millibars and a maximum wind speed of 130 km/hr (36 m/sec) was recorded at 13:45 March 3, 1982. Based on the records cited above, the barometric pressure in Cyclone Issac's eye was estimated as being 950 millibars.

In accordance with Dr. Takahashi's (the former director of the Japanese Weather Bureau) equation, the relationship between the cyclone's maximum wind speed and its barometric pressure can be expressed as follows:

$$V_{max} = 6\sqrt{P_o - P_c}$$

where, V_{max}: Cyclone's maximum wind speed, in m/sec,

P_o: Barometric pressure outside of the cyclone, in millibars

P_c: Barometric pressure at cyclone's centre, in millibars

Therefore,

$$V_{max} = 6\sqrt{1,010 - 950}$$

$$= 46 \text{ m/sec}$$

The above figure is the same as that reported by the boat that was located near Issac's centre on March 3, 1987. This figure was judged to be a reasonable wind speed for the structure design.

(3) Wave Height Estimation

i) Wave Height Estimation Using Wilson's Equation

A wave starting from the original point △ (show in Fig. 4-4) develops in accordance with the cyclone's movement.

Fig. 4-5 (derived from Fig. 4-4) shows the relationship between time change and wind zone.

Wave height can be obtained by superimposing Fig. 4-5 over Fig. 4-6 (Wilson's Wave Developing Curves) and noting that the strong wind area on Fig. 4-5 agrees with the developing curves on Fig. 4-6.

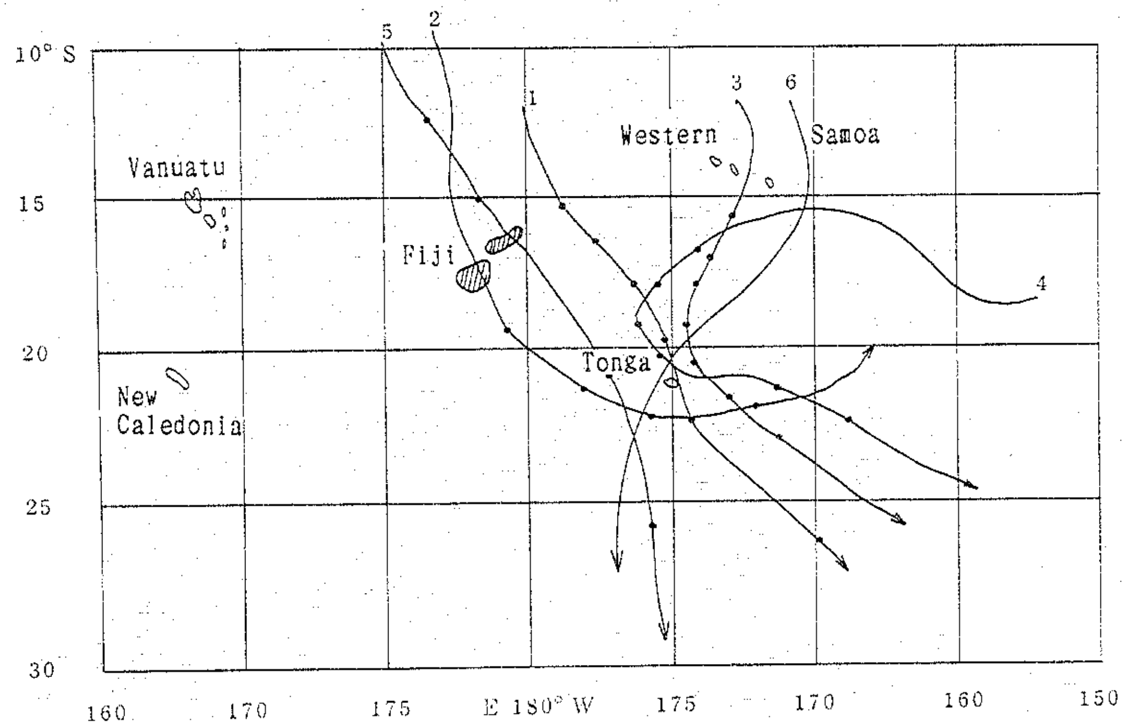
The following results were obtained by using the average wind speed of (25 + 36)/2 = 31 m/sec for 3 hours after the wave left its original starting point△ , and 36 m/sec for 9.4 hours after it left (see Fig. 4-6).

Deepwater wave height:	$H_o' = 11.6$ m
Period:	$T_o = 12.6$ sec
Wave direction:	Northeast (NE)

ii) Wave Height Using Ijima's Method (from the Proceedings of The Coastal Engineering Seminar)

This method is used to obtain the maximum wave height in the vicinity of a cyclone by using, as parameters, the barometric pressure in the cyclone centre, the radius of the strong wind area, and the cyclone's travelling speed. The relationship between these parameters are as follows:

- $P_o - P_c$: Difference of barometric pressures at the centre and outside of the cyclone, in millibars.
- γ_o: Distance from the maximum wind speed point, in km.
- A: $(P_o - P_c)^{3/4} \times \gamma_o^{1/4}$
- V: Cyclone's travelling speed, m/sec.
- Hmax and Tmax: Maximum wave height and its period. Hmax and Tmax, the functions of A/V^2 , can be obtained from a graph.



1. Dec 1949 : Tropical Low Pressure
2. Dec 1958 : Cyclone
3. Mar 1961 : Cyclone
4. Mar 1963 : Tropical Low Pressure
5. Dec 1978 : Tropical Low Pressure
6. Mar 1982 : Cyclone Issac

Fig. 4-1 Passing Routes of Cyclones

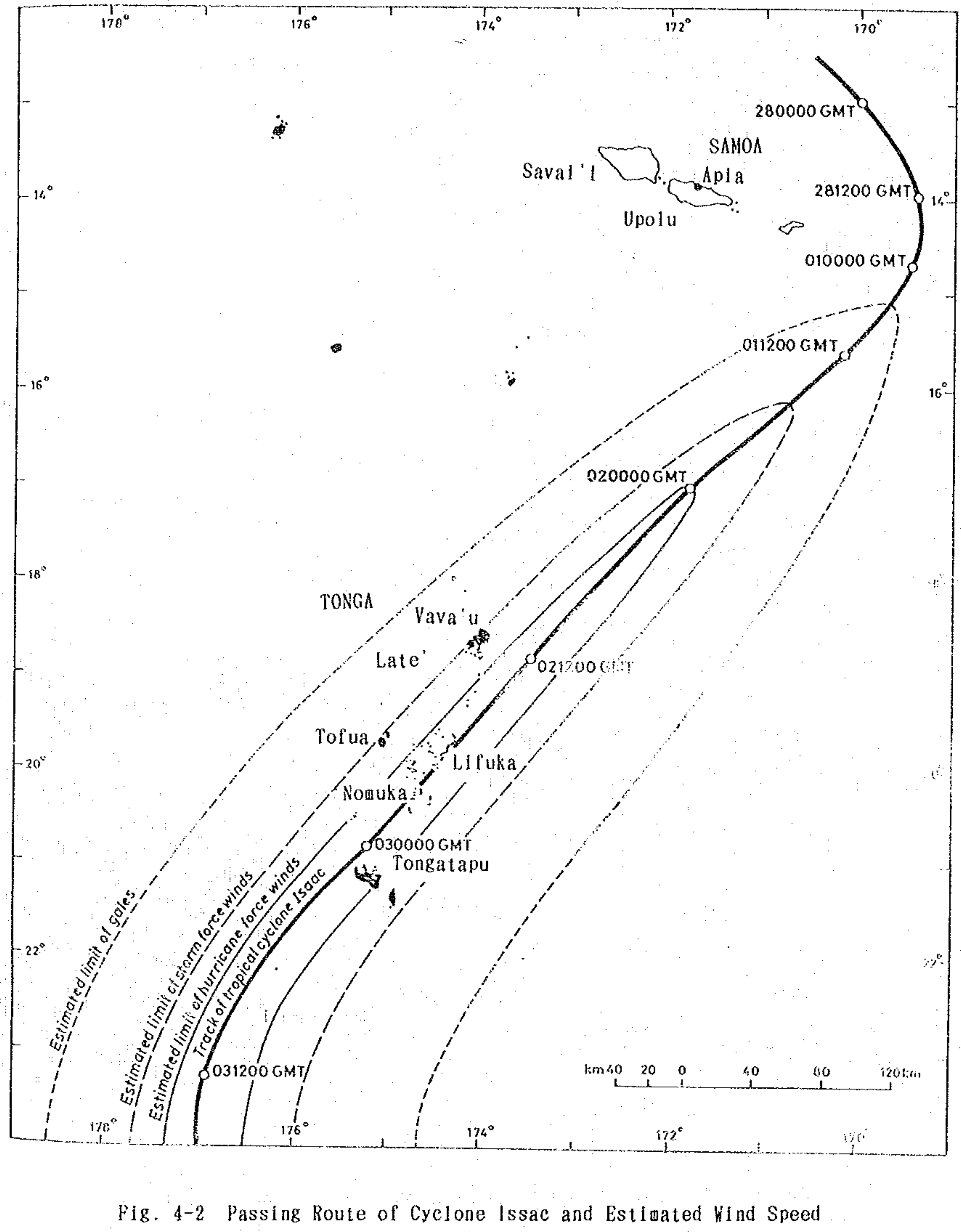


Fig. 4-2 Passing Route of Cyclone Issac and Estimated Wind Speed
(Courtesy of the Fiji Meteorological Service)

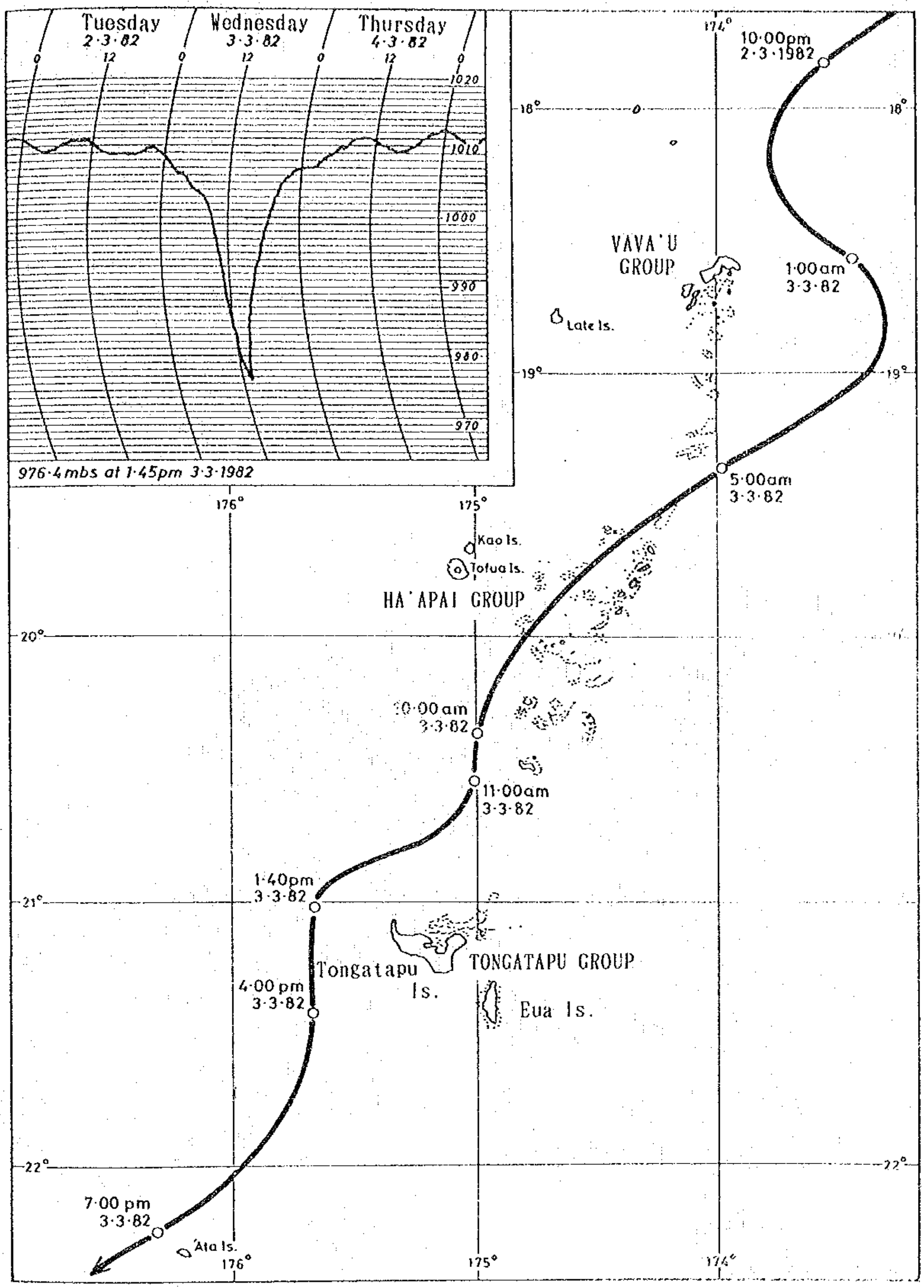


Fig. 4-3 Detail Route of Cyclone Issac
(Courtesy of the Nuku'alofa Meteorological Officer)

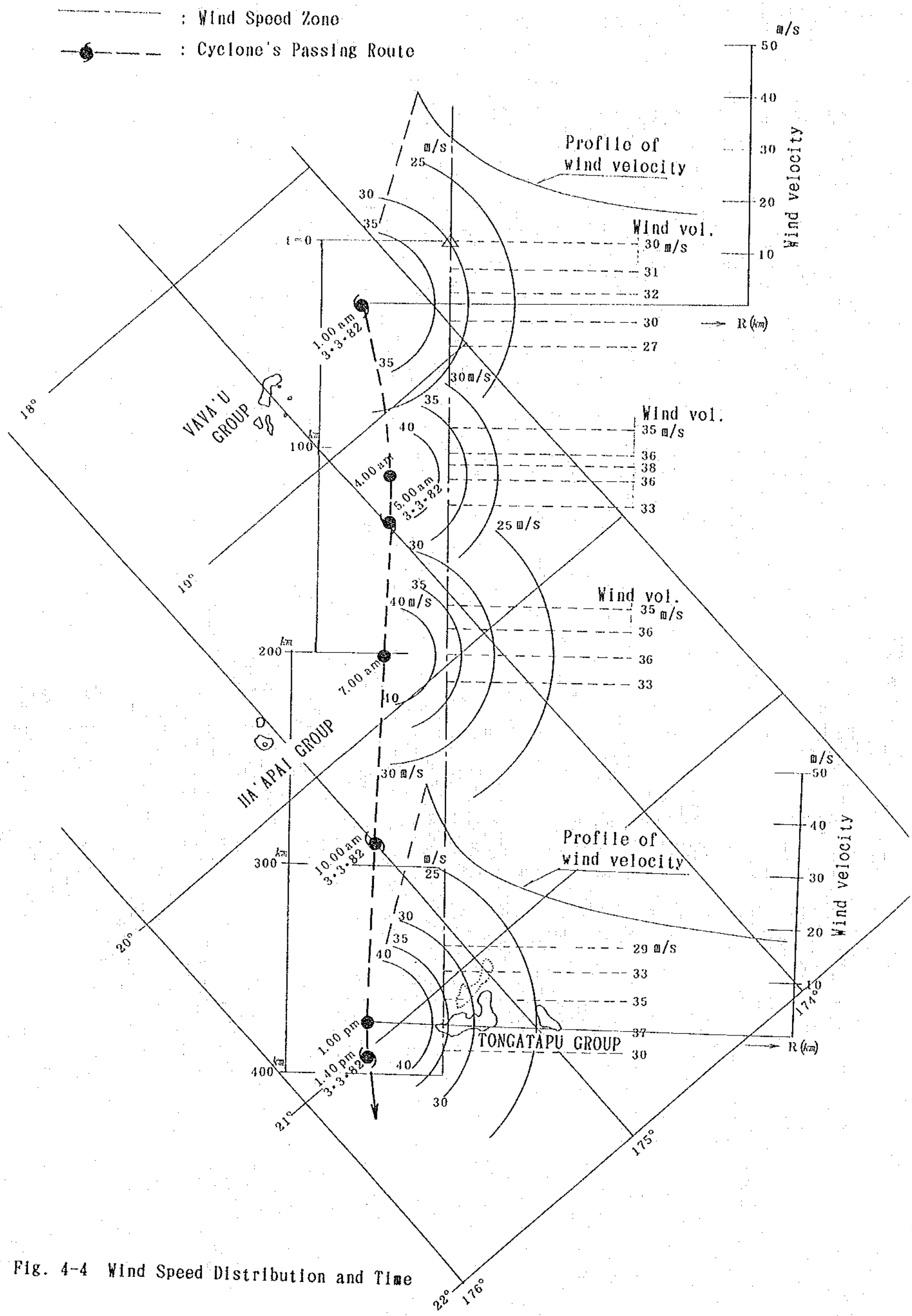


Fig. 4-4 Wind Speed Distribution and Time

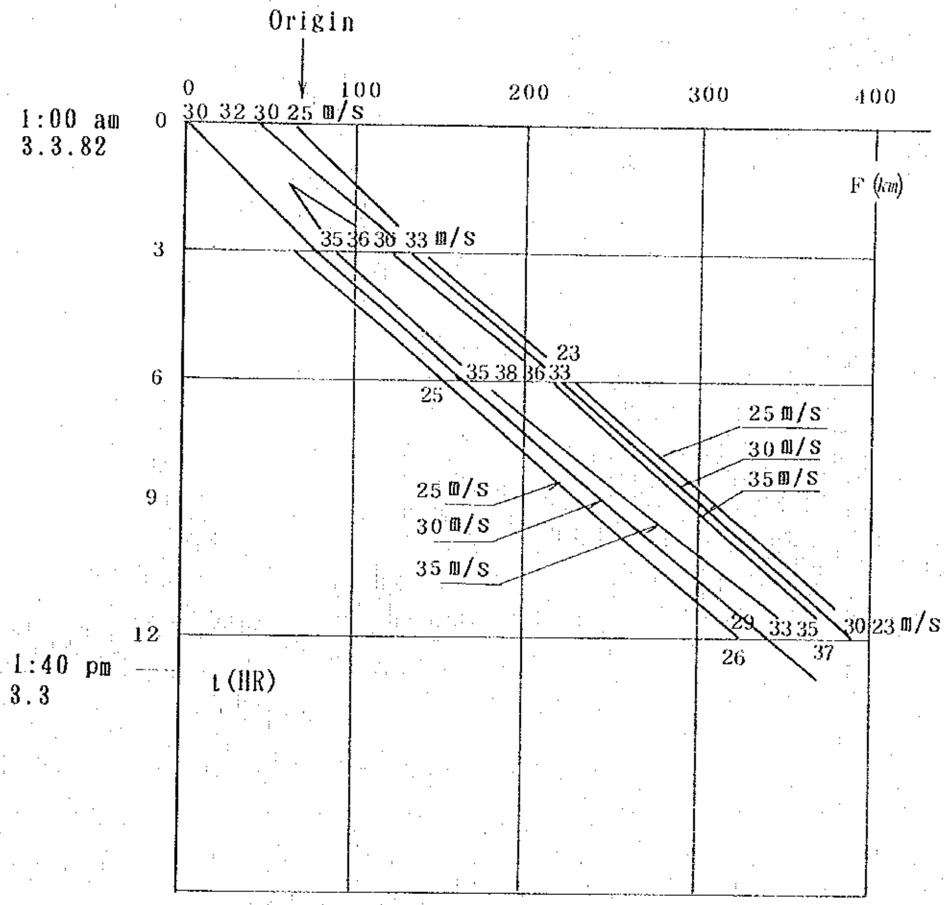


Fig. 4-5 Wind Speed Distribution and Time Change

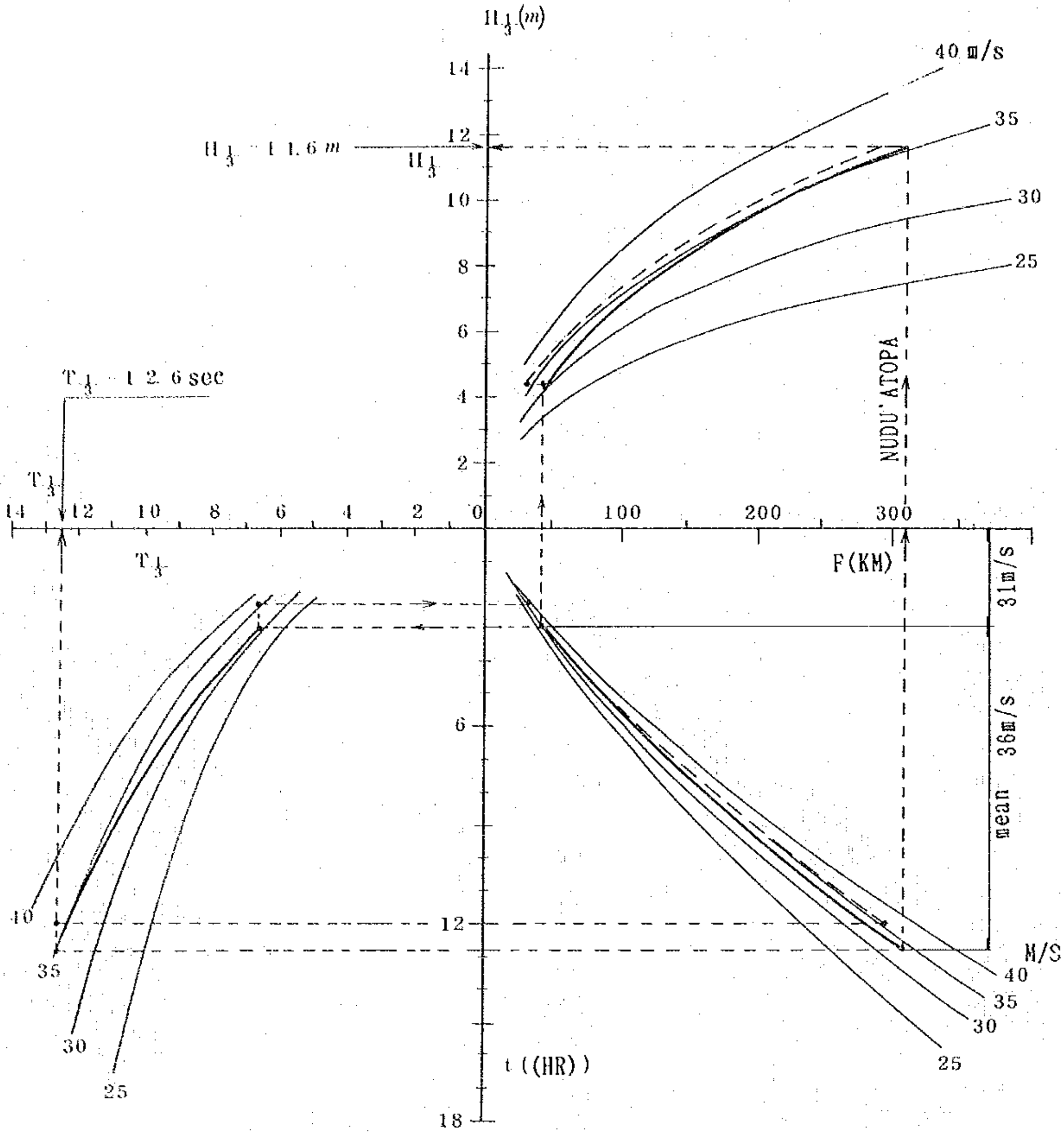


Fig. 4-6 Wilson's Wave Developing Curves

Using the actual recorded figures for each parameter, Hmax and Tmax were obtained as follows:

$Po - Pc = 1{,}010 - 950 = 60$ millibars

$\gamma o = 24$ km

$V_{mean} = 8.0$ m/sec

$A/V^2 = (60^{3/4} \times 24^{1/4}) / V^2$

$= 0.746$

$H_{max}/V^2 = 0.175 \quad T_{max}/V = 1.65$

Thus, $H_{max} = 11.2$ m, $T_{max} = 13.2$ sec

The above figures are almost the same as those obtained by using Wilson's equation; they appear to be very reasonable values. Therefore, the design deepwater wave height and its period were determined as follows:

$H_o' = 11.6$ m

$T_{1/3} = 12.6$ sec

(4) Wave Height at the Nuku'alofa Foreshore Protection Structure Wave heights at the representative points A, B, and C in the Study Area (see Fig. 4-9) were calculated.

When a wave moves into the shoaling water, it refracts and changes its profile under the influence ofthe seabed conditions. Fig. 4-10 is a wave refraction diagram showing waves coming from a northeasterly direction with a wave period of 12 seconds in the area that is -45 m deep to the front of the reef area. From this figure, the wave refraction coefficient in front of the reef area (on a line between Hakau Mama'o and Malinoa) was obtained as,

$K\gamma = 0.77$

Waves taking the course shown in Fig. 4-10 do not directly reach the Project Area due to the effect of the reef areas.

Waves that reach points A, B, and C are superposed waves of the following :

i) Diffracted waves between Hakau Mama'o and Malinoa:
The diffraction coefficient K_D can be obtained using the Angular Spreading Method (Fig. 4-9).

ii) Waves passing through the reef areas:

The average width of the reef areas is about 3 km with a depth of 3 meters when waves approach from a northeasterly direction.

When deepwater waves reach the reef areas they break. Their height $H_{1/3}$ was calculated by the empirical equation that was proposed by Dr. Takayama in his Study on Wave Profile Changes on Reefs (Port and Harbour Technical Research Data No. 278)

Wave height and set-up were calculated as follows:

$$H_{1/3} / Ho' = B \cdot \exp\left(-A \frac{\chi}{Ho'}\right) + \alpha \frac{h + \bar{\eta}\infty}{Ho'} \quad \cdots\cdots (1)$$

$$\frac{\bar{\eta} + h}{Ho'} = \sqrt{Co - \frac{3}{8}\beta\left(\frac{H_{1/3}}{Ho'}\right)^2} \quad \cdots\cdots (2)$$

where,

$H_{1/3}$	:	Wave height on reef
Ho'	:	Equivalent deepwater wave height in front of reef
h	:	Still water depth on the reef
χ	:	Distance from the reef front point
$\bar{\eta}a$	:	Average set-up at $\chi = \infty$
$\bar{\eta}$	:	set-up on the reef
A, α, β	:	Coefficients, $A = 0.05$, $\alpha = 0.3$, and $\beta = 0.56$

B and Co were obtained by the following equations:

$$B = \frac{H_{1/3\ \chi=0}}{Ho'} - \alpha \frac{h + \bar{\eta}\infty}{Ho'} \quad \cdots\cdots (3)$$

$$Co' = \left(\frac{\bar{\eta}_{x=0} + h}{Ho'}\right)^2 + \frac{3}{8}\beta\left(\frac{H_{1/3\ x=0}}{Ho'}\right)^2 \quad \cdots\cdots (4)$$

$$\frac{\bar{\eta}\infty + h}{Ho'} = \sqrt{\frac{Co}{1 + \frac{3}{8}\beta \cdot \alpha^2}} \quad \cdots\cdots (5)$$

where:

$H_{1/3}$ x=0 : Wave height at χ = 0 m

$\overline{\eta}$ x=0 : set-up at χ = 0 m

H_o' = 11.6 x 0.77 = 8.9 m

Lo = 1.56 x 12.6^2 = 247.7 m

Seabed slope in front of the reef: θ = 1/10

h/H_o' = 3.0/8.9 = 0.34

h/Lo = 3.0/247.7 = 0.012

H_o'/Lo = 8.9/247.7 = 0.036

From Fig. 4-7 and 4-8,

$H_{1/3}$ (x=0)/Ho' = 0.48

$H_{1/3}$ (x=0) = 0.48 x 8.9 = 4.27 m

$\overline{\eta}$ (x=0)/Ho' = 0.095

$\overline{\eta}$ (x=0) = 0.095 x 8.9 = 0.85 m

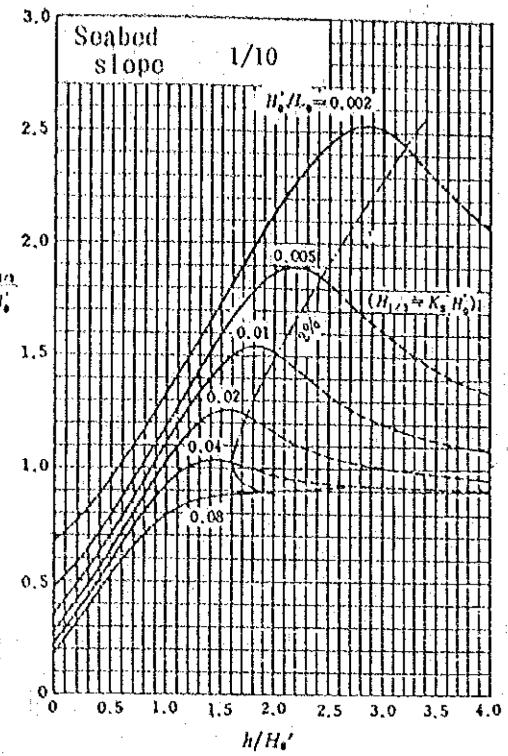


Fig. 4-7 Relative Depth h/Ho
Wave Height in the Breaking Zone
(Seabed slope: 1/10)

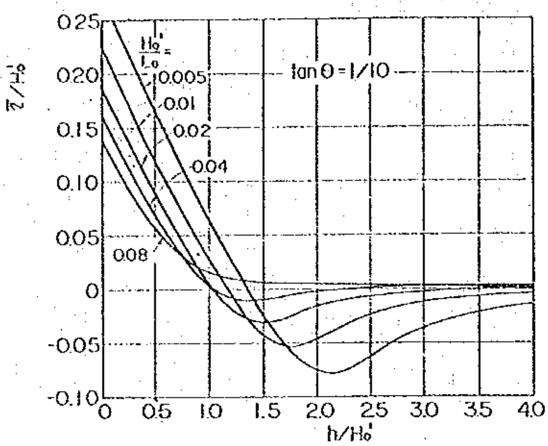


Fig. 4-8 Average Water Level Change caused by Irregular Wave in Shoaling Water
(Seabed slope: 1/10)

From equation (4),

$$Co = (0.095 + 0.34)^2 + 3/8 \times 0.56 \times 0.48^2$$

$$= 0.238$$

From equation (5),

$$\frac{\bar{\eta}_\infty + h}{Ho'} = \sqrt{\frac{0.238}{1 + \frac{3}{8} + 0.56 \times 0.3^2}}$$

$$= 0.483$$

From equation (3),

$$B = 0.48 - 0.3 \times 0.483$$
$$= 0.335$$

From equation (1),

$$H_{1/3} / Ho' = 0.335 \exp(-0.05 \times 3{,}000/8.9) + 0.3 \times 0.483$$
$$= 0.145$$
$$H_{1/3} = 0.145 \times 8.9$$
$$= 1.29 \text{ m}$$

From equation (2),

$$\bar{\eta} / Ho' = \sqrt{0.238 - \frac{3}{8} \times 0.56 \times 0.145^2} - 0.34$$
$$= 0.143$$
$$\bar{\eta} = 0.143 \times 8.9$$
$$= 1.27 \text{ m}$$

Based on the above figures, the waves that would reach the representative points A, B, and C were analyzed as the superposed wave energy of the refracted waves and the waves that passed over reef areas.

K_D was obtained by the Angular Spreading Method using the direction function of $S_{max} = 10$.

1. Refracted waves that pass between the reef areas:
   At point A: $Ho' \cdot Kr \cdot K_D = 11.6 \times 0.77 \times 0.60 = 5.36$ m
   At point B: $Ho' \cdot Kr \cdot K_D = 11.6 \times 0.77 \times 0.32 = 2.86$ m
   At point C: $Ho' \cdot Kr \cdot K_D = 11.6 \times 0.77 \times 0.14 = 1.25$ m

2. Waves that pass over the reef areas:

The diffraction coefficient of the waves that pass over the reef areas are as follows:

At point A: +2° to +48° , K_D = 0.63

At point B: -34° to +33° , K_D = 0.81

At point C: -52° to +29° , K_D = 0.85

Therefore, the wave height at each point becomes the superposed wave energies of 1 and 2 above.

At point A : $H_{1/3} = \sqrt{5.36^2 + (1.29 \times 0.63)^2} = 5.4$ m

At point B : $H_{1/3} = \sqrt{2.86^2 + (1.29 \times 0.81)^2} = 3.0$ m

At point C : $H_{1/3} = \sqrt{1.25^2 + (1.29 \times 0.85)^2} = 1.7$ m

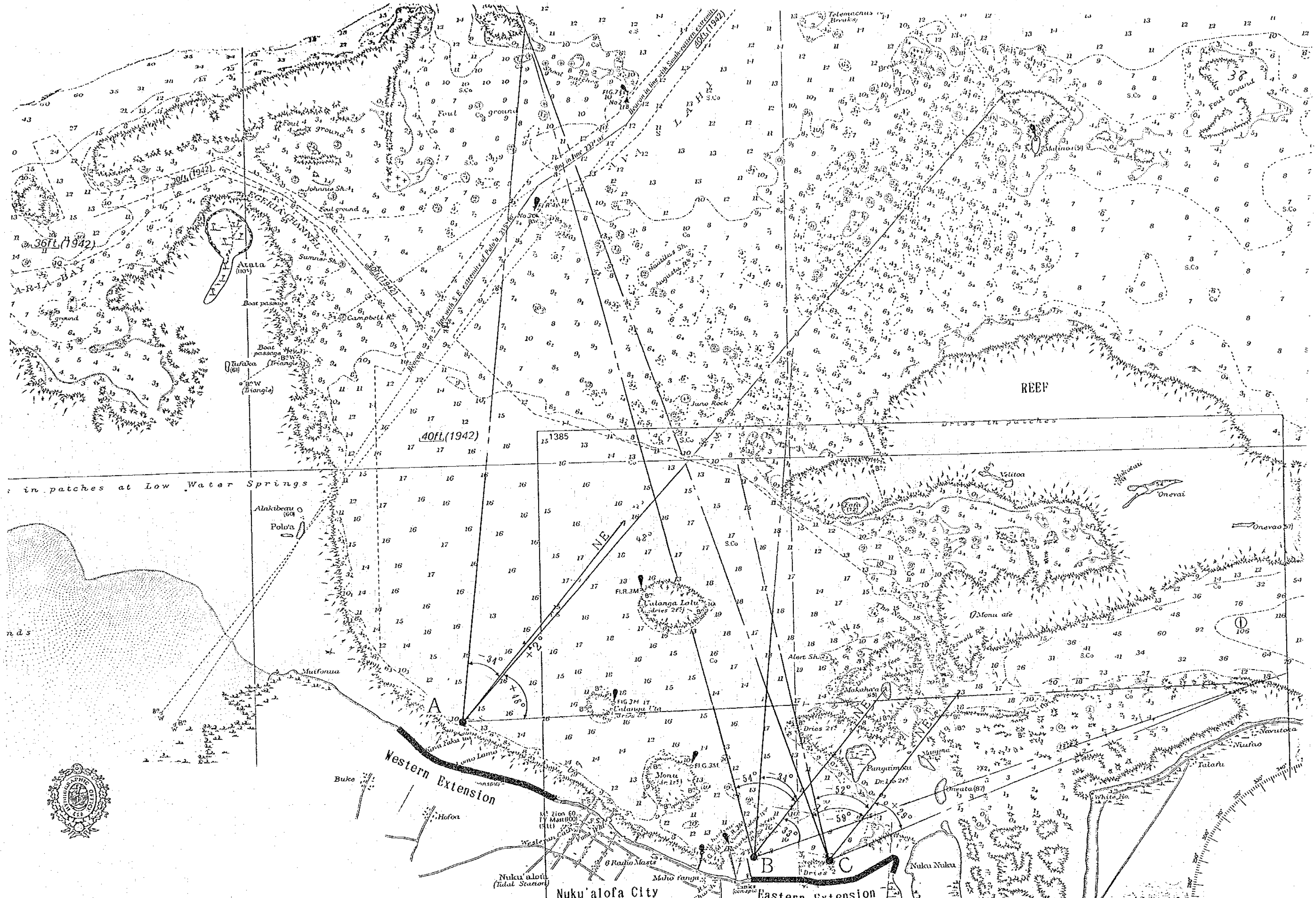


Fig. 4-9 Wave Height Estimation by Angular Spreading Method

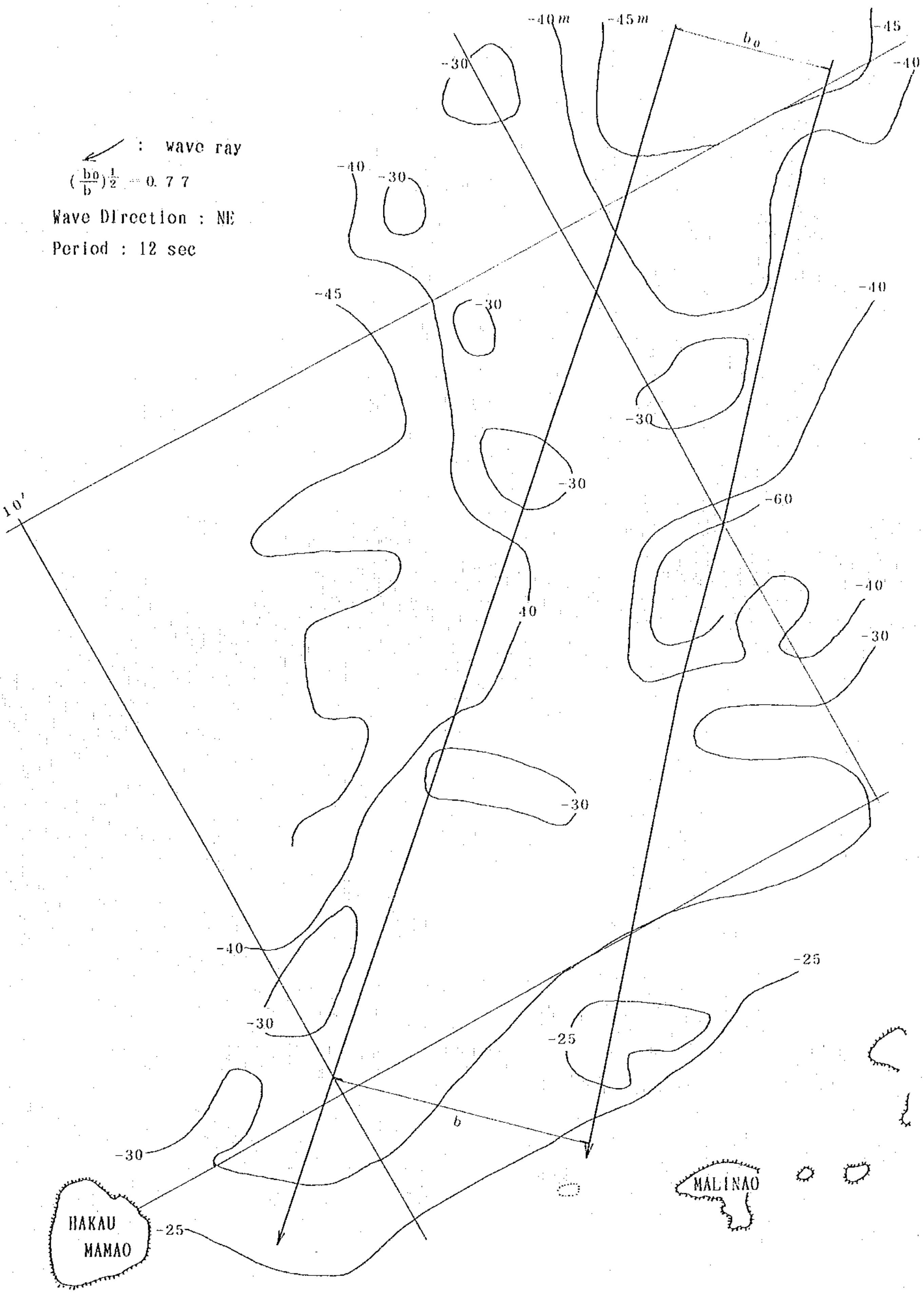


Fig. 4-10 Wave Refraction Diagram

4.2.2 Design Tide Level

In order to determine the construction datum level of the foreshore structure and the design tide level, tidal observations were conducted as follows:

Observation period: From November 3 through November 18 (a full fifteen days).

Observation location: Yacht berthing pier in Queen Salote Harbour (see Fig. 4-11).

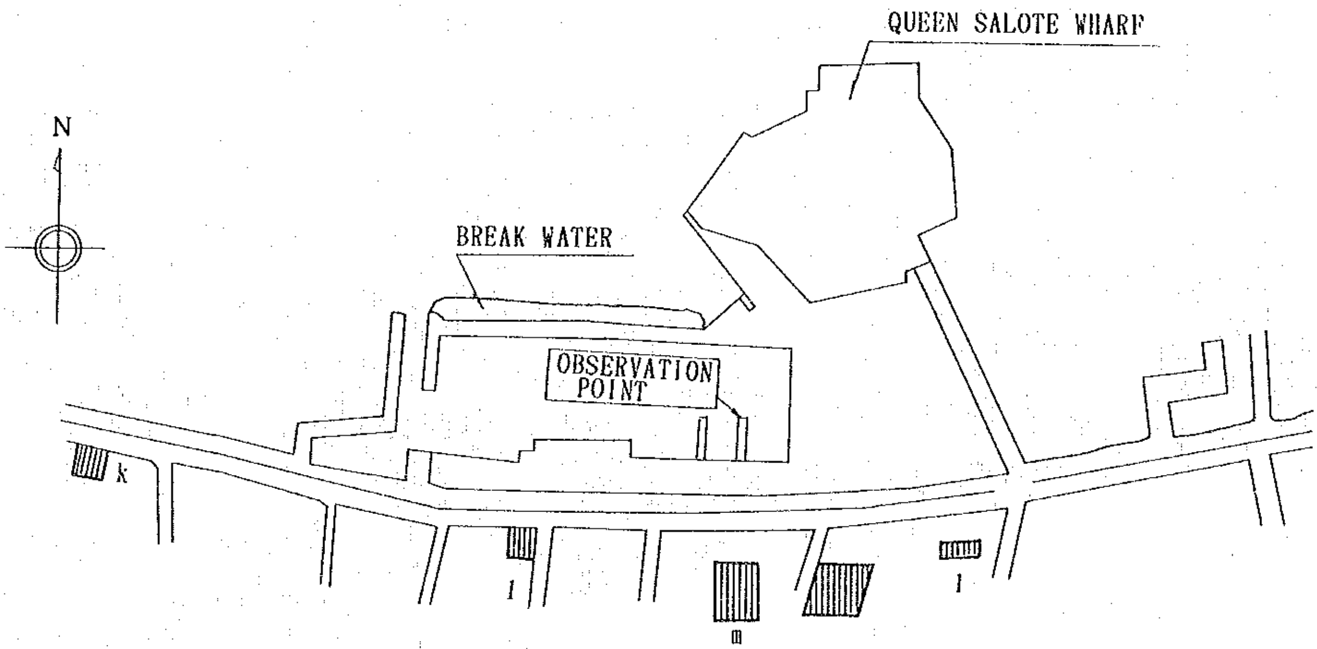


Fig. 4-11 Tidal Observation Location Map

(1) The tidal level difference during the observation period was 1.50 m. Major tide levels are as follows:

Highest Water Level (H.W.L.): +1.42 m

Mean Sea Level (M.S.L.): +0.71 m

Lowest Water Level (L.W.L.): -0.08 m

The datum line of the above elevation was obtained taking as a base the Prince Wellington Memorial (+2.99 m) in the Royal Palace.

(2) Harmonic Analysis

Based on the obtained tidal data, the tidal harmonic analysis was made. As a result of the analysis, major tidal harmonics constants (M2, S2, K1, 01) were obtained (see Table 4-1).

Table 4-1 Major Tidal Harmonic Constants

Name of Constant	Amplitude (m)	Period (hr)
M_2	0.528	12.421
S_2	0.097	12.000
K_1	0.096	23.935
O_1	0.046	25.819

From the above table, $Z_0 = M_2 + S_1 + O_1 + K_1 = 0.77$

Thus, MSL (+0.71) $\pm Z_0$ becomes as follows:

H.W.L. = +1.48 m

L.W.L. = -0.06 m

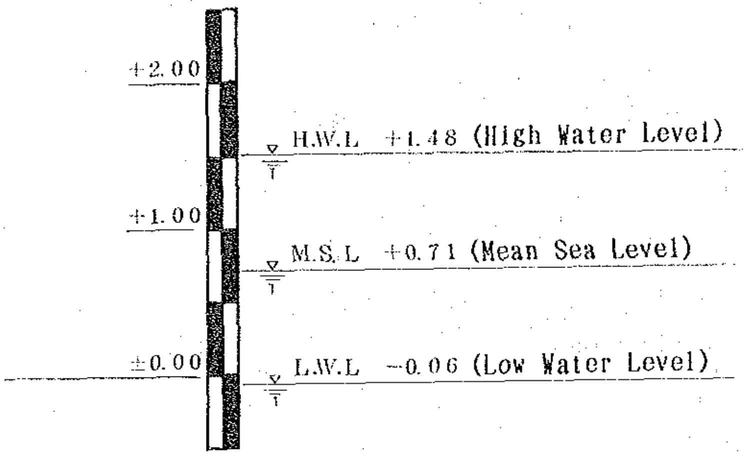
The above figures are almost in agreement with the observed figures.

The above figures reveal that the tide at the Project Area is a mixed type of M_2 (main lunar semidiurnal tide), S_2 (main solar semidiurnal tide), and K (solitary lunar diurnal tide).

The tide table obtained at Nuku'alofa City lists the major harmonic constants as $M_2 = 0.52$, $S_2 = 0.06$, $K_1 = 0.08$, $O_1 = 0.05$, and $Z_0 = 0.75$. These figures are very close to those obtained by the tidal data analysis.

(3) Determination of Datum Level

As a result of the tidal observations conducted during the field survey period, the harmonic analysis result deviates several centimetres from the figure listed in the present tide table. Because no tidal observation record at the Project Area existed, the tidal datum level for the area was determined based on the tidal observation result as shown below:



(4) Design Highest Water Level

The design highest water level for the coastal protection structure can be arrived at by using either one of the following methods:

① Recorded highest water level.

② High water level + recorded highest water level deviation.

Since there were no records indicating the highest water level in the Project Area, the design high water level for the Project Area was determined by using method ② as follows:

The approximate high water level (H.W.L.) can be given by the following equation:

H.W.L. = M.S.L. + (M_2 + S_2 + K_1 + O_1)

The four major tidal constituents analyzed in the Project Area were:

Z_0 = M_2 + S_2 + K_1 + O_1 = 0.77 m.

Thus,

H.W.L. = 0.71 + 0.77 = + 1.48 m, say + 1.50 m

According to the results of the field survey, the abnormally high water level trace mark made by Cyclone Issac when it hit the islands of Tonga March 3, 1982 (high water level of from +2.50 to + 2.60 m) occurred along the entire approximately 8.0 km long coastal area in the Project Area.

On the other hand, set-up that will be caused by the design wave (described in later section) will be about + 0.9 m. Therefore, H.W.L. plus set-up will be 1.50 + 0.9 = 2.40 m. Judging from the high water level mark made by Issac, it can be assumed that the highest water level deviation is about 20 cm.

In order to examine the static set-up caused by low barometric pressure, field surveys were conducted at the western and southern coasts of Tongatapu Island where storm waves were insignificant. The field surveys revealed that the static set-up at Kolovai Beach on the western coast was insignificant when Cyclone Issac hit the area.

According to the tide table, low tide on March 3, 1982 occurred two times; at 7:00 and 20:00. High tide occurred at 1:00 and 13:30. The recorded high tide at 13:30 was + 1.45 m.

According to a report made by residents, wave overtopping started about 10:00 and ceased about 16:00. These times coincide with the high tide time of 13:30.

Taking into consideration the above information, the design highest water level was determined by adding the highest water level deviation of 20 cm as follows:

H.H.W.L. = +1.50 + 0.20 = +1.70 m

4.2.3 Allowable Rate of Overtopping

The determination of the allowable rate of overtopping shall be made by taking into account the shore protection structure type, duration time of wave, land use conditions, and the draining capacity of the area behind the structure.

Dr. Gohda estimated the rate of overtopping for the coastal levees and shore protection structures that were actually damaged by typhoons, and reported the critical rate of overtopping for coastal levees and shore protection structures as shown in Table 4-2.

Additionally, the Japanese Ministry of Transport published the rate of overtopping as standards for foreshore protection structures based on the importance of the area behind the structure; these rates are listed in Table 4-3.

Table 4-2 Critical Rate of Overtopping

Type of Structure	Protection Work	Rate of Overtopping ($m^3/m \cdot sec$)
Coastal Levee	No protection work on levee crown and on back slope	Less than 0.005
	Protection work on levee crown, but no protection work on back slope	0.02
	Protection work on levee crown and on front and back slope	0.05
Sea Wall	No protectin work on crown	0.05
	Protection work on crown	0.2

Source: Design of Structures to Withstand Waves at Port and Harbours, by Yoshimi Gohda, Kajima Publishing Co.

Table 4-3 Referential Rate of Overtopping

Area Condition	Expected rate of Overtopping ($m^3/m \cdot sec$)
In the area behind the protection structure there are houses and public facilities that are likely to be subject to serious damage by overtopping waves or by wave spray.	About 0.01
Important areas that are not included in the above category.	About 0.02
Other areas.	0.02 to 0.06

Source: Technical Aspects for Coastal Protection Facility Construction, by Yasuhira Nagai, Port and Harbour Administration Research Data, Japan Association of Port and Harbour Engineers.

The beach zone in the Project Area is approximately 8 km long. Important facilities for political, economic, and commercial activities are concentrated along approximately 3 km of the centre section. The extension areas, about 2.5 km each, are presently being used as housing areas, but there is a plan to utilize these areas for hotels and recreational facilities in the future.

In view of the above land use conditions, the 3 km long centre section will fall into the categories shown in Table 4-3 as being an area likely to be subject to serious damage or as an important area.

Both extension areas can be classified as "other areas" having an expected rate of overtopping of 0.02 to 0.06 $m^3/m \cdot sec$.

The allowable rate of overtopping for the foreshore protection structure without crown protection is 0.05 $m^3/m \cdot sec$ (see Table 4-2).

For the above reasons, the allowable rate of overtopping for the Project structure design was set as 0.05 $m^3/m \cdot sec$.

4.3 Basic Plan

4.3.1 Calculation of Wave Height and Set-up on Reef

Wave height and set-up in zones A, B, C, and D were calculated (see Fig. 4-12)

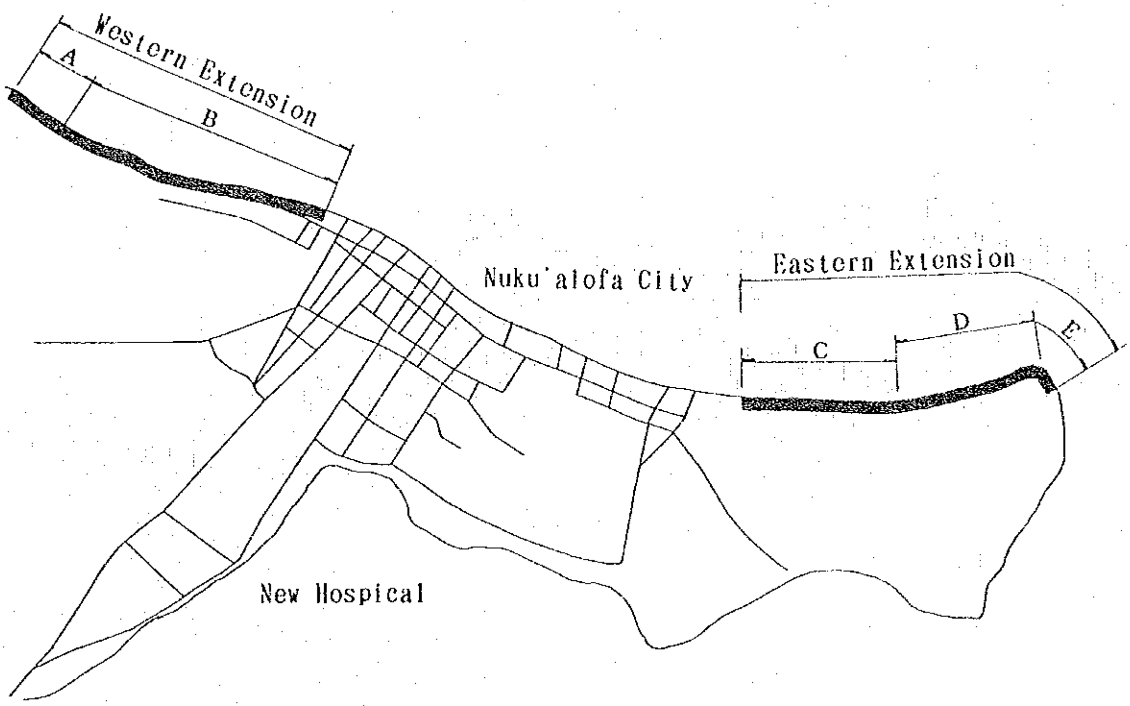


Fig. 4-12 Zoning for Protection Structure Design

Reef length and height in each zone are as shown in Table 4-4.

Table 4-4 Reef Features

Zone	Length (m)	Height (m)
A	500	+0.4
B	400	+0.2
C	300	-0.2
D	300	-0.4

(1) Zone A

$H_o' = 5.4$ m

$L_o = 1.56\ T^2 = 1.56 \times 12.6^2 = 247.7$ m

Seabed slope at the reef front: $\theta = 1/10$

$h/H_o' = (1.70 - 0.4)/5.4 = 0.241$

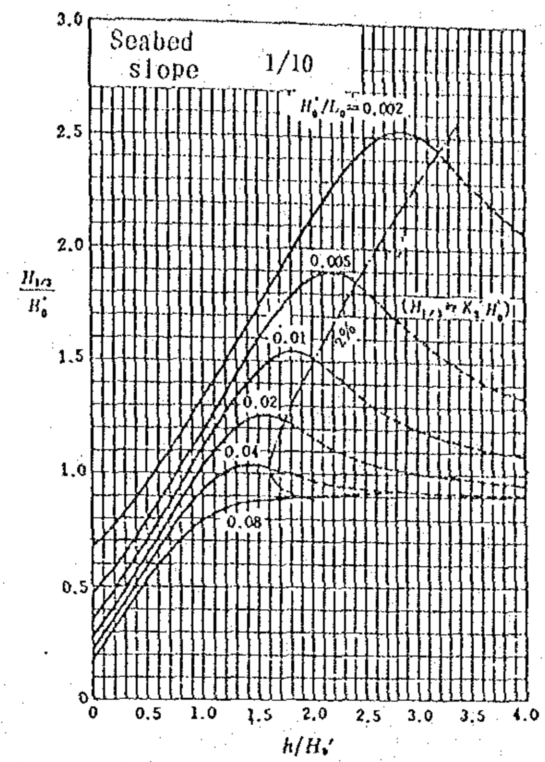
$h/L_o = (1.70 - 0.4)/247.7 = 0.005$

$H_o'/L_o = 5.4/247.7 = 0.022$

From Fig. 4-13 and 4-14,

$H_{1/3}\ \chi = o/H_o' = 0.41$

$\bar{\eta}\ (\chi = o)/H_o' = 0.13$



Relative Depth h/Hó
Fig. 4-13 Wave Height in the Breaking Zone
(Seabed slope: 1/10)

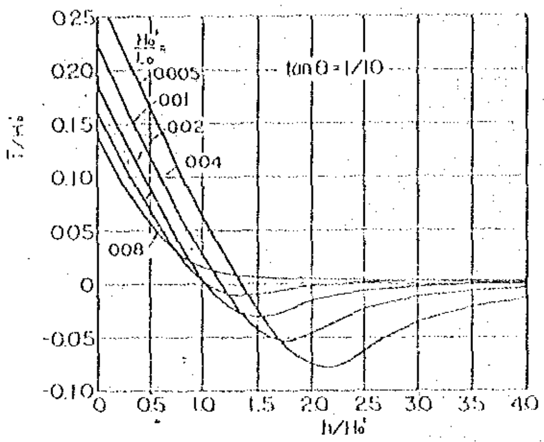


Fig. 4-14 Average Water Level Change caused by Irregular Wave in Shoaling Water
(Seabed slope: 1/10)

From equation (4),

$$Co = (0.13 + 0.241)^2 + 3/8 \times 0.56 \times 0.41^2 = 0.173$$

From equation (5),

$$\frac{\bar{\eta}\infty + h}{Hó} = \sqrt{\frac{0.173}{1 + \frac{3}{8} \times 0.56 \times 0454^2}}$$

$$= 0.407$$

From equation (3),

$$B = 0.41 - 0.454 \times 0.407$$
$$= 0.225$$

From equation (1),

$$H_{1/3} / Ho' = 0.225 \exp(-0.05 \times 500/5.4) + 0.454 \times 0.407$$
$$= 0.187$$

Thus, the wave height on the reef is:

$$H_{1/3} = 0.187 \times 5.4 = 1.01 \text{ m}$$

From equation (2),

$$\bar{\eta} / Ho' = \sqrt{0.173 - \frac{3}{8} \times 0.56 \times 0.187^2} - 0.241$$
$$= 0.166$$

Thus, set-up on the reef is:

$$\bar{\eta} = 0.166 \times 5.4 = 0.90 \text{ m}$$

The wave heights and set-up at zones B, C, and D were calculated using the same procedures as described above. The results of the calculations are shown in Table 4-5.

Table 4-5 Wave Height and Set-up on Reef

Zone	Ho' (m)	To (sec)	Reef length (m)	Reef height (m)	$H_{1/3}\,x{=}0$ / Ho'	$\bar{\eta}\,x{=}0$ / Ho'	$H_{1/3}$ (m)	η (m)
A	5.4	12.6	500	+0.4	0.41	0.13	1.01	0.90
B	5.4	12.6	400	+0.2	0.42	0.125	1.10	0.86
C	3.0	12.6	300	-0.2	0.77	0.085	1.08	0.45
D	1.7	12.6	300	-0.4	1.35	0.005	1.05	0.21

4.3.2 Examination of the Rate of Overtopping

The wave overtopping discharge was estimated by using "Exposition of Coast Protection Facilities Construction Standards" charts prepared by the Liaison Council of Coast Protectrion Facilities Construction Standards.

(1) Zone A:

$H1/3 = 1.01$ m

To = 12.6 seconds

set-up: $\bar{\eta} = 0.90$ m

Water depth: $h = H.H.W.L. - GL + \bar{\eta}$

$= 1.70 - 0.4 + 0.90 = 2.20$ m

Wave length in a water depth of 2.20 m is:

$L = 57.96$ m

$H_{1/3}/L = 1.01/57.96 = 0.017$

$h/H_{1/3} = 2.20/1.01 = 2.18$

$q/\sqrt{2g \cdot H_{1/3}{}^3} = 0.0111$

From Fig. 4-15

$hc/H_{1/3} = 0.35$

$hc = 0.35 \times 1.01 = 0.35$

Structure crown height = 1.70 + 0.90 + 0.35 = +2.95 m

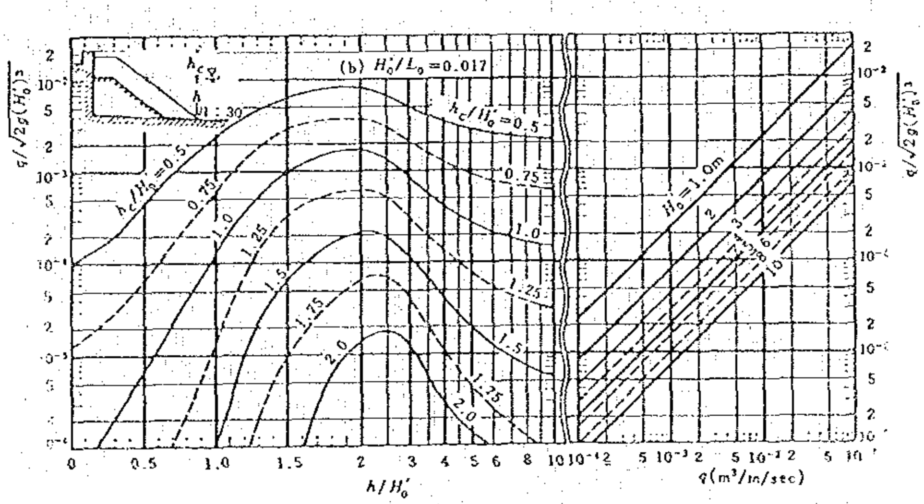


Fig. 4-15 Expected Rate of Overtopping Diagram

Required crown heights at zones B, C, and D were calculated using the same procedures as described above. The results of the calculations are listed in Table 4-6.

Table 4-6 Protection Structure Crown Height

Zone	$H_{1/3}$ (m)	$\bar{\eta}$ (m)	h (m)	L (m)	$\frac{h}{H_{1/3}}$	$q/\sqrt{2g \cdot H_{1/3}^3}$	$\frac{hc}{H_{1/3}}$	hc	Crown Height (m)
A	1.01	0.90	2.20	57.96	2.18	0.011	0.35	0.35	+2.95
B	1.10	0.86	2.36	59.99	2.15	0.010	0.40	0.44	+3.00
C	1.08	0.45	2.35	59.87	2.18	0.010	0.40	0.43	+2.58
D	1.05	0.21	2.31	59.36	2.20	0.0105	0.37	0.39	+2.30

4.3.3 Calculation of Required Weight of Stone Masonry

The required weight of stone masonry was calculated by Hudson's equation as follows:

$$W = \frac{\gamma r \times H_D^3}{K_D \ (\gamma r/Wo - 1)^3 \cot \alpha}$$

where,

W : Weight of stone masonry, in tons

γr : Unit weight of stone in air, in tons/m³

Wo : Unit weight of sea water, in tons /m³

α : Slope angle from horizontal line, in degrees

K_D : Coefficient related to the kind of stone

H_D : Height of a progressive wave at the slope tip, in metres

K_D was determined as 2.8 from Table 4-7.

Table 4-7 Value of K_D

Type of Stone	Number of Layers	Value of K_D
Round Stone	Two or less	2.1 to 2.6
	Three or more	2.5 to 3.2
Sharp-edged Stone	Two or less	2.8 to 3.5
	Three or more	3.1 to 4.3

(1) Zone A

$$W = \frac{1.8 \times 1.01^3}{2.8 \times (1.8/1.03 - 1)^3 \times 2.0} = 0.8 \text{ ton}$$

With the same procedure, the required weight of stone masonry in zones B, C, and D was calculated as 1.0 ton, 1.0 ton, and 0.9 ton respectively.

Judging from the relatively flat shape of the coral stones and their durability, it was decided to place 1.2 ton coral stone pieces on top of the entire section of stone masonry.

4.3.4 Determination of Final Crown Height

The crown height of the coastal protection structure was determined as follows:

Crown height = Design Tide + Required Height for Design Wave
+ Allowable Height

The design tide and required height for design wave were discussed in the previous sections.

The estimated settlement value of the protection structure shall be included in the allowable height. The allowable height shall be determined from all aspects by taking into account some uncertainties.

During the field study period, the cross sections of the rehabilitated foreshore protection structure were measured. The measured heights of the structure's cross sections were 0 to 10 cm lower than the original design. The rehabilitation work was completed about three years ago. The height differences between the measured values and those of the original design were negligible from the viewpoint of construction work and surveying accuracy.

In light of the above, the crown height of the protection structure was determined, as shown below, by adding the maximum allowable height of approximately 30 cm for the uncertainties of the field surveys, design, construction work, possible structure settlement, etc.

	Western Extension		Eastern Extension	
	Zone A	Zone B	Zone C	Zone D
Final Structure Crown Height (m)	+3.00	+3.30	+2.80	+2.30

4.3.5 Structure Crown Width

As the crown width of the protection structure shall have sufficient width to resist wave force and overtopping waves, it was decided that at least three pieces of armour stone would be 2.5 m wide.

4.3.6 Beach Material

(1) Selection of Beach Material

The selection of beach material shall be made by taking into account beach stability and possible effects on the surrounding environment. From the viewpoint of beach stability, coarse sand is generally preferable. On the other hand, fine sand (not silty) is preferable if the beach is to be used a clean appearance is desired.

The beach material for the Project beach was determined from the graph (see Fig. 4-16) that was derived from the cases of twelve stable beaches in Japan:

By assuming the beach front slope as 1/10 and $Ho/Lo = 0.004$,

$$d_{50}/Ho' = 10^{-3}$$

$$d_{50} = 10^{-3} \times 1.0\ m = 1\ mm$$

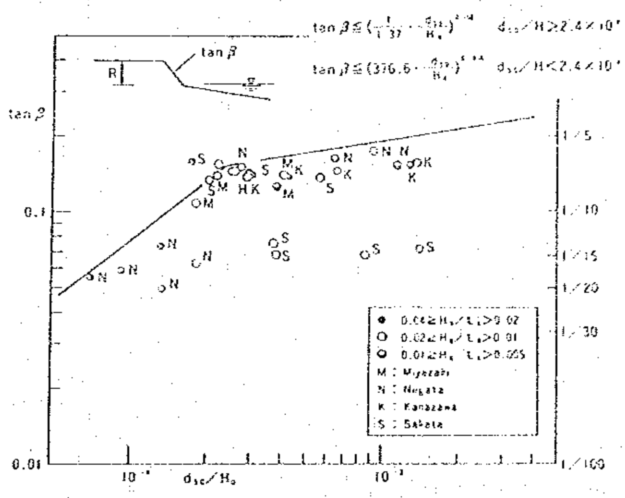


Fig. 4-16 Relationship Between Beach Front Slope and d_{50}/Ho

According to the "Exposition of Coast Protection Facilities, Construction Standards" the relationship between beach erosion and the accretion phenomena is as follows:

$$Ho'/Lo = C\ (\tan\bar{\beta})^{-0.27}\ (d/Lo)^{0.67}$$

where,

C: Parameter between beach erosion and deposition.

If "C" is more than 18, the shoreline will erode. If "C" is less than 18, accretion will occur at the shoreline (see Fig. 4-17).

i) Under Cyclone Conditions (same magnitude as Issac)

$$C = (Ho'/Lo)\ (\tan\bar{\beta})^{0.27}(d/Lo)^{-0.67}$$

$$= 1.0/247.7 \times (1/10)^{0.27} \times (10^{-3}/247.7)^{-0.67} = 8.9 < 18$$

ii) Under Normal Wave Conditions

$$C = 0.5/25 \times (1/10)^{0.27} \times (10^{-3}/25)^{-0.67} = 9.5 < 18$$

Therefore, it can be assumed that the shoreline will be stable under either type of conditions.

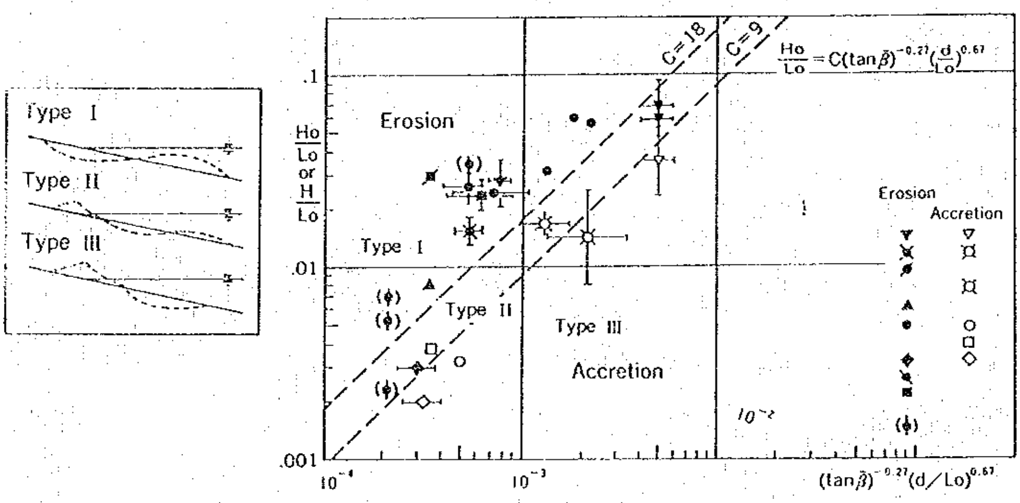


Fig. 4-17 Shoreline Erosion and Accretion (from actual cases)

(2) Results of Seabed Material Surveys

In order to ascertain the relationship between seabed materials and ocean characteristics, seabed material surveys were conducted throughout the entire Project Area, and sieve analyses and specific gravity tests were made.

From the surveys and analyses, it was found that the rain size of the seabed material gradually became smaller from the western extension towards the eastern extension. The grain size change corresponds to the wave conditions in those areas.

The "d_{50}" was about 1.0 mm to 0.6 mm. The average specific gravity of the grain particles was about 2.8.

Based on the results of the above analyses, and by taking into account beach stability, the beach material's grain size "d_{50}" was ascertained to be larger than 1.0 mm.

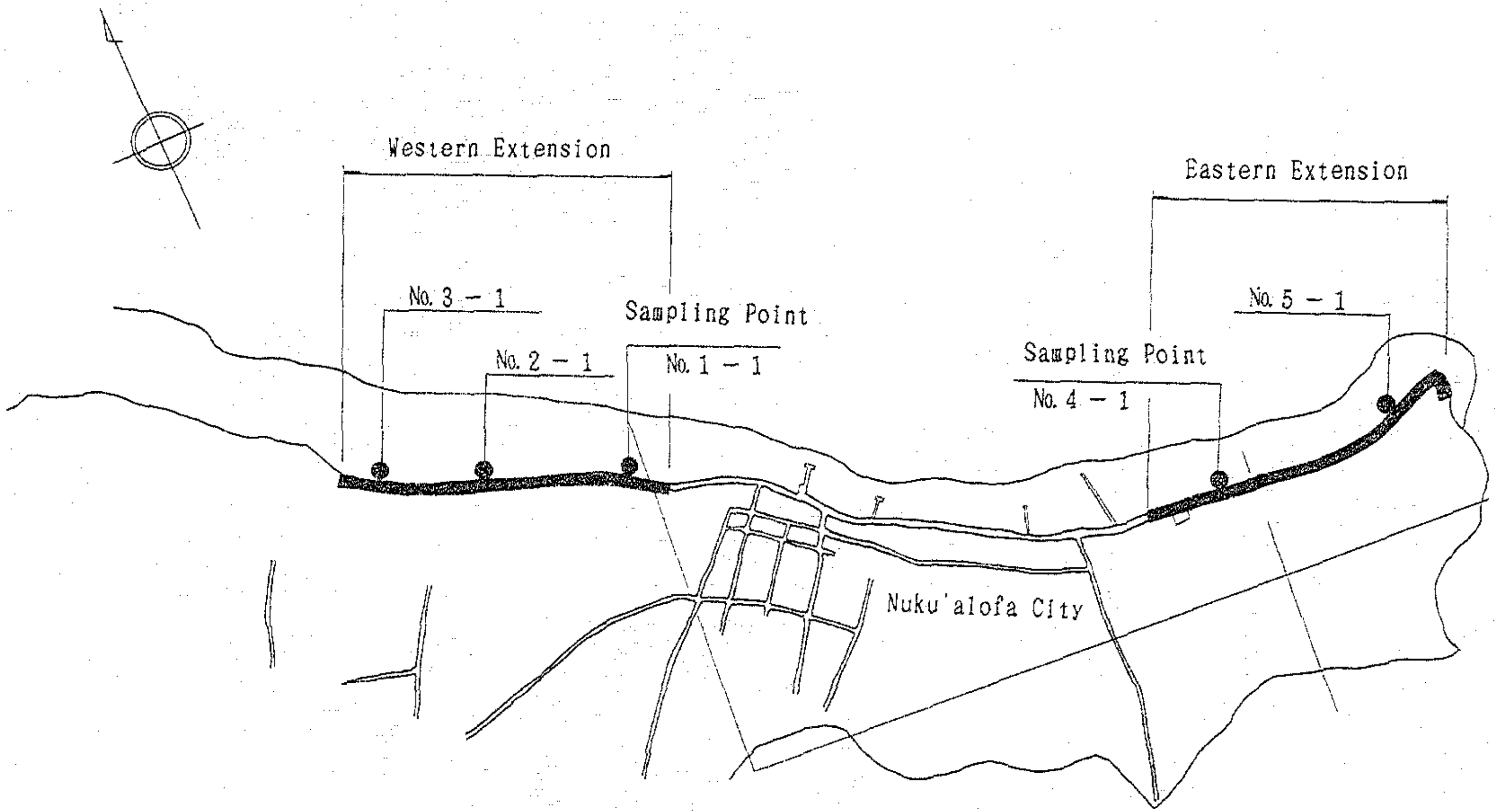


Fig. 4-18 Seabed Material Survey Locations

4.3.7 Foreshore Protection Cross Sections

(See Fig. 4-12 for each zone)

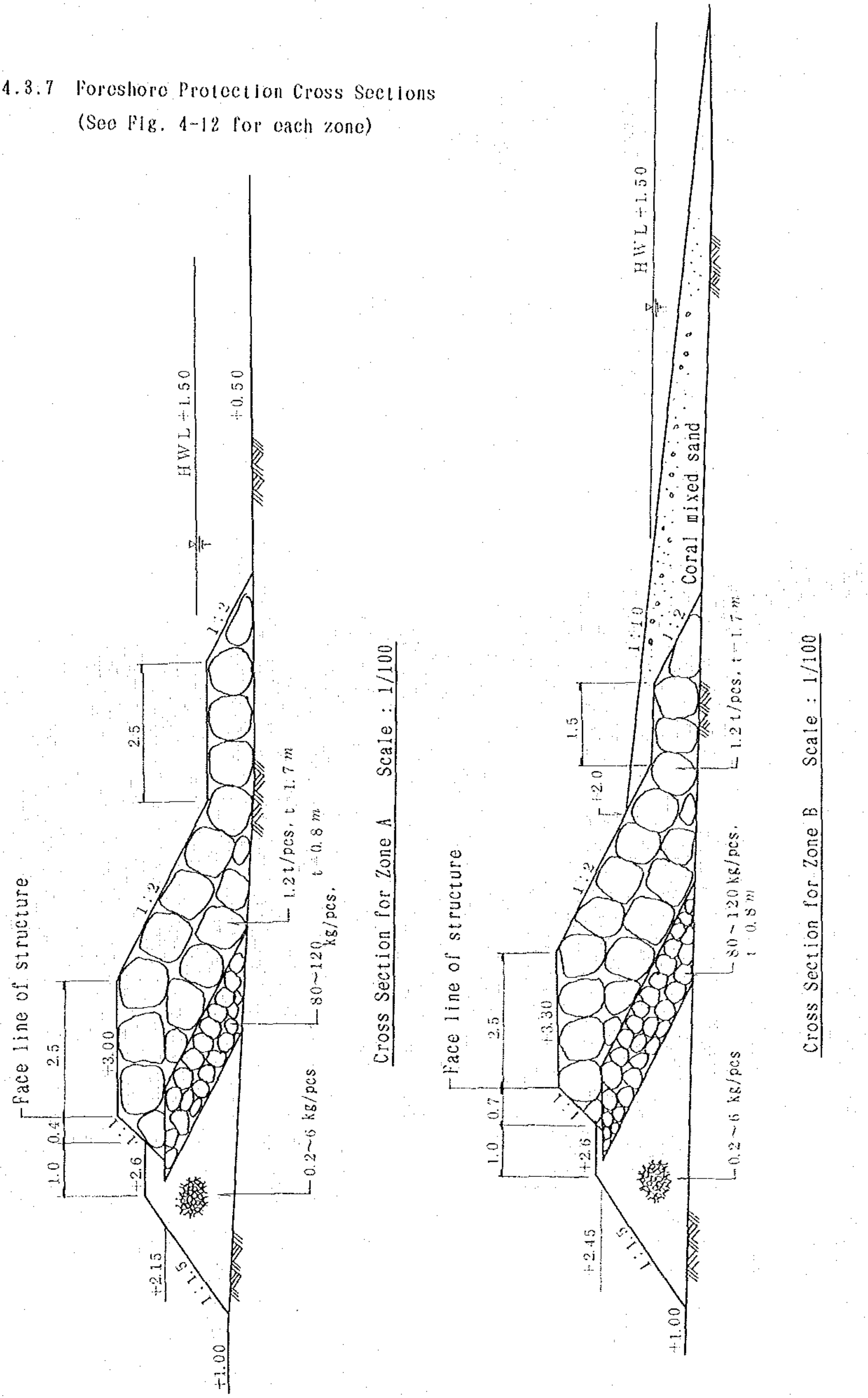


Fig. 4-19 Protection Structure Cross Sections

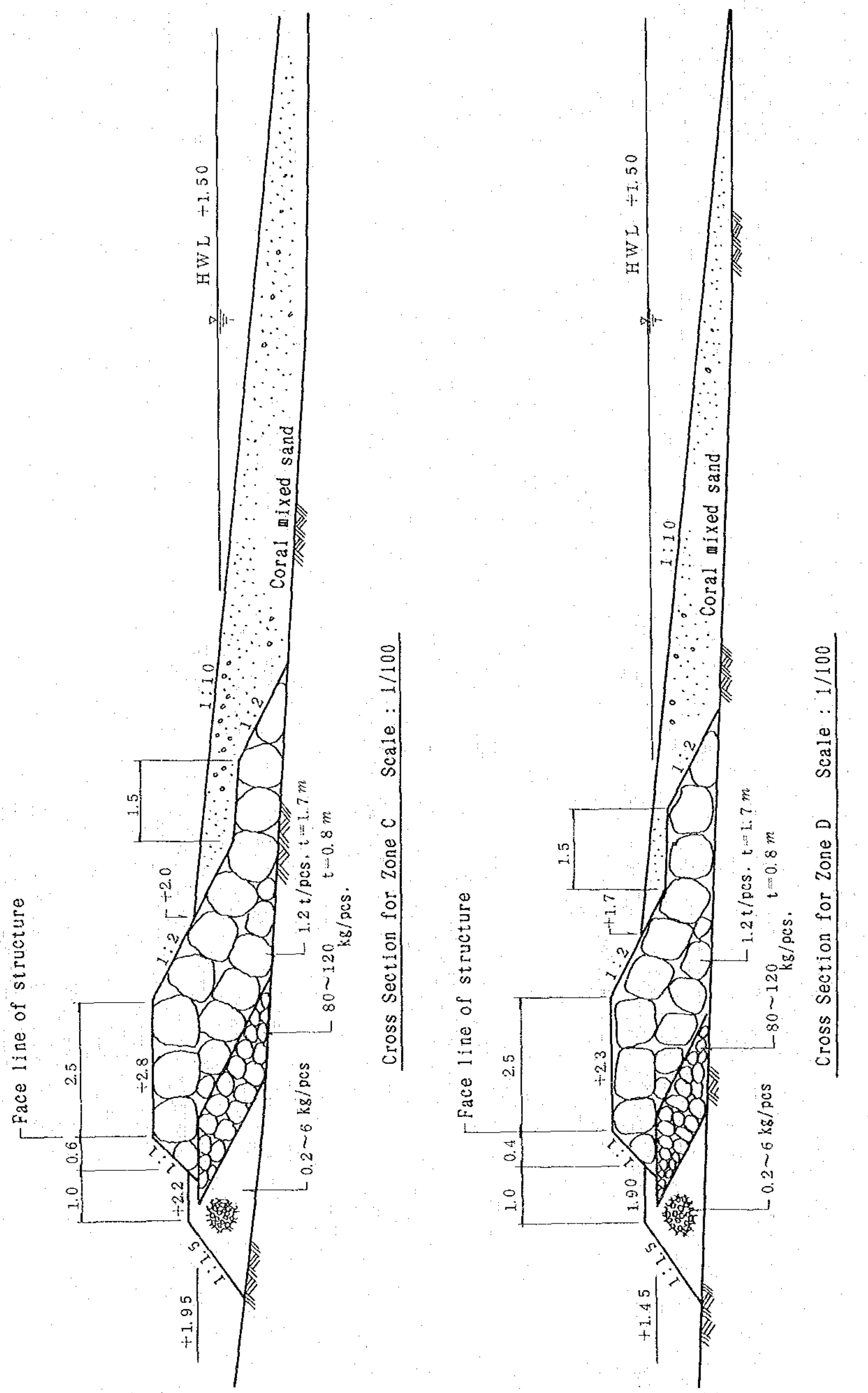
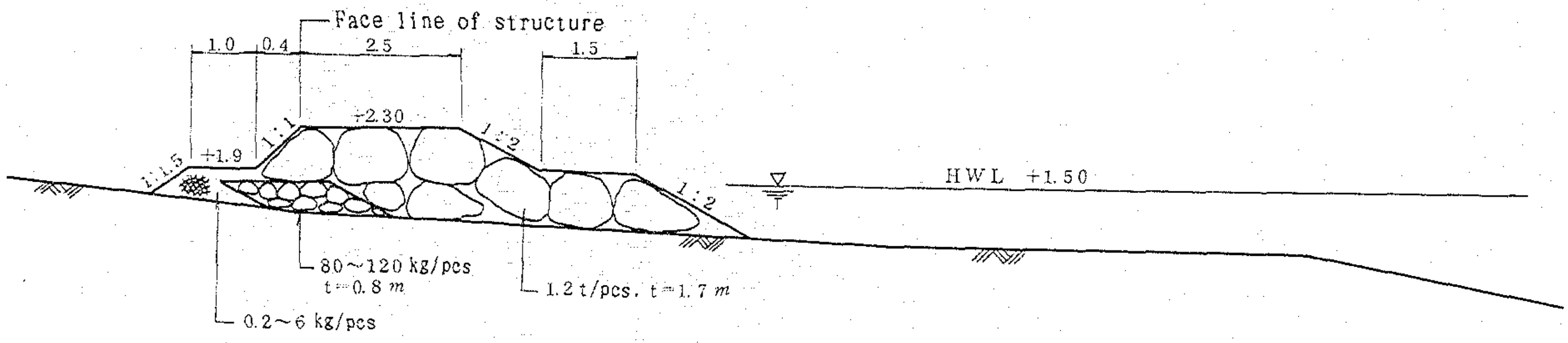


Fig. 4-19 Protection Structure Cross Sections



Cross Section for Zone-E   Scale : 1/100

Fig. 4-19 Protection Structure Cross Sections

4.4 Construction Plan

4.4.1 Construction Policy

(1) Construction Period

In general, a large amount of construction materials and equipment will be required if the constrution period is to be shortened.

If the protection structure must be built within one year, it will be necessary to have a large input of constrution equipment, such as cranes, bulldozers, dump trucks, etc. From an economic viewpoint this does not seem reasonable. Furthermore, an increase in the number of dump trucks will only create traffic congestion and cause vibration and noise problems as they pass along the roads. Therefore, as shown in Table 4-8, and economic comparison was made to evaluate the protection structure's construction in a one year period (Case 1) and a two year period (Case 2). For Case 2 (two year construction period), the western extension of the protection structure would be built prior to the eastern extension in view of the importance of the area.

Table 4-8 Comparison of Construction Periods

	CASE 1 (Construction in one year)	CASE 2 (Construction in two years)
Quarry	3 locations: 3 drilling machines, 3 loaders, 3 bulldozers	2 locations: 1 drilling machine, 2 loaders, 2 bulldozers
Transporting	24 dump trucks	17 dump trucks
Placing Work	4 cranes, 2 bulldozers	3 cranes, 1 bulldozer
Relative Construction Costs	1.14 (based on Case 2 index as 1.0)	1.0
Evaluation	Not preferable	Preferable

Judging from the economic aspects and the effects upon area environment, the foreshore protection structure shall be built in two years as shown in Table 4-8.

(2) Quarry

The Study Team surveyed quarries at five locations and, as a result, concluded that the No. 6 Fualu Quarry and the No. 8 Farm Quarry would be the most suitable for use during the Project construction based on their deposit amounts and quality rock, transporting distance, and mining methods.

i) Estimation of Amounts of Stone and Sand Required for Each Construction Component:

	PHASE I Construction (m^3)	PHASE II Construction (m^3)	Subtotal (m^3)
Armour stone and rubble-mound	35,000	30,000	65,000
Beach sand	18,000	37,000	55,000
Total	53,000	67,000	120,000

ii) Existing No. 6 Fualu Quarry and No. 8 Farm Quarry (see Fig. 4-20):

- The No. 6 Fualu Quarry is located about 12 km from the western extension and about 14 km from the eastern extension of the Project foreshore protection structure.

The quarry with an area of about 5 ha produces sand for fine aggregate and other uses.

After conducting field surveys and holding discussions with the officials concerned of the Government of Tonga, a decision was made to use sand from the No. 6 Fualu Quarry for the beach material.

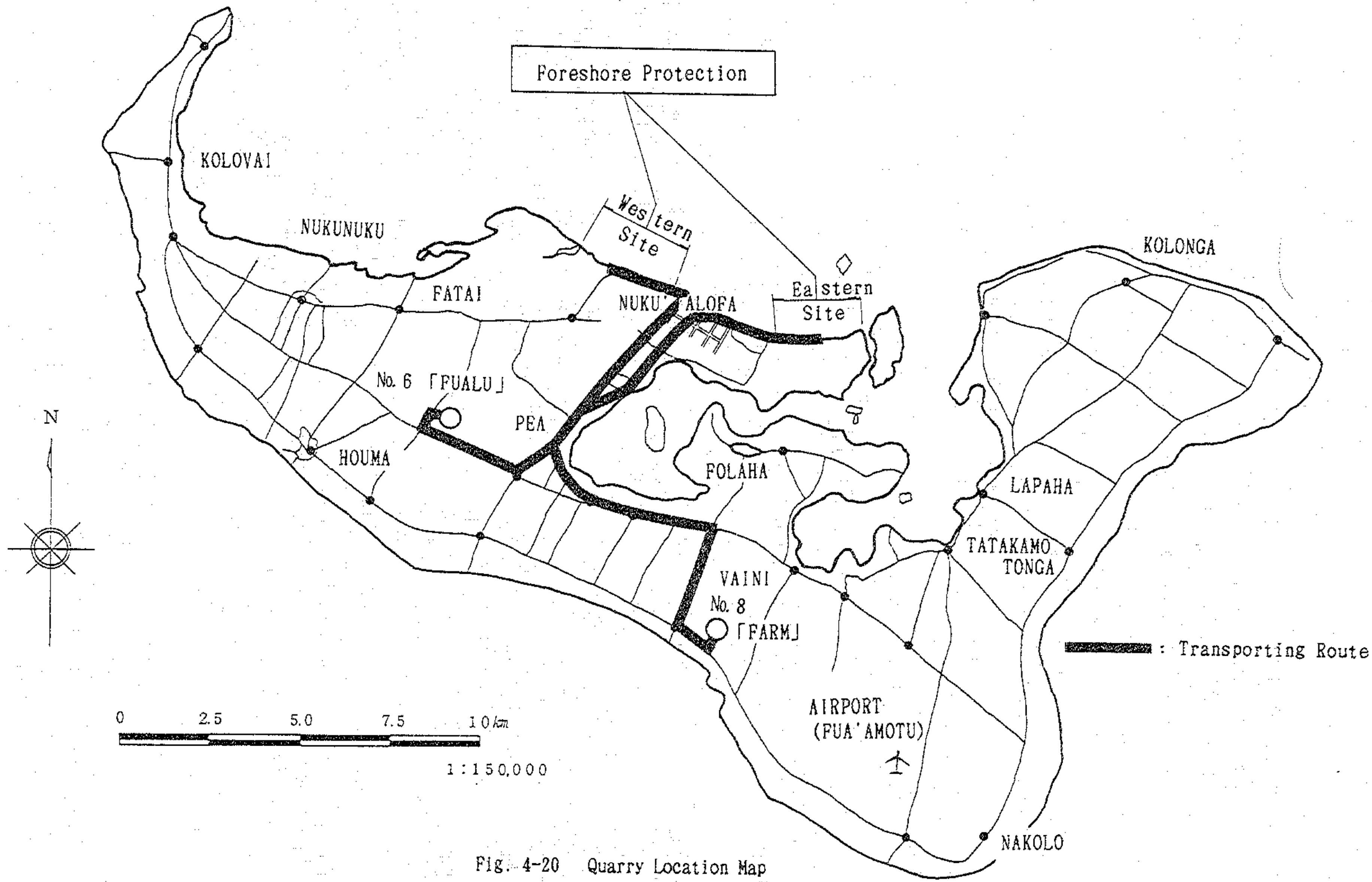


Fig. 4-20 Quarry Location Map

- The No. 8 Farm Quarry is located to the east of the No. 6 Fualu Quarry, and is about 17 km from the western extension and about 19 km from the eastern extension of the Project foreshore protection structure. The quarry is situated along an unpaved road that is about 3.0 km south of a major road that leads to the Tongatapu Airport.

  The quarry area is about 1.6 ha. Hard rock is being mined there. Judging from the size of the deposit and the mining method, a decision was made to use the rock from this quarry for the armour stone and rubble-mound of the protection structure.

iii) Merits and Demerits of Obtaining Beach Material from the No. 6 Fualu Quarry and Armour Stone and Rubble-mound Stone from the No. 8 Farm Quarry:

Merits:

1. Shorter distance for transporting beach material.
2. Beach material can be excavated by rippers.
3. Beach material can be excavated without blasting.
4. It will be possible to avoid traffic congestion (with dump trucks) in the vicinity of the quarries and to keep dust, vibration, and noise to a minimum so as not effect the residents and farms along the roadways.
5. As Project construction vehicles and heavy equipment will be located in two separate places, it will be easier to obtain the space needed for material stockyards.
6. Lower construction costs.

Demerits:

1. Two field management offices will be required.
2. It might be necessary to transport heavy equipment from the No. 6 Fualu Quarry to the No. 8 Farm Quarry or vice versa. After discussions with the concerned officials of the Government of Tonga, a decision was made to obtain beach sand from the No. 6 Fualu Quarry and armour stone and rubble-mound stone from the No. 8 Farm Quarry.

4.4.2 Construction Method

(1) Quarrying

i) Quarrying Flow Chart

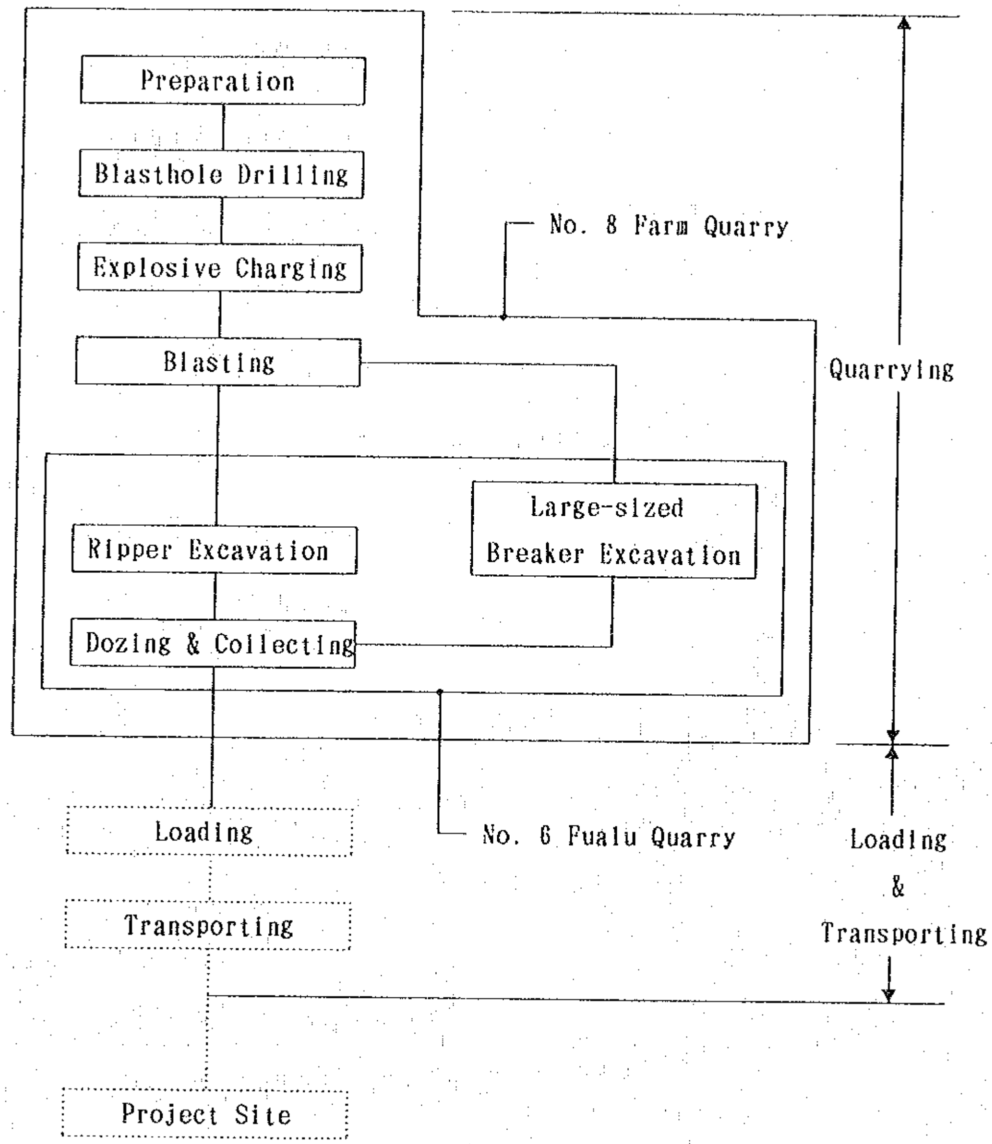


Fig. 4-21 Quarrying Flow Chart

ii) Quarrying Method

a) No. 6 Fualu Quarry:

Excavating Form:

Judging from the quarry topography, the open-cut method is to be adopted.

Excavating Method:

By taking into account the rock quality, the amount of rock to be excavated, and the area conditions, a ripper equipped bulldozer is to be used for excavating and dozing purposes.

The Number of Pieces of Equipment and Machinery:

32-ton ripper equipped bulldozer: one unit Large-sized breaker (0.6 m^3, 1,300 kg): one unit

Amount of Sand to be Excavated:

Beach sand: Approximately 55,000 m^3

b) No. 8 Farm Quarry:

Excavating Form:

Open-cut method is to be adopted from the viewpoint of the quarry's topography.

Excavating Method:

By taking into account the sizes of the armour stones and rubble-mound stones, the amount of stone required, and the amount of stone that can be excavated daily, blasting will be necessary, and there will be the need for a ripper equipped bulldozer, and a crawler drill for excavation use purposes. A large-sized breaker is to be used for secondary breaking, shaping and excavation of armour and rubble-mound stones.

The Number of Pieces of Equipment and Machinery:

Crawler drill (180 kg class) : One unit

Air compressor (17.0 m^3/min) :	One unit
32-ton ripper equipped bulldozer :	One unit
Large-sized breaker (0.6 m^3, 1,300 kg) :	One unit

Amount of Stone to be Excavated:

Armour stones (1.2 tons/pieces) :	Approx. 45,000m^3
Rubble-mound stones : (80 to 120 kg/pieces)	Approx. 9,000m^3
Rubble-mound stones : (0.2 to 6 kg/pieces)	Approx. 11,000m^3
TOTAL	Approximately 65,000m^3

(2) Protection Structure

1) Flow Chart of Protection Structure Construction

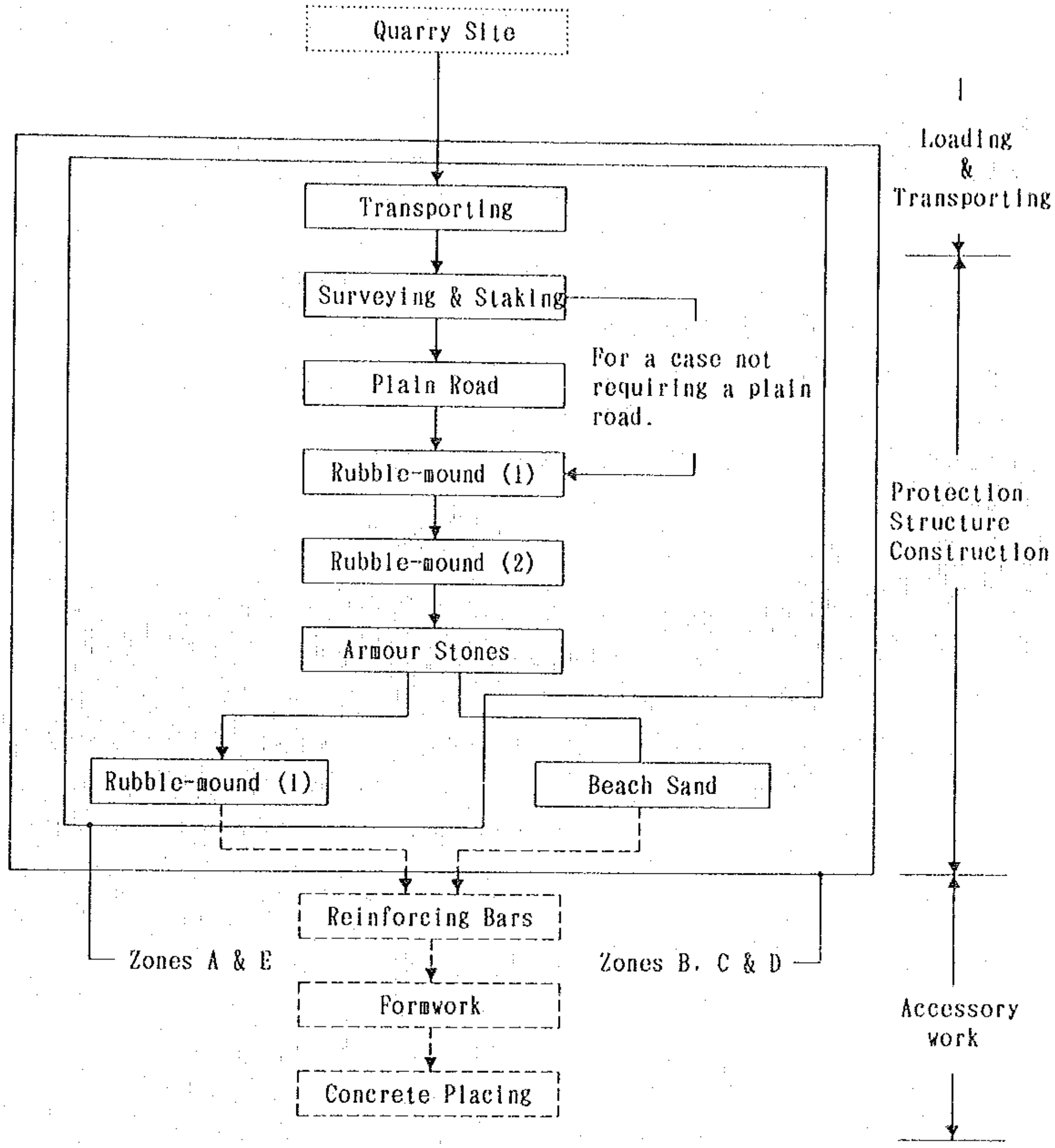


Fig. 4-22 Flow Chart of Protection Structure Construction

ii) Rubble-mound Construction Method:

During periods of low tide, the stones (0.2 to 6/kg piece, and 80 to 120 kg/piece) transported by dump trucks are to be unloaded directly on the construction site and will be shaped either by backhoes or manually.

During periods of high tide, the stones are to be unloaded on the plain road and placed on the construction site by backhoes. They will then be shaped either by backhoes or manually during low tide periods.

Special attention must be paid to not including fine particle material that may cause erosion, and to not leaving large voids in the rubble-mound.

Before placing stones, the correct location of finishing stakes shall be reconfirmed.

iii) Armour Stone Placing

Armour Stones (about 1.2 tons/piece) that are transported from the quarry are to be unloaded within the crawler-crane's load radius. After placement of sling wires around a stone, the crawler-crane lifts the stone and places it on the rubble-mound. The stone's height shall be adjusted to correspond to the levelling cord set on the finishing stakes.

Stones of proper size shall be filled firmly between the armour stones to prevent them from washed away.

iv) Beach Sand Placing

The beach sand transported by dump trucks shall be bulldozed in front of the completed portions of the protection structure.

Elevation of sand shall be adjusted to correspond to the levelling cord set on the finishing stakes.

The sand placement work shall be accomplished during periods of low tide.

4.4.3 Construction Boundary

(1) The construction work to be covered by Japanese grant aid will be as follows:

-Construction of approximately a 5.2 km long section of the Nuku'alofa foreshore protection structure.

(2) Undertaking by the Government of Tonga are as follows:

-Land fill behind the protection structure:

It is planned to construct a new road behind the Project's foreshore protection structure. All work related to the road construction shall be undertaken by the Government of Tonga.

-Access roads:

Providing and maintaining access roads to the Project Site, the quarries and the office from the main road.

- Temporary use of land:

  Providing land temporarily for a construction liaison office, warehouse, stockyard, motor pool, etc. during the construction period.

- To provide and maintain the water and electric supply lines and telephone cables to the liaison office.

- Removal of shipwrecks

- To ensure speedy unloading, tax exemption and customs clearance at ports of disembarkation in the Kingdom of Tonga for the products used in the Project.

- To bear commissions to a Government authorized Japanese foreign exchange bank for the banking services based upon the Banking Arrangement.

- To accord Japanese Nationals, whose services may be required in connection with the supply of products and services under the verified contract, such facilities as may be necessary for their entry into Tonga, and their stay therein for the performance of their work.

- To maintain the foreshore protection structure constructed under the Grant Aid.

4.4.4 Constructin Supervision Plan

In order to complete the construction of the protection structure on schedule in a safe and satisfactory manner, it will be necessary to provide appropriate supervision during the entire construction period.

Project construction supervision work will be carried out by placing emphasis on the following aspects:

(1) Quality Assurance

The quality, size and shape of armour stones, rubble-mound stones, and beach sand will be controlled based on construction specifications. Qutality assurance work will take place at the quarries and at the construction site.

(2) Construction Progress Management

Construction progress will be managed in accordance with the Programme Evaluation and Review Technique (PERT) and the Critical Pass Method (CPM).

By comparing actual construction progress with the originally planned schedule, future construction progress can be forecasted and controlled. By so doing, construction progress can be systematically managed.

(3) Material and Equipment Management

In accordance with the material and equipment schedule plan, material and equipment management will be carried out to provide the proper amounts of materials and equipment at the proper times.

During the construction period, construction equipment being used in the Project will be carefully examined to determine its operating condition, hourly operating efficiency, operating rate, safety measures, maintenance and repair condition, operation difficulties, etc., and to learn if there is an excess or shortage of equipment.

(4) Safety Precautions

Throughout the entire construction period, equipment shall be inspected frequently to ensure that it is good working order. Workers shall be provided with proper supervision and guidance in matters relating to on-the-job safety.

4.4.5 Material and Equipment Procurement Plan

Construction situations found in Tonga that may have a bearing on Project construction are as follows:

(1) Tonga relies almost entirely on imported construction equipment.

(2) Large-sized construction equipment that is owned by the Ministry of Works is presently used. In the future, the equipment will be used on the Fifth Five-year Development Plan projects. Only one crusher will be available for Project construction use. Table 4-9 lists all construction equipment owned by the Ministry of Works.

(3) Construction equipment owned by local contractors is limited in type and number. The general repair and maintenance condition of this equipment is not quite satisfactory. Table 4-10 lists the major construction equipment owned by local contractors.

In view of the above findings, and taking into consideration that Project construction must be safely and satisfactorily completed within a certain time frame, the major pieces of construction equipment for Project use are to be shipped from Japan.

Tables 4-11 and 4-12 list the materials and equipment to be procured.

Table 4-9 List of Construction Equipment Owned by the Ministry of Works.

No.	Name of Equipment	No.	Name of Equipment
1.	Bulldozer (D6)	8.	Compressor
2.	Bulldozer (D8)	9.	Rock excavator
3.	Loader	10.	Concrete mixer
4.	Grader	11.	Forklift truck
5.	Excavator	12.	Tractor
6.	Asphalt Sprayer	13.	Side-dump truck
7.	Crusher	14.	Dump truck

Table 4-10 List of Construction Equipment Owned by Local Contractors

Royco Industry	Nuku'alofa Contractors	Veti Motors
1. Loader	1. Loader	1. Backhoes
2. Roller	2. Roller	2. Loader
3. Bulldozer (D8)	3. Bulldozer (D8)	
4. Grader	4. Backhoes	
	5. Grader	

Table 4-11 List of Required Construction Materials

Item	Specifications	Unit	Quantity	Procurement place	Remarks
Stake material		m³	32.0	Tonga	
Miscellaneous metal items			As required	Tonga	
Fuel			As required	Tonga	
Engine Oil			required	Tonga	
Explosives	Kiri No.3, AN-FO	kg	15,500	Japan	3.45kg/10 m³ x45,000 m³
Detonators		ea	2,000	Japan	0.45ea/10 m³ x45,000 m³
Mixed concrete		m³	105.0	Tonga	
Reinforcing bars		tons	3.4	Tonga	
Forms		m²	64.5	Tonga	
Armour stones	1.2 tons/piece	m³	45,000	Tonga	Quarry volume
Rubble-mound stones	0.2 to 6kg/piece 80 to 120kg/piece	m³	20,000	Tonga	Quarry volume
Beach sand	Coral mixed sand	m³	55,000	Tonga	Quarry volume
Surveying instruments		set	1	Japan	Level, transit, etc.
Surveying tools		set	1	Japan	Poles, staves
Safety equipment		set	1	Japan	Barricades, helmets, etc.
Office supplies		set	1	Japan	
Office equipment		set	1	Japan	

Table 4-12 List of Required Construction Equipment

Name of Equipment	Specifications	Number Required	Quarrying	Loading & Trans-porting	Protec-tion Structure	Plain Road	Procure-ment Place	Remarks
Backhoes	0.6 m³	2	○		○		Japan	
Bulldozer	32 tons, with ripper	2	○				Japan	
Bulldozer	11 tons	1			○	○	Japan	
Wheel loader	2.3 m³, 1.7 m³	2	○	○			Japan	
Crawler crane	25 tons	3			○		Japan	
Air compressor	17 m³/min	1	○				Japan	
Crawler drill	180 kg	1	○				Japan	
Large-sized Breaker	1,300 kg	1	○				Japan	
Dump truck	11 tons	17		○			Japan	
Trailer		1	○		○	○	Tonga	
Truck	1.5 tons	1					Japan	Management purpose
Welder		1					Japan	Maintenance purpose
Compactor	50 to 60 kg	1			○		Japan	
Vibrator		1			○		Japan	
Chain saw		1	○		○		Japan	

4.5 Project Implementation Schedule

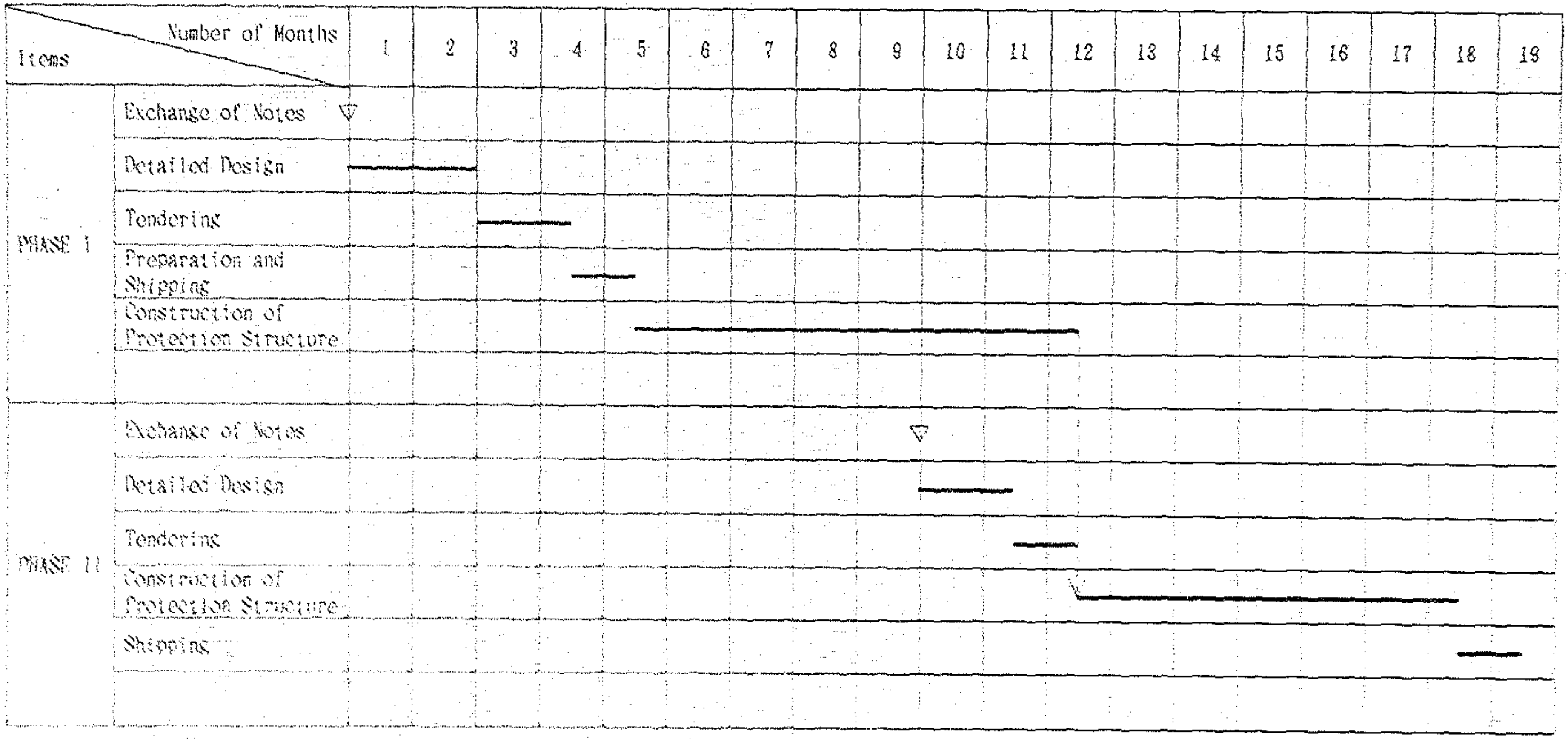


Fig. 4-23 Project Implementation Schedule

4.6 Management and Maintenance Costs

It is not anticipated that the Project's foreshore protection structure will incur any management or maintenance costs. If, however, due to the occurrence of an unforeseen extraordinarily high storm surge or wave that damages the structure, the Ministry of Works will undertake and bear the cost of repairs.

The Ministry of Works' organizational structure is shown in Fig. 3-3.

The Roads Division of the Ministry of Works is presently in charge of the management and maintenance of the country's roads, ports and harbours, and airports. They will also be responsible to effectively manage and maintain the Project's protection structure.

The Ministry of Works annually appropriates about one million yen for the management and maintenance budget. Additional budgetary funds to cover emergency situations can be requested, but need the approval of the Cabinet.

The rehabilitation of the damaged Queen Salote Wharf, the Yellow Pier, the Vuna Wharf access road, and the Nuku'alofa foreshore protection structure was handled expeditiously by the Ministry of Works. Therefore, the Ministry of Works will be able to manage and maintain the Project's protection structure without difficulty.

4.7 Project Cost Estimate

Estimated Project implementation costs are as follows:

Project costs to be borne by the Government of Tonga:
The total estimated Project costs to be borne by the Government of Tonga: T$ 12,800
The estimated breakdown is as follows:

(a) Installation of water and electric supply lines, and telephone cables to the construction liaison office: .....T$ 2,200
(b) Removal of shipwrecks: .... T$ 10,600

TOTAL T$ 12,800

CHAPTER 5 PROJECT EVALUATION

CHAPTER 5 PROJECT EVALUATION

The area behind the Nuku'alofa foreshore protection structure is Tonga's political and economic centre. It is also the area where a large number of people conduct their daily lives.

When Cyclone Issac struck the islands of Tonga it inflicted a tremendous amount of damage on the Nuku'alofa foreshore protection structure. Since that time, only a portion of the structure has been rehabilitated.

To leave the unrehabilitated portions of the structure in their present condition is to place the country's central functions and the people's lives and property in danger.

The propriety and implementation effects of the Project are evaluated as follows:

5.1 Project Implementation Effects

(1) Urgency:

As described above, the existing unrehabilitated protection structure poses a very dangerous situation.

The gravity type concrete parapet and rubble-mound of the western extension are either partially or completely destroyed over its entire length. Some of the area behind the structure is severely eroded.

If a cyclone was to hit the area, the unrehabilitated protection structure would be completely destroyed. If such was the case, not only would the areas behind these sections be destroyed but the areas behind the rehabilitated centre section would also be inundated.

As the areas behind the unrehabilitated sections are about 1.0 to 2.0 m lower than the top of the unrehabilitated structure, flood waters would not drain out easily. Furthermore, if Vuna Road, which is located behind the unrehabilitated protection structure and which is the largest arterial road in Nuku'alofa City were to be destroyed relief activities would be jeopardized.

As people's lives and property are at stake, and as Nuku'alofa City's ability to function is imperiled, the proposed Project's protection structure has become an urgent issue. It is believed, therefore, that the early implementation of the Project construction will have dramatic beneficial effects.

(2) Social and Economic Aspects

Presently, in the area behind the foreshore protection structure there is a construction boom going on that was inspired by a tourism related development plan -- the tourist trade is a mainstay of the Tongan economy. It is essential, therefore, to ensure the safety of this area in order that future urban development plans can be carried out.

(3) Citizen's Lives

By implementing construction of the Project's protection structure, a great contribution will be made towards protecting the residents' lives and property and for raising their standards of living.

(4) Protection Structure Construction Technology

Through Project implementation, knowledge of construction methods and equipment operations will be transferred to the local people. This knowledge can be effectively utilized for the future management and maintenance of the foreshore protection structure.

5.2 Propriety of Project Implementation

The Project foreshore protection structure was designed based on the highest deepwater wave 11.6 m that occured during the past 43 years. If a wave having the same magnitude were to hit the present protection structure, it is understandable that a wave overtopping discharge of 2.0m^3/m・sec would occur thereby destroying the structure.

The designed Project protection structure will allow for a wave overtopping discharge of less than 0.05 m^3/m・sec for a wave of similar magnitude. If such a wave were to occur, the Project protection structure would hold and provide sufficient protection against cyclone damage to the land behind it.

The Ministry of Works will be the Project Implementation agency ; It has longtime experience in constructing and managing Tongan infrastructures as well as implementing various development projects. Therefore, no problems should be encountered in implementing the Project.

As locally obtainable coral blocks and sand will be used as the basic construction materials for the protection structure, the material cost will be low and the management and maintenance of the structure will not be difficult.

Because it will be impossible to procure construction equipment in Tonga, it will be shipped in from Japan. Therefore, Project construction will be surely and safely completed within a prescribed period of time.

Normally, the Projects' protection structure will not require maintenance nor repair. However, if extraordinary high storm surges or waves inflict damages to the protection structure, the Ministry of Works, having experience in managing and maintaining the foreshore protection structure, will perform the maintenance and repair work.

The construction of the Project's protection structure will contribute greatly to the improvement of the Tongan people's livelihood and environment. The Project's financial rate of return, however, will be low.

The Government of Tonga would face financial problems if it were to finance the Project with its own budget or with borrowed funds. For this reason, it can be evaluated that the propriety of implementing the Project through the grant aid programme of the Government of Japan is extremly high.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The Nuku'alofa foreshore protection structure rehabilitation work began in 1983. Due to the substantial delays encountered in the Fourth Five-year Development Plan, only the centre section of the structure was rehabilitated. The remaining sections are in an unsatisfactory and dangerous condition.

The Project protection structure will contribute greatly to Nuku'alofa City's ability to carry out urban functions, to protecting the lives and property of its citizens and to upgrading the country's economy and stability. These positive effects of the Project agree with the long-term objectives of the Fifth Five-year Development Plan, ie., to upgrade the people's living standards, to achieve economic and social development, and to preserve the natural environment.

The Project's Basic Design Study was made by taking into account the land use conditions and the importance of the area behind the protection structure as well as determining the most economical way to build a safe Project structure.

In view of the above, it would be most appropriate and effective to implement the Project through the grant aid programme of the Government of Japan.

6.2 Recommendations

For effective Project implementation and for fulfilling the functions of the Project's protection structure, the Study Team proposes the following recommendations:

(1) The protection structure's western section should be constructed prior to the construction of its eastern section. The reasons for this are as follows:

- Wave height at the western extension is greater than at the eastern extension. Also, the western extension has more extensive damage than does the eastern extension.

- There are more houses behind the western extension than there are behind the eastern extension.

- The area behind the western extension was damaged by floods caused when Cyclone Issac hit Tonga.

- There are more lowland areas behind the western extension than behind the eastern extension.

(2) Earth-fill work for the planned coastal road that is to be behind the protection structure should be conducted considering the following:

- Measures should be taken to prevent earth-fill material from eroding through the foreshore protection structure; filter material or erosion-proof sheets should be used.

- The road slope and filled area should be made to allow for overtopped waves and rainwater to drain directly towards the ocean side.

- Earth-fill work should be accomplished as soon as possible for the sake of the protection structure's stability.

(3) The Foreshore protection structure at the east section of Queen Salote Wharf:
The existing foreshore protection structure at the east section of Queen Salote Wharf is partially destroyed and is in need of urgent rehabilitation. However, the rehabilitation of this section was excluded from the Project because of plans to expand Harbour. If there is a delay in implementing this expansion, a Zone C type foreshore protection structure should be built temporarily.

(4) Existing water supply and drainage pipes for fish ponds:
Water supply and drainage pipes for experimental fish ponds are installed on the existing foreshore protection structure. The new structure should not interfere with the functions of these pipes.

(5) Planned fish ponds

Seawater intake and drain pipes for the planned fish ponds will cross the Project's foreshore protection structure. After completing the detailed design for the planned fish ponds, officials of the bureaus related to fish pond construction and the Project's structure should discuss this matter.

(6) As the Project foreshore protection structure was designed by taking into account the structure's strength and various economic aspects, there is a possibility that some wave overtopping may occur under high wave conditions. Thus, the area behind the structure should be planned on being used for roads, parks, green zones, and walkways instead of for housing and office buildings.

(7) The Project's foreshore protection structure will not normally require maintenance and repair work. However, if subjected to extraordinarily high storm surges or waves, a patrol should conduct an inspection to locate possible damage. Upon the discovery of any damage, repair work should be accomplished as soon as the storm subsides.

Beach sand may move seaward during a storm. However, it is believed that the sand will gradually return to its original position through the action of small waves.

APPENDICES

APPENDICES

MINUTES OF DISCUSSIONS ON THE BASIC DESIGN STUDY FOR THE EXTENSION PROJECT OF NUKU'ALOFA FORESHORE PROTECTION IN THE KINGDOM OF TONGA

In response to the request of the Government of the Kingdom of Tonga, the Government of Japan decided to conduct a basic design study for the Extension Project of Nuku'alofa Foreshore Protection (hereinafter referred to as "the Project") and entrusted the study to the Japan International Cooperation Agency (JICA). JICA sent to the Kingdom of Tonga the study team headed by Mr Hiroshi Hashimoto, Director of the River Department, Public Works Research Institute, Ministry of Construction from 30 October to 19 November 1987.

The team had a series of discussions on the Project with the officials concerned of the Government of the Kingdom of Tonga and conducted a field survey in the Project area.

As a result of the study, both parties have agreed to recommend to their respective Governments that the major points of understanding reached between them, attached herewith, should be examined towards the realization of the Project.

Nuku'alofa, 6 November 1987

Mr Hiroshi Hashimoto
LEADER
BASIC DESIGN STUDY TEAM
JICA

Mr Sione Taumoepeau
DIRECTOR
MINISTRY OF WORKS

MINISTRY OF WORKS TONGA

ATTACHMENT

1. The objective of the Project:

   The objective of the Project is to construct the fore-shore protection structure in front of Nuku'alofa.

2. Responsible and coordinating Agency for the Project:

   Ministry of Foreign Affairs

   Implementing Agency for the Project:

   Ministry of Works

3. Project Sites:

   The Project sites are located at the northern coast of Tongatapu island as shown in Annex I.

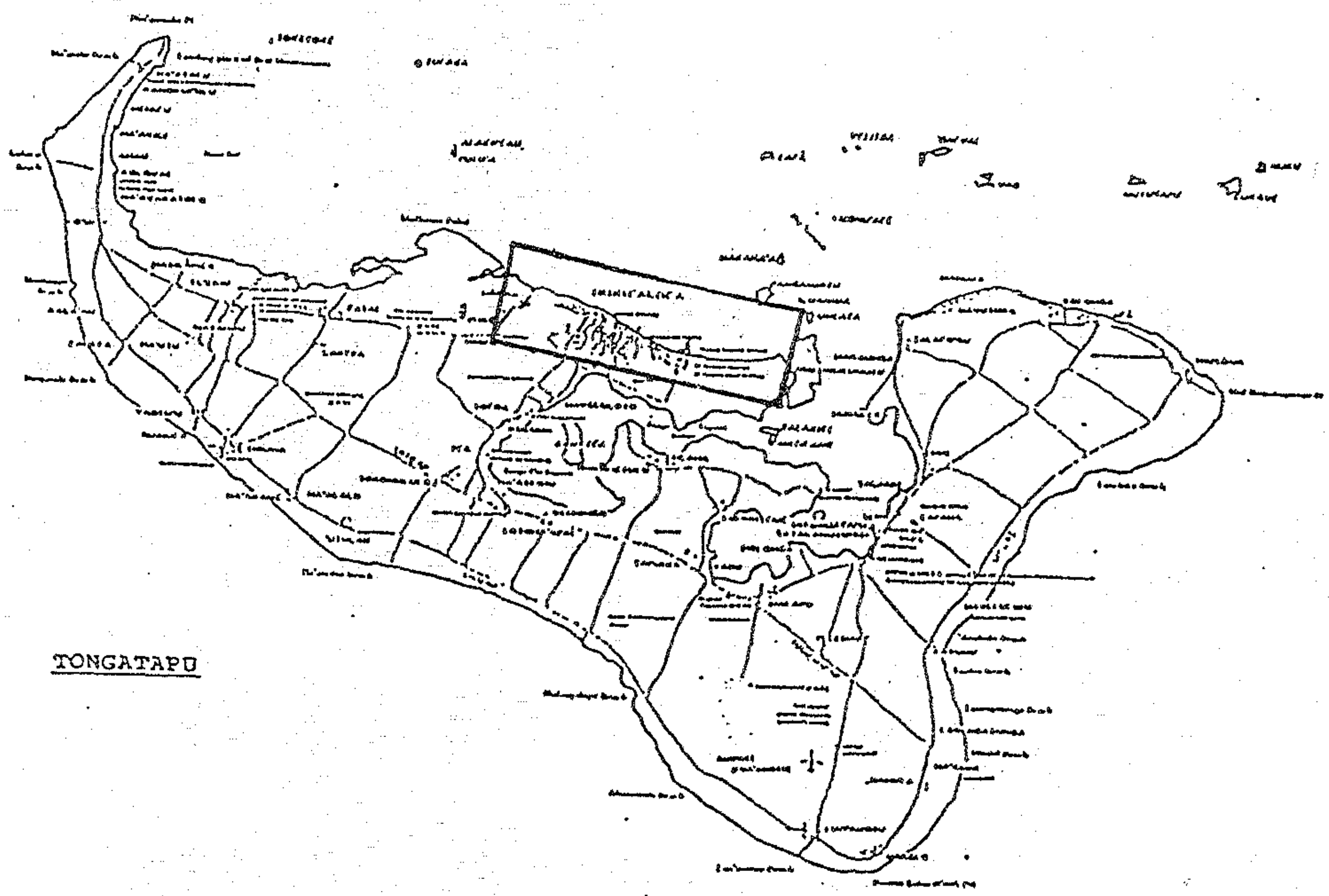
4. The basic concept of the structure is described in Annex II.

5. The team will convey to the Government of Japan the desire of the Government of Tonga that the latter will provide necessary measures and facility to cooperate in implementing the Project within the scope of Japan's Grant Aid Programme.

6. The Government of Tonga has understood the system of Japanese Grant Aid and the necessity of consulting services of a Japanese consulting firm and Contractor for the implementation of the Project.

7. The Government of Tonga will undertake to provide the necessary measures as listed in Annex IV on condition that Grant Aid by the Government of Japan is extended to the Project.

8. The Government of Tonga will undertake to provide the necessary budget and personnel for the proper and effective maintenance of the facility provided under the Grant Aid.


TONGATAPU

ANNEX II

FORESHORE PROTECTION

1. Eastern Extension: From the eastern tip of the coast-line to the east end of Army Harbour.

2. Western Extension: From the west of Royal Palace to the mouth of the swamp. (See Annex III).

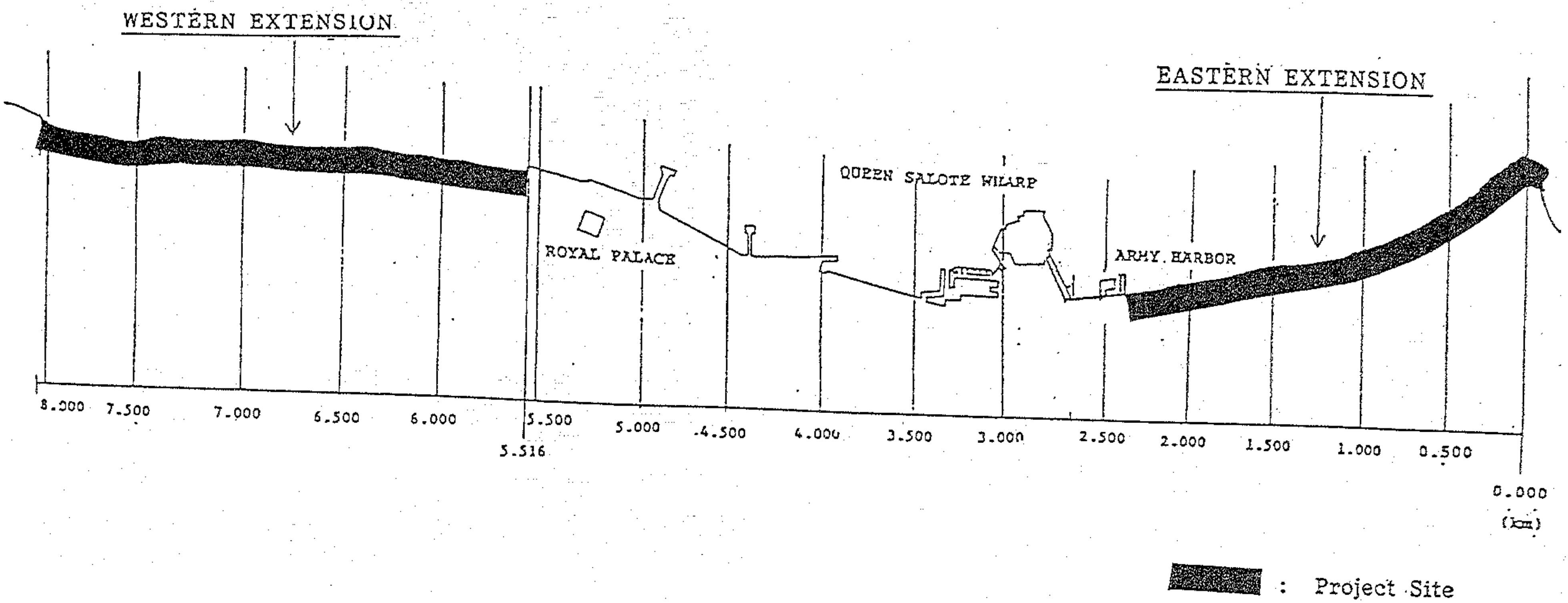
3. Alignment: The alignment shall be laid along the existing shoreline at minimum distance of 20 meters from the land side boundary line of planned road.

4. Basic design concept: The new foreshore structure shall be so designed as to resist forces from water level and waves, and to accept wave over-topping hinterland under the existreme condition of a cyclone.

5. Type of structure: The structure will be made of coral blocks with artificially nourished beach in front of it.

6. Construction limit: Reclamation between existing land and foreshore protection shall be excluded.

ANNEX III


WESTERN EXTENSION
EASTERN EXTENSION
ROYAL PALACE
QUEEN SALOTE WHARF
ARMY HARBOR
8.000
7.500
7.000
6.500
6.000
5.516
5.500
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
(km)
: Project Site

ANNEX IV

UNDERTAKINGS BY THE GOVERNMENT OF TONGA

1. To secure Project sites and other related facilities.

2. To provide the following temporary land for a construction liaison office (hereinafter referred to as "the office"), warehouse, stock yard, motor pool, etc. during the construction period. (400ft x 200ft)

3. To provide accessible roads to the Project site both from quarries and from the office.

4. To provide facilities for distribution of electricity, telephone and other incidental facilities to the office.

5. To ensure speedy unloading, tax exemption, customs clearance at ports of disembarkation in the Kingdom of Tonga, of the products used for the Projects.

6. To bear the following commissions to a Japanese foreign exchange bank for the banking services based upon the Banking Arrangement.
   a) Advising commission of authorization to pay
   b) Payment commission

7. To accord Japanese Nationals whose services may be required in connection with supply of the products and the services under the verified contract as may be necessary for their entry into the Kingdom of Tonga and stay therein for the performance of their work.

8. To maintain and use properly and effectively that the facilities constructed under the Grant.

9. To bear all the reasonable expenses other than those to be borne by the Grant, necessary for construction of the facilities.

10. To provide necessary data and information for a detail design.

APPENDIX II. Members of the Basic Design Study Team

Name	Task	Affiliation
Hiroshi Hashimoto	Team Leader	Director of the River Department, Public Works Research Institute, Ministry of Construction
Minoru Ekuni	Project Coordinator	Grant Aid Division Economic Cooperation Bureau Ministry of Foreign Affairs
Noriaki Nagao	Coastal Revetment Planner	Pacific Consultants International
Isao Hino	Seawater Level Analyst	Pacific Consultants International
Osamu Nogoshi	Survey Supervisor	Pacific Consultants International
Kazuo Fukase	Cost Estimator	Pacific Consultants International

APPENDIX III. Schedule of the Study Team

Date (1987)	Activities
Oct. 30, Friday	Team members departed Narita for Nadi
Oct. 31, Saturday	Arrived at Nadi Departed Nadi for Suva Arrived at Suva Paid a courtesy visit upon JICA and the Embassy of Japan (EOJ)
Nov. 1, Sunday	Held a meeting with JICA and EOJ personnel. Held a meeting among the Study Team members and confirmed study items
Nov. 2, Monday	Held a meeting among the Study Team members. Departed Suva for Tonga via Nadi Arrived at Tonga
Nov. 3, Tuesday	Paid a courtesy visit upon the Ministry of Foreign Affairs of Tonga. Submitted and explained th inception report to the Ministry of Works (MOW). Paid a courtesy visit upon the Tonga Defence Service Office. Installed a tide gauge and prepared for surveying.
No. 4, Wednesday	Inspected the Project Site. Conducted quarry surveys and levelling surveys on reef.
Nov. 5, Thursday	Held a meeting with the officials concerned of MOW about the protection structure alignment and the boundary of the protection structure construction. Confirmed the construction boundary at the Project Site. Collected natural condition data and construction related data. Prepared the Minutes of Discussions.
Nov. 6, Friday	The Study Team Leader and the Director of the Ministry of Works signed the Minutes of Discussions at the MOW office. Visited the Ministry of Foreign Affairs and explained the progress of the study. Conducted topographic surveys and collected social and economic related data. Held a discussion about the protection structure cross sections among the Study Team members.

Date (1987)	Activities
Nov. 7, Saturday	Team Leader, Dr. Hashimoto, and the Project Coordinator Mr. Ekuni, departed Tonga for Suva. Conducted cross section surveys of the existing protection structure. Classified collected data and held a meeting among the Study Team members.
Nov. 8, Sunday	Conducted cyclone damage survey at the western part of Tongatapu Island. Visited local contractors and conducted construction equipment survey.
Nov. 9, Monday	Team Leader, Dr. Hashimoto, and Project Coordinator, Mr. Ekuni, visited JICA and EOJ and explained the progress of the field surveys and departed for Narita. Cnducted cross section an levellig surveys. Collected data related to construction materials and equipment. Conducted cross section and level survey of the new protection structure.
Nov. 10, Tuesday	Confirmed a bench mark at the Land Survey Division. Conducted cross section surveys of rehabilitated protection structure. Studied about the damages caused by Cyclone Issac at the Tonga Chronicle. Requested MOW social, economic, nature and construction situation related data.
Nov. 11, Wednesday	Conducted detailed reconnaissance survey in the entire Project Site. Conducted seabed material and cross section surveys.
Nov. 12, Thursday	Collected survey coordinate data at the Land Survey Division Office. Conducted levelling survey in the Royal Palace grounds. Paid a courtesy visit upon the Harbour Master, Weather Bureau, and the Ministry of Labour, Commerce and Industries.
Nov. 13, Friday	Prepared the Minutes of Meetings. Conducted cross section survey and classified collected data. Held a meeting among the Study Team members.

Date (1987)	Activities
Nov. 14, Saturday	Conducted quarry survey (material sampling). Conducted sounding survey and installed surveying marks. Inspected the MOW's workshop. Team member, Mr. Nagao, departed for Fiji.
Nov. 15, Sunday	Conducted cyclone damage survey in the eastern part of the island.
Nov. 16, Monday	Visited the Government Printing Office and the Statistics Department. Conducted sounding and offshore reef surveys.
Nov. 17, Tuesday	Team member, Mr. Nagao, visited JICA and EOJ in Suva and explained the progress of field surveys. Mr. Nagao collected construction situation information, weather, social, and economic related data in Fiji. Visited the Fisheries Agency and conducted cross section surveey. Obtained survey coordinate calculation sheets at the Land Survey Office.
Nov. 18, Wednesday	Obtained data and information related to construction situations and the protection structure's maintenance and management system. Completed tide observation survey. Mr. Nagao departed for Australia. Messrs. Hino, Nogoshi, and Fukase departed for New Zealand.
Nov. 19, Thursday	Study Team members departed from Australia and New Zealand and arrived at Tokyo.

APPENDIX IV. List of Interviewed Personnel

Ministry of works	Director	Mr. Sione Taumoepeau
	Chief Engineer	Mr. Fintan Mac Manus
	Road Engineer	Mr. Pita Moala
	Surveyor	Mr. Nuku
Ministry of Foreign Affairs	Secretary	Mr. S.T. Taumoepeau
	Acting Secretary	Mr. The Hon. S.M. Tuita
Tonga Defence Service	Commander	Lt. Col. F. Tupou
Land Survey and Natural Resources	Director	Mr. Etueni Tupou
	Secretary	Mr. Sione Tongilava
	Gov. Surveyor	Mr. Tevita Malolo
	District Surveyor	Mr. Aisake Folaumoetui
Ministry of Labour, Commerce and Industries		Mr. V.P. Fotu
Fisheries Agency	Officer	Mr. Viliami Langi
Meteorological Service	Director	Mr. Paul Cheesman
Port and Harbour Bureau	Harbour Master	Mr. Sioeli Fotu
JICA Fiji Office	Resident Representative	Mr. Yoshio Yoshida
Japanese Embassy in Fiji	Envoy Extraordinay and Ambassador Plenipotentiary	Mr. K. Isogai
	Third-class Secretary	Mr. T. Ueshima
Australian Consultant	Associate Director	Mr. Michael Rogers

APPENDIX V. Fifth Five-Year Development Plan (1986 - 1990)

Tongatapu	Ha'apai	Vava'u	Regions/Sectors
-Queen Salote Wharf Tug -Faua Harbour Shipway & Boatlift -Queen Salote Wharf Completion -QSW Cargo Handling Equipment -Coastal Protection Nuku'alofa -Pilot Launch -Fanga'uta Lagoon Causeway Study -Roads		-Small Boat Facilities Neiafu -Neiafu Harbour Entrance Improvement -Roads -Vaipuua Causeway	Ministry of Works
-Airport Expansion -Terminal Improvement -Runway Emergency Repair -Runway Resealing -Security and Safety Equip. -Comms. & Navaids Equip. -Fire Service Improve -Control Tower -Friendly Islands Airways Hangar	-Airport Terminal -Airport Fire Tender -Airport Comms and Navaids -Airport Runway Upgrading	-Runway Lights -Terminal Expansion -Runway Sealing -Communication and Navaids Equip. -Fire Service and Secure -Control Tower -Runway Extension	Civil Aviation
-Power Reticulation Extn. -Steam Generator D.C.F.	-Power Reticulation Expansion	-Power Reticulation Extension	Energy
-Small Industry Centre Expansion -Desiccated Coconut Factory -TOB Snackfood Factory		-Small Industry Centre	Industry
-Rural Telecommunications Improvement -Telephone and Telex Equipment	-Rural Telecommunications Improvement	-Rural Telecommunications Improvement -Telephone and Telex	Tele-communications
-Village Water Scheme Improvement	-Dessalination Study and Pilot Programs -Domestic Water Tanks	-Resources Neiafu -Domestic Water Tanks	Natural Resources
• Vaiola Hospital -Dental Clinic -Physiotherapy -Psychiatry Unit -Dispensary -Xray Machine -Staff Accommodation -Rainwater Rese -Others: -Urban Health Centre -Pharmacy and Medical Store Improvement -Sewage Disposal Vehicles -Refuse Disposal Vehicles -Health Training Centre	-Diagnostic Services Niu'ui Hospital	-Health Launch -Dental Mobil Clinics -Hospital Staff Accommodation	Health
-Agric. Extension Centre -Agric. Machinery Workshop -Banana Expert Scheme -Quarantine Facilities	Agricultural Extension Centre	Quarantine Facilities	Agriculture & Forestry

VI Meteorological Data (New Zealand Meteorological Services)

(1) Rainfall (Nuku'alofa City)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1945	142	182	138	152	182	99	113	132	73	21	37	12	1,283
1946	10	101	174	33	139	30	49	89	11	276	40	36	988
1947	118	248	94	73	84	74	142	69	287	115	32	272	1,608
1948	255	212	112	225	49	226	28	44	120	22	331	256	1,880
1949	243	217	201	210	24	26	103	203	66	83	7	251	1,634
1950	245	249	334	210	17	67	259	148	155	131	146	132	2,097
1951	202	564	304	104	127	72	104	26	187	42	21	3	1,756
1952	582	443	289	126	25	153	164	130	100	21	119	154	2,306
1953	128	198	193	288	69	116	49	36	23	39	72	115	1,326
1954	110	218	114	450	65	242	38	133	302	133	49	581	2,435
1955	197	83	388	78	61	64	122	122	38	103	289	220	1,765
1956	259	342	340	334	153	27	190	86	133	274	150	6	2,294
1957	401	447	131	48	74	242	69	147	94	47	62	70	1,832
1958	31	306	269	138	38	7	118	116	56	337	138	77	1,631
1959	203	61	366	118	114	84	56	273	184	192	41	106	1,798
1960	70	328	469	194	101	163	102	34	54	133	207	221	2,081
1961	372	228	242	112	47	58	83	152	89	65	202	66	1,716
1962	382	188	263	111	139	75	85	53	41	70	116	242	1,765
1963	145	147	227	69	203	102	60	150	107	135	11	24	1,380
1964	99	288	280	141	117	8	256	102	191	105	255	215	2,057
1965	357	289	211	40	210	31	67	131	76	129	178	17	1,776
1966	85	93	24	456	63	45	52	46	181	180	29	159	1,477
1967	189	185	243	283	55	25	63	32	152	147	25	15	1,254
1968	527	244	296	96	59	85	27	204	92	93	26	51	1,800
1969	177	296	348	85	22	43	136	17	132	50	52	5	1,362
1970	179	373	137	110	96	83	63	57	61	373	106	352	1,976
1971	187	210	248	176	188	36	18	112	198	131	368	783	2,685
1972	197	162	386	124	166	151	160	209	341	343	33	167	2,373
1973	22	256	206	303	37	102	102	25	207	117	343	294	2,023
1974	247	462	279	346	78	115	67	90	196	452	151	74	2,552
1975	203	83	174	163	140	135	95	160	84	133	322	54	1,746
1976	252	371	231	365	94	50	61	59	212	129	246	46	2,116
1977	377	284	266	43	46	17	73	130	56	17	6	68	1,363
1978	48	151	214	248	204	48	52	250	102	272	225	72	1,930
1979	115	77	261	183	208	243	75	237	271	68	—	—	1,730
1980	139	122	291	267	45	111	144	161	189	399	114	143	2,126
1981	60	96	118	72	102	94	23	56	66	54	90	41	874
1982	336	236	253	136	241	58	87	148	75	34	19	57	1,733
1983	37	102	73	9	26	69	118	66	41	108	24	165	838
1984	222	217	71	126	26	75	70	41	142	64	80	177	1,311
1985	97	162	212	54	102	140	56	27	28	53	3	427	1,363
1986	12	69	113	285	118	215	62	92	16	57	25	199	1,269
1987	57	204	169	17	85	35	54	17	25				

(2) Temperature (Nuku'alofa City)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1949		26.1	25.7	25.2	23.2	22.4	20.9	21.1	21.2	21.8	23.9	24.9	
1950	25.5	26.8	26.1	24.9	22.9	23.9	21.6	22.0	21.7	22.9	25.4	25.8	24.1
1951	24.6	24.4	25.7	24.4	22.3	22.2	19.6	20.8	20.7	22.1	24.1	25.4	23.0
1952	26.3	26.0	26.2	24.4	24.2	23.4	22.1	21.1	21.5	22.6	24.3	26.2	24.1
1953	26.8	26.2	26.3	25.9	23.4	21.3	21.6	20.4	21.1	22.7	24.4	24.4	23.7
1954	25.4	25.2	25.7	25.3	24.3	22.7	21.9	21.1	22.2	22.9	23.2	25.4	23.8
1955	24.8	26.4	25.7	25.2	23.8	22.8	21.6	22.4	22.9	22.8	21.7	25.4	23.8
1956	25.0	26.0	25.4	25.1	23.6	21.8	21.7	21.5	22.3	24.1	25.2	24.8	23.9
1957	25.8	25.7	25.3	24.9	23.1	21.8	20.3	21.3	22.4	22.1	22.8	24.4	23.3
1958	24.9	25.9	26.4	24.8	23.3	22.1	20.9	21.7	21.0	22.3	23.1	24.0	23.4
1959	25.6	26.0	24.9	25.8	22.8	22.4	21.4	22.0	22.0	23.6	23.5	24.8	23.7
1960	25.7	25.8	25.9	24.5	22.8	22.1	21.3	21.3	22.5	22.4	23.7	24.6	23.6
1961	25.7	27.6	25.6	25.6	23.5	23.3	22.0	21.5	23.2	21.6	23.4	24.3	23.9
1962	25.2	26.2	26.0	24.7	23.3	21.0	20.9	21.0	21.2	23.2	23.4	24.4	23.4
1963	25.7	25.8	25.8	25.1	22.6	23.1	22.2	20.6	20.7	21.0	23.4	24.7	23.4
1964	25.9	25.7	25.3	24.8	23.5	23.0	21.1	22.2	22.3	23.1	24.4	24.1	23.8
1965	25.6	25.8	25.5	24.4	22.9	21.3	20.9	20.4	20.1	21.2	22.1	24.5	22.9
1966	25.2	25.2	26.2	24.5	22.6	21.9	23.6	20.1	20.9	21.3	22.4	24.0	23.3
1967	25.6	26.7	26.2	25.0	22.2	20.7	20.4	22.2	22.9	22.3	23.7	24.8	23.6
1968	25.7	26.9	26.3	23.9	22.8	24.1	22.6	21.3	21.2	22.2	23.3	24.9	23.8
1969	24.9	26.7	26.3	24.6	22.3	21.9	19.4	20.4	22.2	22.1	22.9	24.2	23.2
1970	26.0	25.4	26.3	25.4	23.8	23.2	21.9	21.2	22.4	23.2	23.9	24.8	24.1
1971	26.0	25.8	26.8	25.9	26.1	23.3	21.6	22.2	22.5	23.8	25.1	24.3	24.3
1972	25.5	26.0	26.8	25.1	23.3	21.7	20.3	21.1	21.7	21.9	23.7	25.2	23.5
1973	26.7	27.3	26.3	25.1	23.8	24.0	22.2	22.4	22.8	23.5	24.9	26.5	24.6
1974	27.4	26.4	26.3	24.4	23.7	23.0	22.2	22.0	23.1	24.7	25.8	25.6	24.6
1975	26.5	26.4	26.2	25.0	24.0	22.6	22.2	22.2	23.6	24.8	24.6	24.0	24.5
1976	26.9	27.0	25.8	25.4	23.2	21.7	20.7	21.2	21.0	22.8	23.7	24.1	23.6
1977	26.3	26.7	26.1	24.5	22.4	22.6	21.2	20.6	20.1	21.3	22.8	25.6	23.4
1978	26.0	25.3	25.8	24.2	23.3	22.8	21.5	21.1	21.0	22.6	22.7	24.8	23.5
1979	26.2	27.2	26.6	24.4	23.6	22.8	20.7	20.7	22.4	23.7	23.5		
1980	25.8	27.1	27.2	25.8	22.6	21.7	21.1	21.0	22.7	23.6	24.0	24.3	23.9
1981	26.7	26.5	26.7	25.2	23.9	22.6	20.9	21.6	20.7	22.3	24.3	26.4	24.0
1982	26.3	26.9	26.3	25.3	23.9	22.5	21.0	20.7	21.0	22.1	23.9	24.5	23.7
1983	25.5	26.3	26.6	24.9	23.3	22.8	21.5	21.1	21.9	22.6	24.1	25.5	23.8
1984	26.2	27.4	26.2	25.8	24.5	23.5	22.0	21.8	22.2	21.6	23.3	25.4	24.2
1985	25.5	27.8	26.7	25.6	23.0	21.3	21.5	22.1	21.6	22.8	24.3	24.9	23.9
1986	25.4	26.3	26.5	24.7	22.2	22.1	20.3	20.5	21.2	22.8	23.5	25.4	23.4
1987	26.0	27.0	25.4	25.0	22.8								

Ⅶ Result of the Tidal Observation

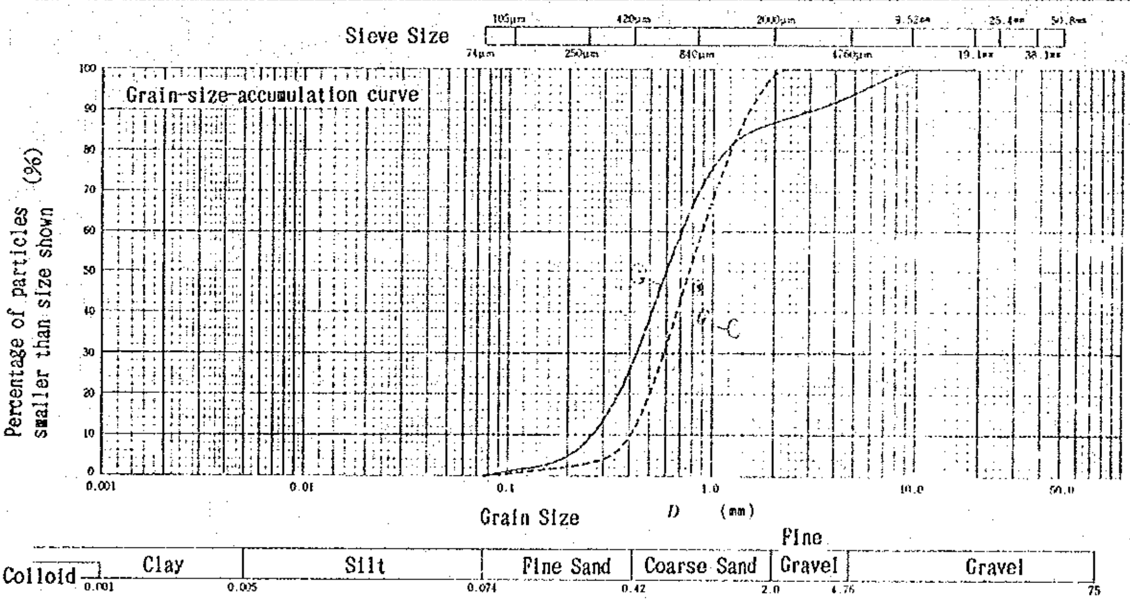
	11/3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0 : 00		2.80	2.80	2.94	3.21	3.47	3.67	3.80	3.95	4.00	3.90	3.82	3.70	3.52	3.30	3.15
1 : 00		2.93	2.78	2.73	2.90	3.12	3.31	3.51	3.72	3.90	3.90	3.90	3.80	3.70	3.50	3.20
2 : 00		3.20	2.90	2.71	2.71	2.85	3.00	3.20	3.45	3.70	3.80	3.90	3.90	3.87	3.70	3.42
3 : 00		3.50	3.20	2.90	2.71	2.75	2.81	2.95	3.20	3.45	3.65	3.80	3.90	3.95	3.82	3.65
4 : 00		3.80	3.50	3.18	2.90	2.80	2.80	2.80	3.00	3.20	3.40	3.60	3.80	3.90	3.90	3.80
5 : 00		4.04	3.80	3.52	3.21	3.05	2.95	2.85	2.90	3.00	3.20	3.40	3.60	3.80	3.90	3.85
6 : 00		4.10	4.00	3.81	3.52	3.39	3.20	3.03	2.91	2.95	3.00	3.17	3.40	3.62	3.80	3.80
7 : 00		4.00	4.10	4.05	3.86	3.68	3.49	3.28	3.10	2.97	2.95	3.00	3.20	3.45	3.60	3.66
8 : 00		3.80	4.00	4.10	4.01	3.94	3.72	3.60	3.31	3.13	3.03	3.00	3.10	3.20	3.40	3.50
9 : 00		3.50	3.78	4.00	4.10	4.10	3.95	3.75	3.55	3.35	3.15	3.10	3.10	3.14	3.20	3.31
10 : 00		3.20	3.49	3.75	3.95	3.99	4.05	3.95	3.80	3.60	3.39	3.28	3.17	3.10	3.10	3.17
11 : 00	2.94	2.95	3.19	3.41	3.70	3.80	3.92	4.00	3.91	3.80	3.60	3.49	3.34	3.22	3.10	3.07
12 : 00	2.94	2.81	2.95	3.12	3.40	3.50	3.71	3.90	3.91	3.90	3.80	3.70	3.60	3.40	3.27	
13 : 00	3.10	2.90	2.85	2.90	3.16	3.22	3.49	3.70	3.80	3.90	3.90	3.82	3.78	3.62	3.46	
14 : 00	3.40	3.11	2.95	2.90	3.00	3.10	3.30	3.45	3.65	3.85	3.90	3.90	3.90	3.85	3.71	
15 : 00	3.70	3.50	3.20	3.00	2.98	3.00	3.11	3.25	3.45	3.67	3.80	3.90	3.95	3.95	3.90	
16 : 00	3.96	3.83	3.52	3.22	3.12	3.10	3.09	3.10	3.26	3.50	3.60	3.80	3.95	4.00	4.00	
17 : 00	4.12	4.10	3.85	3.55	3.40	3.30	3.18	3.12	3.15	3.30	3.40	3.60	3.80	3.93	4.00	
18 : 00	4.16	4.21	4.10	3.81	3.73	3.60	3.30	3.21	3.13	3.18	3.26	3.40	3.60	3.80	3.85	
19 : 00	3.98	4.20	4.20	4.10	4.00	4.00	3.59	3.42	3.20	3.15	3.18	3.25	3.40	3.60	3.70	
20 : 00	3.70	4.00	4.19	4.20	4.20	4.13	3.89	3.65	3.40	3.25	3.20	3.20	3.30	3.40	3.45	
21 : 00	3.40	3.67	3.99	4.15	4.20	4.20	4.08	3.80	3.61	3.42	3.30	3.20	3.20	3.25	3.28	
22 : 00	3.08	3.31	3.63	3.90	4.09	4.10	4.12	4.02	3.82	3.65	3.49	3.33	3.23	3.15	3.15	
23 : 00	2.89	3.00	3.25	3.59	3.80	3.92	4.05	4.05	3.97	3.80	3.69	3.50	3.32	3.20	3.05	

Values are measured in scale of staff.

JIS A 1204	Result of soil Grain Size Analysis
Test Name & Sampling Location	Date :
	Tested by : Susumu Narita

Sample No. Depth	No. 1－1 (m～ m)		No. 2－1 (m～ m)	
	Grain Size mm	Percent by Weight %	Grain Size mm	Percent by Weight %
Sieving	50.8		50.8	
	38.1		38.1	
	25.4		25.4	
	19.1		19.1	
	9.52	100.0	9.52	
	4.76	93.6	4.76	100.0
	2.00	87.1	2.00	99.0
	0.84	69.7	0.84	57.0
	0.42	29.4	0.42	12.3
	0.25	9.6	0.25	3.7
	0.105	1.9	0.105	1.3
	0.074	0.4	0.074	0.5
Hydrometer Reading				

Sample No. Depth	No. 1－1 (m～ m)		No. 2－1 (m～ m)	
Grain less than 4.76mm %	6.4	12.9	0.0	1.0
Fine gravel (4.76 ～2mm)%	6.5		1.0	
Coarse sand (2～ 0.42mm)%	57.7	86.7	86.7	98.5
Fine sand(0.42～0.074mm)%	29.0		11.8	
Silt (0.074 ～ 0.005 mm)%	0.4		0.5	
Clay (less than 0.005mm) %				
Colloid (less than 0.001mm) %				
Percentage of particles smaller than 2000 μm %	87.1		99.0	
Percentage of particles smaller than 420 μm %	29.4		12.3	
Percentage of particles smaller than 74 μm %	0.4		0.5	
Maximum grain size mm	9.5200		4.7600	
60% grain size mm	0.6980		0.8770	
30% grain size mm	0.4241		0.5772	
10% grain size mm	0.2539		0.3928	
Uniformity Coefficient Uc	2.75		2.23	
Curvature Coefficient Uc'	1.01		0.97	
Specific gravity of soil grain Gs	2.788		2.815	
Used dispersing agent				



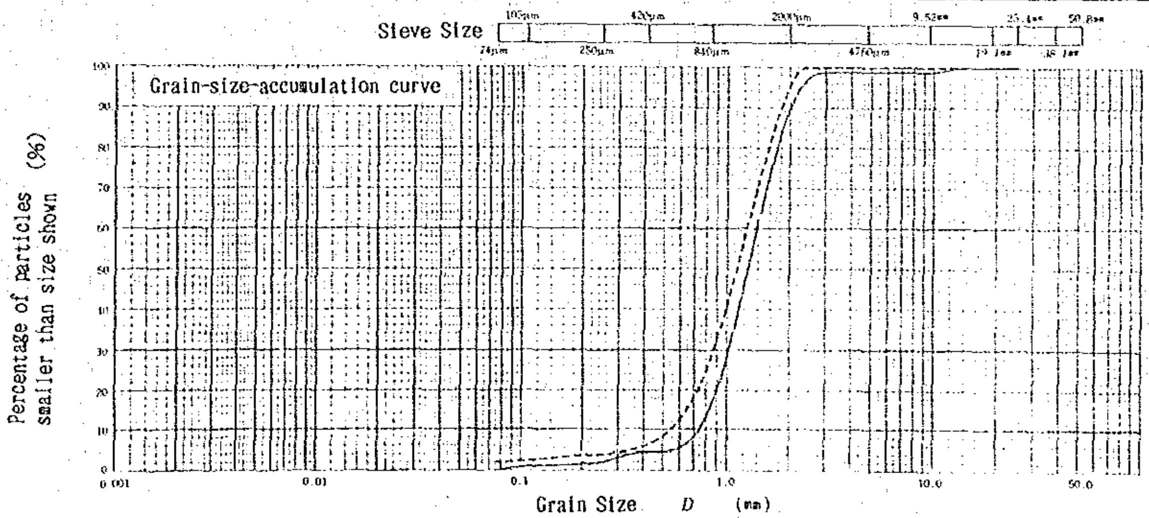
JIS A 1204	Result of soil Grain Size Analysis

Test Name & Sampling Location .... Date : ....

Tested by : Susumu Narita

Sample No. Depth	No. 3－1 (m～ m)		No. 4－1 (m～ m)	
	Grain Size mm	Percent by Weight %	Grain Size mm	Percent by Weight %
Sieving	50.8		50.8	
	38.1		38.1	
	25.4		25.4	
	19.1	100.0	19.1	
	9.52	98.1	9.52	100.0
	4.76	94.3	4.76	98.9
	2.00	89.8	2.00	95.2
	0.84	16.5	0.84	28.5
	0.42	5.2	0.42	7.1
	0.25	2.8	0.25	4.7
	0.105	1.7	0.105	3.2
	0.074	0.7	0.074	2.6
Hydrometer Reading				

Sample No. Depth	No. 3－1 (m～ m)		No. 4－1 (m～ m)	
Grain less than 4.76mm %	5.7	10.2	1.1	4.8
Fine gravel (4.76 ～2mm)%	4.5		3.7	
Coarse sand (2～ 0.42mm)%	84.6	89.1	88.1	92.6
Fine sand(0.42～0.074mm)%	4.5		4.5	
Silt (0.074 ～ 0.005 mm)%	0.7		2.6	
Clay (less than 0.005mm) %				
Colloid (less than 0.001mm) %				
Percentage of particles smaller than 2000 μm %	89.8		95.2	
Percentage of particles smaller than 420 μm %	5.2		7.1	
Percentage of particles smaller than 74 μm %	0.7		2.6	
Maximum grain size mm	19.1000		9.5200	
60% grain size mm	1.3858		1.2409	
30% grain size mm	1.0101		0.8574	
10% grain size mm	0.7259		0.5212	
Uniformity Coefficient Uc	1.91		2.38	
Curvature Coefficient Uc'	1.01		1.14	
Specific gravity of soil grain Gs	2.785		2.818	
Used dispersing agent				



Colloid	Clay	Silt	Fine Sand	Coarse Sand	Fine Gravel	Gravel
0.001	0.005	0.074	0.42	2.0	4.76	75

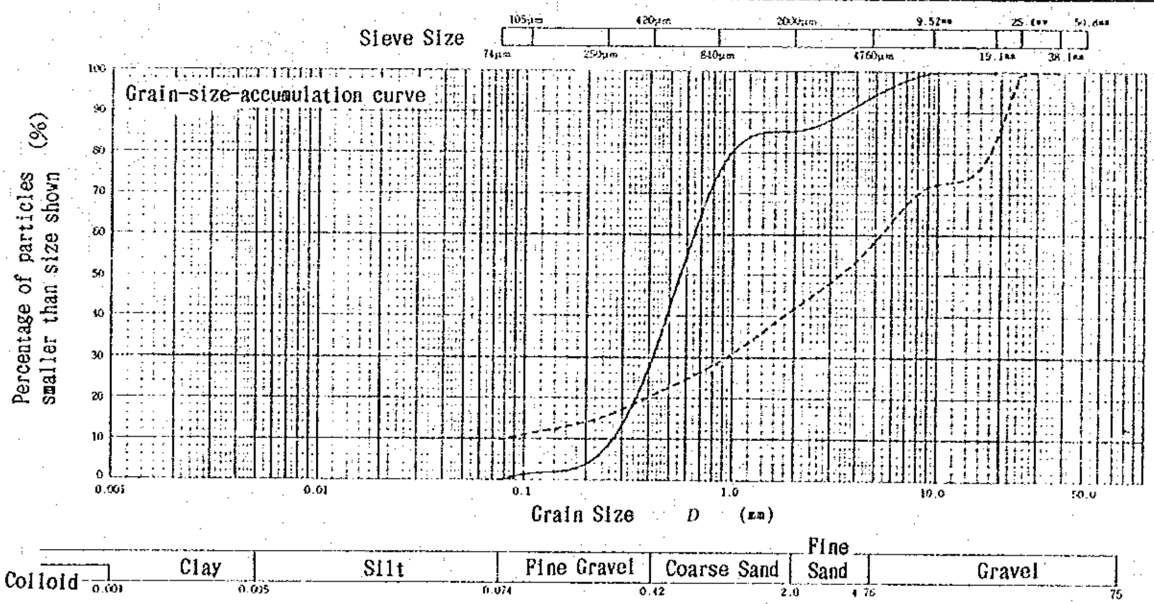
JIS A 1204	Result of soil Grain Size Analysis

Test Name & Sampling Location .... Date : ....

Tested by : Susumu Narita

Sample No. Depth	No. 5 − 1 (m~ m)	
	Grain Size mm	Percent by Weight %
Sieving	50.8	
	38.1	
	25.4	
	19.1	
	9.52	100.0
	4.76	94.0
	2.00	85.7
	0.84	75.4
	0.42	31.5
	0.25	9.1
	0.105	2.5
	0.074	0.9
Hydrometer Reading		

Sample No. Depth	No. 5 − 1 (m~ m)	
Grain less than 4.76mm %	6.0	14.3
Fine gravel (4.76 ~2mm)%	8.3	
Coarse sand (2~ 0.42mm)%	54.2	84.8
Fine sand(0.42~0.074mm)%	30.6	
Silt (0.074 ~ 0.005 mm)%	0.9	
Clay (less than 0.005mm) %		
Colloid (less than 0.001mm) %		
Percentage of particles smaller than 2000 μm %	85.7	
Percentage of particles smaller than 420 μm %	31.5	
Percentage of particles smaller than 74 μm %	0.9	
Maximum grain size mm	9.5200	
60% grain size mm	0.6395	
30% grain size mm	0.4096	
10% grain size mm	0.2581	
Uniformity Coefficient Uc	2.48	
Curvature Coefficient Uc'	1.02	
Specific gravity of soil grain Gs	2.821	
Used dispersing agent		



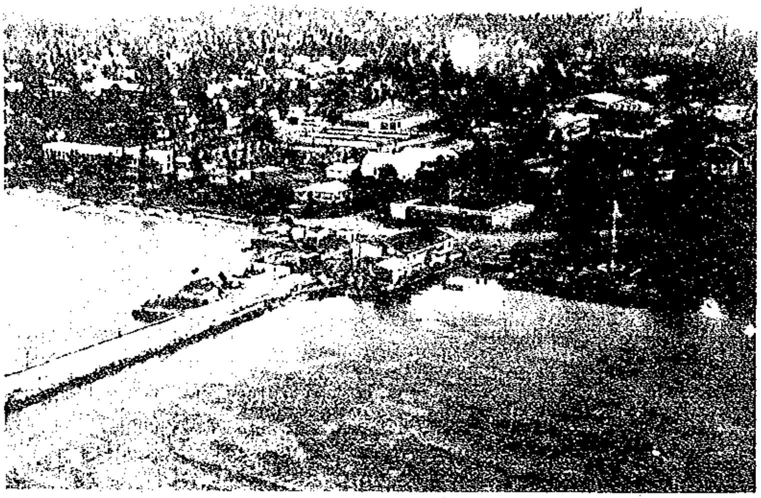
JIS A 1202	Specific Gravity Test of Soil Particles						
Test Name & Sampling Location				Date :			
				Tested by : Susumu Narita			
Sample No. and Depth		No. 1 − 1 (m〜 m)			No. 2 − 1 (m〜 m)		
Test No.		1	2	3	1	2	3
Pycnometer No.		146	147	148	33	34	35
Weight of oven dried soil (or Saturated Soil) +distilled Water, and pycnometer mb g		169.9046	168.3073	167.5082	169.3800	161.6419	161.5169
Soil temperature when mb was measured T℃		17.0	17.0	17.0	17.0	17.0	17.0
Weight of oven dried soil in pycnometer ms g	Container No.						
	Weight of Dry soil and container g						
	Weight of container g						
	ms g	32.3738	33.2371	32.9926	30.7986	31.5583	30.4927
Converted weight of distilled water and pycnometer at T℃ ma g		149.0578	146.9740	146.4473	149.5840	141.2607	141.8173
ms + (ma − mb) g		11.5270	11.9038	11.9317	11.0026	11.1771	10.7931
Specific gravity of soil particles at T℃ $Gs(T℃/T℃) = \frac{ms}{ms + (ma - mb)}$		2.8085	2.7921	2.7651	2.7992	2.8235	2.8252
Correction coefficient K		0.9997	0.9997	0.9997	0.9997	0.9997	0.9997
Specific gravity of soil particles at 15 ℃ Gs(T℃/15℃) = K・Gs(T℃/T℃)		2.8077	2.7913	2.7643	2.7984	2.8226	2.8244
Average		Specific Gravity (T℃/15℃) = 2.7878			Specific Gravity (T℃/15℃) = 2.8151		
Specific gravity of water at T℃ GT		0.9988	0.9988	0.9988	0.9988	0.9988	0.9988
Specific gravity of soil particles at 4℃ Gs(T℃/4℃)=GT・Gs(T℃/T℃)		2.8052	2.7888	2.7618	2.7959	2.8201	2.8218
Average		Specific Gravity (T℃/4℃) = 2.7853			Specific Gravity (T℃/4℃) = 2.8126		
Remarks							

Sample No. and Depth		No. 3－1 (m～ m)			No. 4－1 (m～ m)		
Test No.		1	2	3	1	2	3
Pycnometer No.		42	43	44	76	77	78
Weight of oven dried soil (or Saturated Soil) +distilled Water. and pycnometer mb g		164.5499	154.6057	156.4214	164.0907	159.1231	159.6486
Soil temperature when mb was measured T℃		17.0	17.0	17.0	17.0	17.0	17.0
Weight of oven dried soil in pycnometer ms g	Container No.						
	Weight of Dry il and container so g						
	Weight of container g						
	ms g	21.4958	21.5717	20.9228	20.6109	21.0299	20.9602
Converted weight of distilled water and pycnometer at T℃ ma g		150.7571	140.8023	142.9983	150.8344	145.5428	146.0920
ms + (ma －mb) g		7.7030	7.7683	7.4997	7.3546	7.4496	7.4036
Specific gravity of soil particles at T℃ $Gs(T℃/T℃) = \frac{ms}{ms + (ma - mb)}$		2.7906	2.7769	2.7898	2.8024	2.8229	2.8311
Correction coefficient K		0.9997	0.9997	0.9997	0.9997	0.9997	0.9997
Specific gravity of soil particles at 15 ℃ Gs(T℃/15℃) ＝K・Gs(T℃/T℃)		2.7897	2.7760	2.7890	2.8016	2.8221	2.8302
Average		Specific Gravity (T℃/15℃) ＝ 2.7849			Specific Gravity (T℃/15℃) ＝ 2.8180		
Specific gravity of water at T℃ GT		0.9988	0.9988	0.9988	0.9988	0.9988	0.9988
Specific gravity of soil particles at 4℃ Gs(T℃/4℃)＝GT ・Gs(T℃/T℃)		2.7872	2.7736	2.7865	2.7991	2.8196	2.8277
Average		Specific Gravity (T℃/4℃) ＝ 2.7824			Specific Gravity (T℃/4℃) ＝ 2.8155		
Remarks							

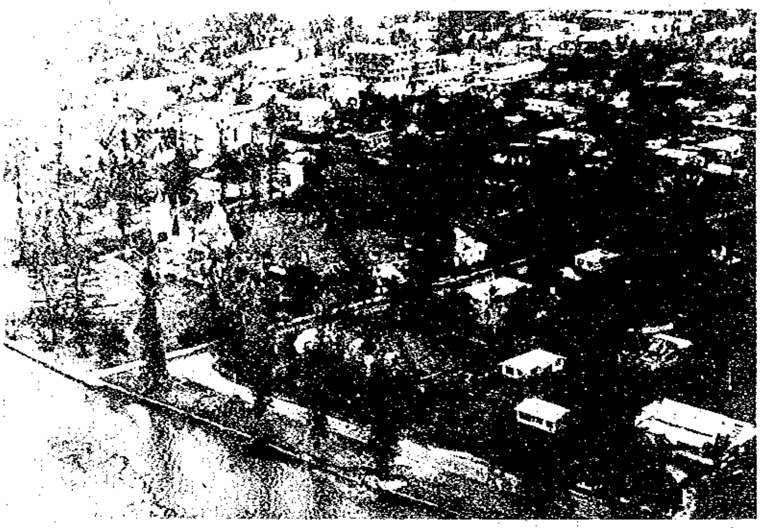
Note1 : Obtain from prepared chart   Note2 : Obtain from a JIS chart

JIS A 1202	Specific Gravity Test of Soil Particles			
Test Name & Sampling Location			Date :	
			Tested by : Susumu Narita	

Sample No. and Depth		No. 5 − 1 (m～ m)		
Test No.		1	2	3
Pycnometer No.		143	144	145
Weight of oven dried soil (or Saturated Soil) +distilled Water, and pycnometer mb g		163.6653	174.8580	166.0374
Soil temperature when mb was measured T℃		17.0	17.0	17.0
Weight of oven dried soil in pycnometer ms g	Container No.			
	Weight of Dry soil and container g			
	Weight of container g			
	ms g	30.1110	30.4484	30.2077
Converted weight of distilled water and pycnometer at T℃ ma g		144.2656	155.2031	146.4860
ms + (ma − mb) g		10.7113	10.7935	10.6563
Specific gravity of soil particles at T℃ $Gs(T℃/T℃) = \frac{ms}{ms + (ma - mb)}$		2.8111	2.8210	2.8347
Correction coefficient K		0.9997	0.9997	0.9997
Specific gravity of soil particles at 15 ℃ Gs(T℃/15℃) = K・Gs(T℃/T℃)		2.8103	2.8202	2.8339
Average		Specific Gravity (T℃/15℃) = 2.8214		
Specific gravity of water at T℃ GT		0.9988	0.9988	0.9988
Specific gravity of soil particles at 4℃ Gs(T℃/4℃)=GT・Gs(T℃/T℃)		2.8078	2.8176	2.8313
Average		Specific Gravity (T℃/4℃) = 2.8139		
Remarks				

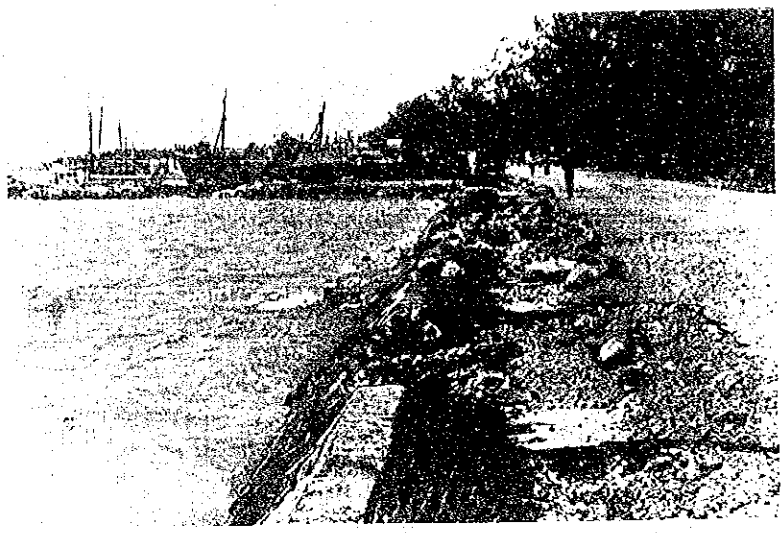


Vuna Wharf



Palace

In front of Dateline Hotel



Faua Harbour

Queen Salote Wharf

Western Extension

APPENDIX X. List of Data Collected in Tonga

No.	Name of Data	Contents	From
1	Organization of Tonga Government		MOW
2	Organization of MOW		MOW
3	Development of Army Harbour	Study of Development Plan	Defence Services
4	Newspaper	Damage by "ISSAC"	Chronicle
5	Report of the Ministry of Works	Budget, 1982～1986	MOW
6	Maintenance of Foreshore Protection	Implementing Agency	MOW
7	Budget of Tonga	1987～1988	Printing Office
8	Report on Fisheries in Tonga	Study on the Experimental Pond	Fishery Services
9	Foreign Trade Report	1985	Statistics Dept.
10	Statistical Bulletin	Consumer Prices Jan.1985～Jun.1987	Statistics Dept.
11	Fourth Five-year Development Plan	1980～1985	MOW
12	Fifth Five-year Development Plan	1986～1990	MOW
13	Report of the Minister of Finance	Statistics of MOW	Statistics Dept.
14	Report of the Minister of Labour, Commerce and Industries		Statistics Dept.
15	Population Census	1986	Statistics Dept.
16	Regulation or Rule of Labour Service	Min. Rates, 1986	MOW
17	Mow's Project in 1987		MOW
18	Map of Tonga	1:50,000, 1:25,000	Ministry of Land Survey
19	Aerophotograph	1:1,000	MOW