Generally the sub-soil conditions here are suitable for gravity type structures; thus, no ground settlement will be taken into consideration even after reclamation and/or the placing of heavy materials.

On the other hand, base rock in the passage sinks in deep and is covered by coral sand by several meters. This condition can be seen in the inner port basin of Avarua and Avatiu Harbours of northern coast.

12.2.2 Structural Conditions

1) Materials

General conditions of the materials to be used for coastal protection work are listed hereunder:

• Rocks, stones, gravel specific gravity	:	g = 2.65 Material sources are the government managed quarries including Black Rock.
• Reclamation material	:	g = 1.7, General earth taken from inland deposits or dredged material by project
• Concrete	:	with R-bars
• Unit Weight		γ = 2.45 t/m³ for reinforced concrete γ = 2.30 t/m³ for plain concrete

2) Required Weight of Armour Rocks

The required weight of rocks covering the slope surface directly receiving wave forces should be calculated by the Hudson formula.

$$W = \frac{\gamma_r H^3}{K_D (S_r - 1)^3 \cot \alpha}$$

where,

W	:	Minimum weight of rubble or concrete blocks (ton)
γ_r	:	Unit weight of rubble or block in air (ton/m³)
S_r	:	Specific gravity of rubble or block to sea water
α	:	Angle of the slope to the horizontal plane (degrees)
H	:	Wave height at site (m)
K_D	:	Constant determined by the armoring material and damage rate.

It is recommended that an appropriate safety factor should be considered due to unknown factor of the high rush current on lagoon. Weight of covering layer at the breakwater head should be increased by 50 % against figure by the formula.

3) Normal Weight of Armour Rock

Using the Hudson formula, normal weight of armour rock for seawall and breakwater is calculated.

Conditions

i. When rock weight is over 2 tons, wave dispersion concrete block will be utilized.

ii. The weight of rock (concrete block) at the breakwater head should be increased by 50 % than weight shown below.

iii. Constant K_D.

Armour rock, $K_D = 2.8$

Concrete block, $K_D = 8.4$

In case of $\cot\alpha$ = 1.5

Armour rock

$$\frac{2.65 \times H^3}{2.8 \times (2.65/1.03 - 1)^3 \times 1.5} = \frac{2.65H^3}{4.2 \times 3.89} = 0.162\ H^3\ \text{t/pc}$$

Concrete block

$$\frac{2.30 \times H^3}{8.4 \times (2.30/1.03 - 1)^3 \times 1.5} = \frac{2.30H^3}{12.6 \times 1.87} = 0.098\ H^3\ \text{t/pc}$$

Wave H(m)	Required Weight (t)		Standard Rock Size (ton)	Standard Concrete Block Size (ton)
1.0	0.16	-	0.4	
1.5	0.55	-	1.0	
2.0	1.30	-	2.0	
2.3	1.97	-	2.0	
2.5	-	1.53		2.0
3.0	-	2.65		3.2
3.5	-	4.20		5.0
4.0	-	6.27		8.0
4.5	-	8.93		10.0
5.0	-	12.25		16.0
5.5	-	16.30		20.0
6.0	-	21.17		25.0

In case of Cotα. = 2.0

Armour rock

$$\frac{2.65 \times H^3}{2.8 \times (2.65/1.03 - 1)^3 \times 2.0} = \frac{2.65 \times H^3}{5.6 \times 3.89} = 0.122\ H^3\ \text{t/pc}$$

Concrete block

$$\frac{2.30 \times H^3}{8.4 \times (2.30/1.03 - 1)^3 \times 2.0} = \frac{2.30 \times H^3}{16.8 \times 1.87} = 0.073\ H^3\ \text{t/pc}$$

Wave H(m)	Required	Weight (+)	Standard Rock Size (ton)	Standard Concrete Block Size (ton)
1.0	0.12	-	0.4	
1.5	0.41	-	1.0	
2.0	0.97	-	1.0	
2.5	1.91	-	2.0	
3.0	-	1.97		3.2
3.5	-	3.13		4.0
4.0	-	4.67		6.3
4.5	-	6.65		8.0
5.0	-	9.13		10.0
5.5	-	12.15		16.0
6.0	-	15.77		20.0

In case of Cotα. = 3.5

Armour rock

$$\frac{2.65 \times H^3}{2.8 \times (2.65/1.03 - 1)^3 \times 3.5} = \frac{2.65 \times H^3}{9.8 \times 3.89} = 0.070\ H^3\ \text{t/pc}$$

Concrete block

$$\frac{2.30 \times H^3}{8.4 \times (2.30/1.03 - 1)^3 \times 3.5} = \frac{2.30 \times H^3}{29.4 \times 1.87} = 0.042\ H^3\ \text{t/pc}$$

Wave H(m)	Required	Weight (+)	Standard Rock Size (ton)	Standard Concrete Block Size (ton)
1.0	0.07	-	0.4	
1.5	0.24	-	0.4	
2.0	0.56	-	1.0	
2.5	1.09	-	2.0	
3.0	1.89	-	2.0	
3.5	-	1.80		2.0
4.0	-	2.69		3.2
4.5	-	3.83		5.0
5.0	-	5.25		6.3
5.5	-	6.99		8.0
6.0	-	9.07		10.0

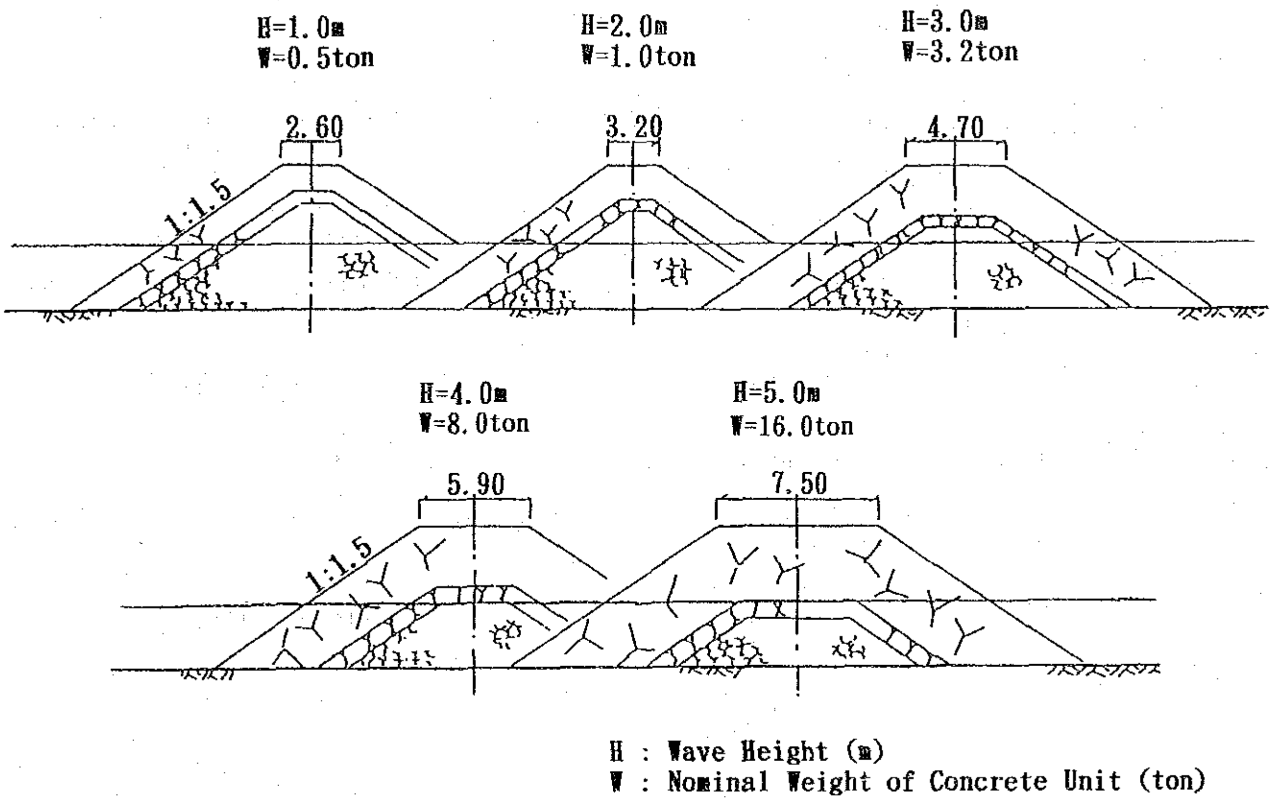
Constant K_D in various conditions are shown below.

Materials	Layer	Laying	K_D	
			Surf Zone	No Surf Zone
Rock				
Smooth Surface	2	Random	2.1	2.4
Smooth Surface	more than 3	Random	2.8*	3.2
Rough Surface	2	Random	3.5	4.0
Rough Surface	more than 3	Random	3.9	4.5
Deformed Concrete Block				
Type A	2	Random	7.6	-
Type B	2	Random	8.1	10.0
Type C	2	Random	8.2	10.0
Type D	2	Random	8.3	10.2
Type E	2	Random	10.0	10.0
Average			8.4*	

Standard bock size and its dimension for Tetrapods are shown below.

Nominal Weight (+)	Actual Weight (+)	Double Laying (m)	Top width by 3 block laying	
			Lower width (m)	Top width (m)
0.5	0.46	1.20	1.80	2.60
1.0	0.92	1.50	2.20	3.20
2.0	1.84	1.90	2.90	4.10
3.2	2.88	2.20	3.30	4.70
4.0	3.68	2.40	3.60	5.20
5.0	4.60	2.60	3.90	5.50
6.3	5.75	2.70	4.20	5.90
8.0	7.36	3.00	4.60	6.50
10.0	9.20	3.20	4.90	6.90
12.5	11.50	3.50	5.30	7.50
16.0	14.49	3.80	5.70	8.10
20.0	18.40	4.10	6.10	8.70
25.0	23.00	4.40	6.60	9.40
32.0	28.75	4.80	7.20	10.40

Standard section of breakwater by Tetrapods are shown below.



Typical Section of Tetrapod Breakwater

12.2.3 Wave Overtopping Criteria

If a large wave over-topping on seawall happens for long period, following various disasters may appear.

a. Sea water may intrude into inland and generate flooding.

b. Sea water may splash to the beach road and disturb vehicle drive. As seen in the past experience, it may break road pavement and airport dike.

c. In case of large scale over-topping, coral fragments including boulders may jump up the street damaging properties and being unable to drive vehicles.

In order to mitigate these type of disasters sea water intrusion over the seawall per unit time period (or over-topping discharge) should artificially be decreased considering,

a. Eliminating wave intensity before arriving at seawall

b. Higher top formation of seawall to reduce such intrusion

In this purpose, it is recommended to analyze the possible correlation between seawall structure and over-topping discharge volume.

In this study, coastal protection work including seawall will be planned in relation with allowable over-topping discharge volume as seen in Table 12-2B based on the past experience in the similar project.

Table 12-2B Allowable Over-topping Discharge (Seawall)

Structural Condition *		Allowable Over-topping Discharge ($m^3/m/sec.$)	Application
A.	Paved Surface	0.200	General land use
B.	Paved Surface	0.050	Urbanized area
C.	Exposed Ground	0.050	General land use
D.	Exposed Ground	0.020	Urbanized area

Note, Structural condition is concerned about the grade of ground protection behind seawall.

Source, Design Standards of Coastal Protection in Japan.

Figures in this table should be used in design of seawall considering following aspects.

a. Objective to be protected by seawall
b. Importance of objective
c. Utilization of surface during cyclone

Over-topping discharge can be calculated using following formula.

$$V = A \cdot \Delta R^2 / T \qquad (m^3/m/sec.)$$

where, V: Over-topping discharge ($m^3/m/sec.$)
A: Constant for determining over-topping water body
$A = 0.10 \sim 0.20 = 0.15$
ΔR: Net over-topping height over the seawall top (m)
T: Period of wave (Sally)
$T = 12.5$ (sec.)

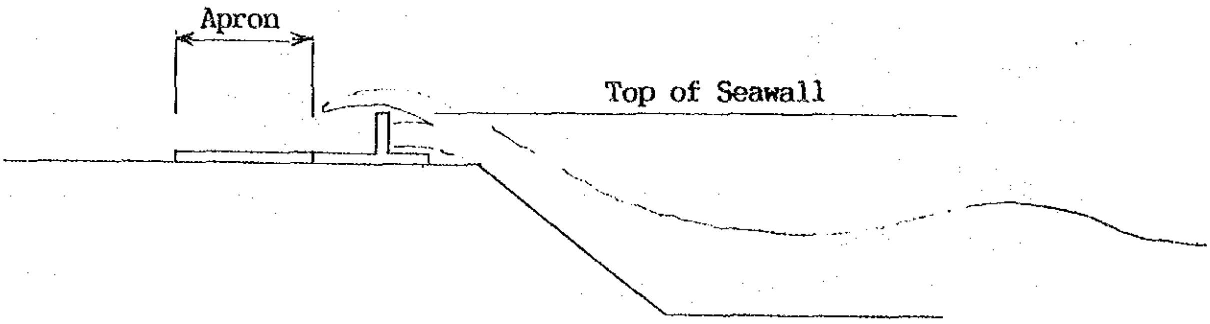
Thus, $V = 0.15 \cdot \Delta R^2 / 12.5$
$= 0.012 \cdot \Delta R^2$ ($m^3/m/sec.$)

Purpose of seawall construction in the northern coast is for protection of important facilities. Thus design of seawall should basically be planned by Conditions A and B in Table 12-2B.

Wave overtopping should be within an allowable rate Va.

$Va \leq 0.20\ m^3/m/sec$ ------- For general land use area
$Va \leq 0.05\ m^3/m/sec$ ------- For urbanized area

This rate should apply to the design of seawall formation. Top elevation should be examined by this rate and drainage should be provided if so required. Apron pavement should be provided immediately behind the top of slope.



Using the over-topping discharge formula and allowable rate, the maximum allowable wave run-up height (ΔR) can be calculated.

For general land use area:

$$0.200 \geq 0.012 \cdot \Delta R^2$$

Thus, $\Delta R \leq 4.0$ m

For urbanized area:

$$0.050 \geq 0.012 \cdot \Delta R^2$$

Thus, $\Delta R \leq 2.0$ m

However, it is recommended to add safety factor to these rates covering various unknown hydromechanics of water movement in lagoon.

12.2.4 Wave Run-up

1) Calculation Method Applicable to Rarotonga Island

Wave run-up should be estimated using an applicable formula for the particular site. In this study, the modified Saville formula for double slopes is used. Related data for this formula are:

(1) Equivalent Offshore Wave Height, Ho' (m)
Refer to item 2) in subsection 12.2.1
(2) Width of lagoon, B (m)
(3) Astronomical tide, A (m)
(4) Air depression rise, D (m)
(5) Wave Set-up, S (m)
(6) Slope foreshore before reef
(7) Slope of seawall

In Fig. 12-6, items (3) to (7) were fixed at an average value, and wave run-up curves were developed as shown.

This curve was developed by the study team in order to estimate wave run-up at 172 observation points in the island. For the simplicity of estimation, following conditions have been provided.

Table 12-2C Coefficient Used

Unit:m

Ho'	A	D	S	A+D+S
2	0.2	0.2	0.35	0.75
3	0.2	0.2	0.53	0.93
4	0.2	0.2	0.70	1.10
5	0.2	0.2	0.88	1.28
6	0.2	0.2	1.05	1.45
7	0.2	0.2	1.23	1.63
8	0.2	0.2	1.40	1.80
9	0.2	0.2	1.58	1.98
10	0.2	0.2	1.76	2.16

Note, Figure by A+D+B shows a water level in the lagoon after set-up.

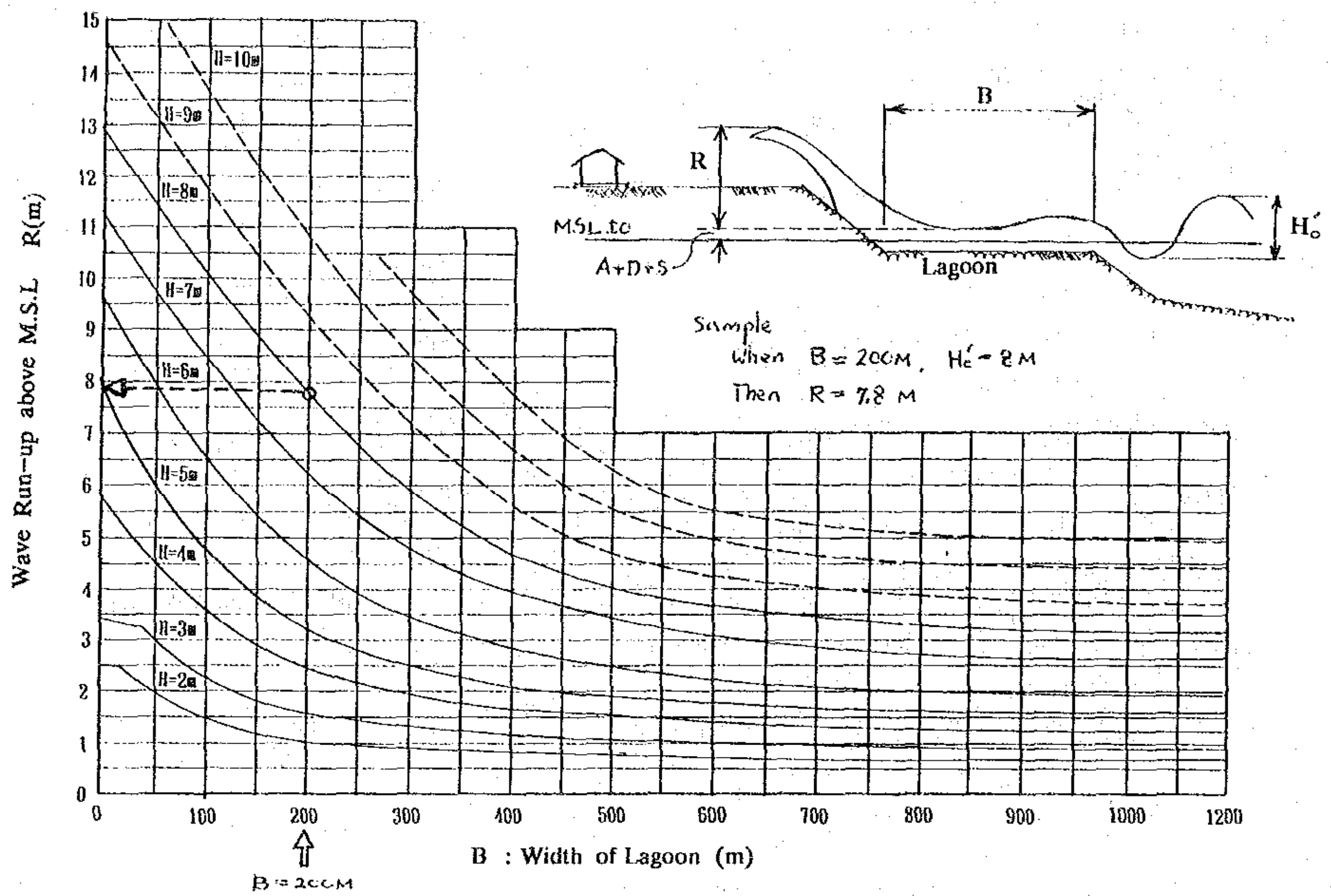


Fig. 12-6 Wave Run-up Height

(i) Astronomical tide was fixed as constant indicating a mean value between he MSL and High Tide. MSL + 0.2 m

(ii) Air depression rise was also fixed as constant showing two third of maximum rise by Sally.

(iii) Wave set-up is a mean value (1.4 m) between set-up on reef (1.3 m) and end set-up at beach (1.5 m) for Sally wave. Wave set-up for other wave intensity was calculated proportionally to wave height.
Saville's method may include wave set-up effect, thus figure in Fig. 12-6 will provide conservative ones.

(iv) Foreshore slope was fixed as 1/10 or 10 % which was steeper than the existing one, in 1/100 or 1 %.

(v) Slope of seawall was fixed as 1/3 gradient since the deference of set-up for slopes 1/2, 1/3 and 1/10 were less than 5 %.

Substituting lagoon width (B) and wave height (H) in Fig. 12-6, wave set-up can easily be obtained.

Wave here is a significant wave (equivalent offshore wave).

2) Saville's Method

This method is utilized widely for wave run-up estimation when seawall is constructed in shoal or near mean sea level.
This method can apply to the complex slopes consisting of various gradient including seawall, lagoon and foreshore. There is no alternative for such condition than this method. It can be said that application of this is supported by the existing sea bottom configuration in the island where flat lagoon near MSL is existing.

Until other suitable method for this particular condition is developed and authorized, Saville's method will last.

Basic method developed by Saville is as follows: (Refer to Fig. 12-6A).

(i) Calculate a breaking point (A) of the design wave. $h_b \fallingdotseq 1.5 \sim 2.0\ Ho'$

(ii) Substitute a tentative wave run-up (R')

(iii) Draw a line between the breaking point on seabed and a point of tentative wave run-up. Calculate gradient of this line. (cot α)

(iv) Calculate a wave gradient

Ho'/Lo

where, Ho' : Equivalent offshore wave (m)

Lo : Wave length (m)

(v) Road R/Ho' in Fig. 12-6A using Cot α and Ho'/Lo.

For example, R/Ho' = A then,

Wave run-up, R = A•Ho'

(vi) Check if this R meets with R' in the first step.

If meets, R is an answer.

If does not meet, repeat calculation by new R' starting the step (i).

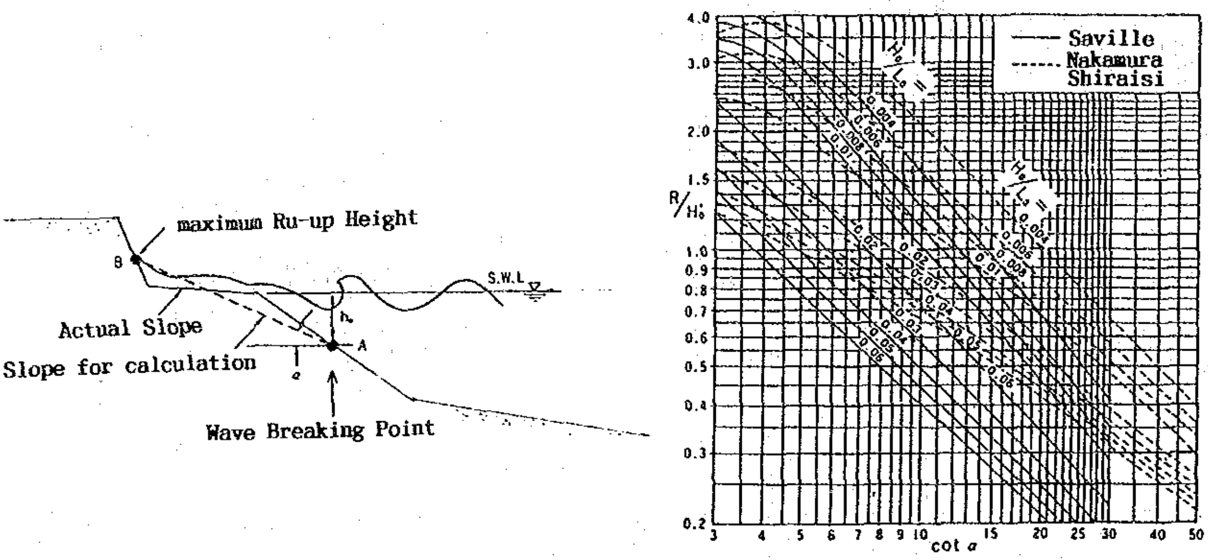


Fig. 12-6A Wave Run-up Curve

Curve in Fig. 12-6 was obtained with same method by computer calculation, as a function by wave height (Ho') and lagoon width (B).

3) Wave Run-up and Coastal Flooding

It is possible to provide coast with coastal protection which does not allow any over-topping against all the waves, however such work is neither practical measures nor economical means.

As recommended in subsection 12.2.3, it is a normal design concept that an allowable wave over-topping may happen even after the proper protection work is performed. Thus, it is necessary to accept wave over-topping in few meter even after the coastal protection work.

As discussed in previous subsection, coastal flooding may happen when over-topping discharge exceeds certain quantity. This means that all the intruded water body per certain period is not evacuated away due to low drain-off capacity.

Over-topped water body may be withdrawn by one or combination of following means.

(i) Return to the nearest lagoon by gravity surface flow
(ii) Trap by drainage or a like
(iii) Drop in river and stream
(iv) Stay while in swamp
(v) Permeate into the soil
(vi) Evaporation

Items (v) and (vi) are not so active. If items (ii), (iii) and (iv) are not provided or not enough, coastal flooding may happen. If intruded water quantity is minor, it may be drained by item (i).

Thus, it is important to analyze possible coastal flooding during a large amount of over-topping. Required sectional area of drainage will be 1.25 ~ 5.0 m^2 if an allowable over-topping discharge (0.05 ~ 0.20 $m^3/m/sec.$ as discussed in subsection 12.2.3) should be evacuated by an open channel with discharging outlet to the lagoon each 50 meter.

$$Q = 50\ (0.05 \sim 0.20)$$
$$= 2.5 \sim 10.0 \qquad m^3/sec.$$

$$A = Q/\upsilon$$
$$= (2.5 \sim 10.0)/2.0$$
$$= 1.25 \sim 5.0 \qquad m^2$$

Where, Q : total discharges of over-topped water body for 50 meter $m^3/sec.$
A : Required sectional area of drainage m^2
υ : Average flow velocity in channel, $\upsilon = 2.0$ m/sec.

It is preferable that the drainage capacity behind the seawall meets an expected over-topping discharge.

Drainage at the Avarua coast should be moderate size because it locates in urbanized area. Since practical drain size here is 1.0 ~ 1.5 m^2, it is recommended to limit allowable over-topping discharge within 0.05 $m^3/m/sec.$ or less. Thus wave over-topping above the seawall top should be two meters or less, if it is applicable.

Benefit of the on-land drainage is similar to the passage effect, i.e. wave jumps over the reef onto lagoon and returns to foreshore area through the passage. Large amount of wave set-up appears if no passage exists.

For demonstrating more clear figure, it is interesting to estimate the water depth of return flow in case (i) "Return to lagoon by gravity flow on ground surface". Fig. 12-6B indicates this return flow. Return flow can be shown by following simple formula.

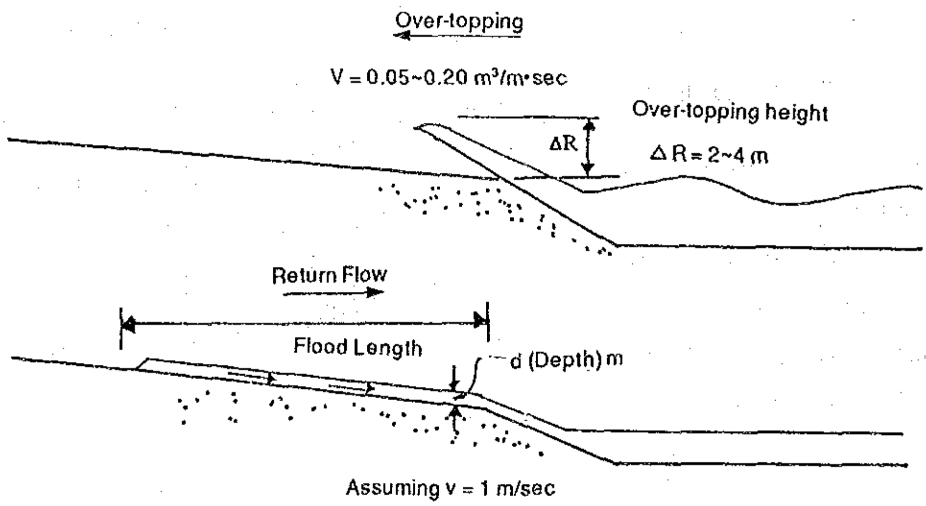
$$V = d \cdot \upsilon$$

where,	V	:	Over-topping Discharge	0.05 ~ 0.20 m^3/sec.
	d	:	Depth of return flow	m
	υ	:	Velocity of return flow	
			Assuming $\upsilon = 1.0$	m/sec.

Thus,	d	=	V/υ	
		=	(0.05 ~ 0.20)/1.0	
		=	0.05 ~ 0.20	m

This indicates that return flow of 5 ~ 20 cm depth may appear continuously in case over-topping discharge of 0.05 ~ 0.20 m^3/sec. Actual depth may be 10 ~ 40 cm since the return flow may be disturbed by periodical over-topping. The former is return depth by 2 m over-topping and the latter represents water depth by 4 m over-topping above the seawall top.

Fig. 12-6B Over-topping and Return Flow



As discussed above, it is assumed that return flow depth (d) may be approximately 10 % over-topping height (ΔR).

It is also interesting to estimate the flood length during the over-topping as indicating in Fig. 12-6B. Unit over-topping per wave (V) can be shown by following formula as discussed in subsection 12.2.3.

$$V = 0.15\ \Delta R^2 \qquad m^3/m/wave$$

In case, $\Delta R = 2 \sim 4$ m

$$V = 0.15\ (2 \sim 4)^2$$
$$= 0.6 \sim 2.4 \qquad m^3/m/wave$$

Since the total water volume flooding is shown as L•d assuming same depth for entire flood length, balance between the unit over-topping and return flow can be maintained.

$$V = L \cdot d$$

Thus, $L = V/d$
$= 0.6 \sim 2.4/0.05 \sim 0.2$
$= 12$

Considering this figure is for over-topping height in 2 ~ 4 m, it is recommended that width of buffer zone against over-topping is two or three times of this. Thus, minimum over-topping buffer zone width should be larger than 25 ~ 30 meters.

4) Wave Over-topping and Rock Over-topping

It is well known that a cyclone dumps rock on the coastal bank.

When wave over-topping (ΔR) exceeds in certain level, sand over-topping may happen then rock over-topping will follow. Dumped sand may move easily by water flow however its deposit on land will not generate large problem.

While, rock dumping is other matter that it may not only destroy onland facilities but also become obstacles to land transport. For removal these obstacles, the Government together with villagers should work hard.

As discussed in subsection 5.4.2, dumping rock generate not only various troubles in the island but also natural deposit for new land. However it seems that countermeasures for the former is more important than the latter in the developed coastal bank and urbanized area.

According to the dumped rocks indicating in the photographs taken after Sally in 1978 and direct observation by the study team after Gene in 1992, it can be said that rock size various in wide ranges.

a.	below 10 cm	below 1.6 kg/ea
b.	10 ~ 20 cm	1.6 ~ 13 kg/ea
c.	20 ~ 50 cm	13 ~ 200 kg/ea
d.	50 cm or more	Over 200 kg/ea

It is understood that the volume and size of dumped rocks may relate with over-topping velocity at the seawall top and its discharge volume. If supply of rocks are limited, dumping volume will be moderate.

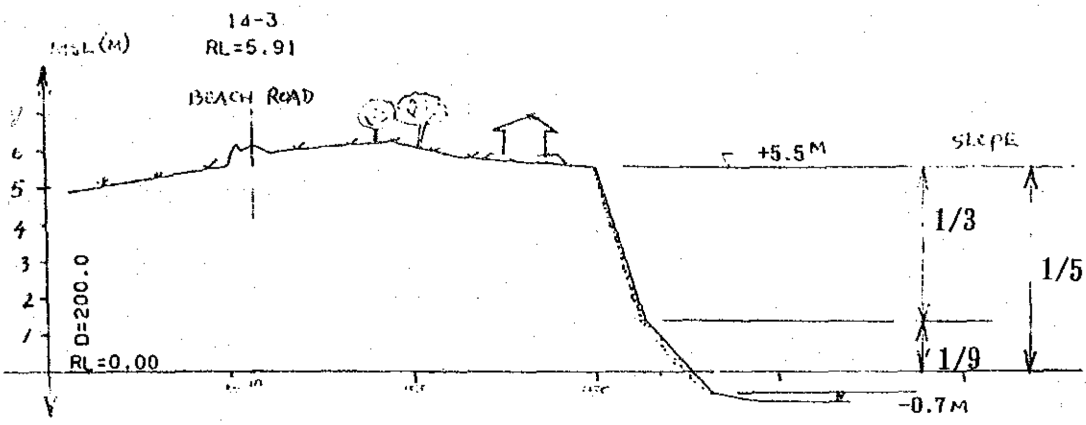
It is interesting to assume an allowable limit of over-topping height (ΔR) by the past data. Cyclone Gene attached the island northern coast at the middle of March, 1992 when the study team made its third visit to Rarotonga. It is recorded that Gene went through near by the island around 21 Hours of March 15th when high tide.

(1) Estimation of Wave Intensity

Since the climatic chart for Gene was not available, wave height was estimated by the actual wave run-up at the northern coast. It was observed that prevailing wind direction was North to Northern East. Observation of wave run-up was conducted at the natural coast facing to NNE in front of a hotel at the West end of KiiKii Village where the study team stayed.

Fig. 12-6C shows the cross section surveyed by the team in 1991.

Fig. 12-6C Cross Section of Coast Bank (No. 14-3) near the Tamure Resort KiiKii Station Point 5026.



Beach slope consists of coarse coral fragment of 1/5 gradient. Width of lagoon is about 160 meter long. The maximum wave overtopped the slope upper edge MSL +5.5 m and damaged wooden observation platform (3 m x 7 m) partly overhunged to lagoon. This platform was lifted up in 30 cm by wave forces and its wooden pile foundation was exposed by wave scouring. Since only few rock dumping was made, it is assumed that only the maximum wave might overtop the top of beach.

If it is expected that the significant wave ran up MSL +5.0 m, equivalent deep-sea wave might be 5.8 m by Fig. 12-6.

In order to evaluate the relationship between the run-up rock size and wave over-topping (ΔR), typical four sites are selected. Observed rock dumping by Gene wave are as follows.

Table 12-2D Rock Dumping by Gene

Site and Location		Beach top	Lagoon width	Dumped Rocks		Run-up	
		MSL+m	B (m)	Width W(m)	Dia* D (m)	R (m)	ΔR (m)
Site 1	Health Department	+3.5	100	10	0.15	5.6	2.1
Site 2	Avarua East	+2.0	160	15	0.25	4.5	2.5
Site 3	Avarua Coast	+4.0	200	0	-	3.9	-0.1
	Avatiu West	+3.3	50	5	0.15	7.0	3.7
Site 4	Airport East tank yards	+3.7	100	15	0.20	5.6	1.9

Notes. 1. Based on observation by the study team.
2. "Dia" indicates an average size of rock dumped.
3. R indicates total run-up above MSL.
ΔR indicates overtopping height above beach top.

As shown in Fig. 12-2D, relationship between ΔR and W can be stated as,

$$W = 5\Delta R \qquad \text{m}$$

Relationship between ΔR and D will be as follows,

$$D = 0.1\Delta R \qquad \text{m}$$

Using these formulas, co-relation among ΔR, W and D can be shown as follows.

Run-up ΔR (m)	Dumping Width W (m)	Rock Size D (m)	Rock Weight (kg)
1	5	0.1	3
2	10	0.2	20
3	15	0.3	70
4	20	0.4	160

Note. Rock weight indicates an unit weight per rock using rock specific gravity of 2.5.

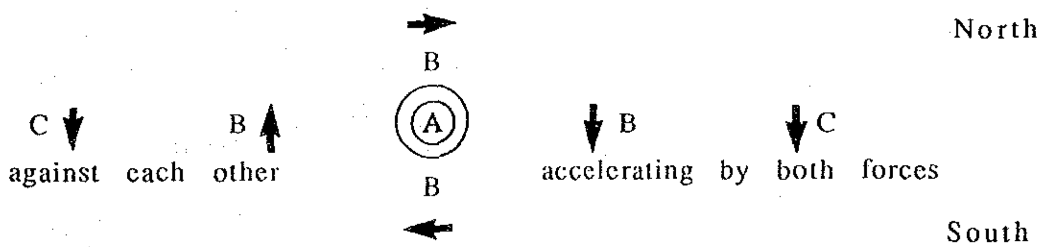
From this table, an outline of rock movement by wave run-up can be seen though they are only approximate value since observation data is so limited.

It is recommended that over-topping height (ΔR) should be 2 m or less at the coastal area behind which important public infrastructures or urbanized area are located. Over-topping (ΔR) in 2 meters may dump rock in 20 kg, however their removal for cleaning can be easily performed by hand.

12.2.5 Cyclone Arrivals

Cook Island Meteorological Observation Service (MET) has prepared a chart showing the number of cyclones recorded in every two degree grid. Fig.12-7 shows MET study results. According to this valuable data, there is a main cyclone street that runs in a northwest to southeast direction. It is 300 km from the island at its closest approach. This main stream appears to be located West of the island.

Cyclones in the southern hemisphere have a clockwise vortex. Since cyclones here pass from north to south, wind velocity on their eastern side is larger than on the western side. This can be demonstrated by following figure.



Legend;

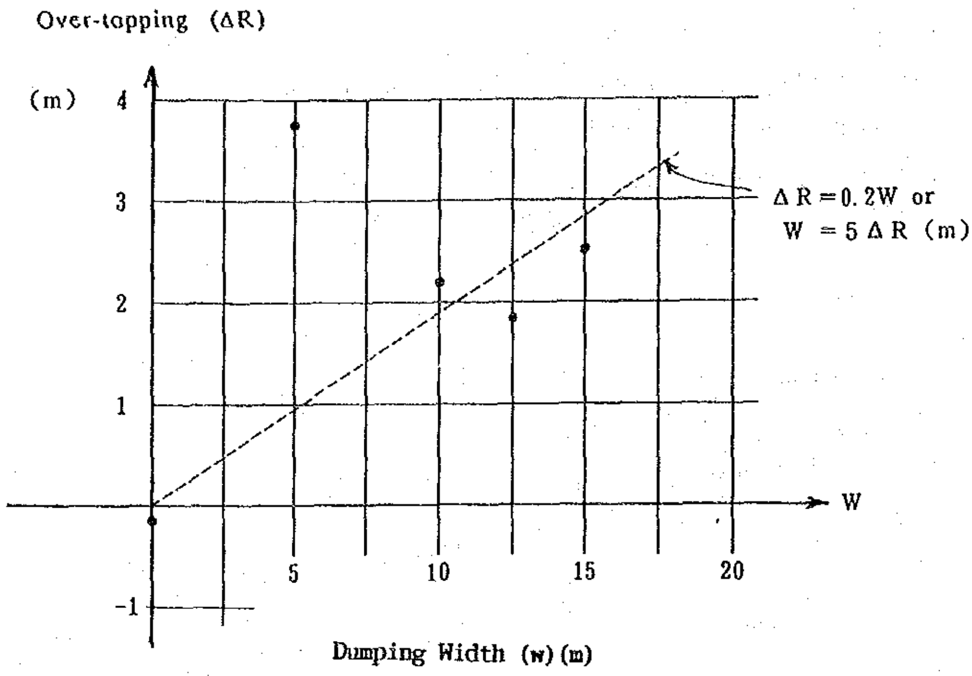
A, Center of cyclone

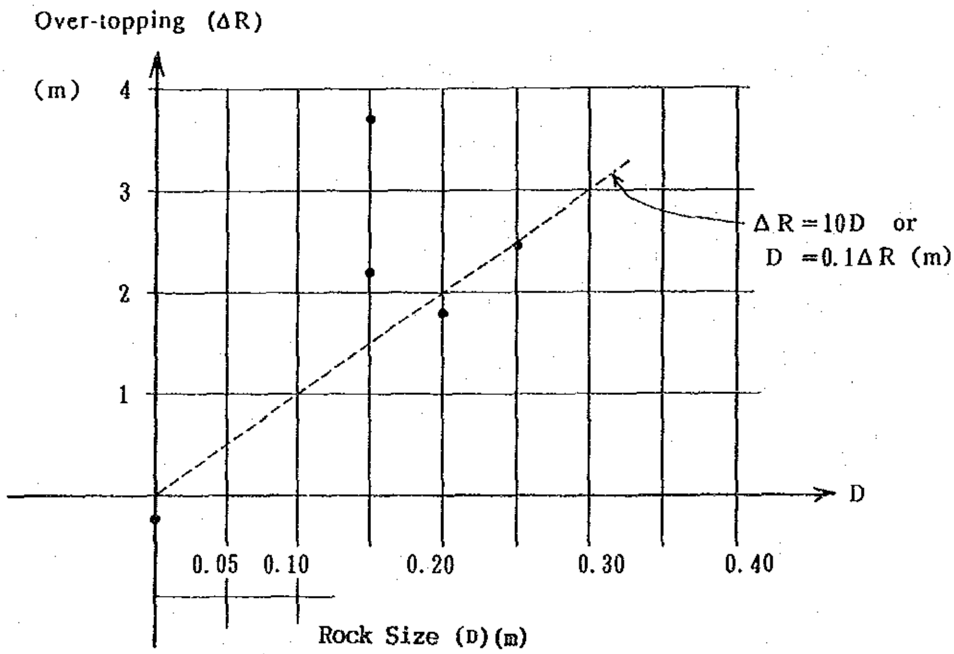
B, Wind velocity by cyclone, showing clockwise turn

C, Additional wind velocity by cyclone advance

This means that the South Group of Cook Islands is located in the most dangerous zone against cyclone. The chart shows that Samoa is under the same situation.

Fig.12-6D Relationship among Over-topping (ΔR), Dumping Width (W) and Rock Size (D)





Number in the figure indicates number of all cyclones observed over the past 52 years, from 1939 to 1991. It is assumed that the island's danger zone is an area covered by 7 degrees both in the West and the East (800 km). The total number of cyclones in this range is 82.

Rarotonga Is.
↓

| 6 | 7 | 9 | 9 | 9 | 8 | 6 | 6 | 6 | 5 | 3 | 3 | 3 | 2 | = 82

167° 166° 165° 164° 163° 162° 161° 160° 159° 158° 157° 156° 155° 154° 153°

West (Longitude) East

Thus, it can be said that an average number of cyclones affecting the island yearly is 1.6.

Estimated number of cyclones in thirty years is 47.

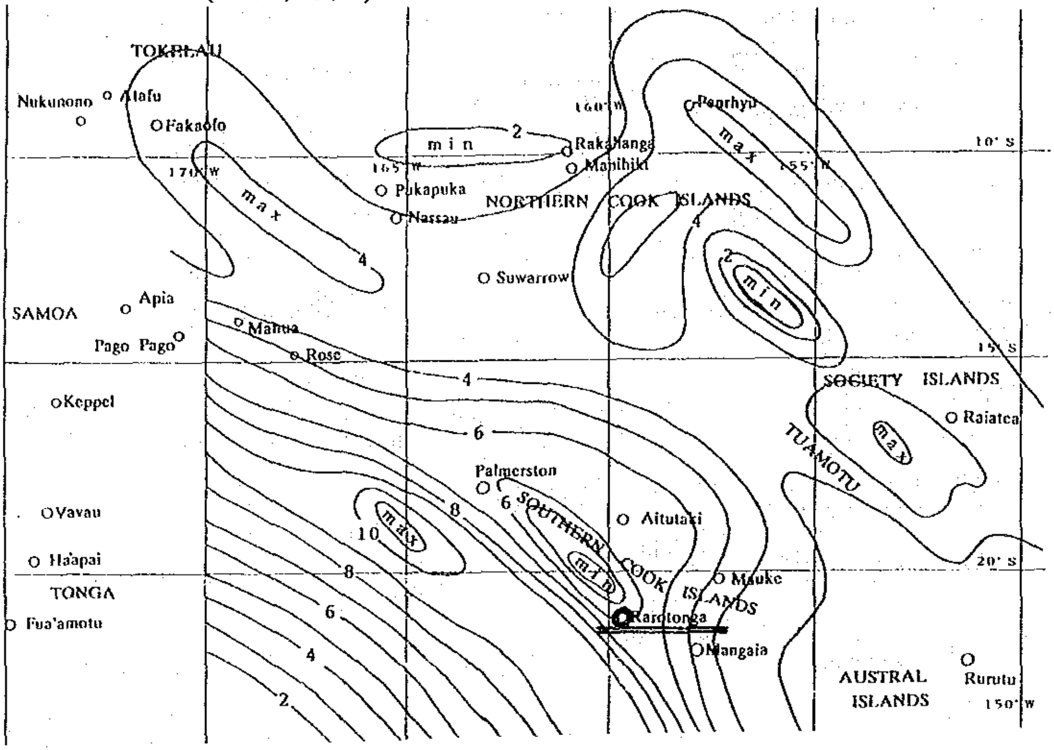
$$\frac{30 \text{ years}}{52 \text{ years}} \times 82 \text{ cyclones} = 47 \text{ cyclones}$$

Note: Thirty years is a unit of time length for project evaluation, because that is the average life of major facilities.

Some villager feels that recent cyclone arrivals are increase than before, but there is no evidence. Groval climatic change may happen by so called "Green House Effect" by accumulated carbon dioxide in air by means of forest fire, fire from burn, volcanic activity, and burning oil and coal.

There is no data yet between cyclone occurrence and accumulated carbon dioxide.

Fig. 12-7 Number of Cyclones Recorded in the South Pacific Ocean (1939/1991)



12.2.6 Return Period of Cyclone Wave

The return period of cyclone waves in Grid Square No. 5 is shown in Fig. 12-8 which shows observed return periods by wave heights. These return period are summarized in Table 12-2E.

Table 12-2E Cyclone Wave Height by Return Period

Return Period (Years)	Wave Height (m)
1	5.4
2	5.9
5	6.5
10	7.3
15	7.7
20	7.9
25	8.1
30	8.2
50	8.5
100	9.2

Source : Ship report data
Grid Square No. 5 (15.0° - 25.0° S, 155.1° - 165.0° W)

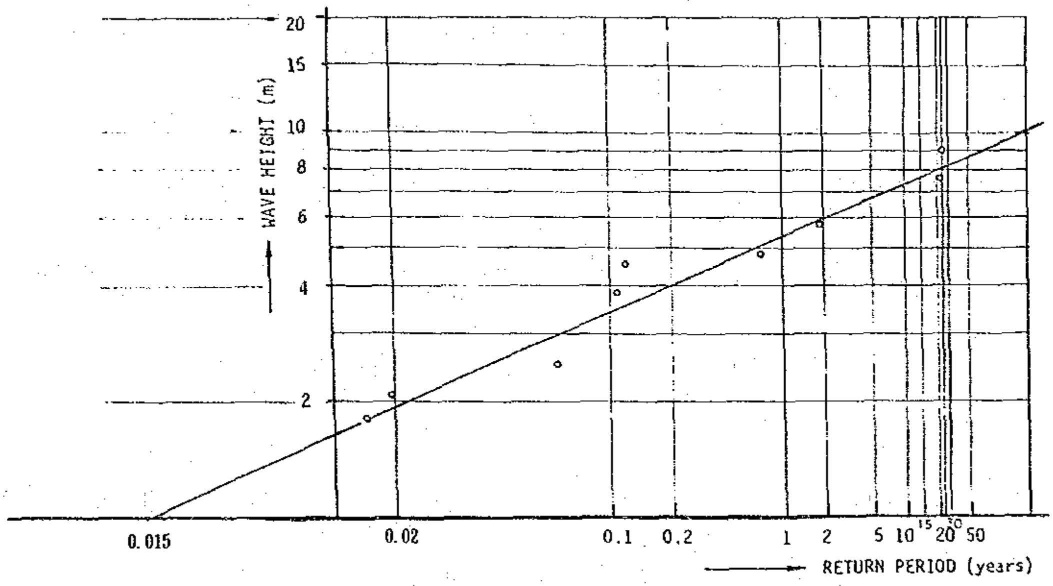


Fig. 12-8 Return Period Estimates
Ship report data from grid square No.5
(15.0 - 25.0°S, 155.1 - 165.0°W)

12.2.7 Effect of Coastal Protection Work

The purpose of coastal protection work is to decrease the damages on public and private properties and villagers lives caused by cyclone waves and surges. In order to design the protection as an optimum scale for maximum economic benefits, the rate of damage reduction by protection work is calculated in respect to a model cyclone.

It is assumed here that property damage is proportionally changes by seawater volume of over-topping. If twice the over-topping volume, damage may double.

Cyclone Sally was selected as the model due to the availability of various information. The following formula is used:

$$\boxed{Nr = No - Np} \quad \text{--------------------------------} (1)$$

where, Nr = Number of reduced model cyclones for 30 years by project effect.

No = Number of model cyclones for 30 years without the project.

Np = Number of model cyclones for 30 years with the project.

$$\boxed{No = \frac{Io}{Im}} \quad \text{--------------------------------} (2)$$

where, Io = Integrated damage indicator, accumulating damage indicators of 47 cyclones, for 30 years without protection.

$Io = \Sigma C \cdot A \cdot \Delta Ro^2$

C : Constant, unit damage by over-topping of one m^3 (Dollar/m^3)

A : Occurrence of cyclone for 30 years by return period

ΔRo : Wave over-top (m) above the existing beach top without protection

Im = Damage indicator of one model cyclone without protection work. A = 1

$Im = C \cdot \Delta Rm^2$

ΔRm: Wave over-top (m) above the existing beach top by model cyclone without protection. Wave by cyclone Sally is applied since her return period is 30 years as same as project life.

Thus, $$No = \frac{Io}{Im} = \frac{\Sigma C \cdot A \cdot \Delta Ro^2}{C \cdot \Delta Rm^2} = \frac{\Sigma A \cdot \Delta Ro^2}{\Delta Rm^2}$$

$$\boxed{Np = \frac{Ip}{Im}} \quad \text{--------------------------------} (3)$$

Where, Ip = Integrated damage indicator, accumulated damage indicator of 47 cyclones for 30 years, when protection work is provided.

$Ip = \Sigma C \cdot A \cdot \Delta Rp^2$

ΔRp; Wave over-top (m) above the proposed seawall top when protection work is provided.

Thus, $Np = \frac{Ip}{Im} = \frac{\Sigma C \cdot A \cdot \Delta Rp^2}{C \cdot \Delta Rm^2} = \frac{\Sigma A \cdot \Delta Rp^2}{\Delta Rm^2}$

Therefore,

$$
\begin{aligned}
Nr &= No - Np \\
&= \frac{\Sigma A \cdot \Delta Ro^2}{\Delta Rm^2} - \frac{\Sigma A \cdot \Delta Rp^2}{\Delta Rm^2} \\
&= \frac{1}{\Delta Rm^2}(\Sigma A \cdot \Delta Ro^2 - \Sigma A \cdot \Delta Rp^2)
\end{aligned}
$$

Detailed calculation will be demonstrated in each subsection together with the typical cross section. Table 12-3 shows the summary of this study.

The average effect of coastal protection by the proposed Short-term Plan is reducing 6.2 number of model cyclones.

Table 12-3 Effect of Project: Coastal Protection
(In Number of Reduced Model Cyclones)

Sites	Coastal Length(m)	Number of Model Cyclone		Effect of Project (Model Cyclone)	Weighted Figure
	L	No	NP	Nr	L•Nr
Site - 1 Health Dep.	300	12.5	2.8	9.7	2,910
Site - 2 Avarua					
(1) Avarua East	290	13.3	6.7	6.6	1,914
(2) Avarua Central	370	7.4	1.2	6.2	2,294
(3) Avarua Central	420	6.7	4.0	2.7	1,134
(4) Avatiu H.	(470)	-	-	-	-
Site-3 Airport East	350	9.7	2.4	7.3	2,555
Site-4 Airport West					
(1) MET	80	6.2	2.0	4.2	336
(2) North West	150	10.0	0.2	9.8	1,470
(3) West End	130	6.9	4.4	2.5	325
Total (Weighted average)	2,090 m	9.3	3.1	6.2	12,938

12.2.8 Major Protection Materials

Material for the coastal protection should be durable and available with reasonable cost. Table below shows the comparison between the reinforced concrete materials and rocks.

Table 12-3A Comparison between Concrete and Rocks

Evaluation Point	Reinforced Concrete	Rocks
Availability	Available	Available, however new quarry should be developed.
Durability	Good	Better than concrete.
Importation	Cement and reinforcement should be imported.	All rock materials are available locally thus no importation.
Cost	NZ900 Dollars/m³	Only NZ60 Dollars/m³
Total Evaluation	—	Preferable

It is strongly recommended to use rock material for major part of coastal protection works as MOW undertaken presently. Reinforced concrete members are so expensive that project can not be performed.

Thus, reinforced concrete may be used only for limited purposes including parapet wall, apron pavement and U-shaped drainage.

12.3 Preliminary Design : Site - 1 "Health Department"

This section deals with the alignment of the coastal defense line and the basic section proposed for the preservation of Health Department and its surrounding public facilities.

12.3.1 Existing Condition

The Health Department is located on the village boundary between Vaikai and Pue. On eastern side, there are various governmental facilities including, Ministry of Education, Office of Secretary and Conservation Department. These public facilities occupy the strip of land between the beach road and the coastal line. Width of the land is approximately 80 meters. They face the ocean through the 250 meter long natural beach.

The beach top elevation and the main road elevation are MSL +3.5 m and +5.0 m respectively.

According to the calculation, the 8.1 m design wave of the Sally class runs up to MSL + 10.4 m. It is reported that this area was also damaged by Cyclones Val/Wasa at the end of 1991, and Cyclone Gene in March 1992.

The beach slope is 1:5 to 1:8 and is relatively moderate. The beach surface is covered by sand on the down slope and by coral fragment on the upper slope. This beach is one of the best place for local people to swim. The top of the existing beach is covered by various kinds of trees which provide the swimmers with nice shade.

Near the top of beach, there is concrete seawall which seems embedded in the beach bank. However, the southern fifteen meters of the bank was destroyed by Cyclone Sally in 1987 and Cyclones Val/Wasa in 1991.

This site is classified as the Grade II area (See subsection 7.3.2 and Table 7-4) where wave overtopping and beach erosion were recorded during the said cyclones.

12.3.2 Scale of Proposed Coastal Projection

The main objective of coastal protection here is to mitigate wave overtopping and to reduce beach sand erosion. The most important objective is to prevent the said public facility areas from sea water intrusion.

Considering this beach is for swimming zone, it is not suitable to construct protection work in lagoon. Such facility is normally expensive and disturb open view form beach and access to sea. Thus seawall at upper edge of beach slope will be suitable one.

The scale of coastal protection work against waves and surges can be shown by wall top elevations. The higher the top elevation, the less water body intrusion, but the higher the investment cost and the worse the open view.

Table 12-4 shows an expected damage reduction by the project. As shown in the Table, it is assumed that this area will be affected by 10.5 Sally class cyclones over the next thirty years if no coastal protection is provided.

Note: It is estimated as shown in subsection 12.2.5 that 47 cyclones will attack the island during the next thirty years. According to the calculation for Site-1, total disastrous influence by the said 47 cyclones is equivalent to disasters by 12.5 model cyclones. Sally is the model cyclone. Refer to subsections 12.2.4, 12.2.5 and 12.2.6.

The recommended seawall top height is MSL +6.0 m which is approximately one meter above the existing beach road.

According to the calculation, the estimated damage will be in the amount of 2.8 Sally class cyclones over the next thirty years if coastal protection work is performed. Thus, benefits from the work can be counted as reduction of damages of 9.7 Sally class cyclones.

Table 12-4 Damage reduction Estimate by Project: Site - 1

Design Wave Height Ho' = 8.1 m

Lagoon Width (without Project) = 100 m
Lagoon Width (with Project) = 100 m

Return Period	Cyclones/30yr A	Without Project					With Project				
		Ho' (m)	Run-up (MSL+)	Ground (MSL+)	ΔR (m)	A·ΔR²	Ho' (m)	Run-up (MSL+)	Wall (MSL+)	ΔR (m)	A·ΔR²
1 yr	30times/30yr	5.3	+5.5	+3.5	2.0	120	5.3	+5.5	+6.0	-0.5	-
5 yr	6times/30yr	6.7	+7.8	+3.5	4.3	111	6.7	+7.8	+6.0	1.2	9
10 yr	3times/30yr	7.3	+9.0	+3.5	5.5	91	7.3	+9.0	+6.0	3.0	27
15 yr	2times/30yr	7.7	+9.8	+3.5	6.3	79	7.7	+9.8	+6.0	3.8	29
20 yr	1.5times/30yr	7.9	+10.0	+3.5	6.5	63	7.9	+10.0	+6.0	4.0	24
25 yr	1.2times/30yr	8.0	+10.1	+3.5	6.6	52	8.0	+10.1	+6.0	4.1	20
30 yr	1times/30yr	8.1	+10.4	+3.5	6.9	45	8.1	+10.4	+6.0	4.4	19
Total	47.7					561					128

Evaluation:

Equivalent Number of Sally Class cyclone without project ---------- 561 ÷ 45 = 12.5 Model Cyclones
Equivalent Number of Sally Class cyclone with project ---------- 128 ÷ 45 = 2.8 Model Cyclones
Reduction of damage in Sally Class cyclone ---------- 12.5 - 2.8 = 9.7 Model Cyclones

As seen is this Table, the proposed section can not be fully protected since 2.8 equivalent cyclones will remain. However, this should be accepted considering protection economy.

Over-topping height (ΔRp) by wave of return period more than 15 years will exceed 2.0 m, however this should be accepted in order to maintain good open-view from land.

12.3.3 Proposed Defense Line

The existing beach shapes rather simple and straight alignment. Thus, the defense line will be parallel to the existing beachline as shown in Fig. 12-9.

The proposed defense line is about two meters behind the existing seawall. Ground height here is about MSL +3.5 m. This arrangement aims at:

(1) Cost Reduction and
(2) Maintaining the existing sandy beach

On this line, there are no existing public facilities but coral fragment.
If the defense line advances foreshore, reflected wave by seawall may wash out the existing beach sand.

12.3.4 Basic Section and Type of Structure

Basic sections of the proposed coastal protection in Site-1 are shown in Fig. 12-10. The main dimensions of the structure are designed as follows.

1) Type of Structure

Basic structural type here is seawall type and similar to the existing seawall constructed by MOW at the Avarua Coast. Characteristics of structure are as follows:

(1) Defense line is locating near the existing beach top.

(2) Gradient is 1 : 2

(3) Front armour rock will be embedded up to MSL +1.50 m for preventing structure from scouring.

(4) On the top of structure, reinforced concrete parapet wall will be provided.
This wall will be rest on base rock, surface of which will be reinforced by concrete for structural strengthening and better accessibility.

(5) Filter sheet will be provided for preventing earth from leakage.

(6) Land behind the wall will be filled up to MSL +4.8 m by coral fragment obtained by excavation works.

2) Parapet Wall

Proposed crown top of the parapet wall is MSL +6.0 m which has been discussed in the previous section. A wave overtopping discharge by Sally wave will be roughly estimated by the following formula:

$$V = \alpha \cdot \Delta R^2 / To \qquad m^3/m/sec.$$

Where,

V	:	Overtopping discharge	($m^3/m/sec.$)
ΔR	:	Run-up height above parapet	(m)
To	:	Wave period, $To = 12.5$	(sec) by Sally
α	:	Coefficient depending on slope, wave dimensions and others. Generally, $\alpha = 0.1 \sim 0.2$, using $\alpha = 0.15$	

Therefore

$$V = 0.15 \times 4.4^2/12.5$$
$$= 0.23 \ m^3/m/sec$$

While the allowable overtopping rate for this site is assumed to be Va = 0.05 $m^3/m/sec$.

Thus, the crown top of MSL +6.0 m seems not enough height to protect, however is proposed considering better open-view and accessibility to beach, thus suitable in the Site-1.

3) Armour Rocks

The size of armour rocks is to be calculated by the Hudson's formula as seen in the design criteria, subsection 12.2.2.

Wave height on the lagoon is estimated from the wave height in subsection 5.3.8.

Thus, design wave height for armour rock is

B = 100 m (Width of lagoon)
H = 1.86 m

The minimum required weight of the armour rocks is:

$$W = \frac{2.65 \times 1.86^3}{2.8 \times (2.65/1.03 - 1)^3 \times 2} = 0.122 \times 1.86^3 = 0.79 \text{ ton/pc}$$

However, by considering safety factor armour rocks of 1 ton size shall be used at the foot of the protection to avoid scouring.

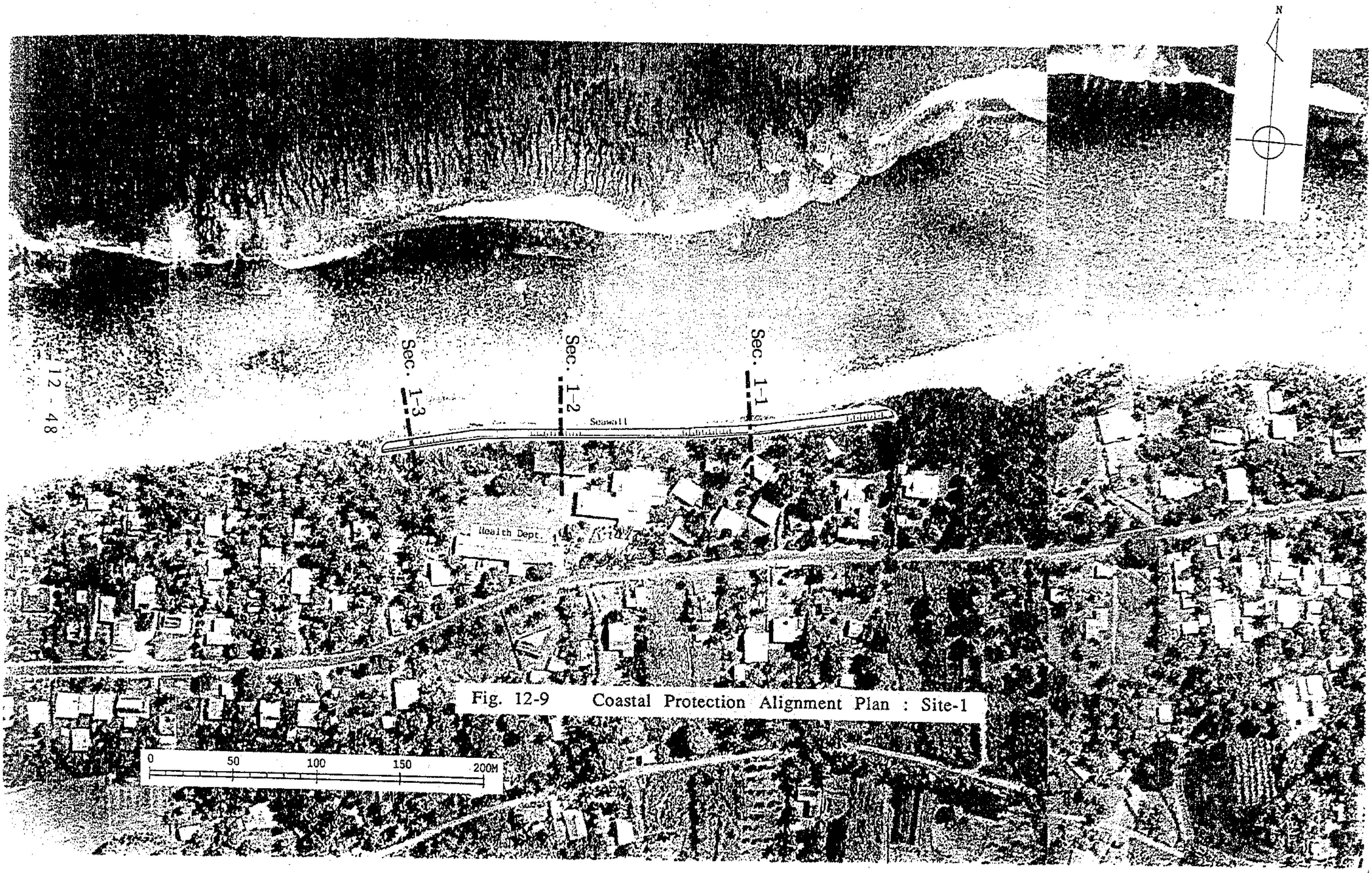


Fig. 12-9 Coastal Protection Alignment Plan : Site-1

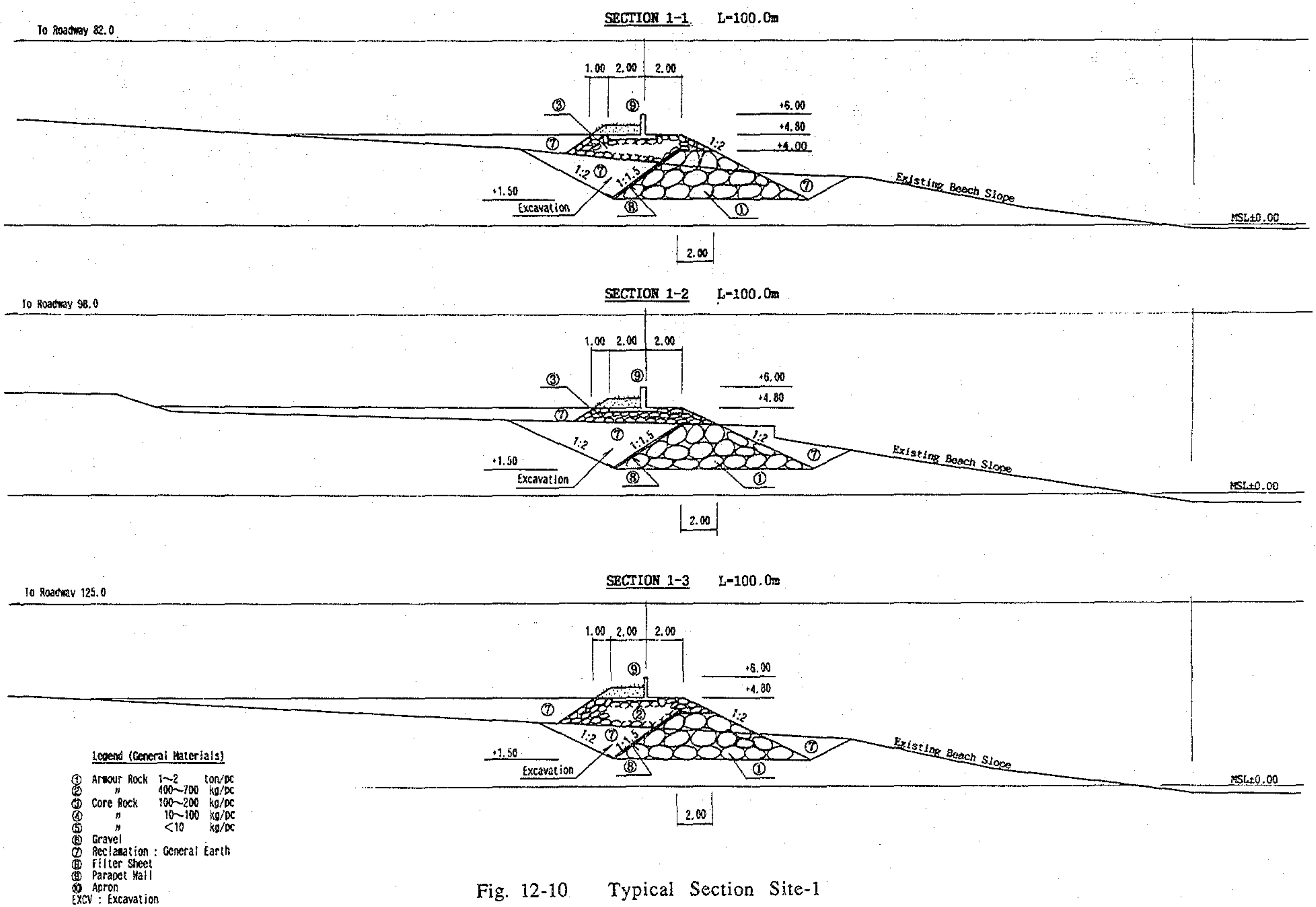


Fig. 12-10 Typical Section Site-1

12.4 Preliminary Design : Site 2 "Avarua/Avatiu Urbanized Area"

This section deals with the proposed alignment of the coastal defense line and the basic structural section for the existing coast along the Avarua Urbanized area. This site is the main target of the Short-term Development Plan.

12.4.1 Avarua East

A. Existing Conditions

There is natural sandy beach beyond the existing Avarua East Breakwater. A 50 meter wide strip of land between the beach road and the coast is occupied by restaurants, a sports club, market shops and government offices. Half of this land is occupied by plantations and vegetation.

The elevation of the beach road ranges between MSL +2.5 m and +3.5 m. The beach top formation is about MSL +2.0 m. There is no artificial construction on coastline. A wreck named "Yankee" rests on the foreshore, 190 m from the existing breakwater. The lagoon is about 150 meters wide.

According to the calculation, Sally class waves runs up to MSL +9.0 meters. Thus, overtopping (ΔR) here is MSL +7.0 meters. It is reported that this area was severely damaged by Cyclone Sally, in 1987. Other damage was observed during the Cyclone Gene in March, 1992.

This site is classified as a Grade II and III area where wave overtopping and beach erosion were observed during Sally.

B. Purpose of Proposed Coastal Protection

The main objective of coastal protection here is to minimize cyclone damage caused by waves overtopping to the beach bank and the existing facilities. It is also required to relocate the existing breakwater seaward for the future marina construction

Due to the low formation of the existing land, it is recommended that a buffer zone be constructed by means of land reclamation behind wall.

C. Scale of Proposed Coastal Protection

Basic protection type is combination of seawall and buffer zone by land reclamation.

The seawall formation is evaluated in order to maximize protection efficiency.

Table 12-5 shows the expected damage reduction by project.

Calculation Conditions

a. Design Wave height: Ho' = 8.1 m for run-up
b. Lagoon width: 150 m without project
100 m without project (reclamation)
c. Buffer zone: 50 m
d. Top of proposed wall:
Concrete parapet wall: MSL+4.5 m
Armour rock: MSL+3.3 m
e. Existing ground height: MSL+2.0 m
The recommended seawall height is MSL +4.5 m which is 2.5 m above the existing ground formation.

Table 12-5 Damage Reduction Estimate by Project: Site-2 (1) Avarua East

Design Wave Height Ho' = 8.1 m

Lagoon Width (without Project) = 150 m
Lagoon Width (with Project) = 100 m

Return Period	Cyclones/30yr A	Without Project					With Project				
		Ho' (m)	Run-up (MSL+)	Ground (MSL+)	ΔR (m)	A·ΔR²	Ho' (m)	Run-up (MSL+)	Wall (MSL+)	ΔR (m)	A·ΔR²
1 yr	30times/30yr	5.3	+4.3	+2.0	2.3	159	5.3	+5.5	+4.5	1.0	30
5 yr	6times/30yr	6.7	+6.8	+2.0	4.8	138	6.7	+7.8	+4.5	3.3	65
10 yr	3times/30yr	7.3	+7.8	+2.0	5.8	101	7.3	+9.0	+4.5	4.5	61
15 yr	2times/30yr	7.7	+8.4	+2.0	6.4	82	7.7	+9.8	+4.5	5.3	56
20 yr	1.5times/30yr	7.9	+8.7	+2.0	6.7	67	7.9	+10.0	+4.5	5.4	44
25 yr	1.2times/30yr	8.0	+8.8	+2.0	6.8	55	8.0	+10.1	+4.5	5.6	38
30 yr	1times/30yr	8.1	+9.0	+2.0	7.0	49	8.1	+10.4	+4.5	5.9	35
Total	47.7					651					329

Evaluation:

Equivalent Number of Sally Class cyclone without project ---------- 651 ÷ 49 = 13.3 Model Cyclones
Equivalent Number of Sally Class cyclone with project ---------- 329 ÷ 49 = 6.7 Model Cyclones
Reduction of damage in Sally Class cyclone ---------- 13.3 - 6.7 = 6.6 Model Cyclones

As shown in the Table, it is assumed that this site will be affected by 13.3 Sally class cyclones during the next thirty years if no coastal protection is provided.

According to the results of the calculation, the estimated damage over the next 30 years will amount to the damage caused by 6.7 Sally class cyclones if the proposed coastal protection work is provided. Even after protection works, remaining over-topping height (ΔR) by Sally class cyclone will be about 5.9 m, however this should be accepted for better open view. This weakness should be covered by means of provision of buffer zone. Thus, the benefits of the project can be counted as damage reduction in 6.6 Sally class cyclones.

D. Proposed Defense Line

Since Avarua Harbour should be developed as a new marina, the inner port basin should be protected by a breakwater. To preventing construction from double investment, it is recommended that the existing East breakwater be realigned to meet future requirements.

Thus, the new breakwater alignment was designed as discussed in sections 8.6 and 13.4.

According to the wave calmness study, the head of the existing East breakwater seems too conservative and should be moved 120 meters to the reef side. The new East breakwater in Short-term Development will be 90 meter long and will be in a northwest direction.

The new northern seawall will be connected with this new East breakwater at its western end and will make contact with the existing natural beach at its eastern end. The basic alignment of these facelines aims at smoothing the waterfront.

West of this area will face to port basin and will be retained by a rock mound dike. Discharge from the existing Takuvaine Stream will run in front of this wall. This arrangement will mitigate inland flood by means of more rapid discharge by larger head, since water level in the port basin is lower by 50 cm than lagoon during a cyclone.

The lagoon enclosed by the breakwater, seawall and stream dike will be reclaimed for a buffer zone. This new land can be utilized for public use as a part of the "Port Park Complex". Refer to section 12.7.

As seen in Table 12-5, Sally class wave will easily over-top the proposed seawall by 6 m, thus this area will be so important in respect to mitigation of water dumping. Although the required width of buffer zone will be 25 m, however it is proposed a 50 m width considering effective land use during the normal climatic condition.

It is recommended that apron concrete pavement be provided along the seawall and dike in order to mitigate damage caused by wave over-topping. The width of this surface protection should not be less than 10 meters.

E. Basic Section and Type of Structure

The basic section of the proposed coastal protection (Sec. 2-1 A) appears in Figs. 12-11 and 12-12A. The main dimensions of the structure are discussed hereinafter.

1) Type of Structure

Basic structural type is seawall type and similar to the existing seawall constructed by MOW at the Avarua Coast. Characteristics of structure are as follows:

(1) Defense line advances seaward by 50 m.
(2) Gradient of slope is 1 : 3.5.
(3) Front armour rock will touch upon the base rock MSL ±0.0 m for preventing structure from scouring.
(4) On the top of structure, reinforced concrete parapet wall will be provided.
(5) Armour rock will be two layers.
(6) Filter sheet will be provided for preventing filling earth from leakage.
(7) Behind the seawall, apron pavement in 11 m width will be provided at MSL +3.0 m.
(8) Area behind apron will also be reclaimed by earth (+3.5 m).

2) Parapet Wall

Proposed crown top of the parapet wall here is MSL +4.50 m which has been discussed in the previous section. The wave overtopping discharge by Sally class cyclone is roughly estimated as follows:

$$
\begin{aligned}
V &= \alpha \cdot \Delta R^2/To \\
&= 0.15 \times 5.9^2/12.5 \\
&= 0.42 \ m^3/m/sec.
\end{aligned}
$$

While the allowable overtopping rate for this section is assumed at $Va = 0.20\ m^3/m \cdot sec$.

Thus, estimated discharge is larger than allowable figure. It is recommended that dumped water should be kept between reclamation dike (+3.5) and apron (+3.0) and drain to the inner port basin.

3) Armour Rocks

Wave height on the lagoon is estimated from the wave height in subsection 5.3.8. Thus, design wave height for armour rock is,

B = 100 m

H = 1.86 m

The minimum required weight of the armour rock is:

$$
W = \frac{2.65 \times 1.86^3}{2.8 \times (2.65/1.03-1)^3 \times 3.5} = 0.07 \times 1.86^3 = 0.45 \ \text{ton/pc}
$$

Thus, 1 ton armour rocks or larger shall be used to avoid scouring.

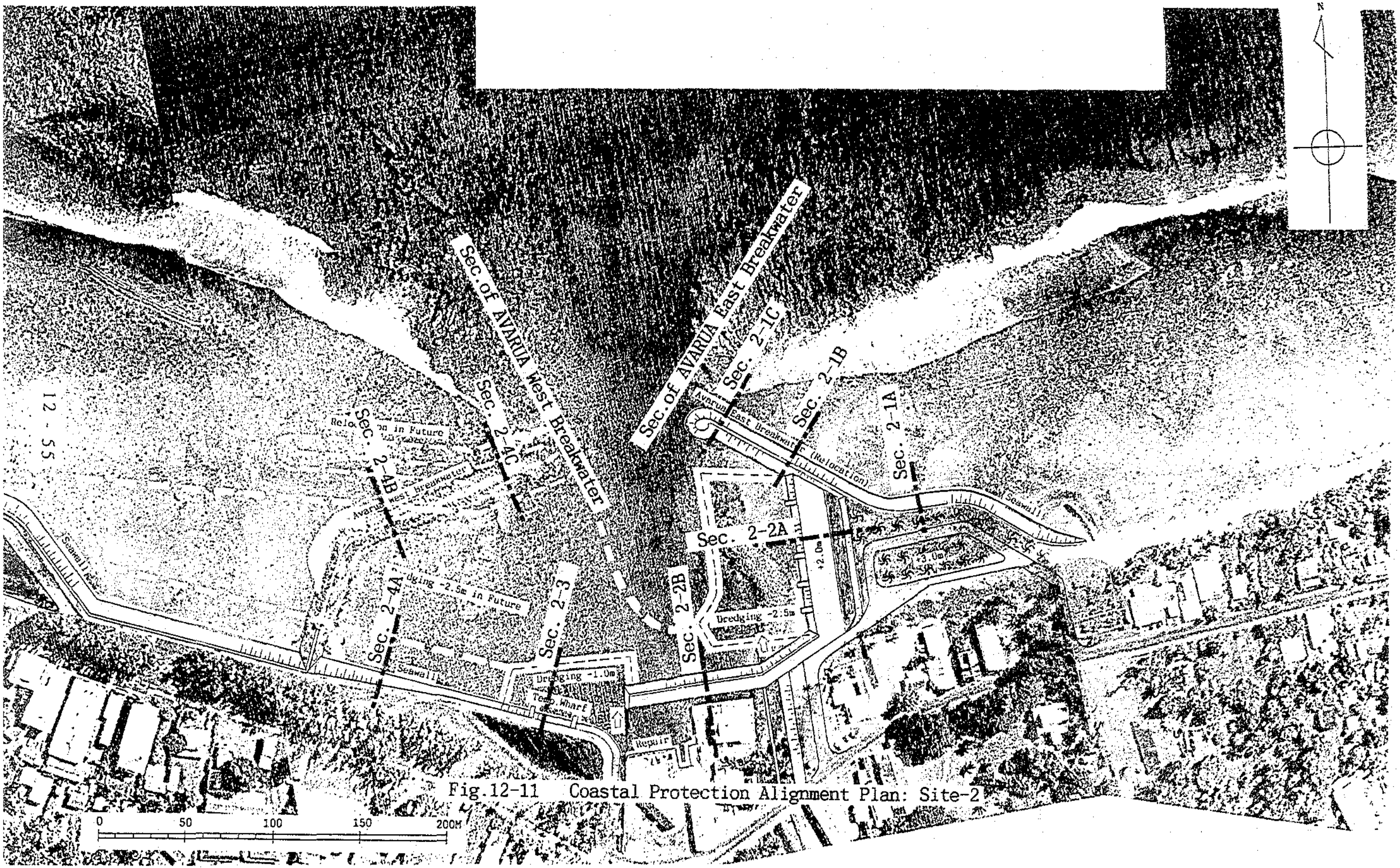
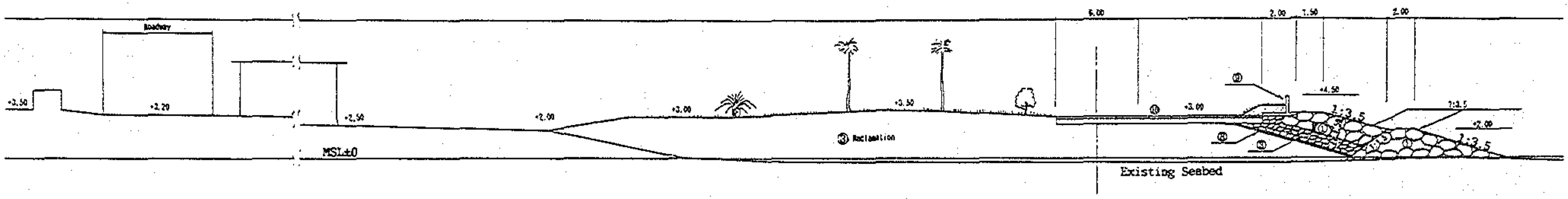


Fig.12-11 Coastal Protection Alignment Plan: Site-2

SECTION2-1A L=125.0m



Legend (General Materials)

① Armour Rock 1~2 ton/pc
② 〃 400~700 kg/pc
③ Core Rock 100~200 kg/pc
④ 〃 10~100 kg/pc
⑤ 〃 <10 kg/pc
⑥ Gravel
⑦ Reclamation : General Earth
⑧ Filter Sheet
⑨ Parapet Wall
⑩ Apron
EXCV : Excavation

Fig.12-11A Typical Section,Site-2

12.4.2 Avarua Harbour
(Takuvain stream outlet to Avarua West Breakwater)

This subsection deals with coastal protection in the Avarua Harbour. Breakwater design will be discussed in Section 13.6.

A. Existing Conditions

The existing coastline between the outlet of the Takuvaine stream and the western breakwater is relatively calm due to protection by the two existing breakwaters. The total length of this coast is about 280 meters. The eastern 80 meter portion is provided with a seawall, wharf and slipway which are severally damaged by low maintenance efforts and frequent cyclone attacks. The western end of this developed area is protected by wall construction from the leading dike to the existing outlet of Stream Vaikapuangi.

Land depth up to the beach road is about 60 meters where four buildings are located, including a restaurant, a shop, a fish market and TLT headquarters.

It is reported that the wharf front building was severely damaged by Cyclone Sally. Photographs taking during Cyclones Val/Wasa indicates wave run-up to MSL + 4.0 meters.

The waterfront structure of the western half is a steel sheet pile wall supported by tie-rods with a concrete apron and pavement. The top of this wall is severely corroded as there is no concrete protection. The apron has settled due to the removal of foundation earth by wave suction.

The 40 meter long front wharf is, however, currently utilized by pleasure boats for game fishing and diving and marine life training by boy scout.

The existing wharf formation and beach road height are MSL +2.0 m and +2.5 m respectively. The formation of the existing wharf is about +2.0 m. The beach road elevation is about MSL +2.5 m. The ground height here is the lowest in the Avarua urbanized area.

The western end of the 200 meter coast that faces the shallow lagoon is not developed yet for port use but randomly riprapped slope. A large armour rock layer is not provided here because the area is protected by the existing breakwaters.

A 40 meter wide strip of land between the beach road and the coastal slope is being developed by MOW for the second beach road and cyclone buffer zone in 1992. This construction effort is scheduled to be completed by the end of 1992. The ground formation rises gradually westward. The ground level changes from MSL +2.5 m at the bottom to +3.7 m at the root of the West breakwater.

B. Purpose of the Proposed Coastal Protection

The main objective of coastal protection here is to strengthen the existing slope and wharf. The existing wharf structure should be repaired with a minimum cost to extend its service life or rebuilt completely.

The coastal bank, 100 meter westward of the Vaikapuangi Stream outlet, will require a buffer zone since the largest waves in the port appear here. The existing slope should be strengthened by rock riprapping work.

During the third site visit, the study team was requested by the government to develop partially Avarua Harbour as Marina. As a conclusion the request was accepted by the study team and marina wharf was planned in the area behind the new East breakwater. Based on this situation, two alternative layout were developed in respect to coastal protection.

C. Scale of Proposed Coastal Protection

Alternative - A

The formation of coastal protection will basically be the same as it is at present. The wharf structure will be maintained as is by means of additional concrete coping. Pavement damage will be rehabilitated accordingly. 100 meters west of the Vaikapuangi Stream outlet will be reclaimed for a cyclone buffer zone, the proposed formation of which is +2.0 m. Infront of this buffer zone temporary jetties for small boat berthing will be provided. The scale of this new land will be about 1,500 m^2.

A rock riprapping wall will retain newly reclaimed earth and a 10 meter wide concrete apron will be provided for protecting the backfill and the space for public use.

100 meters of the west end slope will be strengthened when required.

Alternative - B

This alternative is developed in order to built a marina during the Short-term Development Plan. In addition to alternative-A facilities, new reclamation of damaged wharf and marina wharf behind the East breakwater will be provided. This arrangement will be discussed further in Section 13.4.

D. Proposed Defense Line

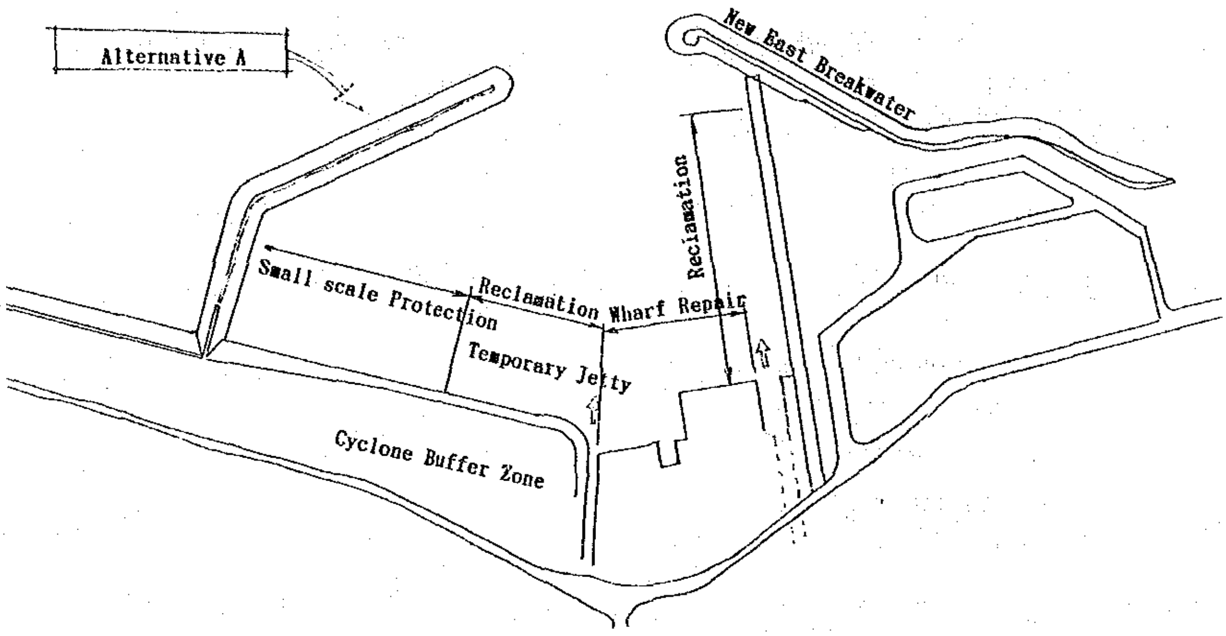
Alternative - A

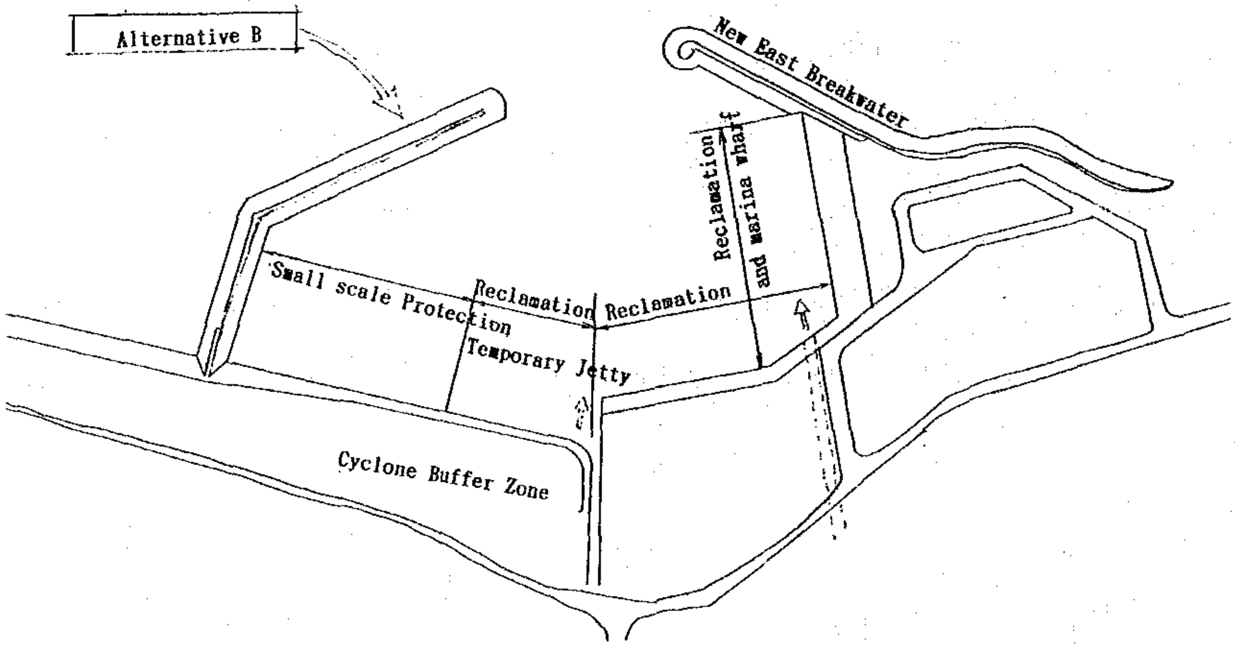
The faceline in 80 m between the outlets of the two streams will be the same as at present.

The proposed faceline west of Vaikapuangi St. sets back 10 meters from the quayline of the future new marina.

Alternative - B

The south faceline will advance further seawards. New marina wharf faceline will remove eastwards by 25 m. Detailed plan of this will be shown in Section 13.4.


Alternative A
New East Breakwater
Reclamation
Small scale Protection
Reclamation
Wharf Repair
Temporary Jetty
Cyclone Buffer Zone


Alternative B
New East Breakwater
Reclamation
and marina wharf
Small scale Protection
Reclamation
Reclamation
Temporary Jetty
Cyclone Buffer Zone

12.4.3 Avarua/Avatiu Coast
(Avarua West Breakwater to Avatiu Stream)

A. Existing Conditions

The coast is about 600 meters long. Behind the coastline, there is a 750 meters long beach road. The eastern 450 meters of the coastal area is protected by a new rock slope constructed by MOW. Formation of this area ranges between MSL +3.7 m and +4.8 m. The remaining western 150 meters is rather natural coast for a dumping site of surplus earth and dredged materials. The elevation of this area is only MSL +2.3 meters. Survey Department currently prepares a development plan of a festival plaza for October 1992.

At the center of the coast, the beach road elevation reaches its highest point (+4.8 m). The elevation drops to the lowest MSL +2.5 m at the two port areas.

Table 12-6 Beach Road Formation: Avarua Coast

Point	Beach Road Level (m)	
Vaikapuangi Str.	MSL + 2.50	Avarua Harbour
Avarua West B/W	+ 3.70	↑
Mama Court	+ 4.34	
Cathedral	+ 4.80	600 m
Customs	+ 4.13	↓
Avatiu Str.	+ 2.73	Avatiu Harbour

Source: Surveyed by the study team in 1991.

The average lagoon width is 200 meters. According to wave run-up calculation, Sally class design waves (significant wave) will run-up to MSL +7.3 m.

The most important characteristic of this site is the concentration of various establishments including restaurants, supermarkets, souvenir shops, banks, churches, car rental shops, fuel stations and various government offices. These facilities constitute the core of both the national economic and political activities. There is no other site as important as this in the country.

B. Purpose of Proposed Coastal Protection

The main objective of coastal protection here is to prevent these vital activities from being damage by cyclones. Cyclone damage here is mainly caused by wave overtopping together with coral fragment dumping. Other purpose of work is to generate more lands for public use.

For the above reasons, it is recommended that a buffer zone be constructed by land reclamation. To meet this requirement, MOW executed coastal protection work that consists of the following:

(i) A thirty meter wide buffer zone where a parallel secondary beach road, a parking space and plantation are provided.

(ii) Strengthening of the coast slope by armour rock riprapping.

The proposed layout here should be incorporated with this MOW construction work.

According to the Master Plan, the commercial port sector in Avatiu Harbour should be expanded by 1.5 Ha eastward to meet future increased cargo traffic needs. Thus, another aim of the protection work is to generate a flat land along the existing port area.

C. Scale of the Proposed Coastal Protection

Basic protection type is combination of seawall and buffer zone by land reclamation. The seawall formation is evaluated in order to maximize protection efficiency.

(i) In case of Maximum Use of MOW Section, Section 2-5.

It is assumed that the MOW seawall can remain as is with minimum strengthening in the eastern 130 m coast.

Proposed work in addition to the MOW section is as follows:

- Provision of foot protection rock mound
- Provision of concrete parapet wall (+5.5 m)
- Provision of U-shaped drainage (1.5 m x 1.0 m)

Table 12-7 shows expected damage reduction by the project.

Calculation Conditions

a. Design wave height: Ho' = 7.7 m for run-up
b. Lagoon width: 200 m
c. Buffer zone executed by MOW: 30 m
d. Top of proposed parapet wall: MSL +5.5 m
e. Existing concrete pedestrian
   Executed by MOW: MSL +3.5 ~ +4.0 m

Table 12-7 Damage Reduction Estimate by Project : Site - 2 (2)
Avarua Coast East

Design Wave Height Ho' = 7.7 m

Lagoon Width (without Project) = 200 m
Lagoon Width (with Project) = 200 m

Return Period	Cyclones/30yr A	Without Project					With Project				
		Ho' (m)	Run-up (MSL+)	Ground (MSL+)	ΔR (m)	A·ΔR²	Ho' (m)	Run-up (MSL+)	Wall (MSL+)	ΔR (m)	A·ΔR²
1 yr	30times/30yr	5.0	+3.2	+3.5	-0.3	-	5.0	+3.2	+5.5	-2.3	-
5 yr	6times/30yr	6.3	+5.2	+3.5	1.7	17	6.3	+5.2	+5.5	-0.3	-
10 yr	3times/30yr	6.8	+6.1	+3.5	2.6	20	6.8	+6.1	+5.5	0.6	1
15 yr	2times/30yr	7.1	+6.5	+3.5	3.0	18	7.1	+6.5	+5.5	1.0	2
20 yr	1.5times/30yr	7.4	+7.0	+3.5	3.5	18	7.4	+7.0	+5.5	1.5	3
25 yr	1.2times/30yr	7.6	+7.2	+3.5	3.7	16	7.6	+7.2	+5.5	2.2	6
30 yr	1times/30yr	7.7	+7.3	+3.5	3.8	14	7.7	+7.3	+5.5	2.3	5
Total	47.7					103					17

Evaluation:

Equivalent Number of Sally Class cyclone without project ----------- 103 ÷ 14 = 7.4 Model Cyclones
Equivalent Number of Sally Class cyclone with project ----------- 17 ÷ 14 = 1.2 Model Cyclones
Reduction of damage in Sally Class cyclone ----------- 7.4 - 1.2 = 6.2 Model Cyclones

As seen in the Table, it is assumed that this site will be affected by 7.4 Sally class cyclones during the next thirty years if no coastal protection is provided. If the project is executed, the estimated damage will be in the amount of 1.2 Sally class cyclones over the next thirty years, thus benefits from the project can be counted as reduction of 6.2 Sally class cyclones.

(ii) In case of Relaxation of MOW Section Foreshoreward, Section 2-6

It is recommended to relocate the MOW seawall 50 meters foreshoreward of the western 470 meter coast. This aims at generating more public land for various use, to including future port expansion, and the provision of a larger buffer zone to prevent an extensive cyclone damage.

The proposed relocation works here is as follows:

- Relocation of the existing MOW seawall seawards by 50 m
- Expansion of cyclone buffer zone (50 m)
- Provision of concrete parapet wall (+5.5 m)
- Provision of U-shaped drainage (1.5 m x 1.0 m)

Table 12-8 shows expected damage reduction by the project.

Calculation Condition

a. Design wave height: Ho' = 7.7 m for run-up
b. Lagoon width:
   without project (MOW section): 200 m
   with project (Reclamation): 150 m
c. Buffer zone by MOW: 30 m
   Additional buffer zone 50 m
d. Top of proposed parapet wall: MSL+5.5 m
e. Existing concrete pedestrian: MSL+4.0 m
f. Elevation of reclaimed land (New): MSL+4.3 m

Table 12-8 Damage Reduction Estimate by Project : Sit-2 (3)
Avarua Coast West

Design Wave Height Ho' = 7.7 m

Lagoon Width (without Project) = 200 m
Lagoon Width (with Project) = 150 m

Return Period	Cyclones/30yr A	Without Project					With Project				
		Ho' (m)	Run-up (MSL+)	Ground (MSL+)	ΔR (m)	A·ΔR²	Ho' (m)	Run-up (MSL+)	Wall (MSL+)	ΔR (m)	A·ΔR²
1 yr	30times/30yr	5.0	+3.2	+4.0	-0.8	-	5.0	+3.8	+5.5	-1.7	-
5 yr	6times/30yr	6.3	+5.2	+4.0	+1.2	9	6.3	+6.1	+5.5	0.6	2
10 yr	3times/30yr	6.8	+6.1	+4.0	+2.1	13	6.8	+7.1	+5.5	1.6	8
15 yr	2times/30yr	7.1	+6.5	+4.0	+2.5	13	7.1	+7.5	+5.5	2.0	8
20 yr	1.5times/30yr	7.4	+7.1	+4.0	+3.1	14	7.4	+7.9	+5.5	2.4	9
25 yr	1.2times/30yr	7.6	+7.4	+4.0	+3.4	14	7.6	+8.2	+5.5	2.7	9
30 yr	1times/30yr	7.7	+7.3	+4.0	+3.3	11	7.7	+8.4	+5.5	2.9	8
Total	47.7					74					44

Evaluation:

Equivalent Number of Sally Class cyclone without project ---------- 74 ÷ 11 = 6.7
Equivalent Number of Sally Class cyclone with project ---------- 44 ÷ 11 = 4.0
Reduction of damage in Sally Class cyclone ---------- 6.7 - 4.0 = 2.7

As seen in the Table, it is assumed that this site will be affected by 6.7 Sally class cyclones during next thirty years if no coastal protection is provided. If the project is executed, the estimated damage over the next thirty years will amount to damages caused by 4.0 Sally class cyclones.

Thus, the benefits of the project can be counted as the damage reduction of 2.7 Sally class cyclones.

D. Proposed Defense Line

The proposed defense line for two sections was drawn to meet following requirements:

(i) Eastern 130 meters
- Maintaining of the existing buffer zone by 30 m.
- To remain lagoon space for future marina basin in Avarua Harbour

(ii) Western 470 meters
- Provision of buffer zone 50 m or more
- Reclamation of new land for future public land use and port
- Connecting new seawall to the Avatiu East breakwater.

E. Basic Section and Type of Structure (Eastern 130 m)

The basic section of the proposed coastal protection (sec. 2-5, 2-6 & 2-7) appears in Fig. 12-12 and 12-12A. Major dimension of structure are designed in the following.

1) Type of structure (Section 2-5)
This section is the existing seawall executed MOW in 1991/1992. Section 2-5 in Fig. 12-12A shows typical section of this wall.
However, foot dike has been added to the existing MOW section in order to mitigate toe rock from scouring by wave. This strengthening work will reduce the wave run-up and provide more stability against larger wave than the design wave.

2) Parapet Wall

As shown in Fig. 12-12A, it is recommended to add concrete parapet wall (+5.5 m) to the MOW section. As seen in Table 12-7, parapet wall will be required since wave run-up is increased by 0.8 m ~ 1.0 m due to narrow lagoon by land reclamation. However it is also possible to make parapet top height lower for better over-view form land side to sea. Final decision on this matter will be conducted during the detailed design with more discussion and study.

3) Armour Rocks

Wave height on the lagoon is estimated from the wave height in subsection 5.3.8. Thus design wave height for armour rock is,

B = 200 m

H = 1.26 m

The minimum required weight of the amour rocks is:

$$W = \frac{2.65 \times 1.26^3}{2.8 \times (2.65/1.03 - 1)^3 \times 3.5} = 0.070 \times 1.26^3 = 0.14 \text{ ton/pc}$$

Armour rocks larger than 400 kg size shall be used for the foot protection to avoid scouring.

F. Basic Section and Type of Structure (Western 470 m)

1) Type of structure (Section 2-6)

Basic structural type is seawall type and similar to the existing seawall constructed by MOW. Characteristics of structure are as follows:

(1) Defense line advances seaward by 50 m than MOW alignment.

(2) Gradient of slope is 1:3.5

(3) Front armour rock will touch upon the base rock MSL -0.3 m for preventing structure from scouring.

(4) On the top of structure, reinforced concrete parapet wall will be provided.

(5) Armour rock will be two layers.

(6) Filter sheet will be provided for preventing filling earth from leakage.

(7) Behind the seawall, apron pavement in 6 m width will be provided at MSL +4.0 m.

(8) Area behind apron will also be reclaimed by earth.
At middle section (2-6) MSL +4.5 m
At west end section (2-7) MSL +3.0 m to meet port use

2) Parapet Wall

The proposed crown top of the parapet wall for the area is MSL +5.50 m as previously discussed. A wave overtopping by Sally wave is roughly estimated as follows:

$$V = 0.15 \times 2.9^2/12.5$$
$$= 0.10 \ m^3/m/sec$$

This figure exceeds the allowable overtopping rate for this section assumed as $Va = 0.05 \ m^2/m/sec$. However, it should be accepted for better over-view from land side to sea. Final decision on further lowering the height will be made during the detailed design stage to follow.

3) Armour Rocks

Wave height on the lagoon is estimated from the wave height in subsection 5.3.8. Thus, design wave height for armour rock is,

B = 150 m
H = 1.46 m

The minimum required weight of the armour rocks is:

$$W = \frac{2.65 \times 1.46^3}{2.8 \times (2.65/1.03-1)^3 \times 3.5} = 0.070 \times 1.46^3 = 0.22 \ ton/pc$$

Thus, larger than 400 kg size rock shall be used to avoid scouring.

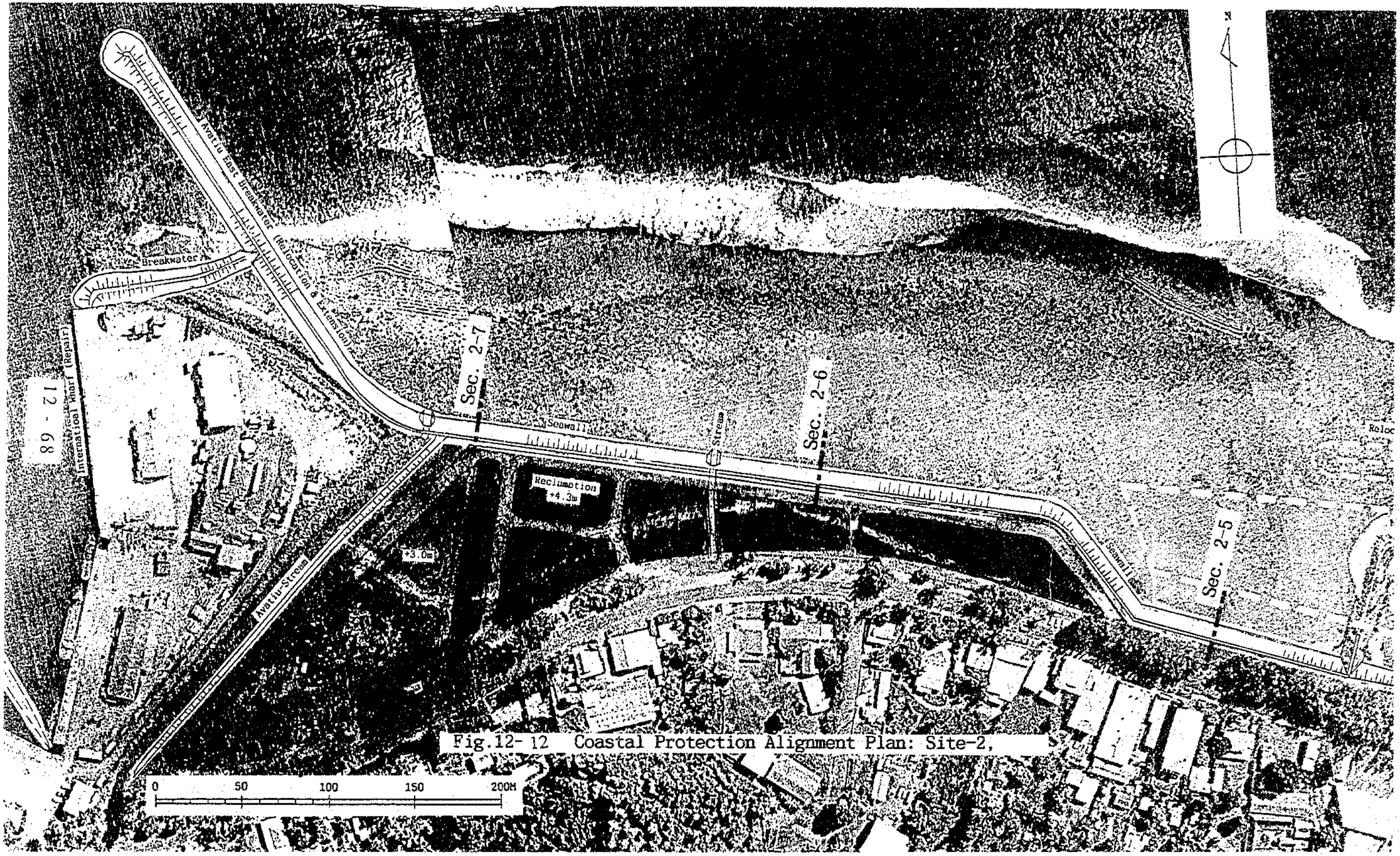


Fig.12- 12 Coastal Protection Alignment Plan: Site-2,

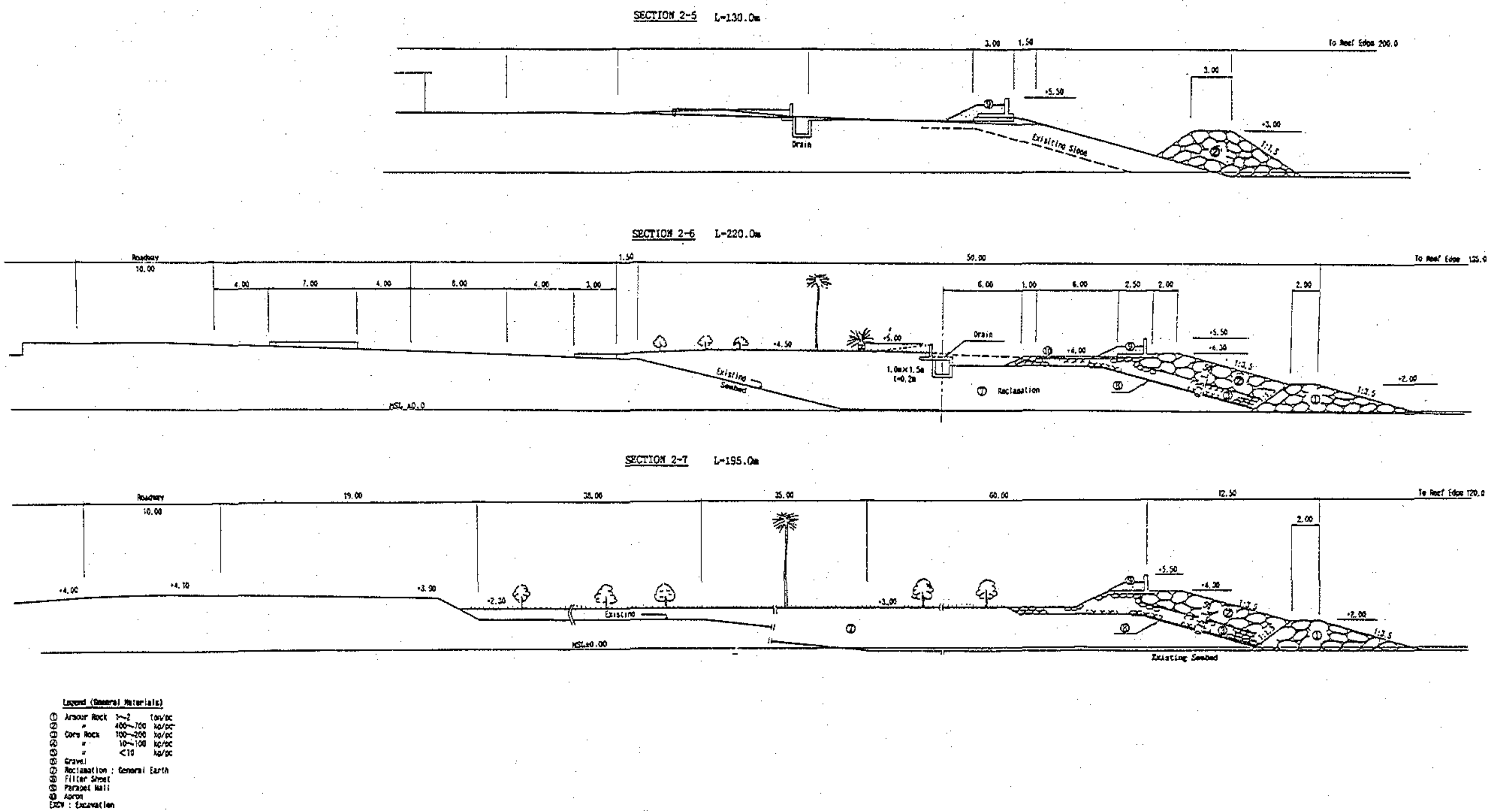


Fig.12-12A Typical Section,Site-2

12.5 Preliminary Design : Site 3 "Airport East"

This section deals with the alignment of the coastal defense line and the basic section proposed for the fuel storage areas and their surroundings at the eastern end of the existing airport.

12.5.1 Existing Conditions

In the opposite direction to the airport terminal building, there are two fuel storage areas, a laundry factory, etc. facing to the lagoon.

The existing coastline here is occupied by the following facilities:

a. JUHI Fuel Storage	120 m
b. Outlet of Kaikaveka Steam	7 m
c. Laundry factory	83 m
d. TRIAD Fuel Storage	70 m
Total	280 m

This coastal area belongs to Village Kaikavcka. However, the JUHI Fuel Storage is categorized as "Airport Area" in this report.

These facilities are located on the 50 m (approx.) wide coastal bank between the beach road and the upper shoulder of the coastline. Cemeteries are located at both end of this area.

The elevation of the existing road ranges between MSL +3.7 m (West) and +4.5 m (East). Beach top elevation is about MSL +3.7 m.
Small earth dikes are constructed along the beach top in front of both fuel storage yards.

The tank yard of JUHI seems partly built on the reclaimed land that has an elevation of approximately MSL +5.5 m. This yard is protected by an earth dike seaward and by concrete walls on the other three faces. The seaward dike is covered by armour rock riprapping, top elevation of which is approximately MSL +6.0 m. This slope is about 1:2 and is partly damaged. Placed rock seems to be a random mound.

The TRIAD tank yard is also protected by earth dike. Its top elevation is about MSL +5.0 m. Rock protection work seawards is provided but its top elevation is +3.8 m and it is a rather light construction.

The faceline of the existing rock riprapping seems to be advancing seaward and is eight meters away from the natural beach shoulder. The laundry factory has no protection work but the existing beach 1:5 slope consists of natural coral fragments.

According to the calculation, the design wave (8.7 meters) of a Sally class cyclone runs up to MSL +9.8 meter; thus, the overtopping height here is about six meters. It is reported that this area was severely damaged by waves caused by Sally. The lagoon width varies from 90 meter at the eastern end to 190 meters at the western end. This site is classified as a Grade III area where a heavy wave over-topping was recorded during the Cyclone Sally.

12.5.2 Purpose of Proposed Coastal Protection

Purpose of protection works here are to mitigate disasters by over-topped wave to fuel storage facilities etc. Fuel supply to the existing airport should be maintained by adequate coastal protection.

12.5.3 Scale of the Proposed Coastal Protection

The main objective of coastal protection here is to mitigate damage caused by wave overtopping to the important private facilities which are the sole source of fuel supplies to the island and airport. Thus, protection work here should be strong enough to counter wave forces and maintain wave over-topping moderate.
It is recommended to provide here rock riprapping seawall.
The scale of rock riprapping work against waves and surges can be shown by the top elevation of the seawall.

Note: The detached breakwater will not work properly here since the lagoon is too narrow.

Table 12-9 shows expected damage reduction by the project

Calculation Condition:

a. Design wave height: Ho' = 8.7 meter for run-up
b. Lagoon width: 150 meters
c. Top of proposed seawall:
   Concrete parapet wall: MSL+6.0 m
   Armour rock: MSL+4.8 m
d. Existing ground height: MSL+3.7 m

As shown in the Table, it is assumed that this area will be affected by 9.7 Sally class cyclones during next thirty years if no coastal protection is provided. Recommended seawall top height is MSL +6.0 m which is 2.3 meters higher than the existing ground and beach road.

According to the results of the calculation, estimated damages during the next 30 years will be the amount of damage caused by 2.4 Sally class cyclones if the coastal protection work is provided. Thus, benefits of the work can be counted as damage reduction in 7.3 Sally class cyclones.

Table 12-9 Damage Reduction Estimate by Project: Site - 3

Design Wave Height Ho' = 8.7 m

Lagoon Width (without Project) = 150 m
Lagoon Width (with Project) = 150 m

Return Period	Cyclones/30yr A	Without Project					With Project				
		Ho' (m)	Run-up (MSL+)	Ground (MSL+)	ΔR (m)	A·ΔR²	Ho' (m)	Run-up (MSL+)	Wall (MSL+)	ΔR (m)	A·ΔR²
1 yr	30times/30yr	5.6	+4.8	+3.7	1.1	36	5.6	+4.8	+6.0	-1.2	-
5 yr	6times/30yr	7.0	+7.3	+3.7	3.6	78	7.0	+7.3	+6.0	1.3	10
10 yr	3times/30yr	7.6	+8.2	+3.7	4.5	61	7.6	+8.2	+6.0	2.2	15
15 yr	2times/30yr	8.0	+8.8	+3.7	5.1	52	8.0	+8.8	+6.0	2.8	16
20 yr	1.5times/30yr	8.4	+9.6	+3.7	5.9	52	8.4	+9.6	+6.0	3.6	19
25 yr	1.2times/30yr	8.5	+9.7	+3.7	6.0	43	8.5	+9.7	+6.0	3.7	16
30 yr	1times/30yr	8.7	+9.8	+3.7	6.1	37	8.7	+9.8	+6.0	3.8	14
Total	47.7					359					90

Evaluation:

Equivalent Number of Sally Class cyclone without project ---------- 359 + 37 = 9.7 Model Cyclones
Equivalent Number of Sally Class cyclone with project ---------- 90 + 37 = 2.4 Model Cyclones
Reduction of damage in Sally Class cyclone ---------- 9.7 - 2.4 = 7.3 Model Cyclones

As seen in the Table, the effect of proposed work can be justified although 2.4 equivalent cyclones remain.

In addition to this main seawall, auxiliary side dikes will be constructed in front of the existing two cemeteries. These supplemental protection work will be constructed on the same faceline of main seawall.

12.5.4 Proposed Defense Line

The shape of the existing beachline is slightly curved. The defense line of the coastal protection will be parallel to the existing beach. The proposed faceline of the seawall is about five meters seaward of the existing JUHI and TRIAD seawalls. This arrangement aims at:

a. Cost reduction and
b. Utilization of the existing rock work as the core of the new seawall.

However, the faceline in front of the laundry will be advanced ten meters seaward in order to make a smooth defence line. Auxiliary side dike will be connected to the main seawall and top height will be MSL +2.0 m.

12.5.5 Basic Section and Type of Structure

The basic sections of the proposed coastal protection in Site-3 are shown in Figs. 12-13 and 12-14. The main dimensions of the structure are as follows.

1) Type of Structure

Basic structural type is seawall type and similar to the existing seawall constructed by MOW at the Avarua Coast. Characteristics of structure are as follows:

(1) Defense line advances seaward by 5 m.
(2) Gradient of slope is 1 : 3.5.
(3) Front armour rock will touch upon the base rock MSL -0.4 m for preventing structure from scouring.
(4) On the top of structure, reinforced concrete parapet wall will be provided.
(5) Armour rock will be two layers.
(6) Filter sheet will be provided for preventing filling earth from leakage.

Typical section of auxiliary rock dike is shown in Fig. 12-14 (section 3-5). Rock mound type is adopted.

2) Parapet Wall

Proposed crown top of the parapet wall is MSL + 6.0 m. This has been discussed in the previous section.

A wave topping volume by Sally wave can be roughly estimated as follows:

$$V = 0.15 \times 3.8^2/12.5$$
$$= 0.17 \ m^3/m \cdot sec.$$

While the allowable overtopping rate for this site is assumed as being $Va = 0.20 m^3/m \cdot sec$.

However, it is recommended to provide drainage for over-topped water to discharge into the existing Kaikaveka Stream outlet. This matter should be discussed with oil storage managements during the detailed design.

3) Armor Rocks

The minimum required weight of the armour rocks is calculated by the Hudson's formula. Wave height in the lagoon is estimated from the wave height in subsection 5.3.8.

$$B = 150 \ m$$
$$H = 1.54 \ m$$
$$W = \frac{2.65 \times 1.54^3}{2.8 \times (2.65/1.03-1)^3 \times 3.5} = 0.07 \times 1.54^3 = 0.26 \ ton/pc$$

However, armour rocks over 400 kg size shall be used to avoid scouring. The same size rocks will be used for the side dike.

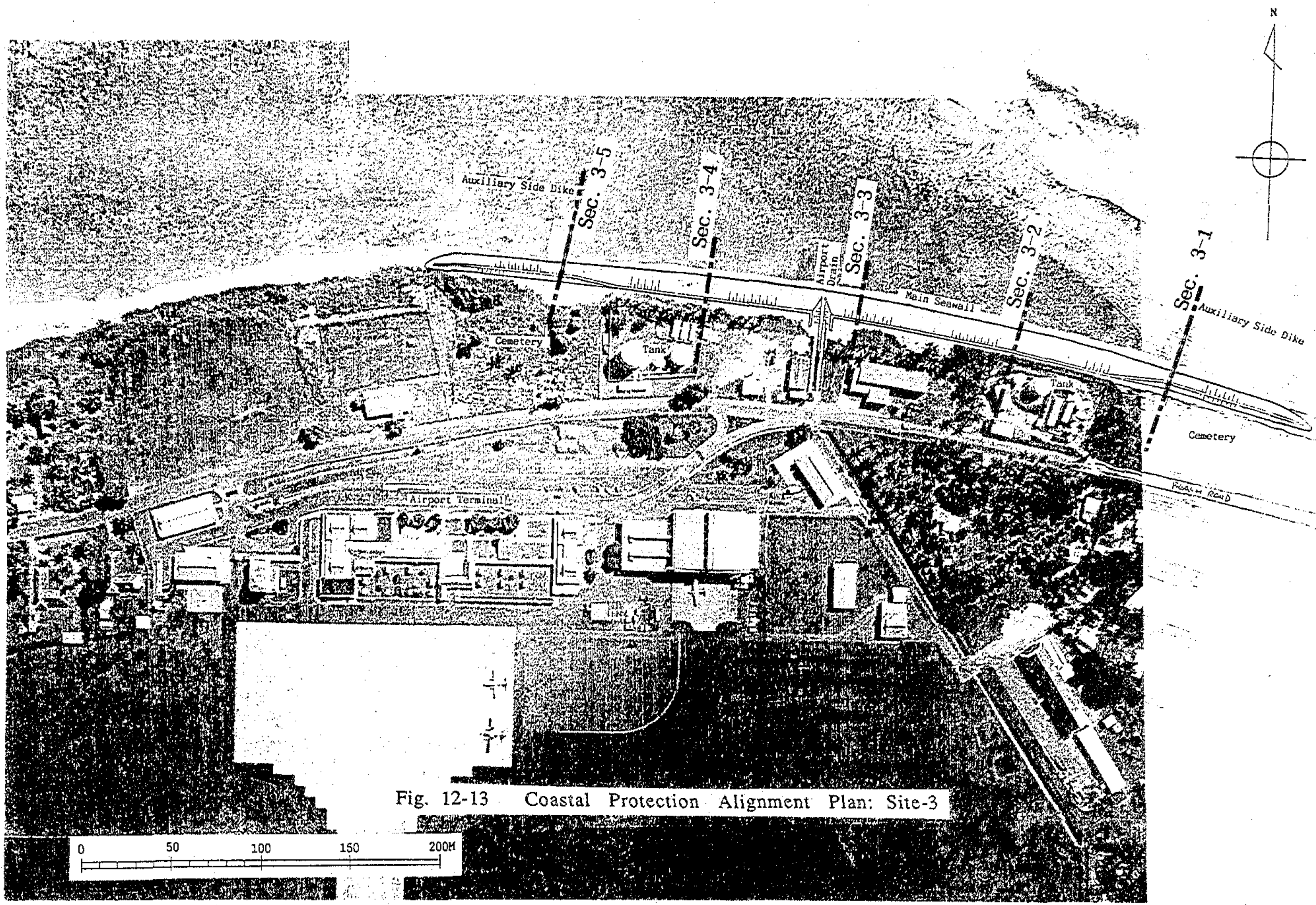


Fig. 12-13 Coastal Protection Alignment Plan: Site-3

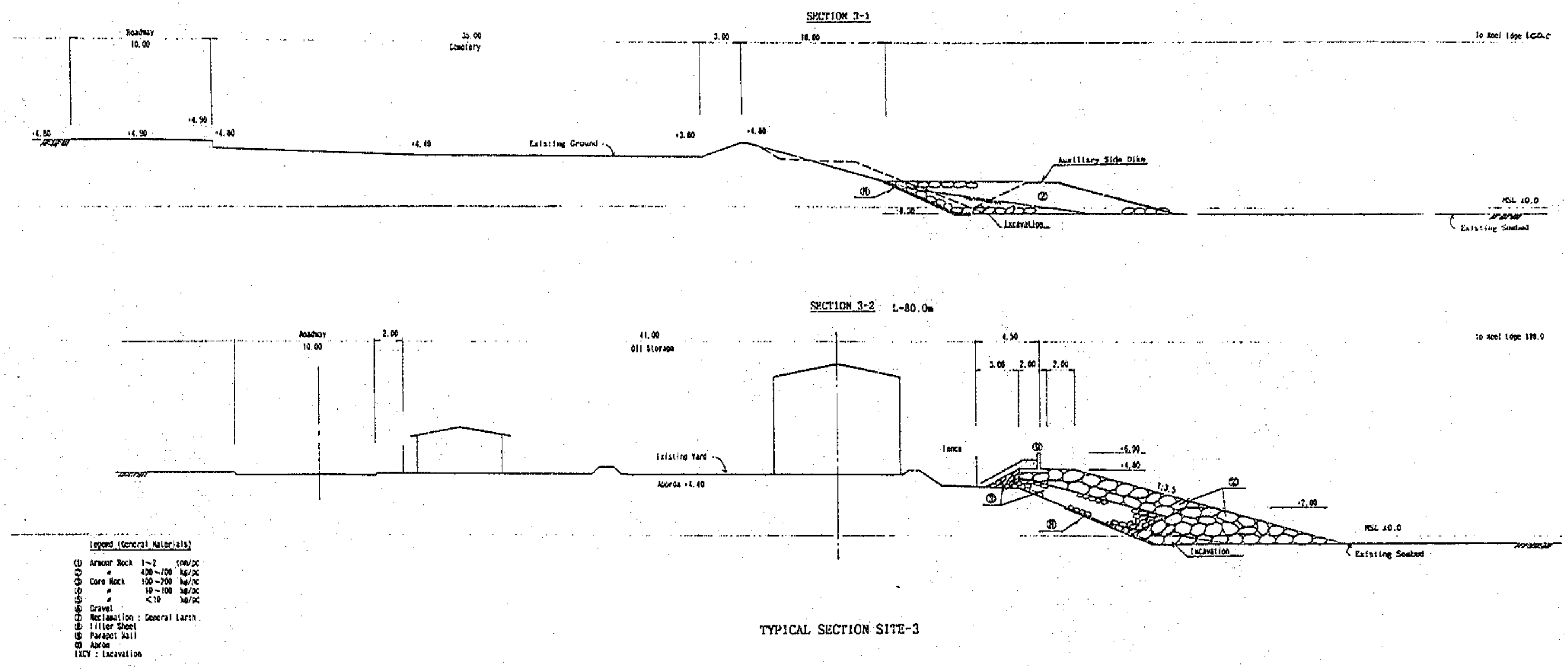


Fig.12-14 Typical Section,Site-3,(1/2)

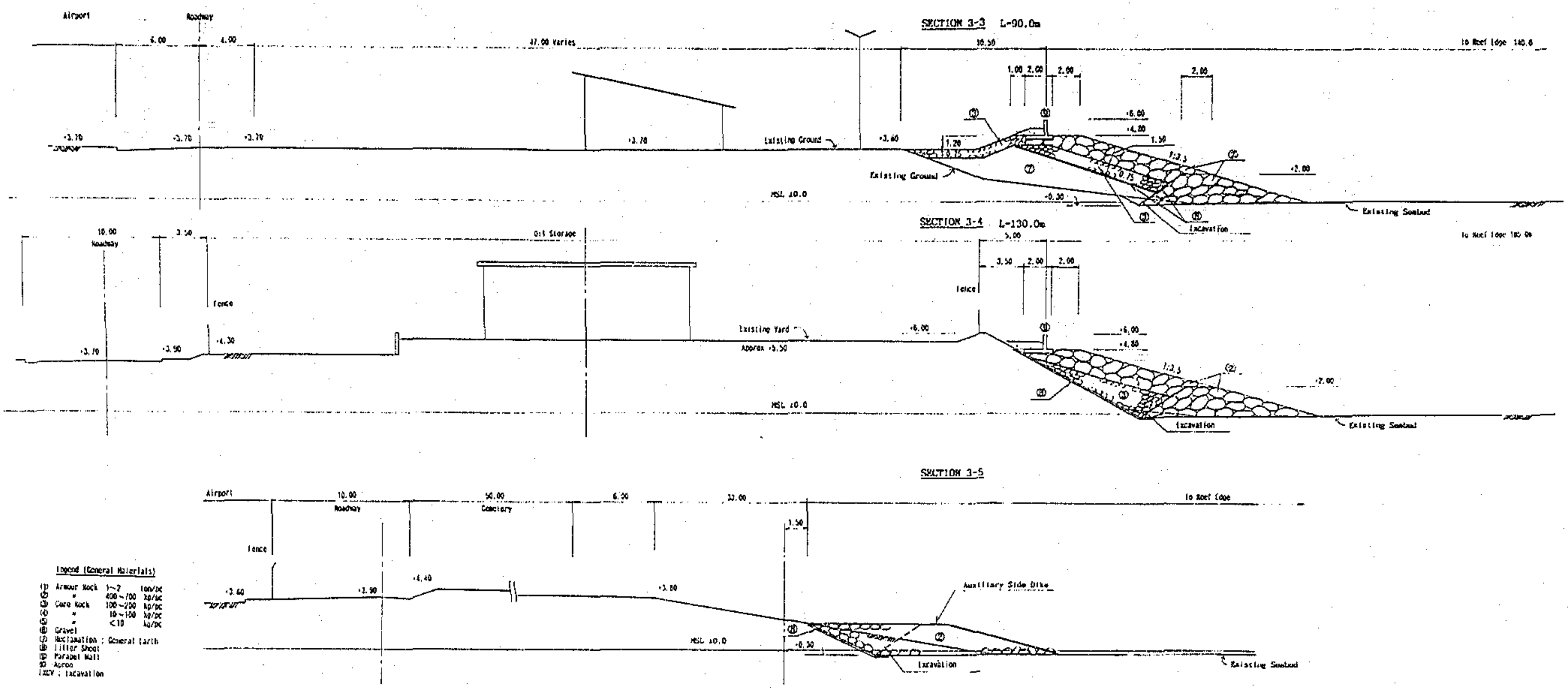


Fig.12-14 Typical Section,Site-3,(2/2)

12.6 Preliminary Design : Site 4 "Airport West"

This section deals with the proposed alignment of the coastal defense line and the basic structural section for the existing seawall improvement along the western airport end.

12.6.1 Existing Condition

The western end of the existing airport was constructed on the reclaimed land. The beach road runs on the causeway along the dike here. The causeway consisting of reclaimed earth with a 500 meter long concrete vertical wall is constructed to protect the road and airport dike from waves. The road formation is about MSL +2.5 meter in order to maintain necessary clearance for vehicles under the airport construction limit. The elevation of the existing runway is about MSL +5.5 meters.

Causeway East End, near MET

The average road width is about eight meters. It is made of asphalt concrete with a pedestrian path on the seaward side. The road is protected by a continuous concrete wall, top height of which is MSL+4.0 meters.

At the eastern end of causeway, the road elevation gradually rises to MSL +6.0 meter and departs from the existing shoreline. At the middle point of the slope, the sea-side concrete wall connects to another type of concrete seawall protecting MET.

It is reported that this connection point was severely damaged by Cyclones Val and Wasa in 1991. Same disaster happened by Cyclone Gene in 1992. According to the photographs taken immediately after these storms in 1991, a 50 meter length of pavement was completely destroyed and its foundation was eroded. The airport dike was partly damaged and embedded utility lines were exposed. It is assumed that the main reason in the damage was the failure of the seawall. A possible sequence for this will be as follows:

a. Coastal current from an eastward direction and moves along the seawall's northern face may hit the junction of the two seawalls.

b. Energy of current and wave may concentrate here and scour foundation of the seawall that was extended from the MET side.

(Note; It is assumed that the existing airport causeway is structurally firm since its foundation seems to be resting on the coral bedrock. However, the MET side seawall may not be strong enough to withstand a wave attack.)

c. MET's 15 meter long side seawall was broken.

d. Wave penetration freely to the asphalt pavement

e. Damage of pavement and its foundation earth

f. Damage to airport dike and utility mains

This disaster will happen repeatedly if the necessary structural improvement is provided here.

North-West Corner

At the northwest corner of the causeway, Cyclones Sally and Val/Wasa caused large-scale overtopping. There was, however, no severe damage except for the partial failure of the airport dike by the washing action of waves. The concrete parapet wall is MSL +3.9 meter high, however, this seems too conservative against such large wave, 8.7 meter high height during Cyclone Sally. Wall top of MSL +3.9 meter is however the limit height if a car driver requires an open view.

The wall structure itself seems sound enough to wave force since its foundation rests on coral rock.

Causeway West End

From the West end to the East end of causeway, the road elevation rises gradually from MSL +2.5 m to +4.0 m. The road crosses a stream on the concrete culvert outlet coming from the South boundary of the airport. The stream outlet is 35 meter long and is an open channel made of concrete covered by gabion. The Nikao school is on the opposite side to the channel. West of this outlet is mainly private land where small shops and houses are located.

Causeway protected by concrete wall ends 30 m before this open channel and is followed by natural beach. This beachline is normal to the causeway, thus the wave energy concentration appears also to the East end of causeway. This natural beach was severely eroded and asphalt pavement in 30 m was completely damaged by Cyclones Val/Wasa in 1991 and Gene in 1992.

The lagoon here is about 250 m wide. It is an excellent swimming spot for tourists and local people. Within 150 meters west of the channel, there is a public facility so called Social Centre that provides a parking space and a shower system with local swimmers. The toilet shed was partially damaged by Cyclone Sally. The remaining portion of the roof has been blown off by Cyclones Val and Wasa in 1991. The western end of the causeway and the stream outlet were also damaged.

12.6.2 Purpose of the Proposed Coastal Protection

The main objective of coastal protection here is to mitigate damages caused by waves overtopping and scouring to the causeway and to prevent the beach road and the airport dike from being destroyed. It is also required to protect the foundations at the junction points between the existing causeway and the connecting coastal protection. Smoothing the defense line will also be required to prevent natural coast from being damaged by energy concentration.

Note; If the beach road pavement is concrete one, it will be more durable than the existing asphalt pavement. Airport dike can be protected by rock riprapping or concrete slab. It is recommended to study these plans in future.

12.6.3 Seawall near MET : Section 4-1

A. Scale of the Proposed Coastal Protection

The purpose of coastal protection here is as follows:

(i) protection of the existing MET seawall against scouring by waves and coastal current.

(ii) Reduction of the effects of wave over-topping

Table 12-10 shows expected damage reduction by the project.

Calculation Conditions:

a. Design wave height: Ho' = 8.7 meter for run-up

b. Lagoon width:
 320 meters without project
 300 meters with project

c. Buffer zone: 8 meters

d. Top of proposed wall:
 Concrete parapet wall: MSL+5.0 m
 Armour rock: MSL+3.8 m

e. Existing ground height: MSL+3.8 m

Table 12-10 Damage Reduction Estimate by Project : Site-4 (1) Causeway East

Design Wave Height Ho' = 8.7 m

Lagoon Width (without Project) = 320 m
Lagoon Width (with Project) = 300 m

Return Period	Cyclones/30yr A	Without Project Ho' (m)	Run-up (MSL+)	Ground (MSL+)	ΔR (m)	A·ΔR²	With Project Ho' (m)	Run-up (MSL+)	Wall (MSL+)	ΔR (m)	A·ΔR²
1 yr	30times/30yr	5.6	+2.9	+3.8	-0.9	-	5.6	+3.1	+5.0	-1.9	-
5 yr	6times/30yr	7.0	+4.5	+3.8	0.7	3	7.0	+4.8	+5.0	-0.2	-
10 yr	3times/30yr	7.6	+5.2	+3.8	1.4	6	7.6	+5.4	+5.0	0.4	1
15 yr	2times/30yr	8.0	+5.6	+3.8	1.8	7	8.0	+6.0	+5.0	1.0	2
20 yr	1.5times/30yr	8.4	+6.1	+3.8	2.3	8	8.4	+6.4	+5.0	1.4	3
25 yr	1.2times/30yr	8.5	+6.2	+3.8	2.4	7	8.5	+6.5	+5.0	1.5	3
30 yr	1times/30yr	8.7	+6.3	+3.8	2.5	6	8.7	+6.6	+5.0	1.6	3
Total	47.7					37					12

Evaluation:

Equivalent Number of Sally Class cyclone without project ---------- 37 + 6 = 6.2 Model Cyclones

Equivalent Number of Sally Class cyclone with project ---------- 12 + 6 = 2.0 Model Cyclones

Reduction of damage in Sally Class cyclone ---------- 6.2 - 2.0 = 4.2 Model Cyclones

As shown in the Table, it is assumed that this causeway will be affected by 6.2 model cyclones, Sally, over the next thirty years if no protection work is provided. The recommended seawall top elevation is MSL +5.0 meters which is 1.2 meters above the existing beach road elevation. Results of calculation indicate that the estimated damages over the next thirty years will be an equivalent to that caused by 2.0 Sally class cyclones if the proposed protection work is provided.

Thus, the benefits of the work can be counted as damage reduction in 4.2 Sally class cyclones.

B. Proposed Defense Line

The existing defense line here caves in landward. The new defense line is located 10 meter seaward to maintain a buffer zone and a smoother faceline. This 70 meter long defense line covers the western MET area for thirty meters.

C. Basic Section and Type of Structure

1) Type of structure

Basic structural type is seawall type and similar to the existing seawall constructed by MOW at the Avarua Coast. Characteristics of structure are as follows:

(1) Defense line advances seaward by 10 m.
(2) Gradient of slope is 1 : 3.5.
(3) Front armour rock will touch upon the base rock MSL -0.4 m for preventing structure from scouring.
(4) On the top of structure, reinforced concrete parapet wall will be provided.
(5) Armour rock will be two layers.
(6) Filter sheet will be provided for preventing filling earth from leakage.

2) Parapet Wall

The basic section with plan appears in the Figs. 12-15 and 12-16. Proposed crown top of the parapet wall is MSL +5.0 m. Wave overtopping discharge here is roughly estimated for Sally wave as follows:

$$V = 0.15 \times 1.6^2/12.5 \text{ sec}$$
$$= 0.03 \text{ m}^3/\text{m/sec}$$

The allowable overtopping rate for seawall is $Va = 0.2 \text{ m}^3/\text{m/sec}$. Thus parapet wall height is enough.

However, 0.03 $\text{m}^3/\text{m/sec}$ is rather large value than allowable discharge for roadway. Thus the vehicular traffic during a cyclone should be carefully controlled. Drainage system to meet this discharge should be provided.

3) Amour Rocks

Wave height on the lagoon is estimated wave height in subsection 5.3.8. The minimum required weight of the armor rock is;

B = 300 m

H = 1.35 m

$$W = \frac{2.65 \times 1.35^3}{2.8 \times (2.65/1.03-1)^3 \times 3.5} = 0.07 \times 1.35^3 = 0.17\ ^{ton}/pc$$

Considering wave concentration, rock of 400 kg or larger will be used.

12.6.4 North-West Corner, Detached Breakwater : Section 4-2
(At the North-West corner of causeway)

A. Scale of Proposed Coastal Protection

Causeway here is the most projected part into the lagoon. Remaining free lagoon is only 120 m. In order to mitigate a wave energy concentration here, detached breakwater will be provided.

Purpose of this breakwater here is two holds namely:

(i) Reduction of wave energy by dispersion, thus reducing wave run-up at the causeway seawall.

(ii) Departing coastal current along the seawall to the mid of lagoon, thus moderate energy concentration at the both causeway ends.

Table 12-11 shows expected damage reduction by breakwater construction.

Calculation Conditions

a.	Design wave height:	Ho' = 8.7 meters for run-up
b.	Lagoon width:	120 meters
c.	Top of the existing concrete wall:	MSL +3.9 meters
d.	Existing lagoon depth:	MSL -0.5 meters
e.	Rate of wave run-up reduction by breakwater:	50 %
f.	Top of proposed breakwater	MSL +3.2 meters

Top of breakwater (h) was decided by following consideration.

$$h = h_1 + 0.5H$$

Where, h_1 : Water level including wave set-up, h_1 = MSL+2.2 m

H : Wave height, assuming 1.8 m as shown in subsection 5.3.8.

Thus, $h = 2.2 + 0.5 \times 1.8$

$= \text{MSL} + 3.2$ m

Table 12-11 Damage Reduction Estimate by Project : Site-4 (2)

Design Wave Height Ho' = 8.7 m

Lagoon Width (without Project) ≈ 120 m
Lagoon Width (with Project) = 100 m

Return Period	Cyclones/30yr A	Without Project Ho' (m)	Run-up (MSL+)	Ground (MSL+)	ΔR (m)	A·ΔR²	With Project Ho' (m)	Run-up (MSL+)	Wall (MSL+)	ΔR (m)	A·ΔR²
1 yr	30times/30yr	5.6	+5.4	+3.9	1.5	68	5.6	+2.7	+3.9	-1.2	-
5 yr	6times/30yr	7.0	+8.0	+3.9	4.1	101	7.0	+4.0	+3.9	0.1	0.1
10 yr	3times/30yr	7.6	+8.8	+3.9	4.9	72	7.6	+4.4	+3.9	0.5	0.8
15 yr	2times/30yr	8.0	+9.5	+3.9	5.6	63	8.0	+4.8	+3.9	0.9	1.6
20 yr	1.5times/30yr	8.4	+10.2	+3.9	6.3	60	8.4	+5.1	+3.9	1.2	2.2
25 yr	1.2times/30yr	8.5	+10.5	+3.9	6.6	52	8.5	+5.3	+3.9	1.4	2.4
30 yr	1times/30yr	8.7	+10.7	+3.9	6.8	46	8.7	+5.4	+3.9	1.5	2.3
Total	47.7					462					9.4

Considering the effect of Breakwater of 50% lowering run-tup

Evaluation:

Equivalent Number of Sally Class cyclones without project ---------- 462 ÷ 46 = 10.0 Model Cyclones

Equivalent Number of Sally Class cyclones with project ---------- 9.4 ÷ 46 = 0.2 Model Cyclones

Reduction of damage in Sally Class cyclones ---------- 10.0 - 0.2 = 9.8 Model Cyclones

As shown in the Table, it is assumed that this causeway will be affected by 10 Sally class cyclones over the next thirty years if no breakwater is provided. Result of calculation indicates also that estimated damage over the next thirty years will be that of 0.2 Sally class cyclones if the breakwater is provided. Thus, the benefits of the project is damage reduction in 9.8 Sally class cyclones.

In addition to this effect, direct wave overtopping to the airport dike will be remarkably reduced. Besides, sand deposit in front of the causeway is expected.

B. Proposed Defense Line

As the lagoon is only 120 meters wide, the center line of the detached breakwater will be located 25 meters off and parallel to the causeway. The total length of the breakwater is 150 meters. Refer to Fig. 12-15. Since splashed water may cover the road surface if breakwater is constructed close to the existing concrete wall, breakwater should be separated from the existing parapet wall.

C. Basic Section and Type of Structure

1) Type of structure

The existing causeway and its concrete wall seem durable, thus it should be maintained as it is. Proposed detached breakwater will be constructed separated from the wall by 25 m. Type of breakwater is rock-mounted dike type as seen in Avatiu Harbour. Major structural characteristics are as follows:

(1) Defense line in 25 m offshoreward from the existing causeway wall.
(2) Crown top MSL +3.2 m
(3) Width of top 4.0 m
(4) Gradient 1 : 1.5
(5) Amour rock should rest on the base rock at MSL -0.6 m.
(6) Amour rock should be two layers.

As discussed in 12.2.8, rock material should be used avoiding expensive concrete work. The proposed breakwater costs 2,000 Cook Dollars per meter.

2) Amour Rocks

The basic layout and section appears in Figs. 12-15 and 12-16. Design wave height is assumed based on wave height in subsection 5.3.8. The minimum required weight of the armor rock for the detached breakwater is:

$$B = 100 \text{ m}$$
$$H = 1.80 \text{ m}$$
$$W = \frac{2.65 \times 1.8^3}{2.8 \times (2.65/1.03-1)^3 \times 1.5} = 0.162 \times 1.8^3 = 0.94 \ \text{ton/pc}$$

Therefore rock material of 1 ton or larger will be used.

3) Existing Concrete Wall

Wave overtopping discharge in the existing concrete wall by a Sally class wave is roughly estimated as follows:

$$V = 0.15 \times 1.5^2/12.5$$
$$= 0.03 \quad m^3/m/sec$$

The allowable overtopping rate for seawall is $Va = 0.2\ m^3/m/sec$. Thus the existing concrete wall height might be enough.

However, $0.03\ m^3/m/sec$ is rather large value than an allowable discharge for vehicular traffic. Thus traffic during a cyclone should be carefully controlled. Drainage system to meet this discharge should also be provided. As previously discussed, road pavement should be changed from asphalt pavement to concrete pavement.

12.6.5 Seawall at the Western End of Causeway : Section 4-4

A. Scale of Proposed Coastal Protection

The purpose of coastal protection here can be summarized as follows:

(i) Protection against the scouring of the existing natural beach west of the existing causeway by waves and coastal current

(ii) Reduction of the effects of wave over-topping to the beach road.

(iii) Reduction of sand deposit into the existing airport open channel carried by an excessive wave over-topping.

It is also recommended to protect the existing natural beach immediate West of the open channel. Thus, following two parts will be protected by rock-mound dike.

- Between the western end of causeway and the existing open channel -------------------------- 65 m

- West side of the existing channel------------------------- 50 m

Table 12-12 shows the expected damage reduction by the project.

Calculation Conditions

a.	Design wave height:		Ho' = 8.7 meters for run-up
b.	Lagoon width:	250 m-----------	without project
		220 m-----------	with project
c.	Existing ground height:		MSL+3.8 meters

d. Buffer zone: average 17 meters

e. Top of proposed wall:

Concrete parapet wall: MSL+5.0 meter

Armour rock: MSL+3.8 meter

Table 12-12 Damage Reduction Estimate by Project : Site - 4 (3)

Design Wave Height Ho' = 8.7 m

Lagoon Width (without Project) = 250 m

Lagoon Width (with Project) = 220 m

Return Period	Cyclones/30yr A	Without Project Ho' (m)	Run-up (MSL+)	Ground (MSL+)	ΔR (m)	A·ΔR²	With Project Ho' (m)	Run-up (MSL+)	Wall (MSL+)	ΔR (m)	A·ΔR²
1 yr	30times/30yr	5.6	+3.3	+3.8	-0.5	-	5.6	+3.8	+5.0	-1.2	-
5 yr	6times/30yr	7.0	+5.4	+3.8	1.6	15	7.0	+6.0	+5.0	1.0	6.0
10 yr	3times/30yr	7.6	+6.3	+3.8	2.5	19	7.6	+6.8	+5.0	1.8	9.7
15 yr	2times/30yr	8.0	+6.9	+3.8	3.1	19	8.0	+7.4	+5.0	2.4	11.5
20 yr	1.5times/30yr	8.4	+7.4	+3.8	3.6	19	8.4	+8.1	+5.0	3.1	14.4
25 yr	1.2times/30yr	8.5	+7.5	+3.8	3.7	16	8.5	+8.2	+5.0	3.2	12.3
30 yr	1times/30yr	8.7	+7.7	+3.8	3.9	15	8.7	+8.4	+5.0	3.4	11.6
Total	47.7					103					65.5

Evaluation:

Equivalent Number of Sally Class cyclone without project ---------- 103 + 15 = 6.9 Model Cyclones

Equivalent Number of Sally Class cyclone with project ---------- 65.5 + 15 = 4.4 Model Cyclones

Reduction of damage in Sally Class cyclone ---------- 6.9 - 4.4 = 2.5 Model Cyclones

As shown in the Table, it is assumed that this area will be affected by 6.9 Sally class cyclones during the next thirty years if no seawall is provided. Study results indicate that the estimated damage over the next thirty years will be equivalent to that caused by 4.5 Sally class cyclones if the proposed protection work is provided. Thus, the benefits of the work can be counted as damage reduction in 2.4 Sally class cyclones.

B. Proposed Defense Line

The existing coastal bankline here caves in landward. New faceline of seawall is proposed to be located 17 meters seaward to maintain an appropriate buffer zone and a smoother faceline.

New seawall will be constructed in both bank of the existing drainage channel. A leading jetty at the channel outlet will also be provided. The total protection length is about 130 m including a 65 m wall at right bank, leading jetty and a 50 m wall at left bank.

C. Basic Section and Type of Structure

1) Type of structure

Basic structural type is seawall type and similar to the proposed seawall at causeway East end. Characteristics of structure are as follows:

(1) Defense line advances seaward by 17 m.

(2) Gradient of slope is 1 : 35.

(3) Front armour rock will touch upon the base rock MSL -0.6 m for preventing structure from scouring.

(4) On the top of structure, reinforced concrete parapet wall will be provided.

(5) Armour rock will be two layers.

(6) Filter sheet will be provided for preventing filling earth from leakage.

(7) Behind the seawall, apron pavement in 5 m width will be provided at MSL +3.8 m.

(8) Behind apron will also be reclaimed by earth (+3.8 m).

2) Parapet Wall

The basic plan and section appears in Figs. 12-15 and 12-16. Wave overtopping here by a Sally wave is roughly estimated as follows:

$$V = 0.15 \times 3.4^2/12.5$$
$$= 0.14\ m^3/m/sec$$

The allowable overtopping rate for seawall is $Va = 0.2\ m^3/m/sec$, thus the proposed parapet wall height is suitable. However this $0.14\ m^3/m/sec$ is rather large volume than allowable discharge for vehicular traffic. Thus, traffic during cyclone should be carefully managed. Drainage system connecting to the existing open channel should also be provided.

3) Armour Rocks

Design wave height is estimated based on wave height in subsection 5.3.8. The minimum required weight of the armor rocks is;

$$B = 220\ m$$
$$H = 1.35\ m$$
$$W = \frac{2.65 \times 1.35^3}{2.8 \times (2.65/1.03-1)^3 \times 3.5} = 0.07 \times 1.35^3 = 0.17\ ton/pc$$

Considering wave concentration, 400 kg or larger rock size will be used.

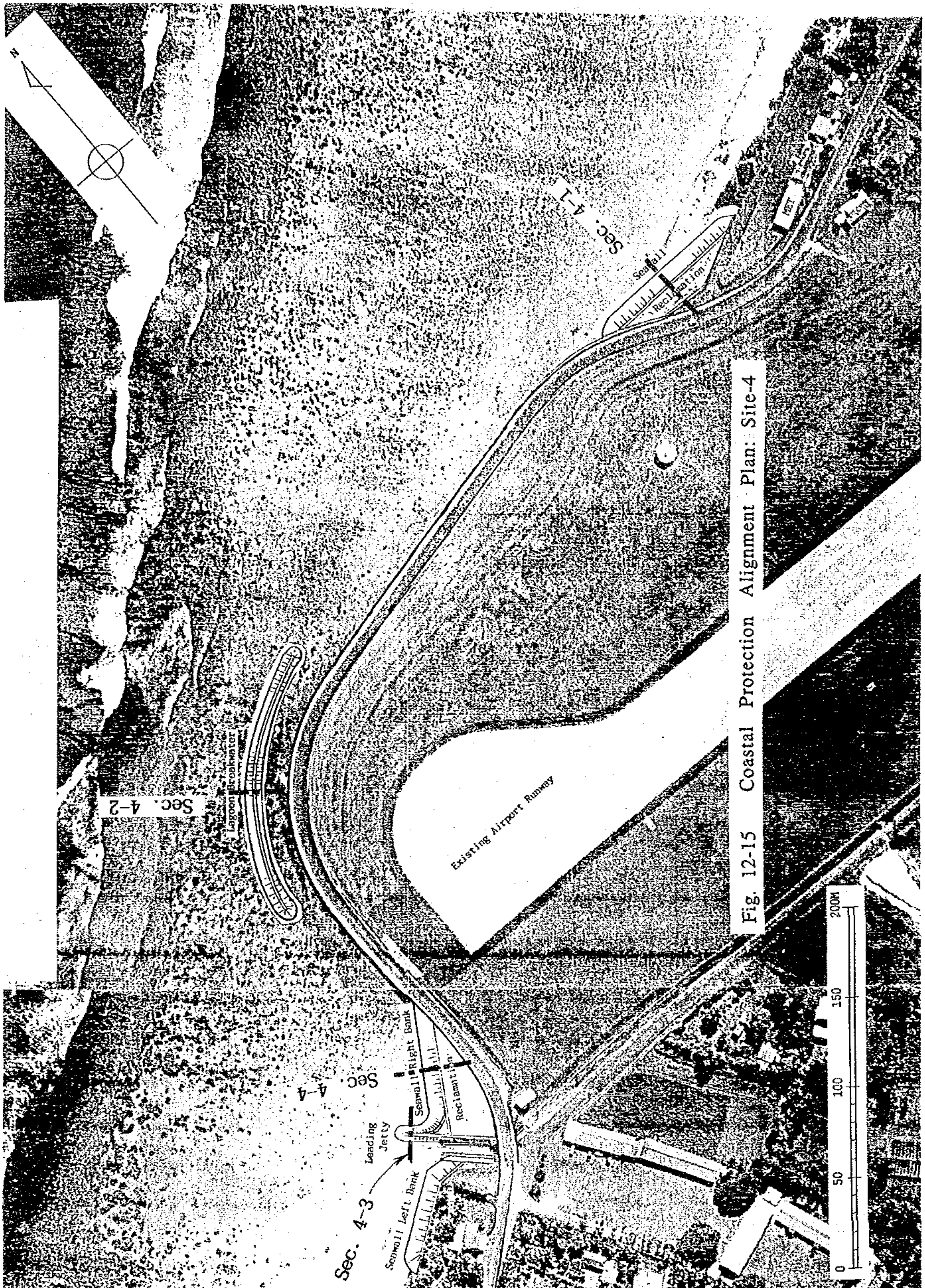


Fig. 12-15 Coastal Protection Alignment Plan: Site-4

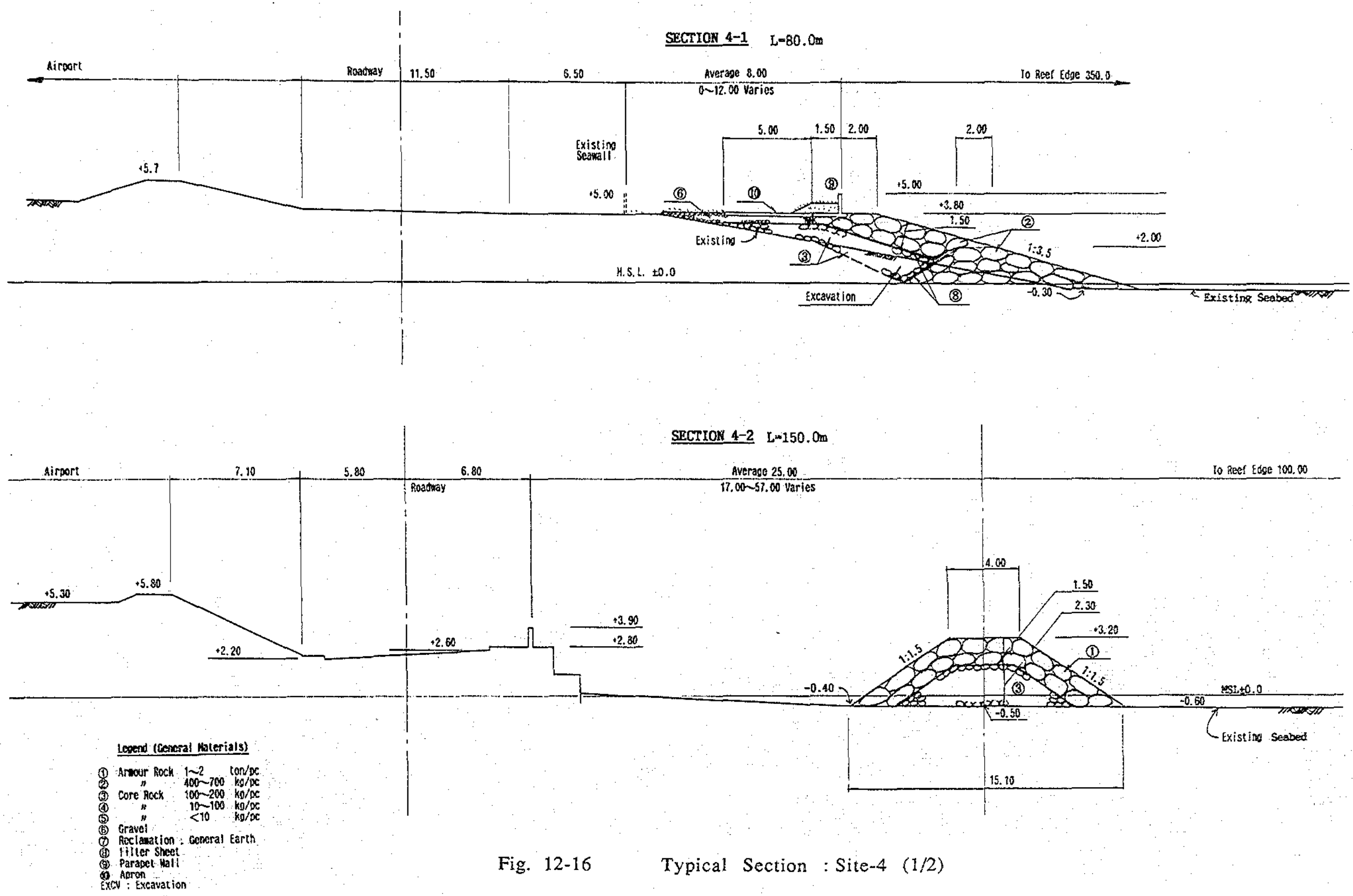


Fig. 12-16 Typical Section : Site-4 (1/2)

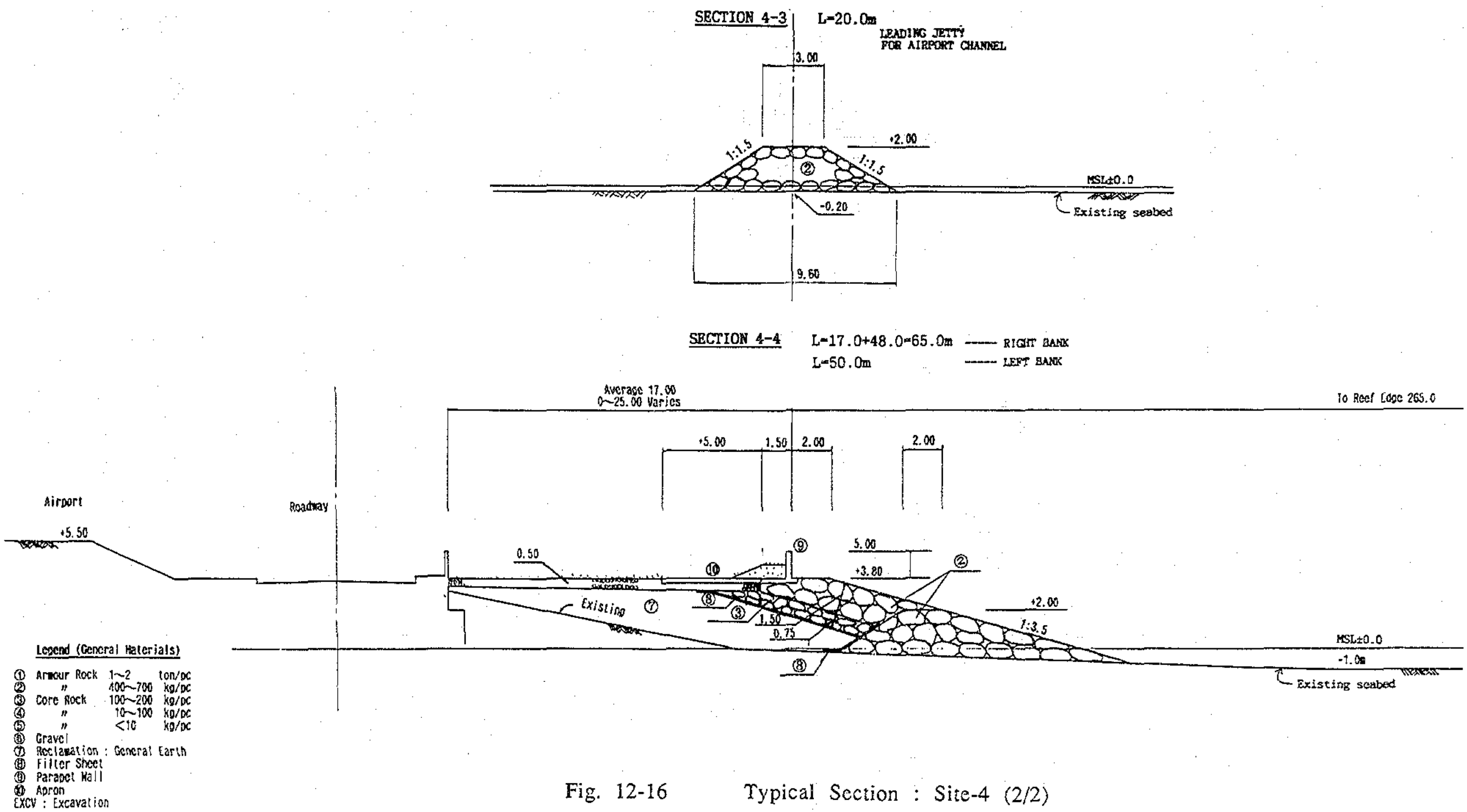


Fig. 12-16 Typical Section : Site-4 (2/2)

12.7 Preliminary Design : "Port Park Complex"

As discussed in subsection 12.4.3, the coastal area at Avarua/Avatiu areas will be reclaimed as a part of coastal protection work. Newly reclaimed area will be not only to be cyclone buffer zone but also additional space to public use which is currently in short of supply along the coastal area. This area is named the "Port Park Complex".

This section deals with the proposed planning concepts in the onland facilities of the Port Park Complex.

12.7.1 Existing Conditions

1) Shortage in Public Land
As discussed in subsection 12.4.3, this area is not only the core of Rarotonga Island but also the center of the Cook Islands. There is few empty land along the coast since a rapid increase of private facilities. Popularity of vehicular transport results traffic congestion at the beach road. Parking space and public park are also so limited. It is recommended to take an action to generate more land space for preferable amenities to islanders and tourists.

2) Land Creation along the Beach Road
For the creation of new land, there is no other choice than to reclaim lagoon. Lagoon width here varied from 170 m to 220 m before MOW reclamation. Thus an average lagoon width at present is about 170 m. Landward lagoon in 30 m was reclaimed by MOW in 1991/1992 for cyclone buffer zone by urgent needs. This new land is currently utilized by the secondary beach road and car parking area.
It seems that this coastal protection work consisting of rock mound dike works well during a cyclone. After Cyclone Gene, coral fragment in 300 m^3 was deposited at the outer corner of Avarua west breakwater. This means that MOW seawall works not only for coastal protection but also coastal stabilization.

3) MOW Reclamation
MOW executed successfully the scheduled coastal protection and reclamation work at the Avarua Coast (Job No. C.P 91-30) in 1991/1992. This work includes:

a. Land reclamation in 30 m for 600 m (1.8 Ha)
b. Slope protection by rock riprapping, 1 to 3.5
c. Second Beach Road 8 m wide
d. Car park 4 m wide (for 250 vehicles)
e. Landscaping
f. Extension of the existing stream outlet

According to MOW, total cost for this urgent work was one million NZ Dollars for 600 m coastline. Thus unit rate per meter was 1,750 NZ Dollars (or 120,000 Japanese Yen). In order to maximize MOW's efforts, proposed land use at the Complex should meet the general arrangement made by MOW. It is reported that the same work will be executed by MOW at Avarua East and is included in the 1992 budget.

12.7.2 Scale of New Land by the Project

Areas to be reclaimed by the project are as follows: (Remaining lagoon width in 170 m after the MOW work will partially be reclaimed.)

Reclamation at Avarua East

This 1 Ha area is located along the existing 160 meter coastline. Its average land depth for reclamation is 60 meters. The beach main road runs parallel to the coastline. The existing strip of land (50 meters wide) between the road and beachline currently provides space for existing buildings including restaurants, a sports club, shops and government offices.

Reclamation at Avarua Coast

This 5 Ha area is located along the existing 600 meter coastline. Its average land depth is 80 meters. The beach main road runs also parallel to the existing coastline. The eastern two-thirds of the strip of land foreshoreward is narrow.
At the western one-third of the strip is land space of 2 Ha which has been reclaimed by the government. The elevation of this land is about MSL+2.0 meters.

Thus, the total area for the Port Part Complex is 6 Ha. Fig. 11-2 shows this area. After this reclamation, minimum lagoon width about 120 m will be maintained thus 7.8 Ha of lagoon will be remained.