4.3.2 Villages

All of the village names shown in Table 4-1 were picked from the existing maps prepared by the Department of Survey and Land Information of New Zealand and the Survey Department of the Cook Islands.
There are fifty one villages; forty-seven of them are directly exposed to the ocean.

Note: The airport is assumed to be one of the subdivisions since village limits along the coastline are not yet clear. Thus, along the coastline there are forty-seven villages (forty-six official villages and one temporary village).

As shown in the Table, the total length of Ara Tapu as measured from the maps is 30,990 meters. This length (the accumulated length of the road running through forty-seven subdivisions) is likely the same length as the shoreline since it runs near the beachline.

The average shoreline length per village is 660 meters, and ranges from 2,560 meters for the "Village Airport" as the maximum length to 130 meters for Village Ruatonga as the minimum length.

Population distribution has been assumed by means of counting each household mark (black square) on the map. Table 4-2 shows the results of this counting work. Counting was conducted at two classified zones: the first zone defining the first 100 meters from the beach and the second zone the next 200 meters.

The Avarua constituency shares about 25.0% of population. It has the highest density of 2,393. The lowest population density is 394 at the Nikao constituency due to the existance of the airport. The density of other constituencies range from 520 at Arorangi to 905 at Tupapa.

(Note: The villages named here should be reviewed.)

This shows that the Avarua District together with its surroundings have the highest population density due to it being the most active place for industry, economy and culture. The names of all villages having a density of 1,500 or more are as follows:

Order	Village Name	Density	Population
1.	Avatiu	2,837	400
2.	Ruatonga	2,564	100
3.	Ngatipa	2,535	365
4.	Avarua	2,137	750
5.	Pue	1,809	255
6.	Vaikai	1,734	130
7.	Te Puna	1,600	240

The ten most populated villages are:

Order		Density	Population
1.	Avarua	2,137	750
2.	Avatiu	2,837	400
3.	Ngatipa	2,325	365
4.	Akaoa	904	290
5.	Matevera/Tupapa	643	270
6.	Pue	1,809	255
7.	Te Puna	1,600	240
8.	Arerenga	1,415	225
9.	Pokoinu	823	195
10.	Kiikii	545	180

Table 4-1 CONSTITUENCY AND VILLAGE OF RAROTONGA ISLAND

No.	Const/Village	Shore Length (m) (Road Length)	No.	Const/Village	Shore Length (m) (Road Length)
1.	Arorangi		4.	Matavera	
101	Pokoinu I Raro	900	401	Pouara	430
102	Tokerau/Inave	1,200	402	Vaenga	180
103	Arerenga	530	403	Matavera/Tupapa	1,400
104	Akaoa	1,070	404	Titama	600
105	Vaiakura	700		Subtotal	2,610
106	Kavera	850			
107	Aroa	880	5.	Tupapa	
108	Rutaki	1,330	501	Araitetonga	700
	Subtotal	7,460	502	Kiikii	1,160
			503	Punataia	160
2.	Titikaveka		504	Tapae	390
201	Vaimaanga	1,530	505	Tapae I Uta	0
202	Avaavaroa	1,150	506	Pue	470
203	Totokoitu	300	507	Vaikai	250
204	Turoa	600		Subtotal	3,130
205	Arakue	630			
206	Kauare	400	6.	Avarua	
207	Titikaveka	300	601	Ngatipa	480
208	Te Puna	500	602	Tauae	0
209	Akapuao	770	603	Avarua	1,170
210	Tikioki	800	604	Ruatonga	130
211	Maii	700	605	Avatiu	470
	Subtotal	7,680		Subtotal	2,250
3.	Ngatangiia		7.	Nikao	
301	Vaii	170	701	Atupa	520
302	Aremango	500	702	Kaikaveka	450
303	Areiti	300	703	"Airport"	2,560
304	Nukupure	310	704	Puapuautu	0
305	Aroko	310	705	Nikao	0
306	Avana	770	706	Pokoinu	790
307	Ngati Vaikai	230		Subtotal	4,320
308	Ngati Maoate	150			
309	Ngati Au	230			
310	Turangi	570			
	Subtotal	3,540		Total Shore Length	30,990 m

Source : Study Team

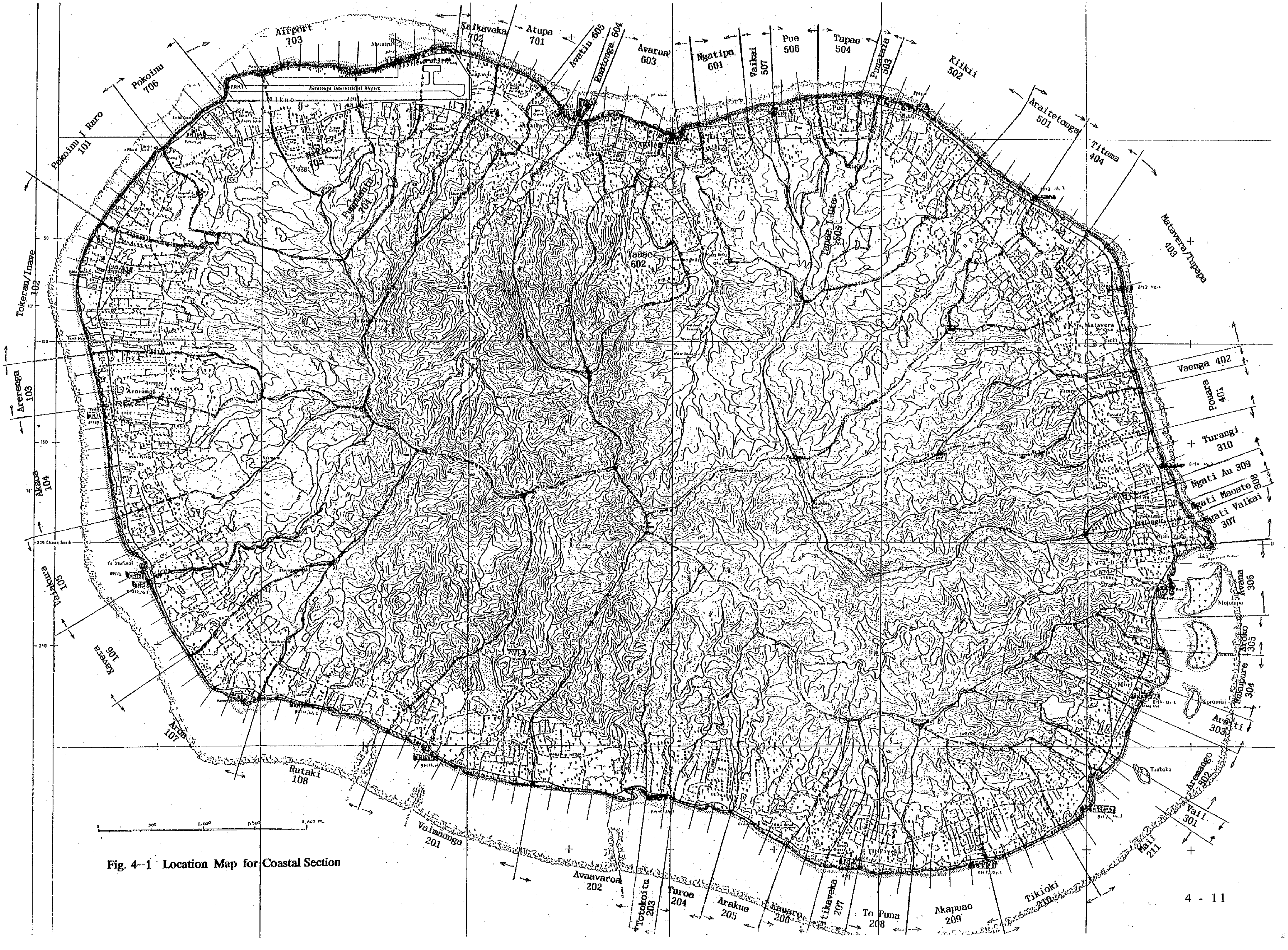


Fig. 4–1 Location Map for Coastal Section

4.3.3 Land Use Classification

Based on the existing community, its activities and population in the longshore 300 meter range, forty seven villages are regrouped into five zones.

Land use zone one: Established Urban Areas

A typical section can be seen at Avarua District as shown in Fig. 7-1-b. The beach main road runs immediately behind the coastline. Shopping centers, restaurants, car rental services and street vendors are located along the road. Most of the government offices are located within one hundred meter landward.

Public open space here is a narrow strip between the road and beach top, ranging from five to twenty meters. From the beginning of August, 1991, new reclamation work, including shore protection, was commenced by MOW with local finance.

- Avarua,	1,170 meters long
- Ruatonga,	130 meters long
- Avatiu,	470 meters long
Total	1,770 meters long

These areas are the most active zones in the island.

Land use zone two: Rural Areas A

The beach road in this area runs within 30 meters landward from the beach top. The first 10 meter area is covered by flora. Architectural facilities are located behind the road. Public spaces such as hospitals, sports grounds and schools are often developed behind the road. According to the government agencies, utilities, such as water supply and power distribution mains are embedded under the road shoulder shoreward.

Most of the local shops and restaurants are located along the road.

In some areas the road runs just along the beach. The distance between the beach top and the road is shown in Appendix C1,"Coast File".

Most of the remaining villages either belong to this category or to zone four, Rural Areas B.

These areas are:

-	Kavera	(650 meters out of 850 meters)
-	Aroa	(600 meters out of 880 meters)
-	Rutaki	(600 meters out of 1,330 meters)
-	Vaimaanga	(600 meters out of 1,530 meters)
-	Avaavaroa	(600 meters out of 1,150 meters)
-	Totokoitu	(100 meters out of 300 meters)
-	Turoa	(200 meters out of 600 meters)
-	Arakue	(200 meters out of 630 meters)
-	Akapuao	(600 meters out of 770 meters)
-	Tikioki	(400 meters out of 800 meters)
-	Avana	(200 meters out of 770 meters)
-	Atupa	(320 meters out of 520 meters)
-	Airport	(1,160 meters out of 2,560 meters)
-	Pokoinu	(190 meters out of 790 meters)
	Total	6,420 meters out of 13,480 meters

Table 4-2 Households per Village (1/2)

Constituency, Village Number and Village Name		Beach Road (m)	Household Marks						Population	
			First 100m		Second 200 m		Total		Heads	Density head/km^2
1. Arorangi										
101	Pokoinu I Raro	900	9	(2.0)	8	(1.8)	17	(3.8)	85	
102	Tokerau/Inave	1,200	8+	(1.3)	16+	(2.7)	24	(4.0)	120	
103	Arerenga	530	14	(5.3)	31	(11.7)	45	(17.0)	225	
104	Akaoa	1,070	24	(4.5)	24	(6.4)	58	(10.8)	290	
105	Vaiakura	700	11	(3.1)	13	(3.7)	24	(6.9)	120	
106	Kavera	850	6	(1.4)	5	(1.2)	11	(2.6)	55	
107	Aroa	880	14+2	(3.2)	5+2	(1.1)	19+2	(4.3)	95	
108	Rutaki	1,330	17	(2.6)	18	(2.7)	35	(5.3)	175	
	Subtotal (Average)	7,460	103+3	(2.8)	130+3	(3.5)	233+3	(6.2)	1,165 (18.0%)	520
2. Titikaveka										
201	Vaimaanga	1,530	18	(2.4)	15	(2.0)	33	(4.3)	165	
202	Avaavaroa	1,150	19	(3.3)	7	(1.2)	26	(4.5)	130	
203	Totokoitu	300	8	(5.3)	3	(2.0)	11	(7.3)	55	
204	Turoa	600	9	(3.0)	10	(3.3)	19	(6.3)	95	
205	Arakue	630	20	(6.3)	7	(2.2)	27	(8.6)	135	
206	Kauare	400	14	(8.0)	10	(5.0)	24	(13.0)	120	
207	Titikaveka	300	11	(7.3)	9	(6.0)	20	(13.3)	100	
208	Te Puna	500	25	(10.0)	23	(9.2)	48	(19.2)	240	
209	Akapuao	770	15+2	(3.9)	7	(1.8)	22+2	(5.7)	110	
210	Tikioki	800	9	(2.3)	10	(2.5)	19	(4.8)	95	
211	Maii	700	9	(2.6)	2	(0.6)	11	(3.2)	55	
	Subtotal (Average)	7,680	157+2	(4.1)	103	(2.7)	260+2	(6.8)	1,300 (20.1%)	564
3. Ngatangiia										
301	Vaii	170	1	1.2	1	1.2	2	2.4	10	
302	Aremango	500	7	2.8	8	3.2	15	6.0	75	
303	Areiti	300	8	5.3	5	3.3	13	8.6	65	
304	Nukupure	310	3	1.9	12	7.7	15	9.6	75	
305	Aroko	310	1	0.6	4	2.6	5	3.2	25	
306	Avana	770	14	3.6	10	2.5	24	6.1	120	
307	Ngati Vaikai	230	4	3.5	8	7.0	12	10.5	60	
308	Ngati Maoate	150	2	7.7	10	13.3	12	21.0	60	
309	Ngati Au	230	3	2.6	6	5.2	9	7.9	45	
310	Turangi	570	2	0.7	9	3.2	11	3.9	55	
	Subtotal (Average)	3,540	45	2.5	73	4.1	118	6.6	590 (9.1%)	555

Constituency, Village Number and Village Name		Beach Road (m)	Household Marks						Population	
			First 100m		Second 200 m		Total		Heads	Density head/km²
4. Matavera										
401	Pouara	430	5	(2.3)	12	(5.6)	17	(7.9)	85	
402	Vaenga	180	2	(2.2)	4	(4.4)	6	(6.6)	30	
403	Matavera/Tupapa	1,400	21	(3.0)	33	(4.7)	54	(7.7)	270	
404	Titama	600	5	(1.7)	7	(2.3)	12	(4.0)	60	
	Subtotal (Average)	2,610	33	(2.5)	56	(4.3)	89	(6.8)	445 (6.8%)	568
5. Tupapa										
501	Araitetonga	700	15	(4.3)	11	(3.2)	26	(7.5)	130	
502	Kiikii	1,100	16+2	(2.9)	20+	(3.6)	36	(6.5)	180	
503	Punataia	160	6	(7.5)	5	(6.3)	11	(13.8)	55	
504	Tapae	390	13	(6.7)	7	(3.6)	20	(10.3)	100	
505	Tapae I Uta	0	-	-	-	-	-		-	-
506	Pue	470	20+	(8.5)	31	(26.4)	51	(34.9)	255	
507	Vaikai	250	8	(6.4)	18	(14.4)	26	(20.8)	130	
	Subtotal (Average)	3,130	78+3	(5.0)	92+	(5.9)	170+3	(10.9)	850 (13.1%)	905
6. Avarua										
601	Ngatipa	480	48	(20.0)	25	(10.4)	73	(30.4)	365	
602	Tauae	0		-		-	-		-	-
603	Avarua	1,170	55	(9.4)	95	(16.2)	150	(25.6)	750	
604	Ruatonga	130	5	(7.7)	15	(15.0)	20	(22.7)	100	
605	Avatiu	470	25	(10.6)	55	(23.4)	80	(34.0)	400	
	Subtotal (Average)	2,250	133	(11.8)	190	(16.9)	323	(28.7)	1,615 (25.0%)	2,393
7. Nikao										
701	Atupa	520	8	(3.1)	15	(5.8)	23	(8.9)	115	
702	Kaikaveka	450	7	(3.1)	10	(4.4)	17	(7.5)	85	
703	"Airport"	2,560	24	(1.9)	0	(0)	24	(1.9)	120	
704	Puapuautu	0		-		-	-	-	-	-
705	Nikao	0		-		-	-	-	-	-
706	Pokoinu	790	9	(2.3)	29	(7.3)	39	(9.6)	195	
	Subtotal (Average)	4,320	48	(2.2)	54	(2.5)	102	(4.7)	510 (7.9%)	394
Total		30,990 m	597+8	(3.9)	698+4	(4.5)	1,295+8	(8.4)	6,475 (100%)	696

Source : Study Team

Notes
1. It is assumed that about 30% of the total 9,500 people (heads) are inhabiting the nearest 300 meter zone to the beach. 9,500 x 0.7 = 6,650 heads.
2. It is assumed that a household mark on the map represents five heads. 6,650 ÷ 1,295 = 5.1
3. Figures in parenthesis show the household marks per unit 200 meter along the beach road.
4. Density shows population per square kilometer.

Land use zone three: Tourism Development Areas

Land composition of this zone is similar to zones two or four except for the following:

a) The space between the beach and the road is occupied by private enterprises.

b) Frequently the beach is reshaped for the coastal protection work and for creating beautiful scenery.

c) So often the beach landward is reclaimed for more housing land and walkway.

Most of the hoteliers built their facilities in the narrow space between the road and beach. Land reclamation protected by a small seawall in same area have been constructed by them. The new lands were frequently damaged by cyclones.

The Sheraton, under construction currently at Village Vaimaanga, seems to be located well behind the road and has a wide space for future expansion. This type of hotel layout should be well appreciated by because it provides safety for the guests and has natural beach conservation.

This zone will be mixing with the zones two and four since the concentration of tourism development here has not yet been achieved. Related facilities are actually scattered all over the island's coastal area.

Name of villages where existing tourism industries take place.

Name of Village	Type of Facilities
- Pokoinu	Sport activity: Golf course
	Hospital
- Pokoinu I.R.	Medical care: Hospital
	Motel: Rarotongan Sunset Motel
- Arorangi	Hotel: Arorangi Lodges
- Vaiakura	Motel: Whitesands Motel
- Tokerau/Inave	Hotel: Hamure Tavern
	Hotel: Edgewater Resort
	Diving Station: Beach Hotel
	Hotel: Manuia Beach Hotel
- Aroa	Hotel: Rarotongan Hotel
- Vaimaanga	Hotel: Sheraton
- Te Puna	Hotel: Moana Sands Resort
- Akapuao	Hotel: Little Polynesian Motel
- Areite	Marine Activity: Sailing Club
- Nukupure	Hotel: Muri Beachcomber
- Aroko	Hotel: Pacific Resort
- Kiikii	Hotel: Tamure Sesort
	Kiikii Motel
	Punamaia Motel
- Pue	Medical care: Health Department
- Ngatipa	Historical Monuments:
- Avarua	Information and Police:
	Restaurants:
	Shopping areas:
	Car rental services:
	Port facility:
- Ruatonga	Shopping areas:
- Avatiu	Port facility:
	Shopping area
	Restaurants
- Atupa	Historical monuments
- Kaikaveka	International airport

Among these, the following are the tourism beach areas used by hotels and motels.

- Tokerau/Inave	Hotel:	Edge Water
	Hotel:	Hamure Tavern
	Hotel:	Beach Hotel
- Aroa	Hotel:	Rarotongan Hotel
- Vaimaanga	Hotel:	Sheraton
- Akapuao	Hotel:	Little Polynesian Motel
- Kiikii	Hotel:	Tamure Resort
	Motel:	Kiikii Motel
	Motel:	Punamaia Motel

Each facility occupies of about 100 meters of beach. Thus, the total beach length in front of the hotels is about 1,000 meters.

<u>Land use zone four</u>: Rural Areas B

The beach road in this area runs about 75 meters landward from the beach top. The first 25 meter area is covered by flora and architectural facilities including houses that are located within next 50 meters. When a house is built near the shoreline, natural trees are often cut down for grading flat lawn areas. Public spaces, such as for hospitals, sports grounds and schools are often developed in this area.
According to the government agencies, utilities, such as water supply and power distribution mains are embedded under the road shoulder shoreward.

Most of local shops and restaurants are located along the road.

Most of the remaining villages belong to this category. Among them, there are satellite villages where rural activities are conducted, namely:

- Arerenga (530 m) and Akaoa (1,070 m) as the center of Arorangi District.
- Kauare (400 m), Titikaveka (300 m) and Te Puna (500 m) as the center of Titikaveka.
- Avana (770 m), Ngati Vaikai (230 m), Ngati Maoate (150 m) and Ngati Au (230 m) as the center of Nga Tangia.
- <u>Matavera/Tupapa (1,400 m) as the center of Matavera.</u>

Total 5,580 meter long in length of beach road.

Land use zone five: Natural areas

A typical section of this zone is similar to zone four except for the following:

a) Wider space between the road and beach

b) Very little artificial impact within the first 50 meters from the beach

Of course, one can easily approach to nearby beach through a narrow walkway covered by the beach forest.

Since accessibility to beaches is generally good here, there is very little natured area. These areas remain at the northern end of Avana and at the southern end of Ngati Vaikai.
In zones two and four, rural areas, undeveloped areas still remain. These areas only received a few artificial impacts; thus, more natural sceneny can be seen.

The following villages are rich in flora, including Utu, Iron trees and coconut trees that cover more than 50% of the area:

Name of Village	Flora Covering Rate
- Pokoinu I.R.	52 %
- Tokerau/Inave	55 %
- Arerenga	50 %
- Viamaanga	65 %
- Pouara	70 %
- Vaenga	60 %
- Punataia	60 %
- Avaavaroa	55 %
- Turoa	53 %
- Ngati Vaikai	50 %
- Ngati Maoate	50 %
- Turangi	53 %

While some villages maintain a few high trees, they cover less than 20% of area.

Name of Village	Flora Covering Rate
- Aroa	14 %
- Titikaveka	15 %
- Avana	17 %
- Ngaiti Au	15 %
- Vaikai	20 %
- Ngatipa	10 %
- Avarua	3 %
- Ruatonga	20 %
- Avatiu	20 %
- Airport	14 %

Note: These rates have been estimated from the existing maps.

4.3.4 Land Ownership

Land within fifty meters of the High Water Mark (HWM) is under the control of the Conservation Department for better environment of coastal areas. It is requested that artificial changes to this area be registered at that department and an approval for orderly development should be obtained.

(Note, In some countries, certain areas from the HWM belongs to the government for common use and for better environmental control.)

No industry can be developed without a provision of land. Thus, developers should gain the land title for their activities. According to information provided by Land Commission, changes to land titles are governed by regulations such as:

a) The buying and selling of land is prohibited by the Commission. Thus, only rental land is available.

b) Land rental contracts should be referred to the Commission and registered accordingly.

c) The average number of rental years is from 50 to 60.

d) Various land owner rights are supported by the regulations.

It is considered that this system makes lessees reluctant to build structures that are expensive and strong enough to withstand cyclones.

4.4 Perception Study of Villagers' Opinions

The team has collected available data for the coastal protection and port improvement. These data were mostly prepared by the government agencies. In order to obtain data from the other side, a direct interview survey to villagers was conducted by the joint working group led by Chief Economist, Dr. Charito Chapman, of MOPED and the team.

This section deals with the perception study of the villagers' general opinion concerning the changes to the coast and cyclone disasters.

Appendix C-4 shows more information of this study.

4.4.1 Purpose of the Perception Study

The purpose of the interview is to:

a) Collect data on the past history of coastal changes

b) Collect data on damage caused by cyclone waves and surges.

c) Obtain the villagers' requests and recommendations regarding coastal protection.

A questionnaire has been prepared containing the requirements shown above. It consists of the following nine items:

Item 1. The facesheet requesting personal information from interviewee
2. Names of the worst three cyclones and the main causes of damage
3. Wave run-up, flood and damage cost caused by the worst cyclone with respect to waves.
4. Changes of coast and beach sand (Coastal erosion/Beach erosion)
5. Effectiveness of coastal protection work
6. Grade of villagers fear of cyclones
7. Intentions of relocating house
8. Main reason why damage is caused by cyclone waves
9. Recommendations concerning the best countermeasures to use against wave disasters including coastal erosion.

4.4.2 Distribution and Recovery of Questionnaire

By 28 Oct. 1991, one hundred twenty questionnaires were printed and distributed immediately by two MOPED staff members. By 20 Nov. 1991, one hundred sheets were recovered by the study team. They provided villagers with necessary explanation on survey items and conducted hearing. The team brought them back to their home office in Tokyo and conducted the data processing analysis using a computer.

4.4.3 Summary of Study

1) About Interviewees

The average interviewee is 40 years old and has been living his 125 sq. meter house for 21.5-years. He owns his land which is located within 150 meters from the beach.

2) Names of the worst three cyclones and the main causes of property damage

The interviewee ranks the three worst cyclones as being Sally, Peni and Dolly. He thinks that main causes of property damage was wind or a combination of wind and waves.

3) Damage by the waves of the worst cyclone

Sally had the highest and most damaging waves. They ran up to the top of beach, close to the beach road.

The interviewee estimated that 9,500 dollars in damages was caused to his house, furniture, garden and farm.

4) Changes of coast and beach sand

The interviewee remembered past coastal changes and answered that nearest coast to his house has eroded about 1.8 meter over the past ten years. He said that sometimes there had been an advance of coast line. However he believes that there is erosion after all.
He noted that this erosion occurred only since cyclone Sally attacked the island in early 1987. He said that the actual erosion speed might be 1.8 meter for five years (1987 to 1991).

Regarding the beach sand movement, he responded that the width of the sand beach became three meters narrower since Cyclone Sally.

He noted that the sand movement by waves and current is more sensitive than erosion and deposit of coral fragments. He said that sand movement is about fifteen times easier than coral rock movement.

5) Effectiveness of coastal protection work

The interviewee believes that proper coastal protection work may increase his property value by 12%.

6) Grade of villagers fear to cyclone disasters

He answered that he was very afraid that his family would suffer injuries and that his property would be damaged by cyclone waves.

7) Intention of relocating his house in order to avoid the cyclone waves

He estimated it would cost 50,000 dollars to relocate. However, he denied that he had intentions of moving.

8) Main reason why damage is caused by cyclone waves

He said that coastal erosion is just nature in the island. However, he said the government did not provide enough coastal protection work.
And, he acknowledged that he did build his house too close to the beach.

He felt that the invasion of waves to the inland are due to the digging of sand and the cutting down of trees on the beach banks.

9) His recommendations concerning the best countermeasures to use against cyclone waves

He pointed out three methods:

- Provision of coastal protection work
- Planting trees for barrier along the beach bank
- Stopping the digging of sand at the coastal area.

4.4.4 Utilization of Perception Study

A detailed analysis has been conducted by the team. Conclusion of the analysis was reflected in Chapter 7 "Master Plan for Coastal Protection".

4.5 Efforts on Coastal Protection Conducted

This section deals with the various efforts conducted by the Government in the past and present for coastal protection. The direct purpose of these works are to maintain the safety of society against damages due to cyclone waves and surges.

These works aim also at the preservation of the natural environment as one of the most valuable national resources.

4.5.1 Protection Work in National Policies

Assurance of safety against cyclones may make the socio-economic losses resulting from disasters reasonably lower, but not to zero. If proper countermeasures are provided, economic activities along the coastal area will recover to their normal conditions and various industrial activities including tourism will be encouraged. This will create more job opportunities and increase prosperity.

The Second Development Plan (1988 - 1992) shows the development philosophy, polices and objectives.

Following are the policy direction and objectives which are excerpts from the Plan, page II.

PHILOSOPHY IN DEVELOPMENT POLICY DIRECTION

The people of the Cook Islands are its most precious natural resource. She has a proud heritage, strong family ties with high moral and ethical standards which form the foundation of Cook Islands' society. Pride in our country is fundamental to the success of personal endeavours and the welfare of our country. Self reliance is self respect. Our land and sea holds resources which, depending on the capacity and ability of our minds, hands and efforts, can produce that extra closeness to the wealth we aspire to. The people and the Government must work together to solve our economic and social problems. The Government is the servant, not the master.

National Development Objectives

Government has identified five broad national development policies that will encompass its endeavours over the next five year plan period. These policies are consistent with the first development plan's objectives, but are narrowed down for more realistic and practical purposes.

1. To raise the level of prosperity of the people of the Cook Islands (to stem further migration).

2. To attain a larger measure of economic independence.

3. To ensure that economic development proceeds in a manner compatible with social, cultural and natural values.

4. To promote a more equitable distribution of the benefits of development.

5. To cooperate closely with Pacific neighbors and other nations in economic affairs and other matters of mutual interest.

The government must now look at the factors and strategies that will assist us towards some degree of achieving the objectives, at least in the medium term as identified by the plan.

If it is believed that the coastal area will be damaged again when a large-scale cyclone attacks, a private investor will keep it in mind when thinking his next investment. If the sandy beach continues to erode, the island's ability to attract tourists will decline.
It is assumed that the people here are watching carefully what the Government will do to prevent the island from cyclone damage in the near future.

As previously described, the total beach bank area (most useful and valuable area) only occupies ten percent of the island. Thus, the coastal area is a limited national resources. The width of the existing sandy beach is about six meters; this is well under the acceptable limit for beach resorts.

For tourism development here, coastal protection work is a must.

4.5.2 Protection Work before 1990

The Government has made efforts to improve the coastal areas. One project was the coastal protection for Avatiu Harbour, the sole gate port to the island. Breakwaters at both sides of entrance were constructed in order to maintain safe ship navigation and to protect of the on-land port backup facilities against cyclone. Port improvement work was completed in 1986.

During the 1970's land reclamation work was undertaken by the Government at the western half of the Avarua coast. In early 1987, Cyclone Sally struck directly the island and people here were awakened to the nature of island given to them. In March 1987, JICA's study team and other experts conducted a preliminary analysis on Cyclone Sally and its damage and compiled their recommendations. In 1989, the Government constructed the breakwaters at Avarua Harbour.

4.5.3 Building Codes

Due to a large amount of damage caused by Cyclone Sally, the insurance account ran into a deficit. In order to balance the account for future disaster, insurance rates were raised. Thus, the people here faced higher payments for their property insurance.

To cope with this situation, the Government appointed MOW to prepare countermeasures. MOW responded immediately and took the following action:

a) Surveyed the damage caused by Cyclone Sally

b) Undertook the 700 meter long coastal protection work at the Avarua coast

c) Distributed the New Building Codes prepared based on past experience by the island's Pacific neighbours

Building codes were prepared carefully in close cooperation with the neighbouring countries. They were prepared so that they could easily be understood by the people. Various figures and tables are incorporated in them. The codes have been enforced since 1989.

The codes show the minimum structural requirements for withstanding cyclone forces.

4.5.4 Coastal Protection Work in 1991

Following Government policies, MOW prepared an urgent Avarua coast protection plan. The work consists of land reclamation and slope protection. The former aims at widening the space between the beach road and the coast. The latter is for providing the armour rock riprapping on the slope surface to prevent reclamation work from erosion. It is reported that national budget allocated one million dollars for this to work. It is also reported that same work will be conducted at the eastern coast of Avarua Harbour and will be included in the 1992 budget.

The new reclamation will form the buffer-zones which may be effective against cyclone waves and surges and will provide additional public space on the busiest part of the island.

The work in Avarua coast commenced in August 1991 and nearly completed in March 1992. It can be noted that MOW made a great job within 8 months after commencement. The work was good quality and proved its efficiency when cyclone Gene coming in March 1992. The reclaimed buffer zone was utilized as the second beach road and parking area which was in short at that time. This means MOW made both works, coastal protection and creation of new public land. The team should have respect for the Cook Government effort through MOW.

Material for this reclamation was coral fragment mainly diggings from the beach banks at Village Araitetonga where three large-scale holes were seen in October 1991. All the holes were located just behind the beach top. It was observed, however, that these holes are being refilled with ordinary earth which that is much fine than the original one.
It should be maintained that the coastal protection work at the Avarua coast is not causing damage to other coastal areas.

4.5.5 Conservation Efforts

General control of coastal areas is coordinated by the Conservation Department located in Village Pue. The department watches for any changes in the coastal areas that are within fifty meters from the High Water Mark (HWM). Officers in this important government agency well acquainted duties.

According to the Department, Coastal Environment Guidelines was under preparation for government approval by the middle of 1992. The guidelines may specify new control area, criteria for domestic effluent etc.

The department has prepare a map showing coastal area damage caused by Cyclone Sally including.

a) Topography
- Contour
- Current Direction
- Road
- Stream
- Swamp
- Reef line

b) Geotechnical Information
- Gravel, Mud, Sand
- Beachrock
- Limestone (non-beachrock)
- Volcanics
- Beach escarpment

c) Artificial Coastal Protection Works
   Boulders as Protection
   Cemented wall as protection
   Groins

d) Record of Damages
   Cyclone Sally Damage
   Active Erosion
   Low Erosion
   Deposition
   Stable beach

The above data together with the damage survey records prepared by MOW are useful for the preparation of the coastal protection plan.

It is expected that the department could provide proper recommendations concerning coastal land use in order to maintain orderly development. It is also expected that the monitoring of coastal area changes will not only be conducted from the structural aspect but will take in the natural environment including water quality, natural scenery and marine life.

It is expected that the department may be involved in the decision making relating to the digging of coral rock near the beach top. According to the perception study of villagers, many show their deep concern about such digging. The Government has banned sand digging in coastal areas since 1988.

Annex to Chapter 4, Definition of Technical Terms

In this study, the following terms are used.

a) Reef

A reef is the seaward end of a lagoon elevation that is about at mean sea level (MSL) and is connected to deeper water by a submerged cliff. Most waves break at this zone between this face and 300 m offshore of it. The toe of the cliff is located at -3 meter and the relatively flat seabed goes gently down into a deeper area, the offshore area.

b) Lagoon

A lagoon is a reef flat having a coral bed between the reef and the beach. The elevation of this area is about the same as that of reef top. The width of this area varies from 10 meters at the Northeast coast to 700 meters at the South coast. A lagoon is a natural buffer zone where remaining wave energy is gradually eliminated upon hitting the reef while the water level is setting up due to the change of wave energy from the dynamic one to static one. This is one of the causes of frequent wave run-up along the shoreline slope. The base beach rock is coral *sand united by chemical action and is seen often at the landward end.*

c) Beach

The beach is the slope between the landward end of a lagoon and the flat area where people reside. The degree of slope varies from place to place between 1:2 to 1:10. (Note: Slope 1:2 or 1/2 or 50% means a slope of 0.5 meter rise per one meter horizontal distance.)
The elevated top of the beach varies from +2 meters to 6 meters above Mean Sea Level (MSL).

The beach mainly consists of piles of coral rock. Most of the beach toe is covered by coral sand. However, the base beach rock layer is exposed in some areas.
The top of the beach is generally covered by vines and climbers.
In other places, beach tops consist of general earth which might have been reclaimed artificially in the past.

The beach can be divided into two parts; the foreshore and the backshore. The former means the lower part of slope where normal waves can run-up. The latter shows upper part of the slope up to where waves caused by large cyclones may run up. Eroded beach often shows notch and terrace at the upper slope.

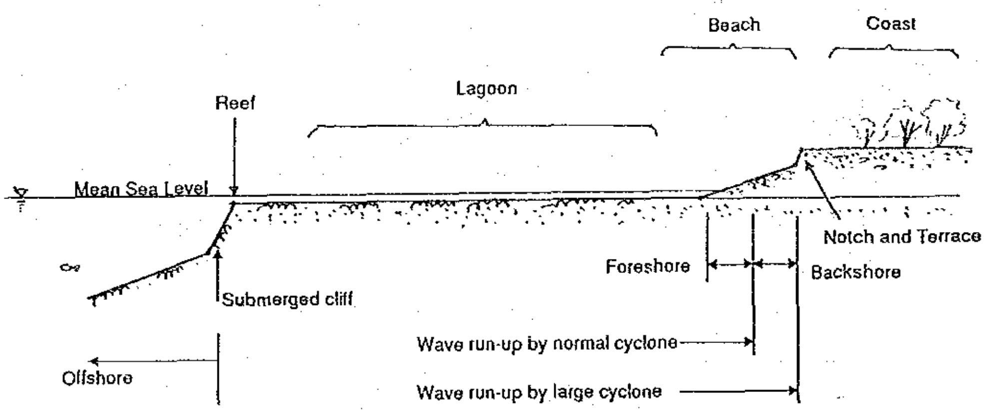
d) Coast

The coast is the relatively flat area behind the beach slope where the natural forest consisting of trees, (coconut, Utu trees etc.) can be seen. The natural coast is about 20 to 50 meters wide where coral segment piles with sand layers can be seen. The combination of trees and rock piles are forming a good buffer against wave run-up and overtopping into the coastal area. Ara Tapu, the main the beach road, runs through here.

e) Coastal Area

In this study, the coastal area means beaches, coasts and the further landward zone that were affected by waves and surges in past and might possibly be damaged in the future.

Thus coastal protection should cover the countermeasures for this coastal area.



f) Passage

The passage is the notch of the lagoon at the stream mouth where deeper water is maintained and forms a natural channel for vessels approaching the coastal area.

The island has seven passages. Three of them are utilized as harbour entrances. Among them, Avarua and Avatiu passages are the most developed.

A passage may be formed for the following reasons:

i) Fresh water discharged by streams and rivers may deactivate marine life.

ii) Fine particles containing in the fresh water during flood may affect marine life.

iii) *Rip current (or return current) may affect marine life.*

A passage is a natural return canal of rip current by coastal current acceralated in the lagoon. It is assumed that passage may mitigate water set up in the lagoon. However, larger waves can easily be propagated to shallow water through the passage. It is reported that return currents may decrease incoming wave energy.

g) Tide

Tide is change of water level by astronomical forces. It is possible to calculate future tidal level at fixed time.

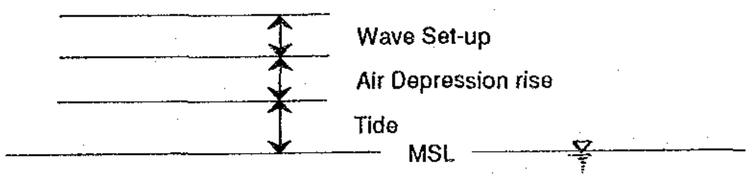
These data are shown in the Tide Table.

h) Air Depression Rise

Atmospheric pressure relates with water level. During a cyclone, atmospheric pressure becomes low then suck up the water level. Water level indicated in the Tidal Table is when air pressure is 1,013 mb thus no air depression rise is taken into consideration. Air depression in one mb makes water level rise by one cm.

i) Wave set-up

As discussed in item b) above, lagoon water level during a cyclone will rise. Wave set-up is a net rise excluding tide and air depression rise.



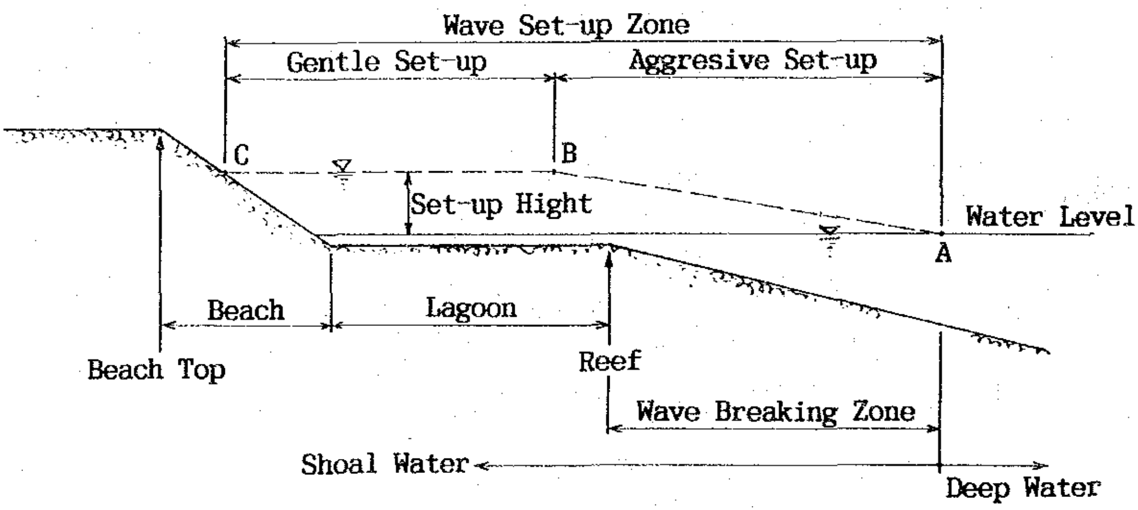
It was assumed that wave set-up might happen only in the lagoon. However, computer simulation proved that reality is different. Simulation results show that:

(i) Wave set-up starts at the beginning of wave breaking zone, Point A as shown figure below.

(ii) Wave set-up is so rapid in the aggressive set-up zone which is are between Point A and Point B.

Point B is near the reef edge or slightly lagoon side.

(iii) After Point B an incremental set-up is minor. Thus water level between Point B and Point C is nearly flat.



j) Wave

Waves are generating by wind. Long duration by heavy wind blow may generate large wave. According to wave observation at certain time length, it can be seen that there are various size of waves consisting of light, average and heavy ones. This situation is called as "Irregular Waves".

Following table shows typical wave intensity before and after the cyclone.

Unit: m

Day	Maximum Wave Hmax	Average Wave H	Significant Wave $H_{1/3}$
before 5 days	3.0	1.3	2.0
before 4 days	3.0	1.3	2.0
before 3 days	4.5	1.9	3.0
before 2 days	6.5	2.7	4.3
before 1 day	8.0	3.4	5.3
the day of cyclone	12.2	5.1	8.1
after 1 day	10.2	4.3	6.8
after 2 days	7.5	3.2	5.0
after 3 days	5.5	2.3	3.7
after 4 days	3.0	1.3	2.0
after 5 days	3.0	1.3	2.0
after 6 days	3.0	1.3	2.0
after 7 days	3.0	1.3	2.0
after 8 days	3.0	1.3	2.0
after 9 days	3.0	1.3	2.0
after 10 days	3.0	1.3	2.0
after 11 days	3.0	1.3	2.0
after 12 days	3.0	1.3	2.0
after 13 days	3.0	1.3	2.0
:	:	:	:
:	:	:	:
after 95 days	3.0	1.3	2.0
Total 100 days		Average	2.2 m

Note: Definition of the Maximum wave, Average Wave and Significant Wave are shown in subsection 12.2.1.

These waves are "Offshore Waves" (Ho) which are not affected by both reflection and diffraction.

Design structure and wave calmness study are normally conducted by significant wave representing its wave group.

Figures in the table indicate that there are one hundred wave groups. Each group has its significant wave.

If the table shows a series of wave groups by a cyclone,

- Design wave for structure like breakwater is 8.1 m observed on the day of cyclone arrival and
- Wave calmness is

  (100 - 5) ÷ = 95 %

  in case that the port can not be used with 4 m offshore wave or more.

Offshore wave will be affected by both the sea bottom friction and configuration, then its shape will be transformed. Major factors of these wave transformation are:

- Wave refraction
- Wave diffraction and
- Shoaling effect

Among these, offshore wave affected by refraction and diffraction is called "Equivalent Offshore Wave". (Ho')

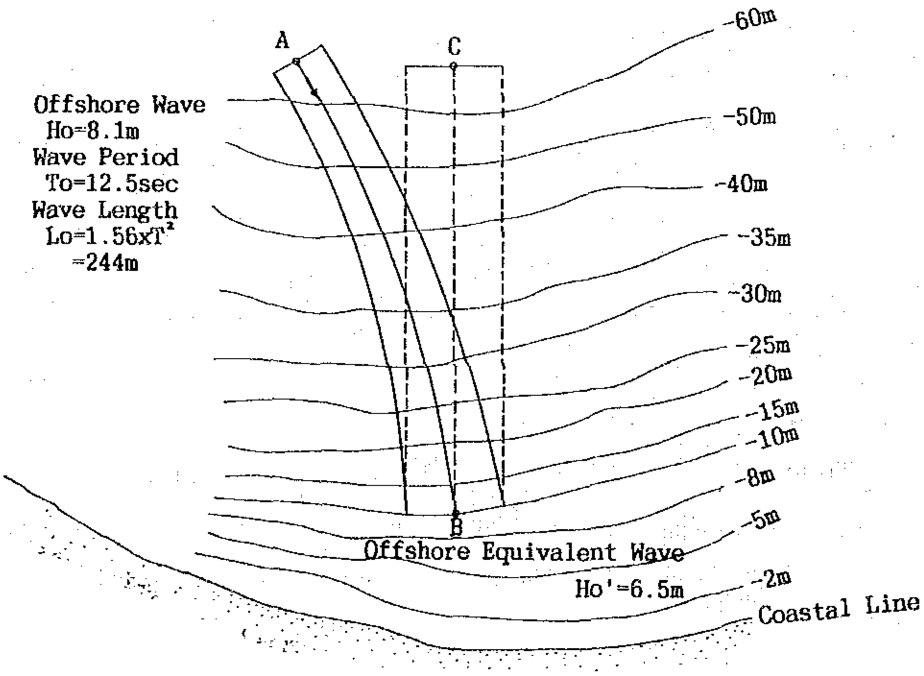


Figure above demonstrates mean of the offshore wave Ho and offshore equivalent wave Ho'. Point A is deep enough that offshore wave will not be affected. If water is deeper than a quarter of wave length, transformation by seabottom is negligibly small.

Offshore wave goes through Point A then wave transformation may commence gradually by turning slightly to right. Finally wave may arrive at Point B where wave may start to break. (Note, Wave breaks at water depth of 1.5 times of wave height).
At Point A wave direction is not normal to the contour line, however wave direction at Point B is almost normal to the contour line.

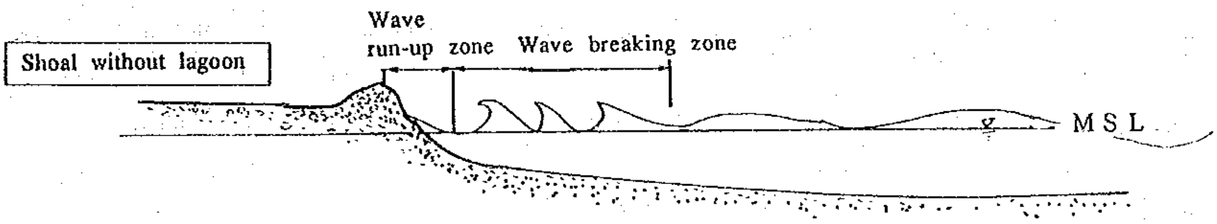
It is better to remember the purpose of Offshore Equivalent Wave in the marine engineering. Reasons are as follows.

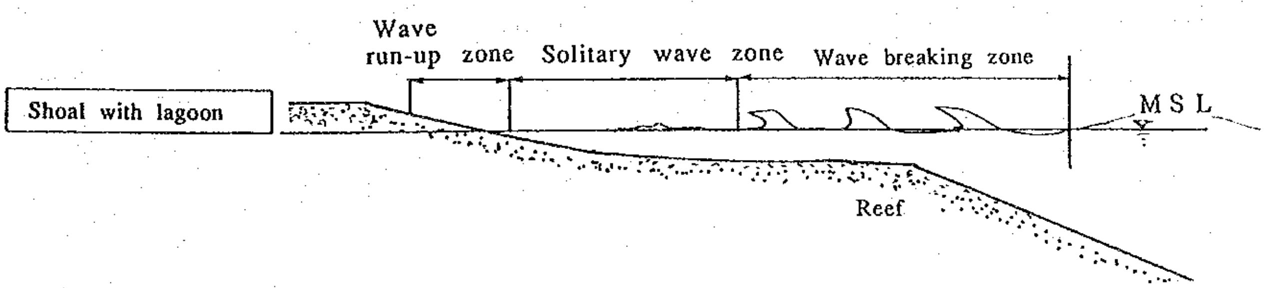
a. Wave height at Point B is not always same with Point A.
b. Most of study data are based on the standardization that wave used is Offshore Equivalent Wave.
c. Thus, only Offshore Equivalent Wave can be used for such established diagram.

It is assumed that wave at Point B propagates from Point C. It is also assumed that line BC is straight thus no wave transformation.

When wave approaches closing to shoaling area and the shoreline, it will arrive at the wave breaking zone, and transforms its shape further.

Wave deformation in and after the breaking zone are shown in figures below.

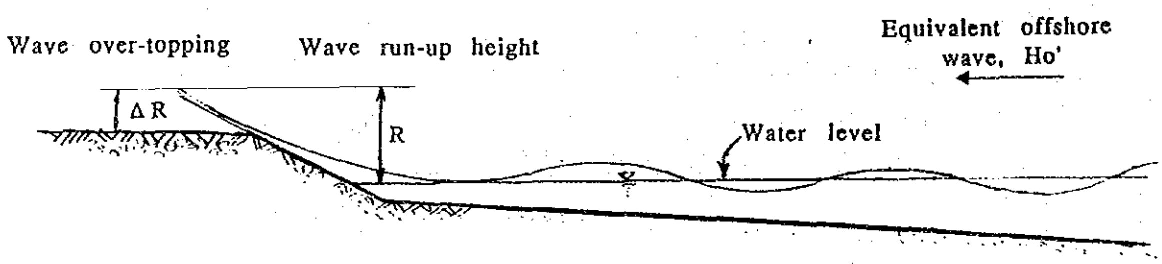




In the shoal without lagoon, breaking zone may move toward the shoreline, and wave will run up immediately. While in the shoal with lagoon like here, breaking zone locates at the reef edge or offshoreward. Thus, broken wave should go through the shoal lagoon then run up the beach. In this zone solitary wave may propagate and rush forwards.

k) Wave run-up

Wave run-up can be seen when wave arrives at beach front. Water body rush up on beach slope. Part of kinetic wave energy may consume and remaining one may reflect and return to lagoon. Wave run-up height is measured against water level at beach front.



Equivalent offshore wave should be used for calculation of wave run-up height.

l) Wave Over-topping

When run-up height is higher than the existing beach top or seawall, wave will over-top into inland. Wave over-topping height is shown as ΔR in above figure. Damage by cyclone wave is mainly caused by this over-topping. It is assumed that scale of damage is proportional to over-topping discharge per unit time which can be calculated in relation to wave over-topping height ΔR.

Chapter 5: Damage by Waves and Surge

Chapter 5 Damage by Waves and Surges

Cyclone damage can be divided into two categories: the loss of ground and the destruction of onland property. The former happens when the accumulated coastal areas are washed up by large waves with unexpected surges. While the latter occurs when any coastal area facility is exposed to large waves accompanied by strong winds.

This chapter deals mainly with the possible disasters occurring at coastal areas due to waves and surges caused by cyclones.

According to the perception study conducted by the team, about 80 percent of property damage was caused by the heavy wind. It should be noted that the coastal protection work aims mainly at the mitigation of coast erosion and property damage by waves and surges.

This chapter also deals with the types of damage, the past record of damage and the major mechanism of such disasters. Especially, the physical characteristics of wave set-up, wave run-up and erosion here will be studied in general. The objective of coastal protection and the influence of the development of measures to counter disasters will also be discussed.

Cyclone Sally in 1987 is selected as design cyclone for this study. The perception study indicates that Sally was the worst one ever attacking the island and damaged in the largest scale along all the island coast. There are many data and records of Sally, thus it is preferable for analysis.

5.1 Types of Damage

5.1.1 Source of Damage Records

The following available damage records about Cyclone Sally were prepared by two government agencies, MOW and Conservation Department.

a) Material Loss by Cyclone Sally

This record was compiled by MOW immediately after the cyclone in 1987 with the cooperation of other governmental organizations. This study focused mainly on the material loss of property damage, both by private and public facilities.

Data shown:

- Name of organization
- Facilities
- Grade of damage determined by the material cost estimation for restoration work

Note: Since the restoration cost was not classified by the cause of damage (waves or wind) the team requested MOW to divide the data into two causes. MOW, in Nov. 1991, made the classification accordingly.

b) Major Damage along the Coastal Areas

This record was prepared by the Conservation Department in June 1989 with the assistance from the Survey Department. All field observation records were plotted on a map. This record mainly coveres the damage to the coastal area including beach erosion. Refer to Fig. 5-1-a.

Together with these existing data, the study team has conducted a perception study of villager's opinions concerning coastal damage in the past. Section 4.4 provides information about the study.

According to these data, the type of damage by cyclone waves and surges can be classified as follows:

a) Direct Damage

Damage which can be counted in a quantitive manner, including:

- On-land property damage
- Coastal erosion and beach erosion

Analysis of these type of damages will be conducted in this Chapter.

b) Indirect Damage

Disasters which can not be counted in a quantitive manner including:

- Adverse effect on environment
- Adverse effect on national economy
- Damage not covered by insurance
- Others

Note: Adverse effect on the national economy will be discussed in the feasibility study for the Short-term Development Plan of Volume II of the report.

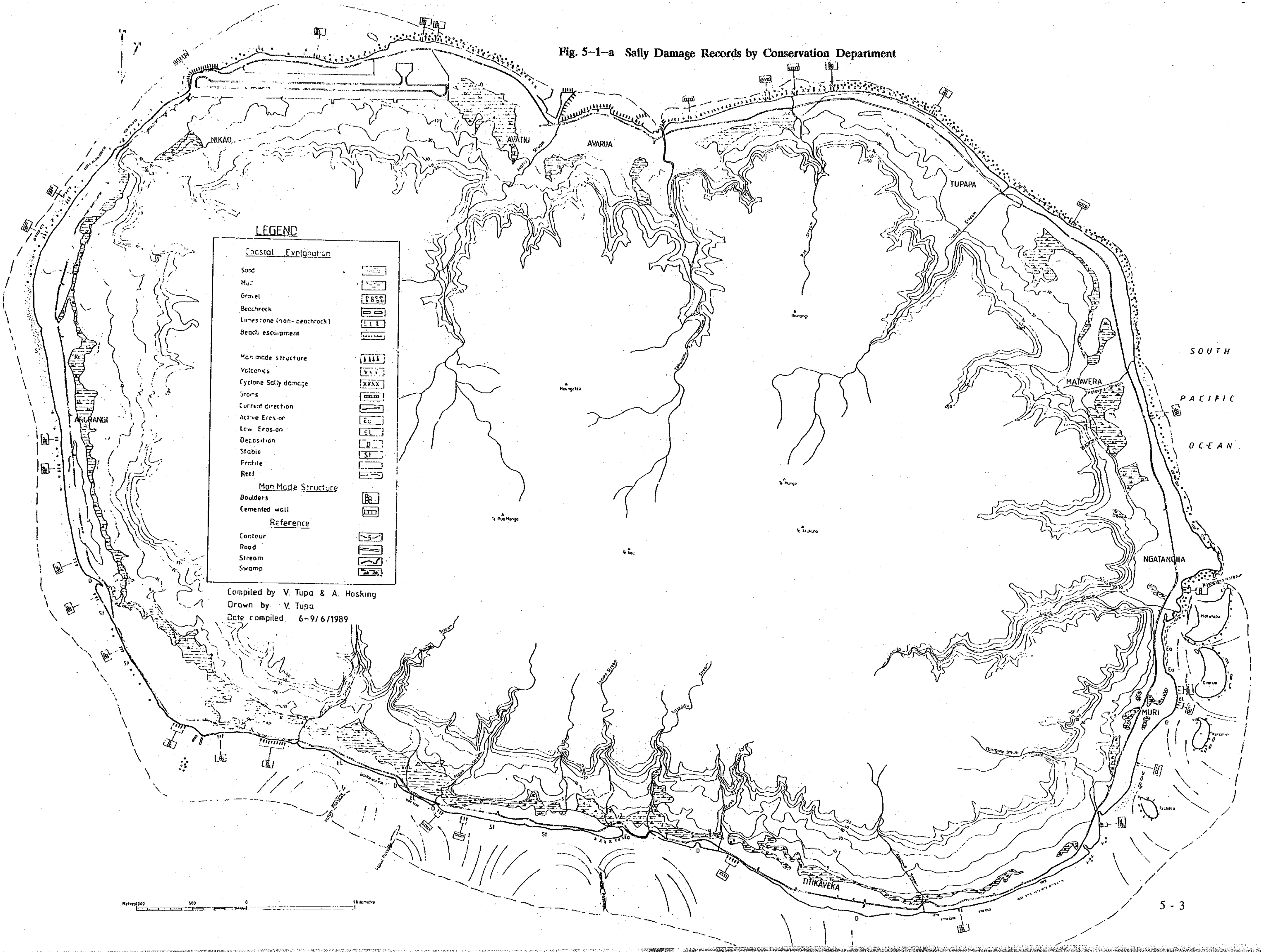


Fig. 5-1-a Sally Damage Records by Conservation Department

5.1.2 Cyclones

The property damage records for Cyclone Sally Jan. 1987 were prepared by these two organizations. However, the cyclones that affected the island were not only limited to Sally.

The perception study shows the grade of damage caused by each cyclone. According to this data, the worst cyclone in respect to coastal damage was Cyclone Sally which was much more serve when compared to the others. Table 5-1 shows the villagers feeling about disaster grade of each cyclone.

Table 5-1 Cyclones and Damage Grade

Unit : share of support by interviewees

No.	Cyclone	Year	Worst One by Waves (%)	Worst Three by Wave and Wind (%)	Remarks
1.	Peni	1990	4.9	31.5	Second worst
2.	Sini	1990	0	0.6	
3.	Wini	1987	0	2.2	
4.	Sally	1987	88.5	49.7	Worst
5.	Ima	1976	1.6	1.1	
6.	Charlie	1976	0	3.3	
7.	Dolly	1965	4.9	10.5	Third worst
8.	Ofa	-	0	1.1	
			100.0%	100.0%	

Source : Perception Study made by a joint team between MOMEP and the team.

From the standpoint of damage by waves/surges and winds, the worst cyclone was Sally in 1987. The second was Peni in 1990 dominated by winds, and the third was Dolly in 1965.

Wave intensity of the top two cyclones was estimated by the study team as follows.

Cyclone	Wave height* (m)	Wave period (sec.)	Direction
Sally	8.1	12.5	N6°W
Sally	7.1	13.1	N21°W
Peni	3.4	7.3	S

Source: Study team

Note: Wave characteristics in this Table are in respect to offshore significant waves. The actual wave characteristics in shoal water will be affected by seabed configuration.

The study on property damage in this report is only in respect to those caused by Cyclone Sally. Fig. 5-1-b shows the return period of cyclone waves at Rarotonga Island. An offshore wave intensity of 8.1 meter like Sally is a wave having a 30 year return period, i.e., it may occur every 50 years.

5.1.3 Direct Damage on On-land Facilities

The scope of damage survey conducted by MOW covers a wide range of facilities, since most of the island's development, including the provision of public utility mains, is conducted along the beach road. Direct on-land facility damage can be divided into two categories: damage to the public sector and damage to the private sector. Based on the MOW's damage records, a breakdown of the items is as follows:

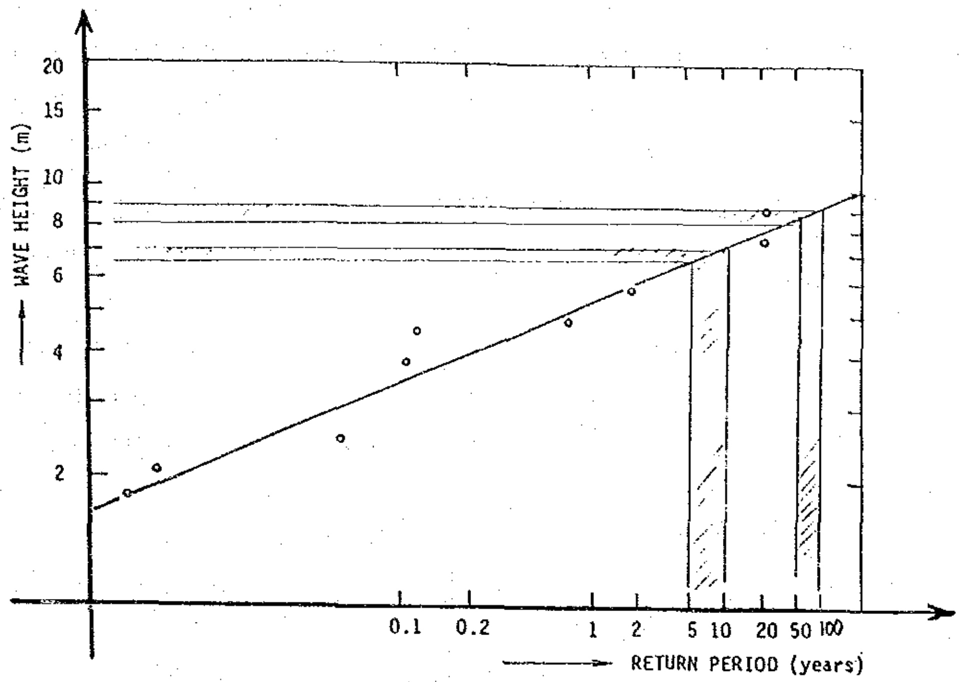
a) Public Sector:

- Government buildings
- Church buildings
- Clinics, community halls
- Water supply system
- Power supply system
- Roads and drains
- Bridges and culverts
- Stream embankment
- Foreshore erosion protection
- Others

b) Private Sector:

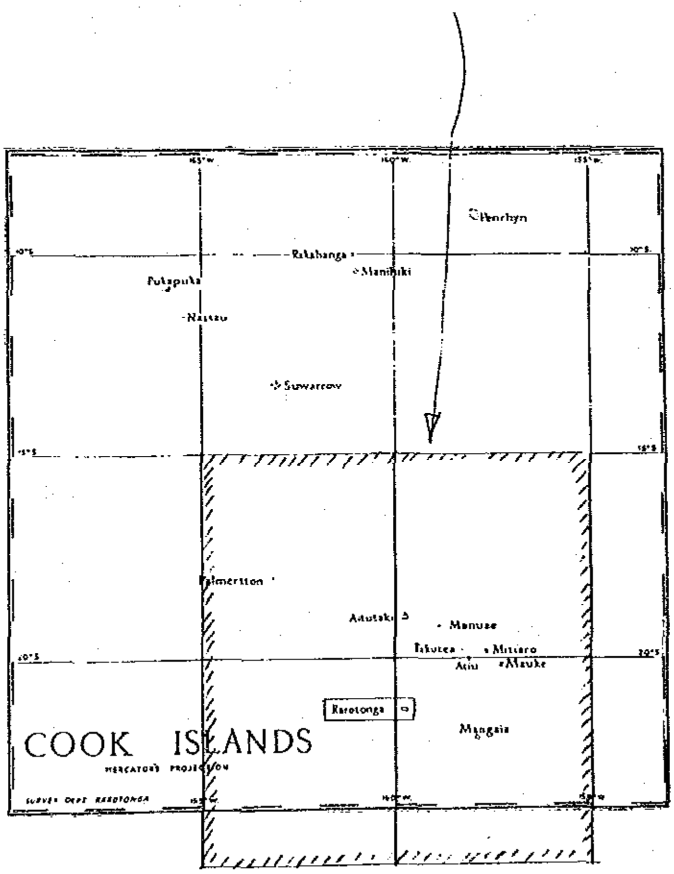
- Residential houses
- Hotels and motels
- Shops and stores
- Others

Fig. 5-1-b Expected Return Period of Cyclone Offshore Wave at Rarotonga Island



Return period estimates:

Ship report data from grid square No 5 (15.0-25.0°S, 155.1-165.0°W)



5.1.4 Direct Damage along the Shoreline

Waves and littoral currents during the cyclone frequently wash out the deposits along the shorelines. This action makes the beach area narrower. Direct beach damage can be divided into two categories: damage to fine particles such as sand, and damage to coarse particle such as the coral segment and gravel. In this report following definitions are used.

a) Damage to fine particles: Beach Erosion

b) Damage to coarse particle: Coastal Erosion

The former may be caused even by small-scale cyclones due to the high sensitivity of fine particles to coastal current forces. While the latter may be caused by large-scale cyclones. In some cases the coarse particles like a coral fragment may be dumped on top of beach banks and form permanent land. It is assumed that beach banks have been created by this type of phenomenon for long period.

Another type of direct shoreline damage is the washing out of waterfront lines made by artificial land reclamation.

c) Damage on the reclaimed land

This type of damage happens frequently if the seawall foundations for reclamation are not suitable.

5.2 Past Direct Damage caused by Cyclones

This section deals with the direct damage caused by Cyclone Sally. Most of the figures are taken from the report titled "Hurricane Damage Reconstruction Programme for Rarotanga" issued by MOW, 27 January 1987.

5.2.1 General Descriptions

The report covers a wide range of damage in both the private and public sectors. Required material cost for restoration is estimated in detail. Summary of material cost is shown in Table 5-2.

Table 5-2 Material Cost of Damage Caused by Sally

unit 10^3 Dollars in 1987

Work Items	By Wave	In Total
a) Public Sector:		
- Government buildings	230.2	1,033.0
- Church buildings	3.2	58.7
- Clinic, community halls	5.1	93.5
- Water supply system	90.1	409.7
- Power supply system	-	-
- Roads and drains	440.3	1,407.0
- Bridges and culverts including stream embankment and foreshore erosion	875.0	1,750.0
- Coastal loss *	1,841.4	1,841.4
- Others (20% of above total)* 3,485.3 x 0.2 =	697.1	1,318.7
Subtotal	4,182.4	7,912.0
b) Private Sector:		
- Residential houses	189.2	1,719.7
- Hotels and motels	3.6	65.5
- Shops and stores	7.6	68.8
- Others (20% of above total)* 200.4 x 0.2 =	40.1	370.8
Subtotal	240.5	2,224.8
Total material costs	4,422.9	10,136.8

Notes,

1. Cost for other islands in original report is excluded.
2. "By wave" means the estimated costs of damage due to waves and surges. All the costs shown in the MOW report are not yet categorized.
   The study team clarified the damage using MOW information.
3. "In total" means the cost for all types of cyclone damage.
4. "Coastal loss" and "Others" are estimated by the study team.

Damage cost by coastal erosion of national land was estimated by the study team as follows.

$$C = L \cdot E \cdot P$$

Where, C: Estimated cost of eroded land

L: Total shoreline length 31,000 m

E: Average land loss by Sally for 31,000 m shoreline, 1.8 meter

P: Average unit land cost per sq. meter

Unit land cost was surveyed by the Land Commission in Feb. 1992. It is assumed that present average cost is about 40 Dollars per sq. meter. Unit land cost in 1987 was obtained reducing by 28 % of present cost.

$$P = 33 \text{ Dollars/m}^3$$

Thus, $C = 31{,}000 \times 1.8 \times 33$

$= 1{,}841{,}400$ Dollars

Restoration cost will be made up not only of material, but also of labour, machinery and fuel. Considering the characteristics of the work, the cost component was estimated as follows:

Cost item	Shear
Material	25%
Labour	25%
Machinery	20%
Fuel	10%
Overhead and management	20%
Total	100%

Thus, actual construction cost should be four times that of the material costs. An inflation cost of five percent over five years is also added. Table

5-3 shows the estimated total restoration cost by Sally's wave action in 1992 prices.

Table 5-3 Total Restoration Cost in Damage by Wave: Sally

unit 10^3 Dollars in 1992 price

Work Items	By Wave
a) Public Sector:	
- Government buildings	1,151.0
- Church buildings	16.0
- Clinic, community halls	25.5
- Water supply system	450.5
- Power supply system	-
- Roads and drains	2,201.5
- Bridges and culverts including stream embankment and foreshore erosion	4,375.0
- Coastal loss*	2,356.9
- Others (20% of above total) 10,576.4 x 0.2 =	2,115.3
Subtotal	12,691.7
b) Private Sector:	
- Residential houses	946.0
- Hotels and motels	18.0
- Shops and stores	38.0
- Others (20% of above total) 1,002.0 x 0.2 =	200.4
Subtotal	1,202.4
Total damage costs	13,894.1

Note, 1. Rate of increase for coastal loss is 28 % (5 years by 5% growth)
2. Other items than coastal loss are increased considering 5 year by 5 % increase and other necessary cost than material.
3. Damage to hotels, motels, and shops seems low.

5.2.2 Evaluation of Estimated Damage

Total estimated damage was 13.9 million Dollars. The public sector's share is 91 percent. It is assumed that the actual damage to the private sector larger than the estimated value. According to the perception study of villagers, the average wave damage per household was 9,300 dollars. Thus, the estimated number of households damaged by waves is about one hundred. The total number of households damaged by waves and wind is 136 according to the report, although 50 of which are located at Arorangi, close to MOW. The concentration of 29 households are at Avatiu, Ruatonga and Avarua.

Property loss was 11.1 million Dollars which is about 80 percent of the total damage caused by waves. The remaining 20 percent (2.8 million Dollars) was the loss of national land by coastal erosion.

5.2.3 Total Damage in Next 30 years

As discussed in Chapter 16, an average life of coastal protection work is assumed as 30 years. During this period only one Sally Class cyclone may attack the island, however other smaller cyclone than Sally will also arrive at.

As discussed in section 12.2.7, it is meaningful to estimate total cyclone wave disasters by various size of cyclone for 30 years. Same section shows that it is 9.3 Sally class ones if all cyclones damage for 30 years are integrated and converted into Sally class one. This estimation is made for the Short-term Coastal Protection area.

It can be said that it is not economical to provide coastal area with perfect works, since necessary cost for them will exceed extensively the benefits, decreased damage. Thus, it is estimated that damage by 6.2 Sally equivalent will be decreased. While the Master Plan should cover an entire coast 31 km of Rarotonga Island. There is lower priority areas than those of Short-term Protection Plan.

For the time being, it is recommended that Master Plan should aim at reducing damage by two Sally equivalent in next 30 years.

5.2.4 Indirect Damages

There may be other damage which can not be counted in monetary figures, namely indirect damage.

a) Damage to beach roads may disrupt vehicular traffic and have an adverse impact on the island economy.

b) Damage to the existing airport may disrupt international transport and tourism industries.

c) Damage to the port facilities may disrupt not only the importing of daily consumption but also the domestic maritime transport.

d) The downing of power supply mains embedded along the beach road may affect industrial activities.

e) Shortage of water supply as a result of damage to the distribution main embedded in the beach road may have an effect on the daily lives of villagers.

f) Closing of stream mouth may cause inland flooding.

g) Erosion of the beach shoulder may affect tree life, and have an adverse effect on the natural environment.

h) Large-scale damage in the Avarua area may affect the tourist industry.

i) Large-scale property damage may cause insurance rates to rise.

j) Investor may be reluctant to develop facilities for their business along the beachline where large-scale damage was experienced. Thus, an expected employment opportunity may be lost.

A detailed study on the indirect damage will be conducted during the upcoming feasibility study as shown in Chapter 16 Vol. II of the report.

5.3 Cyclone Sally

This section deals with the intensity of Cyclone Sally which attacked the island in 1987. Wave hindcasting by Sally at the island is attached in Appendix C-5.

5.3.1 Outline of Cyclone Sally

Cyclone Sally went down to the South passing the Suwarrow Island located in 13° South Latitude on the December 27, 1986. When it arrived at the Palmerstone in 18° South Latitude, its propagating speed slow down pivoting there from Dec. 28 to Dec. 31. Then it turned its head for the South-East direction waiting the new year, and arrived finally at the Rarotonga Island in the early morning of January 2nd, 1987.

Average propagating speed was 21 km per hour.

According to the observed air pressure section by MET, Sally was fully developed January 1st, the day before arriving at Rarotonga. It was assumed that Sally faded slightly when it arrived at Rarotonga.

It is estimated by calculation that the center air pressure in January 1st was 955 mb. When it arrived at Rarotonga, center air pressure was 968 mb. Radius of 1,000 mb contour was about 900 km.

Note: "mb" is unit to measure the air pressure. Normal air pressure in 20°C is 1,013 mb. Thus, if pressure is larger than this, it is called high air pressure and normally good climatic condition. On the contrary, lower pressure than 1,013 mb called as low pressure during which climatic condition is foggy and rainy.
If the balance between the normal pressure and low pressure is large, heavier wind may blow.

The maximum average wind velocity was 29 m/sec continuously blowing in the most aggressive zone, about 80 km form the cyclone center. The instantaneous maximum wind velocity was 44 m/sec observed at 2:15 hours of January 2nd. The lowest average velocity was about 7.5 m/sec during three hours when the cyclone center was passing the island.

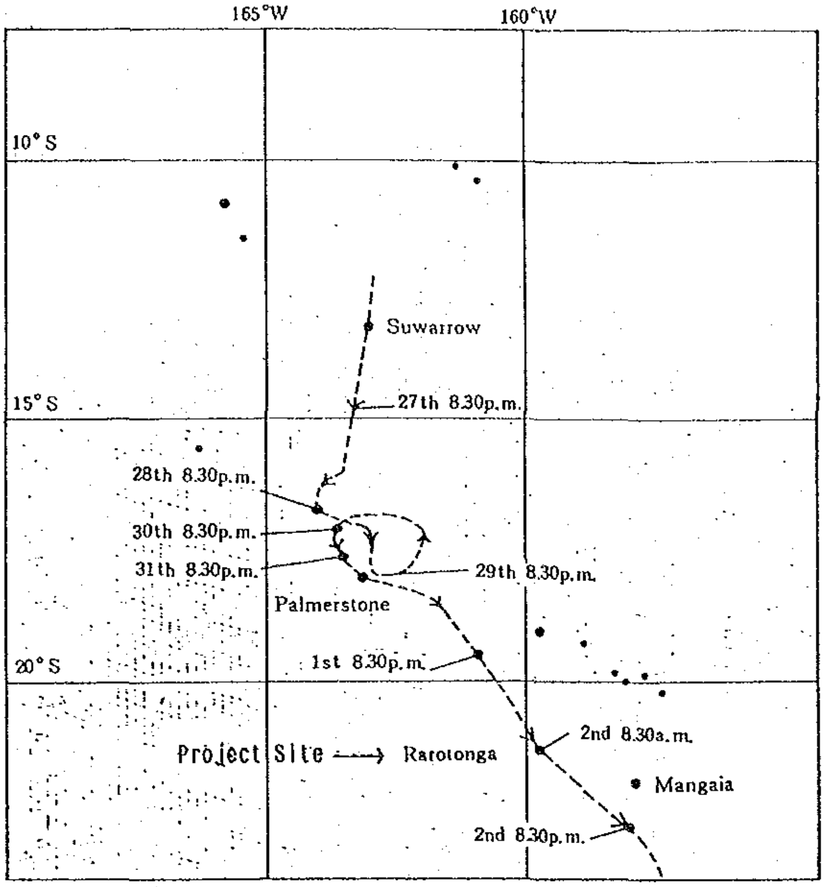


Fig. 5-1-c Route of Cyclone Sally (Dec. 1986 - Jan. 1987)

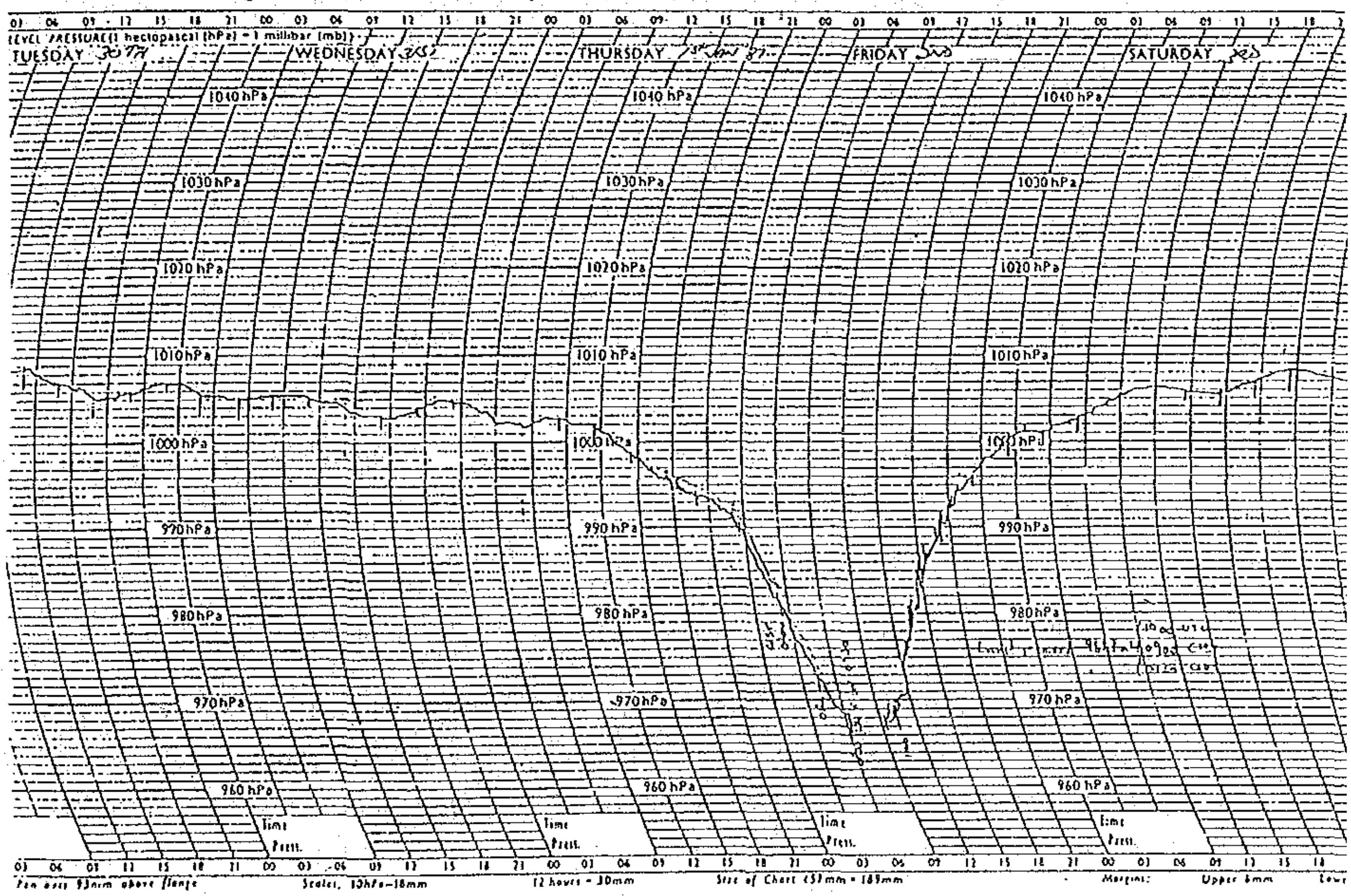


Fig. 5-1-d Air Pressure of Cyclone Sally at Rarotonga Island

Note: The average wind velocity is wind velocity averaging all wind observed for ten minutes.
This averaging is carried out normally each hour. The maximum average wind velocity is the maximum one of averaged winds. The instantaneous wind velocity means original wind intensity before averaging. This velocity shows wind intensity at instance, say for five seconds. The instantaneous maximum wind velocity is the largest one of instantaneous wind.

The main wind direction immediately before the center was arriving at the island and immediately after were ESE and WSW respectively.

Following figures may show the propagating route of Sally and air pressure observed by the MET in Rarotonga.

5.3.2 Proposed Design Offshore Waves

For the planning of coastal protection works, design offshore waves should be selected. It is proposed to adopt Sally's offshore waves as the design offshore waves by following reasons.

(i) This study was origainally started for the urgent need of coastal protection master plan after the large scale damage by cyclone Sally.

(ii) Accoring to the perception study on villager's feeling on cyclone disasters, Sally was selected unanimously as the worst one at every coast of 31 km long.

(iii) Cyclone Sally recorded various data by which required analysis can be made.

(iv) The expected return period of Sally is about 30 years. This length of period is similar to the average life of coastal protection works.

Although future cyclone larger than Sally may happen, however it is recommended to adopt Sally for estimation of design offshore waves since Sally was the worst one ever experienced by Rarotonga villagers in respect to disaster by wave actions.

Possible offshore waves generated by Sally that come from five directions and waves caused by Cyclone Peni coming from one direction have been hindcast by the study team.

Design offshore waves are shown in Table 5-4.

Table 5-4 Proposed Design Offshore Wave

Direction	Cyclone	Ho (m) Wave height	To (sec) Period
N6°W	Sally	8.1	12.5
N21°W	Sally	7.1	13.1
WSW	Sally	4.9	7.9
SSW	Sally	4.3	7.5
S	Peni	3.4	7.3
ENE	Sally	5.2	8.7

Source : Study Team

5.3.3 Equivalent Offshore Wave ; Ho'

Waves generating in deep water are defined as the offshore waves which are not yet influenced yet by seabottom friction. When these waves approach the shoal water, their height may be affected. Waves in shoal tend to refract towards the shallowest side. When they reach the wave-breaking zone, their height may gradually be reduced and rush to beach by their remaining momentum. This refracted offshore wave before breaking is an equivalent offshore wave. This wave may be large and small depend on refraction.

Equivalent offshore wave can be calculated as follows:

$$Ho' = Kr \cdot Ho$$

where, Ho' : Equivalent offshore wave height m

Kr : Refraction coefficient

Ho : Offshore wave height m

Total Rarotonga coastal area in 31 km is divided into 13 sections considering the existing coast configuration. Refraction coefficient for each section was calculated as follows:

(i) It is assumed that refraction will start at water depth of -100 m in 500 m offshore.

(ii) Wave may penetrate into lagoon by right angle at the reef edge.

Fig. 5-1 Refraction Coefficient and Equivalent Offshore Waves for 13 Zones

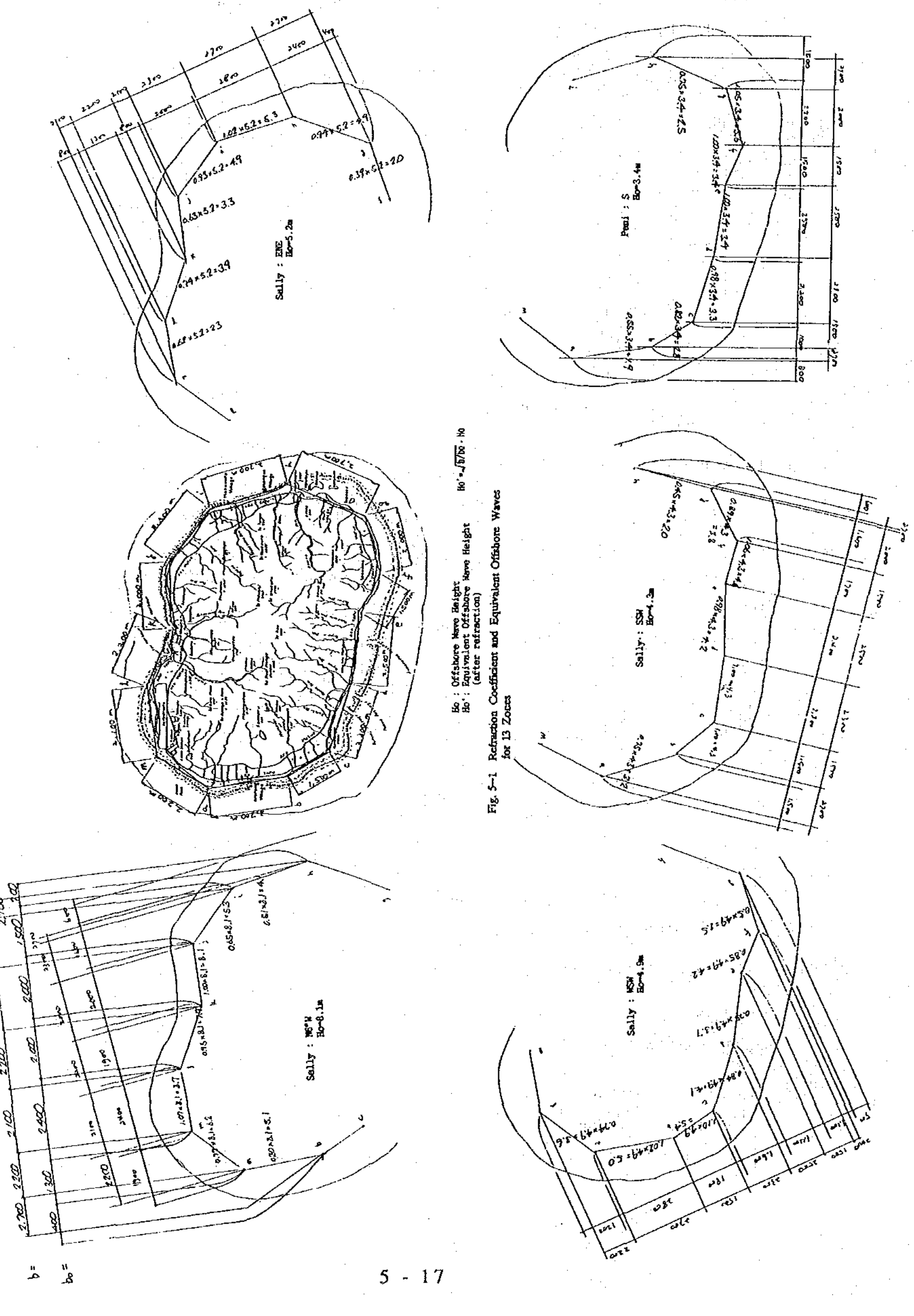
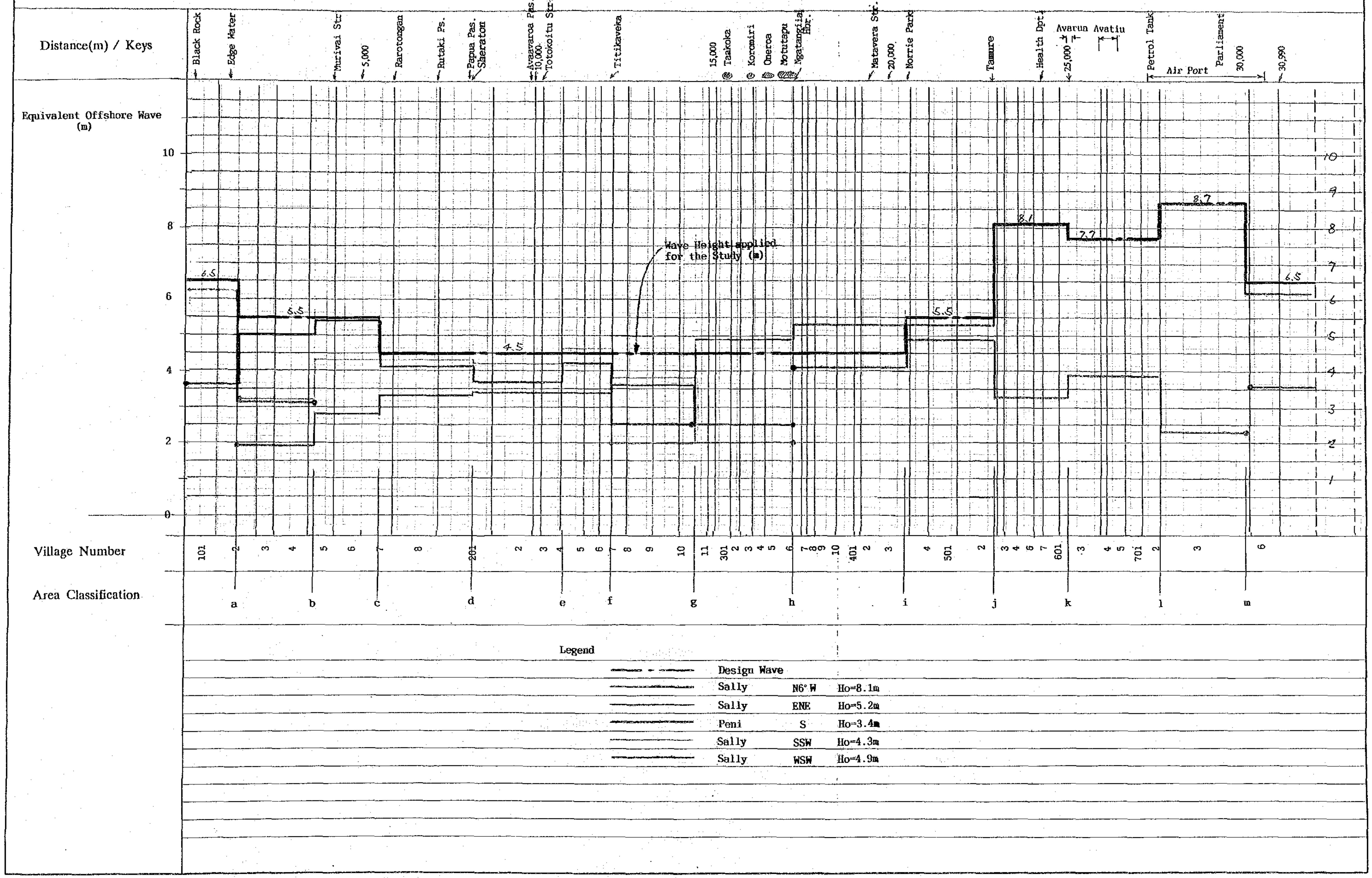


Fig. 5-2 Equivalent Offshore Waves by Village



(iii) Refraction Coefficient Kr

$$Kr = \sqrt{b/bo}$$

where b : unit width at the offshore

bo : width at the reef edge

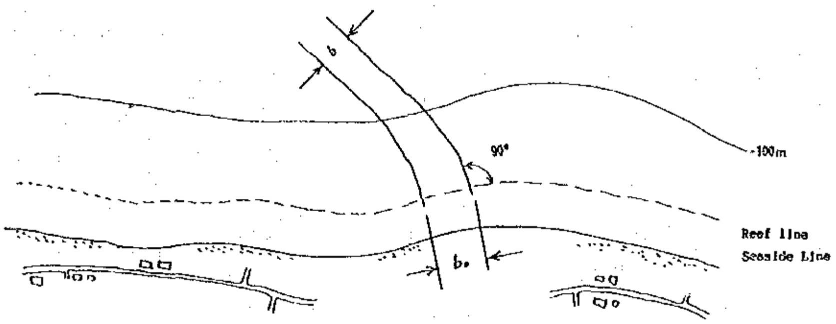


Fig. 5-1 shows the refraction coefficients (Kr) and equivalent offshore waves (Ho') by 13 coastal zones.

Fig. 5-2 shows equivalent offshore waves (Ho') by village.

5.3.4 Wave Set-up

Cyclone generates not only heavy wave but also water level rising by "wave set-up". This wave set-up happens when:

(i) In the deep bay

(ii) In the long shoal

Being a circular coast shape covered by lagoon except the passages, the Rarotonga Island meets with the latter. It is well known here that during a cyclone water level in the passage rises but water level in the lagoon rises much higher. According to the simulation results by computer, wave-set-up at the Avarua coast during Sally was as follows.

Passages(on the reef line)		0.9 ~ 1.0 m
Lagoon (reef line)		1.3 ~ 1.4 m
Balance	Average	0.4 m

This will be discussed in detail in subsection 5.3.7. Wave-setup may accelerate not only wave over-topping but also inland flood by back water in the stream.

5.3.5 Lagoon Width and Beach Top Height

Is a cyclone an evil? Cyclone might affect here, since this island appeared. Cyclone like Sally occasionally damages the artificial facilities along the coast, through they were mainly built since 18th centuries. Since the beginning and even now, the cyclone dumped coral sand and fragment on beach bank and made the coastline go seaward.

There are generally two different types of coastal bank growth.

(i) Material supplied from inland sources

Raining water transports soil, sand and rock into the stream. They may deposit along the stream and stream mouth. Some of them may drift into the sea. Part of these material will deposit along the beach and stay there. If the material supply continue, the coastal bank may grow and beachline may go seaward.

(ii) Material supplied from seaside sources

No material supply from the stream, but coastal bank may be supplied sand and gravel from the seaside sources.

Coastal bank in the Rarotonga Island has mainly been generated by the latter. There are many evidences showing this. Under-ground soil composition along the coast can be seen at the exposed surface by excavation. The soil consists of coral sand and/or coral fragment. This shows that villagers here are living on the deposited coraline earth. If no cyclone, no dumping of coraline materials by cyclone wave run-up and no flat coastal bank.

Thus, the cyclone is the creator of land. Rarotonga villagers seem to know this well.

The map prepared by the Survey Department shows that the lagoon width at the southern coast where wave intensity is light generally has a wide space. However, lagoon those at the northeast and north coasts faced to heavy wave are narrow. This pattern may suggest that larger wave energy makes the growth of lagoon moderate.

(D)

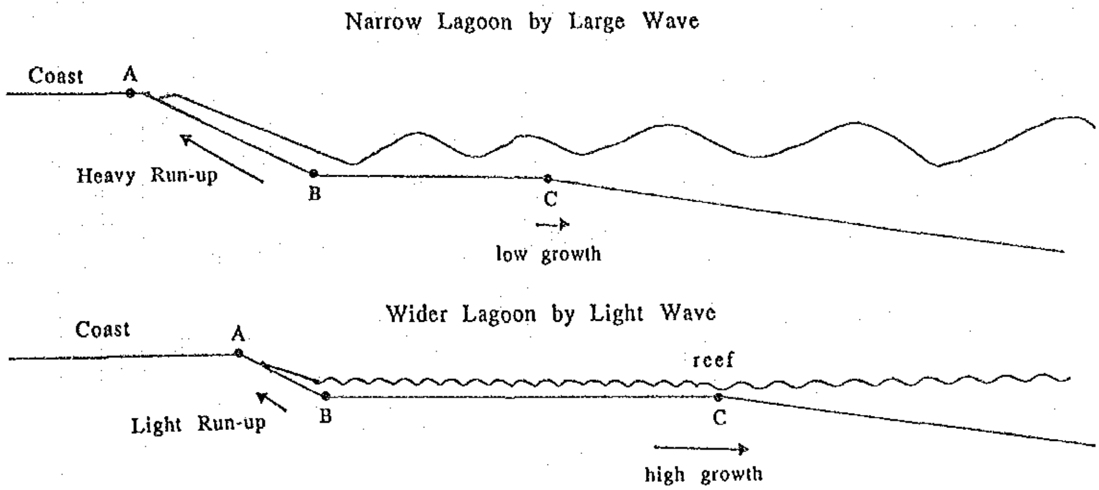


Fig. 5-3 shows the width of lagoon every 200 meters. The figures were obtained from the said map and from the survey conducted by the study team. The same figure also shows changes of beach top elevation by village and is based on the survey performed by the study team. Datum for both is the Mean Sea Level (MSL).

It seems the wider lagoon, the lower the beach top.

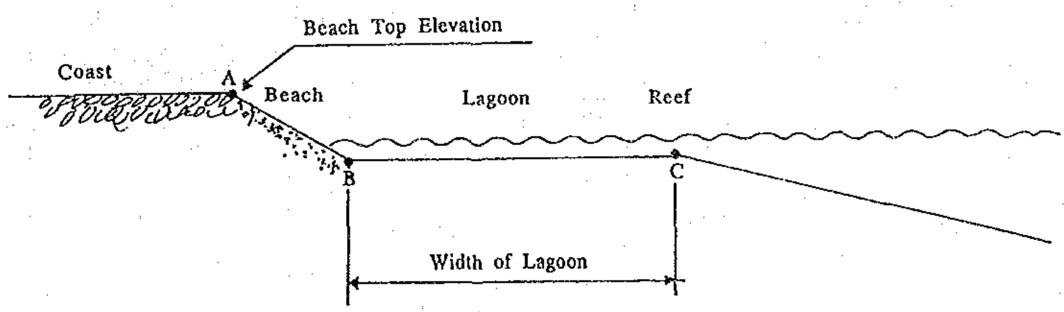


Fig. 5-4 Shows the relationship between these two data.

It is clear that each coast has its own characteristics. The south coast does shows no correlation between the lagoon and the beach height. This may indicate that the beach top level is not related to the wave run-up. Correlation at the north coast is good; thus, beach generation may be related to wave run-up.

Fig. 5-3 Lagoon Width and Ground Height of Beach Top

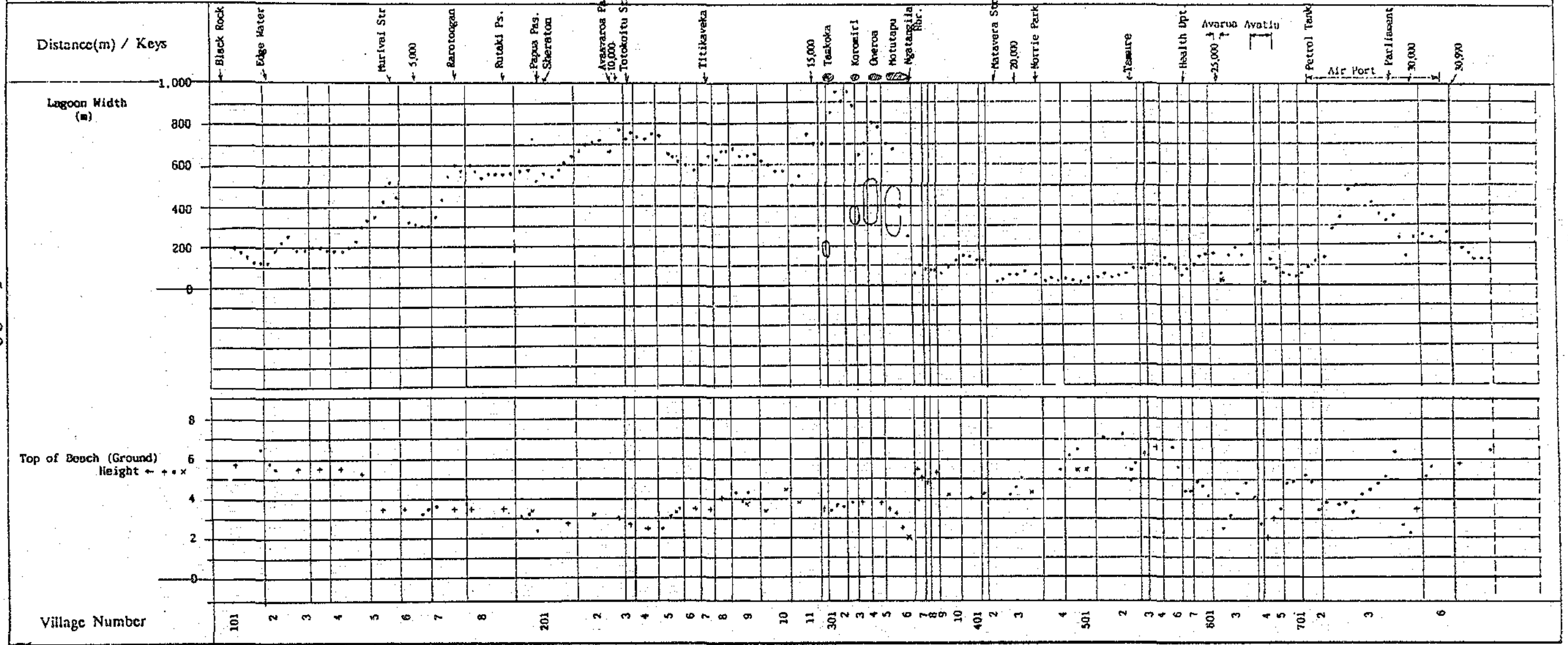
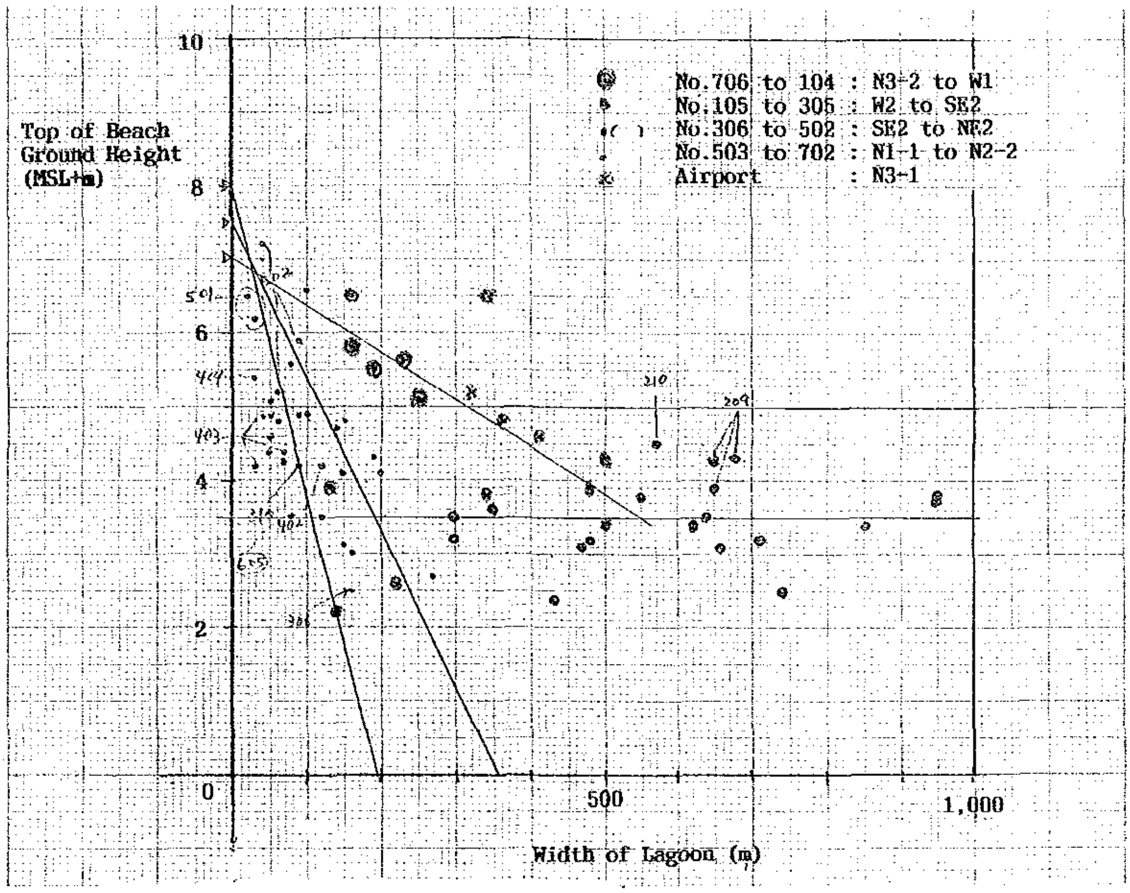


Fig. 5-4 Relationship between Lagoon Width and Beach Top Height



5.3.6 Wave Height Limits by Coast Profile

As discussed in the previous subsection, the beach top elevation at the Northern coast is likely related to the lagoon width.

Summary of previous subsection is as follows,

(i) Coastal banks in the northern coast and northeast coast are consist of coraline sand and fragment dumped by the cyclones

(ii) The narrow lagoon, the higher beach top. For the same wave height, high run-up height of sand and rock will happen in narrow lagoon than wide one.

In order to analyze this, the height of a water body which may run up towards the top of beach is estimated using the Saville's formula.

Wave run-up calculation in 172 coastal sections were carried out by the Saville's method. All the study results are shown in Appendix C-1. It is assumed that waves approach normal to the reef edge. It is also assumed that width of lagoon is as shown in the said appendix.

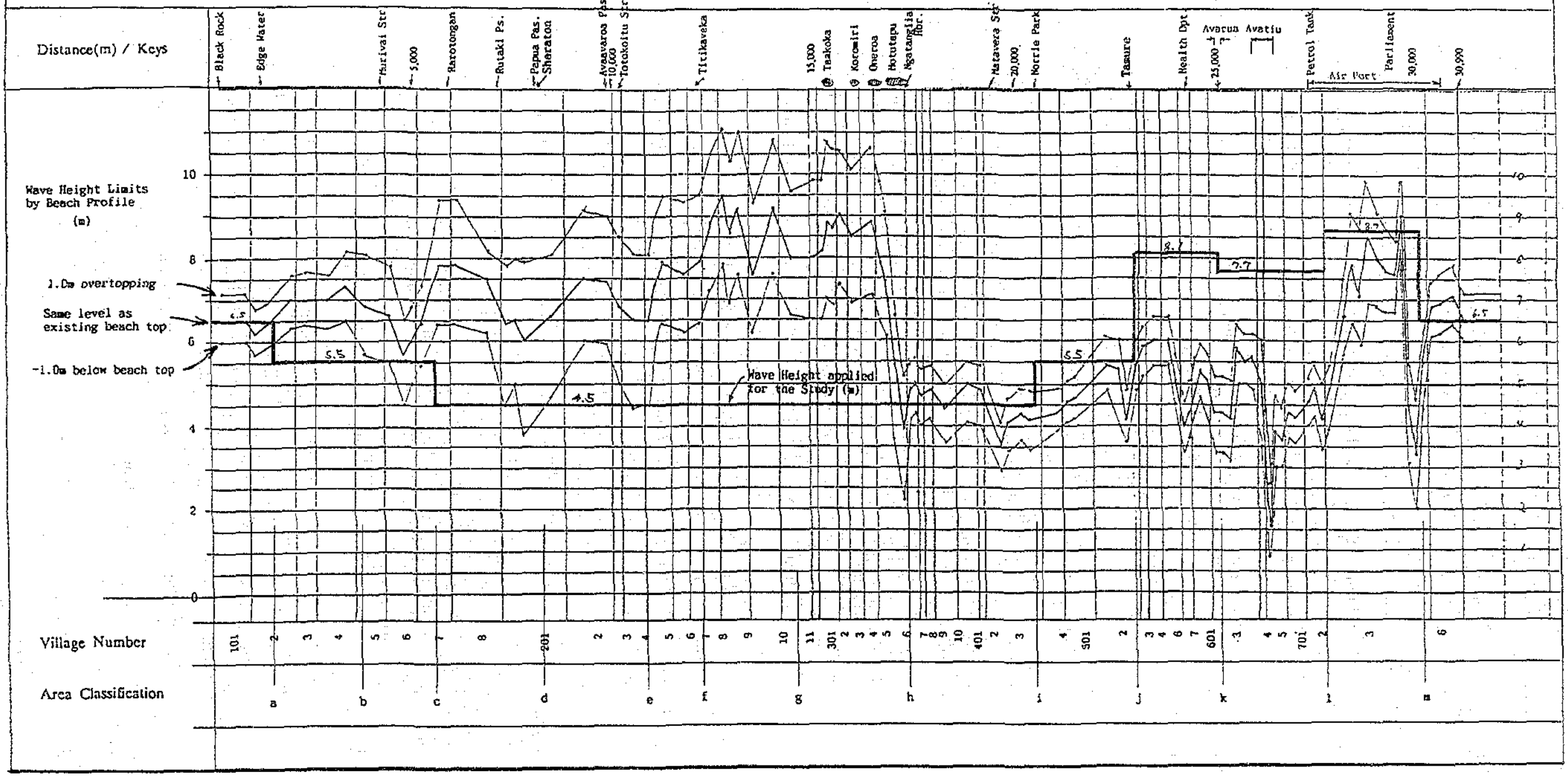
Note : This formula was developed to estimate the elevation of the highest water bodies running up the beach slope under the specified conditions including wave intensity and coast section. Detailed discussion will be made in subsection 12.2.4.

Study - 1	Calculation of the critical wave running-up to the existing beach top.

Fig 5-5 shows the wave height limits by the existing beach profiles. In other words the figure shows the wave intensity to meet the existing beach top elevation.

Wave height limits at the northern coast are about five meters and are moderate. This means that the maximum wave height giving no over-topping is about five meters, if no protection work is provided. The southern coast shows higher allowable wave limits than the northern. This means that the southern coastline is safer than the northern one, if same wave is provided here.

Fig. 5–5 Wave Height Limit by Village



Study - 2 Calculation of wave run-up by the design wave

Using the same formula, wave run-up elevations by the design waves at the 172 coast sections were calculated. Fig. 5-6 shows the results of this study. Based on the study results, 31 km coast were divided into two zones, namely the "Safety Zone" and the "Dangerous Zone". The former areas have wave over-topping by 2 meter or less, however the latter areas have larger over-topping than 2 meter.

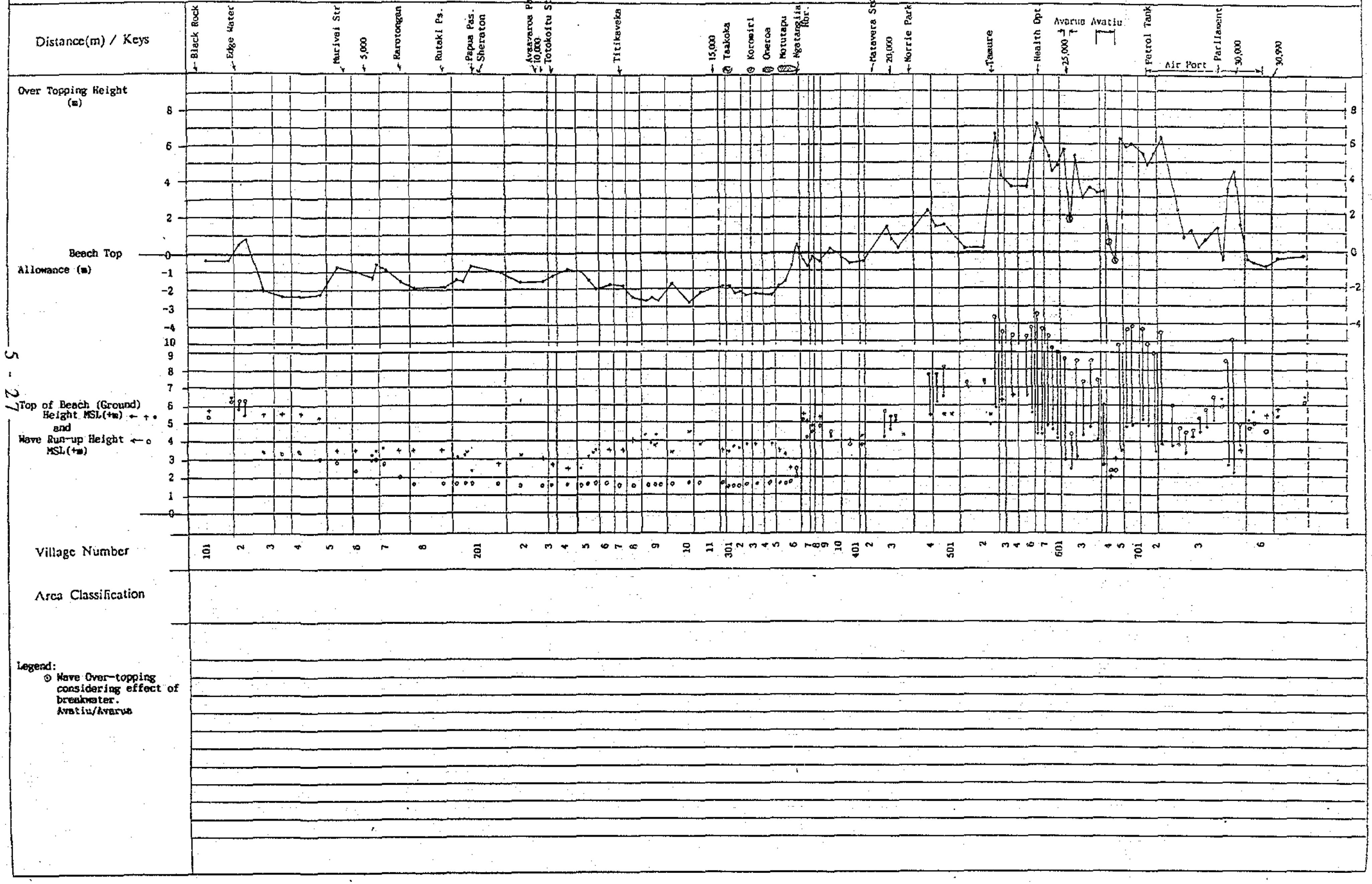
Note: When wave run-up height is higher than the existing beach top, wave will over-top into inland area. Refer to subsection 4.1.5 item 1).

This data conforms to the records of damage prepared by the Conservation Department. Four most dangerous coastal areas are:

a) Village Vaikai, near the Health Department
b) Avarua coast
c) Villages Atupa and Kaikaveka,
This zone is between Avatiu and the eastern end of the existing airport. (Note: The first 200m of the airport area is also indicated as a dangerous zone.)
d) West end of the Airport
Where the beach road elevation is as low as MSL +2.5 meter.

This data will be utilized in Chapter 7 for the Master Plan of Coastal Protection.

Fig.5-6 Wave Run-up and Overtopping Elevation by Design Waves



5.3.7 Modelling Cyclone Sally at Avarua Coast

There were no accurate quantitative measuring data on wave, current and wave set-up on the lagoon under the attack of Sally. It is technically difficult to carry out these works under the most severe climatic condition, and very risky job. This is confirmed by the study team whey they watch cyclone Gene, even it is minor one. Many villagers wanted to know what happen in the sea. Some person imagines the situation based on his watching. However, watching can not provide him with accurate figures. And watching is only for situation on the lagoon and does not provide him any data about happenings out of reef.

A computer simulation study about Sally was conducted by the study team. The study area was the 1,500 meter width from the middle of the Avatiu Harbour and the eastern end of Village Ngatipa. This area includes the Avarua coast which was severely damaged by Sally. The purpose of study was to simulate the reappearance of so complicate happens at the most dangerous instance when Sally came.

<u>Input for simulation:</u>

a) Wave

8.1 meter of 12.5 sec period as the maximum significant offshore wave by Sally is given at deep sea of 120 m depth. This wave was hindcast by the study team.

Direction is N6°W

(six degrees measuring the north to west direction)

b) Water depth

c) Seabottom configuration

d) Water level

Water level is fixed MSL +0.7 m including tide and low air pressure suction. Wave set-up should be added on this.

Note; River discharges through both the Avatiu Stream and Takvaine Stream and tidal current are neglected.

<u>Output of simulation:</u>

a) Wave Direction and Height

b) Littoral Current, velocity and direction

c) Wave Set-up above MSL + 0.7 meter

Computer Used

To meet the large amount of repeated calculation, following computer owned by the Pacific Consultant International (PCI), leading consultant of study team, was used.

a) Name of machine Fuji-tsu, VP-30E

b) Capacity (1) Super Computer

c) Capacity (2) 8MB Memory

Outline of simulated result are demonstrated as follows.

Wave Direction

As seen in Fig. 5-7, a wave gradually changes its direction until it reaches the beach front. In shoal water, wave refracts considerably due to seabottom configuration. It arrives almost perpendicular to the beachline.

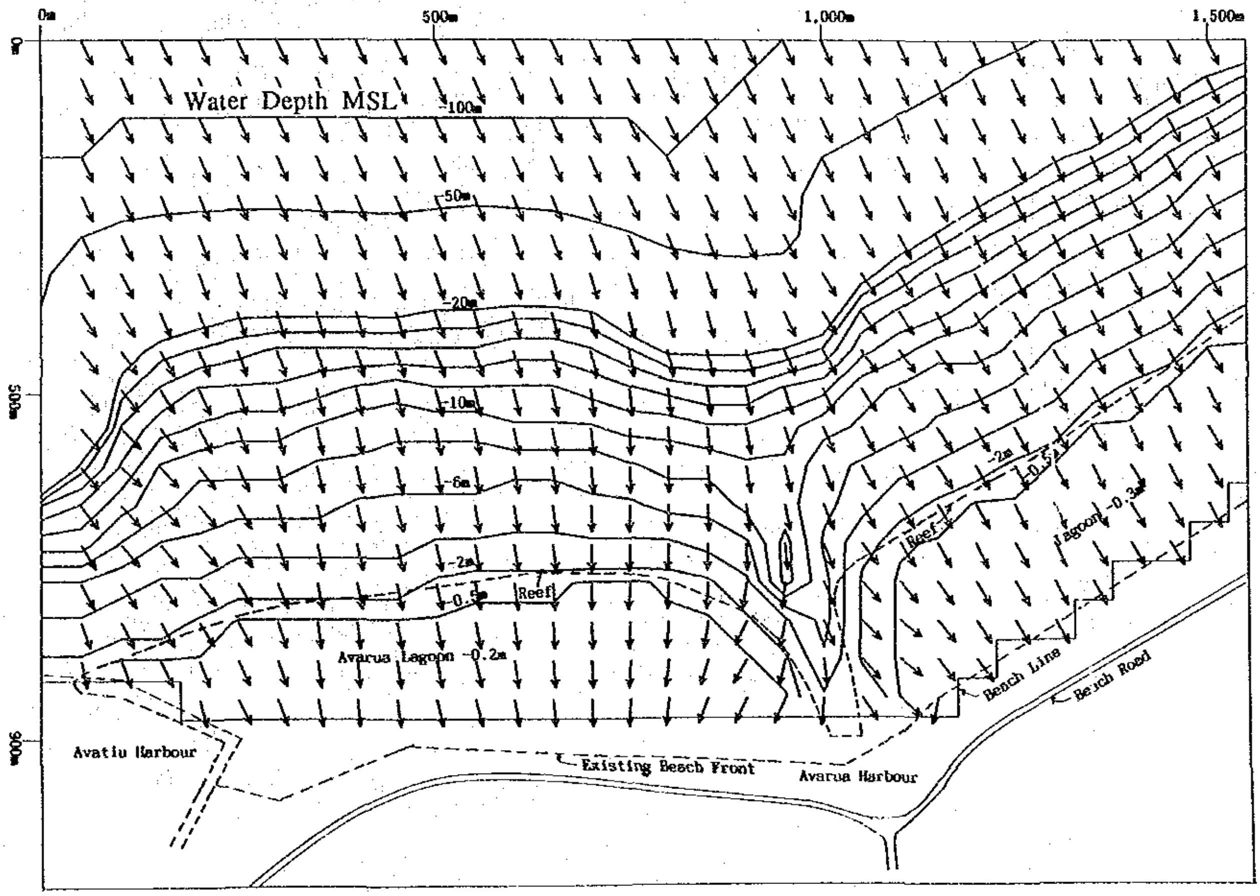


Fig. 5-7 Wave & Current Simulation (Case : Sally as of Jan. 1987)
Water Depth vs. Wave Direction

Wave Height

As seen in Fig. 5-8 an offshore wave starts breaking at about the MSL - 15 meter contour line and ends it at about 50 meter after the reef. Wave height decreases gradually and becomes about two or three meters at the reef edge. Wave height is one meter at 50 m from the reef edge and after it. Large waves can penetrate into the passage because the water is deeper than the lagoon. The seven meter wave contour line here goes offshoreward due to the return current which may reduce the wave energy approaching here.

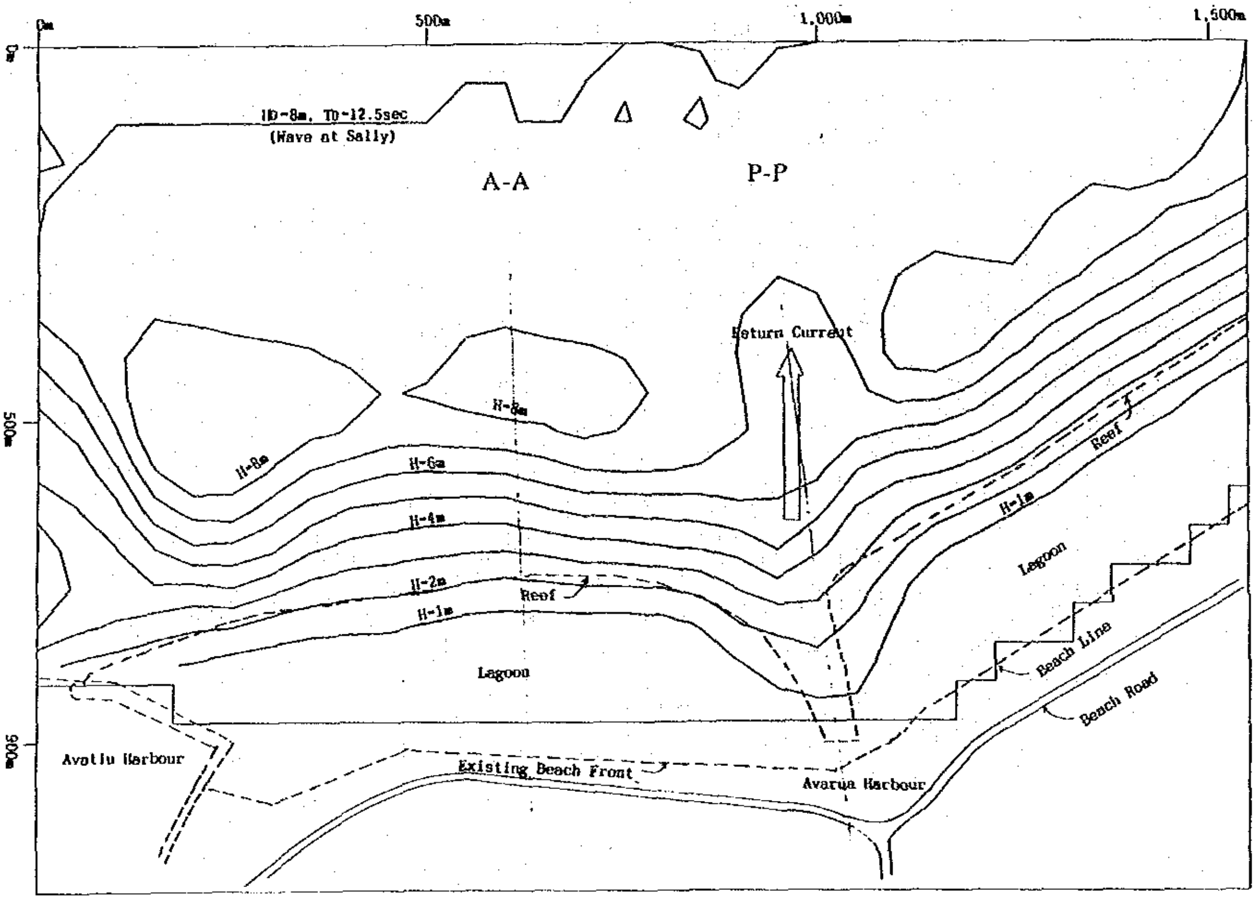


Fig. 5-8 Wave & Current Simulation (Case : Sally as of Jan. 1987)
Wave Height

Fig. 5-8A shows relationship between the water depth and wave height at both locations, the center of Avarua coast as section A-A and the Avarua passage as section P-P. These indicate followings:

(i) From the deep sea to the MSL -15 m contour line, the given offshore wave height as Ho = 8.1 m is maintained constantly.

(ii) After the MSL -15 m contour line, wave height decreases suddenly.

(iii) Wave height on the reefline of MSL -0.2 m is about 2.5 m. While wave height in the passage on the extended line of reef edge in MSL - 9.0 m is about 3.5 m.

Note: "MSL -0.2 m" and "MSL -9.0 m" mean the depth under the datum, MSL. Actual water depths here are as follows:

Components	On the reefline	Passage on reefline
Depth under the datum	0.2 m	9.0 m
Tide and low pressure suction	0.7 m	0.7 m
Wave set-up in Fig. 5-11	1.3 m	1.1 m
Total depth	2.2 m	10.8 m

(iv) The most shoreward wave height is 1 m namely at landward end of both lagoon and passage.

Note: Actual water depths here are as follows.

Components	On the reefline	Passage on reefline
Depth under the datum	0.2 m	1.5 m
Tide and low pressure suction	0.7 m	0.7 m
Wave set-up in Fig. 5-11	1.6 m	1.4 m
Total depth	2.5 m	3.6 m

As seen in Fig. 5-8A, propagating wave height is restricted by the actual water depth. Another finding by simulation study is that decreasing of wave height starts at 300 m offshore than reef. It is not correct to believe that reduction of Sally wave starts on the reefline. Wave height in the lagoon at the 50 m area from the reef edge is only 1 meter, then few change can be observed. Here also it is known that wave height is restricted by the actual water depth, 2.2 m to 2.5 m. Same happenings are observed in the passage, however further reduction is made by the return current discharged from the lagoon.

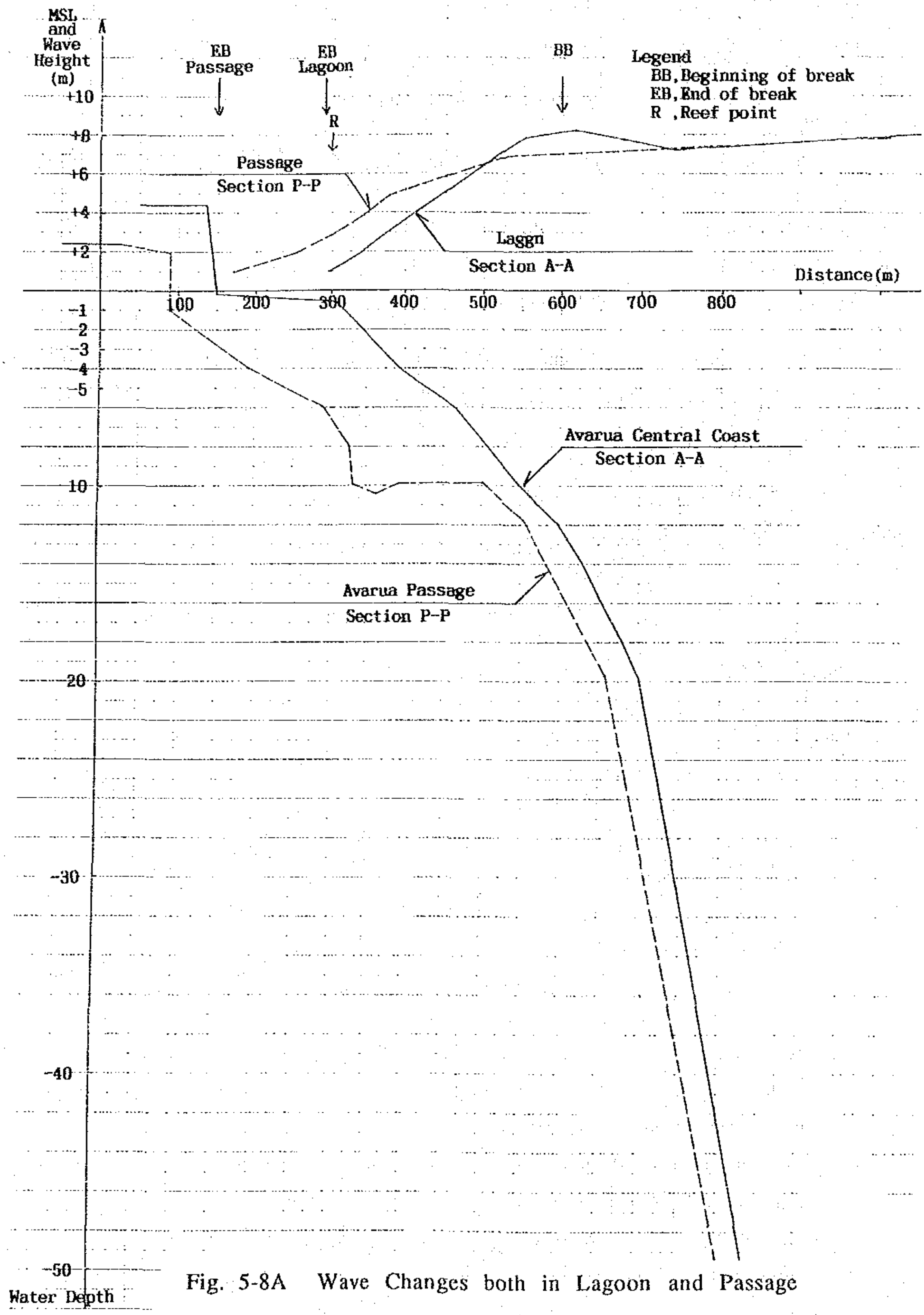


Fig. 5-8A Wave Changes both in Lagoon and Passage

Coastal Current

Fig. 5-9 shows the current vector which indicates the current velocity and direction. The length of the arrows indicate the velocity, thus the longer the arrow the higher the speed. The velocity is shown at the bottom of figure. Current velocity is almost zero before the wave-breaking zone, but appears immediately after reaching it. Current velocity at 100 m offshore from the reef shows the peak value then current changes its direction to the passage. All the currents finally to go the passage where the highest current velocity can be observed. Fig. 5-10 shows current circulation patterns. There are two circulation cores besides the center of the return current. The eastern one appears to circulate clockwise; the opposite one turns anti-clockwise.

Fig. 5-9 Wave & Current Simulation (Case : Sally as of Jan. 1987)
Water Depth vs. Current Vector

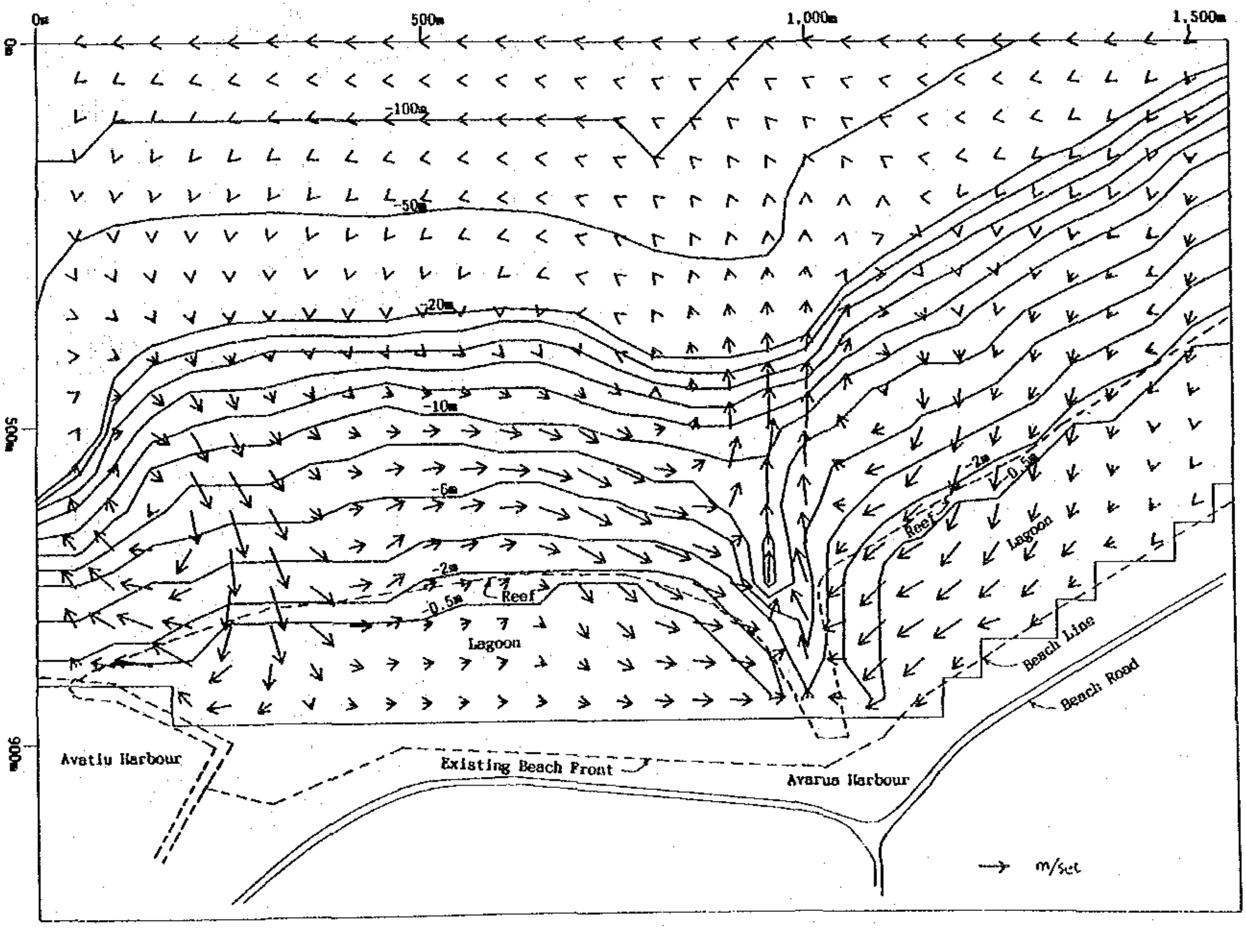
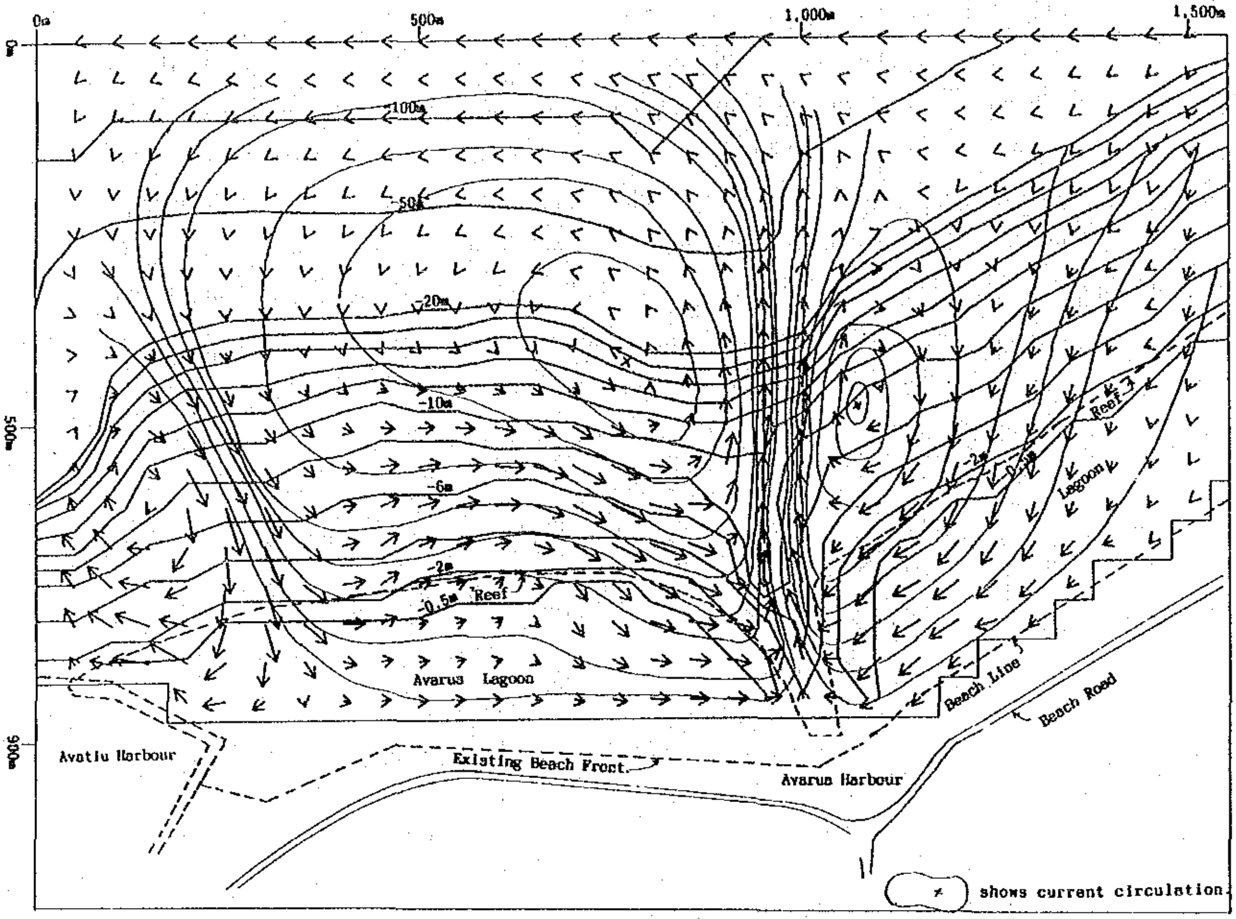


Fig. 5-10 Wave & Current Simulation (Case : Sally as of Jan. 1987)
Current Circulation



Centers of these two circulations are located at the water depth both MSL -8 m and MSL -16 m. These locations are the wave breaking zone. The return current goes offshore until MSL -50 m. Another particular is current direction on the lagoon is parallel to the coast.

Wave Set-up

The most interesting one in the simulation is the wave set-up. Fig. 5-11 shows this. The water level offshore that is not affected by this phenomena is MSL +0.7 m above MSL(Mean Sea Level). This means:

High water plus low pressure suction plus allowance
= 0.36 + 0.24 + 0.10
= 0.7 m

Thus, it is assumed that Sally arrived offshore and hit the island during the high tide.

As shown in Fig. 5-11, the water level dereases slightly at the middle of the wave-breaking zones. After this, radical wave set-up starts suddenly around the MSL -10 meter line, which is almost the same magnitude as the design offshore wave height. This area is the skirts to the top of the heaved water. The water level rises steadily until it reaches the reef edge where the wave set-up is about 1.3 meter. The travelling distance to this point is about 200 meters. Thus, average gradient is 0.65 percent. The water rise continues for until the first 100 meter after reaching the reef edges. However, set-up is only about 0.2 to 0.4 meter. After this, the water rise is very little until it reaches at the beach front.
Tuning to the passage, wave set-up here is less than at the lagoon. The water level at mid-passage is 0.3 to 0.6 meter lower than those in the parallel lagoon. At the landward end, wave set-up is about 1.4 meter.

Fig. 5-11 Wave & Current Simulation (Case : Sally as of Jan. 1987)
Wave Set-up above MSL 0.7 m

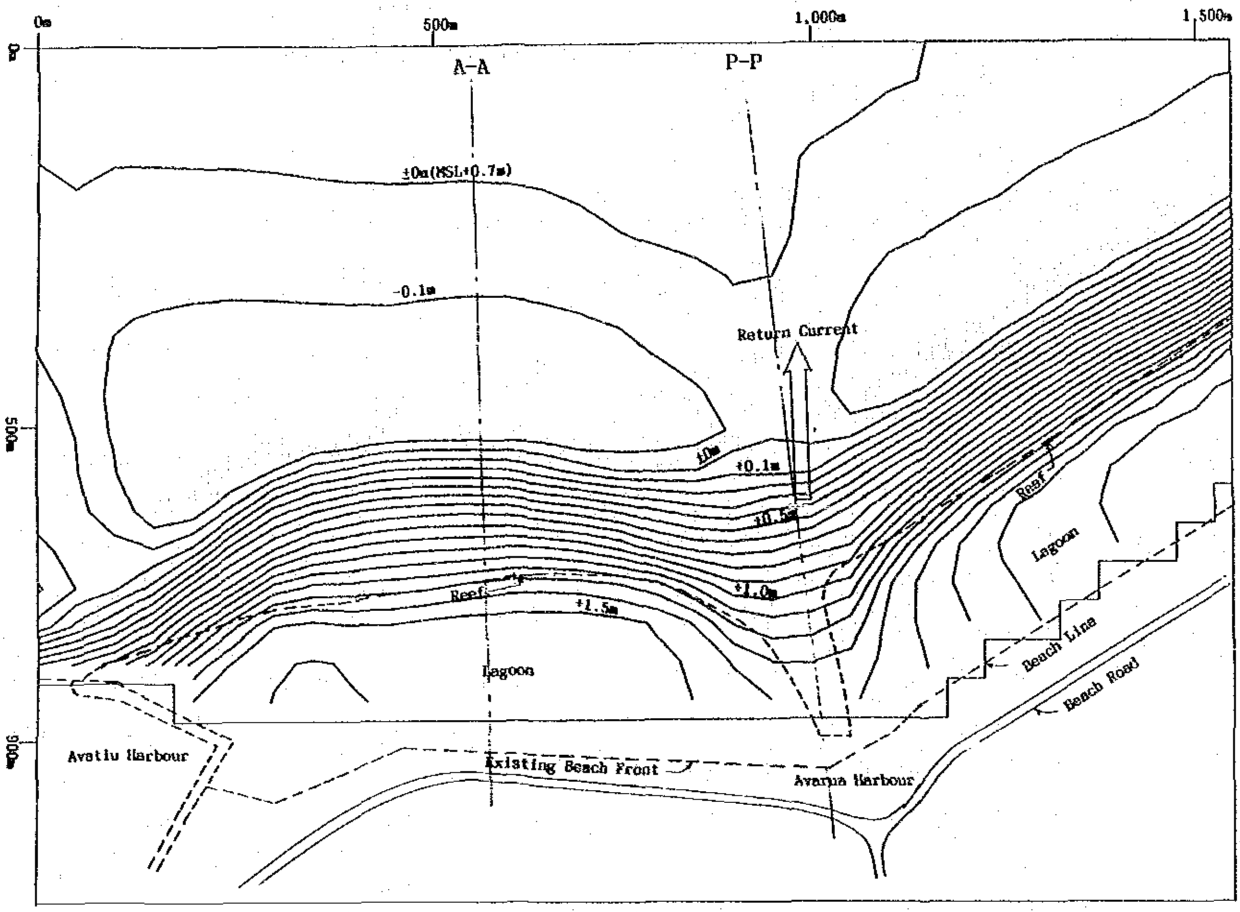


Fig. 5-11A indicates the sequence of wave set-up both in lagoon and the passage. If this figure is superimposed on Fig. 5-8A, more clear relationship can be seen.

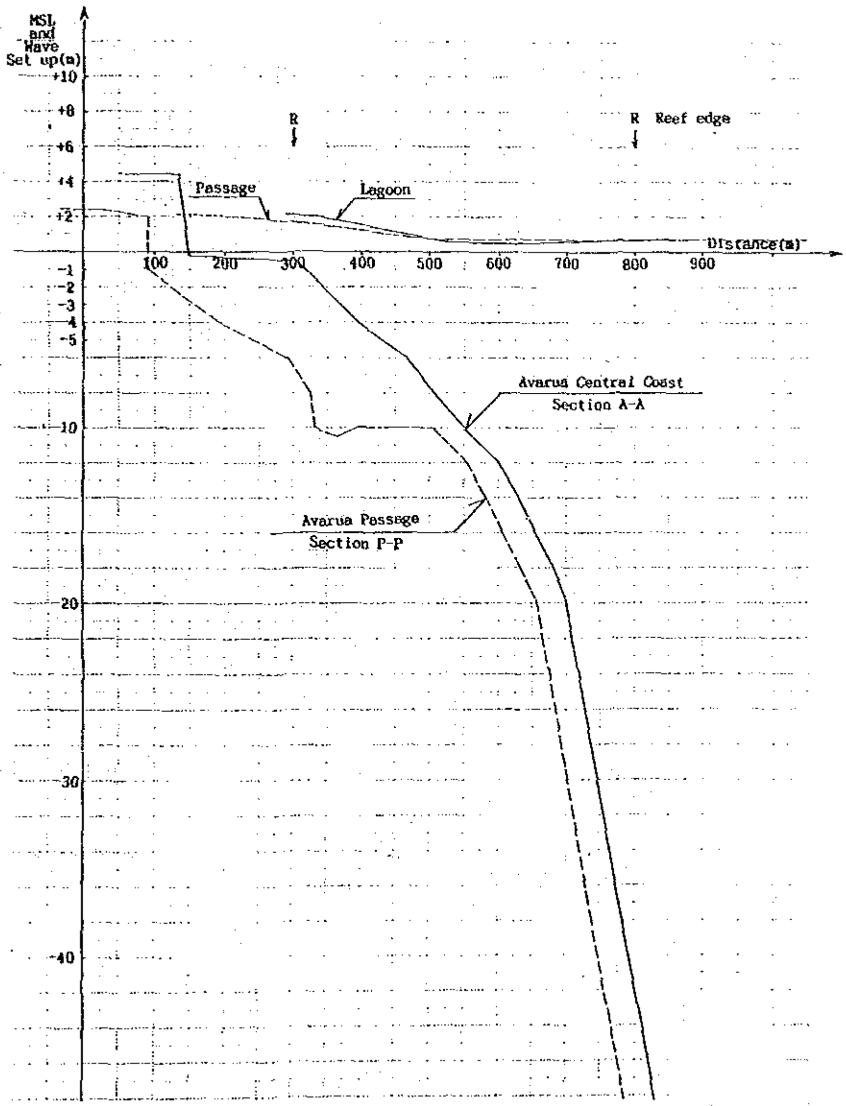
(i) Starting point of wave reduction and starting point of wave run-up is same at the contour line of MSL +10 m.

(ii) Similarly, the ending point of wave reduction is same with the peak point of wave run-up.

This indicates that the wave breaking relates deeply with the wave set-up. Someone believes that the wave set-up starts at reef. However, simulation results shows wave set-up begins at 250 m offshore the reef of MSL -10 m.

(Note: Figures in section 7.6.3 will demonstrate another computer simulation study in order to assume possible happenings after the coastal protection work is completed.)

Fig. 5-11A Wave Set-up both in Lagoon and Passagen



5.3.8 Estimation by Conventional Method

In order to verify the correctness of computer simulation, comparison study was conducted on both the wave height and the wave set-up on the lagoon. The Northern coast was selected for this evaluation.

The conventional method can be applied only to a simple coast which has the parallel coast which has same cross section.

1) Coast to be studied
Northern coast is divided into three zones major characteristics of which are shown in table below.

Zone	Start	End	Length	Ho' (m)	Facilities
North-East	Kiikii West to 5025	Avarua East 6031	2,000 m	8.1 m	Tamure Sesort Conservation Dep. Health Dep. Government Offices Avarua Harbour
Central North	Avarua East to 6032	Airport East 7031	2,200 m	7.7 m	Avarua Harbour Shopping Center Avatiu Harbour R.C. Cemetery Tank yard
North-West	Airport East to 7032	Airport West 70312	2,100 m	8.7 m	Airport Cemetery Parliament MET Airport

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

Wave height and set-up can be calculated by following formula:

$$H_{1/3}/H\acute{o} = B \cdot \exp\left(-A\frac{x}{H\acute{o}}\right) + \alpha\,\frac{h - \eta_{\infty}}{H\acute{o}} \qquad \text{-------------------------- (1)}$$

$$\frac{h - \eta}{H\acute{o}} = \sqrt{Co - \frac{3}{8}\beta\left(\frac{H_{1/3}}{H\acute{o}}\right)^2} \qquad \text{-------------------------- (2)}$$

where,

$H_{1/3}$	:	Wave height on the lagoon
H_0'	:	Equivalent deepwater wave height
h	:	Still water depth on the lagoon
x	:	Distance from the reef edge
η_∞	:	Average set-up at $x = \infty$ (infinite)
η	:	Set-up on the lagoon
A, α, β	:	Coefficients, $A = 0.05$, $\alpha = 0.3$, and $\beta = 0.56$

B and Co are obtained by the following equations:

$$B = \frac{H_{1/3\, x=0}}{H_0'} - \alpha \frac{h + \eta_\infty}{H_0'} \quad \text{---------------------------- (3)}$$

$$Co = \left(\frac{\eta_{x=0} + h}{H_0'}\right)^2 + \frac{3}{8}\beta \left(\frac{H_{1/3\, x=0}}{H_0'}\right)^2 \quad \text{---------------------------- (4)}$$

$$\frac{\eta_\infty + h}{H_0'} = \sqrt{\frac{Co}{1 + \frac{3}{8}\beta \cdot \alpha^2}} \quad \text{---------------------------- (5)}$$

Common condition to the study areas:

Seabed slope off the reef edge, $\theta = 1/10$

Still water depth on the lagoon, $h = 1.0$ m

Lagoon bet	MSL -0.3 m
Still water	MSL +0.7 m

Wave length (offshore)

$Lo = 1.56 \times 12.5^2 = 244$ m

Following two diagrams will be used.

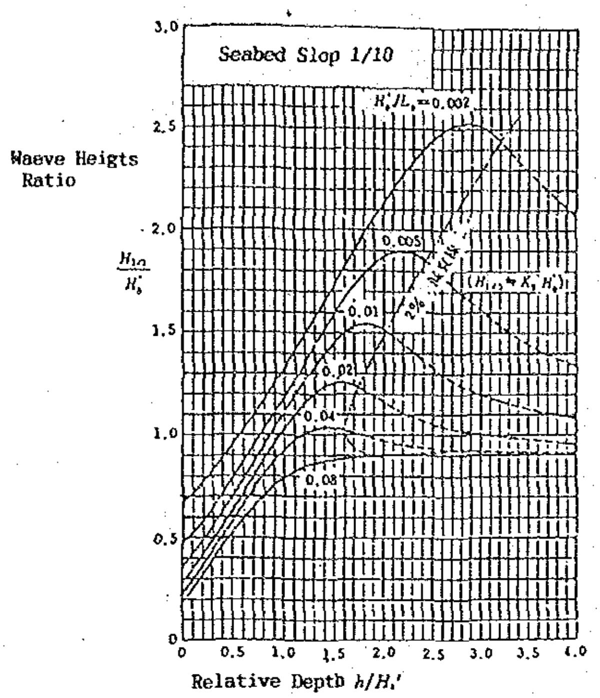


Fig. 5-11B Wave Height Diagram in wave breaking zone (Slope 1/10)

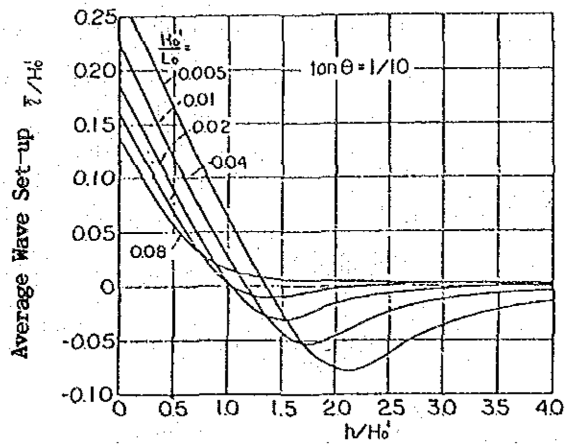


Fig. 5-11 C Wave Set-up by shoaling change of irregular wave (Slope 1/10)

3) Study at the Central Coast

(i) Wave Height on the Reef

Parameters of diagrams, h/Ho', h/Lo and Ho'/Lo

h/Ho' = 1.0/7.7 = 0.13

h/Lo = 1.0/244 = 0.004

Ho'/Lo = 7.7/244 = 0.032

From Fig. 5-11 B,

$H_{1/3}$ (x = 0)/Ho' = 0.35

Where, $H_{1/3}$ (x = 0) shows the wave height on the reef edge.

Thus, $H_{1/3}$ (x = 0) = 0.35 x 7.7
= 2.70 m

(ii) Wave Set-up on the Reef edge

From Fig. 5-11 C,

η(x = 0)/Ho' = 0.14

Where, η (x = 0) shows the wave set-up on the reef edge.

Thus, $\eta\,(x = 0) = 0.14 \times 7.7$

$= 1.08$ m

Actual water level at the reef edge is,

MSL + 0.7 + 1.08 = MSL + 1.78 m

(iii) Wave Height and Wave Set-up on the Lagoon

Figures on the lagoon (x = 50 m) will be as follows:

From equation (4),

$$Co = (0.14 + 0.13)^2 + \frac{3}{8} \times 0.56 \times 0.35^2$$
$$= 0.099$$

From equation (5),

$$\frac{\eta_\infty + h}{Ho'} = \sqrt{\frac{0.099}{1 + \frac{3}{8} + 0.56 \times 0.3^2}}$$
$$= 0.312$$

From equation (3),

$$B = 0.35 - 0.3 \times 0.312$$
$$= 0.256$$

From equation (1),

$$H_{1/3}/Ho' = 0.256 \exp(-0.05 \times 50/7.7) + 0.3 \times 0.312$$
$$= 0.279$$

$$H_{1/3} = 0.279 \times 7.7$$
$$= 2.15 \text{ m}$$

From equation (2),

$$\eta/Ho' = \sqrt{0.099 - \frac{3}{8} \times 0.56 \times 0.279^2} - 0.13$$
$$= 0.157$$
$$\eta = 0.157 \times 7.7$$
$$= 1.21 \text{ m}$$

Thus, wave height $H_{1/3}$ and wave set-up (η) on the lagoon ($x = 50$ m) are as follows.

$H1/3 = 2.15$ m

$\eta = 1.21$ m

$= MSL + 1.21 + 0.70 = MSL + 1.91$ m

Similar to the calculation above, figures in the lagoon, $x = 100$, $x = 150$ and $x = 200$ were obtained.

Distance from the Reef Edge		x (m) 50	100	150	200
Wave Height,	$H_{1/3}$ (m)	2.15	1.75	1.46	1.26
Wave Set-up,	η (m)	1.21	1.29	1.32	1.36
	MSL + m	1.91	1.99	2.02	2.06

4) Summary of Study Results

The North-East zone and the North-West zone were also studied in respect to wave height and wave set-up. Table below shows summary of calculated figures together with the Central Coast zone.

Zone	Date		Distance from the reef edge (x m) 0	50	100	150	200
North-East	Wave	$H_{1/3}$ (m)	2.84	2.28	1.86	1.56	1.34
	Set-up	η (m)	1.13	1.26	1.34	1.39	1.42
		MSL + (m)	+1.83	+1.96	+2.04	+2.09	+2.12
Central East	Wave	$H_{1/3}$ (m)	2.70	2.15	1.75	1.46	1.26
	Set-up	η (m)	1.08	1.21	1.29	1.32	1.36
		MSL + (m)	+1.78	+1.91	+1.99	+2.02	+2.06
North-West	Wave	$H_{1/3}$ (m)	2.61	2.15	1.80	1.54	1.35
	Set-up	η (m)	1.31	1.41	1.47	1.51	1.53
		MSL + (m)	+2.01	+2.11	+2.17	+2.21	+2.23
Average	Wave	$H_{1/3}$ (m)	2.71	2.19	1.80	1.52	1.32
	Set-up	η (m)	1.17	1.29	1.37	1.41	1.43
		MSL + (m)	+1.87	+1.99	+2.07	+2.11	+2.13

5) Evaluation of Conventional One and Computer Simulation

Data at the North-East zone and the Central North zone were compared in respect to wave height and wave set-up.

Zone		Figures		Distance from the Reef Edge (x m)				
				0	50	100	150	200
North-East								
	A.	Wave Height $H_{1/3}$ (m),	Convent. C.	2.84	2.28	1.86	1.56	1.34
	B.	Wave Height $H_{1/3}$ (m),	Computer C.	3.20	1.00	1.00	1.00	1.00
	C.	Ratio A/B		0.89	2.28	1.86	1.56	1.34
	D.	Set-up, η (m),	Convent. C.	1.13	1.26	1.34	1.39	1.42
	E.	Set-up, η (m),	Computer C.	1.40	1.65	1.85	1.85	1.85
	F.	Ratio, D/E		0.81	0.76	0.72	0.75	0.77
Central North								
	G.	Wave Height $H_{1/3}$ (m),	Convent. C.	2.70	2.15	1.75	1.46	1.26
	H.	Wave Height $H_{1/3}$ (m),	Computer C.	2.00	1.00	1.00	1.00	1.00
	I.	Ratio, G/H		1.35	2.15	1.75	1.46	1.26
	J.	Set-up, η (m),	Convent. C.	1.08	1.21	1.29	1.32	1.36
	K.	Set-up, η (m),	Computer C.	1.30	1.50	1.55	1.55	1.55
	L.	Ratio, L/K		0.83	0.81	0.83	0.85	0.88

Comparison of Wave Height

Difference of wave height on the reef edge between two methods is 10 % to 35 %. Wave height on the lagoon by conventional method is larger than computed one by 25 % ~ 130 %.

The most significant difference happens on the lagoon 50 meter from the reef edge. By this point, wave height simulated by computer is already settled, however, wave height by conventional method is still active at the deep lagoon, x = 200 m.

Comparison of Wave Set-up

At all the points, wave set-ups by computer are larger by 20 % to 30 % than those by conventional method.

At the North-East zone, computer simulation shows larger figure than conventional data by 40 cm. At the Central North zone, simulated wave set-ups show larger figure than conventional data by 25 cm.

5.4 Consideration to Erosion

This section deals with the general phenomenon of the island's coastal and beach erosion. Most of erosion here is made by wave forces, coastal current and wave run-up. Outline discussion on the material sources will be also carried out.

5.4.1 General Descriptions

The coast section here is geotechnically composed of the following four typical components:

(i) Beach rock consists mainly of coral particles held together by chemical action.
Other than this, there is exposed black coloured base rock which seems to be volcanic material. These rocks will not be eroded and will form a good foundation for supporting any overburden.

(ii) Beach gravel consists mainly of coral fragment and broken pieces of beach rock.
Most of the beach bank deposition belong to this category. It is assumed that strong lift-up wave force during large cyclones cause this piling. Thus, a large cyclone not only causes coastal erosion, but also generates new land as discussed in subsection 5.3.5.
Ground of these coarse particles contain many pores that are partially filled with coral sand. Thus, this layer has a larger permeability and less capability to contain water. It is observed however that these materials can form a high shearing resistance due to friction by each contact and adhesion by the chemical action under a certain pressure.

Beach Rock

Beack Gravel

Beach Sand

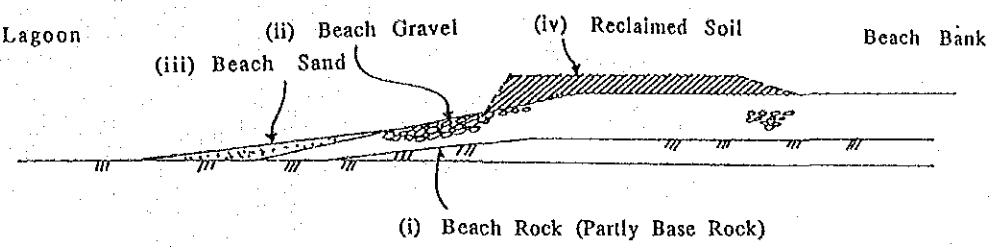
Reclamation

(iii) Beach sand is mixed in and is lying on coral fragments or beach rock. This covering layer has so little resistance to coastal currents that it drift easily downstream. Cyclone waves cause sand to scramble and then drift by lateral littoral currents. Most of the sand consists of Helimeda, a fine fragment of marine life. Groups of this material can form beach rock if they remain in contact for a certain period of time.

(iv) Reclamation soil is ordinary earth reclaimed near the beach top in order to provide more land to improve living conditions. Some areas are reclaimed for space required for public works including the beach road.

Fig 5-12 shows a typical profile of the beach and the foreshore coast bank.

Fig. 5-12 Typical Beach Profile



5.4.2 Possible Erosion in the Island

Erosion may occur to three surface layers: the beach sand layer, the beach gravel layer, and the reclaimed earth layer.

a) Beach sand erosion (hereinafter defined as Beach erosion)

Due to the fineness of the particles of beach sand, it is more sensitive than beach gravel. Moderate coastal current can easily cause it to drift.

Appendix C-3 shows the density and grain-size analysis of beach sediments. According to this survey data, average density is 2.37 gr/cm^3 and average grain-size is 0.54 mm.

b) Beach gravel erosion (hereinafter defined as Coastal erosion)

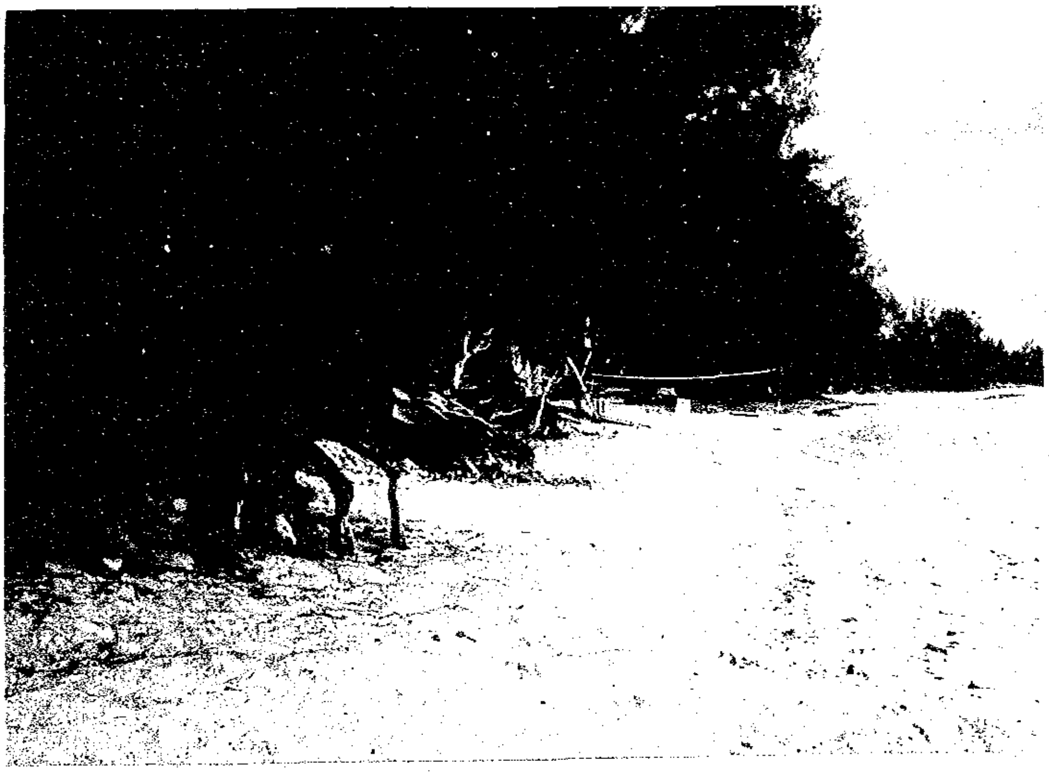
Beach gravel is more stable than sand due to its larger sized particles and the adhesion between each gravel particle. However, gravel may be dumped on the coastal bank, when wave over-topping is large. Over-topping more than four meters may dump gravel by 40 cm radius. This material is more active on coastal disasters.

c) Erosion of Reclaimed Earth (hereinafter defined as Earth erosion)

Relcaimed soil may vary by location. On the island, most of the reclamation earth is ordinary soil having particles that are much finer than sand. Such material if not properly protected by a sealed wall is less able to withstand coastal currents than sand.

Objectives of erosion study here are items a) and b) shown above.

Coconut trees fallen down due to beach erosion at the mouth of Taipara Stream, Avaavaroa District

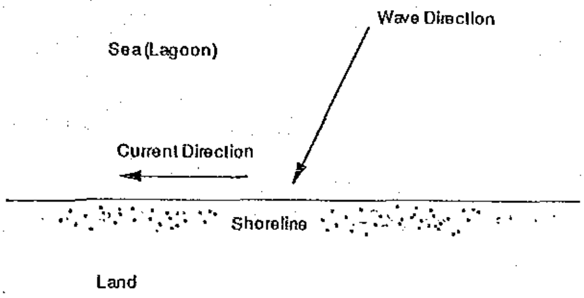


Exposed root of iron trees and narrow beach in front of Sail's Restaurant, Muri Beach

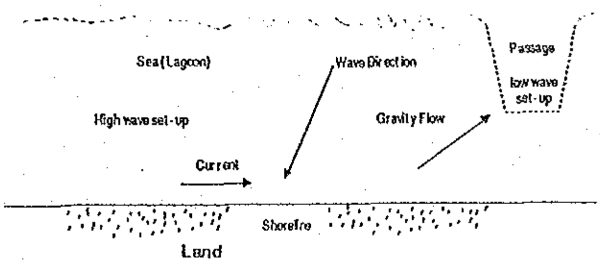
5.4.3 Affect of Cyclone

1) Outline

The drifting of materials may occur when the coastal current intensity become greater than the limit velocity of a particle size. Direction of current depends generally upon the wave direction.



The direction and velecity of coastal current may vary from cyclone to cyclone. In a particular condition, the current direction may be relatively constant depending upon the seabed configuration including the existence of a passage. If Fig. 5-7 is superimposed on Fig. 5-9, it can be seen that current direction is completely independent against the wave direction. This situation may happen when a main momentum of current by wave set-up seeks the shortest gravity flow to the offshore area. This can be also seen at the various passages including Rutaki, Avaavaroa and Ngatangiia.



Under the normal weather conditions, the current force is not enough to cause the drifting of materials. However, a cyclone's large offshore waves may generate large currents in the lagoon where the depth may become much deeper by wave set-up.

2) Change of Coast by Cyclone Scale

Small-scale cyclone, say four meter offshore wave, may cause sand to drift. A medium cyclone with five meter offshore wave, may move gravel. A large one, say six meter offshore wave, may cause gravel to drift and overtop the beach top containing beach gravel and rock. Fig. 5-13 shows typical beach profiles in three cyclone grades.

Fig. 5-14 and 5-15 show the possible progress of beach profiles both for fine particles and coarse particles.

Fig. 5-13 Typical Beach Profile During Cyclone

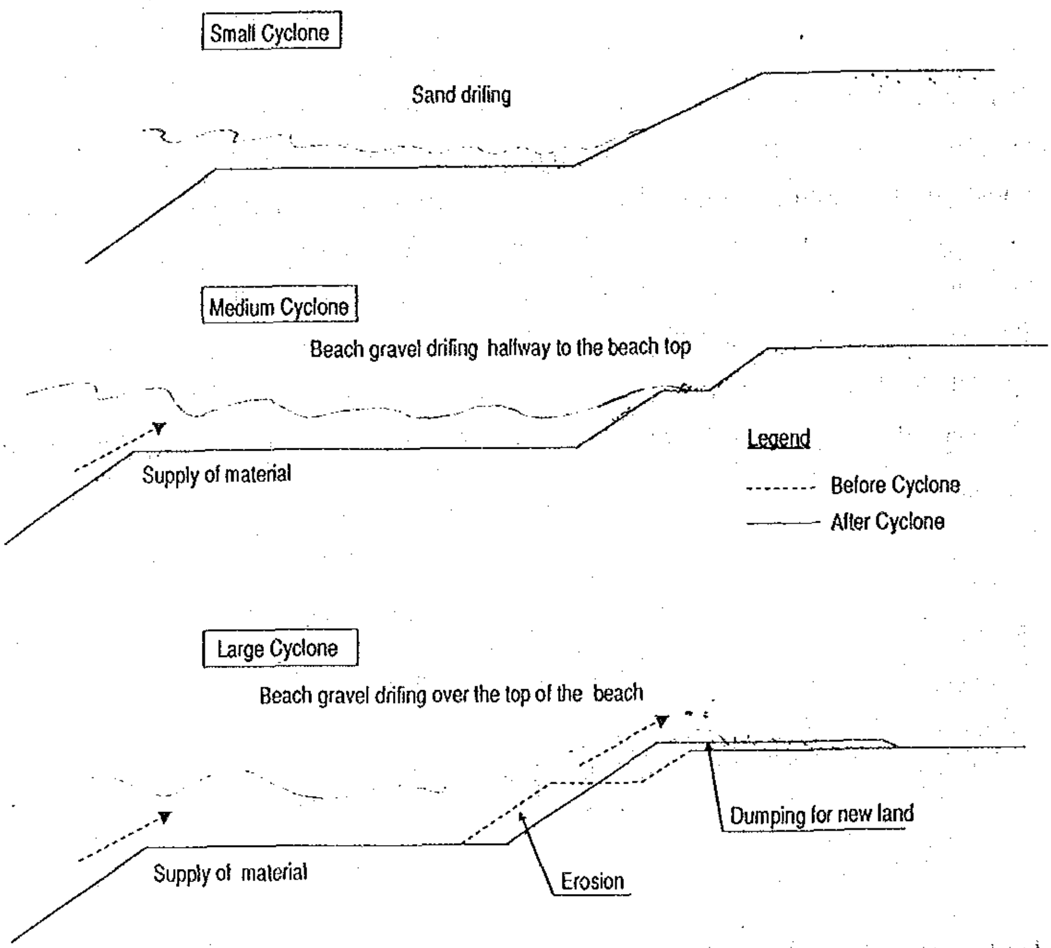
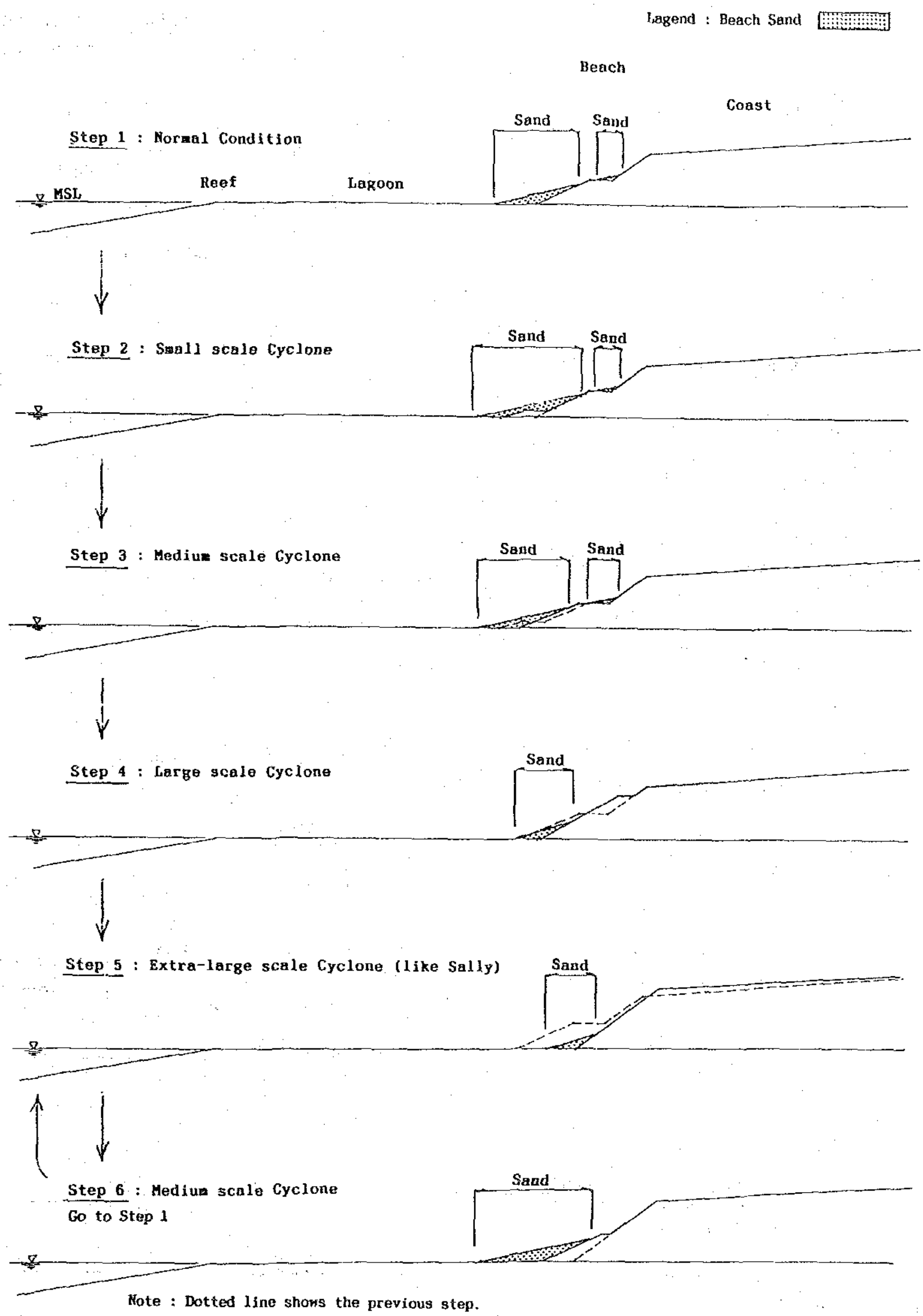


Fig. 5-14 Progress of Beach Profile (Fine Particles)



Note : Dotted line shows the previous step.

Fig. 5-15 Progress of Beach Profile (Coarse Particles)