7.6.2 General Layout at Avarua - Ruatonga - Avatiu Coast

The urbanized coastal area most affected by Cyclone Sally is Avarua - Ruatonga - Avatiu Coast (hereinafter called as Avarua Coast). When the study team made its first visit to the island Oct. 1991, discussions concerning the general layout of coastal protection work for this particular area were held.

At the first meeting, the study team was about to discuss the plan prepared by MOW (Fig. 7-15A), however it was found that plan had not yet been authorized by the government. Thus, discussions about layout should commence from the beginning. The study team prepared alternative layouts for discussion purposes. Thus, this subsection deals with discussions about the general layout of Avarua coast and technical study to finalize the layout.

It is assumed that Avatiu Harbour should be utilized continuously after necessary improvements are made. Thus, the discussions concentrated on the layout plan at the Avarua coast around Avarua Harbour.

1) Background Requirements

General requirements for preparation of Avarua Coast General Layout are as follows:

(i) In respect to 700 m coastline between two harbours

- Most durable and sound protection works should be provided.
- To provide on-land buffer zone, as required
- Additional public area should be prepared since land for road, park and carparking is in short.
- Flat land of 1.5 ha should be prepared for the future Avarua Harbour extension.
- Scenery should be maintained.

(ii) Avatiu Harbour

- Function of this port is commercial port and fisheries.
- Priority should be given to Avatiu Harbour comparing to Avarua.
- East breakwater extension by 150 m should be considered.

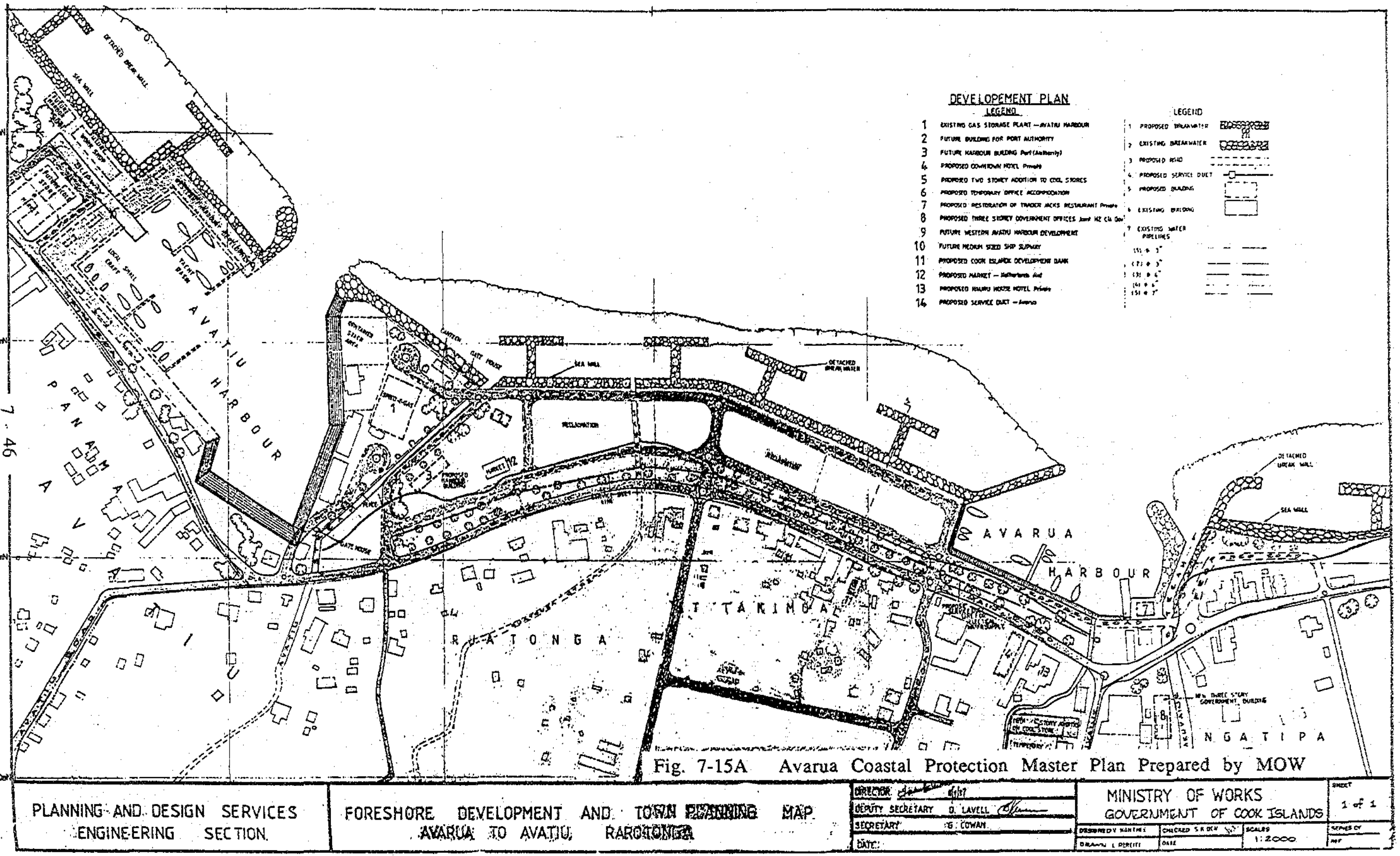


Fig. 7-15A Avarua Coastal Protection Master Plan Prepared by MOW

(iii) Avarua Harbour

- Function of this port is tourism oriented port like a marina. Wharf of MSL-2.5 m depth and 380 m long will be constructed for 60 boats.
- Workable rate should be more than 90 % through the year.
- East breakwater extension should be considered.
- Better scenery should be maintained.
- In the Short-term Plan, development should be only minor improvement.

(iv) Avarua Harbour East

- Damage at coastal area behind the East breakwater should be mitigated.
- Back water of Takuvaine Stream should be minimized.

(v) Common Condition

- Wave by Sally will be the design wave for structure stability and wave over-topping.
- General layout should harmonized with the MOW's efforts in the Avarua coast.

2) Merits and Demerits of Breakwater

Among the background requirements, most of important aspect is merits and demerits of breakwater in respect to coastal protection.

Merits

Wave forces will be reduced by breakwater and more wave calmness can attain along the shoreline than exposed condition. There is no doubt about this.

Demerits

One of committee members adhered to insist that the existing Avarua breakwater increased dangerous situation to coastal protection as follows:

(i) In the Avarua coast of 500 m long bounded on two existing breakwaters Avatiu and Avarua, cyclone wave setup would increase dramatically comparing to no breakwater provision. Thus safety coast during the cyclone could be achieved if the existing breakwaters were scrapped.

(ii) Wave intensity in the Avarua passage would increase, since the breakwaters would reduce the return current to the passage. Thus, incoming wave height to the passage would decrease if the existing breakwaters are taken out.

The study team provided the committee member with an explanation as follows:

(i) Although the Avatiu East breakwater is minimal, it protects well the port.

(ii) It provides cargo handling operation and passenger's use with safety condition.

(iii) The East Avatiu breakwater should be expanded rather than present one for more safety operation.

Addition to these, an explanation was given that demerits of breakwater might be exaggerated.

(i) It is assumed that wave setup within lagoon 100 m shoreline from reef would not increase anymore since the wave breaking finished.

(ii) The return current might flow along the seaward face of breakwater and dived into the lagoon. This current might crash into intruded waves in lagoon and decreased the wave height.

Note: Immediately after the first visit to the island, a serial computer simulation study was conducted by the study team in order to clarify the questions. Results are shown in subsections 5.3.7 and 7.6.3. Answers on the questions are as follows:

(i) The wave breaking zone terminated at the point of lagoon 50 m landward from the reef edge. Wave setup afterward was less than 0.1 m which was negligible minor than a total wave setup of 1.6 m.

(ii) There is no significant charge on the height of wave intruding into the lagoon between with/without breakwaters.

By these clear evidences, it was found that it was simply conjecture that the existing Avarua Breakwater might amplify the coastal damage.

3) Defense Line Alternative between two Harbours (Double Breakwater in Avarua)

This is a conservative layout which consists of land reclamation with the seawall and the harbour protected by two breakwaters. In this layout, there are three alterniative seawall facelines, "A" "B" and "C".

Line "A"	Reclamation width in 40 meters,	Remaining lagoon 180 m
Line "B"	Reclamation width in 80 meters,	Remaining lagoon 140 m
Line "C"	Reclamation width in 120 meters,	Remaining lagoon 100 m

Average lagoon width at this coast is about 220 m long. Line "C" was drawn at the middle of Avarua lagoon. Thus, remaining lagoon by Line "C" is 100 m long which is considered the minimum lagoon width after land reclamation. This limitation aims also at prevention of the seawall from the large wave attack.

Note: As seen in Fig. 5-8A, wave height on the lagoon except seaward 50 m is only one meter when Sally wave comes.

Line "A"

This normal line is similar to the seawall line constructed by MOW in 1991/1992. However the both end of the line is drawn to join smoothly to the existing breakwaters. This arrangement aims at provision of smooth current to the passage. However, there is limited land expansion for public use.

Line "B"

This defense line is drawn seaward Line "A" by 50 m. Both ends of line connect with corner of breakwaters of two ports. A new land by 2 Ha will be gained comparing to the Line "A".

Line "C"

This line was planned to put further seaward by 40 m. Thus, this arrangement maintains the minimum free lagoon of 100 m. An additional new land against the line "B" is 2.4Ha.

Advantages of these three defense lines are:

i. New land can be gained for various public uses.

ii. Among them, strip land along the new seawall will be buffer zone against wave over-topping during a cyclone.

Disadvantages are:

i. These arrangement make remaining lagoon width narrow, thus, wave over-topping will increase.

ii. If the seawall top height rises by reason above, natural scenery may be disturbed.

Questions are:

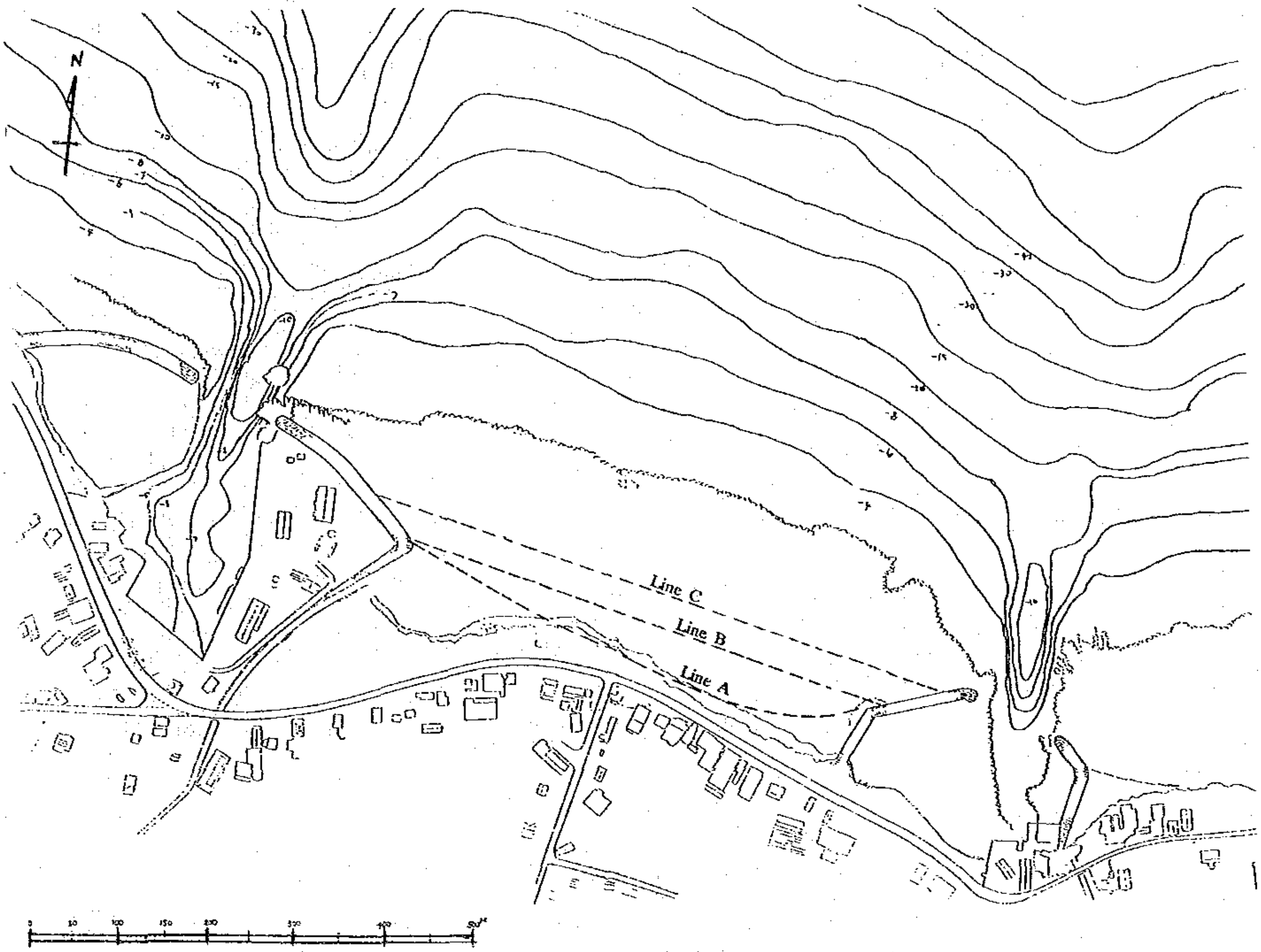
i. Will wave setup increase if the defense line gets into the existing lagoon?

ii. Are there any specific spacies to be preserved here?

iii. Will the number of tourists visiting the island decrease by these defence lines?

Discussions on these matters were carried out between the Committee and the study team. Some member suggested that the Line "B" was reasonable, however final conclusion in the first meeting was postponed for further study.

Fig. 7-15B Defense Line Alternative
(Avarua Harbour protection by two breakwaters)



Note: Both eastern breakwaters in Avarua and Avatiu Harbours will be extended further seaward.

4) Experimental Alternatives (Single Breakwater in Avarua)

These are experimental layouts which were presented to the Committee at the end of first visit. They consist of three alternative layouts. All the layouts include radical concepts, namely: no Avarua Eastern breakwater. These layouts are shown in Fig. 7-15C.

It seems that concept of no Avarua eastern breakwater based on the assumption as follows.

i) No yacht currently visits the island during the cyclone season. Same situation will continue for future. There is no user of marina in the cyclone season. Thus, no breakwater against the cyclone is required.

ii) The Avarua eastern breakwater may accelerate wave setup at the Avarua East coast.

Note: This seems just a conjecture and must be tested by the technical study.

Characteristics of these alternative plans are as follows:

Experimental Plan A

This is similar layout with the defense line alternative, Line "A", except for the removal of the Avarua East breakwater.

Experimental Plan B

This layout is similar to the defense line alternative, Line "B", except for the removal of the Avarua East breakwater.

Experimental Plan C

This consists of a short detached breakwater with an artificial channel running in front of the reclaimed beach front. The width of the reclamation is about 50 meters. This plan expects lowering wave set-up by the provision of a 70 meter wide 700 meter long channel having a depth of 3 meters.

Advantages of Plan C are:

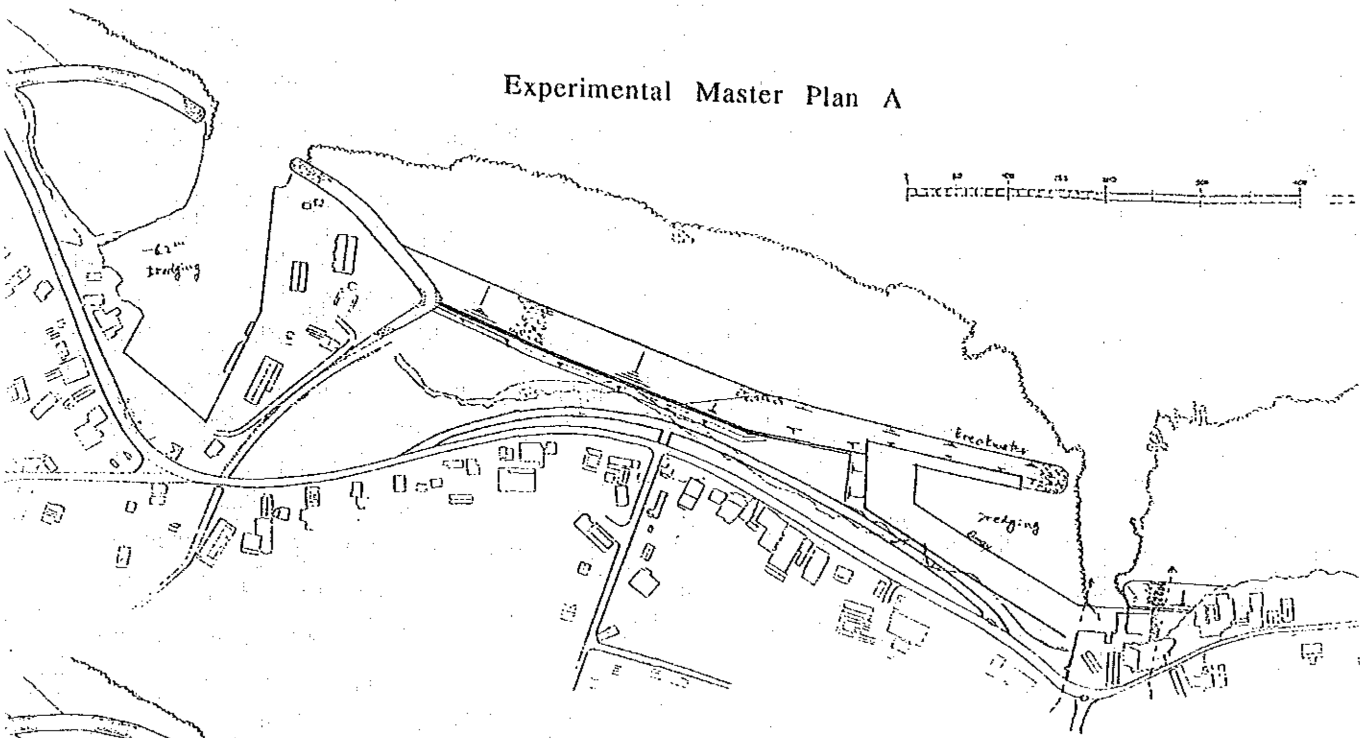
i. Active water circulation in the lagoon may improve marine environment there.

ii. Scenery is better than for plan A and plan B

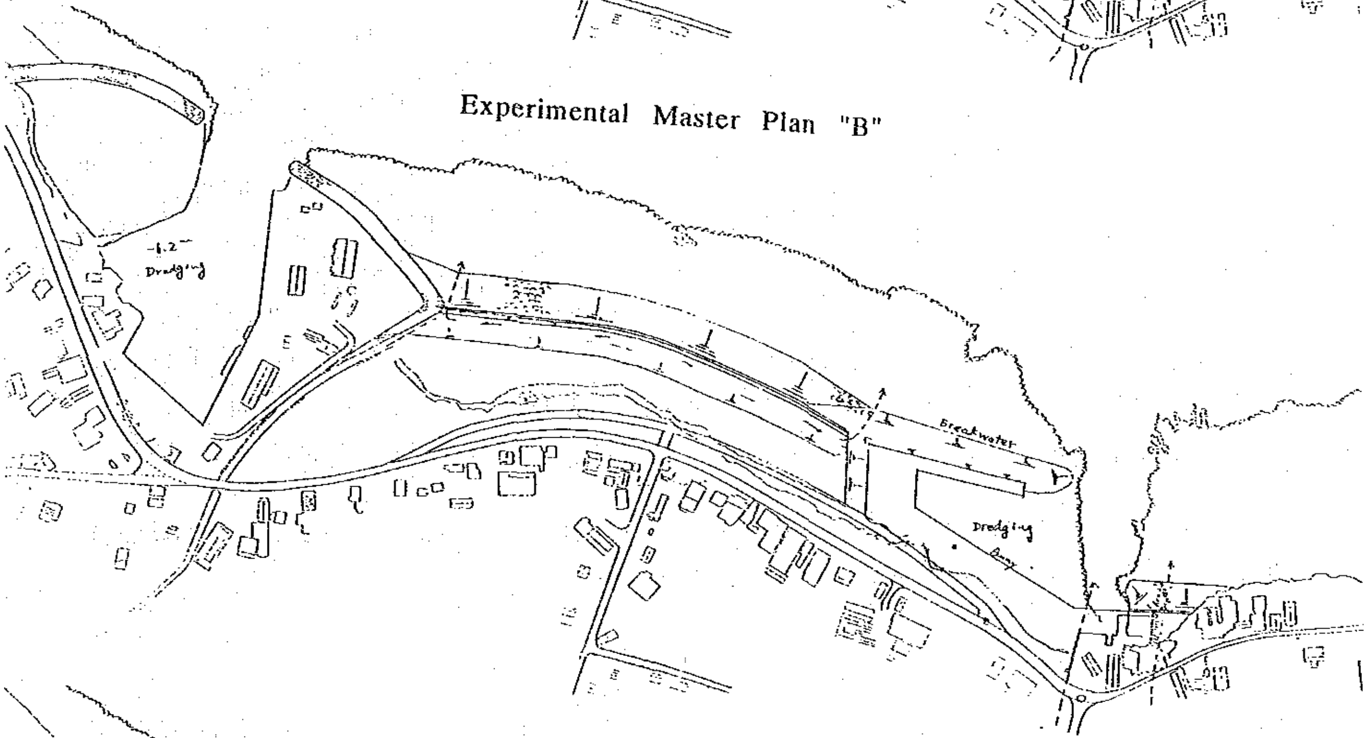
iii. The excess water basin in the channel may be utilized by small boats and pleasure boats.

Fig. 7-15C Experimental Master Plans (Single Breakwater in Avarua)

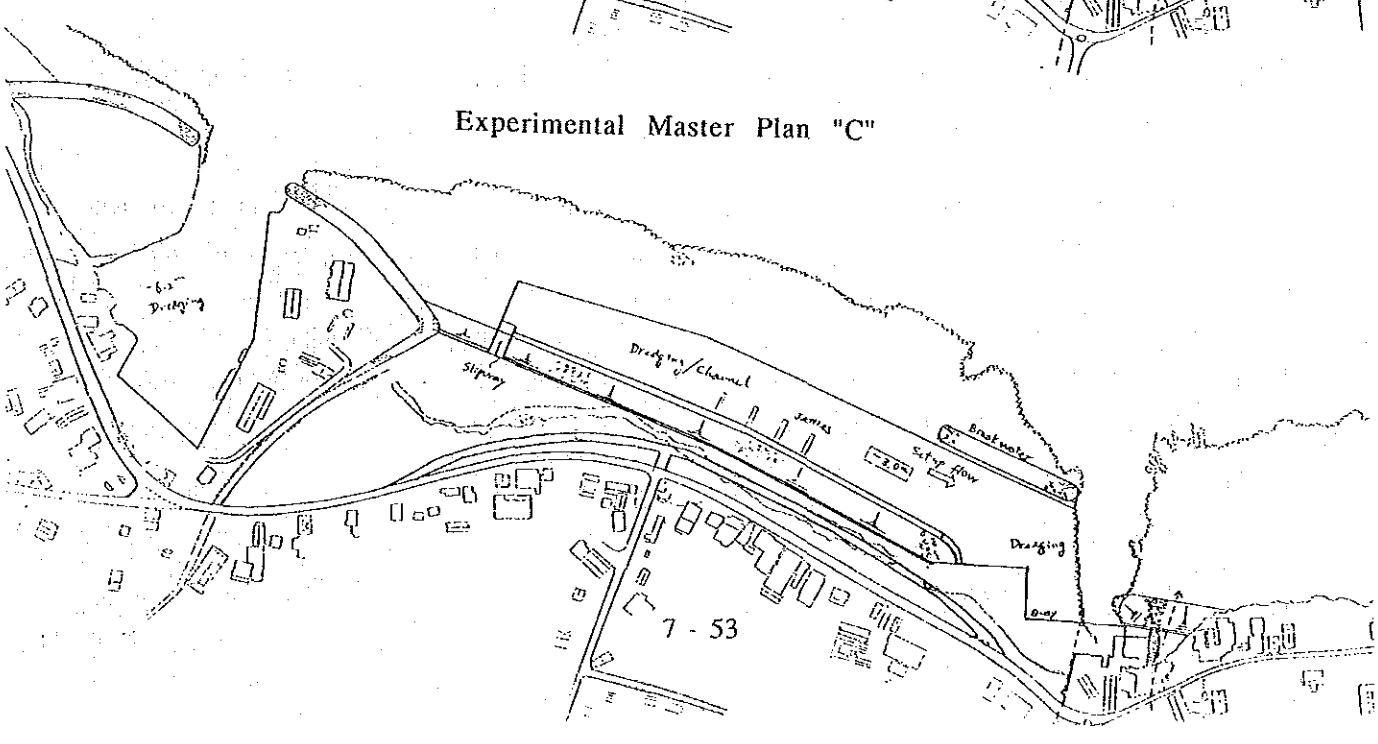
Experimental Master Plan A



Experimental Master Plan "B"



Experimental Master Plan "C"



Questions:

i. Are there any specific spacies to be preserved in the Avarua lagoon?

ii. Will the artificial channel make radical improvements in wave set-up?

iii. Can the channel depth be maintained from sedimentation of particles/coral sand and fragment, which may be transported by littoral current during cyclone ?

If siltation occurs, and the channel depth becomes shallower, then no more channel.

The Experimental Plan C has basically been supported by government officers, subject to an exact effect of an artificial channel in lowering wave set-up. However an idea of artificial channel should go over various barriers including:

i. Estimated construction cost of an artificial channel in the Plan "C" is about 9 Million Dollars in 1992 price.

$$150{,}000 \text{ m}^3 \times 60 \text{ \$/m}^3 = 9{,}000{,}000 \text{ Dollars}$$

Maintenance dredging cost should be added each year.

ii. Even if the channel could lower the wave setup, the channel filled by coral sand and fragment is nothing. Filled channel may give risks to villagers who would think that the channel provides safety.

iii. Most hard barrier is technical justification to prove an artificial channel works as a natural passage does.

Further more, demerits of Plans A, B and C are as follows:

i. Due to removal of the Avarua eastern breakwater, the Avarua Marina can not be protected against cyclone.

ii. Due to removal of the Avarua eastern breakwater, wave calmness of the Avarua Marina can not be assured even during the no cyclone season. It should be reminded that prevailing wave direction is East.

iii. These mean that the Avarua Marina is not suitable not only for tourism use but also any other use.

5) Summary of Master Plan Discussion

Conclusion of previous discussions are as follows:

i. Breakwater

It is concluded that Avarua Harbour should be protected by double breakwaters in order to provide safety service to Marina users. Marina will contribute to tourism industries here. Chapter 8 will provide more explanation on this matter.

ii. Wave setup

Effect of land reclamation on the lagoon against wave setup should be tested technically. Effect of an artificial channel on the lagoon to lowering wave setup should also be tested.

iii. Intrude wave into the passage

Effect of breakwater against neutralizing intrude wave into the passage should be tested.

Thus Plans A, B and C can not be adopted since conclusion (i) above. However technical study on Plan C is conducted for technical knowledge.

The next subsection discusses the computer model simulation on the two selected layouts.

7.6.3 Modelling of Coastal Protection at the Avarua Coast

1) Outline of Modelling

The purpose of the study is to find out characteristics of hydrological knowledge in different type of countermeasures in the lagoon. Computer analysis was employed for this study. Computer simulation may not show every phenomenon; however, it may suggest basic hydrological figures during cyclones with required accuracy.

The simulation model was developed by Professor M. Isobe of Tokyo University. Programing of the computer model was carried out by Pacific Consultants International, PCI, which is the leading consultant of study team. It shows the physical planners the possible phenomena of:

i) Wave direction
ii) Wave height
iii) Current vector, (speed and direction) and
iv) Wave set-up

Because of its complexity, this type of study is a must.

The simulation study has been conducted for the following two protection alternatives:

Case 1 :	Conservative Layout, Fig. 7-16a
	Similar to the Defense Line Alternative, Line C

Case 2 :	Experimental Layout Fig. 7-16b
	Similar to the Experimental Master Plan "C"

Similar to subsection 5.3.7, a computer simulation study was conducted for various coastal phenomenon at coastal area of 1,500 m between the center of Avatiu Harbour and Village Ngatipa. The purpose of study was to simulate the most dangerous instance to these two alternatives when Sally came.

Input data for simulation

a) Wave

8.1 meter of 12.5 sec period as the maximum significant offshore wave by Sally is given at deep sea of 150 m depth.

b) Water depth

c) Seabed configuration

d) Water level (basic water level before the wave set-up)

MSL +0.70 m considering tidal level and air depression.

The simulation was conducted at the consultant's headoffice in Tokyo, the beginning of January, 1992. The grid of calculation was 50 meters. Thus, it is the seabed configuration that should be inputted accordingly. The existing beach line is smooth, however, it is shown as a zigzag line in the outut figure due to this reason. Outputs of the four items shown above can be obtained at each grid. The highlights are the wave set-up and current vector (current speed and direction).

In order to examine the difference of these various phenomena by general arrangements, two alternative countermeasure layouts were prepared (Case 1 and Case 2) as discussed.

Case 1 is the conservative protection work consisting of:

(i) Reclamation work for the 120 meter for future land use and buffer zone

(ii) Seawall of rock mound type in 1 : 3.5 slope.

(iii) Avarua Harbour to be protected by two breakwaters (West and East)

In contrary to Case 1, Case 2 is an experimental protection work consisting of:

(i) Reclamation works for the 50 meter buffer zone

(ii) Seawall as ame with Case 1.

(iii) Avarua Harbour will be an open harbour protected by only one detached breakwater in the West

(iv) Artificial channel in front of the seawall, 700 m x 70 m x 3 m

The former is a plan combined with established methods that provides firm and stable protection to the existing on-land property. While the latter is a provisional plan with an artificial channel aiming at testing the possible effect of channel.

Fig. 7-16a Alternative Case 1: Conservative Layout

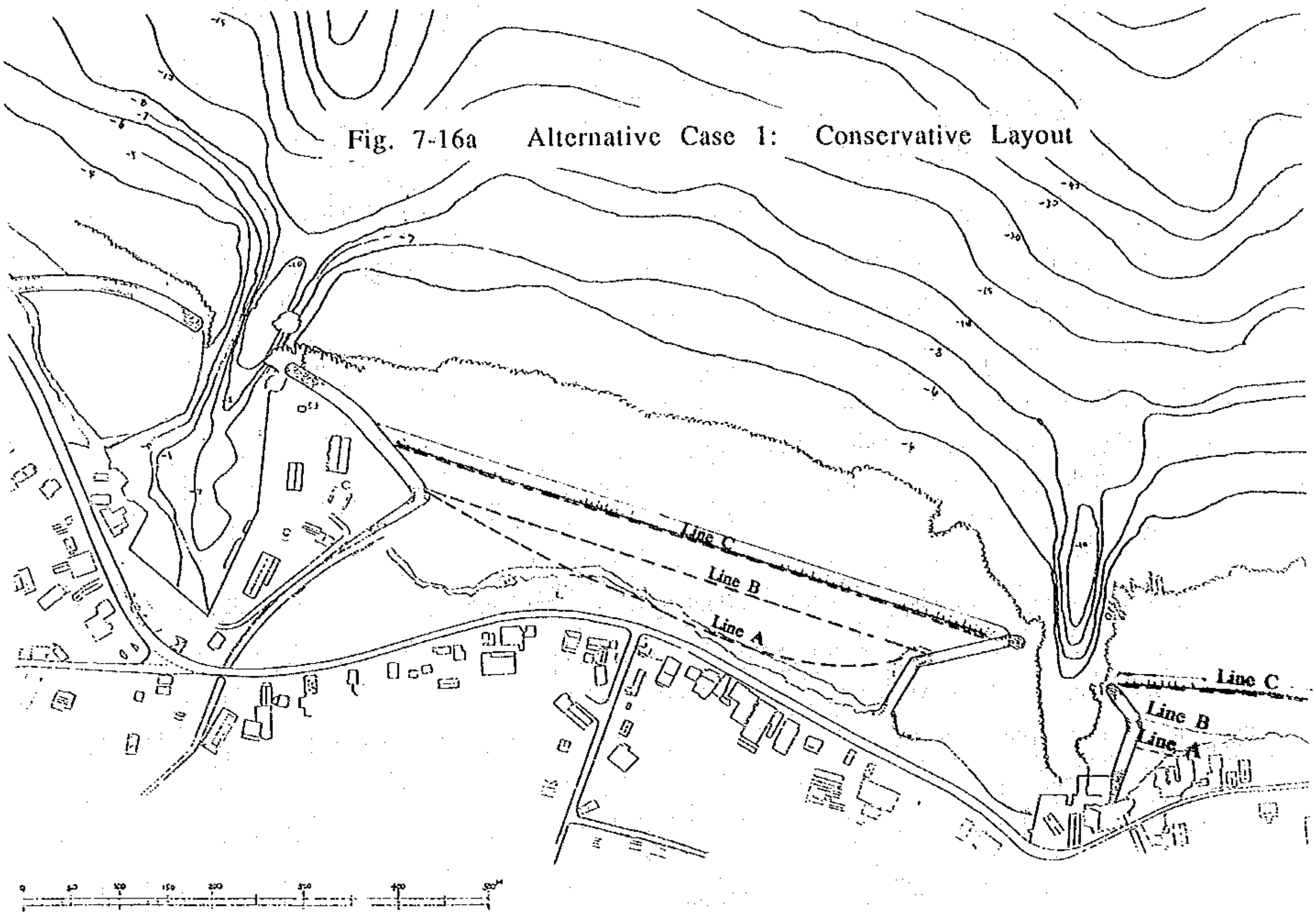
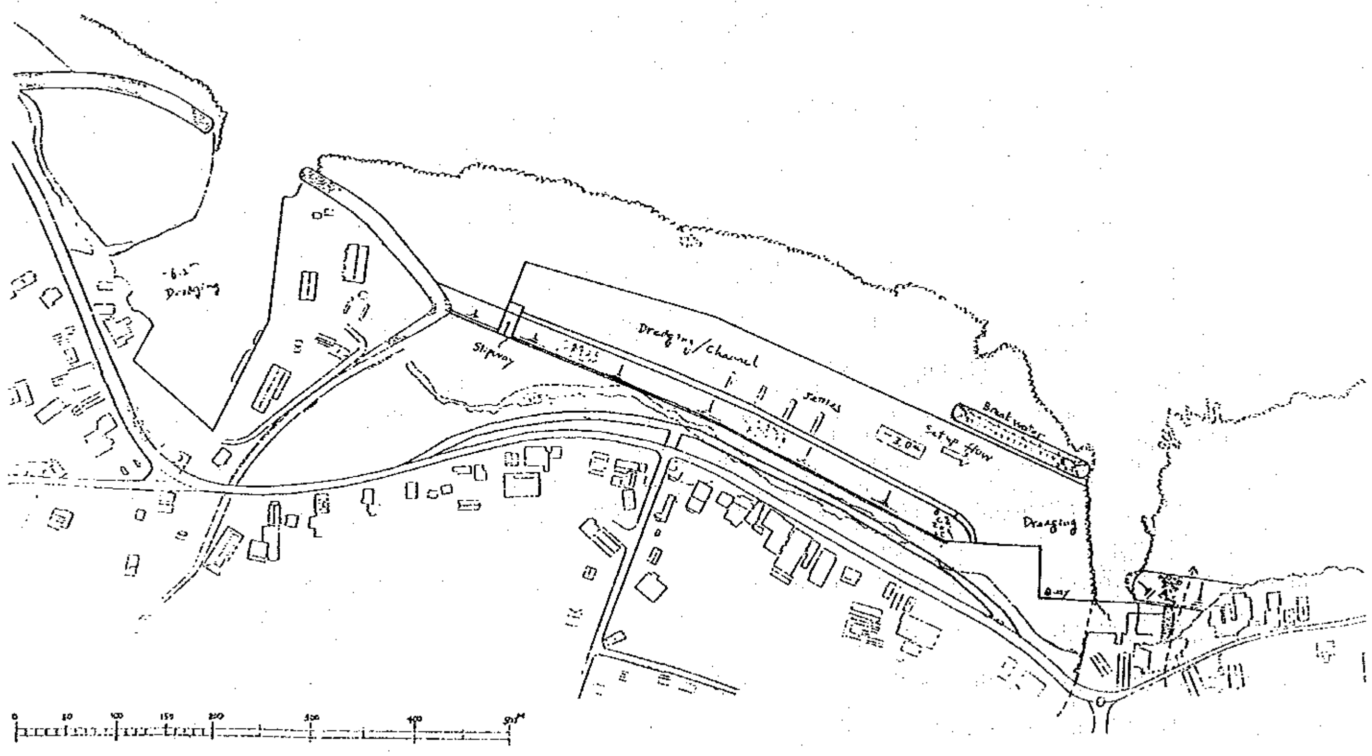


Fig. 7-16b Alternative Case 2: Experimental Layout

Artificial channel



2) Results of Simulation

The evaluation of simulation studies is as follows:

Wave Directions; Figs 7-16c and Fig. 7-17

Waves gradually change their directions after the beginning of wave breaking zone at -15 meter and they arrive almost perpendicular to the beachline. There are minor changes around the breakwaters. There are no significant differences between two cases.

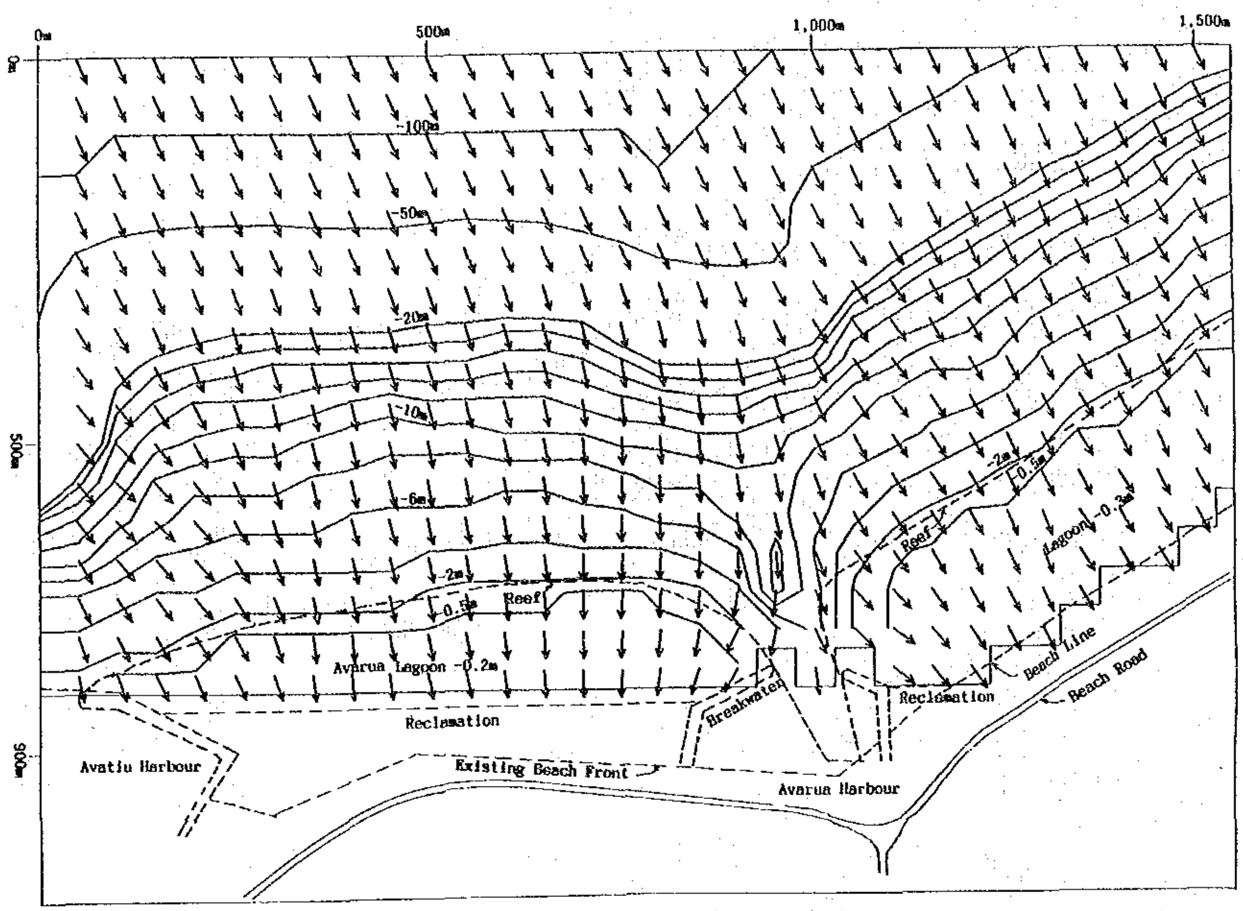


Fig. 7-16c Wave & Current Simulation (Case: 1 Conservative)
Water Depth vs. Wave Direction

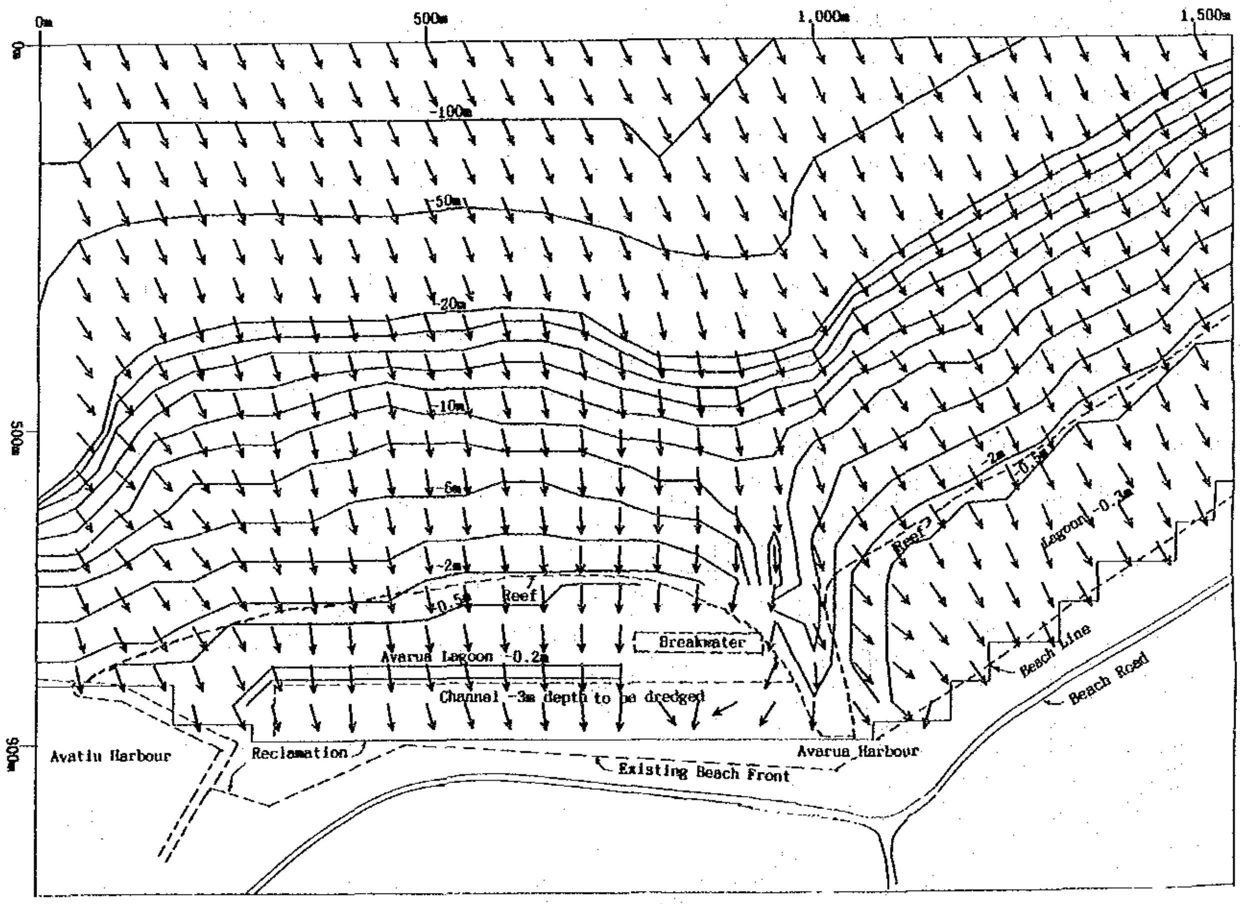


Fig. 7-17 Wave & Current Simulation (Case: 2 Experimental)
Water Depth vs. Wave Direction

Wave Height; Figs. 7-18 and 7-19

An offshore wave starts breaking at about -15 meter depth, then, the height decreases gradually. When it arrives at the reef, the wave height is reduced to an intensity of two or three meters which is one third of its origin offshore. Within 50 m after reef, wave height becomes one meter then maintains same till the shore line.

In the lagoon, there are generally no significant changes in both cases. Advance of reclamation in 70 meter in Case 1 does not affect the wave height. The existence of two breakwaters in Case 1 does not affect the wave height at the lagoon.

Larger waves seem to penetrate deeply into the passage in Case 2. However, the breakwater in Case 1 will protect the passage end.

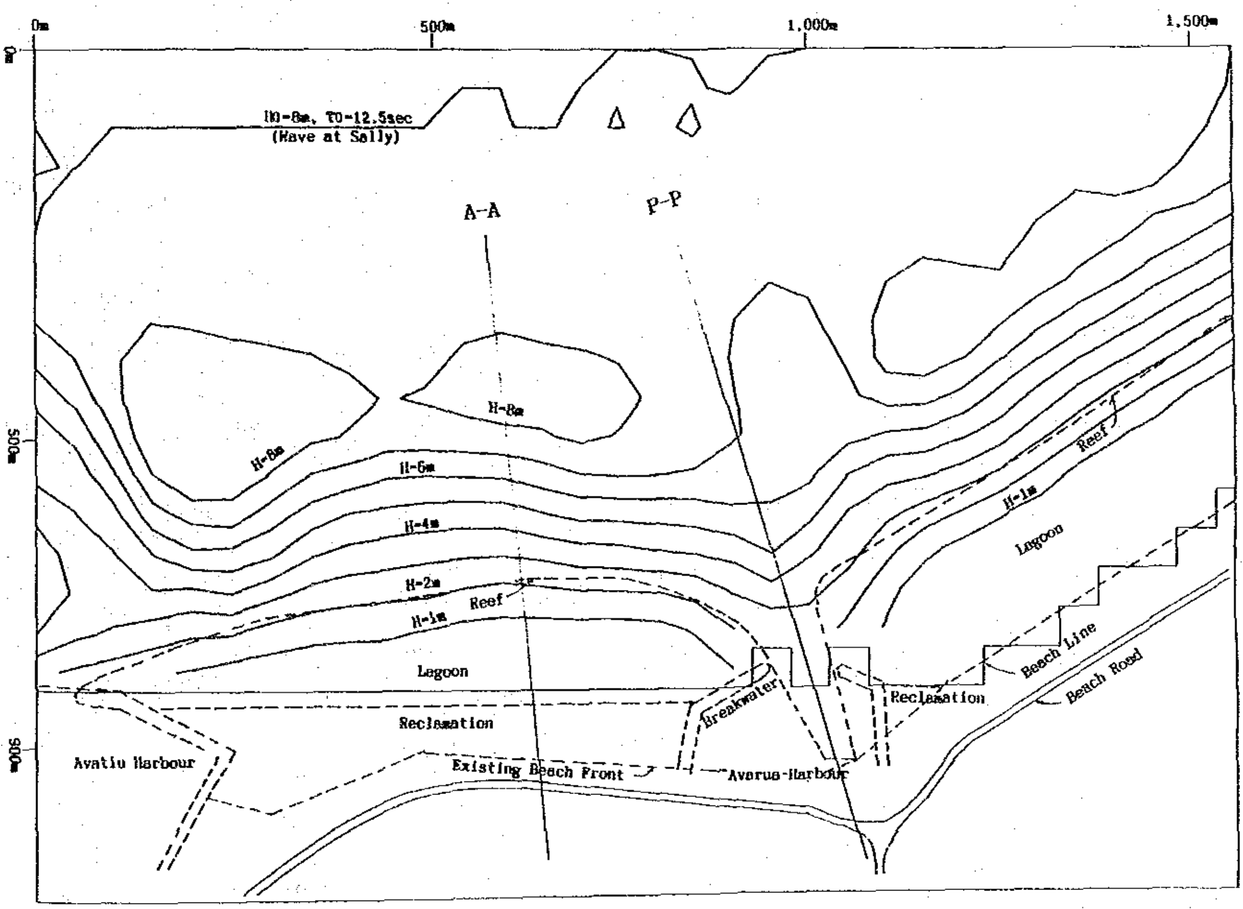


Fig. 7-18 Wave & Current Simulations (Case: 1 Conservative)
Wave Height

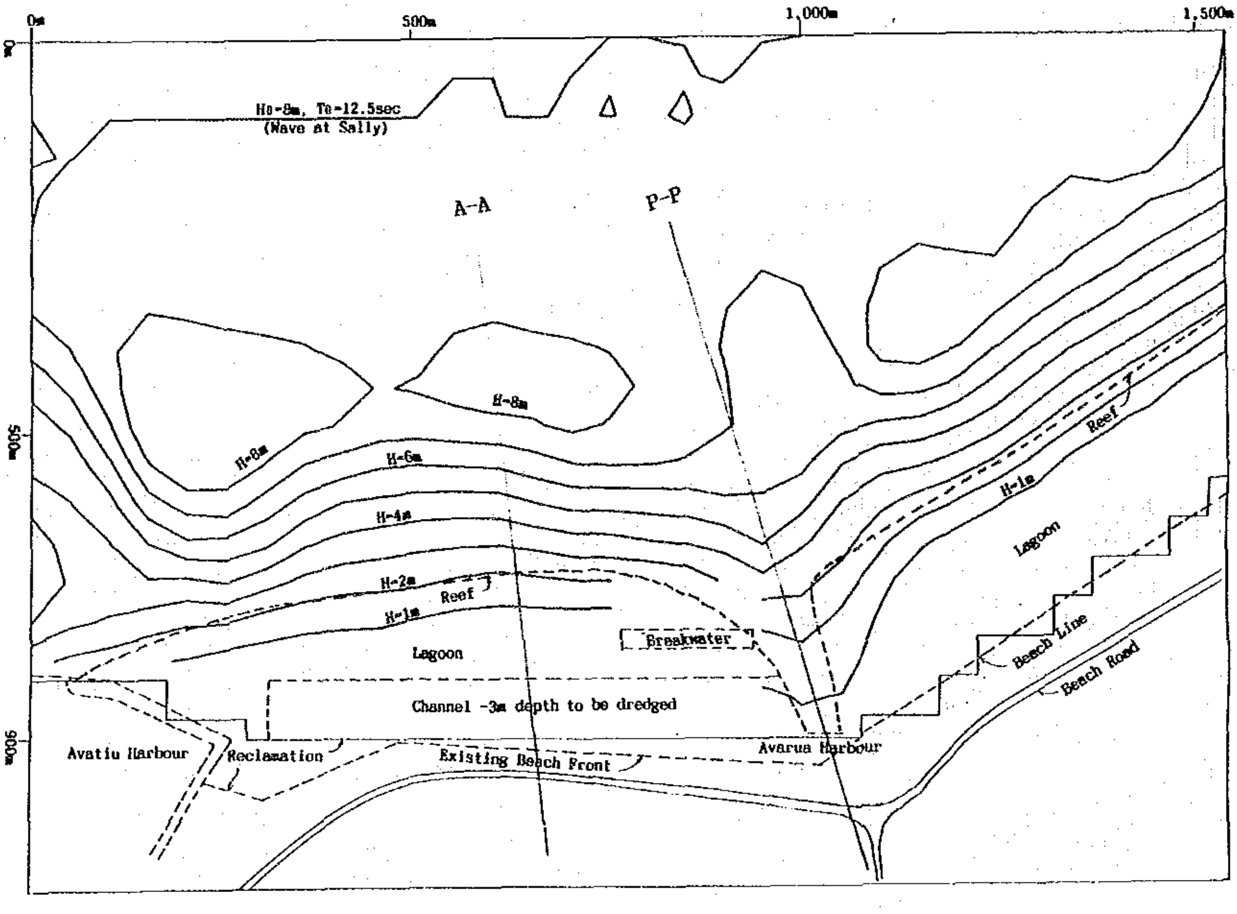


Fig. 7-19 Wave & Current Simulation (Case: 2 Experimental)
Wave Height

Wave height on the lagoon (section A-A) for both cases are very similar. Fig. 7-19A shows wave height comparison between two cases on the Avarua passage. Difference is minor, thus the proposed double breakwater arrangement will not raise the wave height.

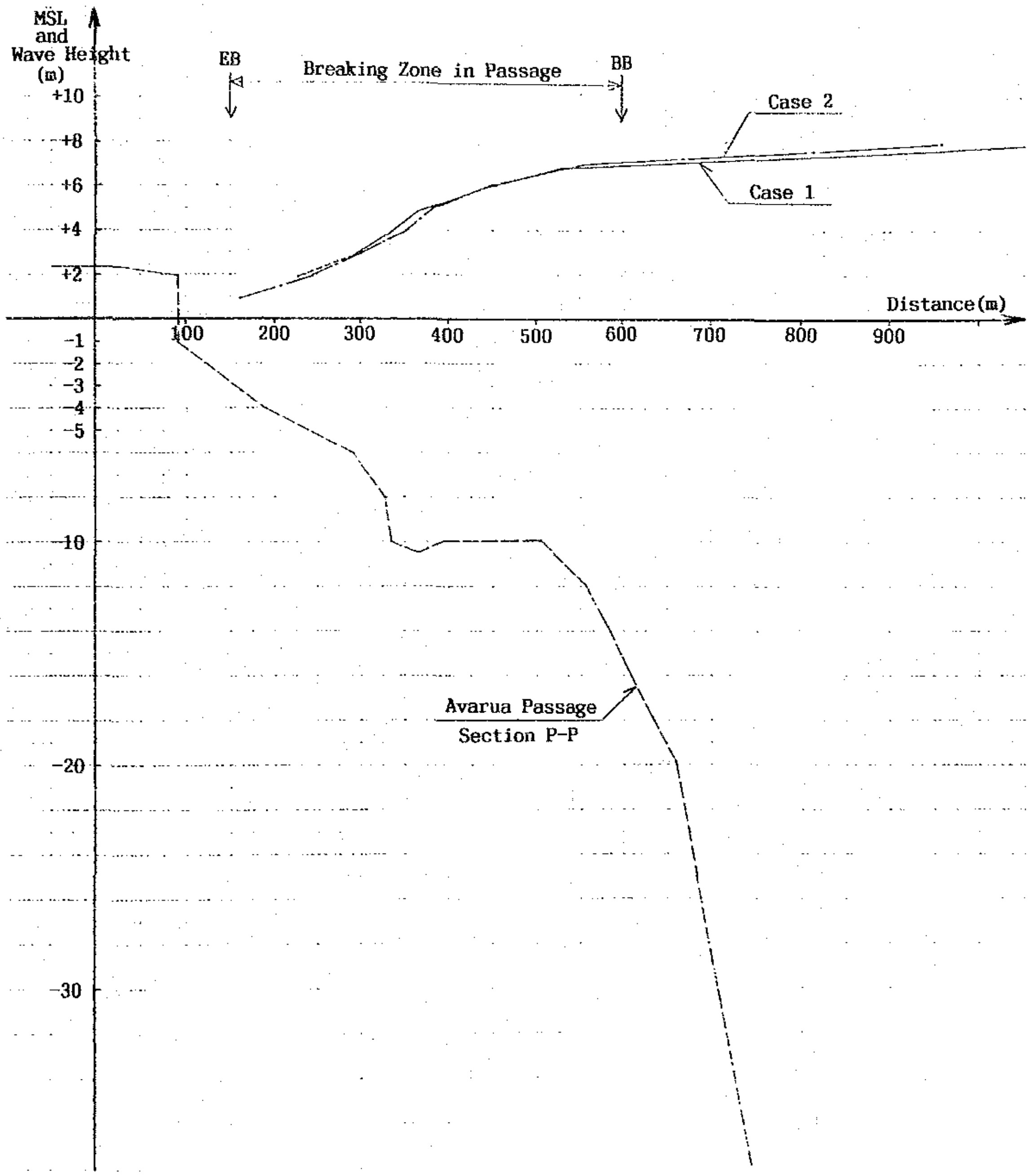


Fig. 7-19A Wave Height Comparison
Case-1 and Case-2

Comparison of wave height between Case-1 and Sally reappeared (Fig. 5-8A) was carried out. As seen is figure below, there is no difference. This means that wave height will not increase by land reclamation of 120 m width.

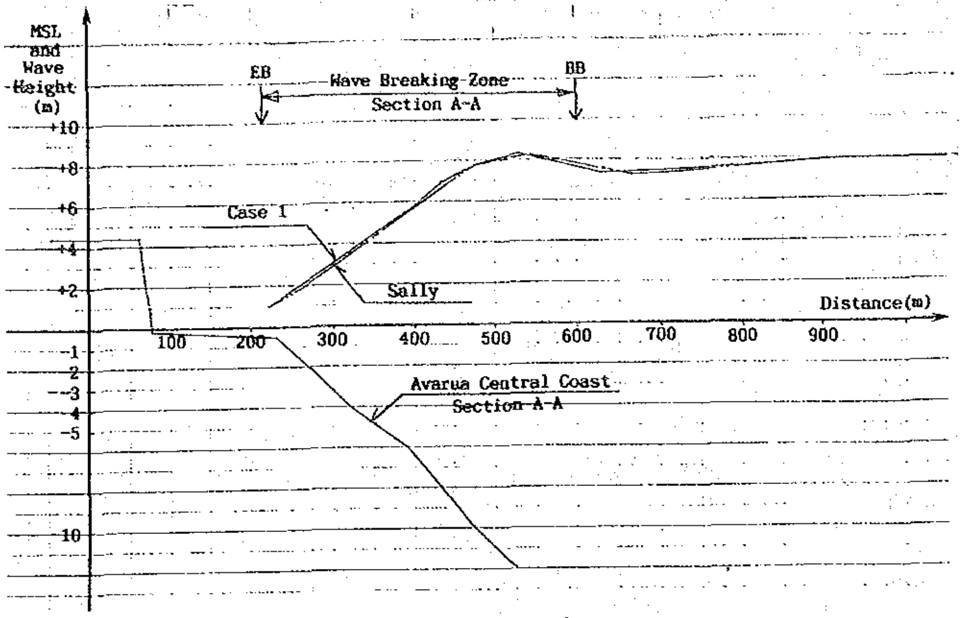


Fig. 7-19B Wave Height Comparison, Case-1 and Sally Reappeared

Similarly to above, comparison of wave height between Case-2 and Sally reappeared was conducted. As seen in figure below, there is no difference. This means that an artificial channel has no effect to lower wave height.

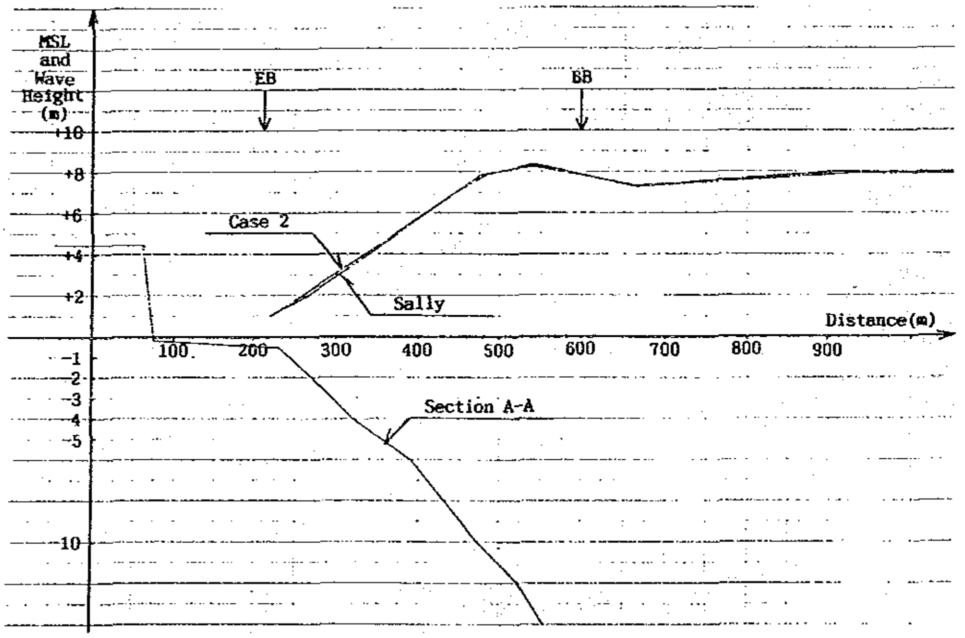


Fig. 7-19C Wave Height Comparison, Case-2 and Sally Reappeared

Current Vector; Figs 7-20 and 7-21

Current appears -15 meter line where the wave starts to break. On the lagoon, currents flow parallel to the beachline. All of the currents go to the passage where they return to the offshore. The maximum speed is about 1.5 meter per second (three knots) in the passage.
These are similar to the current pattern in the Sally reappeared.

In the Case-1, current along the seawall of reclaimed land hits the breakwater then dives into the Avarua Passage. At the head of both breakwaters, two flows, from the East and the West, join and return to the offshore.

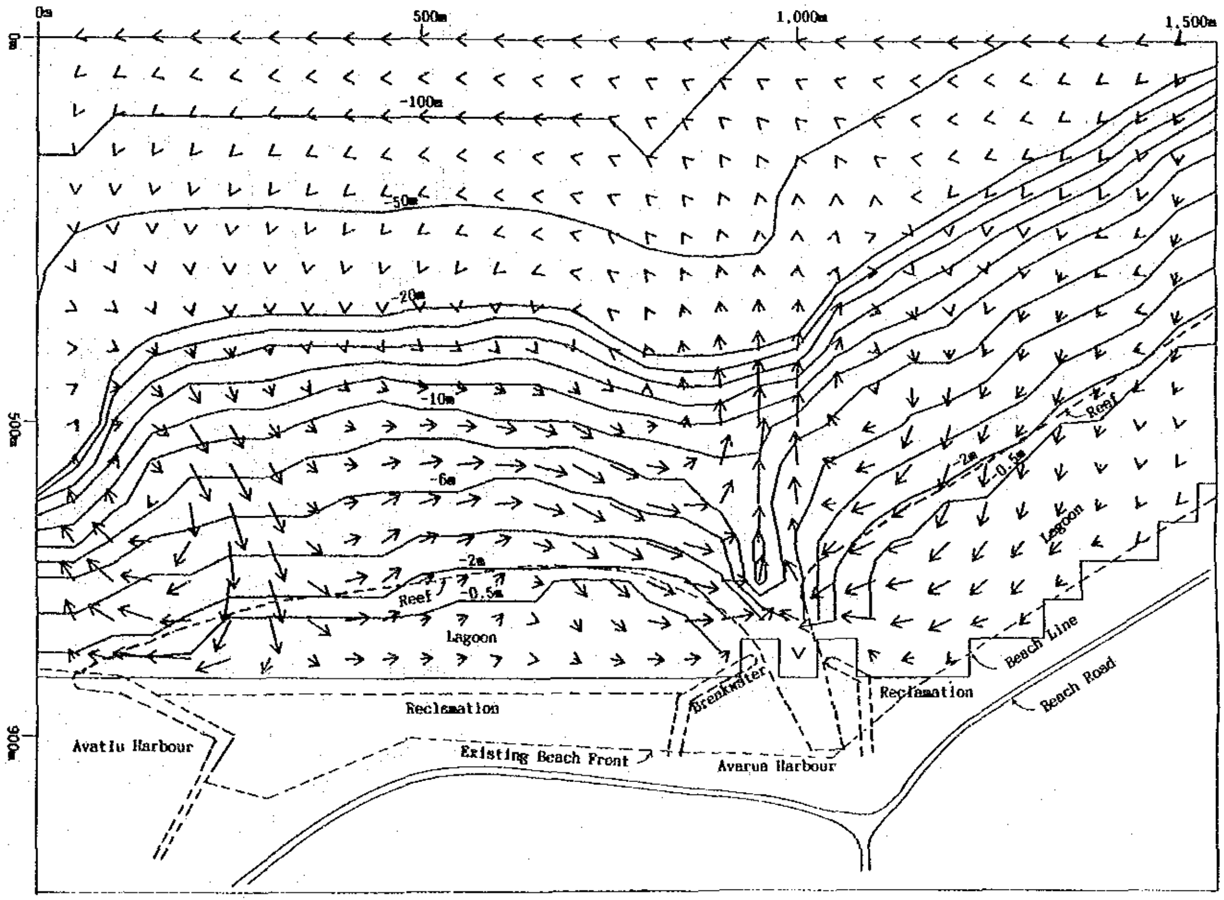


Fig. 7-20 Wave & Current Simulation (Case: 1 Experimental)
Wave Depth vs. Current Vector
→ 1m/sec.

In the Case-2, it can be seen that current gose to the end of Avarua Passage. Then two currents join and turn their heads to the offshore. This pattern is similar to the current of Sally reappeared.

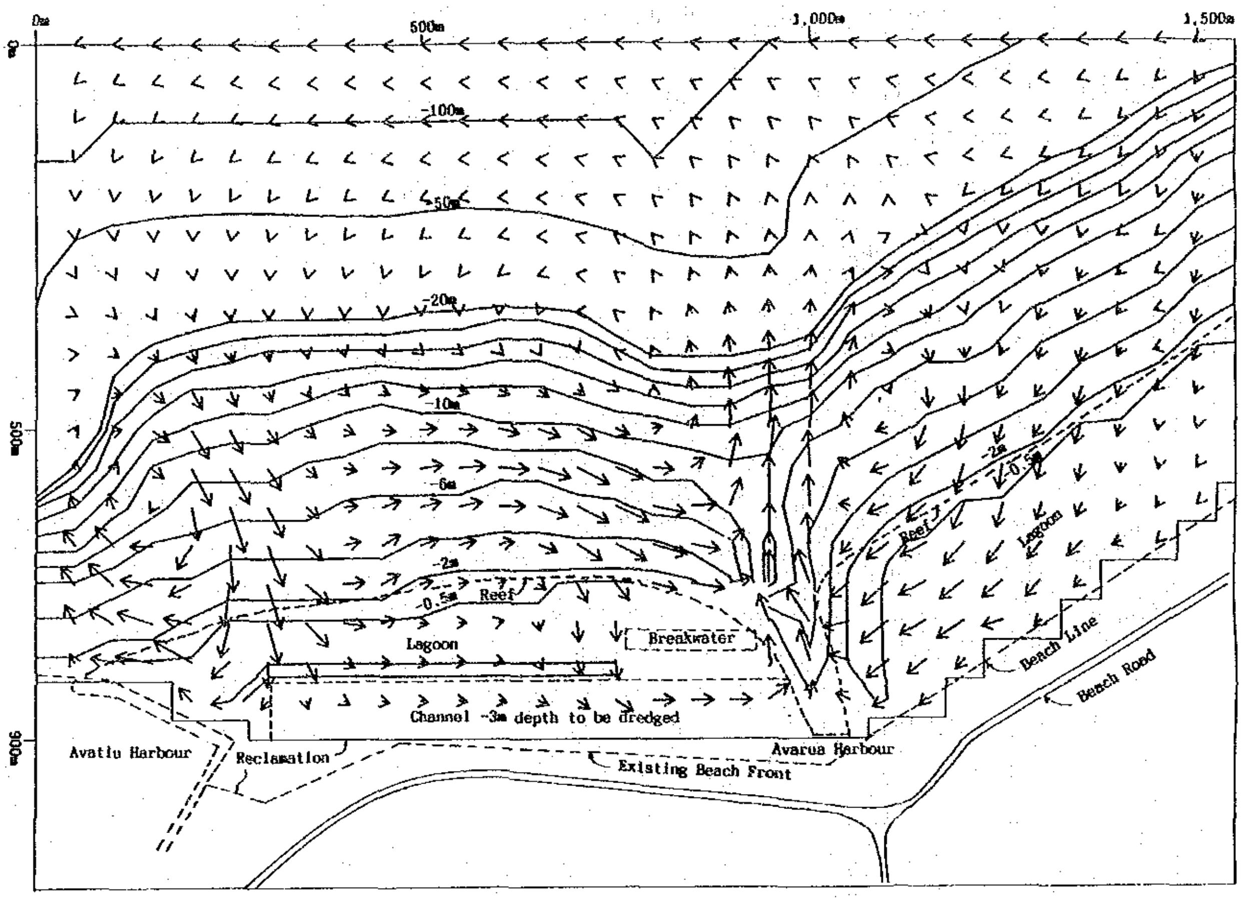


Fig. 7-21 Wave & Current Simulation (Case: 2 Experimental)
Wave Depth vs. Current Vector
→ 1m/sec.

Figs. 7-22 and 7-23 show current circulation patterns. There are two cores besides the center of return current. The eastern one seems to be circulating in a clockwise direction while the opposite one makes a counterclockwise turn. There are no significant differences between the two cases except those around the breakwaters.

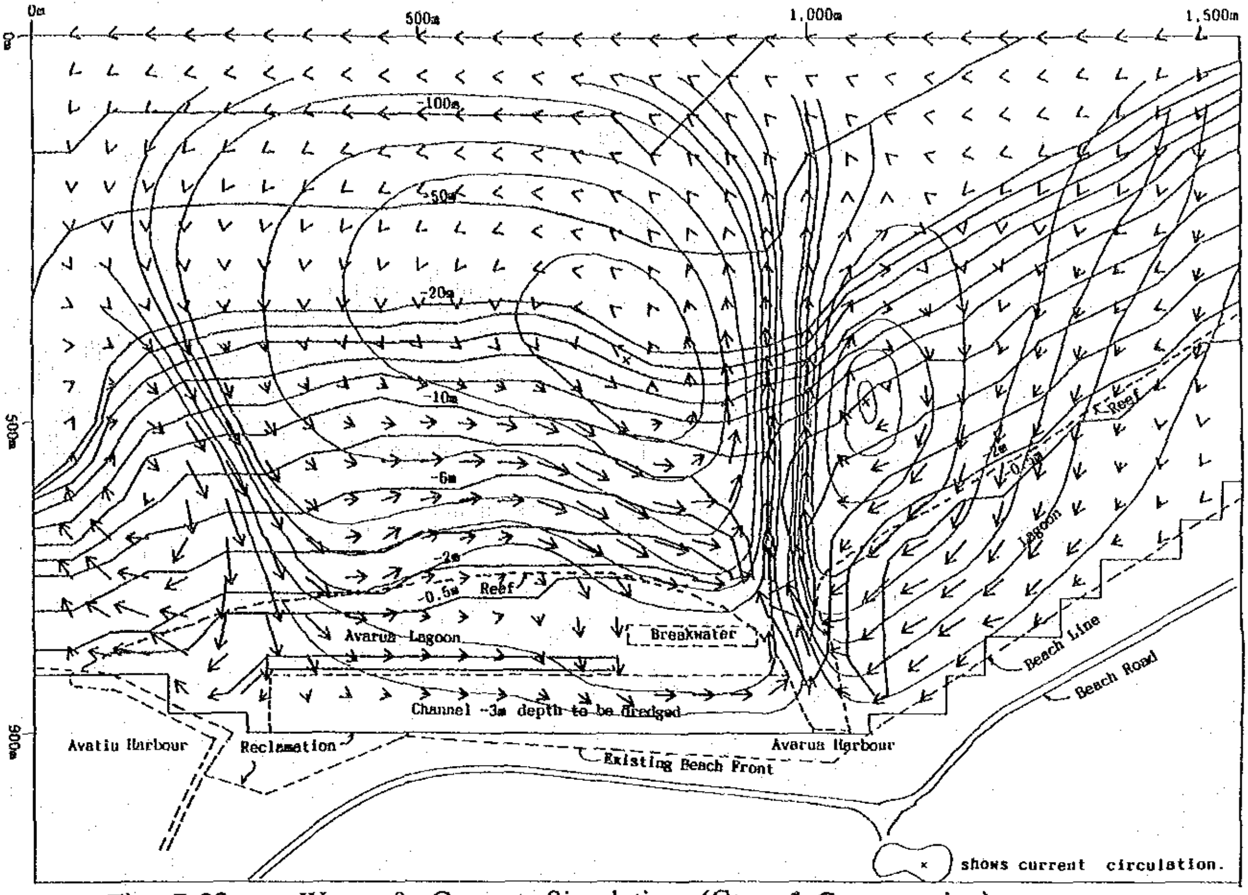


Fig. 7-22 Wave & Current Simulation (Case: 1 Conservative)
Wave Depth vs. Current Vector
→ 1m/sec.

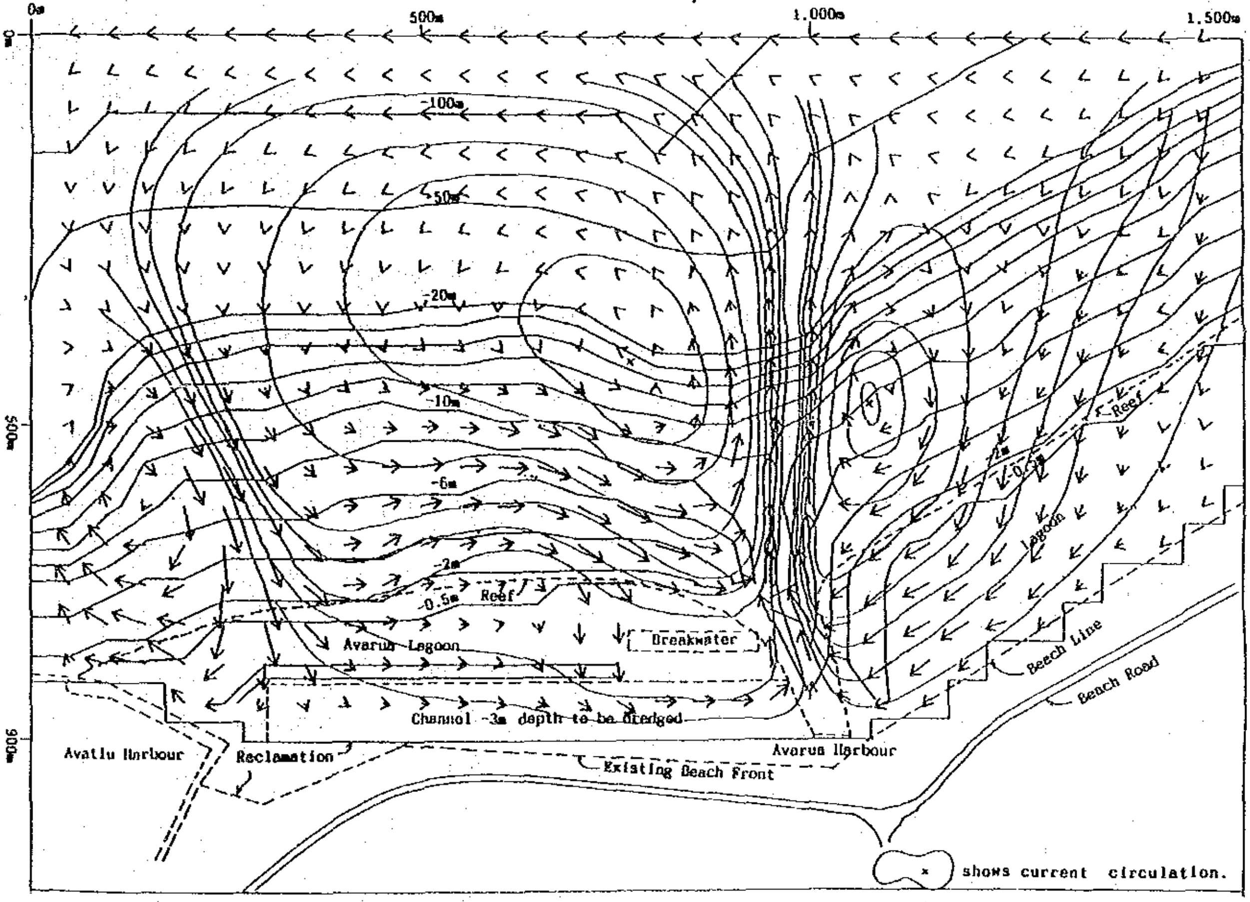


Fig. 7-23 Wave & Current Simulation (Case: 2 Experimental)
Water Depth vs. Current Vector

Wave Set-up; Figs 7-24 and 7-25

Wave set-up pattern is very similar in both cases. The water level goes down slightly in the middle of the wave breaking zones. However, after this area, wave set-up commences suddenly at -9 meter depth. Then, the water level rises steadily until the reef edge where set-up is about 1.3 meter. The water rise continues by the first 100 meter lagoon, however set-up here is 0.2 to 0.4 meter only. After this zone, the rise is very minor until the beach front. Wave set-up in the passage is less than those on the lagoon. Water level at the middle of the passage is 0.3 to 0.6 meter lower than those in the lagoon.

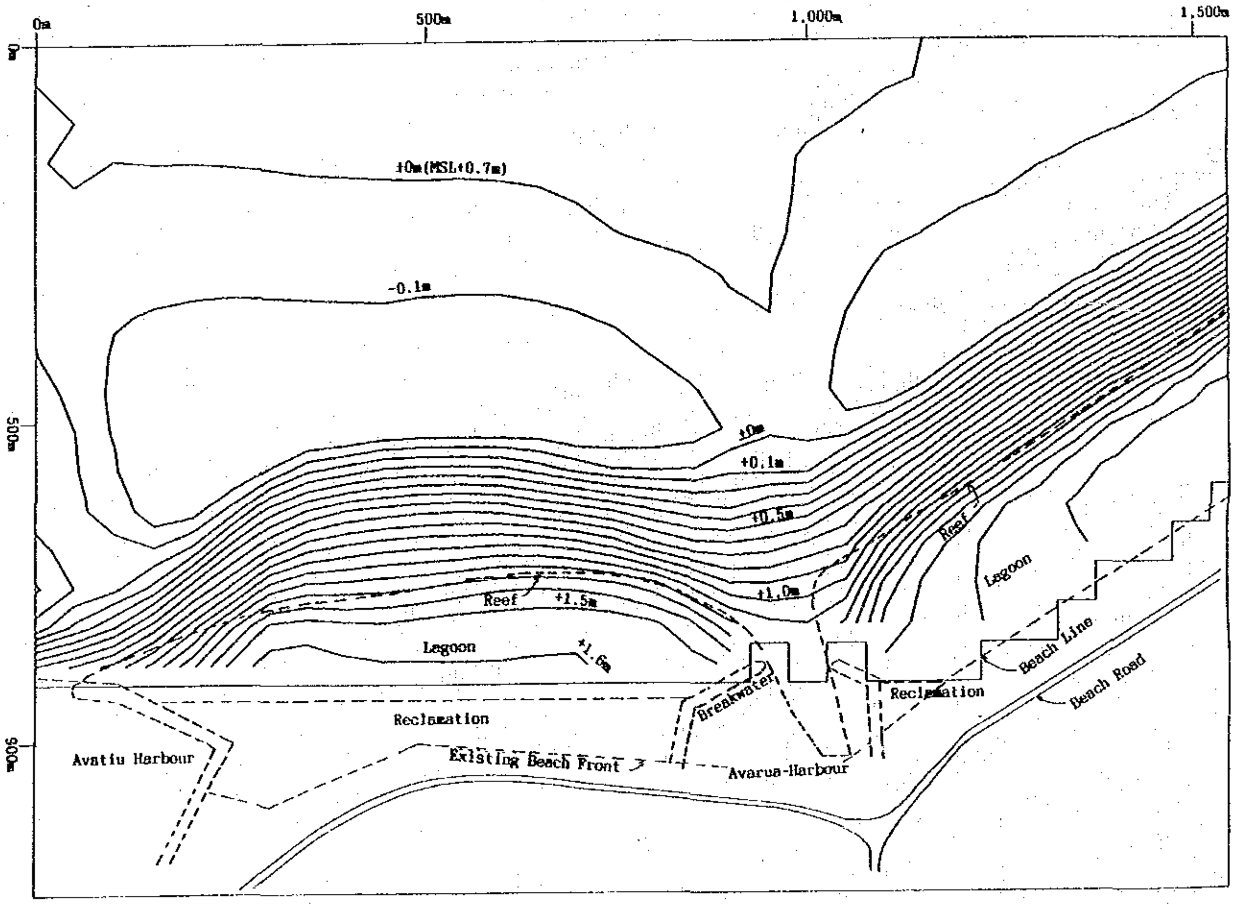


Fig. 7-24 Wave & Current Simulation (Case: 1 Conservative)
Wave Set-up above MSL +0.7 m

The water level of Case 1 is about 0.1 meter higher than in Case 2. The following may be reasons for this difference:

i. 70 meters in advance of the seawall line in Case 1 than Case-2 causes more wave reflection then the water level becomes higher, or

ii. The minus three meter channel having a width of 70 meters causes the water level to become lower by the smooth return current to the passage.

Anyway, the differences in the two cases as minor. Thus, the effect of an artificial channel decreasing the water level in the lagoon could not be confirmed. It can not be justified to invest 9 million Dollars for lowering water level by 0.1 m only.

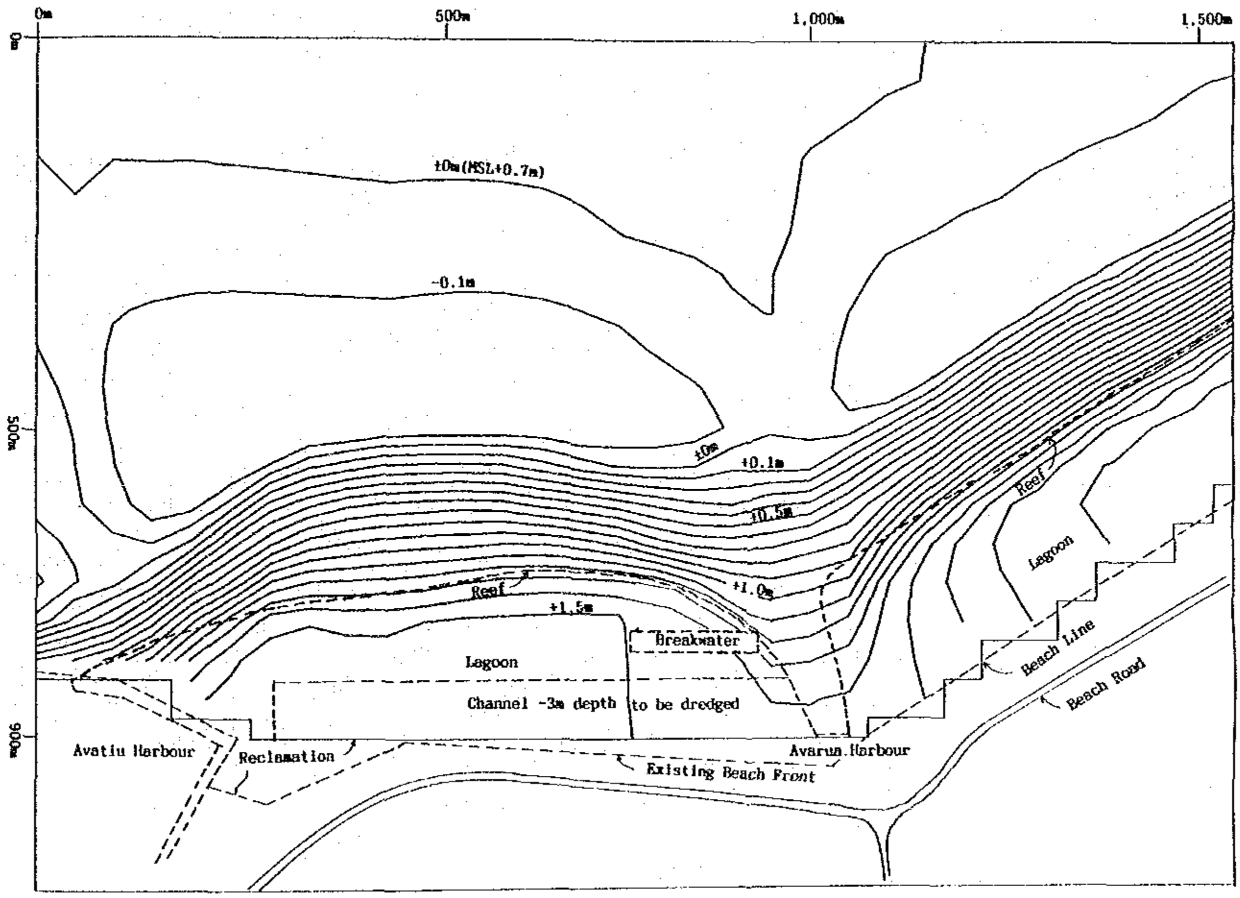


Fig. 7-25 Wave & Current Simulation (Case: 2 Experimental)
Wave Set-up above MSL +0.7 m

Fig. 7-25A shows wave setup comparison between two cases on the Avarua lagoon, Section A-A. It can be seen that wave setup in Case 1 is larger by 0.1 m than Case-2.

The most important fact is that wave setup starts at the offshore area in 250 m from the reef edge. Fig. 7-25B shows this situation in Case-1. It is known that wave height and wave setup are in inverse proportion to each other.

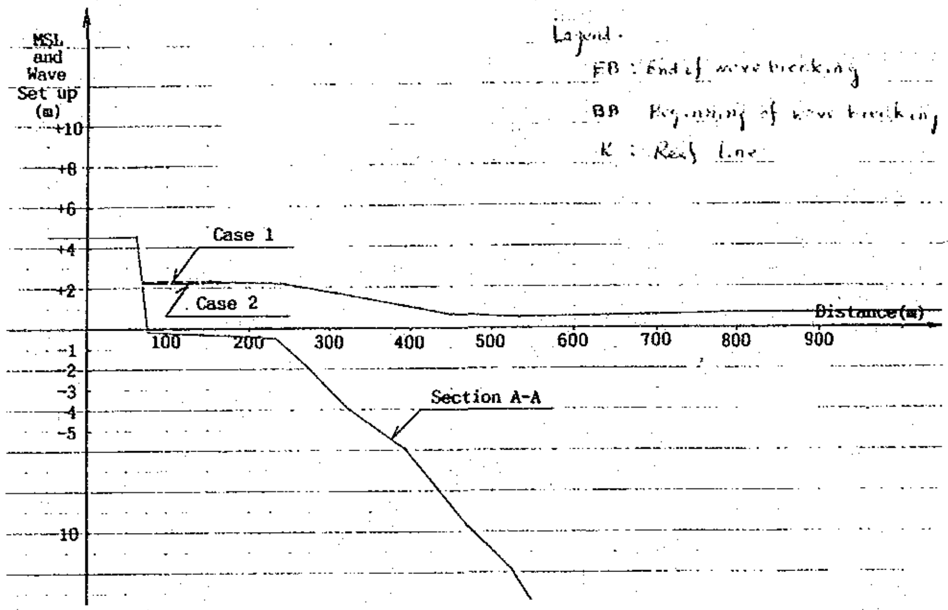


Fig. 7-25A Wave Setup Comparison on the lagoon Case 1/Case 2

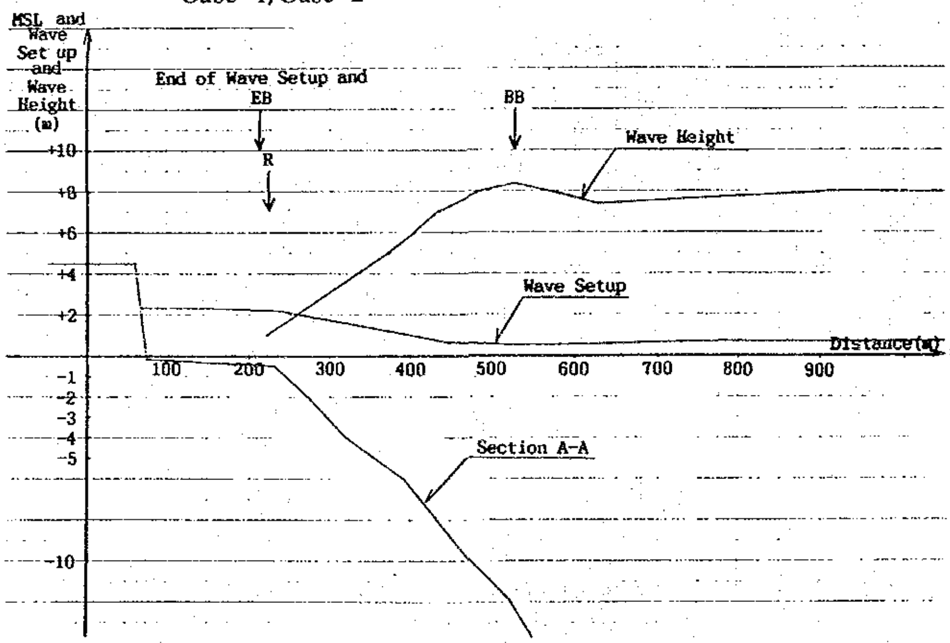


Fig. 7-25B Relationship between Wave Height and Wave Setup: Case 1

Fig. 7-25C indicates wave setup difference between Case 1 and Sally reappeared. Wave setup on the lagoon by both cases is same. Since there were no breakwaters in Avarua and no land reclamation of 120 m depth when Sally came in 1987, it is assumed that breakwater and reclamation works did not increase wave set-up.

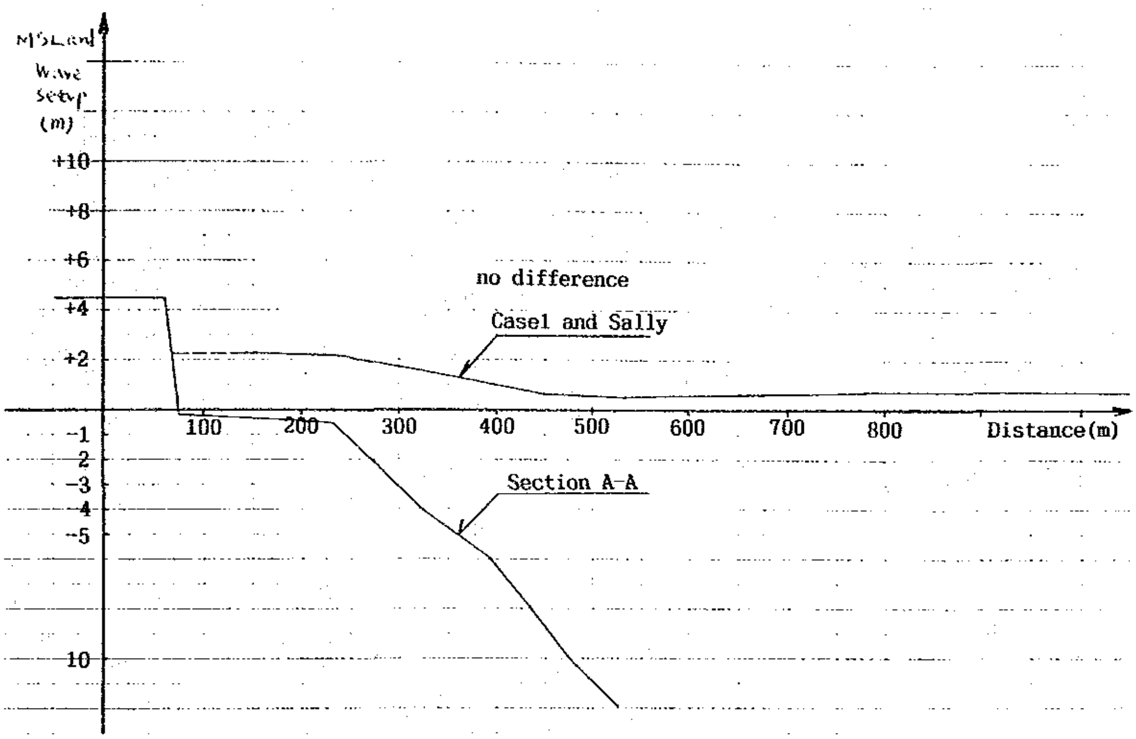


Fig. 7-25C Wave Setup Comparison: Case 1/Sally Reappeared

Fig. 7-25D shows wave setup comparison between two cases in the Avarua Passage. Wave setup by Case 1 is larger by 0.2 m than Case 2.
Fig. 7-25E shows the relationship between wave height and wave setup in the passage. Similar to the lagoon it can be seen that wave height and wave setup are in inverse proportion to each other.

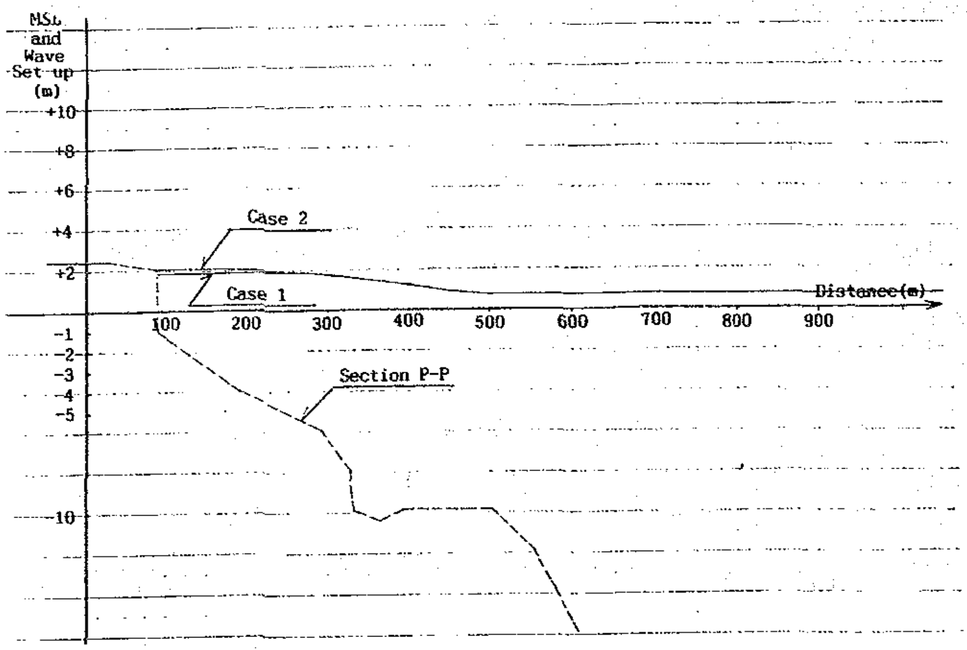


Fig. 7-25D Wave Setup Comparison in Avarua Passage
Case 1/Case 2

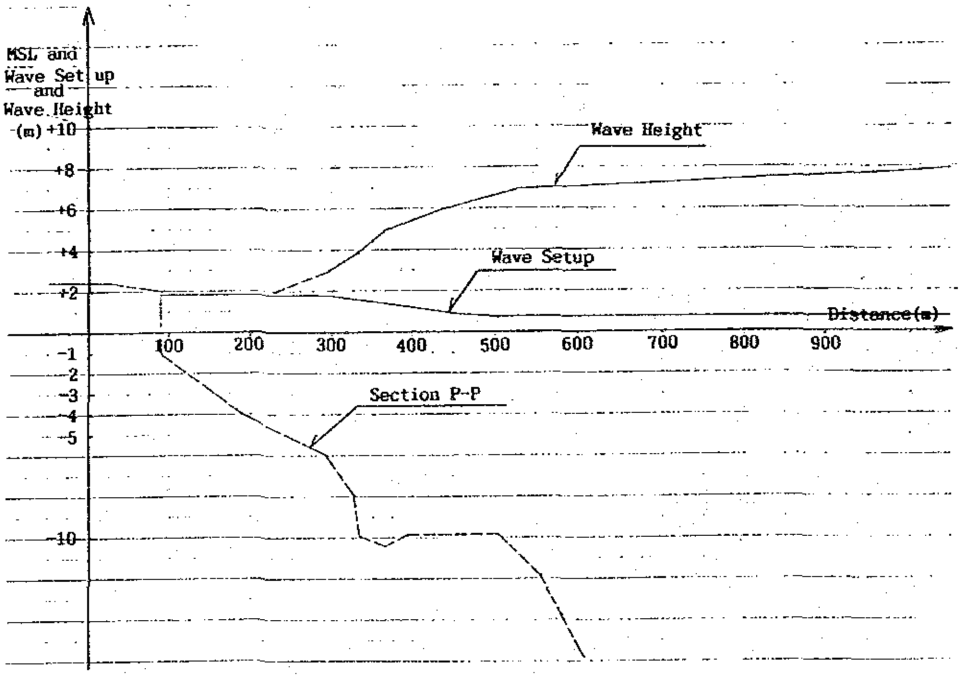


Fig. 7-25E Relationship between Wave Height and Wave Setup: Case 1

3) Evaluation of Simulation Study

(i) Influence of reclamation and breakwater to wave set-up is very minor.

When land reclamation of 120 m width in lagoon and two breakwaters are provided, an additional wave setup is less than 0.1 m. This is very minor comparing to the total wave setup of 1.5 m. Since the existing Avarua East breakwater should extend for the calm Marina basin, width of land reclamation would be about 80 m like Line-B of Conservative Layout.

(ii) Effect of an artificial channel to lower wave setup is only 0.1 m and negligible small in technical value.

This 0.1 m is only 7 % of total wave setup of 1.5 m. Artificial channel in the Case 2 costs 9 million Dollars and has following dimensions.

700 m	long
40 m	width
3 m	deep

If its width and depth are 140 m and 6 m respectively, effect of wave setup may become large. It will cost about 36 million Dollars and 60 % of existing lagoon will excavated. This is not practical in both technical consideration and environmental aspect. Thus, an artificial channel is not adopted in the Master Plan.

(iii) Double breakwaters in Avarua Harbour may increase the height of wave intruded into the Avarua Passage by 0.2 m.

However, this figure is just less than 10% of the intruded wave of 2 ~ 3 m in height. And this additional height will not make any basic difference in structure design.
Thus, two breakwaters in Avarua will not damage the coastal area. The breakwaters have various merits easily to overcome this minor problem.
It is reasonable to improve the existing Avarua breakwaters in order to redevelop the harbour as a Marina.

(iv) What simulation result tells to us is that coastal protection should be discussed by not conjecture but exact technical background.

As a matter of fact, before the simulation study here the study team surmised various phenomena during a cyclone as follows:

a. Wave breaking starts at the reef.
b. Wave setup starts at the reef.
c. Wave height in the lagoon is about 2 m.

These are mere guessworks. The truth is as follows:

a. Wave breaking like a Sally starts at -15 m depth, 250 m off the reef.

b. Wave setup starts at the wave breaking zone and becomes 1.3 m on the reef edge. An additional wave setup in the lagoon is only 0.3 m. Thus about 80 % of the total wave setup is made until the reef.

c. Wave height in the Avarua lagoon is 1 m which is about 40 % of the water depth.
(MSL + 0.7 m + 1.5 m + 0.2 m = 2.4 m)

(v) Conclusions

Case 1 is more practical layout than Case 2 for the Avarua coastal protection.

It is proposed that following concepts should be kept in the Master Plan. Refer to Fig. 7-25F.

Concept ① New seawall normal line should advance in the lagoon by 80 meter from the existing shoreline.

Concept ② Avarua Harbour should be protected by double breakwaters, West and East.

Concept ③ Avatiu Harbour should be also protected by double breakwater alignment.

Note: Arrangement of breakwater should meet with the requirements as discussed in Chapter 8.

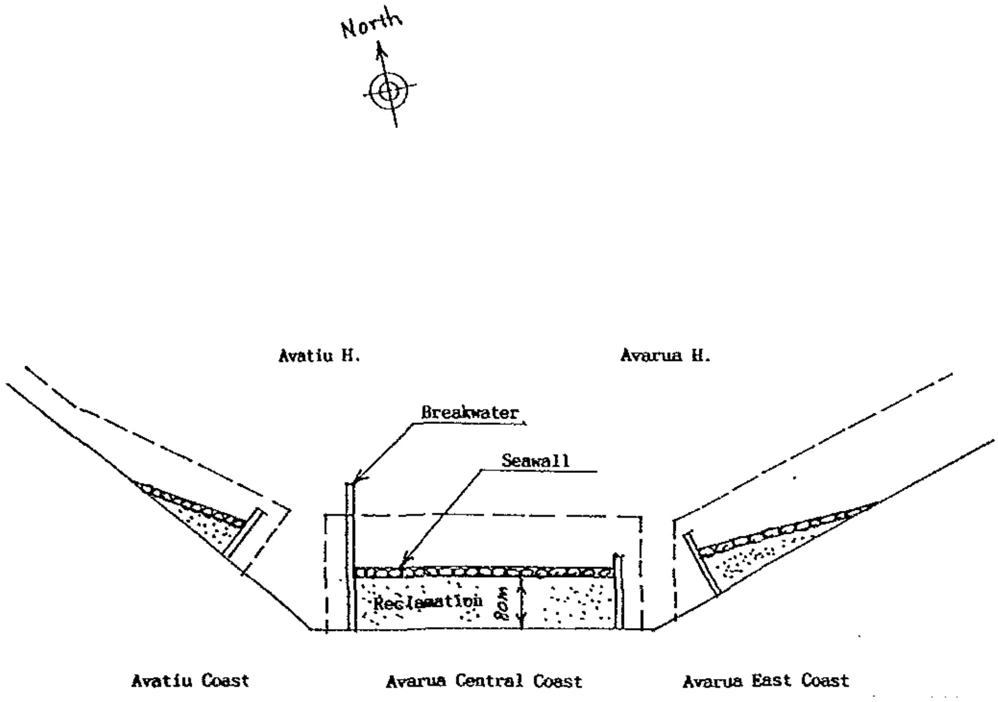


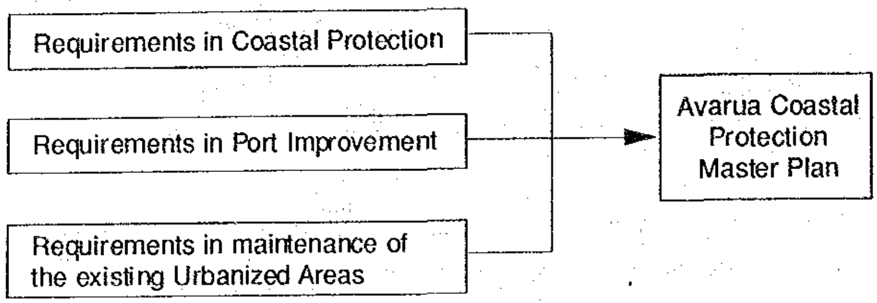
Fig. 7-25F Conceptual General Layout of Avarua Coast Protection

7.7 Avarua Coastal Protection Master Plan

This Section deals with the preparation of Avarua Coastal Protection Master Plan.

7.7.1 Planning Criteria

There are two harbours and most developed urban areas along the Avarua Coast. Coastal protection plan should cover these functions.



1) Requirement in respect to Coastal Protection

As discussed in section 7.6, protection work here consists of land reclamation in about 50~80 m width and seawall construction similar to the works by MOW. Width of new land at the Avarua Central Coast is 50 m. This defense line is similar alignment to "Line-B" in Fig. 7-16a and shapes a straight line connecting corners of two breakwaters. Average land width in the Avarua East Coast is also 50 m.

2) Requirements in respect to Port Improvement

According to the study results in Chapter 8 "Master Plan of Port Improvement", both Avatiu and Avarua Harbours will be provided with various arrangements as follows:

<u>Avatiu Harbour</u>

a. Major function here is both the commercial port and the fisheries port.
b. East breakwater should be extended by 150 m for both calm inner basin and approach channel.
c. New port area of 1.5 Ha should be given along the west part of new reclaimed land.
d. Higher development priority will be given than Avarua Harbour.

Avatiu Harbour

a. Major function here is a marine tourism center as marina.
b. Both breakwaters, West and East, will be constructed. East breakwater will be extended by 100 m seawards.
c. Works to be implemented in the Short-term Development will be the minimal improvement in order to concentrate to Avatiu Harbour improvement.

3) Requirements from the Avarua Urban Areas

New land should be gained for the provision of public land which is currently in short of supply and for future Avatiu Harbour expansion. According to land use estimation, new land should be 5 Ha or more. In the new land long the seawall, cyclone buffer zone will be provided in emergency case. New reclamation will be conducted both in Avarua Central Coast and Avarua East Coast. These new land are called hereinafter as "Port Park Complex".

Port Park Complex

New land reclamation of 6 Ha will be carried out as follows:

Avarua Central Coast ----------	4 Ha	500 m x 80 m
Avarua East Coast --------------	2 Ha	300 m x 50 m

Port park complex will be an open space for the public use, including roads, parking area, bus terminal, park etc,. The complex will be constructed in the reclaimed areas between the existing shoreline and the new seawall to be constructed in the lagoon. The primary purpose of the complex during a cyclone is to maintain the buffer zone in order to absorb cyclone energy before it arrives such dense urban areas as Ngatipa, Avarua, Ruatonga and Avatiu.

7.7.2 Avarua Coastal Protection Master Plan

Two alternative plans, Case-1 and Case-2 were prepared. Figs. 7-26 and 7-27 show these two layouts together with recommended port improvements. Basic characteristics of plans are as follows:

1) Case-1 Fig. 7-26

Characteristics of this plan are as follows;

Between Two Harbours

i. Continuous wall of 500 m long consisting of seawall and breakwater will be provided.

ii. Two third of the beachline will be reclaimed as wide as 50 meters.

iii. Western 100 meters will be utilized as the future Avatiu port area.

iv. Eastern 150 meters will be provided with a marina basin of -2.5 meter depth as a part of new Avarua Harbour.

v. Avatiu stream will be relocated to the East along the proposed port boundary and be joined with the other stream then flow to the lagoon.

East of Avarua Harbour

i. Continuous wall of 300 m long consisting of a breakwater and seawall will be constructed.

ii. The existing eastern breakwater will be relocated seawards by 70 m and be connected to the new seawall.

iii. 50 meter wide land reclamation will be undertaken.

iv. Faceline of marina wharf will advance about 30 meters seaward for providing a wider apron.

Avarua Harbour

i. New western port limit will be relocated 150 m westwards.

ii. New eastern port limit will be same arrangement as present.

iii. New Avarua Harbour will cover coastal area of 400 m long. About 50 yachts will berth here.

2) Case-2 Fig. 7-27

This is a modified layout of Case-1. Half of the new Avarua western breakwater in Case-1 will not be constructed in order to maintain good scenery and environment.

3) Total Evaluation

Two plans were evaluated by seven items.

Table 7-4A Evaluation of Alternatives

Items	Case-1	Case-2	Remarks
a. Construction Cost	3	3	Initial cost
b. Maintenance Cost	3	3	Maintenance dredging
c. Scenery	3	4	-
d. Environment	2	5	Water quality/circulation
e. Wave Calmness	4	3	During a normal climate
f. Wave in port	5	2	During a cyclone
g. Protection efficiency	4	4	-
Total	24	24	

Note: Evaluated by the study team
Point system : Best(5), Better(4), Good(3), Fair(2), Worse(5)

As seen in table above, both plans have been appraised as same marks. There is no major difference in total evaluation. The main difference between two plans are:

i. <u>Case-1</u> will provide more safety basin to marina than Case-2. However this plan is less open-air feeling for marina than Case-2.

ii. <u>Case-2</u> Will maintain an environmental port including open view, however, wave calmness in the inner port basin is worse than Case-1.

It is proposed to adopt Case-2 for further study giving priority on an openly feeling in Marina.

Fig. 7-26 AVARUA COASTAL PROTECTION MASTER PLAN (CASE-1)

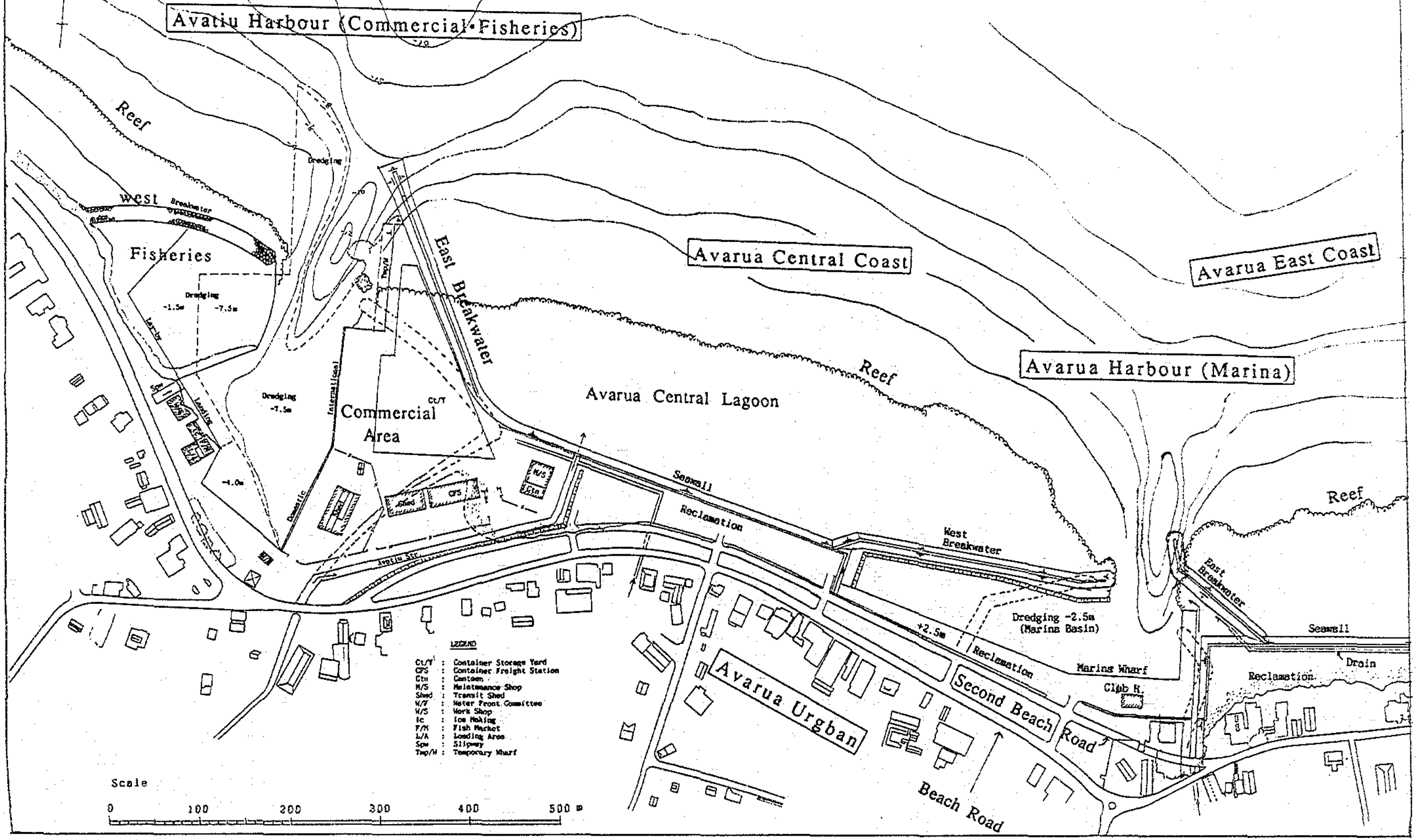
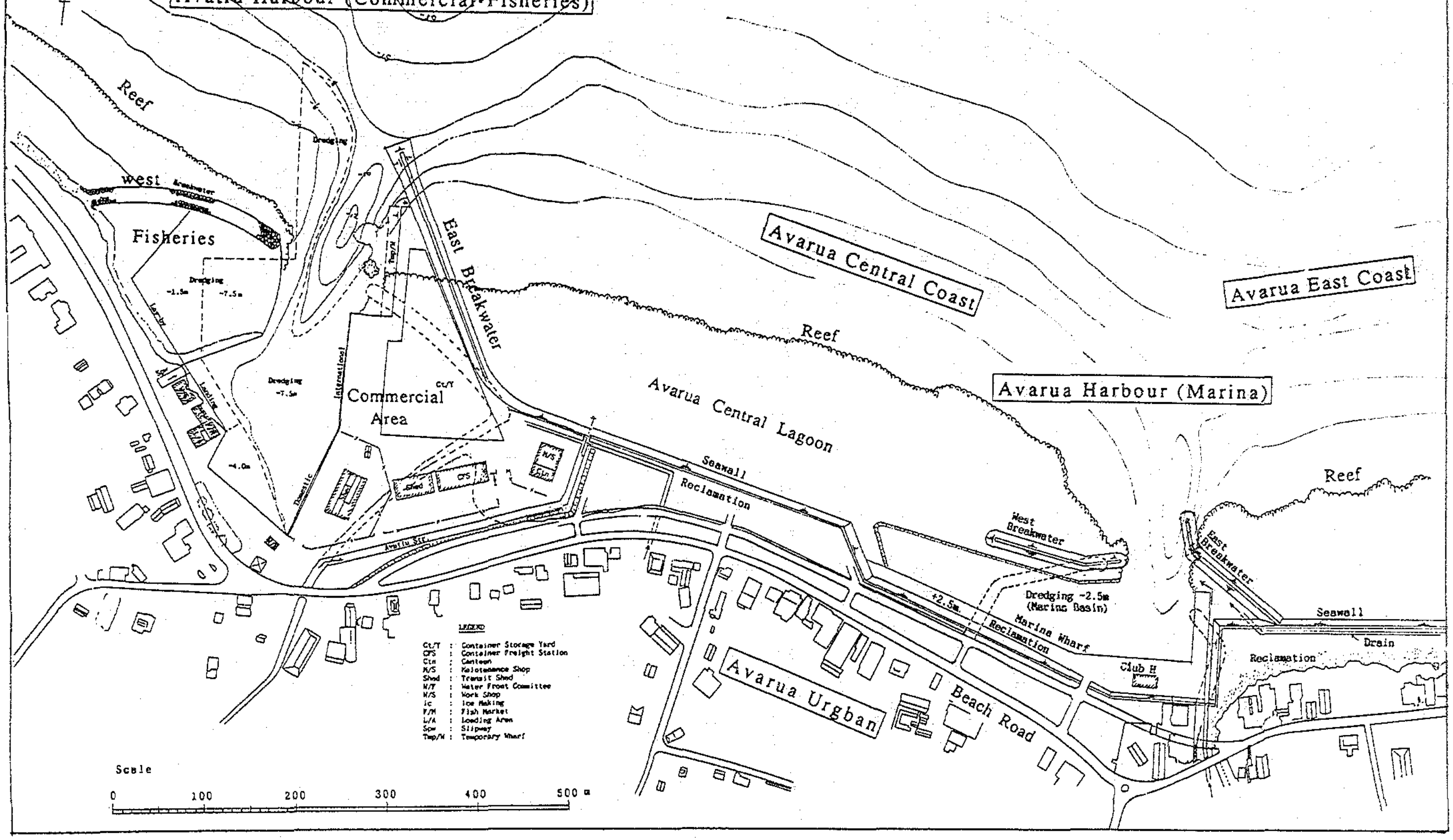


Fig. 7-27 AVARUA COASTAL PROTECTION MASTER PLAN (CASE-2)
("Recommended")



7.8 Summary of Coastal Protection Master Plan

This section deals with the proposed coastal protection work of Rarotonga Island. The cost ceiling on the total cost has been made considering the estimated damage cost during the project life.

7.8.1 Cost Ceiling

1) Estimated Damage during the Project Life

It is assumed that an average project life is 30 years considering type of countermeasures. As shown in subsection 12.2.7, it is 9.3 times of cyclone Sally damage that is equivalent to total disasters by cyclones may happen during the project life. Since the estimated damage in respect to wave disasters by Sally is 13.9 million Dollars, it is 129.0 million Dollars that is 9.3 times of Sally disasters.

2) Reduction of Damage during the Project Life

Among this, reduced damage by the project will be as follows:

a. Damage Reduction in the Master Plan Areas

Master Plan should be respect to all the coastal line of the island. However it is not practical to provide all damaged coast of 15.0 km with coastal protection. It is recommended to provide protection by priority rating from unit damage by unit coastal length.

It is also recommended that damage reduction by Master Plan should be two or less of unit damage by Sally.

b. Short-term Coastal Protection Areas

Unit damage per coastal length in the short-term areas is larger than other low developed areas. Because, the short-term areas are specified as the northern urbanized areas. It is recommended that reduction of damage in this areas should be 4 times of Sally damage. This means disasters in future will be a half of damage amount in case of no project implementation.

Thus, estimated damage reduced by the Master Plan is 27.8 million Dollars.

$$13.9 \times 2 = 27.8 \text{ million Dollars}$$

3) Project Benefits during the Project Life

It is assumed that project benefits amount to 27.8 million Dollars.

4) Scale of Master Plan

It is recommended to ceil the project cost 27.8 million Dollars or less.

5) Implementation Ratio

The total estimated cost of coastal protection work indicated in the Master Plan is 60.4 million dollars before ceiling.

$$27.8 \div 60.4 \times 100 = 45.7 \text{ percent}$$

Thus, about 45 percent of the 60.4 million Dollars will be the maximum amount to be invested. Implementation ratio by year 2010 is 45 %. Table 7-5 shows the total cost before ceiling.

Another consideration is the scale of the government's budget. The maximum budget allocated to the coastal protect work for fifteen years (1996 to 2010) is assumed. If the annual budget level is around 50 million dollars, the required rate of annual investment for coastal protection work among the budget will be:

$$27.8 \ / \ 50.0 \times 15 = 3.7 \text{ percent/year}$$

Table 7-5 Total Coastal Protection Cost Before Ceiling

Zone Land Use	Disaster Grade	Unit Cost NZ D/m	Length m	Total Cost NZ D	Remarks
One	I, II, III	5,400	870	4,698,000	
"Urban"	Reclamation	4,000	870	3,480,000	50 m wide
	IV	3,200	0	0	
	V	1,200	0	0	
	Zone total		870	8,178,000	-
Two	I, II, III	6,400	0	0	
"Rural A"	IV	2,000	1,000	2,000,000	
	V	700	1,170	819,000	
	Zone total		2,170	2,819,000	-
Three	I	5,200	0	0	
"Tourism"	Art. Passage	4,000	0	0	"I" shape
	II	5,200	0	0	
	III	5,200	0	0	
	IV	5,700	400	2,280,000	
	Art. Passage	4,000	400	1,600,000	"I" shape
	V	2,400	200	480,000	
	Zone total		600	4,360,000	-
Four	I, II, III	3,900	7,740	30,186,000	
"Rural B"	IV	2,000	1,850	3,700,000	
	V	1,200	720	864,000	
	Zone total		10,310	34,750,000	
			(13,950)	(50,107,000)	

A.	Total Direct Cost	50,107,000
B.	Management Cost 20.5 % of A	10,273,000
C.	Grand Total Cost, A+B	60,380,000

Notes : 1. Management cost includes physical contingency, engineering cost and training fee.

2. Required cost for both Avarua Harbour and Avatiu Harbour areas are excluded. (about 900 m long coastline)

7.8.2 Total Cost after Ceiling

Actual investment cost for coastal protection can be obtained as follows:

$$Cc = Co \times R$$

Where, Cc : Cost after ceiling

Co : Original total cost before the ceiling

R : Implementation rate (%)

The implementation rate should be decided upon consideration of the land use priority and the disaster grades. Zone One, the urban developed area, should be top priority. Zone three, the tourism area, will also have top priority due to the need of maintaining the largest industry here for the purpose of increasing employment opportunities. Zones Two and Four, the rural areas, will be assigned a lower priority. Considering this, the proposed the implementation rates for each zone will be;

Zone		Land Use	Implementation Rate
Zone One	:	Urbanized Areas	100 %
Zone Two	:	Rural Areas "A"	50 %
Zone Three	:	Tourism Areas	70 %
Zone Four	:	Rural Areas "B"	30 %

Thus the total cost after ceiling will be:

Table 7-6 Total Coastal Protection Cost in Master Plan (After Ceiling)

Zone	R	Original Cost	Cost after ceiling	Share
Zone One	100 %	8,178,000	8,178,000	(35.5 %)
Zone Two	50 %	2,819,000	1,410,000	(6.1 %)
Zone Three	70 %	4,360,000	3,052,000	(13.3 %)
Zone Four	30 %	34,750,000	10,425,000	(45.2 %)
A. Total Direct Cost		50,107,000	23,065,000	(100 %)
B. Management Cost (20.5 % of A.)			4,725,000	
C. Grand Total Cost after Ceiling			27,790,000	

Protected coastal area will be as follows:

Table 7-7 Protected Coast Length in Master Plan (After Ceiling)

Zone	Coastal Length (m) Before Ceiling	After Ceiling		Remarks
Zone One	870	870	(15.9%)	Urban
Zone Two	2,170	1,085	(19.8%)	Rural "A"
Zone Three	600	420	(7.7%)	Tourism
Zone Four	10,310	3,093	(56.6%)	Rural "B"
Zone Five	0	0		Nature
Total	13,950	5,468	(100%)	

Note, Both Avarua Harbour and Avatiu Harbour areas are excluded.

Thus, coverage by the Master Plan is 39% of all the coastal protection required (13,950 meters).

Table 7-8 shows the list of typical countermeasures for each land use category.

Table 7-8 List of Typical Countermeasures per Land Use

Land Use	Disaster Grade		Countermeasure	Damaged Coast(m) x R		Coastline to be protected (m)
Zone One Urban Area	GI.	MIC-1	Gravity Seawall	870 x 100 %	=	870 m
		MAC-1	On-land Buffer Zone			
		MAC-3	Plantation with Dike			
Zone Two Rural "A"	GIV	MIC-4	Flexible Hollow Slope	1,000 x 50 %	=	500
	GV	MIC-5	Flexible Gagion Slope	1,170 x 50 %	=	585
Zone Three Tourism Area	GIV	MIC-3	Stepped Slope	400 x 70 %	=	280
		MIC-6	Groin			
		MIC-8	Beach Nourishment			
		MAC 4	Artificial Passenge "I"			
	GV	MIC-5	Flexible Gabion Slope	200 x 70 %	=	140
		MIC-6	Groin			
		MIC-8	Beach Nourishment			
Zone Four Rural "B"	GI.II	MIC-2	Rock Mound Seawall	7,740 x 30 %	=	2,322
		MAC-3	Plantation with Dike			
	GIV	MIC-4	Flexible Hollow Slope	1,850 x 30 %	=	555
	GV	MIC-6	Groin	720 x 30 %	=	216
			Total	13,950 x 39 %	=	5,468 meter

7.9 Rough Design and Preliminary Cost Estimation

This section deals with the rough design of structures and the preliminary cost estimation for the coastal protection work outlined in the Master Plan.

7.9.1 Rough Design

Coastal protection works here were designed based on the past experience in similar project with design condition discussed previously. Structures in the northern coast will be shown in Chapter 12 of Vol. II.

7.9.2 Basic Condition of Cost Estimate

The unit price of works is estimated based on similar work in the island. Various cost data was also collected from the government agencies including TLT and MOW in November 1991.

It is understood that the unit prices here are 1992 current prices.

Followings are the basic conditions:

a) Land cost is excluded.

b) Taxes are excluded.

c) Most of unit price for on-land work was obtained from MOW. MOW price was adjusted by an additional allowance of 20 %.

d) Marine works, such as dredging cost, is based on the TLT information. It is assumed that most of the previous dredging works for TLT were conducted by foreign construction companies. An allowance of 20 % is added to the TLT price.

e) The government quarry existing behind the Blackrock and another new site can supply the necessary amount of rock and concrete aggregate.
No royalty for the quarry is included.

f) The engineering cost is included as 8 % of the construction cost.

g) The physical contingency is included as 12 % of the construction cost. The physical contingency provided here is only 12 % because there are a few physical unknown factors. Geotechnical conditions here is so excellent that no clayey layer which generates incremental cost was found.

h) Price escalation is not included.

i) Training cost of the government officials is included as 0.5 % of construction cost.

Cost estimation is conducted using the following formula:

$$Ca = (1 + A)\ Cd$$

where, Ca : Actual cost after adding allowance

Cd : Direct construction cost

A : Allowance rate

= 8.0 % + 12.0 % + 0.5 %------- (Item f, g and i)

= 20.5 %

Thus, Ca = 1.205 x Cd.

7.9.3 Unit Direct Cost per Countermeasure

Proposed countermeasure will be utilized solely or in combination with several concepts. A summary of the unit direct cost for each countermeasure is shown in Table 7-9, and the combined unit direct cost is shown in Table 7-10.

Table 7-9 Unit Direct Cost by Each Countermeasure

Unit : Dollars per meter

Type of Protection Concept and Countermeasures	Unit Cost*	Remarks
a) Micro Concepts		
Coastal Defense Works*		
MIC-1; Gravity Seawall	5,000	When necessary, deformed concrete blocks will be provided.
MIC-2; Rock Mound Seawall	3,500	
MIC-3; Stepped Slope	4,000	
MIC-4; Flexible Hollow Slope	2,000	
MIC-5; Flexible Gabion Slope	700	
MIC-6; Groin	1,200	
MIC-7; Lagoon Breakwater	1,200	
Sand Nourishment*		
MIC-8; Beach Nourishment	500	$ 50 for ten years
MIC-9; Trap Nourishment	400	$ 20 for ten years plus trap cost
b) Macro Concepts		
On-land Works		
MAC-1; On-land Buffer Zone	2,000	For 25 meter wide with surfacing
MAC-2; Facility Relocation	2,500	Relocation of road of 7 m width
MAC-3; Plantation with Dike	400	For 20 meters
Works near the Reef		
MAC-4; Artificial Passage "I"	4,000	Effective length 200m, 100 x 30 x 4
MAC-5; Artificial Passage "Y"	8,000	Effective length 200m, 200 x 30 x 4

Notes,
1. Unit cost shows estimated cost per shoreline meter.
2. Land reclamation cost is $ 2,000 for 25 meter width.
3. Cost for sand nourishment is total cost for ten years when five cubic meters per shoreline meter are required annualy for maintenance of the beach.
4. Foot protection work to the coastal defense work will be added, if so required.

Table 7-10 Unit Direct Cost by Combined Countermeasure

Unit: Dollars/m

Zone and Disaster Grades	MICRO CONCEPT Unit Price			MACRO CONCEPT Unit Price		Total Direct Cost	
Zone One, Urban Area							
Grade I,II,III	MIC-1	-	-	MAC-1	MAC-3	(Rec.)	
	5,000	-	-	2,000	400	5,400 + 2,000	= 7,400
Grade IV	MIC-4	MIC-7	-	-	-		
	2,000	1,200	-	-	-		3,200
Grade V	MIC-7	-	-	-	-		
	1,200	-	-	-	-		1,200
Zone Two: Rural Area "A"							
Grade I,II,III	MIC-2	-	-	MAC-2	MAC-3		
	3,500	-	-	2,500	400		6,400
Grade IV	MIC-4	-	-	-	-		
	2,000	-	-	-	-		2,000
Grade V	MIC-5	-	-	-	-		
	700	-	-	-	-		700
Zone three: Tourism Area							
Grade I	MIC-2	MIC-6	MIC-8	MAC-4	-	(Pass.)	
	3,500	1,200	500	4,000	-	5,200 + 4,000	= 9,200
Grade II,III	MIC-2	MIC-6	MIC-8	-	-		
	3,500	1,200	500	-	-		= 5,200
Grade IV	MIC-3	MIC-6	MIC-8	MAC-4	-	(Pass.)	
	4,000	1,200	500	4,000	-	5,700 + 4,000	= 9,700
Grade V	MIC-5	MIC-6	MIC-8	-	-		
	700	1,200	500	-	-		= 2,400
Zone Four: Rural Area "B"							
Grade I,II,III	MIC-2	-	-	MAC-3	-		
	3,500	-	-	400	-		3,900
Grade IV	MIC-4	-	-	-	-		
	2,000	-	-	-	-		2,000
Grade V	MIC-6	-	-	-	-		
	1,200	-	-	-	-		1,200

Note, Rec. = Reclamation work,
Pass. = Artificial passage

Chapter 8: Master Plan of Port Improvement

Chapter 8 : Master Plan of Port Improvement

This chapter deals with the preparation of Master Plan for port improvement together with alternative studies. Port improvement works will be provided for the two harbours, Avatiu and Avarua.

Port area expansion may be recommended based on the facility requirement in future and safety for calling ships.

The Port Park Complex, which will be developed on the newly reclaimed buffer zone to defend Avarua coast against the cyclones is one of items to be studied.

All port improvements will be made in harmony with the coastal protection, one of the other major aspects of this study.

8.1 Objectives

The primary objective of port improvement is to provide proper port facilities and maintain a gateport to the island. This is essential to the people and various industries here. There is no alternative than to improve the existing two ports located along the northern coast of the island.

The two ports are currently being affected by various impacts including

- Changes in marine transport mode by introduction of containers,
- Larger vessel calling,
- Operational day is limited by the severe climatic conditions,
- Incremental requirement for tourism industries,
- Demands in fisheries use, and
- Others

After this section, necessary analysis and study will be conducted and discussed in respect to demands and facilities. The study team has developed various components of the master plan, and has condensed in to the planning ideas.

The following is the proposed ideas to improve both Avatiu and Avarua Harbours:

a) To provide a container storage area to accommodate the increase in container cargoes.

b) To expand the east breakwater, the width of the entrance channel, turning basin and depth of the quay wall and the basin at Avatiu Harbour to ensure the safety of large vessels.

c) To repair the existing quay wall.

d) To prepare the facilities of the fishery port for the increase in both number and size of fishing boats to realize more fish catches.

e) To construct a marina for the increase in the number of pleasure boats, especially large yachts to enhance tourism industry development.

f) To protect small fishing boats from high waves during a cyclone.

For item d), since almost all large yachts come from foreign countries between April and September, the yacht harbor will be a seasonal facility.

8.2 Existing Port Conditions

This section deals with the existing condition of the two ports. Current port traffic will be discussed at the begging of this section. The existing port facilities will be evaluated and the relationship between the port development and coastal protection will be discussed at the end.

8.2.1 Port Traffic

1) International Shipping

International shipping operations into the Cook Islands are mainly provided under the Joint Shipping Services Agreement between New Zealand, Niue and the Cook Islands. Under this agreement, two vessels, Aotea Link and Ngamaru III, are currently operated. And another vessel, Urte, was operated by a Hawaiian shipping service in 1991.

Those three vessels, for general cargoes, operate based on the following schedules and routes;

Table 8-2-1 Shipping Routes and Schedule at Cook Islands in 1991

[General Cargo]

Vessel Name	Service (days approx.)	Route
Aotea Link	21	Auckland - Papeete - Rarotonga - Auckland
Ngamaru III	31	Auckland - Niue - Apia - Rarotonga - Aitutaki - Auckland
Urte	31	Honolulu - Pagopago - Apia - Tonga - Rarotonga - Christmas Is. - Honolulu

Of these three vessels, Aotea Link and Urte mainly transport containerized cargoes, though they are not full-container ships.

In addition to the above vessels, tankers operate at irregular intervals. Pacific Rover and Pacific Explorer are principally used for the

transportation of liquid petroleum products from Lautoka (Vuda Point) of Fiji, and Coral Gas for the transportation of LPG from Fiji.
Particulars of the vessels are given in the following tables.

Table 8-2-2a Dimensions of Vessels for Cargo

[Cargo vessels]

Particular	Aotea Link	Urte	Ngamaru III
D.W.T.	2,671	3,035	2,181
G.T	1,829	2,696	1,464
Length overall (m)	79.58	92.51	72.42
Beam (m)	13.17	13.85	15.52
Full draft (m)	6.4	6.81	5.64
Speed (knots)	11.5	11.5	12
TEUs	118	166	60
Year built	1988	1985	1970

Note: TEU means twenty feet equivalent unit, or one container box of 20 feet long. One 40 feeter is calculated as two 20 feeters.

Table 8-2-2b Dimensions of Tankers

[Tankers]

Particulars	Pacific Rover	Pacific Explorer	Coral Gas
D.W.T.	1.963	1,642	2,366
G.T	1,594	954	1,897
Length overall (m)	80.02	71.94	77.0
Beam (m)	13.3	11.7	12.7
Full draft (m)	4.8	4.2	5.86
Speed (knots)	12.5	12	12.9
Year built	1979	1973	1971

Since the nominal depth of Avatiu Harbour is 6.2 m below M.S.L., vessels having more than a 5.5 to 6 meter full draft must be controlled before port entry into the harbour.
Number of ship calls at Avatiu harbour from 1985 to 1991 (up to September) is shown in Fig. 8-2-1.

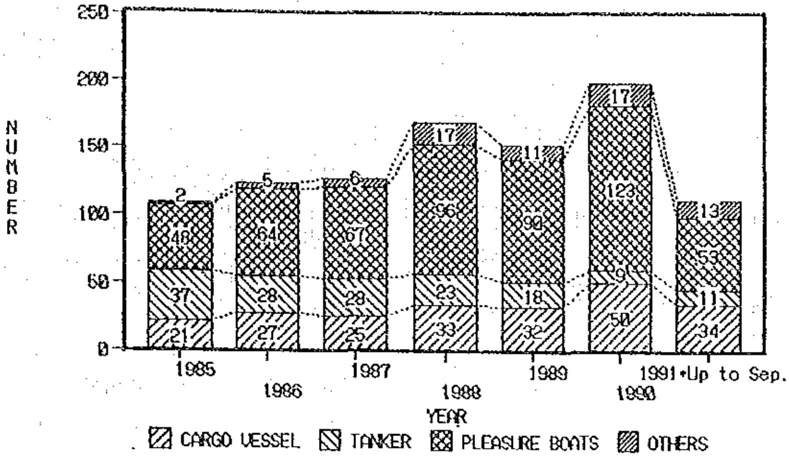


Fig. 8-2-1 Number of Ship Calls at Avatiu Harbour

Imports from overseas ports, mainly New Zealand, but also from Japan, South East Asia and Pacific ports (Fiji, Western and American Samoa, Tahiti) are for consumption in Rarotonga or transshipments to the outer islands.

Cargo volume handled in 1990 in Avatiu Harbour was recorded at approx. 39,200 freight tones. Recently (1988 to 1990), total cargo volume handled has been increasing steadily, but it can be said that total cargo volume has fluctuated in the five-year span from 1986 to 1990.
The cargo volume handled for recent 5 years is shown in Fig. 8-2-2.

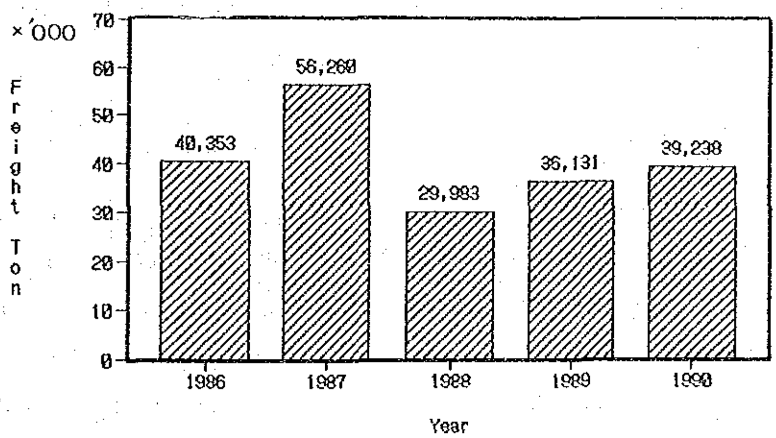


Fig. 8-2-2 Past Records of Cargo Volume (1986 - 1990)

Main imported commodities are foods, construction materials, motor vehicles/parts and petroleum products. Among those commodities, petroleum products such as gasolene, diesel oil, aviation gas and LPG etc. are increasing annually excluding the year 1988 after cyclone Sally attacked the Cook Islands.

Most cargoes are well containerized except liquid fuel and construction materials that are long and heavy such as cement, steel bars and plates, plywood etc. The cargo volume handled and ratio of containerization by main commodities are shown in Table 8-2-3.

Volume of export cargoes are much less than that of imports. Main exports are fresh fruits, vegetables, manufactured goods and pearl shell.

Table 8-2-3 Ratio of Containerization in 1990 (excluding Break Bulk)

	Commodities	Frgt. ton (,000)	Ratio of Contnr.	In Cont. (,000)
1)	Foods	10.0	0.95	9.5
2)	Construction Material	3.7	0.10	0.4
3)	Vehicles	3.8	0.00	0.0
4)	Motorcycles & Parts	0.9	0.71	0.6
5)	Others	9.3	0.69	6.4
	Total	27.7	0.61	16.9

All cargoes are handled by the Waterfront Commission under the control of T.L.T. (Ministry of Trade, Labour and Transport).

2) Inter-island Shipping

Regular inter-island shipping services are provided by Cook Islands Shipping & Development Co. Ltd. using Manava II, approx. 400 G.T. Cargoes to and from the outer islands are all non-containerized. Inward cargoes are mainly agricultural produce and empty fuel drums either from local consumption or transshipments to overseas ports mainly from Aitutaki and Mangaia. Outwards cargoes are mainly fuel, construction materials and equipment, fertilizers and agricultural supplies, foods and beverages.

Outward cargo volume has been consistently recorded at approx. 2,000 to 2,200 freight tones in the last few years.

3) Other Traffic

No regular ferry or passenger boats are presently servicing in the Cook Islands. Passengers are transported by the above-mentioned inter-island vessel when demand arises.

As shown in Fig. 8-2-1 above, more than 50% of the total number of ship calls is accounted for by pleasure boat, mainly small cruisers and yachts. Those pleasure boats are principally moored at the cargo wharves in Avatiu Harbour and moved as requested when a cargo ship arrives. It is undesirable to utilize the harbour for the above purposes since the number of calls for pleasure boats is expected to increase in the future.

Four large passenger ships called at Avatiu Harbour in 1991 (up to October), but could not enter the harbour due to a shallow depth basin and passengers were transported by shuttled boats to a wharf. In this case, a passenger intentionally or unintentionally avoids staying in the Cook Islands.

8.2.2 Port Facilities

The major existing facilities at Avatiu Harbour are shown in Table 8-2-4 and Fig. 8-2-3 below.

Table 8-2-4 Existing Major Port Facilities at Avatiu Harbour

Facilities:		Quantity	Owner	No.
Quay wall	(-6.2m)	226 m	TLT	1
	(-4.0m)	116 m	TLT	2
Eastern breakwater		about 220 m	TLT	3
Western breakwater		about 270 m	TLT	4
Cargo shed	No. 1	580 sq.m	WFC	5
	No. 3	1,056 sq.m	WFC	6
Container freight station		880 sq.m	WFC	7
Maintenance shop		170 sq.m	WFC	8
Canteen		135 sq.m	WFC	
High-tension and low-tension substation		60 sq.m	TLT	13
Area of LPG tank		2,580 sq.m	Cook Is. Gas	9
Fisheries office and shed		230 sq.m	Marina Resources	10
TLT work shop		380 sq.m	TLT	11
Slipway		1	MOT	12
Office of Water Front Committee		226 sq.m	WFC	14
Cargo handling equipments:				
Forklift	25 tons	1		
	8 tons	1		
	3 tons	2		

Note) The numbers on right column of this table correspond to the numbers indicated in Fig. 8-2-3.

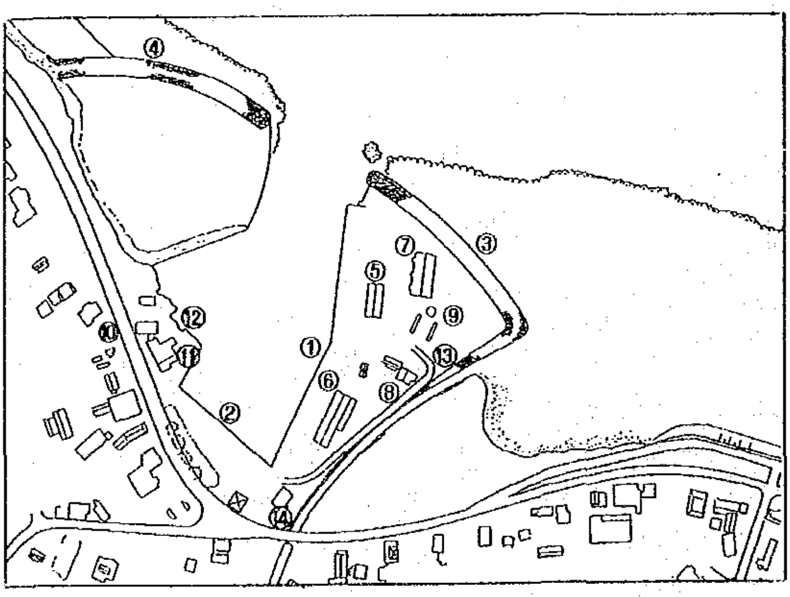


Fig. 8-2-3 The Location of Existing Facilities

The no.1 transit shed and the CFS are used for foreign trade cargoes and the no.3 transit shed is used for domestic cargoes. Almost all of the liquid bulk cargo (major origin is Fiji) is sent to the shortage tranker in the port area from the tanker by pipe line.

There is a small container yard at Avatiu Harbour. The capacity of this yard is about 60 TEUs.

The major users of the deep-sea berths at Avatiu Harbor are three liner vessels for foreign trade which are semi-container vessels, internal conventional liner vessels and liner tankers. The routes of liner vessels are shown in Table 8-2-1. The dimension of these liner vessels and the tankers are shown in Table 8-2-2. The quay wall on the south side at Avatiu Harbour is used by small fishing boats and pleasure boats excluding large yachts. The large yachts are moored at deep-sea berths on the east side of Avatiu Harbour. The widths of the entrance channel and the turning basin at Avatiu Harbour are about 30 meters and 130 meters respectively which are too small for large vessels that present call. Avarua Harbour is used by only small boats for pleasure and fishing. Figures 8-2-4 and 8-2-5 show the current plans of Avatiu and Avarua Harbours.

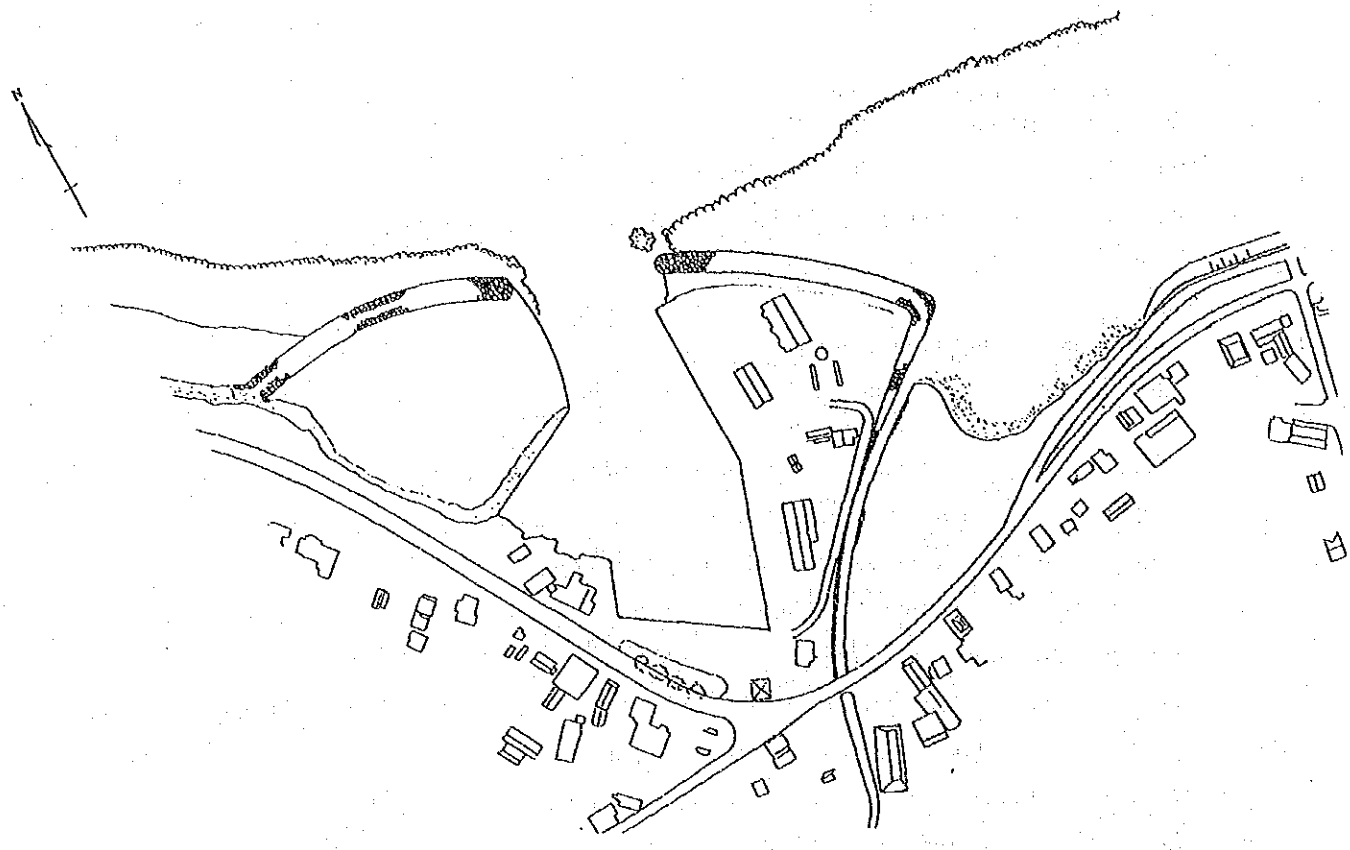


Fig. 8-2-4 Existing Avatiu Harbour

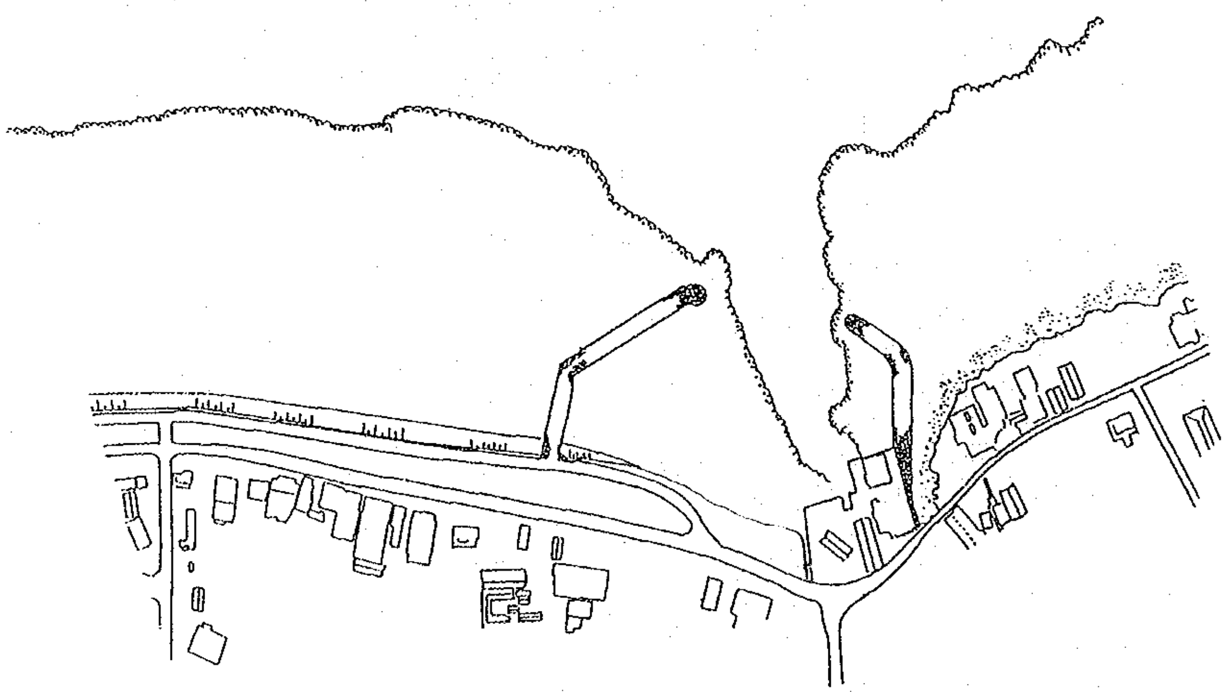


Fig. 8-2-5 Existing Avarua Harbour

8.2.3 Relationship to Coastal Protection

Two ports, Avatiu and Avarua are located at the center of northern coast of island where a large-scale of damage by Cyclone Sally was recorded.

As recommended in Chapter 7, urbanized coastal area surrounding the ports should be defended by protection works. Objective of this coastal protection is to ensure the safety of coastal area use and various concentrated properties.
It is reported that the existing breakwaters at Avatiu worked well as barriers against an extremely large wave of Sally. It is also observed that there was overtopping water bodies over the Avatiu wharf during Sally in 1987, however the intensity of this flood is much less than those at the Avarua coast. This means that the breakwaters reflected wave weather side, thus limited wave could penetrate into the port basin.

It is assumed by local observers that additional wave set-up might happen in the weather side of breakwater and might affect wave run-up to the land. Current induced by wave force might run along the weather side of breakwater and might rush to the root of it. However, demerits of breakwater are easily overridden by the merits. Scale of demerits are so minor than the merits, namely;

- Wave set-up by breakwater is so minor.
- Current direction along the weather side of breakwater is not to coast but offshore. This current will be against the intruded wave through passage and make it height lower.

Note: These are based on the computer simulation at Avarua Harbour.

Wharf front elevation has been planned as MSL + 2.0 meter for easy port operation, cargo handling and passenger services. The immediate port hinterland is low elevation along the streams. Elevation of the beach road which runs within 30 meter behind the end wharf is about MSL + 2.0 meter. Thus if wave overtopping the wharf, water bodies can easily penetrate into the existing inland. The maximum wave during a cyclone at the end of inner basin should be minimized.

More detailed discussion will be performed in section 8.6.

8.3 Port Traffic Forecast

8.3.1 General Description

It is difficult to forecast port traffic demands in the Avatiu Harbour for several reasons:

- presence of a government development project positively affects cargo volume handled; cargo volume is usually much less,
- the lack of time series data on commodity groups and the accuracy of data on cargo movements at Avatiu Harbour,
- shipping service changes in terms of vessel types and call frequencies (though the change is not dramatic).

As for the fishery, an accurate forecast cannot be carried out due to the significant quantity of fish that are caught but not recorded.

Tourism is one of the most hopeful and promising industries in the Cook Islands. Since tourist arrivals are relatively large in comparison to the population of the country (population: approx. 18,000/tourist arrivals: approx. 34,000), it is necessary to carefully consider the impact of tourists for the demand forecast.

Based on the above-mentioned facts, a forecast will be carried out with the following subsections.

8.3.2 Cargo Movements

1) Economic Frame for Future

a) Population

As described in Chapter 3, a peak in population was recorded in 1971 when it subsequently decreased up to 1986. The future trend depends upon both domestic and overseas countries' (especially New Zealand) economic activities; therefore, it is very difficult to assess the future population correctly. Officers of MOPED have divided opinions on population in future, that it will remain constant, fluctuate or occasionally decrease. Accordingly, a 0.3% annual growth rate is to be adopted for this study in order that population in 2010 shall not exceed 20,000 persons for the whole country.

Results of population forecast for the target years are as follows:

Table 8-3-1 Population Forecast

Year	Population	Plan
1997	18,500	Short-term plan
2010	19,200	Master Plan

As mentioned above, tourist arrivals have been considered. In the recent past, although tourist arrivals stagnated from 1981 to 1983, the arrivals were generally increasing annually and are also expected to rise in the future to some extent since tourism is one of the main industries of the Cook Islands.

In the Master Plan report prepared by the Asian Development Bank (ADB) loan, an annual growth rate of around 4% for tourist arrivals and about 106,000 tourist arrivals is forecast for the year 2010.
Considering facilities and attractions for tourism, the numbers seem to be inflated; therefore, a 20-year average growth rate of around 3.5% will be adopted. Results are:

Table 8-3-2 Forecast for Tourist Arrivals

Year	Tourist Arrivals
1997	49,000
2010	73,000

Since the average length of stay for a tourist was approx. 10 days in 1990 (from Tourist Authority), the number of tourists equivalent to permanent residents is as follows.

Table 8-3-3 Equivalent Numbers of Tourists

Year	Equiv. Tourists
1997	1,340
2010	2,000

The nominal growth rate of population is 0.53% annually taking into consideration the equivalent number of tourists.

With regard to visitors by ship, 328 persons were recorded in 1990, about 1% of the arrivals by ship, and so the effect of visitors by ship is negligible for the demand forecast.

b) GDP

As for GDP, MOPED has already estimated it for the period 1991 to 1995 and that trend will be used for the estimate over the period 1996 to 2010. This estimate complies with a simple linear regression analysis based on the data of GDP from 1982 to 1990. In accordance with this analysis, estimates of GDP for the target years are as follows.

Table 8-3-4 Forecast of GDP

	GDP (NZ$ '000)	
Year	at Current Prices	at 1990 Const. Prices
1997	177,560	119,168
2010	309,359	128,900

2) Forecast of Cargo Volume

a) Overseas Cargo (Inward)

As mentioned in 8.2.1, the data of cargos handled available for the study have no time trend, and there is no relation with population or GDP etc. because of fluctuation of the data. The forecast can not be performed using these past records. Therefore, the forecast will be carried out according to the estimated future trend of the economic frames.

Now, the following formula can be used in general as one of the methods of estimating traffic demand.

$$T = (E \times I / 100 + 1) \times (P / 100 + 1) - 1$$

where,
- T: Annual growth rate
- E: Transport demand-income elasticity (1.0 - 1.5 in general)
- I: Growth rate for income in %
- P: Average annual growth rate of population in %

Occurrence of traffic demand is not independent of, but rather has a close relation with economic activities of the back-up areas concerned, especially with the consumption trend. In the Cook Islands, cargo by sea transport consists of, to a large extent, consumption goods such as foods and beverages, clothes and household goods as stated above. In this respect the above formula is applicable for forecasting port traffic demand in this country. When using the formula, GDP data is to be used for the calculation since no information regarding income (or consumption) is available.

As for E, the values between 1.0 to 1.5 are known in general according to past experience with the formula, and 1.1 is used for calculation from the available past data. I, expressed at 1990 constant prices is 1.7% up to 1997, and 0.6% from 1997 to 2010. P is 0.53% including equivalent number of persons from tourists as mentioned above.

Therefore, estimated total cargo volume for the target years based on that of 1990 is as follows.

Table 8-3-5 Forecast of Cargo Volume

Year	Total Cargo Volume Handled ('000 Freight Ton)
1997	46.4
2010	54.2

Next, a forecast for each commodity will be carried out.

Among the five commodities (foods, construction materials, motor vehicles, fuel and others), construction materials, motor vehicles and others are not strongly dependent on the number of visitors but purely on consumption of the Cook Islanders. Therefore, P is to be adopted at 0.3% instead on 0.53% in the above formula. Results are as follows.

Table 8-3-6 Forecast of Cargo Volume by Commodities

Commodities	Cargo Volume Handled ('000 Freight Ton)	
	1997	2010
Foods	11.9	13.9
Construction Materials	4.3	4.8
Motor Vehicles	5.5	6.2
Fuel	13.6	15.9
Others	10.8	12.3
Total	46.1	53.1

Of the above two calculation cases, the latter case will be adopted as the result of forecast.

3) Domestic Cargo (Outward)

Domestic cargo volume handled at Avatiu Harbour destined for outer islands is as follows. A cargo volume of approximately 2,000 freight tones has been recorded in recent years.

Table 8-3-7 Past Records of Cargo Volume for Domestic Cargo

Year	Past records of Outward Cargo Handled ('000 Freight Ton)
1989	2.3
1990	2.1

Forecast for domestic cargo can be estimated by the same procedure as overseas. Since GDP for the respective islands is not available, it is assumed that future GDP of the respective islands has the same tendency as overall GDP of the country. With regard to distribution of population, the proportion of Rarotonga and the other islands has consistently been approx. 55% and 45% respectively since 1971 when a peak in population was recorded and the same proportion is expected to be unchanged up to 2010. Therefore, the growth rate of population P in the formula will be 0.3%.

Results are *shown* below.

Table 8-3-8 Forecast of Cargo Volume for Demestic Cargo

Year	Forecast of Outward Cargo handled ('000 Freight Ton)
1997	2.4
2010	2.8

Also all cargoes are to be non-containerized in the future.

4) Ratio of Containerization for Overseas Cargo

Ratio of containerization for cargo in 1990, excluding break bulk, is 61% as shown in table 8-2-3. From the table, cargoes entering the Cook Islands are well containerized.

When forecasting the ratio of containerization, conditions of the mother port and other ports where a vessel calls have to be considered. The ratio of containerization at the port of Auckland in New Zealand and the port of Suva in Fiji is 69% in 1990 and 74% in 1989 respectively. Since these ports are almost fully containerized, the ratio of containerization in Avatiu Harbour will become 70 to 75% in 2010, depending upon the proportion of commodities.

A ratio of 95% for foods was recorded in 1990, which is practically the maximum value. Most construction materials are long and heavy, so the ratio of 10% recorded in 1990 will be limited in the future, Small machinery, motorcycles and related parts and others can be containerized with a ratio of 90 to 95% in the future.
Consequently, the expected ratio of containerization in 2010 can be shown in Table 8-3-2 below.

Table 8-3-9 Ratio of Containerization in 2010

('000 Freight ton)

Commodities	Frgt. ton (,000)	Ratio of Contnr.	In Cont. (,000)	Non-Cont. (,000)
1) Foods	13.9	0.95	13.2	0.7
2) Construction Material	4.8	0.10	0.5	4.3
3) Vehicles	5.0	0.00	0.0	5.0
4) Motorcycles & Parts	1.2	0.95	1.1	0.1
5) Others	12.3	0.90	11.1	1.2
Total	37.2	0.70	25.9	11.3

In order to determine the required area of CFS etc., a ratio of the number of LCL containers to the total number of containers (LCL ratio) has to be estimated. According to the investigations of cargo manifests, the LCL ratio is from 20 to 30% to the total number of containers though it depends on the proportion of the commodities transported.

Therefore, the LCL ratio is to be a maximum of 30% in the future, as the proportion of imported commodities will basically remain unchanged.

5) Number of Ship Calls

As aforementioned, the total containerized cargo volume in 2010 is 25,900 freight tones. And assuming the ratio of containerization will linearly change from 61% in 1990 to 70% in 2010, the ratio in 1997 becomes 64% and the total containerized cargo volume in 1997 is 20,800 freight tonnes.

An average of approximately 15 freight tones per TEU was recorded in 1990 and using this value, containers of approx. 1390 and 1730 TEUs annually will be handled in 1997 and 2010 respectively. And approx. 35 TEUs per vessel were unloaded at Avatiu Harbour in 1990 and considering this, approx. 40 and 50 calls at Avatiu Harbour annually will be expected in 1997 and 2010 respectively.

As for future trends in the types of container ships, large container ships have been further enlarged at a quite small rate recently in international shipping routes. Shipping route via the Cook Islands and other Pacific countries is much smaller than main international routes in both size and TEUs loaded on ship. Therefore, sizes of container ships in this area will not radically change in the future.

In addition, the number of calls for tankers will be estimated. According to the records in 1990, fuel of approx. 1,000 tonnes/vessel was transported. Using this value, the number of calls for tankers is expected to be 14 in 1997 and 16 calls in 2010.

Numbers of ship calls are summarized as follows.

Table 8-3-10 Forecast of Ship Calls

Year	Number of Ship Calls		
	General Cargo Ship	Tanker	Total
1997	40	14	54
2010	50	16	66

8.3.3 Fishery

There are three typical fishery sectors, namely subsistence, artisanal and commercial fishing in the Cook Islands.

Among the above sectors, commercial fishing could not be developed in the Cook Islands for the following reasons:

- it takes a long time to transport fish caught near outer islands to Rarotonga for transshipment to overseas, thus a freezer on ship and large cold storage area at the fishing port are required,
- generally, the potential of fish resources except migrant fish is not high since a continental shelf does not exist around this area,
- since there is no direct airline route to Asia where a big market for the consumption of fish exists, it is difficult to keep the fish fresh.

Therefore, subsistence and artisanal fishing shall be considered only. That is to say, fish in this country are for domestic consumption.

Since there is no available data for forecasting future demand for fishing facilities at present, the following description is based on an expectant figure of the fishery in the future in the Cook Islands.

Before the forecast (or assumption) hereunder, some reasons can be given for the necessity of developing fishing port facilities, such as landing wharf, lay-by wharf, ice making plant, fish market and so on:

- circulation of much more quantitative and qualitative fish in the market and promotion of protein consumption important for the health of the Cook Islands people,
- benefits for the development of fishery industry by controlling and maintaining fishing gears and facilities systematically,
- contribution to the effective development and utilization of marine resources, a higher standard of living for fishermen and analysis of fishery trend by managing quantity of fish catches intensively,
- demarcation of fishing port area independent of commercial and pleasure activities in the harbour (cargo ships, pleasure boats and fishing boats congest the harbour at present).

1) Forecast of Fish Catch Handled

Approx. 55 fishing boats are in part-time use (occasionally full-time) in Rarotonga at present, and fish with a total weight of approx. 150 tons are annually landed according to the hearing. Accordingly,

$$150/55 \doteqdot 2.7 \text{ ton/year·boat}$$

On condition that the rate of food consumption will be maintained in the future, amount of fish caught will increase according to the growth of population and income (or consumption), the same as in the forecast for cargo volume. When the growth rate of fish catches correlates to the growth rate of population; when including equivalent number of tourists, the rate from 1990 to 2010 becomes approx. 10%. Therefore, fish catches of approx. 170 tons are expected in 2010. Furthermore, the Ministry of Marine Resources intends to vigorously develop the fishery industry in the future, at which point 200 ton will be adopted for the Master Plan.

2) Number of Fishing Boats

It is assumed that fishing methods and fish catches will not grow before 1997; then approx. 35 fishing boats existing at both Avatiu and Avarua Harbour are considered for the year 1997.

The same assumption used for fish catches will be applied for forecasting the number of boats in 2010. The number of boats will reach approx. 60, increasing at a rate of 10% from 1997 to 2010, provided that types of all boats remain unchanged. In the event that 30% of the fishing boats are of a larger type with the maximum length of 10m, the total number of boats would be approx. 50.

The results are summarized as follows.

Table 8-3-11 Forecast of Number of Fishery Boats

Year	Type of Boat	Number of Boats
1997	L = 4 - 6 m (existing)	35
2010	L = 4 - 6 m	40
	L = max. 10 m	10:Total 50

8.3.4 Tourism

In this section, the demand for marina facilities will be forecast. Since pleasure boats using harbours in the Cook Islands are principally from overseas, the number of calls of pleasure boats is basically independent of socio economic conditions in the country; however, they are occasionally affected by the existent facilities of a marina. Fig. 8-3-1 shows that the number of calls of pleasure boats at Avatiu Harbour has consistently grown from 1985 to 1990, and the number can be expected to increase in the future.

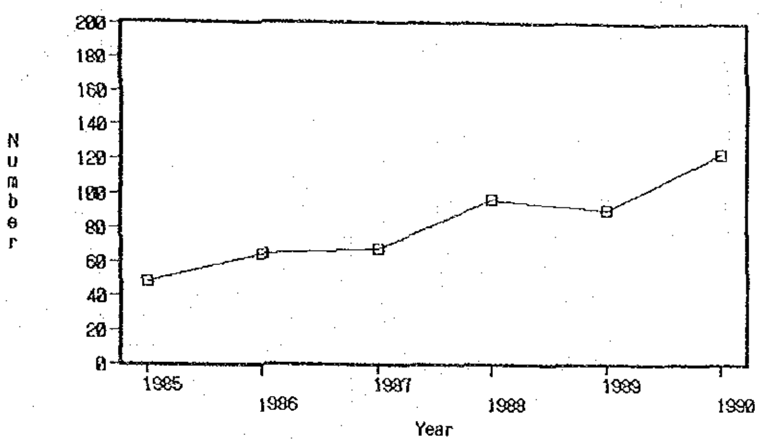


Fig. 8-3-1 Number of Calls for Pleasure Boats at Avatiu Harbour (1985 ~ 1990)

When a simple linear regression analysis is applied for forecasting the number of calls for pleasure boats using the above time series data, the annual number of calls is 190 in 1997 and 340 in 2010. The maximum number of boats simultaneously staying in the harbour was recorded at 20 boats in 1990 as shown in Fig. 8-3-2, 17% of the annual calls. This concentration degree will be applied for estimating the maximum number in the future; so it is expected that approx. 33 in 1997 and 60 boats in 2010 will be moored simultaneously at a marina.

According to past data and information from the Tourist Authority, an average of around three persons are on board. Therefore, the maximum number of persons who will utilize marina facilities can be expected to be 100 in 1997 and 180 persons in 2010 at most. Appropriate facilities will be required to accommodate the above number of pleasure boats and persons.

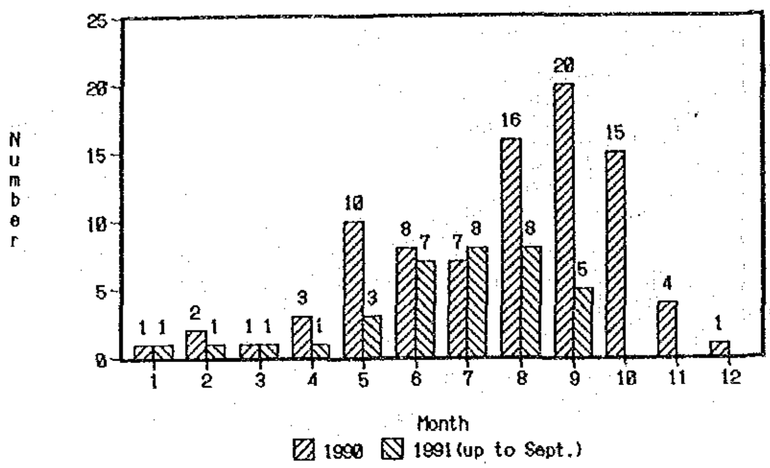


Fig. 8-3-2 Number of Calls for Pleasure Boats Simultaneously Moored at Avatiu Harbour by Month in 1990 and 1991

8.3.5 Port Park Complex

The coastal area between Avatiu and Avarua is the center of commercial activities in Rarotonga Island. This area was reclaimed in 1991 by MOW for buffer zone against cyclone waves and more space for public use and port. New reclamation of this area is proposed in the coastal protection plan as discussed in Chapter 7. This reclaimed area is named as the Port Park Complex, where various land use can be expected including,

a) Buffer zone against cyclone waves and surges,
b) Park with plantation,
c) Sports ground,
d) Car parking space, and
e) Avatiu Harbour expansion area (1.5 Ha)
f) Others,

There are not directly related to the port activities, however, estimation of vehicular traffics are conducted for the smooth road traffic along the Port Park Complex and the port areas.

There are many cars passing through and parking in the area during the day, and this sometimes causes a traffic jam. In order to resolve this relatively overcrowded condition, a parking area will be required as an allowance of land use plan.

An observation of the number of parked cars in this area was conducted at 10 a.m., 12 p.m. and 3 p.m. on 11th (Mon.) to 15th (Fri.) of November 1991. According to the observations, the variation of the number of parked cars in each time during the day was very small while the variation among the five days was slightly larger. The maximum number was observed on Friday, followed by Monday.

Most cars entering this area on week days are used by local people of the island. There are a few cars used by tourists if we consider the number of rental cars in comparison to the total number of cars. Therefore, the expected number of parked cars in the future is subject to the population growth excluding the number of tourists. The population in Rarotonga is 55 % of the total population and is assumed to maintain that proportion as aforementioned. Under this assumption, the population in 2010 will be approx. 1.1 times that of 1991. Since an average of 410 parked cars in a day was observed, approx. 450 cars will be expected in 2010. The maximum number of parked cars was observed on Friday; it was approx. 1.15 times of the average number. Accordingly, a maximum number of approx. 520 cars is expected to park in this area each day in 2010.

Considering time distribution, the number of parked cars did not significantly vary but the peak number was observed at noon, and was approx. 1.04 times greater than the average number by time periods. Using this value, therefore, the maximum number of parked cars can be expected at 180 in 2010 for each time period.

Large vehicles such as buses and trucks were observed at a rate of 3.5 % according to the result of the observation and this rate is used for the calculation of a required area for parking.

According to the Handbook of Traffic Engineering, a required parking area for a common car and a large vehicle is 11.25 sq.m (5m x 2.25m) and 42.25 sq.m (13m x 3.25m) respectively.

The number of large vehicles equivalent to a common car is;

$$180 \times 0.035 \times (42.25/11.25) \fallingdotseq 24$$

The total number of parked cars is;

$$180 \times 0.965 + 24 = 200$$

8.4 Projection of Port Facilities

This section deals with required port facilities. The existing facilities will be utilized as much as possible if they are properly arranged to meet the future traffic demands and mode of transport.
Land use of the Port Park Complex will be discussed in section 8.9.

8.4.1 General Description

The required number of deep-sea berths for foreign trade is determined using the berth occupancy rate. The calling vessels for the foreign trade at the deep-sea berths of this project are assumed to be liner vessels which are semi-container type and tankers. The total number of each type of calling vessel for foreign trade is shown in section 8.3.

The berth for domestic trade should be separated from foreign trade berth to facilitate customs procedures. Therefore, the domestic trade berth will be established at the south side of the east wharf.

The scale of the required facilities for the fishing port and the marina is determined by the number and scale of the fishing boats and the large calling yachts, which are estimated also in section 8.3.

The width of the entrance channel and the scale of the turning basin are decided considering the safety of the large calling vessels in the target year of this project.

The required scale of the cargo handling facilities for the function of a commercial port, namely, the container storage yard, CFS and transit shed, is decided considering the cargo flow and dwelling time of cargoes in these facilities. (Note: Dwelling time means length of stay of cargo.)

8.4.2 Deep Sea Port Area

Function allocation will be discussed in section 8.5. At any rate, the deep sea port area will be located in Avatiu Harbour. Thus, at any rate, facilities required for deep sea berth will be allocated to Avatiu Harbour.

1) Mooring Facilities and Basin

As mentioned in section 8.4.1, the required number of deep sea berths for foreign trade is determined using the berth occupancy rate.
The formula of the calculation is as follows:

$$r = (n/365)/(S \times (m/Va))$$

where r: Berth occupancy rate

n: Number of larger vessels calling per year (General cargo ship: 50 Vessels, Tanker: 16 Vessels)

S: Number of berths (1 berth)

m: Cargo handling capacity (including idle time) per berth per day (General cargo ship: 390 tons, Tanker: 840 tons)

Va: Average cargo handling volume per vessel (General cargo ship: 744 tons, Tanker: 993 tons)

(General cargo ships)

$$r = (50/365)/\{1 \times (390/744)\} \doteqdot 0.261$$

(Tanker)

$$r = (16/365)/\{1 \times (840/993)\} \doteqdot 0.052$$

(Total)

$$r = 0.261 + 0.052 = 0.313$$

The berth occupancy rate of the deep-sea berths for foreign trade in 2010 is about 31.3 percent. Therefore, an additional deep-sea berth for foreign trade need not be constructed in 2010.

The depth of the deep-sea berths for foreign trade at present is about 6.2 meters below the Mean-Sea Level. Consequently, the depth of the berths and the basin for foreign trade vessels will have to be dredged to -7.5 meters because the depth of the berths is currently not sufficient for large vessels.

The quay wall at the south side of the east wharf in Avatiu Harbour will be used by domestic trade vessels in the Master Plan.

The width of the basin in front of the foreign trade berths will have to be expanded to facilitate the safe turning of large vessels. The width of the basin in case of using a tugboat is calculated using the following formula.

$B = 1.5L$

where B: Width of the basin (m)

L: Length of the maximum liner vessel (93.0 m)

$B = 1.5 \times 93.0 \doteqdot 140.0$

The required width of the basin is approximately 140 meters. The depth of the basin is -7.5 meters, the same as the depth of berths.

2) Cargo Handling Facilities

The dimensions of the present transit sheds in Avatiu Harbour do not need to be expanded in the Master Plan because the cargo volume of foreign trade and domestic trade will not greatly increase in the Master Plan. In addition, the present condition of the transit sheds have enough room for sorting and storage.
The required area of the container freight station(CFS) is calculated using the following formula:

$A = (Mc \times Dw \times P)/(w \times r \times Dy)$

where A: Required floor area of CFS (Sq.m)

Mc: Annual cargo throughput of containerized cargo through CFS (7,770 tons)

Dw: Dwelling time at terminal(7 days)

P: Peak ratio(1.5)

w: Volume of cargo per unit area (1.3 tons)

r: Utilization rate of CFS Floor (0.5)

Dy: Operating days(302 days)

$A = (7{,}770 \times 7 \times 1.5)/(1.3 \times 0.5 \times 302) = 415.6$

The result of the calculation shows that approximately 420 square meters will be needed, which is less than the present area. So, the area of the CFS will not be changed in the Master Plan.

The area of the container storage yard is decided based on the required storage number of containers at the storage yard. The required storage number of containers is calculated by the following formula:

$M = (My/Dy) \times Dw \times P$

where M: Required storage number of containers (TEU)

My: Annual container traffic (3,454 TEU)

Dy: Annual operating days (302 days)

Dw: Dwelling time of a container box at the storage yard (8.63 days)

P: Peak ratio (1.5)
(Refer to Appendix D4.3.)

$M = (3{,}454/302) \times 8.63 \times 1.5 = 148.06 = 148$

The required data on the storage condition of the container yard was not available in the Cook islands, therefore, the condition of the storage yard in the Master Plan is decided based on Japanese data. The required area of the container storage yard in case of the forklift system in combination with tractor-trailers is calculated by the following formula.

$Ay = \{(M/Hc) \times As\}/d$

where Ay: Required area of container storage yard (sq.m)

M: Required storage number of containers (148.0 TEU)

Hc: Average *stacking height of container* (1.5)

As: Area of a slot (15.0 sq.m)

d: Utilization rate of storage yard (0.22)

$Ay = \{(148.064/1.5) \times 15.0\}/0.22 \div 6{,}746$

The result of the calculation show that approximately 6,800 square meters are needed for the container storage area in the Master Plan.

The number of storage containers at the marshaling yard is the same as the number of handling containers per vessel. The required area of the marshaling yard is calculated using the following formula.

$Am = [\{(Mi \times P)/Hc\} \times As]/d$

where Am: Required area of container marshaling yard (sq.m)

Mi: Average number of handling container per vessel (70 TEU)

Hc: Average staking height of container (1.5)

P: Peak ratio (1.6)

d: Utilization rate of marshaling yard (0.22)

As: Area of a slot (15.0 sq.m)

$Am = [\{(70 \times 1.6)/1.5\} \times 15.0]/0.22 \div 5{,}103$

The required marshaling area in the master Plan in case of the same container cargo handling system as the system at the container storage yard is about 5,100 square meters.

The following equipment will be required in the Master Plan.

Container handling:	3 large forklifts (32 tons)
	2 tractor-trailers (for transported containers between the marshaling yard and the storage yard and between the alongside and the marshaling yard) 2 forklifts (2.5 tons at CFS)
Conventional cargo handling:	4 forklifts (2.5 tons) for use on board
	4 forklifts (5 tons) for use during ground operation

The cargo handling equipment for conventional cargoes is used for foreign trade and domestic trade.

3) Breakwater

The predominant direction of the offshore wave around Avatiu Harbour is ENE. So, to ensure a calm water space, the improvement of the east side breakwater against these waves is a fundamental necessity. The direction and length of the breakwater are decided considering the result of the wave calmness analysis and the construction cost. The rough plane and the effect of the improved breakwater is mentioned in sections 8.6 and 8.7.

4) Other Facilities

Other facilities to be installed at the deep-sea berths at Avatiu Harbour, including the domestic trade berth, are as follows:

Maintenance shop for the cargo handling equipment
: about 170 sq. meters

Control office of container terminal : 200 sq. meters

Others: Water supply facilities, electric supply facilities and etc.

8.4.3 Fishing Port Area

Some of the required data for the fishery port planning is not available in the Cook Islands because the related offices of the fishery do not yet have a research system or keep statistics. Therefore, required data is substituted with data gathered from similar projects.

1) Landing Wharf

The main factors in determining the length of the landing wharf are the length of the fishing boat, number of mooring boats per day at the landing wharf, working time of the landing wharf and the landing time per boat. However, except the length of fishing boat, the necessary data is not available in the island therefore, the length of the landing wharf is determined using available Japanese data. The required length of the landing wharf is calculated using the following formula:

$$Lr = \{(N/r) \times L\} + A$$

where Lr: Required length of the landing wharf (m)
N: Average number of boats per day (30 boats)
r: Turnover rate (10.0)
L: Berth length per boat (7.2 m)
A: Allowance (7.0 m)

$$Lr = \{(30/10) \times 7.2\} + 7.0 = 28.6$$

$$r = Tw/Tb$$

where Tw: Available working time of the landing wharf (2.5 hours)
Tb: Landing time per boat (0.25 hours)

$$r = 2.5/0.25 = 10$$

According to the result of the calculation, required landing wharf length is approximately 30 meters. So in this study, the length of the landing wharf will be set at 50 meters to allow for future expansion.

2) Lay-by Wharf

The required length of the lay-by wharf is calculated using the following formula.

$La = n \times B$

where La: Required length of the lay-by wharf (m)

n: Average number of boats per day (60 boats)

B: (Boat beam) x 1.5 = 2.0 x 1.5 = 3.0 (m)

$La = 3.0 \times 60 = 180$

The average length of the boat in the Master Plan was determined in section 8.3. The beam of the fishery boat is determined based on the above length using the Japanese standard. (Refer to Table 8-4-1)
The result of the calculation shows that the required length of the lay-by wharf is approximately 180 meters.

3) Sorting Facilities

The required area for the sorting at the market hall is determined using the following formula:

$S = N/(R \times d \times p)$

where S: Required area for sorting (sq.m)

N: Volume of the fish catch per day (700 kg)

R: Turnover ratio per day (1.0)

p: Volume of cargo per unit area (40 kg)

d: Utilization rate of the floor (0.25)

$S = 700/(1 \times 0.25 \times 40) = 70$

According to the result of the calculation, required sorting area is approximately 70 square meters.

There are several activities at a marketing hall, such as sorting, washing, weighing, auction and packing. Therefore, a marketing hall must be composed of three areas, namely, a sorting area, packing area and weighing area. The area of marketing hall is determined to be approximately 200 square meters because the packing area is as large as the sorting area.

Table 8-4-1 Dimension of Fishing Boat

GT (TONS)	L.O.A. (M)	Breadth (M)	Draft	
			Max. (M)	Mini. (M)
1	7	1.8	1	
2	8	2.2	1.2	
3	9	2.4	1.4	
4	10	2.6	1.6	
5	11	2.8	1.8	
10	13	3.5	2.0	1.9
20	17	4.3	2.2	2.1
30	20	4.7	2.5	2.3
40	22	5.2	2.7	2.5
50	24	5.5	2.9	2.6
100	30	6.5	3.7	3.2
150	35	7.2	4.2	3.5
200	40	7.6	4.6	3.8
500	55	9.4	5.9	4.5

Source: Japanese Standard

4) Ice Making Plant

The primary factors in determining the area of the ice making facility are the relation between the volume of fish catch and the volume of ice used per unit fish catch and the capacity of the ice making machine.
According to the actual data in Japan, the relation between the volume of ice used for fish catch and the volume of fish catch is as follows:

(volume of ice used for fish catch)/(volume of fish catch) = 0.86

The capacity of the ice plant is determined using the following formula:

$$Ci = \{0.86 \times (\text{volume of fish catch})\}/(r \times Wd)$$

where Ci: Requisite capacity of the ice plant (tons per day)
r: Working ratio of ice plant (0.517)
Wd: Working day of the ice plant (365 days)

Volume of fish catch per year: 200 tons

$$Ci = \{0.86 \times (200)\}/(0.517 \times 365) = 0.91 \div 1.0$$

The working ratio of the ice plant is determined using actual data in Japan. According to the result of the calculation, the required capacity of the ice maker is approximately 1 ton per day.
The ice making facility requires an area of approximately 55 square meters according to the estimation using Japanese data. (Refer to Table 8-4-2)

The related office of the ice making plant should be located in the same area as the ice making plant itself. Therefore, the area of the ice making facility is determined to be approximately 75 square meters.

Table 8-4-2 Relation Between Area of Ice Machine Building and Capacity of Ice Machine

Capacity of ice machine (tons/day)		1	3	5	10	20	30	50	100
Capacity of storage room of ice (tons)		60	180	300	600	1100	1500	2000	3000
Area of ice machine building (sq.meter)	Ice machine room	24.8	48.4	59.4	86.6	178.2	231.0	376.8	752.4
	Storage room of ice	26.4	72.0	100.7	178.2	290.4	396.0	534.6	772.2
	Machinery room	-	23.1	33.0	49.5	79.2	66.0	89.1	138.6
	Electric supply room	-	-	-	-	-	-	19.8	33.0
	Office	-	9.9	12.4	24.8	46.2	39.6	52.8	52.8
	Others	3.3	11.6	12.4	19.8	33.0	59.4	75.3	161.7
	Total	54.5	165.0	217.9	358.9	627.0	792.0	1,148.4	1,910.7

Source: "Gyokou keikaku no Tebiki", 1980

5) Repair Shop for Fishing boats

The required area of the repair shop for fishing boats is approximately 80 square meters, which is calculated using the Japanese standard.
The area of the current work shop (TLT workshop in Avatiu Harbour) is approximately 380 square meters, which is larger than the required area of the workshop for the fishing boats. Therefore, the area of the workshop in the Master plan will be the same as at present, approximately 380 square meters. It is assumed that the existing one can be utilized moving from present area to the planning area.
The required area is calculated using the following formula:

$$A = (D/P) \times X \times (1/r) = (300/302) \times 40 \times (1/0.5) \fallingdotseq 80$$

$D = V \times N \times d = 60 \times 2.5 \times 2 = 300$

A: Required area of repair shop (sq.m)

D: Total number of days used in the service of boats (300 days)

P: Total number of available working days per year (302 days)

X: Occupied area of a fishing boat for repair (40 sq.m)

V: Number of repair boats per year (60 boats)

d: Number of days for a repair per boats (2 days)

N: Number of repair times per boat per year (2.5 times)

r: Utilization rate of the area at the work shop (0.5)

8.4.4 Marina

Almost all of the required data for the marina is not available in Rarotonga. Therefore, the majority of the required data comes from Japan.

1) Quay wall

The required length of a quay wall differs according to the type of mooring method. In this study, a fixed fork-shaped type is adopted for the mooring facilities of the marina.
The dimensions of the type are shown in fig 8-4-1.

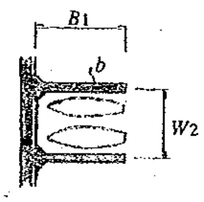


Fig. 8-4-1 Dimensions of Adopted Pier for the Yacht Harbour

where $B1 = (1.0 \sim 1.2) \times L$

$b = 1 \sim 1.5$ meters

$B =$ beam of the yachts: 4.5 m

$W2 = (2 \times B) + b + (1.5 \sim 2.0 \text{ meters})$

$= (2 \times 4.5) + 1.5 + 2.0 = 12.5$

The majority of yachts calling at Rarotonga are cruisers. The length of the large cruisers calling at Rarotonga is 20 meters or more. So, the length of the calling model yacht is assumed to be 20 meters.

The beam of the yacht is estimated using the relation between the length of yacht and a beam of yacht. The data for this is obtained from the Japan Ports and Harbour Association.

According to the result of the estimation, the beam of the model yacht for this plan is approximately 4.5 meters. The number of calling yachts mooring simultaneously at Rarotonga in the target year of the master plan is approximately 60 yachts. (Please refer to section 8.3.)

Therefore, the required length of the wharf for the calling yachts is approximately 300 meters.

8.5 Zoning and Function Allocation

8.5.1 Allocation Alternatives

The required functions both at Avatiu and Avarua Harbours are commercial port, fishery port and marina.
The function of the commercial port will be established at Avatiu Harbor because the deep-sea berths have already been established there; besides, A suitably wide water area for large vessels could not be obtained at Avarua Harbour since the passage length is shorter than Avatiu Harbour. There are four alternatives for zoning of the master plan concerning the functions of fishery port and marina.

Alternative 1: The function of fishery port is established at Avatiu Harbour and the function of marina is established at Avarua Harbour.

Alternative 2: The function of fishery port is established at Avarua Harbour and the function of marina is established at Avatui Harbour.

Alternative 3: The function of fishery port and marina are established at Avarua Harbour.

Alternative 4: The function of fishery port and marina are established at Avatui Harbour.

8.5.2 Evaluation

The fish catch at the North Islands area of the Cook Islands are transported to Avatiu Harbour in Rarotonga by large vessels. Then, the catch is handled at the deep-sea berths in this harbour. Several facilities, such as sorting facilities, ice-plant, fish market, parking area etc., need to be established at the fishery port. For the above reasons, it is recommended that the fishery port be established at Avatiu Harbour because Avarua Harbour does not have the sufficient area to construct the related facilities. In addition, Avarua Harbour currently does not have a deep-sea berth for mooring the large vessels from the North Islands area.

According to the cargo forecast in section 8.3, in the target year of the Master plan year 2010, the number of fishing boats and pleasure boats including large yachts will reach more than 60. So, if the fishery port and marina are both established at Avatiu Harbour, the basin, the land area for the installation of the necessary facilities and the possible faceline length for the required quay wall are insufficient. For the above reasons, alternative 4 is not viable for the Master plan. Therefore, alternative 1 is adopted for the Master plan of this project.

8.6 Countermeasures against Wave and Surge

This section deals with the protection works of port facilities against wave and surge. Studies are conducted in both cases, the cyclone condition and the normal climatic condition. The former aims at estimation of wave heights in order to provide necessary port protection for mitigation of wave overtopping the wharf and rushing into inland areas. While the latter is for forecasting occurrence probability of wave height by size to ensure the port operation safety against the normal wave generated by the prevailing Eastern winds.

Computer simulation of Sally wave at Avarua coast and Avarua Harbour are discussed in subsections 5.3.7 and 7.6.3.

8.6.1 Waves during Cyclone

1) Condition of Study

This subsection will provide necessary wave information at three observation points during the cyclone. Two alternative breakwater arrangements have been studied in respect to the wave intensity at the end wharf which is located at the deepest south.

Observation points are:

(i) Point F.----------- Foreshore -6.0 m
About 120 m off the reef edge

(ii) Point E.----------- Near the reef edge
(Almost port entrance)

(iii) Point O.----------- Southern end wharf

Each observation point for two harbours is shown in Fig. 8-6-1.

Condition of study is as follows:

a) Wave by Cyclone Sally
$H_o = 8.1$ meter
$T_o = 12.5$ sec.

b) Water level

Water level in the inner basin is assumed as follows.

Tide + Air depression rise + wave step-up

= 0.36 + 0.24 + 0.8

= 1.40 m above MSL.

Note: This data is shown in the previous JICA report, however is lower by 0.5 m than simulation results conducted by the team.

2) Wave Refraction

Fig. 8-6-1 shows wave refraction diagram. As seen on it, estimated refraction coefficient at Point F of both ports is relatively small. This is mainly due to the fact that the existing seabed configuration at passages are typical submerged stream valleies. This makes wave dispersion at the passage then wave concentration at the nearby lagoon.

Note: Refer to subsection 5.3.3 for the meaning of refraction diagram.

This phenomenon can be translated that;

a) Wave intensity penetrating into the port basin is smaller ones.

b) while, wave intensity at the closed lagoon is larger ones. Thus, coastal protection works near the passage should be more durable one than other area.

Note: Statement above do not include wave height reduction effect by the possible back-rush through passage. At present technology, it is difficult to take the back-rush into consideration of wave refraction. In this mean, it is recommended to refer to waves in computer simulation, subsection 5.3.7 and 7.6.3.

Wave height at Points F and E can be calculated by following formula.

$$Ho' = Ho \cdot Kr = Ho \cdot \sqrt{bo/b}$$

Where
- Ho': Equivalent offshore significant wave (m) (or wave at Point F/E)
- Ho: Offshore significant wave (m) (or wave before refraction)
- Kr: Refraction coefficient
  $Kr = \sqrt{bo/b}$
  - bo: offshore wave propagating density in meter
  - b: Inshore wave density in meter, refer to Fig. 8-6-1.

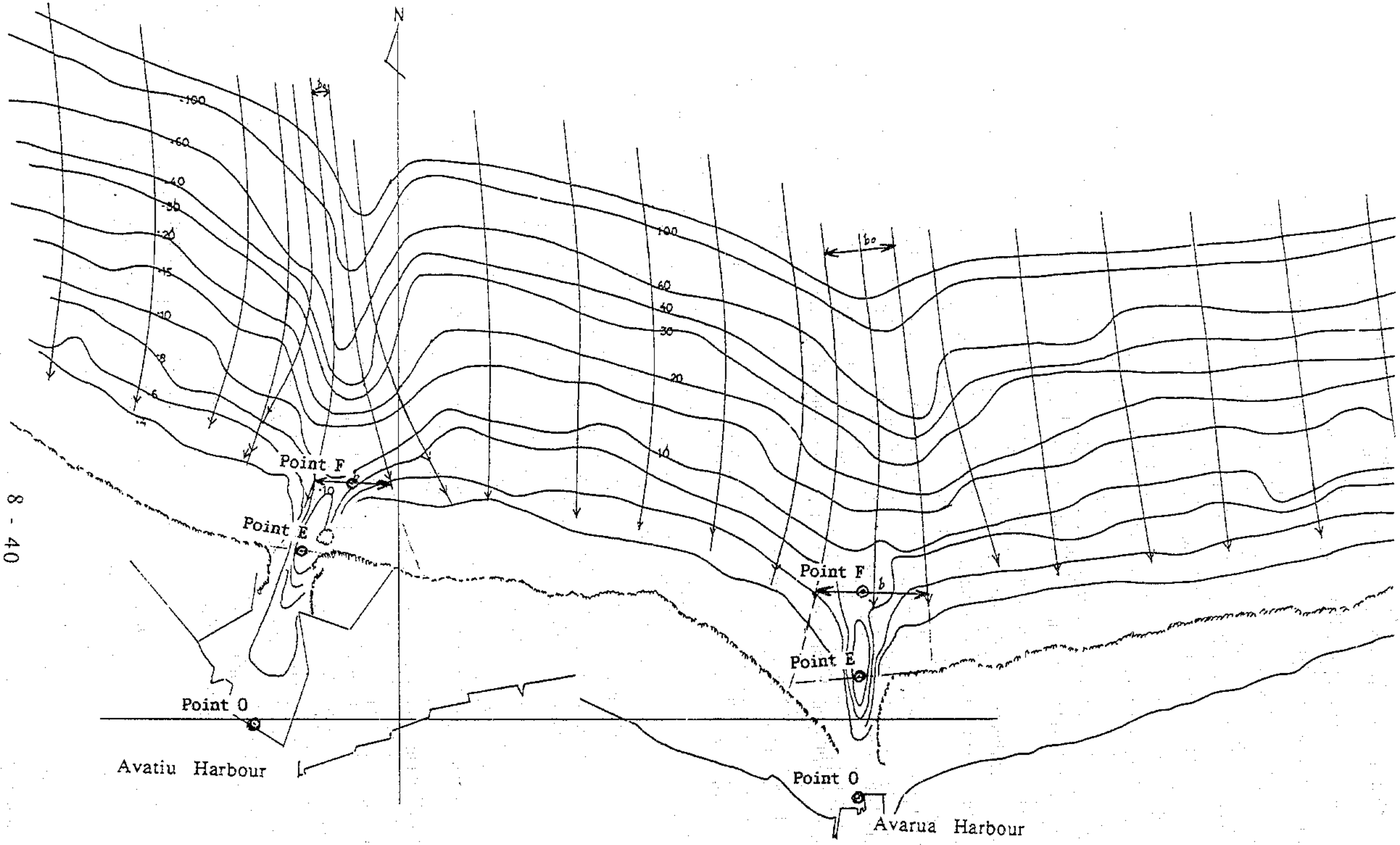


Fig. 8-6-1 Refraction Diagram
Wave Direction : N6°W
Wave Period : 12.5sec.
(Cyclone Sally)

3) Wave height near the Avatiu Port

<u>Point F</u>

$Ho' = 8.1 \times \sqrt{30/130}$

$= 8.1 \times 0.48$

$= 3.9$ meter

<u>Point E</u>

$Ho' = 8.1 \times \sqrt{30/250}$

$= 8.1 \times 0.35$

$= 2.8$ meter

4) Wave height near the Avarua Port

<u>Point F</u>

$Ho' = 8.1 \times \sqrt{120/190}$

$= 8.1 \times 0.79$

$= 6.4$ meter

<u>Point E</u>

$Ho' = 8.1 \times \sqrt{120/270}$

$= 8.1 \times 0.67$

$= 5.2$ meter

5) Wave height in the Avatiu Port: Point O.

Two alternative breakwater layouts are provided to analyze the cyclone wave intensity in the port basin.

<u>Case "Present"; Existing breakwater arrangement, Fig. 8-6-2.</u>

Conditions,

- Wave at Point E (Entrance)	Ho' = 2.8 meter
- Wave period	To = 12.5 sec.
- Water depth	h = 6.2 meter in average
- Wave length in deep water	Lo = 244 meter
- Wave length at Point E	L = 95 meter
- Entrance width	B = 86 meter

- Diffraction coefficient by irregular wave diffraction diagram in Smax = 75
- Wave direction at Point E (entrance) N20°E

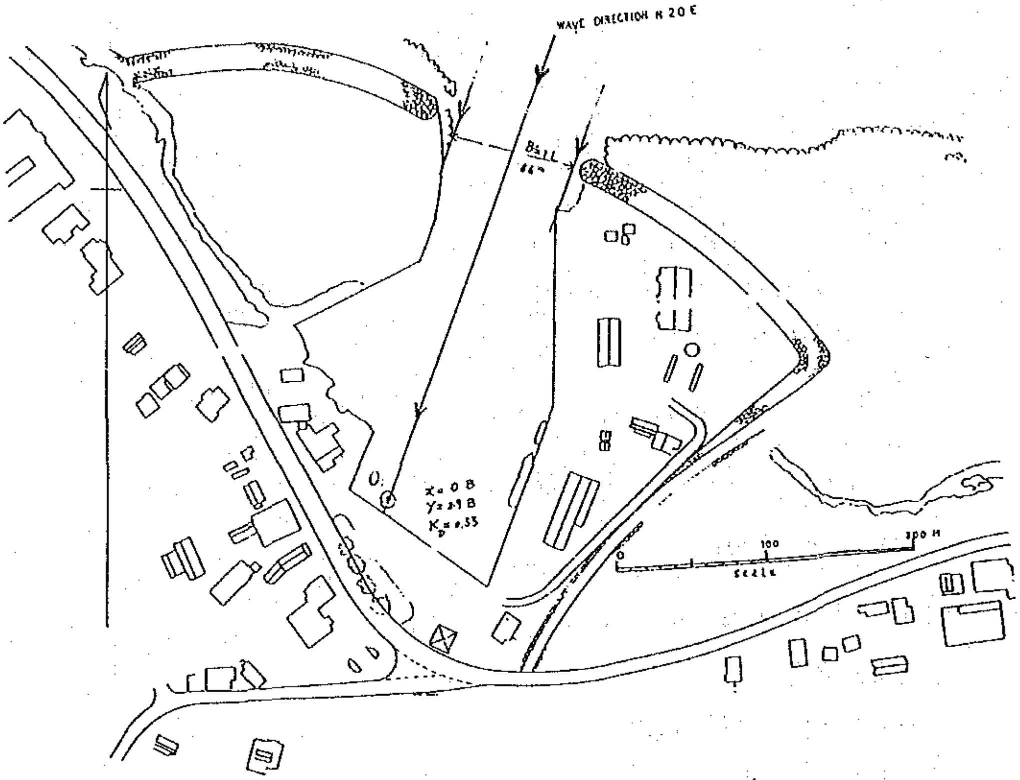


Fig. 8-6-2 Diffraction Coefficient Kd at 01 (Avatiu Port) in the Existing breakwater Arrangement

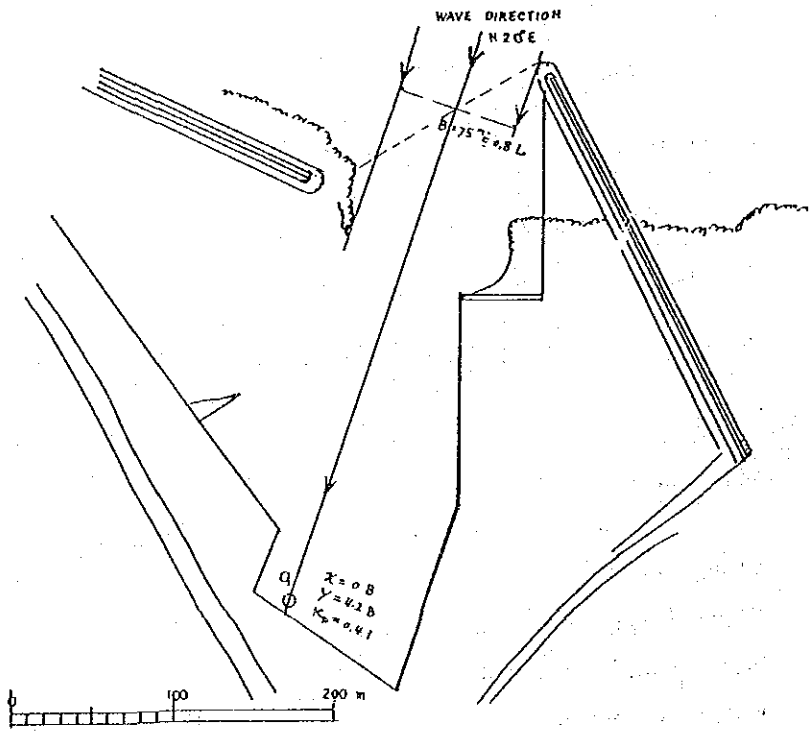


Fig. 8-6-3 Diffraction Coefficient Kd at 01 (Avatiu Port) in the Improved breakwater Arrangement

As shown in Fig. 8-6-2, wave at point 0_1 during cyclone is calculated.

Using Smax diagram, diffraction coefficient K_D is,

$K_D = 0.55$

Thus, wave height is,

$Ho' = 2.8 \times 0.55$

$= 1.54$ meter

Shoaling coefficient Ks is obtained by the diagram,

$h/Lo = 6.2/244 = 0.025$

$Ho'/Lo = 1.54/244 = 0.006$

$Ks = 1.29$

Thus, wave at point 0_1 is

$H = 1.29 \times 1.54$

$= 2.0$ meter

Case "Extension"; Improved breakwater arrangement, Fig. 8-6-3.

$B = 75\ m \doteqdot 0.8L$

Since entrance width is smaller than wave length, K_D in regular wave diffraction diagram is adopted.

$K_D = 0.41$

$Ho' = 2.8 \times 0.41$

$= 1.20$ meter

Shoaling coefficient Ks is obtained by the diagram.

$h/Lo = 0.025$

$Ho'/Lo = 1.20/244 = 0.005$

$Ks = 1.24$

Thus, $H = 1.24 \times 1.20$

$= 1.5$ meter

Wave during cyclone in Case "Extension" is smaller than Case "Present" by 22% in the port basin.

This study result shows that Case "Extension" provides more calm condition in the port basin during cyclone.

Wave run-up on the end wharf by this wave is estimated. Run-up height in MSL is calculated by following formula.

$h r = R + h'$

Where, hr: Wave run-up above MSL m

R: Wave run-up above the water level m

Since water depth in front of end wharf is deep enough not to break wave, run-up height will be as clapotis.

$R = H = 1.5$ m

h': Water level

$h' := 1.4$ m

Thus, $hr = 1.5 + 1.4$

$= MSL + 2.9$ m

Since the existing wharf height is about MSL +2.0 m, wave over-topping may appear on the wharf by 0.9 m. Wharf hight in MSL +2.0 m is reasonable for cargo handling by domestic small vessels, thus this level of wave over-topping should be accepted.

6) Wave height in the Avarua Port: Point 0.

Similar to Avatiu port case, two alternative breakwater layouts are provided to analyze the cyclone wave intensity in the port basin.

Case "Present"; Existing breakwater arrangement, Fig. 8-6-3A

Conditions,

- Wave at Port E (Entrance) Ho' = 5.2 meter
- Wave period To = 12.5 sec.
- Water depth H = 4.5 meter in average
- Wave Length (offshore) Lo = 244 meter
- Wave length (point E) Lo = 82 meter
- Diffraction coefficient by irregular wave diffraction diagram in Smax = 75
- Wave direction at Point E N

As shown in Fig. 8-6-3A, wave at point 0_1 during cyclone is calculated. Using Smax diagram, diffraction coefficient K_D is,

$K_D = 0.40$

Thus, wave height is,

$$Ho' = 5.2 \times 0.40$$
$$= 2.9 \quad m$$

Shoaling coefficient Ks is obtained by the diagram,

$$Ks = 1.25$$

Thus, wave at point 0_1 is

$$H = 1.25 \times 2.9$$
$$= 3.6 \quad m$$

<u>Case "Extension": Improved breakwater arrangement, Fig. 8-6-3B</u>

Similar to Case "Present"

$$Ks = 0.30$$
$$Ho' = 5.2 \times 0.30$$
$$= 1.6 \quad m$$
$$Ks = 1.25$$
$$H = 1.25 \times 1.6$$
$$= 2.0 \quad m$$

Wave during cyclone in Case "Extension" is smaller than Case "Present" by 44% in the port basin. This study result shows the Case "Extension" provides more calm condition in the port basin during cyclone.

Wave run-up on the end wharf (Point 0_1) by this wave is estimates. Run-up height in MSL is calculated by following formula.

$$hr = R + h'$$

Here,

$$R = 2.0 \quad m$$
$$h' = 1.4 \quad m$$

Thus,

$$hr = 2.0 + 1.4$$
$$= 3.4 \quad m$$

Since the existing wharf height is about MSL +2.0 m, wave over-topping may happen on the wharf apron by 1.4 m. Wharf height in MSL +2.0 m is reasonable for small boats in marina, thus this wave over-topping level should be accepted.

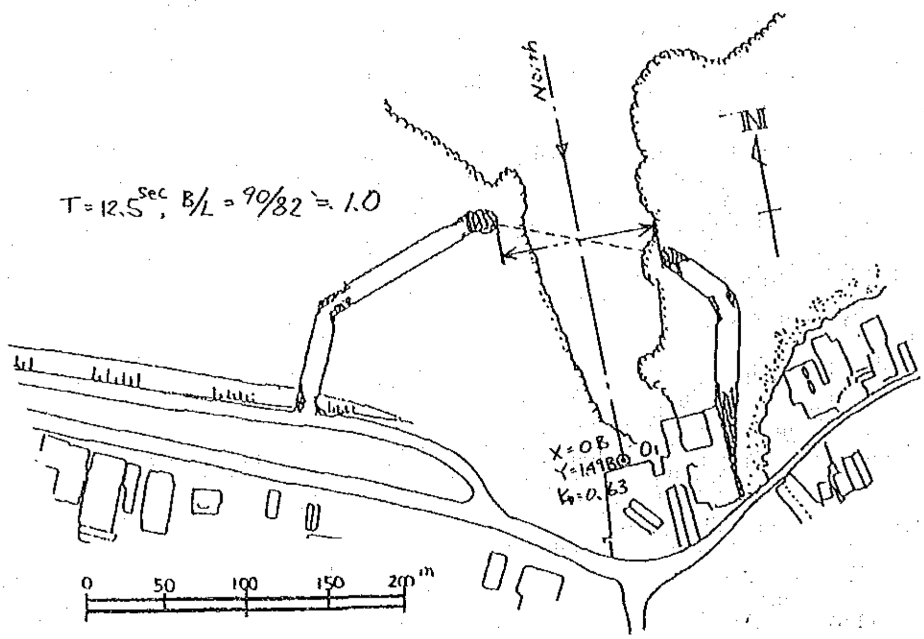


Fig. 8-6-3A Diffraction Coefficient Kd at 01 (Avarua Port) in the Existing Breakwater Arrangement

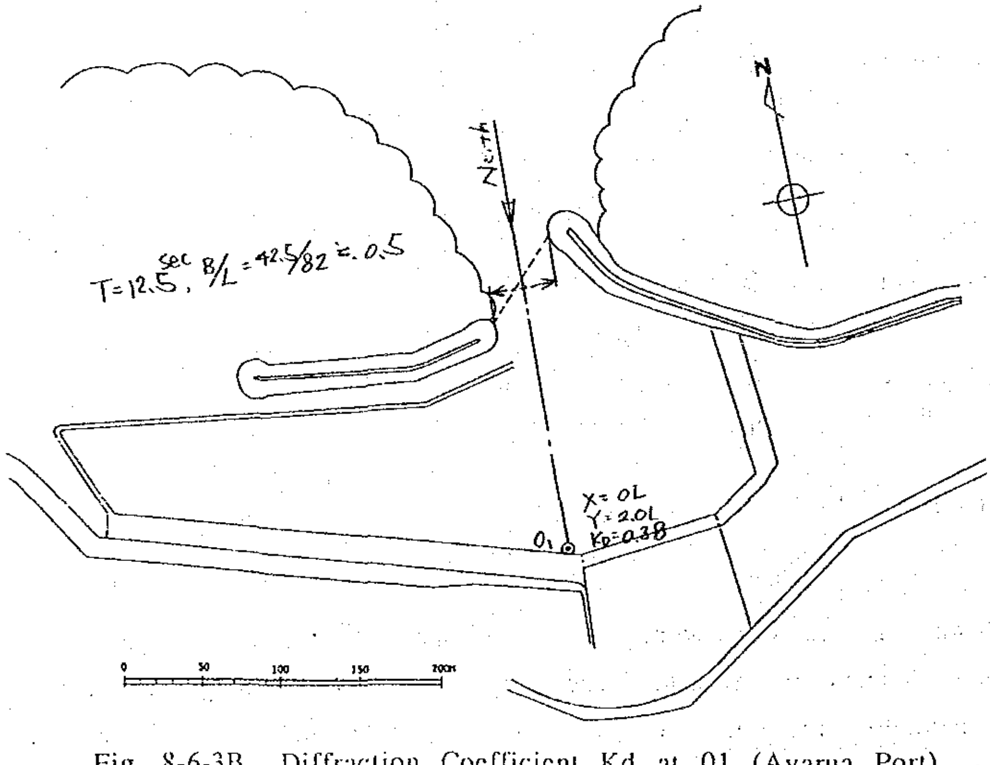


Fig. 8-6-3B Diffraction Coefficient Kd at 01 (Avarua Port) in the Improved Breakwater Arrangement

8.6.2 Wave Calmness during Normal Climatic Condition: Avatiu

It is well known that the prevailing wind direction here, thus wave direction, is the East. In order to estimate the annual workability of port in respect to wave calmness, offshore wave height during normal condition are listed up from the existing wave observation records of the Avatiu Wave-Rider Buoy located at 800 meter offshore for the period of one year, March 1985 to February 1986. During the 365 days observation, available data is 230 days (63% coverage).

Based on these, Scatter diagram in respect to wave height and period has been analyzed. Fig. 8-6-4 shows wave the period diagram using both the peak spectral period and zero crossing period. As seen in the figure, dominant period is different in two analyzes.

By peak spectral period--------------------6 to 12 second
By zero crossing period--------------------5 to 7 second

Considering that the significant wave period is similar to ones by the former, analysis here will be conducted by the peak spectral period.

a) Wave Direction off Avatiu

According to the wave direction record in Ship Report Data (swell), Grid Square No. 5 (15.0-25.0°S, 155.1-165.0°W), prevailing wave direction are E, SE and S. Thus, waves off the Avatiu are assumed ones from the East direction due to the sheltering effect by northern corner of island.

When, a cyclone happens, waves may also come from the opposite direction, however these are neglected from the calculation considering the lower late of cyclone occurrence than the normal climatic condition. There is also NE waves (swell) of 1.5 to 2.5 meter height of 6 % occurrence. Since the rate of this decay is not clear yet, this wave was regrouped into ones from the East direction.

Based on this consideration, wave occurrence diagram is developed as shown in Table 8-6-1.

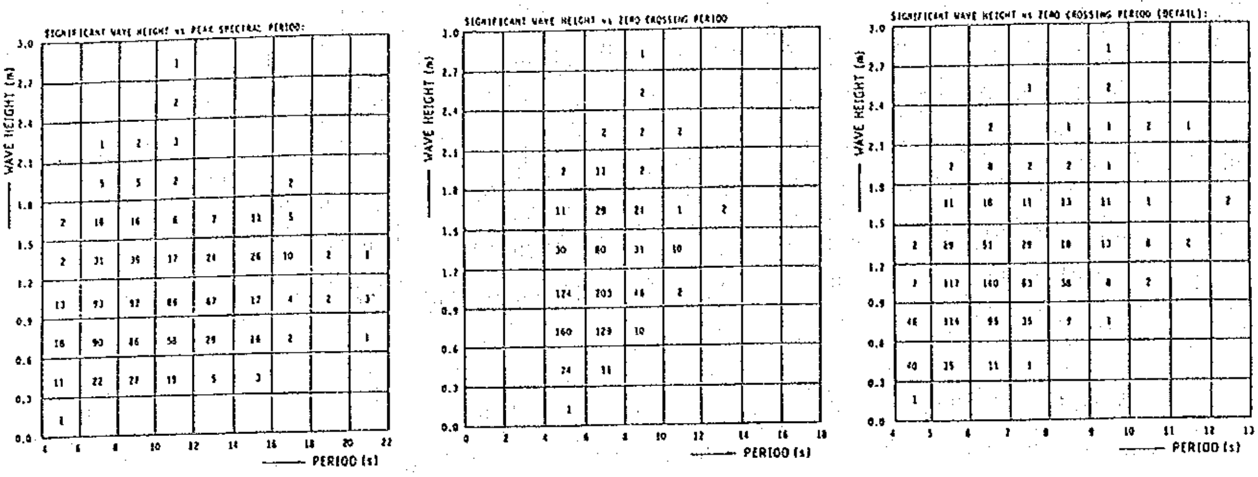


Fig. 8-6-4(1) Avatiu Harbour Wave rider buoy data (one year): Scatter diagrams.

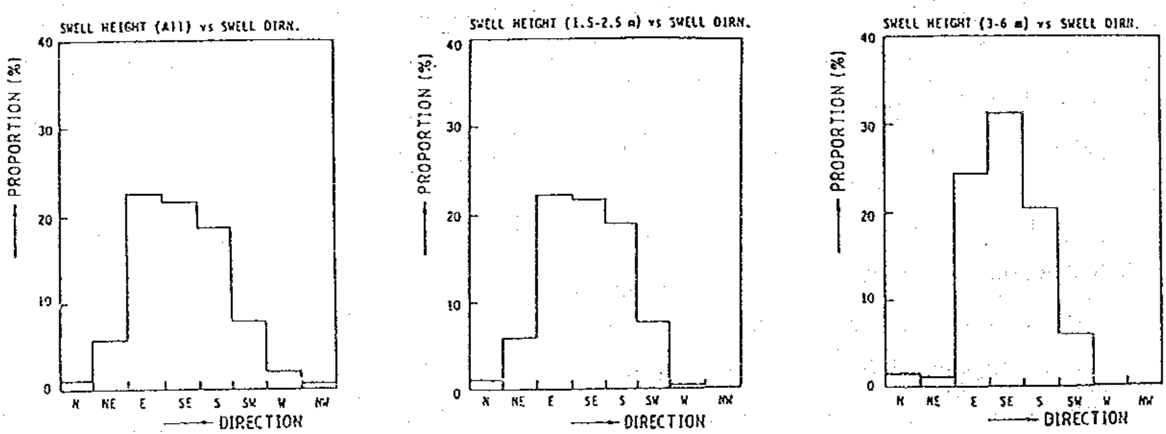


Fig. 8-6-4(2) Ship report data from.grid square No. 5 (15.0=0.25°S, 155.1-165.0°W): Histograms of swell height.

Table 8-6-1 shows the wave occurrence by wave period.

Table 8-6-1 Wave Occurrence by Wave Period.

Wave H (m) \ T (sec.)	Wave Direction, E			Total
	7	9	11	
< 0.9	14.2	11.3	13.3	38.8
0.9 ≦ H < 1.2	10.6	9.2	17.9	37.7
1.2 ≦ H < 1.5	3.3	3.9	8.0	15.2
1.5 ≦ H < 1.8	2.0	1.6	3.1	6.7
1.9 ≦ H < 2.1	0.5	0.5	0.4	1.4
> 2.1	0.1	0.2	0.6	0.9
Total	30.7	26.7	43.3	100.7

Note: 7 sec. line includes ones for five second or less.
11 sec. line represents twelve second or larger period

b) Wave Occurrence near the Port Entrance

Refraction coefficient is calculated to the wave direction of E10°N since the error in refraction diagram in the East direction will be large because wave direction in East is parallel to coast. Refraction coefficient at the entrance is obtained for three wave periods, T = 7 sec., 9 sec. and 11 sec.

Table 8-6-2 Refraction Coefficient at Entrance (Kr) Avatiu

Wave Direction	East		
T. period (sec.)	7	9	11
Kr	0.49	0.46	0.50
Wave direction	N43°E	N39°E	N30°E

Note, Wave direction is those at the port entrance.

Refraction diagrams for three wave periods are shown in Figs. 8-6-5, 8-6-6 and 8-6-7.

Wave occurrence by wave direction and period can be calculated by combining both data in Tables 8-6-1 and 8-6-2.

Table 8-6-3 shows the wave occurrence by wave direction at the Avatiu port entrance.

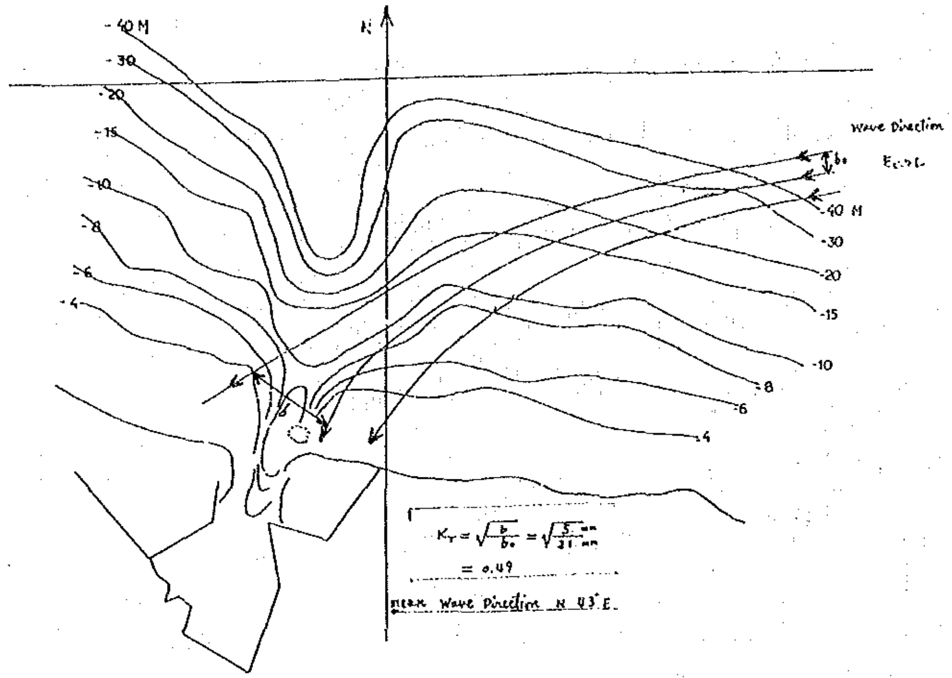


Fig. 8-6-5 Refraction Diagram
Wave Direction E
T: 7sec

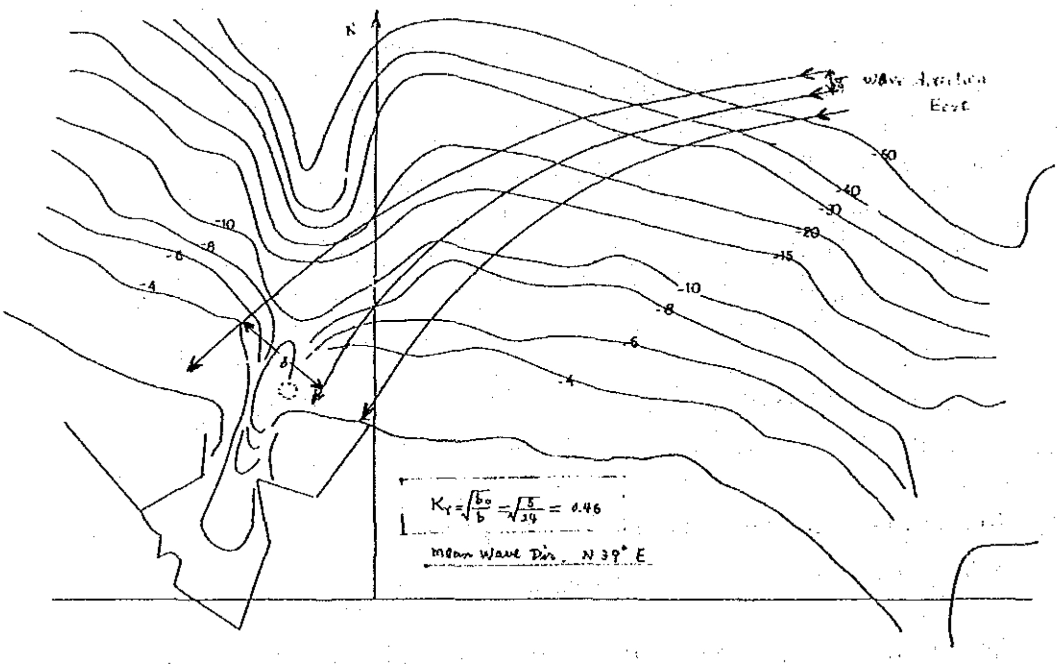


Fig. 8-6-6 Refraction Diagram
Wave Direction E
T: 9sec

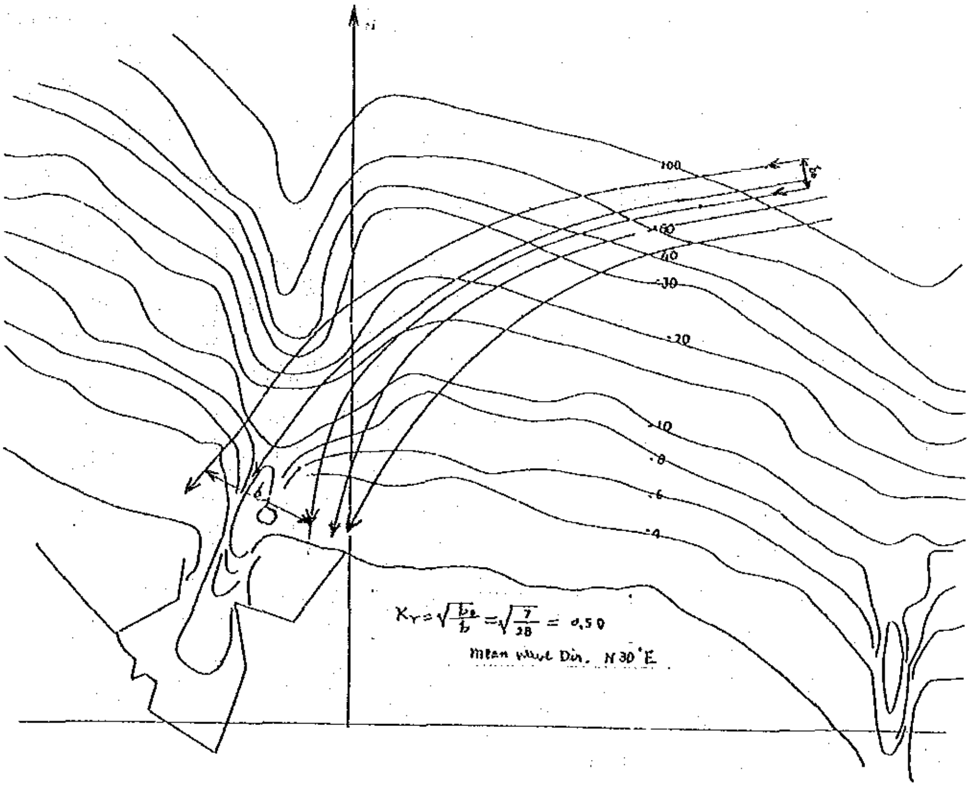


Fig. 8-6-7 Refraction Diagram
Wave Direction E
T: 11sec

Table 8-6-3 Wave Occurrence by direction at Avatiu port entrance

T (sec.) Wave H (m)	Wave Direction, E 7	9	11	Total
< 0.5	19.7	18.0	21.5	59.2
$0.5 \leqq H < 0.6$	5.4	4.3	9.8	19.5
$0.6 \leqq H < 0.7$	2.3	2.1	6.3	10.7
$0.7 \leqq H < 0.8$	1.9	1.4	3.2	6.5
$0.8 \leqq H < 0.9$	0.9	0.6	1.5	3.0
$0.9 \leqq H < 1.0$	0.4	0.2	0.3	0.9
$1.0 \leqq H < 1.1$	0.1	0.1	0.3	0.5
$1.1 \leqq H < 1.2$	-	-	0.2	0.2
$1.2 \leqq$	-	-	0.2	0.2
Wave Direction at the entrance	N43°E	N39°E	N30°E	

c) Wave Calmness inside Port

Port workability is calculated in both Case "Present" and Case "Extension" Four observation points are selected in the inner port basin.

(Note, Port workability in respect to wave effect is the percentage of days when the wave height is 0.3 meter or less. Wave of 0.3 meter is assumed as the limit one allowing the normal container cargo handling.)

Case "Present"; The existing breakwater arrangement, Fig. 8-6-8

i Diffraction Coefficient K_D and Shoaling Coefficient (K_S)

Water depth (h) is -6.2 meter below MSL. Diffraction coefficients have been obtained from the irregular wave diffraction diagram (Smax = 75, B = 1L). Figs. 8-6-8(1) ~ 8-6-8(3) show K_D in the X-Y grids by each wave direction.

Shoaling coefficient K_S are,

T = 7 sec. ---------------------- K_S = 0.98, h/Lo = 6.2/ 76.4 = 0.081

T = 9 sec. ---------------------- K_S = 1.03, h/Lo = 6.2/126.4 = 0.049

T = 11 sec. --------------------- K_S = 1.10, h/Lo = 6.2/188.8 = 0.033

Table 8-6-4 Diffraction and Shoaling Coefficient in Case "Present", at Avatiu Harbour

T (sec.)		7	9	11
Wave Dir.		N43°E	N39°E	N30°E
Pt. No.	1	0.29	0.33	0.40
	2	0.25	0.28	0.40
	3	0.15	0.37	0.48
	4	0.60	0.61	0.53
Ks		0.98	1.03	1.10

ii Wave Occurrence by Wave Direction/Period

Wave occurrence at the observation points by wave direction and period can be obtained multiplying figures in Table 8-6-3 by $K_D \cdot K_S$ in Table 8-6-4.

Table 8-6-5 shows wave occurrence by wave period at the specified four point.

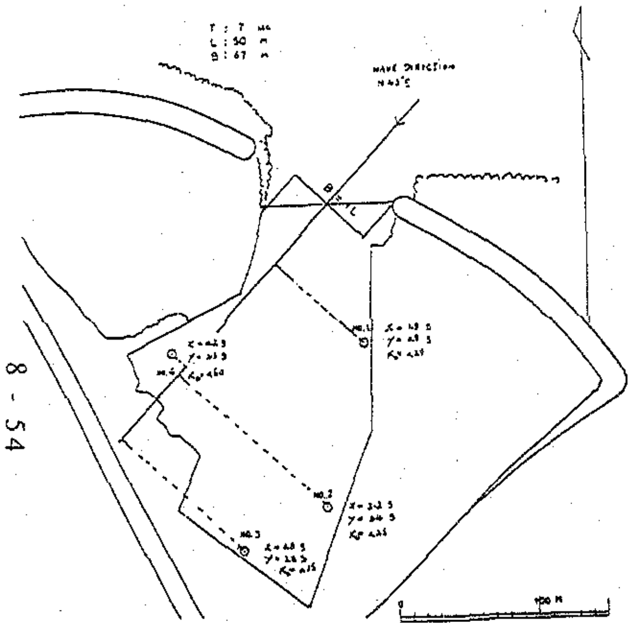


Fig. 8-6-8(1) Grid and Diffraction
Case "Present"
T=7sec , N43°E

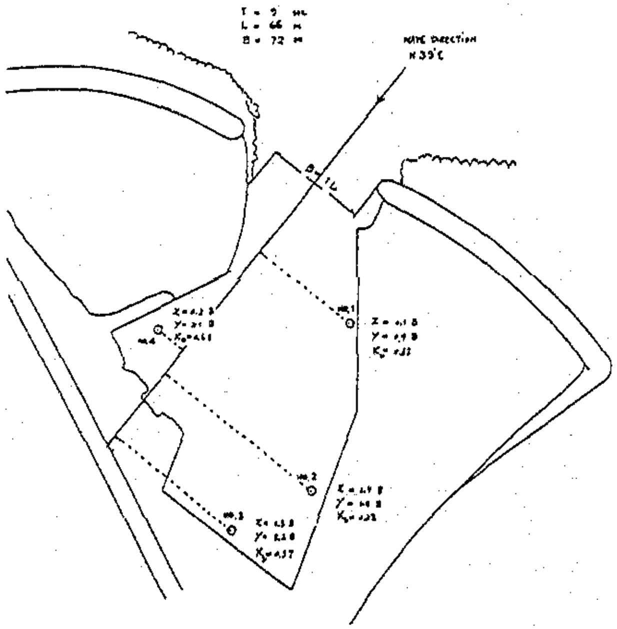


Fig. 8-6-8(2) Grid and Diffraction
Case "Present"
T=9sec , N39°E

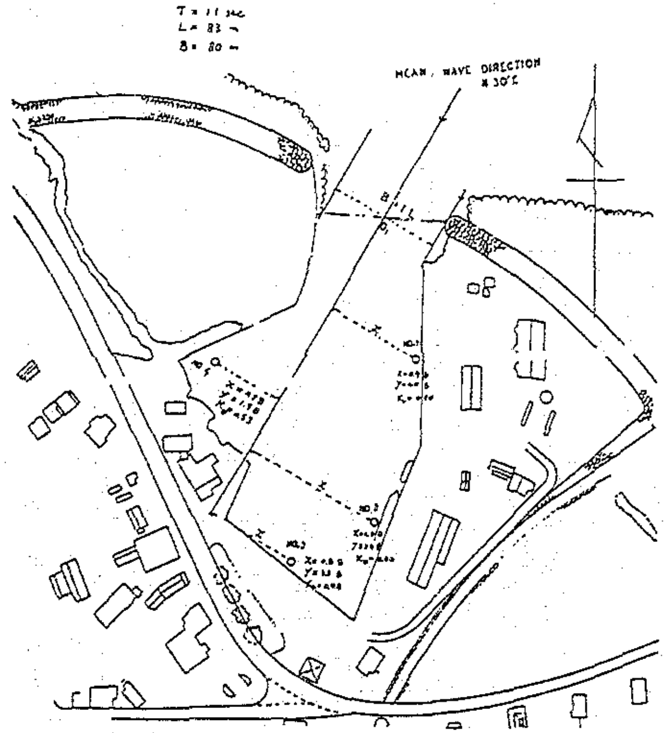


Fig. 8-6-8(3) Grid and Diffraction
Case "Present"
T=11sec , N30°E

Table 8-6-5 Wave Occurrence inside Avatiu: Case "Present"

Pt - No. 1						
T (sec)	7		9		11	
	K = 0.28		K = 0.34		K = 0.44	
H (m)	KH	Ni	KH	Ni	KH	Ni
0.5 ~		11.0		8.7		21.8
0.6 ~		5.6		4.4	0.26 ~	12.0
0.7 ~		3.3		2.3	0.31 ~	5.7
0.8 ~		1.4	0.27 ~	0.9	0.35 ~	0.5
0.9 ~		0.5	0.31 ~	0.3	0.40 ~	1.0
KH ≧ 0.3 m		-		0.4%		6.6%
KH ≧ 0.3 m = 7.0 %						

Pt - No. 2						
T (sec)	7		9		11	
	K = 0.25		K = 0.29		K = 0.44	
H (m)	KH	Ni	KH	Ni	KH	Ni
0.5 ~						21.8
0.6 ~					0.26 ~	12.0
0.7 ~					0.31 ~	5.7
0.8 ~					0.35 ~	2.5
0.9 ~					0.40 ~	1.0
KH ≧ 0.3 m		-		-		6.6%
KH ≧ 0.3 m = 6.6 %						

Pt - No. 3						
T (sec)	7		9		11	
	K = 0.15		K = 0.38		K = 0.53	
H (m)	KH	Ni	KH	Ni	KH	Ni
0.5 ~					0.26 ~	21.8
0.6 ~					0.32 ~	12.0
0.7 ~					0.37 ~	5.7
0.8 ~			0.30 ~	0.9	0.42 ~	2.5
0.9 ~			0.34 ~	0.4	0.48 ~	1.0
KH ≧ 0.3 m		-		0.9%		14.6%
KH ≧ 0.3 m = 15.5 %						

Pt - No. 4						
T (sec)	7		9		11	
	K = 0.59		K = 0.63		K = 0.58	
H (m)	KH	Ni	KH	Ni	KH	Ni
0.5 ~	0.29 ~	11.0	0.31 ~	8.7	0.29 ~	21.5
0.6 ~	0.35 ~	5.6	0.38 ~	4.4	0.35 ~	12.0
0.7 ~			0.44 ~	2.1	0.41 ~	5.7
0.8 ~			0.50 ~	0.9	0.47 ~	2.5
0.9 ~			0.57 ~	0.4	0.52 ~	1.0
KH ≧ 0.3 m		10.0%		8.7%		18.4%
KH ≧ 0.3 m = 37.1 %						

Note: Figure here is accumulated occurrence.
$K = K_D \cdot K_S$, Ni in percent.

From the Table 8-6-5 the port workability at each observation points will be as follows:

Point	Workability
No. 1	93.0%
No. 2	93.4%
No. 3	84.5%
No. 4	62.9%
Average	83.5%

It is recommended to maintain workability in the commercial port 95% or more. Thus, it can be said that breakwater layout Case "Present" is not suitable. The existing breakwater should be rearranged for the better port quality.

<u>Case "Extension"; Improved breakwater arrangement, Fig. 8-6-9.</u>

Fig. 8-6-9 shows new breakwater arrangement. As seen in the figure, K_D diffraction coefficient is small due to narrow port entrance against the prevailing wave directions, by the extension of east breakwater.

Table 8-6-6 shows K_D and K_S.

Table 8-6-6 K_D and K_S; Case "Extension" Avatiu Harbour

Wave Dir.		N43°E	N39°E	N30°E
T (sec.)		7	9	11
Pt. No.	1	0.23	0.28	0.38
	2	0.18	0.21	0.28
	3	0.18	0.22	0.29
	4	0.26	0.29	0.38
Ks		0.98	1.03	1.10

As seen in the table, only waves with 11 second period can be larger than the limit wave, 0.3 meter. Thus waves of 11 sec period larger than the limit height are considered for calmness analysis.

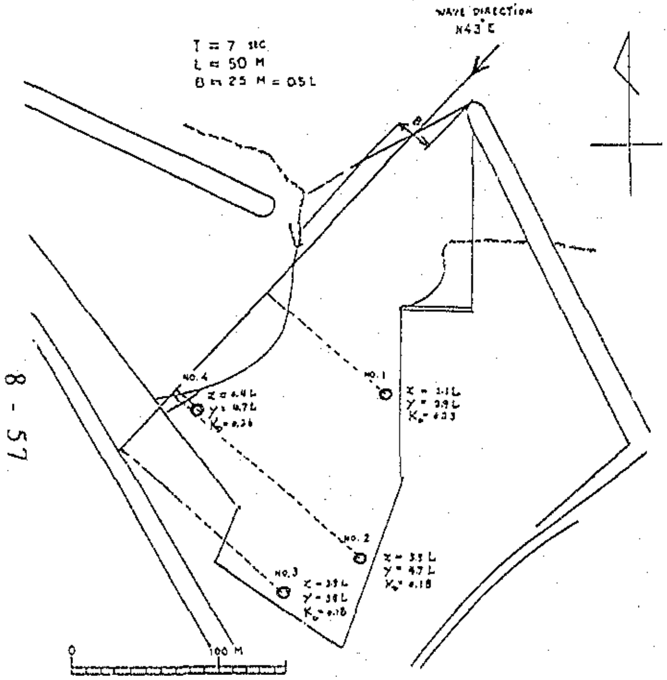


Fig. 8-6-9(1) Grid and Diffraction
Case "Extension"
T=7sec , N43°E

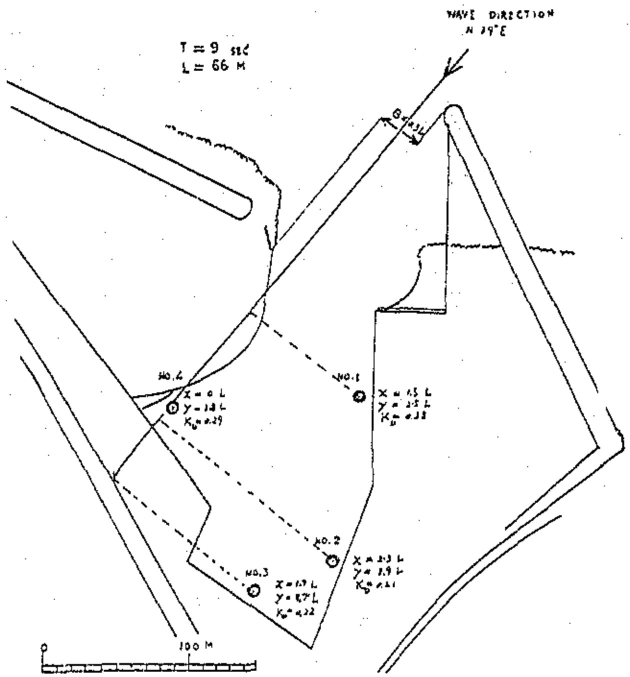


Fig. 8-6-9(2) Grid and Diffraction
Case "Extension"
T=9sec , N39°E

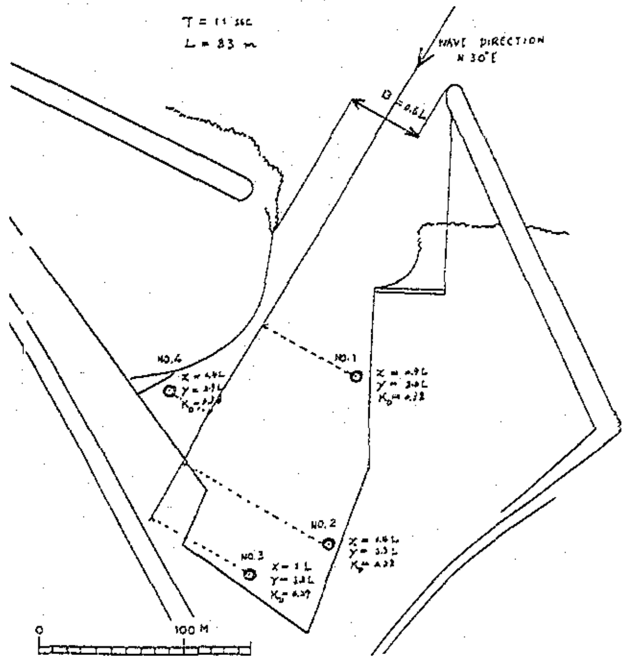


Fig. 8-6-9(3) Grid and Diffraction
Case "Extension
T=11sec , N30°E

Table 8-6-7 Wave Occurrence inside Avatiu; Case "Extension"

Pt. No.	1		2		3		4	
T (sec)	11		11		11		11	
	K = 0.42		K = 0.31		K = 0.32		K = 0.42	
H (m)	KH	Ni	KH	Ni	KH	Ni	KH	Ni
0.7 ~	0.29 ~	5.7					0.29 ~	5.7
0.8 ~	0.33 ~	2.5					0.33 ~	2.5
0.9 ~	0.38 ~	1.0	0.28 ~	1.2	0.29 ~	1.2	0.38 ~	1.0
1.0 ~	0.42 ~	0.7	0.31 ~	0.8	0.32 ~	0.8	0.42 ~	0.7
KH ≧ 0.3 m	4.8%		0.9%		1.1%		4.8%	
Workability	95.2%		99.1%		98.9%		95.2%	
Average workability is 97.1%								

Port workability in Case "Extension" is 95 % or more at every points and better than Case "Present", that it is also confirmed that extension of breakwater proposed here is a suitable scale and not over investment.

Table 8-6-8 shows difference of two schemes in respect to wave calmness during the normal climatic condition.

Table 8-6-8 Comparison of Calmness

Unit: %

	Observation Point	Present	Extension	Balance
No.1	International Wharf	93.0	95.2	+2.2
No.2	Domestic Wharf	93.4	99.1	+5.7
No.3	Small boat Wharf	84.5	98.9	+14.4
No.4	Fisheries Wharf	62.9	95.2	+32.3
	Average	83.5	97.1	+13.6

As seen in the table, large improvement by extension of breakwater can be achieved in both the Small Boat Wharf and Fishery area. Commercial wharfs are also improved.