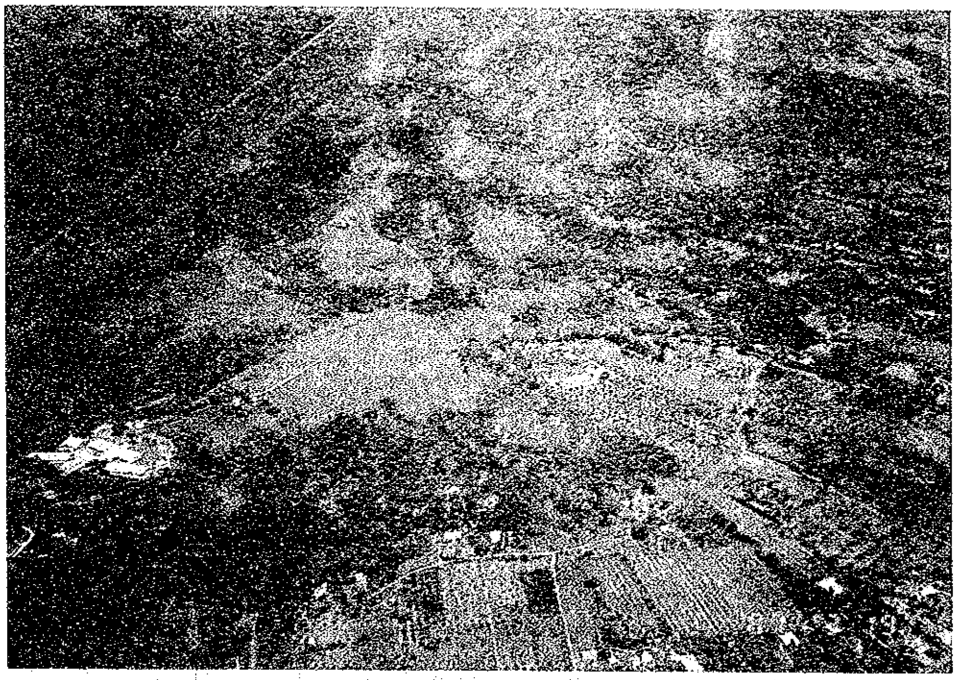
Avatiu River from upstream (above) to outlet (below)



Developed high land area as farms

Report on Countermeasures against Coastal Hazards
by Cyclone in the Cook Islands.

CONTENTS

I. INTRODUCTION

1. Background

On the 1st and 2nd of January 1987, a tropical cyclone named Sally struck Rarotonga, the capital of the Cook Islands, and sustained severe damages in its coastal areas.

The Government of Japan, upon the request of the Government of the Cook Islands, immediately dispactched experts in the field of coastal and harbour engineering from the 10 th to the 17th of January 1987, to investigate the disaster. Following up the findings and views of the experts as well as the request of the Government of the Cook Islands, a survey team for the cyclone disaster restoration was re-dispatched by the Government of Japan through Japan International Cooperation Agency (JICA).

The survey team is composed of nine members, i. e. a harbour engineer, a port planning engineer, two coastal engineers, a town planner, an expert in disaster countermeasures, an expert in sea-shore conservation, a river engineerand a co-ordinator, and stayed at Rarotonga from 26 February to 19 March 1987.

2. Terms of Reference

The terms of reference of the survey team are to assist the Government of the Cook Islands in designing and drafting various infrastructural plans which would form the basis of a blue-print for the major recovery work in the above-mentioned areas.

3. Visits and Activities

During the team's stay in Rarotonga the following offices and organizations were visited to assimilate information on the issue.

(a) Honourable Prime Minister
(b) Honourable Minister of Works
(c) Secretary of the Ministry of Economic Development
(d) Secretary of the Ministry of Works
(e) Chief Surveyor, Survey Department
(f) Harbour Engineer, Ministry of Trade, Labour and Transport (TLT)
(g) New Zealand Government Representative Office, Government of New Zealand
(h) Meteorological Office, Ministry of Transport, Government of New Zealand
(i) Others

Besides the interviews, surveys, measurements and other required activities, the team had a video and a slide show twice on 6 and 13 March 1987, screening introductions of coastal and harbour engineering in Japan to officals concerned in the Cook Islands Government.

II. FINDINGS AND INVESTIGATIONS

1. General

(a) Geography

The Cook Islands consists of 15 islands located between 8 degrees and 23 degrees south latitude and 156 degrees and 167 degrees west latitude (Fig. II. 1. 1.). Compared with a huge sea area of nearly 2 million square kilometers, including exclusive economic zone, the total land mass amounts to only 240 square kilometers.

The 15 islands fall naturally into two groups, i. e. the Southern and Northern Groups. Among the former group, Rarotonga, the main island of the country with a land area of 67 square kilometers (Fig. II. 1. 2), is of volcanic origin with a steep interior and its periphery is covered by coral reef.

(b) Population and Towns

The total population of the country is 17,754 as of 1981. Among others, majority of them, or 9,530 which is 54% of the total, live in Rarotonga.

Avarua, located in the northern coast of Rarotonga, is the capital and its township is the only center of commercial activity (Fig. II. 1. 3).

(c) Economy

The two main productive sectors of the economy are :

i) Agriculture - the growing and processing of fresh fruit and vegitables for both export and domestic consumption, and
ii) Tourism - an increasing and important role in the country's future.

In the northern atolls, output is restricted mainly to coconuts and fish. In the fertile southern islands production is concentrated on bananas, citrus and pineapples.

Importance of tourism is quite evident from a fact that the influx of tourists is more than 31,000 for the year 1985, or more than three times of the total number of residents, which is owing to mainly the beautiful shoreline, subtropical climate, friendly temparament of subjects, etc.

In 1981, the composition of the 5,810 work force was :

Commerce, Transport and Service	54.8%
Agriculture and Fishing	29.1%
Manufacturing and Construction	12.4%
Activities not classified	3.7%

It is estimated that GDP was New Zealand $ 32.4 million and GDP per capita was NZ$ 1,840 in 1983.

(d) Organization

A new constitution was proclaimed in 1965, under which the Cook Islands had complete control over their own affairs in free association with New Zealand.

Executive government is carried out by a Cabinet, consisting of a Prime Minister and six Ministers. The Cabinet is collectively responsible to Parliament.

Ministries concerned with coastal disaster are those of Economic Development (Overall project) ; Foreign Affairs ; Trade, Labour and Transport(Ports); Works (Roads and other public utility facilities) ; Conservation, etc. Survey Department is involved in matters concerning with lands and survey.

It shall be noted that the Government has "Cook Islands Hurricane Safty Plan" based on the Hurricane Safety Act, 1973, which provided legislation to establish a "Hurricane Safety Committee" to co-ordinate and control the activities of government departments and other organizations in the event of a hurricane.

Just after the disaster by cyclone Sally, the Government formed a "Hurricane Recovery Task Force 1987" headed by the Prime Minister and a chairman from the executives. The Task Force consisting of relevant 13 committees was dispersed at the end of February, and a new "Rehabilitation Development Committee" was created by the Cabinet. The committee consists of a chairman (Prime Minister), a technical team leader, administration officials and others. Its function includes managing and co-ordinating the rehabilitation programmes.

2. Natural Conditions

(a) Topography

Rarotonga is a volcanic island surrounded by so-called "Fringing Reef".

The volcanic body itself is in the process of geological sinking, while coral reef is growing on the so-called "eroded terrace". Lagoon, thus created between the volcanic body and the coral reef, has been buried by siltation from rivers and rubbles from coral reef, resulting in forming the sand dunes and back marshes. Sand dune is relatively high and accordingly is used for residental areas, roads, etc. Back marsh is relatively low and is subject to the storm surge and river flooding. However, some parts of back marsh have come to be used for various purposes as a result of expansion of township areas towards the mountain side (Fig. II. 2. 1).

Mountains are steep. Streams run down the mountain slopes, some directly into the sea, while the others into the back marsh. The mountain area is generally used for taro plantation.

The coastline around the island is protected by coral reef. The width of the reef is relatively nallow from the north to the west, and wide from the south to the east. The coastal material is coral rubble in the north and sand in others.

(b) Cyclones

The number of cyclones generated in the South West Pacific is 5 to 10 per year. The frequency distribution by month (1939 to 1968) is shown in Figure II. 2. 2.

The course of cyclone is generally shifted according to SPCZ (The South Pacific Convergence Zone), from the east at the begining of cyclone season in November to the west at the end of the season in April. Rarotonga Island is affected by cyclones mostly in January and February.

South Cook Islands were affected by 34 cyclones during the past 44 years from 1940 to 1983. According to the Meteorological Department, heavy damage has been caused by cyclones in approximately every 20 years and moderate damage in every 5 years. "Sally" was the typical cyclone which directly hit Rarotonga, with the magnitude of historical record. Table II. 2. 1 lists major cyclones experienced by Rarotonga in the past.

(c) Wind, Waves and Storm Surges

The predominant wind direction in Rarotonga is E and SE as it is located in the trade wind zone. In addition to the trade wind, cyclones and extra tropical fronts cause strong wind in various directions in the summer season. These wind and swells cause high waves, but detailed analysis has not been made yet as the data are available at only one observation station.

At the height of cyclone, Rarotonga often experiences storm surge as a combined effect of swelling due to the atmospheric depression, wind pressure from offshore towards the coast, wave setup in lagoons, etc. Especially the Avarua – Avatiu area, the most important place on the island, is susceptible to the storm surge because of its topographical conditions.

(d) Tides and Currents

The tidal range of the island is only more or less one to three feet. However, current is rather swift and complicated according to passages in the coral reef, shape of lagoons, discharge from the rivers, height and direction of the waves, etc.

(e) Rainfall and Flood

Annual rainfall amount is 4,000 to 4,500 mm in mountain areas and 2,000 to 2,500 mm in others, of which roughly 2/3 are during the wet season (November to April). Heavy rainfall brought about by cyclones during the wet season causes stream floods resulting in inundation of low lands and back marshes. If this happens at the same time as the high tide, the situation becomes worse due to the adverse flow of sea water into the stream and ineffective drainage.

The frequency of inundation is roughly once per five years in areas most susceptible to inundation.

(f) Stream Run-off, Sediment Trasport and Siltation

Flood hydrograph of the stream is sharp and its duration is short. The sediment yield may not be much, judging from the conditions of the catchment such as the geology, vegetation, land use and stream conditions. According to the data obtained from rivers of similar conditions in Japan, the annual sediment yield is estimated roughly as at most 300 cubic meters per square km.

During the field survey by the team much sedimentation was not observed in the stream bed, neither at the meandering portion nor at the upstream of the water intake. It was also found by the team that most of deposits at the stream mouths are of sea origin, and accumulation in the lagoon between Avarua and Avatiu is relatively small.

(g) Coral

Rarotonga is surrounded by coral reef with the width of 1.5 km at the widest point. The depth of lagoons is more or less in the order of several tens cm below MSL. At the outlet of major streams, there are deep channels stretching towards the offshore. The channel is one of the factors to control the movement of the current along the shore, because the return current is concentrated to the channel. These channels are called as passages, which are suitable for approach by ships and therefore are used for harbours like Avatiu and Avarua. The passages were formed as the fresh water and siltation from streams had hindered the building up of corals.

As has been made clear from the above-mentioned phenomena, it is important that due consideration should be given to the effect of spreading of fresh water and siltation from streams upon the survival of corals when planning to divert the mouth of a stream.

3. Trade and Shipping Activities

(a) Trades

The Cook Islands suffers from an adverse balance of visible trades, i. e. import $ 36.2 million and export $ 6.5 million in 1984. Major export items are clothing, citrus juice and other agricultural products. Main imports include foodstuffs, oil/petrol, etc., textiles, vehicles/parts and other manufactured products (Table II. 3. 1).

(b) Shipping Movements

The Shipping Corporation of New Zealand (SCNZ) operates fortnightly cargo service from Auckland to Rarotonga and Aitutaki via Niue. SCNZ Vessels have the following particulars: Length overall 78.1 m, dead weight 1,772 ton and draft 5.6 m. Mobile Oil Vessels and a Boral Gas Vessel regularly serve the port, the latter has length of 77.0 m, dead weight of 2,366 ton and draft of 5.86 m.

Inter-island services are provided by Silk and Boyd Ltd. The larger one of its two vessels has length of 43.4 m, dead weight of 390 ton and draft of 2.6 m.

Local fishing and pleasure boats, of which length was not more than 10 m, numbered 45, according to the Harbour Engineer's study done in 1983.

Yachts also visited Rarotonga. Maximum recorded number of yachts called at Rarotonga was 118 in 1981 and noted by the Harbour Engineer that :

i) Over 98 % are over 7.5 m in length,
ii) Less than 5 % are over 20 m long, and
iii) About 80 % are between 8-15 m long.

Those yachts are not calling now, because of lack of protecting port facilities and other reasons.

(c) Ports and Marinas

In Rarotonga there are three ports, i. e. Avatiu, Avarua Harbours both located in Avarua, and Ngatangiia Harbour located at Ngatangiia. Avatiu Harbour is used by international and inter-island vessels. Avarua and Ngatangiia Harbours are for local fishing and pleasure boats.

No special marina has not been developed yet.

Avatiu Harbour is the gateway of sea transport for the country (Fig. II. 3. 1). Before the attack of cyclone Sally, it has wharfs of 233 m in length and 2.4 m to 5.5 m in depth. Three sheds are located on the wharf. Western and Eastern Breakwaters were under construction.

Avarua Harbour has long been untouched which has a small wharf of about 1.5 m in depth (Fig. II. 3. 2).

4. Land Use and Town Planning

(a) Land Use

The land use of Avarua-Avatiu area is almost saturated and is in the process of expansion not only to coastal areas but also to back marsh areas. Among coastal areas, Avarua is located on a low lying area and therefore is threatened by storm surge. As Avarua is the center of administration and commerce of Rarotonga, due consideration should be given to proper land use to get rid of disasters.

The Main Road circling the island runs on the top of the sand dune, and another road called Ara Metua (Back road) runs along the mountain foot.

(b) Town Planning and Building Code

A town plan was drafted sometime before but has not been realized yet.

The Building Code, originally elaborated following the New Zealand's Code, is now under review for a new Code on the basis of recent studies on wind force, etc.

(c) Land Tenure System

Rarotonga has a traditional land tenure system, which might hinder implementation of land use plan and other development plans.

(d) Sewerage System

Sewerage system does not exist at the moment. There is a plan to establish a system for Avarua with technical assistance of WHO and possible financial assistance from ADB.

5. Coastal Conditions

As mentioned earlier, the coast is not only protected by coral reef, but also can be stable with supply of coral rubbles and sand. Where the width of coral reef is narrow the seashore is "steep rubble shore"due to high waves, whereas where the width of coral reef is wide the sea-shore is "gentle sandy shore" due to loss of wave energy. Beach rocks are seen in some parts of the shore, which can stand with further erosion from waves.

It was found that coastal erosion was newly started in some places as a result of imbalance of supply and erosion due to picking up of mass of seashore sand for construction of roads and airport, land reclamation, building construction, etc. In view of this, a regulation was put into force two years ago to restrict removal of sand and presently sand collection is allowed only at the river mouths of Avana and Turangi Streams.

6. Characteristics of Cyclone Sally at Rarotonga

(a) Track

Cyclone Sally was born near the Northern Cook Islands and developed moving southward. She turned one round at near Palmerston Island, and then approached Rarotonga from northwest at a relatively slow speed of approximately 21 km/hr.

The eye of Sally passed the capital island from 7 am to 11 am on 2 January 1987, moving further southeast. (Fig. II. 6. 1).

(b) Air Pressure and Wind

The magnitude of Sally observed at the Meteorological Office at the Rarotonga International Airport was as follows:

Minimum atmospheric pressure: 967 mb
at 8 am on 2 January (Fig. II. 6. 2),
Maximum sustained wind speed : 58 knots from WSW
at 1 pm on 2 January (Fig. II. 6. 3),and
Maximum gust speed : 84 knots from ESE
at 5 am on 2 January (Fig. II. 6. 4).

Cyclone of this scale rarely attacked Rarotonga in the past. It was 1976, when a cyclone passed northeast of Rarotonga. Its lowest recorded pressure at Rarotonga was 975 mb, and the strongest measured wind speed (10 minute average) was 42 knots with a peak gust speed of 81 knots from the south.

It is reminded herewith that decrease of pressure by 1 mb causes the rise of sea water level by 1 cm theoretically.

Due to wind the rise of water level near shore occures, which is called "wind setup", if the sea has a long barrier such as a bay or a long coastline. In case of Avarua, however, wind setup might be negligibly small compared with other phenomena.

(c) Astronomical Tide

Early January was the spring tide period. According to the tidal prediction done by the University of Hawaii, high tides were expected to occure at 10:30 and 23:00 on 1 January and 11:30 and 24:00 on 2 January in Avarua Harbour. Expected tidal levels for these high tides were approximately 1.1, 1.4, 1.2 and 1.4 feet above MSL., respectively (Fig. II. 6. 5.).

(d) Waves

Wave measurement has been performed off Avatiu Harbour of 40 m in depth by means of a wave-rider buoy since June 1980. According to the analysis of data recorded during the cyclone, which was done by Central Laboratories, Ministry of Works and Development of the New Zealand Government, swells as high as 4 m with period of 10 sec were observed in the afternoon of 30 November 1986. The highest significant waves of about 8 m with period of 9 sec were recorded at 24:00 on 1 January 1987. It decreased rapidly down to 2 m with period of 7 sec at 24:00 on 2 January (Fig. II. 6. 6).

On the lagoon, due to energy loss by "breaking" at reef edge, the wave height decreases greatly as it approaches to the shore. Based on the result of hydraulic model tests by Port and Harbour Research Institute, Ministry of Transport of the Japanese Government, it is assessed that the wave height on Avarua lagoon at 24:00 on 1 January was around 0.7 m as far as the area more than 50 m apart from the edge concerned (Fig. II. 6. 7).

At the mouth of a passage, say Avarua Harbour, wave height also decreases due to "refraction" (Fig. II. 6. 8). It is also estimated theoretically that the wave height at the head of Avarua Wharf was around 2.0 m at 24:00 on 1 January (Fig. II. 6. 9).

It must be mentioned that incident waves lose energy when they travel against the current in the passage, which is explained later in (f), although it is difficult to assess how much energy will be lost at the site.

It is also noted that the above-mentioned waves observed by the wave-rider buoy, were checked by a theoretical wave hindcast method developed by Ijima (1967) and the result of estimate of maximum wave height in cyclone Sally was 10 m at 12 sec, which coincides with each other fairly well.

(e) Wave Setup

A wall of breaking waves alongside the reef induces radiation stress to the water, blocking the outlet of water mass, which causes the rise of water level on the lagoon and is called "wave setup". Based on the result of hydraulic model tests by the above-mentioned Institute, the increment of water level at Avarua shoreline was estimated to be of the order of 1.3 m (Fig. II. 6. 10).

At Avarua Harbour, similar phenomenon is anticipated to occure, because of breakers in the passage. The magnitude of water level increase might be of the order of 1/10 of incident wave height, judging from the field observation in Japan.

(f) Currents

Under strong wind action on the sea surface, wind shear causes current in the sea.

On a lagoon difference of sea level due to wave setup and others between the lagoon and neighbouring passages induces "lateral currents" towards the passages. Then the water mass transported into the passage goes back to the open sea as "return current" (Fig. II. 6. 1).

The velocity of return currents during a cyclone is difficult to assess without observation or hydraulic model tests. It is told that the current at certain places on the Avarua lagoon is not less than 10 knots during storm conditions.

If a current of more than 10 knots existed on the lagoon, "shear velocity" at the bottom could be about 50 cm/sec. Such current can transport the bed materials thereon of which diameter is less than 10 cm. It means that almost all bed materials except rubble stones could be swept out from the lagoon by only current forces (besides wave forces).

(g) Combined Storm Surge and Waves

Taking into consideration of the above-mentioned phenomena, it can be roughly estimated that the actual sea water level happened at the midnight of 1 January was about the order of:

(Astronomical tides)		(Air pressure)		(Wave setup)
MSL + 0.36	+	0.24	+	1.34
(Storm surge)				

= MSL + 1.94 m for the Avarua lagoon.

Similarly,

MSL + 0.36 + 0.24 + 0.80

= MSL + 1.40 m for Avarua Harbour.

On the other hand estimated wave height at each area could be around 0.7 m and 2.0 m, respectively.

Unfortunately actual storm surge level could not be measured by the tidal gauge installed at Avarua, because it was too high to be covered. However, according to the University of Hawaii, the last value recorded was 9.70 feet at 23:44, which is interpreted as the water level was 8.05 feet on the new staff or MSL + 2.5 m based on the team's survey and calibration (Fig. II. 6. 12). As shown on the figure this value seems to include the effect of waves to a certain degree.

In addition, the results of our survey of flood marks left on houses and roads in the area show that the highest water level due to overflow were around MSL + 4.0 to 4.5 m at the Main Road and MSL + 2.3 m at the back of Avarua Harbour (Fig. II. 6. 14, Table II. 6. 1).

Therefore, we might conclude that the above theoretical estimate proves the fact fairly well. In case of 1976 cyclone, it was hindcasted by Carter and Steen (1984) that the total rise in water level would be 1.5 m and deep water wave height of 6.25 m at 9.4 sec.

(h) Rainfall and Flooding

According to the record at Totokoitu, the amount of daily rainfall on 1 January 1987, was 225.0 mm which is a very high value (Table II. 6. 1.). Unfortunately its hourly value is not available. Data at Rarotonga Airport could not be taken, because the raingauge was damaged by waves.

Flooding occured at several places on Rarotonga by both sea water at coastal zone and river water at back marsh area (Fig. II. 6. 13). Water level at inundated area in Avarua was approximately MSL + 2.2 to 2.5 m, judging from the marks left on houses.

7. Damages Suffered by Cyclone Sally

(a) Casualty

There was virtually no casualty by the cyclone, owing to precaution by radio, preparedness of the Government, residents and others.

(b) Economic Loss

Loses in terms of economic impact and damages for rehabilitation by reconstruction are summarized by UNDP as follows:

Table II. 7. 1 Total Loss (Economic Impact)

	NZ$
Summary of damages (Rehabilitation and reconstruction)	6,669,533
Economic Loss (Agriculture)	4,300,000
Economic Loss (Tourism) ?	1,000,000
Economic Loss (Business) ?	1,000,000
Project (Harbour)	2,800,000
	....
	15,769,533

Among others, economic losses to agricultural production were most critical (Table II. 7. 2). It is told that 50% of export of agricultural products were decreased as a result of cyclone Sally.

(c) **Port Facilities**

Among the various public utility facilities, port facilities were most severely damaged by storm surges and waves, including apron, reclamation, Eastern and Western Breakwaters, siltation of basin, equipment, etc. in Avatiu Harbour and apron and basin in Avarua Harbour, of which total loss amounts to NZ$ 1.6 million (Table II. 7. 3).

The Eastern and Western Breakwaters were underconstruction. The former had completed 60% when the cyclone came. The latter was still at the initial stage of construction. Dredging of the basin in Avatiu Harbour has been conducted since 1983, and supposed to be able to remove soils of 35 to 40 thousand cubic meters by early 1988. However, considerable retreat of the planning was obliged by the cyclone.

A pontoon and a bottom open barge were also damaged. Dredging works are forced to be done by other means without these floating equipment.

The basin in Avarua Harbour also suffered sedimentation as shown in Fig. II. 7. 1, which was surveyed during the team's stay in Rarotonga.

(d) **Buildings**

Damaged buildings include 30 government offices and 95 private houses due to high tide, flood, wave, wind, rubbles, etc. Huge quantities of coral debris have been washed off the reef and onto the foreshore destroying structures in their path. This was significant in the harbour area and town center. The damage of government offices is estimated by the Government to be about NZ$ 3.8 million. More than 20 private houses require structural replacement or new houses.

(e) **Coastal Protection Facilities and Roads**

Some of the artificial coastal protection works were also damaged, although their magnitudes were not critical, e. g. concrete sea wall at Rarotonga Airport, rubble stone revetment at the east coast of Rarotongan Hotel, etc.

Roads washed by waves and flood were partly destroyed at many places on Rarotonga. The road connecting the airport to Avarua has to be resealed, and numerious holes left on the surface of the other roads were refilled by sand and gravel.

(f) **Others**

The power station and the power reticulation system were extensively damaged. Most power lines were knocked down during the storm. There were other damages of lifelines such as telephone, water pipe lines, gas station, etc.

8. Development Projects and Others Concerned

(a) **Port Development**

The east side of Avatiu Harbour has been developed under New Zealand Aids since 1982, and the total investment until the end of 1986 was NZ$ 3.7 million (Fig. II. 8. 1). The damaged facilities are expected to be reconstructed by the end of 1987. It is also expected that New Zealand Army Task Force composed of 80 to 90 engineers and equipment (2 trucks, 2-3 loaders, 1 D-6 bulldozer) will possibly be dispached to undertake the construction works of the Eastern Breakwater.

The west side of the Avatiu Harbour is under construction with Australian Aids

(Fig. II. 8. 2). An amount of NZ$ 140 thousand has already been spent and additional NZ$ 1 million is anticipated to be required in about 5 years:

		NZ$ (thousand)
Stage I	Western Breakwater	610
	Causeway	56
Stage II	Jetty, etc.	203
Stage III	Others	238
		1,107

In Avarua Harbour, the Government started construction of breakwaters at both sides of its basin from the middle of February 1987, utilizing donated heavy equipment by French Polynesia and Australia: 1 excavator (Proclain 125), 1 bulldozer (Caterpillar 977), 1 loader, 1 rubber tyre dozen and 2 back hoes (Fig. II. 8. 3). In addition 4 trucks are hired from private sources. The west breakwater has a length of about 70 m from the shoreline as of 10 March and construction of the east breakwater just started on 2 March. The unit cost of the breakwaters without armour stones is approximately NZ$ 320 per meter or NZ$ 17 per cubic meter.

(b) Road Development

A plan is now under study to widen the existing two-lane road around the island to four-lane road from the Rarotonga International Airport through Avarua and Avatiu till Health Department. As the inland side of the road is fully utilized as the commercial area, it will be feasible to widen the road to the seaside. In that case, due consideration should be given to the coastal conservation, land use along the road, economic feasibility, etc.

(c) Coastal Conservation

The countermeasures against sea water for Avatiu-Avarua area have the highest priority. In planning the countermeasures, it is important that the plan be established in good harmony with other plans such as town plan, road costruction plan, harbour plan, etc. and also taking into full account of retaining beautiful landscape and environment.

(d) Construction Materials and Machines

Construction materials such as cement, asphalt, iron bars are all to be imported in the Cook Islands, except soils and rocks. Cost of concrete is NZ$ 190 per cubic meter which is not cheap compared with that of rocks, i. e. NZ$ 17 per cubic meter.

As for rocks, it is sometimes difficult to find good quarries where suitable basaltic rocks are available enough.

Furthermore, heavy equipment for earth works are not enough in number and capacity, e. g. cranes, excavators, front loaders, bulldozers, beavy duty trucks (17 ton), compressor and rock breaking equipment, etc. For the works on the sea work vessels such as dredgers, rock cutters, floating cranes are needed and not available at this time. Skilled and qualified civil engineers are also in dearth for planning, design and execution of construction works.

III. TENTATIVE PLANNING OF RESTORATION WORKS

1. Avarua Urban area

(a) Planning Criteria

In planning protection facilities against cyclones, we consider hereinafter a cyclone equivalent to Sally as design object which has a recurrence interval of more than 23 years.

The size or weight of rocks to be utilized for such structures as breakwater, sea wall and groin is to be designed following Hudson (1959):

$W=0.23\,H^3/\cot\,\alpha$,

where W: weight of a rock,
H: wave height, and
α : angle of slope.

Technical judgement shall be made from following points of view:

i) Effect of facility in decreasing storm surge, wave, etc. and in expediting sedimentation, etc.,
ii) Durability of structure against storm surge, wave, etc. and social requirement in the future,
iii) Easiness of construction work,
iv) Cost effectiveness,
v) Environmental impact, and
vi) Others.

(b) Plans against Storm Surges

1) Sea Wall

In order to prevent coastal disaster, it is necessary to protect Avarua by means of sea wall. Sea wall, however, is not effective to stop sea water, because there are three streams or four exits open to the sea in Avarua / Avatiu area, i. e. Takuvaine Stream, Vaikapuangi Stream and Avatiu Stream, unless the residential areas are enclosed by waterproof walls or the exits are able to be closed with gates when required during storm surges and land side water are able to be pumped out, which are very costly and not practical. Nevertheless, sea wall along the shoreline is absolutely required to defend the town from the invasion of waves and rubbles onto land.

The necessary crown height for the sea wall is planned basically to be MSL + 4.0 m in case that there is no foreshore breakwater or reclamation, based on the cross-sectional surveys of the road and lagoon done by the team and Survey Department (Fig. III. 1. 1), and on aforementioned analyses of storm surges and waves.

There are several plans we can conceive:

i) A simple and possibly the cheapest way is to install sea wall alongside the present Main Road (Fig. III. 1. 2.).
ii) Incorporated with the expansion plan of the road width from two-lanes to four-lanes, a new two-lane road and sea wall are constructed sea side of the Main Road (Fig. III. 1. 3).
iii) Same as the above ii) with some detached breakwaters on the lagoon for leasening wave action and expediting depost of coral debris thereon (Fig. III. 1. 4) as the first stage of reclamation.
iv) Same as the above ii) with artificially reclaimed land which can be used as coastal park or possibly land for other purposes such as an under-

ground sewage treatment plant which might require 3,600 square meters for 5,000 persons (6,300 square meters for 10,000 persons) in the future (Fig. III. 1. 5) , and

v) Others.

A comparision of advantages and disadvantages of these plans is made and shown in Table III. 1. 1.

2) Breakwaters

In view of the fact that the most severely damaged area by the storm surges was behind Avarua Harbour, it is reasonable to discuss whether construction of new breakwaters there is beneficial for the protection of its hinterland as well as for the development of the port itself. In addition, such breakwater might enhance sedimentation of river and sea-born sand, rock, and coral debris.

Here the following four plans are compared :

i) To extend the head of the west breakwater into the deeper sea, but retain the head of the east breakwater on the reef. (Fig. III. 1. 6.) .

ii) To shorten the above west breakwater to a certain degree which corresponds to a plan made by the Cook Islands Government (Fig. III. 1. 7.)

iii) To turn the face line of the west breakwater at the middle of lagoon towards the passage, which entails narrower mouth of the harbour (Fig. III. 1. 8.) .

iv) To leave the both breakwaters as they are now (Fig. III. 1. 9.) .

Advantages and disadvantages of these plans are summarized as Table III. 1. 2.

There is an important subject of frequent mouth closure at the Takuvaine Stream due to accumulation of sea-born sand and gravel during storms. Question is whether we shall open the mouth in or out of the east breakwater (Fig. III. 1. 10.) .

Sediment transport of the stream is estimated by the team to be of the order of 1,000 cubic meters per annum. If we open the mouth in the harbour, siltation of the basin is anticipated to a certain degree, and we may possibly need introduction of a floating dredging machine. On the contrary, if we let the mouth open at outside of the breakwater, the harbour basin may become free from accumulation of river sediments. However, the mouth may be closed by sea-born sediments and we need an excavator to maintain the stream. In addition to this physical problem, impact of river water on corals could be aggravated due to diffusion of fresh water.

In any case a training jetty may be required, and if any problem arises in the future, the alignment, structure and / or length of the training jetty can be reconsidered.

3) Restriction of Land Use

Of many damaged places by Sally, those low lying areas inundated (mainly, back marsh) are originally prone to inundation. Without such measures as river improvement works, construction of gates / pumping stations, etc., those areas can not be free from damage when hit by a cyclone with a magmitude similar to Sally. But it is obvious that such measures would require tremendous fund. Therefore, it is recommended that such low lying areas had better be used for taro cultivation, play grounds, etc., and not for such high state of utilization as residential area, business area, etc.

4) Building Methods

The existing building code, which was prepared following the New Zealand's Code, is now under review to incorporate the result of recent studies on wind force,etc.

It is recommended that the new code should have provisions for effective measures against inundation of low lying areas such as mount up of the basement of houses, high-floor buildings, waterproof buildings, etc., through designation of disaster areas subject to flooding.

5) Other Countermeasures

i) Warning System

The Survey Team was informed that damage to person was none owing to smooth operation of warning and evacuation system. It is recommended that any efforts be made for improvement of the disaster preparedness on the basis of lessons learnt from Sally.

ii) Fund

It is considered that it would be meaningful if " Fund " could be established which, being supported by both people's charge and Government's contribution, aims at reducing the burden of those who are affected by cyclones. In this case, it is necessary to define the areas threatened by disasters and to assess their possible magnitude of damage.

iii)Emergency Operations (Flood Fighting, Evacuation)

Flood fighting is, in many cases, meaningful to minimize damage by flooding. Smooth operation of evacuation is essential to prevent damage to human beings.

It is suggested to organize flood fighting squads and their training, and to improve communication facilities for emergency use as well as heavy machines to open roads blocked by debris, fallen trees, etc.

2. Other Coastal Areas

(a) Restriction of Land Use and Sand Removal in the Seashore

The use of the seashore should be made in full consideration of the safety from disaster, characteristics of the seashore, landscape, environment, etc. Therefore it is suggested first, to make people fully aware of relevant information on seashore, and then to take necessary steps by the government for appropriate restrictions. Although efforts have already been initiated for restriction of land use and sand removal in the seashore, further steps should be taken without delay for the enforcement of relevant Acts / Regulations and for their effective implementation, in view of the vital importance of conservation of the beautiful shoreline, the most precious assets of this island.

(b) Coastal Protection

As protective means against coastal erosion from wave, " nourishment " is considered to be the most appropriate from the view point of the harmony with landscape and environment. Revetment is also useful as a protective means, but, in this event, revetment of natural stones with gentle slope is recommended in view of conservation effects, landscape and economy.

As for the protection of coastal road near the airport, suction of filled material from the rear banking of the road and overtopping of wave were the main causes of damage to the road. As a means for the former, some devices such as the flexible joint to connect walls or a concrete plate behind the slit between concrete walls should be considered. As for the later, construction of the wave breaking works is recommended (Fig. III. 2. 2, Fig. III. 2. 3.) .

(c) Follow-up Survey of Coastal Profile

It is recommended to carry out survey of coastal profile on regular basis at selected sites. Thirteen sites have been selected for this purpose as shown in Fig. III. 2. 4.

(d) Drainage of Back Marsh

The back marsh area inundated by Sally is roughly estimated as 200 ha at 17 places throughout the island. In addition to the low elevation of these areas, following facts are considered to have aggravated the situation :

i) No existence of proper drainage channels, or if exist, they did not work well.

ii) Closure of the outlet of the channel by waves, etc.

iii) Choking at bridges, etc.

It is recommended to establish a drainage plan for individual streams to solve these problems. In areas where taro is planted, it is suggested that the channel can be designed for both irrigation and drainage where feasible.

(e) Measures Against Closure of River Mouths

Some streams and drainages were closed at their outlets by accumulation of reef rubbles which aggravated the flooding in residential areas and others. To cope with this problem, means are proposed as follows :

i) Box culvert should be extended to offshore until it will not be influenced by drifting sand. Bending of the top of the box culvert following the direction of the current would be effective.

ii) Jetty (guide levee) should be constructed at the river mouths which are subject to closure during cyclones.

3. Town Planning

(a) Classification of Land Area

Land survey should be made on areas damaged by Sally as well as the actual land use. Areas to be reserved from environmental viewpoint, etc., or areas to be developed on the long-term basis should also be identified reflecting the development plan of the country. With all these information, the land use plan is to be established, so that the island could resist more effectively against cyclones.

(b) Back Road Development

The Main Road circles the island along which commercial / industrial development has been made. Another road, the back road, runs at the foot of mountains, which had been a main road before the Main Road was constructed. It may be meaningful to consider in the town planning to improve the back road and connecting roads. By doing so, it is expected that Rarotonga may be better protected against the onslaught of cyclones, and also too much concentration on areas near seashore may be avoided.

(c) Building Code

The New Zealand's building code has been applied to the Cook Islands. In view of the difference in natural conditions between the two countries, efforts have been made to amend the code so that the code may be more suitable to this island. The draft is now with the parliament for necessary legislation.

It is recommended that further efforts might be valuable to be made to modify the code by including provisions concerning flood prevention, e. g. high floor housing in the back marsh area, etc.

IV. RECOMMENDATIONS

Based on the above analyses, the survey team would like to submit the following recommendations for consideration by the Government of the Cook Islands.

1. Avarua Town Protection

In order to cope with wave and coral debris invation onto the town, sea wall construction alongside the shoreline would be most essential of which design crown height could be 4.0 m. At the same time expansion of lane number of the Main Road and artificial foreshore reclamation might be incorporated for the future development of the capital town.

It is most important to plan and design structures such as sea wall, breakwater, detached breakwater, etc. so as to bear strong wave action expected during cyclones in term of layout (i. e. water depth, etc.) and cross section (i. e. slope, size of armour stone, quality of fill material, etc.) , taking into consideration of available size and volume of stones, number and capacity of heavy equipment, and other related matters.

To make out a Comprehensive Long-term and Short-term Plan for Avarua Town Protection might be beneficial for the Government in order to realize deliberately protection and development of the town, for example, as the commercial and administrative center, the port as a new small boat harbour which enhance the tourism, the coast and land to be reclaimed as the place where people gather, or for other development purposes. Such planning should be done, taking into consideration of coastal conservation and town planning for overall Rarotonga on which recommendations are given below.

2. Other Shore Protection and Coastal Conservation

In view of the vital importance of the coast to Rarotonga Island, it is urgently necessary to rehabilitate the coast which suffered erosion by Sally. Therefore it is recommended to establish as soon as possible shore protection plan which should refer to priority areas, type of protection works, etc.

In addition to shore protection, it is also recommended to effectively implement regulations on restriction of sand removal from the beach and on land use along the coastline. The coast will be well maintained or more improved through the combination of these hard-ware and soft-ware means.

3. Flood Prevention

It is recommended to establish river improvement plan for important streams, in which concrete measures should be proposed to slove problems experienced during Sally, e. g. drainage from the back marsh, closure at the river mouths, etc.

4. Town Planning

In view of the enormous damage caused by Sally, it is recommended to establish a town plan, with primary emphasis on disaster prevention and preparedness, and also on conservation of nature and economic development. Land use plan identifying disaster prone areas, conservation areas and those for development is required as the base for the plan (Fig. IV. 4. 1.) .

5. Studies and Surveys to be Performed

(a) Avarua Harbour

1) Periodical soundings of the passage and the basin of Avarua Harbour to detect siltation or erosion of the bed.

2) Measurement of currents and waves on the lagoon and in the passage of Avarua after the construction of breakwaters to evaluate their effects.

3) Continuation of tide and wave observation by the present equipment and analysis of storm surges, if any, to secure data base for disaster preparedness.

4) Hydraulic model tests of wave and current at the Avarua lagoon and passage, if it will become necessary.

5) Studies for the development of Avarua port as a marina (Planning, design, cost estimates, etc.) .

6) Study for planning and design of Long and / or Short-term Avarua Town Protection and Coastal Development.

(b) Coastal Conservation

1) Periodical survey of the movement of the shoreline at selected sites (13 sites have been proposed as shown in Fig. III. 2. 4.) to prepare for the coastal conservation plan.

2) Survey on littoral current and littoral drift dominant around the island.

3) Survey on the quality, quantity and distribution of drifting sediments in the offshore area, to obtain fundamental data for the study on the supply-demand balance, possibility of sand collection, beach nourishment, etc.

4) Study on run-off characteristics and survey on river bed materials, in order to estimate the volume of sediments from the streams.

5) Monitoring of water pollution of the sea.

(c) Flood Prevention

1) Installation of additional raingauges so that the raingauge network may cover all catchments with proper density.

2) Provability analysis of rainfall data, to review / establish the design discharge for important streams.

3) Investigation of peak water level of floods.

4) Investigation of the depth and the areal extent of inundation of back marsh after each flood, for use in the plan of disaster prevention and preparedness as well as in the study on land use of such areas.

5) Survey and analysis of the condition of river mouth of such streams as Takuvaine, Airport drainage, etc., where closure may take place again at the time of cyclones.

(d) Town Planning (Conservation and Development)

1) Survey on land use, disaster history, historical places, etc.

2) Assessment of damage from possible cyclones of certain magnitude.

3) Review and improvement of existing disaster preparedness plan (Hurricane Safety Plan) .

4) Establishment of town plan incorporating the above disaster plan and in consideration of conservation of nature and economic development.

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