PART II: FIELD RECONNAISSANCE AND FIELD SERVEY IN SEA AND COASTAL AREAS FOR BASIC STUDY

Section 1: Supporting Report

1. Field Reconnaissance

1. Field Reconnaissance Survey

Field reconnaissance was conducted on the entire Fongafale Islet, Tengako Islet (Asagatau Paka Area) adjacent to it on the north, and Funafala and Fuagea Islets located in the southern part of the atoll. This report shows mainly the survey results obtained in October 2009 in the dry season as well as the results obtained in January 2010 in the rainy season for the vicinity of Funafuti Port in Lofeagai Area, the vicinity of the jetty in Vaiaku Area, and the southernmost tip of Kavatoetoe Area, where the conditions of the coast are different in the rainy season.

1.1 Fongafale Islet

Figure 1.1 shows Fongafale Islet. Fongafale Islet is characterized by an approximately 75 degree change in the direction angle of the coastline at its easternmost protrusion. The field reconnaissance results are summarized by each of the areas shown in this figure.

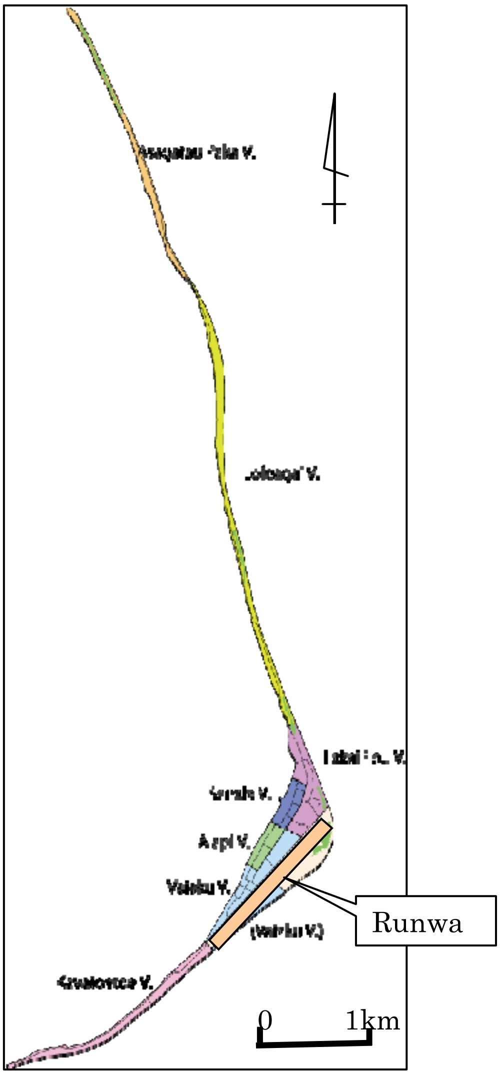


Figure 1.1 Field reconnaissance classification map for Fongafale Islet

1.1.1 Lofeagai Area

(1) Local conditions

1) Ocean side

Like on Tengako Islet, the north side of the beach ridge consists only of gravel (Photo 1.1), containing no sand and forms a steep slope with an approximate gradient of 1 in 3. Going southward, houses have been built closer to the coast, and vegetation has been felled for the sake of development in some areas (Photo 1.2).

Photo 1.1

Photo 1.2

2) Lagoon side

On the south, beach rocks are formed (Photo1.3). On the north of Funafuti Port, on the other hand, beaches are scattered (Photo 1.4). The conditions of the shoreline connecting the new and old jetties of Funafuti port are shown in Photos 1.5 (left bank of the new jetty), 1.6 (right bank of the new jetty), 1.7 (left bank of the old jetty), and 1.8 (right bank of the old jetty), in this order. The new jetty is adjacent to the south side of the old jetty. On the new jetty where sand has been deposited on both sides, there is more sand on the southwestern side (left-bank side) when judged by comparison of the photos. This is considered to be because, despite a permeable type on the front side, the sand was influenced by the jetty that runs in parallel to the coast. On the old jetty, sand has been deposited on the southwestern side (left-bank side) but not on the northeastern side (right-bank side). Whereas these photos were taken in October 2009 in the dry season, the ones taken in January 2010 in the rainy season are shown in Photos 1.9 to 1.12. On the new jetty, unlike in the dry season, more sand is found on the northwestern side (right-bank side). On the old jetty, no significant difference is found between the dry and rainy seasons. From these facts, it is deduced that the direction of the predominant littoral drift is approximately neutral in the dry season and southwest in the rainy season, and that its amount is small.

Photo 1.3

Photo 1.4

Photo 1.5

Photo 1.6

Photo 1.7

Photo 1.8

Photo 1.9

Photo 1.10

Photo 1.11

Photo 1.12

(2) Discussion

・On the ocean side, the coast consists mainly of beach rocks. Going southward, the development by people becomes conspicuous. At some places, the felling of vegetation has caused the ridge to collapse. Although it is true that land for housing is running short due to population growth, we consider it necessary to establish a law to ban the felling of vegetation.

・At Funafuti Port, it is deduced that the direction of the predominant littoral drift is northeast in the dry season and southwest in the rainy season, and that its amount is relatively small.

1.1.2 Fakai Fou Area

As shown in Figure 1.1, this area is located to the north of the runway and faces a narrow trench dug by the American troops during the Pacific War as a borrow pit to obtain earth and sand to construct the runway. Since the houses in this area were built by immigrants from other islets near the ridge, the settlement is located in a narrow strip of land bordering on the South Pacific on the east and a pond formed due to the borrow pit on the west.

(1) Overall conditions of the settlement

A north-south road is connected to a residential district by a narrow path shown in Photo 1.13. A small hut indicated by arrow A on the right side of the path is a pigpen. On the right and left sides of Photo 1.13, there are big ponds (Photos 1.14 and 1.15) around which there are numerous such pigpens. The pig waste flows untreated into these ponds. Although these ponds are not directly connected to the ocean, the beach ridge consisting of gravel is highly permeable so that seawater flows into these ponds due to changes in the tide level of the ocean. On the beach ridge between these ponds and the ocean, houses stand side-by-side as shown in Photos 1.14 and 1.15. Most of the houses are high-floored, but some of them are not high enough.

Photo 1.13

Photo 1.14

Photo 1.15

(2) Ocean side of the settlement

The ocean side of the settlement is a leveled crest of the beach ridge on which houses stand. Ocean waves wash directly into places only a few meters away from the houses. Although these photos were taken on a day with rather high waves, they were not as high as those in a developed depression. The conditions shown in the photos, therefore, indicate that this neighborhood is susceptible to wave run-ups and overtopping waves. A picture taken facing forward near the tires indicated by arrow B in Photo 1.16 is shown in Photo 1.17. The tires for preventing overtopping waves were placed on a masonry seawall consisting of stacked beach rocks. On the ocean side, the beach rock surface was exposed, showing no sign of the usual gravel slope formed by beach rocks deposited by wave actions. This shows that the masonry seawall was made by collecting and stacking stones that had been scattered in front of it and, additionally, setting out the normal of the seawall further toward the ocean in order to expand the planation surface on the land side of the seawall. A picture taken under the masonry seawall, facing north, is shown in Photo 1.18. The stone masonry consists of heavy stones stacked on a slanting slope of gravel, and the seawall height is 1.2 m. Arrow C in Photos 1.18 and 1.19 points to the same rock. The part of the masonry seawall shown in Photo 1.19 consists of smaller stones than those in the southern-side seawall and cannot avoid being washed away by even low waves. Photo 1.20 shows the conditions of the part of the coast located immediately north of the place shown in Photo 1.19, where a saddle is formed due to the lack of a masonry seawall in the vicinity. The beach ridge has been mostly dug away and is low.

Photo 1.16

Photo 1.17

Photo 1.18

Photo 1.19

Photo 1.20

(3) Near the meeting point of the central path of the settlement and the ocean

A rainwater catchment tank (D) is shown a little to the left of the center of Photo 1.20. The conditions near this tank are shown in Photo 1.21. At this place, the ground level is still lower than an altitude of 1.2 m shown in Photo 1.15. According to an interview survey, overtopping waves flow into the other side in the high-tide season in February and March every year. Large rocks shown in the center of this photo are viewed from the land side in Photo 1.22. According to the interview survey, these rocks were not carried by wave actions but lined up by the residents to deal with terrible overtopping waves. Similarly, the adjacent area to the north of the rocks had just one row of rocks as shown in Photo 1.23, which served as a seawall. A scene viewed from the central path of the settlement toward the ocean is shown in Photo 1.24. In the center, stacked rocks observed in Photo 1.22 can be seen. There is no other protective facility, and the path is inclined toward the land side. When overtopping waves come, a fairly strong current flows down this narrow path. One item of evidence of such a phenomenon can be seen in a concrete facility shown on the other side (south) of the rainwater catchment tank in Photo 1.24. The ocean-side foundation of this facility (probably also a catchment tank) has been broken mainly by wave action as shown in Photo 1.25.

Photo 1.21

Photo1.22

Photo 1.23

Photo1.24

Photo 1.25

(4) Discussion

・One basic measure for preventing an increase of problematic places is to prohibit digging of the beach ridge on the ocean side for use as construction materials. The height of a beach ridge is determined in accordance with incoming overtopping waves at the place. Removal of part of the beach ridge always causes overtopping waves.

・One possible solution not premised on the relocation of the settlement at present is to input gravel on the ocean side to construct a gravel levee as high as the original beach ridge in order to alleviate overtopping waves. Gravel is deposited stably with an approximate gradient of 1 in 3, thus requiring a smaller amount of gravel and a narrower strip of land. Note that sand cannot be input because of the fact that there was originally a gravel levee on the ocean side.

1.1.3 Senala Area, Alapi Area and Vaiaku Area

Figure 1.1 shows a satellite image of these areas. These areas were developed by the American troops during the Pacific War by expanding the runway and reclaiming land on the lagoon side, and constitute the western coast of the central part of a town having government office buildings and a large population of residents. Field reconnaissance was conducted on these areas one by one, from the north to the south.

Local conditions

Figure1.2 Lagoon-side central part of Fongafale Islet

Quick Bird (June 2003)

A little to the north of the central part of the western coast, there is a ramp constructed as a base for flying boats of the American troops during the Pacific war (Photo 1.26). In an adjacent area to the north of this ramp, concrete blocks shown in Photo 1.27 have been installed. These blocks, measuring about 30 cm on a side, are nearly regular hexahedrons intended to be carried manually while weighing as much as possible. A common use for them is to line them up and use them as a seawall.

The conditions of the adjacent area to the south of the ramp are shown in Photo 1.28. The left end of this photo shows that many of the above-mentioned blocks are scattered. On the other hand, the water area shown in the right and center of this photo is deep even at low tide because the American troops dug the reef surface to create a passage for boats.

To the south of the groin, many blocks and waste rocks are lined up in the same way as in Photo 1.28, providing very poor access to the shoreline. An area further to the south is under similar conditions as shown in Photo 1.29 but forms a ramp to allow a small boat to be carried down from the front of the house behind it onto the sea.

Going further to the south, there is a beach indicated by arrow A in Photo 1.30. This beach consists of sand that has been deposited stably by the wave-absorbing effect of an offshore reef adjacent to it. With gravel deposited on the land-side edge of the sand beach, the deposition area is clearly divided into sand and gravel areas. Simple measurement conducted on the day of field reconnaissance using a pole found that the sand beach had a gradient of 1 in 12 and that the gravel beach on the shore side had a gradient of 1 in 6. The beach had a composite cross section with well-sorted gravel deposited on the shore side and sand offshore from it. It is noteworthy that the gradient of 1 in 6 of the gravel slope on the shore side is equal to that of the above-mentioned ramp for small boats. This is a point to be considered for future improvements. Furthermore, gravel deposited on the shore side is useful from the viewpoint of shore protection because they have a characteristic of being carried up to the land side when high waves hit the shore (Matsuura et al., 2009).

The sand beach of the study area ends at a certain length, and to the south of it, there is an area where concrete chips and large-sized gravel are scattered once again (Photo 1.31). Although a masonry seawall has been installed here, strong wave actions have bored cavities near the high-tide shoreline on the seawall, causing the destruction to progress on it (Photo 1.32).

To the south of this place, there are several groins extending at right angles to the coastline. For example, Photo 1.33 shows a permeable jetty extending beside a hotel. Scenes viewed from this jetty to the north and south are shown in Photos 1.34 and 1.35, respectively. As shown in the northward scene in Photo 1.34, there is an upright bulkhead in front of the hotel, which is becoming old. To the south, the gravel beach continues.

Further to the south of this jetty, there is groin B, which is shown in Photo 1.36. In Photo 1.37 that shows the north side of the groin, there is no gravel beach at all in front of the seawall. In Photo 1.38 that shows a scene to the south, a triangular-shaped gravel beach is formed toward the base of the groin. This asymmetry of the shoreline reveals that a northward littoral drift is predominant at this point. The conditions in the rainy season (January 2010) were the same as those shown in these photos taken in October 2009 in the dry season.

To the south of this groin, there is another small groin, on the northern side of which there are exposed beach rocks as shown in Photo 1.39, indicating a depletion of gravel that can be moved. On the southern side of the groin, however, a gravel beach has been formed in the same way as shown in Photo 1.40. This reveals the same characteristics as shown in Photos 1.37 and 1.38, i.e., a northward littoral drift is predominant around this place.

Photo 1.26

Photo 1.27

Photo1.28

Photo 1.29

Photo 1.30

Photo 1.31

Photo 1.32

Photo 1.33

Photo 1.34

Photo 1.35

Photo 1.36

Photo 1.37

Photo 1.38

Photo 1.39

Photo 1.40

Photo 1.41

(1) Discussion

As shown in Photos 1.37 and 1.38 or 1.39 and 1.40, sand and gravel are deposited on the south of a groin and tend to be eroded on the north of it. Therefore, a northward littoral drift is generally predominant in the central part of the western coast of Fongafale Islet. This is because the northern part of Fongafale Islet leans a little to the west, restricting the development of wind waves on the lagoon side when northerly winds blow, but letting waves from the western side reach the coast uninterrupted by the islet. In this case, the relationship between the coastline and the wave directions makes a northward energy flux predominant.

・In the case of gravel beach nourishment conducted on Jinkouji beach in Ibaraki prefecture, input gravel with grain size of 3 to 15 mm were deposited stably with a gradient of 1 in 6 in front of the seawall (Matsuura et al., 2009). In this case, the deposition status of gravel was the same as shown in Photo 1.41. This demonstrates that beach nourishment using gravel (beach rock and coral fragments), namely,. beach nourishment with coarse-graded materials, will be effective in the study area. Such gravel materials are advantageous in that they are highly stable and more easily available in Tuvalu than sand.

・In the study area, small boats are pulled up onto land when not in use. Some small boats are left moored in the sea. In view of the convenience in using small boats, it is necessary to differentiate a sea area with a certain depth and a beach nourishment area and install a groin-shaped facility on the border between them.

In this case, as shown in Photo 1.41, sand with an approximate grain size of 1 mm is deposited with a gradient of 1 in 12 whereas gravel is deposited with a gradient as steep as 1 in 6. The input of sand will make the groin longer whereas the input of gravel will make it shorter. In actuality, a decision on the amount of gravel and fine sand based on beach nourishment conditions will often make the procurement difficult. Rather, it is more rational to calculate the amounts of sand and gravel that can be supplied based on the material procurement conditions, and make a beach procurement plan by considering these amounts to some extent.

・We consider it best to conduct beach nourishment using gravel or sand in front of the hotel shown in Photo 1.34. This is because this area is close to the center of the town and therefore the beach nourishment will be seen by many citizens, facilitating people's understanding of the effects of beach nourishment.

・In the study area, a northward littoral drift is predominant on a long-term basis. It is necessary to construct a medium-length groin to retain gravel on the coast while allowing movement of fine sand. In this case, fine sand will flow out to the north, going around the tip of the groin. It is desirable that earth and sand supplied from the southern part of the islet will gradually spread to the northern part, but this also means that fine sand will sink and be deposited at the boat basin. It is necessary to discuss which is more desirable, having it both ways and maintaining the beach from a dynamic point of view or dividing the coastline with several groins and impermeable jetties to stabilize the beach from a static point of view.

・At present, the northern part already has a breakwater extending from the port, which completely prevents a littoral drift. Therefore, even if the shape of the causeway is improved in the future to allow foraminiferal sand to be carried into the lagoon, all the sand will be prevented by the breakwater on the northern side.

Reference:

Takeo Matsuura, Takaaki Uda, Yoshio Suwa, Koji Yamada, Takashi Fukumoto (2009): Discussion on Effectiveness of Beach Nourishment with Coarse-Graded Materials for Designation as Coastal Protection Works on Sand Beach, Collection of Papers on Ocean Development, Volume 25, pp.1119-1124.

1.1.4 Kavatoetoe Area

The study area is located in the southernmost tip of Fongafale Islet. The normal line of the coast roughly points to the south.

(1) Local conditions

A picture taken of the ocean side of the islet looking toward east shows the formation of a slightly elevated beach ridge due to constant actions of overtopping waves from the South Pacific (Photo 1.42). The foreshore is a steep slope with a gradient of 1 in 3 and is connected offshore to the planation surface of the reef, from which a reef edge extends as can be seen in the conditions of white waves in the offing. A picture taken at the same position looking west is shown in Photo 1.43. The reef and the beach ridge are continuous, and vegetation such as screw pines has grown to the back of the berm on the ridge. The foreshore deposit, as shown in Photo 1.44, is gravel rounded to an approximate diameter of 3 to 10 cm, containing no sand. A close shot of the spit-shaped tip with another islet in the background is shown in Photo 1.45. Gravel is deposited here, too. Lastly, a picture taken of the beach ridge extending towards the Lagoon side of the islet is shown in Photo 1.46. On the southernmost tip of the islet, a large amount of gravel is deposited in a protruding spit shape but, going northward, the deposited area abruptly narrows down. Photo 1.46 taken in the dry season (October 2009) shows that the tip of the spit faced somewhat the lagoon side. In the rainy season, however, it faced the ocean side as shown in Photo 1.47.

Photo 1.42

Photo 1.43

Photo 1.44

Photo 1.45

Photo 1.46

Photo 1.47

(2) Discussion

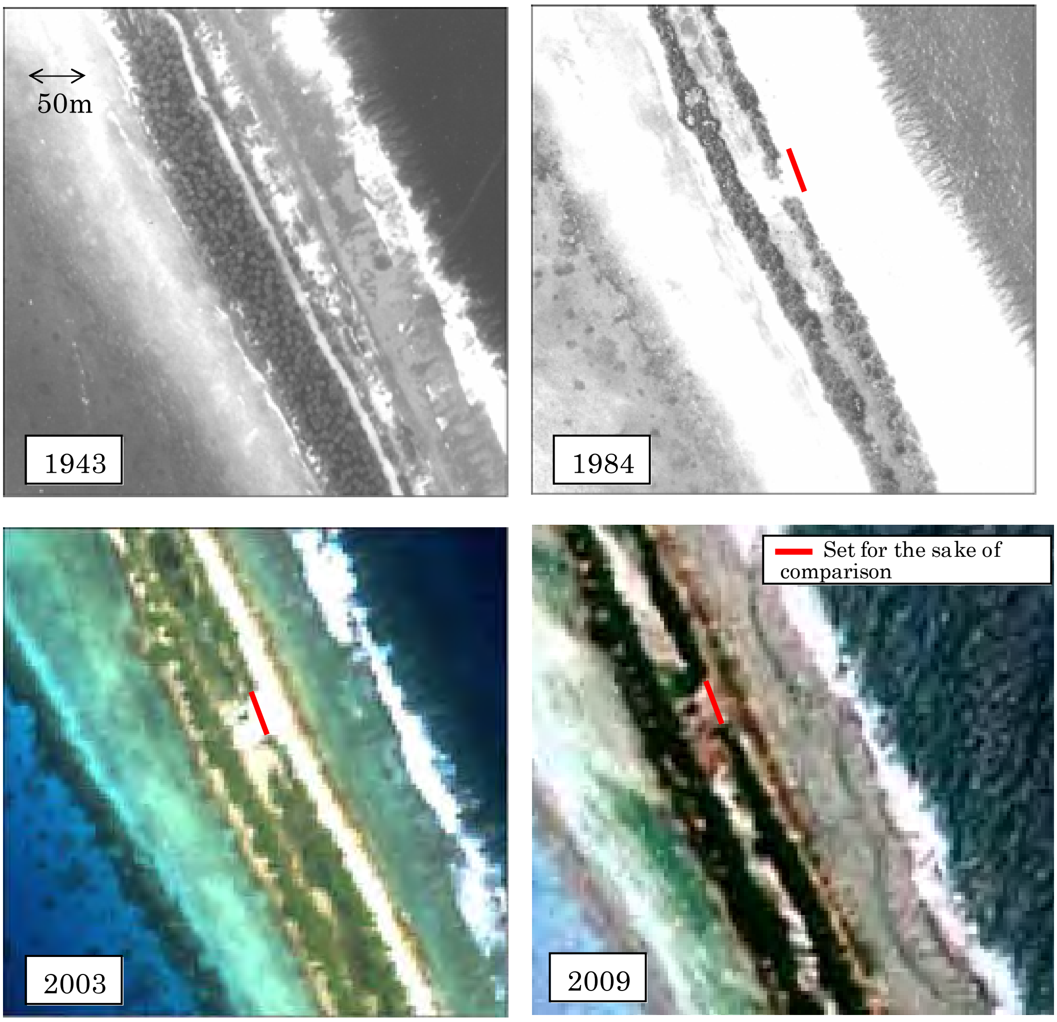
On the southernmost tip of the islet, gravel derived from the coral reef (either beach rock or coral fragments) was deposited and then carried to the lagoon side in the dry season due to the diffraction effect of waves at the protruding islet tip. In the rainy season, the direction of the tip was changed to the ocean side. This is a natural phenomenon caused by directions of predominant waves but can provide an important clue in considering the following points in the future examination of countermeasure works and material procurement.

・On the lagoon side of the islet, not only gravel is deposited but also sand is supplied. How does the sand go around the southernmost tip of the islet? If it is foraminiferal sand, there must be some mechanism for this phenomenon. Or was the gravel shown in the photo worn down to become sand, which was then carried? This question must be considered from a qualitative point of view.

1.2 Tengako Islet

1.2.1 Investigation of Breaching

As shown in the satellite image in Figure 1.3, the breaching was generated when a storm ridge developed along the eastern coast collapsed and the resultant sand and gravel poured into a narrow trench that ran lengthwise in the central part of the islet, which was dug by the American troops during the Pacific War to obtain earth and sand to construct a runway.



Source: 1943-2003: EU EDF 8/9 – SOPAC Project Report 54, Reducing Vulnerability of Pacific ACP States
TUVALU TECHNICAL REPORT –COASTAL CHANGE ANALYSIS USING MULTI-TEMPORAL IMAGE COMPARISONS – FUNAFUTI ATOLL, April 2006

Figure 1.3 Changes in the opening of the breaching

(1) Local conditions

1) Cutting of beach ridge

Around the place where breaching is occurring, namely, the eastern coast of the northern part of the islet, the reef is developing well due to constant action of rough waves of the South Pacific. Since a large amount of coral debris was washed ashore by waves and emerged out of the sea, the solvent action of rainwater and so on cause calcium carbonate to consolidate again, resulting in continuous development of beach rocks. These conditions are shown in Photo 1.48. Beach rocks, completely consolidated, demonstrate considerable roughness effects against waves and torrents. On the shore side of these beach rocks, there is sedimentation of coral and beach rock fragments carried to the shore by wave actions as shown by a dotted line in Photo 1.48 and its ocean-side threshold can be distinguished as a clear line. This phenomenon occurred because deposited gravel washed ashore by wave actions has as high an equilibrium gradient at about 1 in 3, causing the gravel to stabilize at a higher gradient than that of a plane formed by the beach rocks. These characteristics are commonly found at every ocean-side coast.

Photo 1.49 shows that the beach ridge consists only of gravel and contains no sand. Therefore, the gradient is as steep as 1 in 3. The ridge is about 3 m high above sea level and has a top covered with vegetation such as coconut palms and screw pines at present.

A picture taken at the position of Photo 1.49 facing south is shown in Photo 1.50. In this photo, the zone vegetated by palms, etc. abruptly disappears, and white gravel that constituted the ridge has been driven to the land side. This is where breaching occurred. The depression in the center of the deposition area of white gravel, shown by a dotted line in this photo, reveals that the gravel has been carried by wave actions in a direction indicated by an arrow in this photo. Driftwood A in the center, in view of its species and form, is not wood that grew on this islet but an exotic drift.

Turning a little to the west from Driftwood A in the center (Photo 1.51), another piece of driftwood B can be seen. Driftwood B was washed ashore diagonally with little space between it and the ridge in the north but much space in the south. Therefore, the incoming seawater poured into the trench mainly southward, carrying a large quantity of drifts and gravel with it.

Photo 1.48

Photo 1.49

Photo 1.50

Photo 1.51

2) Deposition of drifts in the trench

A picture showing both Driftwood A and the northernmost end of the cut ridge is Photo 1.52. The cross section of the cut beach ridge is clearly shown in the top of the belt-shaped deposition area of gravel. Photo 1.53 shows a scene looking toward the horizon from the land side of Driftwood B. It reveals that a funnel shape formed by a combination of Driftwood B and the southern beach ridge caused water current to be concentrated between these two elements, carrying in a large amount of gravel with it. In contrast, drifts were accumulated on the back of Driftwood B because water currents were weak there.

Photos 1.54 and 1.55 show a large amount of wastes washed ashore near the border line between a trench where breaching occurred and the western coast. Having low specific gravities, they were carried deep into the southern side of the trench (near the place indicated by an arrow in the photo). On the northern side, on the other hand, the driftwood shown in Photo 1.51 prevented many drifts from being carried in.

3) Southernmost end of the cut beach ridge

Photo 1.56 shows the cut part of the beach ridge. The root of a screw pine has been exposed due to erosion. To the south of this place, however, a stable beach ridge continues (Photo 1.57). Flat gravel derived from Acropora coral has been thickly deposited in layers, forming a typical beach ridge.

Photo 1.52

Photo 1.53

Photo 1.54

Photo 1.55

Photo 1.56

Photo 1.57

(2) Discussion

・The observation results show that a large amount of earth and sand was carried into the narrow trench extending in the central part of the islet, through a cut in the ocean-side beach ridge. Originally, breaching refers to a phenomenon in which a barrier is cut and seawater and earth and sand flow in from the ocean side to the lagoon side. Precisely speaking, the phenomenon observed in this study is not breaching. However, it is quite similar to breaching in that a large quantity of substance was carried into a central, narrow trench after the beach ridge collapsed. In a broader sense of the term, therefore, the observed phenomenon can be included in breaching.

・According to the observation of the local conditions, breaching caused a large amount of earth and sand to be carried into the trench but, as a result, raised the ground level at the place where seawater flowed in. This means that every wave action carries in gravel from the surrounding coast, promoting restoration of the beach ridge.

・The landward transport of a large amount of gravel by breaching raises the ground level of the trench, consequently reducing the wave force acting on the narrow ridge between the trench and the western coast. Therefore, the stability of the lagoon-side ridge increases as time passes. Thus, there is no fear that this bridge will be cut. However, this prediction is premised on a sufficient supply of beach rock fragments or coral heads that constitute the beach ridge. If there is only a limited amount of supply, for example, the opening at the breaching position is not sufficiently blocked, preventing sufficient development of the beach ridge. In this case, overflows over the beach ridge are not stopped and, therefore, the ridge does not stop moving to the lagoon side. If the coral is dead, the supply of gravel to the beach ridge stops, causing it to move to the land side accordingly.

1.2.2 Causeway

A field survey was conducted to study the possibility of transportation of earth and sand that passes through the causeway connecting Fongafake and Teagako islets.

(1) Local conditions

1) Ocean side of the causeway

A scene of the causeway viewed from the north to the south is shown in Photo 1.58, showing the lagoon side on the right and the ocean side on the left. A scene of the causeway viewed from the northernmost tip, a little to the ocean side, facing south is shown in Photo 1.59. A large amount of gravel with large grain sizes has been deposited, forming a beach ridge. The ocean side of the central part of the causeway is a little elevated, where beach vegetation grows. In contrast, an area from this place to the camera position is free of vegetation but half covered with gravel that must have been carried there by waves. From this fact, it can be deduced that

the movement of gravel over the causeway is more significant in the northern half than in the center of the causeway.
When viewing the coast facing north from the southernmost tip of the causeway, as shown in Photo 1.60, the beach ridge is covered with white gravel with large grain sizes, which has been deposited at a steep gradient. The ocean-side gravel in the deposition area has been consolidated and is covered with beach rocks with many protrusions. The border line between the gravel deposition area and the beach rocks is depressed toward the land side at the causeway. This corresponds to the inflow of gravel to the lagoon side when high waves hit. Moving to the ocean side shown in Photo 1.60, the beach rocks can be seen in the coastal direction as shown in Photo 1.61. On the offshore side, the beach rocks have less projections and depressions and continue to a planation surface. The shallow water area offshore from the planation surface is inhabited by foraminifera. The reasons why the beach rocks have less projections and depressions are considered to be that the further offshore, the more influenced by wave actions, and the faster the gravel carried onshore, resulting in stronger abrasive actions. A scene seen from the causeway toward the foraminifera habitation area is shown in Photo 1.62. In comparison with the gravel deposition area with significant projections and depressions near the beach ridge, the foraminifera habitation area is flat.
Photo 1.63 is a picture taken of the beach ridge from the southern side of the causeway facing south. Vegetation, including coconut palms, has grown on the ridge, in front of which gravel washed ashore has been deposited in bands. Photo 1.64 is taken at approximately the same position at low tide. This reveals that the gravel deposition area, beach rock area, and foraminifera habitation area further offshore are distributed in bands, the borders of which are classified by altitude, and gravel is deposited in the uppermost one.

Photo 1.58

Photo 1.59

Photo 1.60

Photo 1.61

Photo 1.62

Photo 1.63

Photo 1.64

Photo 1.65

Photo 1.66

Photo 1.67

2) Lagoon side of the causeway

Since the causeway is located 1.3 m above the MSL, it is apparent by the comparison with Photo 1.64 that gravel deposited in the uppermost layer on the ocean side is carried to the lagoon side by overflows over the causeway depending on the wave conditions and tide levels. At the same time, the causeway is a steep slope toward the lagoon side, overflows run down in a jet flow, consequently carrying gravel with large grain sizes deep into the lagoon. The gravel deposition area shown on the right in Photo 1.65 is shown in Photo 1.66. It reveals that gravel is deposited in a semicircular shape on the planation surface of the lagoon. This is considered to correspond to the flow velocity distribution on the causeway. A scene of the causeway viewed from the rear side of it is shown in Photo 1.67. Since the level difference just below the concrete ramp becomes larger going northward, overflows are estimated to have larger flow rates in the north than in the center of the causeway.

(2) Discussion

・The observation results described below about the breaching position show that a large amount of earth and sand was carried into the narrow trench extending in the central part of the islet, through a cut in the ocean-side beach ridge. At this time, breaching caused a large amount of earth and sand to be driven into the trench and raised the ground level at the place where seawater flowed in. Thus, there is no fear that this bridge will be cut. However, this prediction is premised on a sufficient supply of beach rock fragments or coral heads that constitute the beach ridge. If there is only a limited amount of supply, for example, the opening at the breaching position is not sufficiently blocked, preventing sufficient development of the beach ridge. In this case, the overflows over the beach ridge are not stopped and, therefore, the ridge does not stop moving to the lagoon side. If the coral is dead, the supply of gravel to the beach ridge stops, causing it to move to the land side accordingly.

・The current causeway has a crown height of 1.3 m over the MSL, which is equal to the height of the gravel deposition area. The deposition of gravel, as shown in Photo 1.60, moves mainly in the coastal direction along the beach ridge, facilitating the passage of gravel deposited in the same altitude zone through the causeway.

・Foraminifera grows in a depth zone near the LWL, which is lower than the present crown of the causeway. To enable movement of sand derived from foraminifera, therefore, it is necessary to lower the crown height of the causeway. If this is done, however, gravel movement occurs through the above-mentioned mechanism, resulting in deposition of gravel that blocks the causeway. If the causeway has a narrow width, it is immediately backfilled by gravel carried in from both sides through this mechanism. Enlarging the opening width of the causeway expands the deposition space in relation to the transport of gravel from both sides, making the opening less likely to be backfilled. On the whole, important parameters are considered to be the crown height (over the MSL) and opening width of the causeway, wave specifications, altitude of the gravel deposition area, and altitude of the foraminifera dwelling zone.

1.2.3 Northernmost Tip of Tengako Islet

The study area is the northernmost tip of Tengako Islet, from which Amatuku Islet can be seen beyond the reef that submerges at high tide. Field reconnaissance was conducted, going northward along the lagoon-side coastline.

(1) Local conditions

1) Beach formation

Going northward along the lagoon-side coast and approaching the northernmost tip of the islet, fine sand starts to cover the beach rocks as shown in Photo 1.68. The beach width gradually expands going northward, up to a few tens of meters (Photo 1.69). Approaching a place where Amatuku Islet can be seen, gravel with small grain sizes starts to be deposited thinly on the surface of the beach (Photo 1.70). As shown in Photo 1.71, this is well-sorted gravel with grain sizes of two or three centimeters, consisting mostly of coral fragments. Going further closer to the northernmost tip, gravel starts to be deposited, forming cusps as shown in Photo 1.72. The beach width is extremely large around this place, with vegetation thickly grown. Arriving at the northernmost tip of the islet, a large amount of coral-originating gravel is deposited, forming a high berm (Photo 1.73). This coral-originating sand and gravel is white and rises at a steep angle from the planation surface of the rough beach rocks offshore, resulting in a well-developed round berm such as the one shown in Photo 1.74.

After moving over to the eastern side of the islet along the berm, however, the amount of sand derived from the coral reef and gravel deposition suddenly decreases as shown in Photo 1.75, with only a thin layer of white sand and gravel remaining on beach rock fragments, resulting in a lower berm height. Photo 1.76 shows the conditions of the beach ridge facing the ocean, immediately east of the place where Photo 1.75 was taken. The beach ridge consists of beach rocks with large grain sizes, a totally different material from white sand derived from the coral reef and gravel shown in Photo 1.74. The offing of the beach ridge is widely covered with beach rocks. From the above conditions, the following characteristics can be pointed out.

・On the lagoon side of the islet, there is initially a fine sand deposition area. Going closer to the northernmost end, you find increasingly more gravel derived from the coral reef with grain diameters of two or three centimeters.

・In the northernmost tip of the islet, a large amount of white sand and gravel has been deposited to form a high berm. Going around the tip to the eastern side of the islet, the deposition area of white sand and gravel abruptly becomes narrow. The white sand and gravel deposition area is long on the lagoon side and short on the ocean side. The deposition area has a clear asymmetry.

・On the ocean-side coast, you come to a point where there is no longer deposition of white sand and gravel derived from the coral reef, and the area to the south of this place is covered with beach rock fragments with large grain sizes.

・The altitude of berms is low on the lagoon side and becomes higher as it gets closer to the northernmost tip of the islet. The area facing the ocean is covered with gravel with exceedingly large grain sizes, not white sand and gravel with small grain sizes that are found from the lagoon side to the northernmost tip of the islet. The area is totally isolated from the movement of white sand and gravel described above.

2) Characteristics of the channel between islets

Photo 1.77 shows a distant view of Amatuku Islet, located to the north of Tengako Islet, with an expansion of a planation surface covered with beach rock and coral fragments. Similarly, Photo 1.78 shows Tengako Islet seen from the channel. In some parts of the center of the channel, not so much gravel is scattered, unlike near the shore. Photo 1.79 is a picture taken near its border facing the ocean. To the north (left) of the border line, there is an area with active currents from the ocean to the lagoon side. To the right, on the other hand, land continues to Tengako Islet, and there is significant deposition of gravel.

Photo 1.68

Photo 1.69

Photo 1.70

Photo 1.71

Photo 1.72

Photo 1.73

Photo 1.74

Photo 1.75

Photo 1.76

Photo 1.77

Photo 1.78

Photo1.79

(2) Discussion

The sediment movement near the northernmost tip off Tengako Islet (including the lagoon side) is considered to have the following mechanism: From the northernmost tip of the islet to the lagoon side, waves from the ocean are blocked by the islet itself. Sand and gravel derived from the coral reef with small grain sizes are carried along the coastline of the islet and deposited on the lagoon side of the islet. Sand thus supplied is not large in quantity, and as such, moves unitedly as a sand body. When sand moves to the northernmost tip of the islet, the coastline has a large curvature like a hairpin and, in the same way as for the tip of a spit, the littoral drift abruptly decreases near the northernmost tip. Therefore, sand movement occurs only in a limited range. As is obvious from the formation of large berms, sand movement occurs only at high tide, and the sandbar maintains its appearance at low tide levels.

1.3 Other Islets

A field survey was conducted on two islets in the atoll to examine them as possible candidates from which to obtain beach nourishment materials.

1.3.1 Funafala Islet

(1) Satellite image interpretation

Figure 1.4 Funafala Islet (Google)

Funafala Islet is located in the southern part of the atoll. The reef surrounding the islet shifts direction significantly at the protruding easternmost tip. With the northern part facing the Pacific on the east and the southern part facing the Pacific roughly on the south, this islet is separated into smaller islets on the north and south by a shallow channel between them. Waves are driven into the reef edge, causing the water level to rise on the reef. When the driven seawater flows out in the northwestern direction to the lagoon side, such a shallow channel is formed. The shape is quite similar to a topographical feature with a one-directional flow of currents (such as an estuary terrace or ebb tidal delta), which provides a characteristic depth on the lagoon side and forms shallows surrounding it.

Let us tentatively call the northern islet B, the southern islet C, and a small islet between them A. Islets B and C are roughly symmetrical in relation to the central line of the channel. This means that waves coming from the east to Funafala Islet and those coming from the south have approximately equal energy. Islets B and C have two pairs of protrusions, respectively (B1 and B2 and C1 and C2). Each of them has a spit-like form. The mechanism underlying the formation of this topographic feature can be deduced as follows: Coral heads and coral sand washed ashore from the reef were carried by wave actions to the lagoon side. However, gravel with large grain sizes were not carried so far because the wave height abruptly decreased during transportation from the reef edge to the lagoon side, resulting in accumulation of coral gravel to develop Spits B1 and C1 consisting of gravel. On the other hand, sand derived from foraminifera and small-grain sand derived from the coral reef was carried by nearshore currents to the lagoon, reached the lagoon side and got deposited offshore from B3 and C3, but by the actions of wind waves on the lagoon side, was further carried onshore along the sandbar and formed stable sandbars B2 and C2.

The fact that the small islet A in the center has A1, a narrow comet tail on the lagoon side, and A2, one extending deep into the lagoon, demonstrates that there are constant strong currents from the reef edge to the lagoon side. Such a topographic characteristic results from nearshore currents derived from breaking waves and is irrelevant to tidal currents.

(2) Local conditions

A view seen from B3 shown in Figure 1.4 looking toward the reef edge is shown in Photo 1.80. There is islet A in the center, toward which islets B and C jut out from both sides like peninsulas. Photo 1.81 shows the beach conditions with the left side facing the embayment between B2 and B3 shown in Figure 1.4. Around this place, the beach consists of sand because the sea is tranquil, not directly influenced by high waves from the reef edge. The ocean-side of B1, as shown in Photo 1.82, is a seashore crowded with coral heads, which have been washed ashore from the reef edge.

Photo 1.83 shows the southern side of islet A, which is surrounded by beach rocks washed ashore by waves and then covered with coral heads congealed on them. These beach rocks have many irregular projections and an exceedingly high degree of roughness. A distant view of the reef edge from islet A is shown in Photo 1.84. It can be seen that the reef edge has a slightly elevated gravel deposition area, and that this elevation extends completely in parallel with the horizon. Simple measurement using a pole found that the height was 1.1 m above the reef surface.

Photo 1.85 shows the conditions of the southeastern tip of islet A. Islet A, being protected by a large beach rock area and therefore free of strong wave actions, has a deposition of coral sand. In the southern area (side) of the islet, on the other hand, currents to the lagoon side are predominant so that any movable sand cannot remain on the coast, resulting in a gravel beach (Photo 1.86). A view of the comet tail in the back of islet A shown in Figure 1.4, seen from the base of islet A facing northwest, is shown in Photo 1.87. In the center of the wide deposition area of coral heads, sand is deposited in an approximately triangular shape. This reveals that, around islet A, sand can be deposited only where wave actions are blocked and, elsewhere, all the sand is carried away to the lagoon side.

Photo 1.88 shows a distant view of a sandbar near C2, a tip of islet C, seen from the eastern side. The sand beach at C3 remains to have an approximate thickness of one meter over a congealed planation surface. Photo 1.89 is taken standing on sandbar C3, which shows a broad expanse of sand beach. The constituent materials of sandbar C3, shown in Photo 1.90, are red sand derived from foraminifera and well-sorted sand such as seashell chips. Although such sand is ideal as a beach nourishment material, the question is whether a sufficient amount of it is available. Therefore, a detailed survey was conducted near sandbar C3. Photo 1.91 shows a view of islet 3 seen from the center of C3, and Photo 1.92 shows a view of the tip of the sandbar in the opposite direction. It appears as if there is sufficient sand near this place. However, digging an area a little distant from sandbar C3 in the west that seemed to be covered with sand revealed that the thickness of deposited sand is only about 7 cm as shown in Photo 1.93, and that there is little available sand. In an area further to the east of it (Photo 1.94), the surface was white, appearing to have a deposition of sand, but was actually firm ground, having little sand unlike in Figure 1.89 and 1.91.

Photo 1.80 **Photo 1.81**

Photo 1.82 **Photo 1.83**

Photo 1.84

Photo 1.85

Photo 1.86

Photo 1.87

Photo 1.88

Photo 1.89

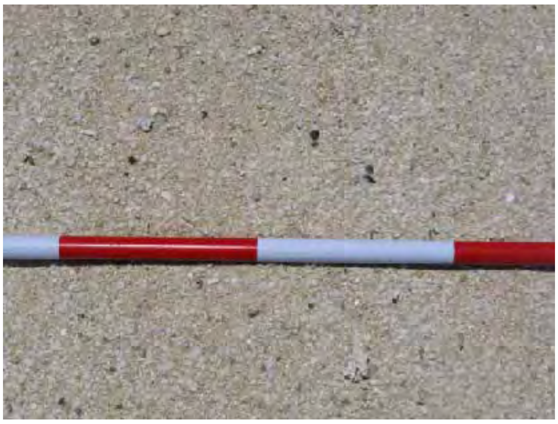


Photo 1.90

Photo 1.91

Photo 1.92

Photo 1.93

Photo 1.94

(3) Discussion

・The field reconnaissance of Funafala Islet found that the distribution of deposited sand is determined based on nearshore currents derived from breaking waves near the reef edge and going from the reef edge to the lagoon, and the degree of wave actions. Where the wave actions are strong, coral heads have been deposited and congealed to form beach rocks. On the lagoon side, on the other hand, sand has been carried in by currents.

・Among the sand carried from the reef edge to the lagoon side, sand with relatively large grain sizes has been deposited, forming sandbars B3 and C3. Sand deposited near this place is a good material for beach nourishment, but limited in amount.

・In the satellite image, a sea area covered with white sand was found to the east of sandbar C3. However, the amount of deposited sand was so small that it is impossible to collect sand there.

・ In the lagoon-side tip of the channel from the reef edge to the lagoon, sand carried from the reef edge has been deposited; although the amount of available sand is unconfirmed it is though to be limited.

1.3.2 Fuagea Islet

(1) Local conditions

1) Overview of the cay

Fuagea Islet, located to the west of the atoll, is a beautiful cay that has been built up through accumulation of dead foraminifera. The altitude of this islet is high in the southernmost tip where coconut palms and screw pines grow thickly. Toward the north, a narrow sandbar has been developed (Photo 1.95). On the eastern side of the islet, there is an expanse of shallow reef covered with fine sand on the surface (Photo 1.96). The foreshore of the cay was measured to have an approximate gradient of 1 in 10 and consists of well-sorted sand (with grain sizes of few millimeters) (Photos 1.97 and 1.98). The red material forming the beach is sand derived from foraminifera.

The center of the islet seen from the sandbar extending thinly to the north of the islet looking south is shown in Photo 1.99. Swash oscillations from both sides of the islet cause drifts to be washed ashore from both sides. This cay, as long as it is shown in this photo, looks stable. However, the conditions on the other side (southern side) of the islet were not clear. Therefore, the conditions of the beach were checked while we walked around this islet counterclockwise along the shoreline.

2) Western side of the cay

First, Photo 1.100 was taken of the islet from the western side of the islet looking south. The foreshore of the cay starts as a steep slope from the planation surface of the reef. Photo 1.101 was taken after moving further to south along the shoreline. There is a clear border between the zone of sand that constitutes the cay and the planation surface of the reef, at which the planation surface of the reef abruptly changes to a slope consisting of sand. This phenomenon is due to the following cause: Since the equilibrium gradient of sand is as high as about 1 in 10, any sand deposited on the reef planation surface is subject to strong onshore littoral drift. If there is an impermeable wall (an islet itself in this case) that blocks sand movement on the other side of the incoming direction of waves, a slope with a gradient of 1 in 10 is built up and gets stabilized (Kobayashi et al., 2008).

Near the southernmost tip of the islet, some coconuts drifted ashore and pushed out new shoots that were growing as shown in Photo 1.102. However, this area where coconuts were growing abruptly ends near arrow A. Near A, a small beach scarp has been formed, and a berm is being formed again on the ocean side of it. This status is considered to be due to the following cause: The cay was eroded once to form a beach scarp, on which sand was deposited to form a berm. Then, coconuts that drifted ashore before this temporary erosion pushed out new shoots.

3) Eastern side of the cay

Going around the southernmost tip of the cay and reaching the eastern side of the islet, the beach conditions are completely different. First, Photo 1.103 shows a beach scarp that began to be observed near the southernmost tip of the cay. At this position, the beach scarp has an elevation difference of 0.4 m. Going along the eastern side of the islet, the erosion conditions were photographed as shown in Photos 1.104, 1.105 and 1.106. The vegetation fell due to the erosion, and the beach scarp has increasingly greater elevation differences of 0.8 m, 1.1 m and 1.2 m in Photos 1.104, 1.105 and 1.106, respectively. Going down from the position where Photo 1.106 was taken, Photo 1.107 was taken at the shoreline facing southeast. In this photo, many rows of beach rocks inclined toward the shore side are observed offshore from the present shoreline. Considering that beach rocks are formed in the sand beach, these conditions show that the beach rocks shown in Photo 1.107 were developed in an area that used to be covered with a sand beach in the past, and that erosion of the sand beach exposed the beach rocks. Near the place shown in Photo 1.106, the shoreline is estimated to have backed off for about 12 m based on the beach scarp's elevation difference of 1.2 m and an approximate foreshore gradient of 1 in 10. Therefore, it is understood that the area with beach rocks shown in Photo 1.107 was initially covered with sand, but was later exposed when the beach moved approximately in parallel and that erosion occurred on the eastern side of the cay in recent years. Going further, the beach scarp has smaller elevation differences of 1.1 m and 0.6 m as shown in Photos 1.108 and 1.109. Near the back (northern side) of the islet, there is almost no beach scarp as shown in Photo 1.110.

4) Comet tail extending to the back of the cay

At the same time as the cay erosion described in the above, a narrow comet tail extended on the north of the cay. Photo 1.111 shows the comet tail seen from the northernmost tip of the cay facing north. The sprouting of many coconuts observed at the base of the comet tail shows that sand has just been accumulated at this place and that a stable comet tail has been formed. The comet tail is not straight but bends sharply to the east near the tip (Photo 1.112). Arriving at the tip of the comet tail, it was found to have a cut as indicated by an arrow in Photo 1.113, where a channel has been formed (Photo 1.114). On the lagoon side of this channel, a semicircular comet tail extends over two cays. This channel has no deposition of sand and is covered with gravel. On the side covered with gravel, a strong current was running from the ocean side to the lagoon side as shown by the arrow. On the other hand, littoral drift generated when wind waves broke in the lagoon carried sand to the channel as shown by the dotted line and, immediately thereafter, the strong current in the channel carried the sand to the eastern (inner) part of the lagoon. This shows that, in this opening, dynamic equilibrium is approximately maintained by circulation of drift sand through a similar mechanism to the formation of an ebb tidal delta (Uda et al., 2008).

Photo 1.95

Photo 1.96

Photo 1.97

Photo 1.98

Photo 1.99

Photo 1.100

Photo 1.101

Photo1.102

Photo 1.103

Photo 1.104

Photo 1.105

Photo 1.106

Photo 1.107

Photo 1.108

Photo 1.109

Photo 1.110

Photo 1.111

Photo 1.112

Photo 1.113

Photo 1.114

(2) Discussion

・In Fuagea Islet, erosion has been progressing on the eastern side of the cay in recent years, and a beach scarp with an elevation difference of 1.2 m at the maximum has been formed. At places with significant beach scarp formation, several rows of beach rocks were observed near the low-tide shoreline. It was concluded that these beach rocks were formed while the cay extended to the eastern side and got exposed due to erosion that occurred in recent years.

・In view of the beach scarp erosion and beach rock exposure conditions, waves that caused the erosion are considered to have come from the eastern to southeastern direction. In the atoll, there is a cut in the eastern to southeastern direction of this islet. Therefore, the entry of high waves from this direction is considered to be the cause of the erosion.

・In view of the exposure of beach rocks, which are formed in a relatively long period of time, it is deduced that the cay used to be stable despite wave actions for a long time. However, it was significantly deformed as a result of stronger action of waves from the east to southeastern direction due to some cause.

・Sand generated by intensive erosion that occurred on the eastern side of the cay was carried by littoral drift mainly toward the north, resulting in the development of a narrow comet tail.

・On the tip of the sandbar extending northward as a comet tail, a cut has been formed in the sandbar. This is because a water level rise due to wave setup on the ocean side of the reef generated currents from the ocean side to the lagoon side, thus forming a topographical feature similar to an ebb tidal delta.

・Fuagea Islet consists of well-sorted sand derived from foraminifera. Although this is a good material for beach nourishment, it is difficult to collect or transport sand because the water depth is small around the cay.

・Moreover, there is an exceedingly good environment on this islet. Therefore, it is a questionable idea to improve the environmental conditions of other islets by sacrificing this environment.

Reference:

Akio Kobayashi, Takaaki Uda, Yasuhito Noshi and Masumi Serizawa. 2008. Model for sand beach development in a coral reef, Collection of Papers on Marine Development, Volume 24, pp.1231-1236.

Uda, T., M. Serizawa, T. San-nami and K. Furuike. 2006. Model for predicting dynamically stable beach based on analogy with two-dimensional potential flow, Proc. 30th ICCE, pp. 3911-3923.

2. Field Observation in Sea and Coastal Areas for Basic Study

2. Field Observation in Sea and Coastal Areas for Basic Study

2.1 Wave Observation

(1) Overview of Survey

Wave observation was conducted during field surveys in this study, using one set of Sontek Acoustic Doppler Profilers (Mini-ADP) and one set of I.O-Technic Wave Gauge (Wave Hunter WH403) shown in Table 2.1.

Wave observation was conducted at two points: The frontage of Vaiaku Lagi Hotel on Fongafale Islet (WG-1) and the sea area to the south of Tepuka Islet (WG-2) shown in Figure 2.1. Data sampling was made on wave height, period, wave direction and drift for 10 minutes before and after every hour on the hour (for 20 minutes) at intervals of 2 hours and recorded at intervals of 0.5 sec.

Table 2.1 Instrumental Parameters of Wave Gauges

Instrument	Mini-ADP	Wave Hunter
Make	Sontek	I.O.Technic
Model	Mini ADP	WH 403
Serial No.	M 510	8032
Type	Pressure & Acoustic (1.5MHz)	Pressure, Acoustic & Electro-magnetic
Data Recorder	Internal	Internal
Data recorded	Pressure, Water Column Velocity, Temperature	Pressure, Temperature, Velocity & Water Level

The details of the deployments of wave gauges and the observation period of waves are shown in Table 2.2 and Table 2.3, respectively.

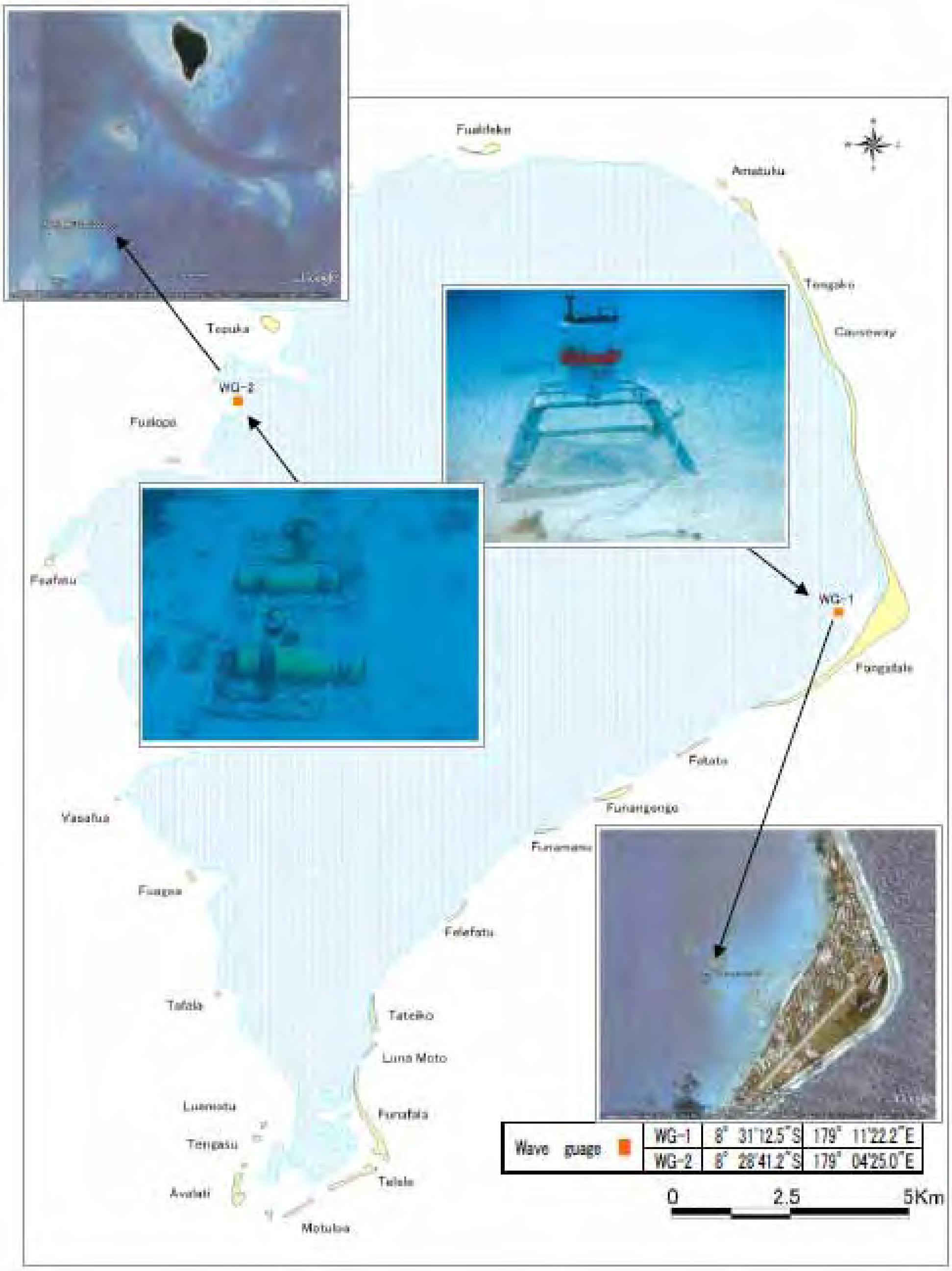


Figure 2.1 Location of Wave Observation Points and Overview of the Wave Gauge

Table 2.2 Deployment of Wave Gauges

St. No.	WG – 1	WG – 2
Location	Vaiaku	Tepuka
Instrument	Wave Hunter	Mini-ADP
Longitude	179.18957°E	179.07383°E
Latitude	8.51972°S	8.47738°S
Water Depth	approx. 10 m	approx. 15 m
Height above Seabed	0.4 m	0.4 m

Table 2.3 Observation Period of Waves

Observation Point	Observation Duration		
WG-1	First Deployment	November 1 to November 21, 2009	20 days
	Second Deployment	February 2 to February 19, 2010	16 days
	Third Deployment	February 20 to March 19, 2010	27 days
WG- 2	First Deployment	November 17 to January 8, 2010	51 days
	Second Deployment	January 9 to February 20, 2010	41 days

(2) Results of Wave Observation

The details for the wave observation results at two points, the frontage of Vaiaku Lagi Hotel on Fongafale Islet (WG-1) and the sea area to the south of Tepuka Islet (WG-2), are provided in "Data Book". This section describes the overview of the wave characteristics observed at the two points (WG-1 and WG-2).

a) Frontage of Vaiaku Lagi Hotel (WG-1)

Regarding the wave characteristics at the frontage of Vaiaku Lagi Hotel (WG-1) obtained from the first deployment (from November 1, 2009 to November 21, 2009), the second deployment (from February 2, 2010 to February 19, 2010) and the third deployment (from February 20, 2010 to March 19, 2010), Table 2.4 shows the statistics for wave observations.

Figure 2.2 to Figure 2.4 show the variations of wave conditions with time (heights, average periods, and average wave directions for significant wave) and the occurrence frequency histograms for significant wave.

The range of wave height, wave period and wave direction (traveling direction) obtained from the first observation were respectively 0.2 to 0.3 meters (average: 0.2 m), 2 to 4 seconds (average: 2.5 sec) and 49 to 83 degrees with hydrographical convention (average: 70.7°). The range of wave height, wave period and wave direction obtained from the second and third observations were respectively 0.2 to 1.4 meters (average: 0.4 m), 2.1 to 4.5 seconds (average: 3.1-3.6 sec) and 51 to 99 degrees (average: 76-80°).

Comparing the results of the second and third observations with those of the first observation, it was indicated that the wave characteristics from the second and third observations were influenced more strongly by western wind or roar.

Table 2.4 Statistics for Wave Observations (WG-1)

Wave Dimension	First Deployment (Nov.1 to 21, 2009)	Second Deployment (Feb.2 to 19, 2010)	Third Deployment (Feb.20 to Mar.19, 2010)
Wave Height : Maximum	0.3 m	0.9 m	1.4 m
Mean	0.2 m	0.4 m	0.4 m
Minimum	0.2 m	0.2 m	0.2 m
Wave Period : Maximum	4.0 sec	4.5 sec	4.5 sec
Mean	2.5 sec	3.6 sec	3.1 sec
Minimum	2.0 sec	2.5 sec	2.1 sec
Wave Direction: Maximum	83.0°	89.0°	99.0°
Mean	70.7°	79.8°	76.8°
Minimum	49.0°	67.0°	51.0°

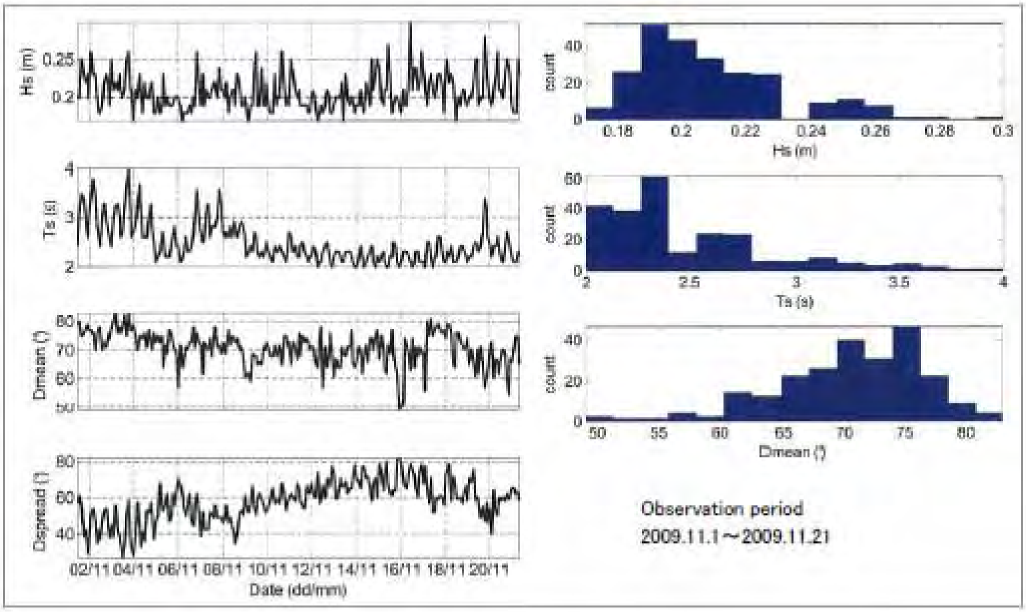


Figure 2.2 Time Series Plot of Wave and Occurrence Frequency Histograms (WG-1: First Deployment)

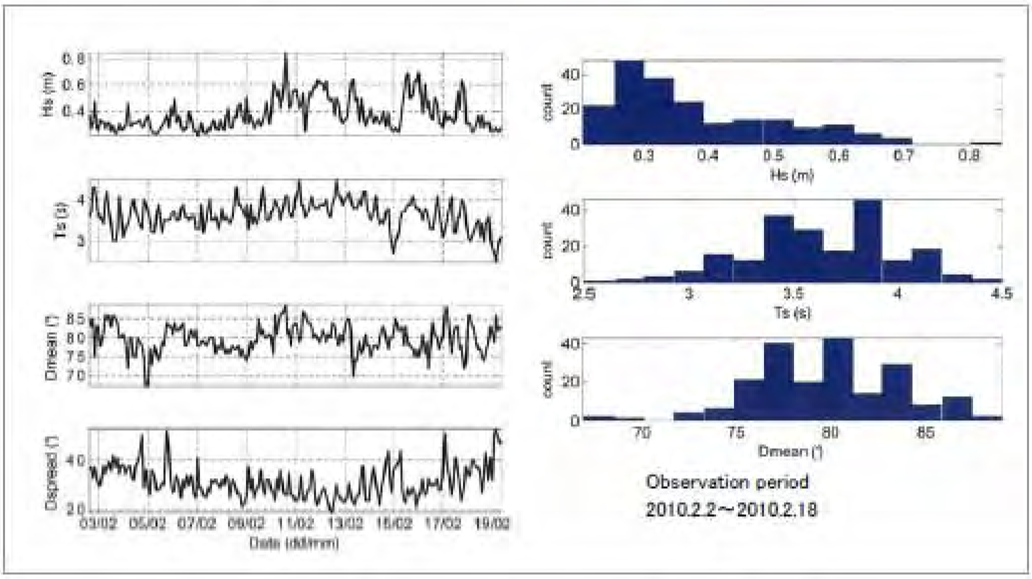
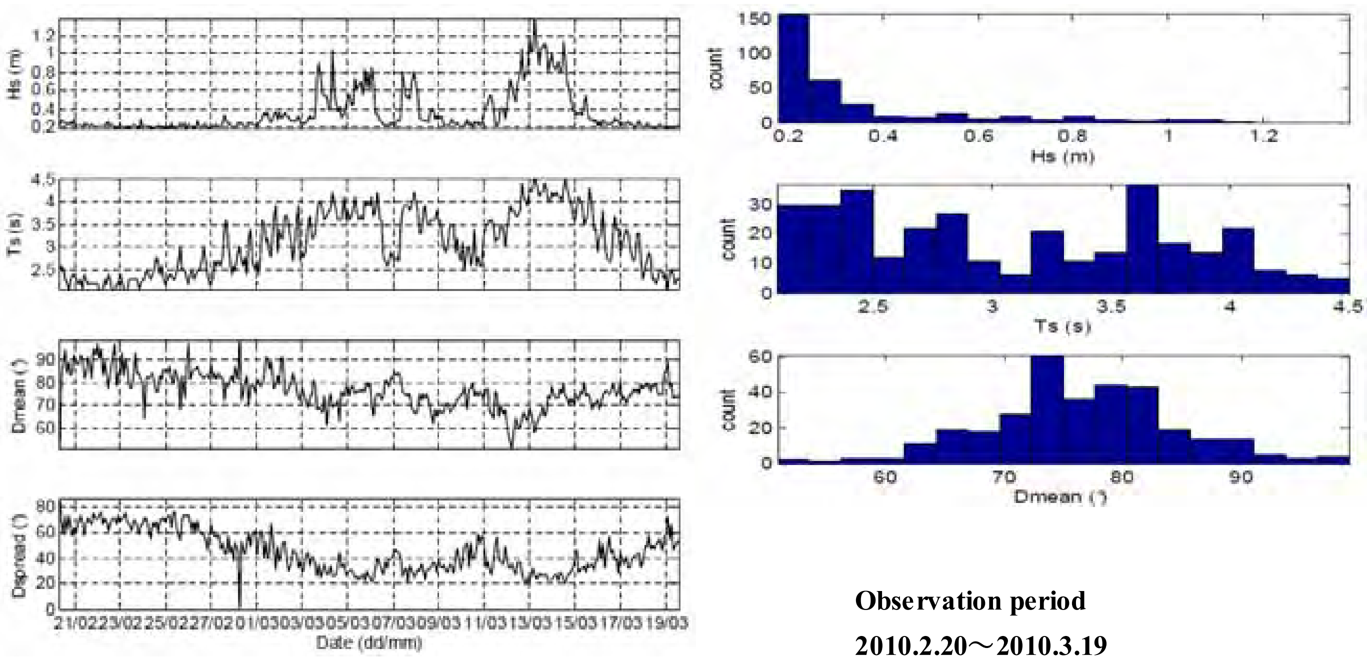


Figure 2.3 Time Series Plot of Wave and Occurrence Frequency Histograms (WG-1: Second Deployment)



(Note) Hs : Significant Wave Height, Ts : Significant Wave Period
Dmean : Mean Wave Direction, Dspread : Wave Average Dispersion Angle

Figure 2.4 Time Series Plot of Wave and Occurrence Frequency Histograms (WG-1: Third Deployment)

b) Sea Area to the South of Tepuka Islet (WG-2)

Regarding the wave characteristics in the sea area to the south of Tepuka Islet (WG-2) obtained from the first observation (from November 17, 2009 to January 8, 2010) and the second observation (from January 9, 2010 to February 20, 2010), Table 2.5 shows the statistics for wave observations.

Figure 2.5 and Figure 2.6 show the variations of wave conditions with time (heights, average periods, and average wave directions for significant wave) and the occurrence frequency histograms for significant wave.

The range of wave height, wave period and wave direction (traveling direction) obtained from the first observation were respectively 0.2 to 1.1 meters (average: 0.3 m), 5.3 to 14.9 seconds (average: 8.9 sec) and 22.4 to 310.1 degrees with hydrographical convention (average: 193.9°). It was indicated that the wave characteristics from the first observation were influenced strongly by northern swell. The range of wave height, wave period and wave direction obtained from the second observation were respectively 0.2 to 1.1 meters (average: 0.5 m), 5.3 to 14.0 seconds (average: 8.9 sec) and 204.5 to 225.0 degrees (average: 219.3°).

Comparing the results of the second observation with those of the first observation, a marked difference in the wave height and wave period was not found. Regarding the wave direction, the occurrence frequency for significant wave with 220 degrees predominated. However, it was indicated that the wave characteristics from the second observation were influenced more strongly by northeastern wind or swell.

Table 2.5 Statistics for Wave Observations (WG-2)

Wave Dimension	First Deployment (Nov.17. 2009 to Jan.8, 2010)	Second Deployment (Jan.9, 2010 to Feb.20, 2010)
Wave Height : Maximum	1.1 m	1.1 m
Mean	0.3 m	0.5 m
Minimum	0.2 m	0.2 m
Wave Period : Maximum	14.9 sec	14.0 sec
Mean	8.9 sec	8.9 sec
Minimum	5.3 sec	5.3 sec
Wave Direction: Maximum	310.1°	225.0°
Mean	193.9°	219.3°
Minimum	22.4°	204.5°

Figure 2.7 shows the frequency occurrence diagram by wave direction at two observation points for each deployment period. On this diagram, the wave directions are shown as “going to”, which means the hydrographical convention.

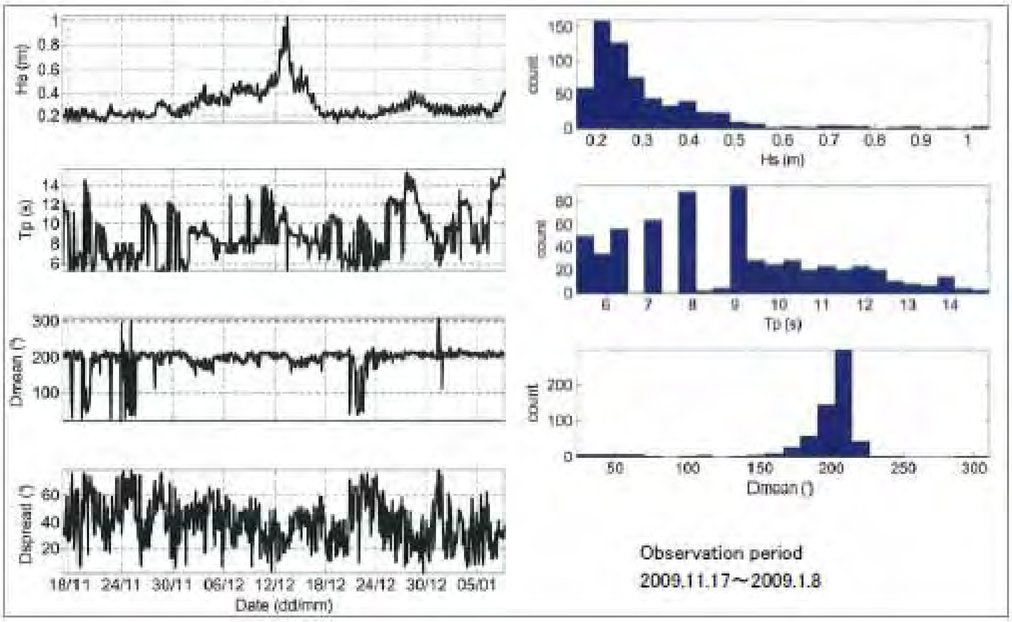


Figure 2.5 Time Series Plot of Wave and Occurrence Frequency Histograms (WG-2: First Deployment)

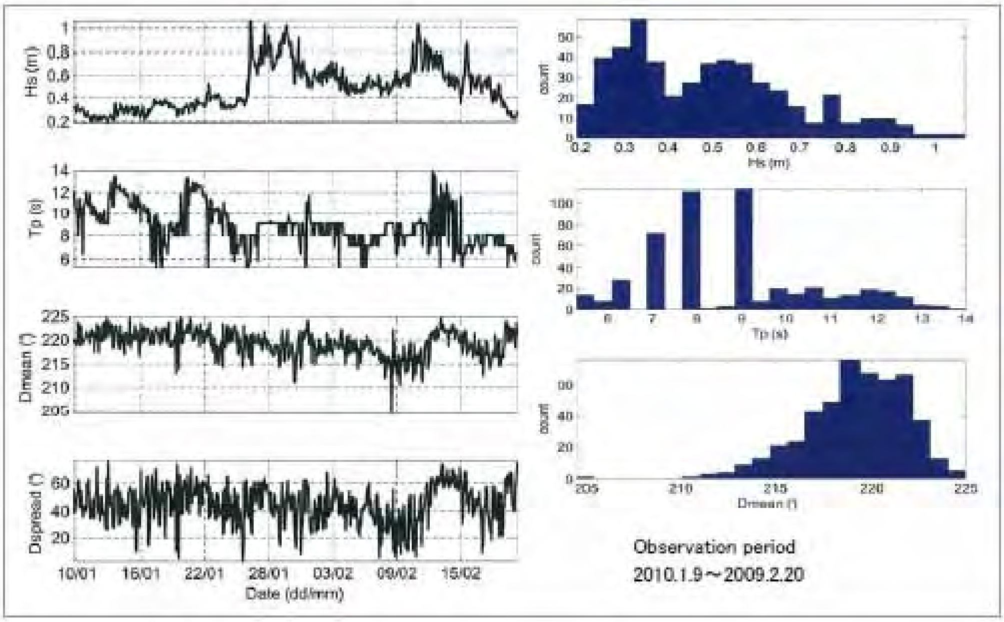
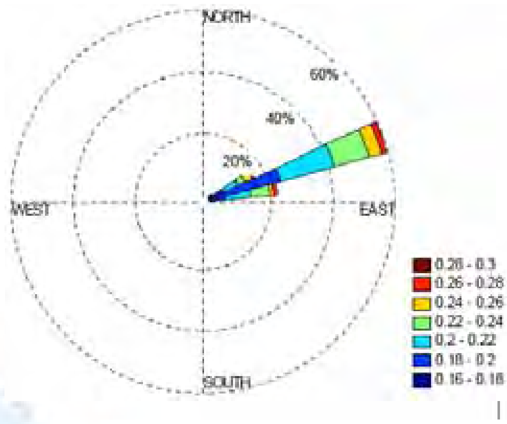


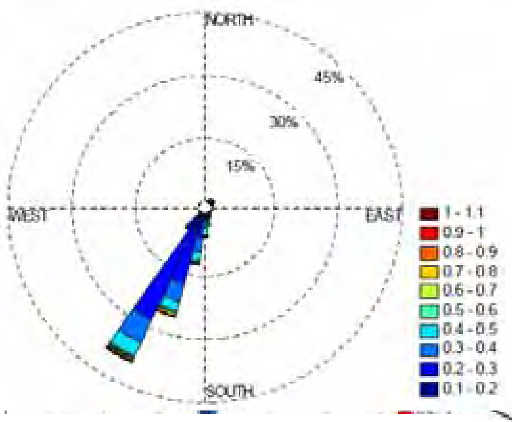
Figure 2.6 Time Series Plot of Wave and Occurrence Frequency Histograms (WG-2: Second Deployment)

VAIAKU



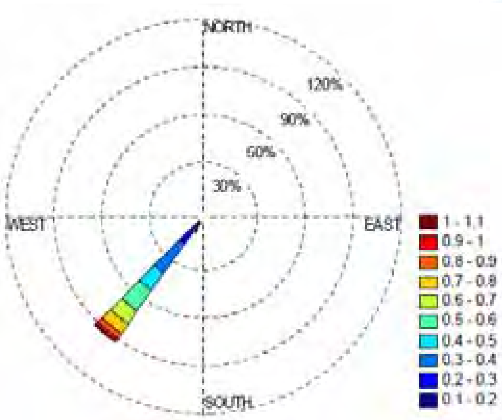
Observation Period
2009.11.1 – 2009.11.21

TEPUKA

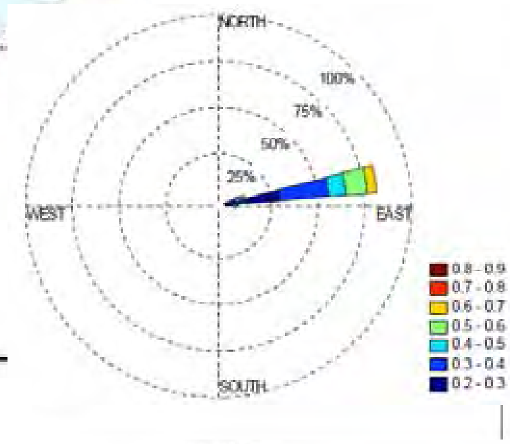


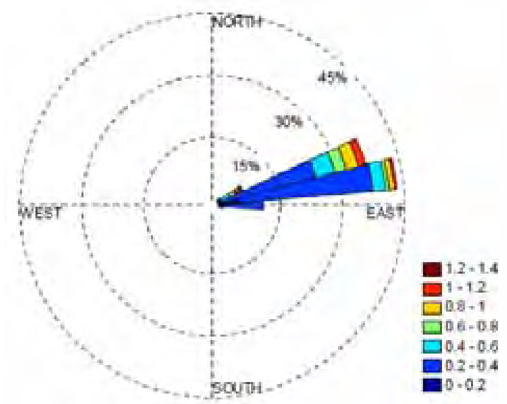
Observation Period
2009.11.17 – 2010.1.8

Observation Period
2010.2.2 – 2010.2.19



Observation Period
2010.1.9 – 2010.2.20





Observation Period
2010.2.20 – 2010.3.19

(Note) Directions are shown as "going to".

Figure 2.7 Frequency Diagram by Wave Direction

2.2 Currents Observation

(1) Current Meter Deployments

Water flow velocities, current speeds and directions, were measured using two Sontek Acoustic Doppler Profilers (ADP) and one JFE-ALEC Electro-magnetic current meter (Infinity-EM AEM-USB) during the baseline data collection phase on the JICA Study (refer to Table 2.6). The current meters were deployed on the lagoon floor at three locations shown in the overview map and in detailed satellite images of Figure 2.8.

The ADPs were set on the seabed in an upward configuration and the AEM-USB measured current speed and direction at the sensor head, 0.7 meters above seabed, for 30 seconds at 10 minutes intervals. The detailed deployment of current observation are summarized in Table 2.7.

Table 2.6 Instrumental & Operating Parameters of Current Meters (ADPs and AEM-USB)

Instrument	ADP (C-510)	ADP (C-503)	AEM-USB
Make	Sontek	Sontek	JFE ALEC
Model	ADP	ADP	AEM-USB
Serial No.	C-510	C-503	176
Type	Acoustic (500kHz)	Acoustic (500kHz)	Electromagnetic
Data recorded	Velocity profiles	Velocity profiles	Velocity
Sampling interval	0.5 sec	0.5 sec	0.5 sec
Sampling time	-	-	30 sec
Averaging interval	30 sec	30 sec	-

Table 2.7 Deployment of Current Meters (ADPs and AEM-USB)

Station No.	Location	Water Depth	Observation Period	Duration
ADP(C510)	Causeway	10 m	Nov.8 (12:00) to Nov.23 (10:00), 2004	15 days
ADP(C503)	Tepuka Vili Vili	15 m	Nov.1 (12:00) to Nov.23 (09:00), 2004	21 days
AEM-USB	Vaiaku	10 m	Nov.7 (12:00) to Nov.23 (12:10), 2004	16 days

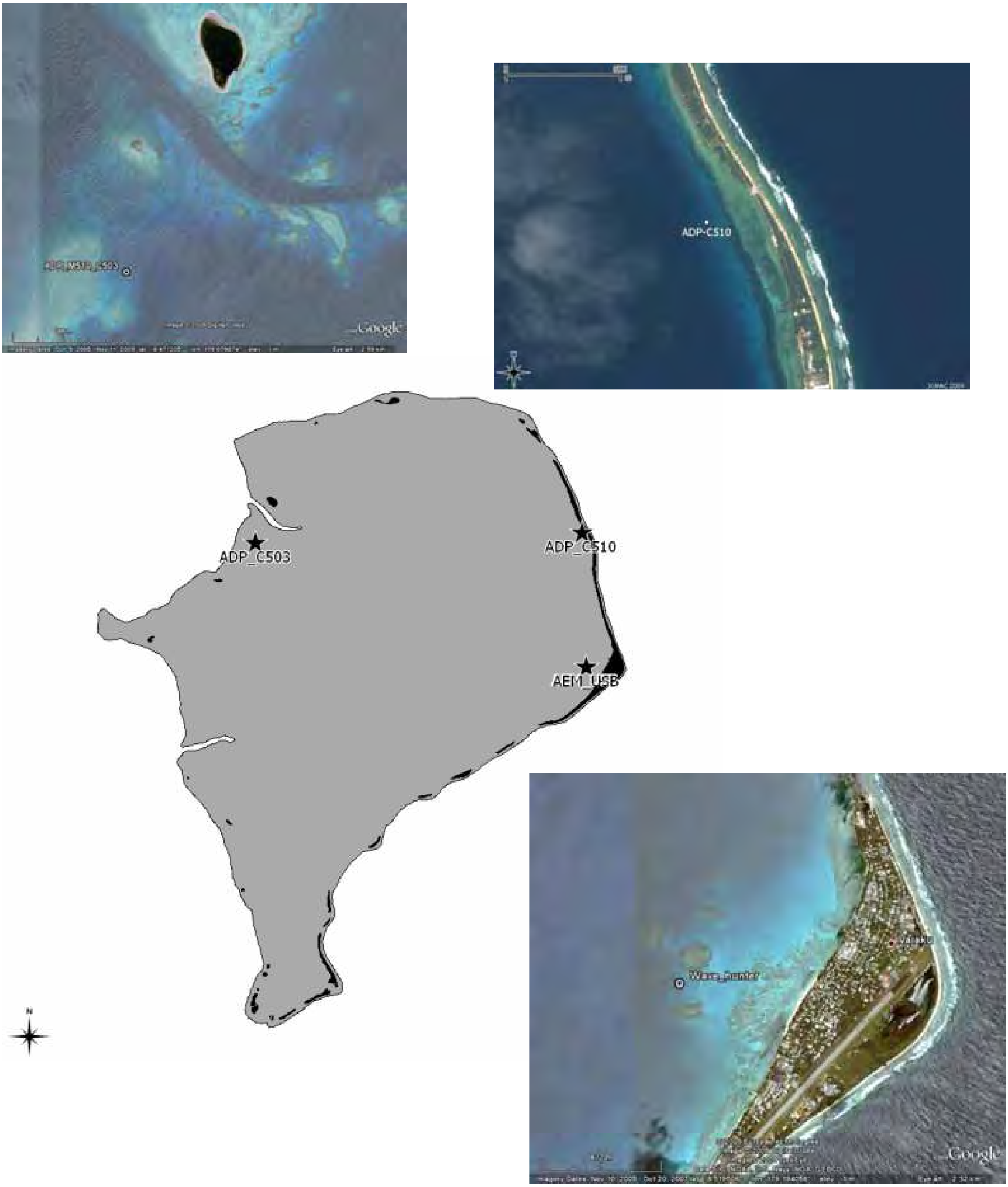


Figure 2.8 Location Map of Current Observation

(2) Results of Current Observation

Results of the current observation are shown in Figure 2.9 as “Histogram of Current Speed and Current Direction” and in Figure 2.10 as “Current Rose Diagram”. Maximum current speeds, mean speeds and main current directions recorded at each observation station are summarized in Table 2.8. The current speeds and directions shown in these figures and table are statistics of depth averaged velocity for ADPs at Causeway and Tepuka Vili Vili stations and time averaged current velocity at the sensor head for AEM-USB at Vaiaku station.

At Causeway Station (ADP-C510), the maximum speed was 18cm/sec and direction was prevailed around 175˚ which means “going to inner lagoon side” along the coastal line. The mean speed was comparatively week as 5cm/sec.

The maximum speed of 45cm/sec during the observation period was recorded at Tepuka Vili Vili Station (ADP-C503) with direction of 320˚ which means “going to outer ocean from lagoon” through the channel between Tepuka Vili Vili and Fualopa islet. The mean speed was also comparatively strong as 14cm/sec.

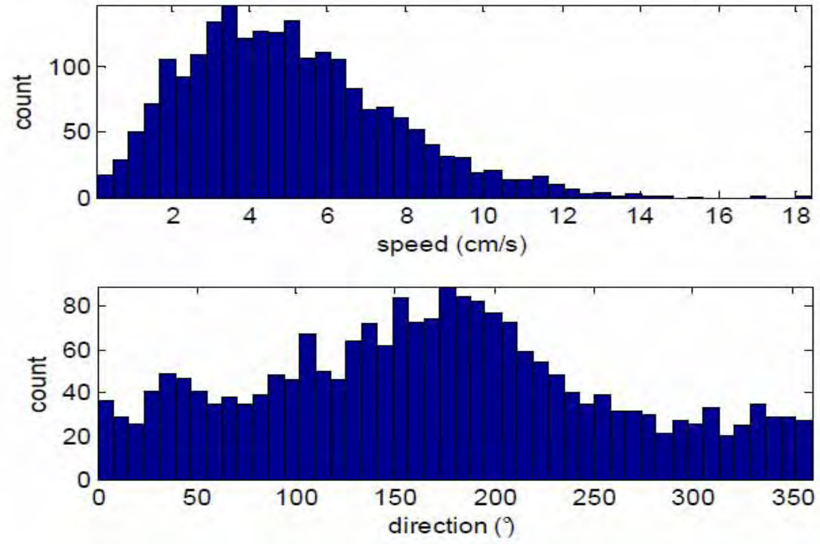
The current speed at Vaiaku Station (AEM-USB) was weak as a whole with maximum speed of 12cm/sec and mean speed of 2cm/sec, and an alternative motion to the direction of 90˚- 270˚ was observed at this point.

Table 2.8 Results of Current Observation by ADPs and AEM-USB

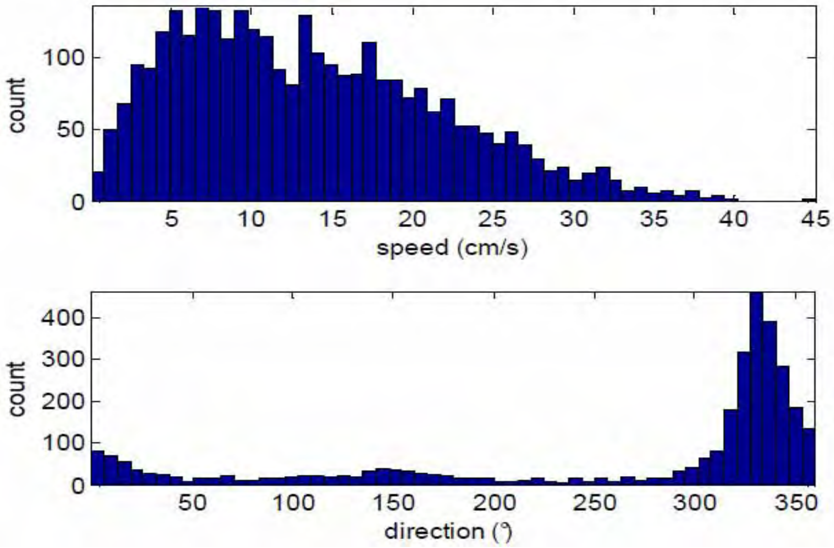
Location	Max. Speed	Mean Speed	Mean Dir.	Main Dir.	Remarks
Causeway	18 cm/sec	5 cm/sec	169˚	175˚	going to south
Tepuka Vili Vili	45 cm/sec	14 cm/sec	264˚	320˚	going to ocean
Vaiaku	12 cm/sec	2 cm/sec	188˚	90˚- 270˚	alternative motion

(Note) Directions are given in “going to”.

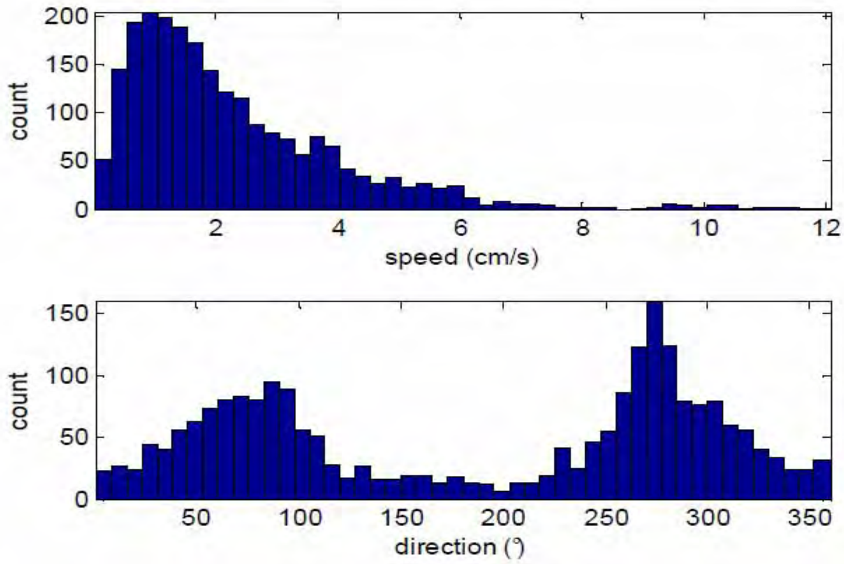
Causeway



Tepuka Vili Vili

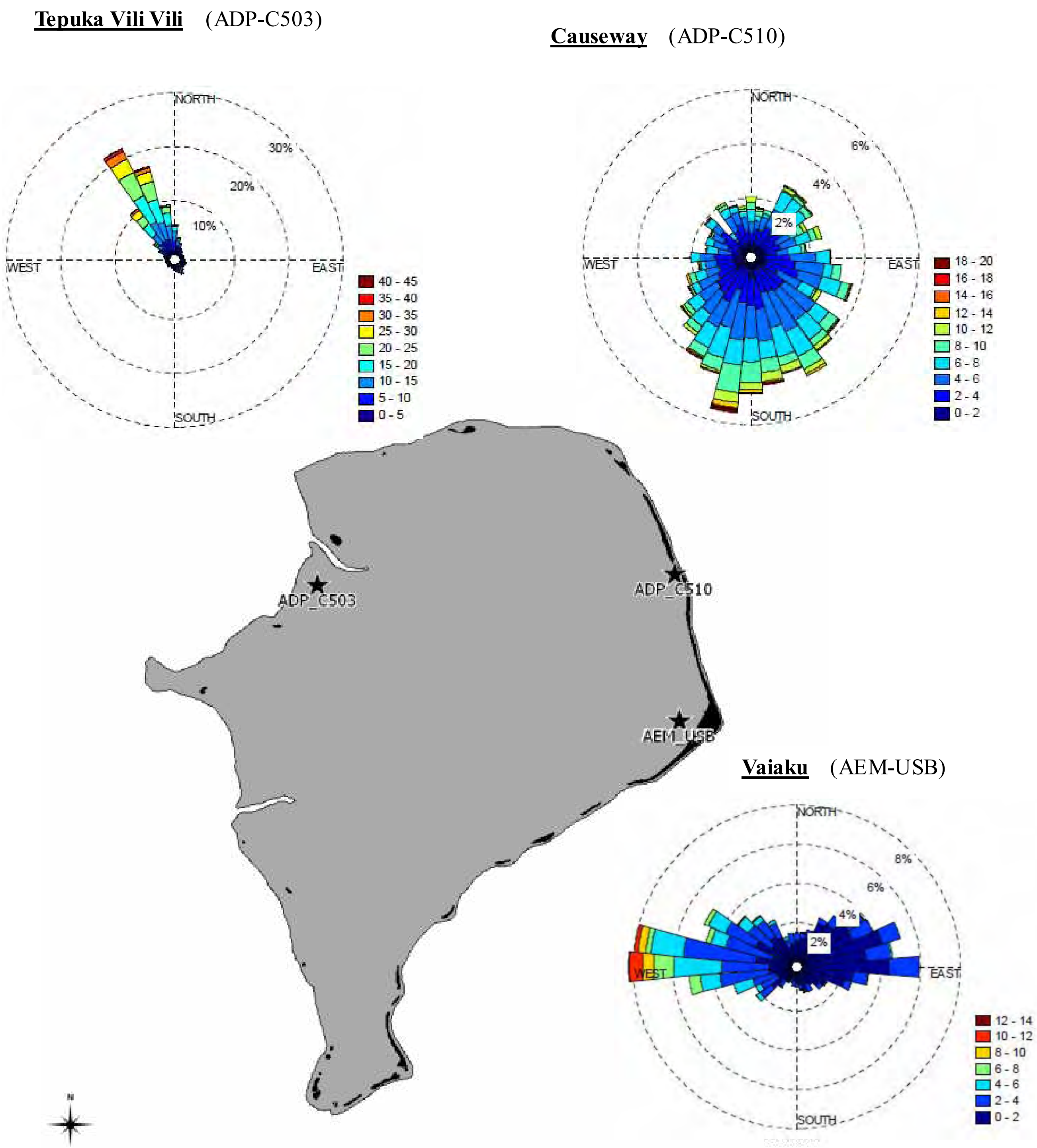


Vaiaku



(Note) Directions are shown as “going to”.

Figure 2.9 Histogram of Current Speed and Current Direction



(Note) Directions are shown as “going to”.

Figure 2.10 Current Rose Diagram

The harmonic analysis for current data recorded at three locations was also carried out to grasp the periodical characteristics of currents in this lagoon area. The results of harmonic analysis using current data are shown in Table 2.9 for the principal four constituents of the principal lunar semidiurnal constituent: M2, the principal solar semidiurnal constituent: S2, the luni-solar declinational diurnal constituent: K1 and the lunar declinational diurnal constituent: O1.

The results show that harmonic constants are very small except Tepuka Vili Vili station, at which the semi-diurnal constituents of M2 and S2 are comparatively large as 10,9cm/sec comparing with 3.0cm/sec of the diurnal constituents of K1 and O1.

Table 2.9 Harmonic Constants of Currents (Principal Four Constituents)

Location	M2		S2		K1		O1	
	Major	Phase	Major	Phase	Major	Phase	Major	Phase
Causeway	0.8 cm/s	40.8°	0.3 cm/s	54.8°	0.6 cm/s	22.1°	0.3 cm/s	-10.9°
Tepuka Vili Vili	7.7 cm/s	3.0°	3.2 cm/s	17.0°	1.9 cm/s	148.9°	1.1 cm/s	115.9°
Vaiaku	0.4 cm/s	-1.6°	0.2 cm/s	12.4°	1.1 cm/s	52.9°	0.6 cm/s	19.9°

2.3 Topographic Survey

The topographic survey on this study was conducted on October 2009 to March 2010 during the baseline study in Phase 2 in the coastal area, including the land area, of Funafuti atoll as shown in Figure 2.11. The survey was composed mainly of the control point survey, the cross sectional survey from ocean side to lagoon side including beach areas, and bathymetric survey (sounding) in lagoon area.

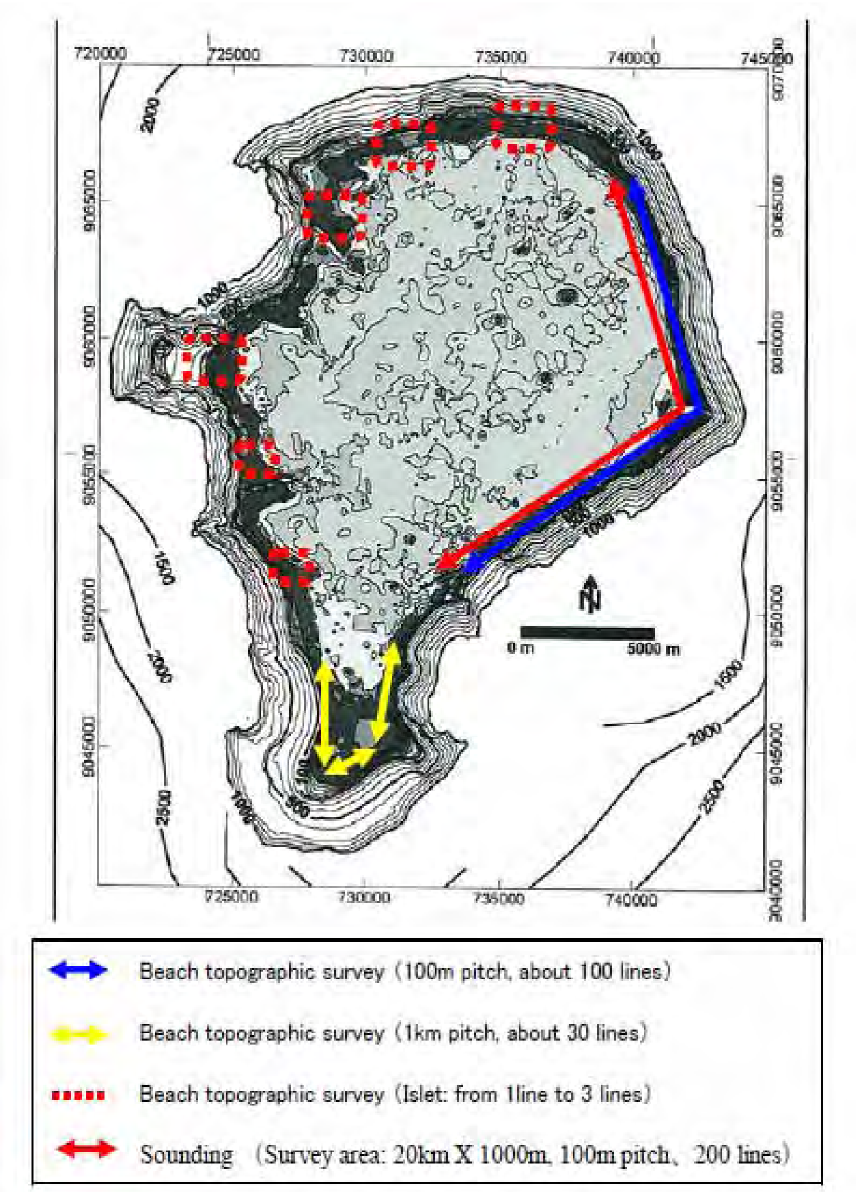


Figure 2.11 Scope of Topographic and Bathymetric Survey on This Study

(1) Control Point Survey

a) Method of Control Point Survey

The control point survey was conducted using the known points all over the Fongafale islet and on other main islets. The control points were marked with survey stakes planted in bedrock or structures on firm ground determined in the field reconnaissance. After the control points were marked, the traverse survey was conducted using RTK-GPS survey equipment (VRS method) or Total Station to obtain locations (northing and easting) and heights. Before starting, the GPS equipment was checked through verification observation at a known control point to ensure that there would not be any observation errors exceeding 0.5 meters.

The supplementary point survey was conducted using supplementary control points placed as control points for measurement in a cross sectional survey. The supplementary control points were marked with wooden piles, etc. on the survey cross-sections determined in the field reconnaissance. Then, their positions (northing and easting) and heights were measured using Total Station based on the main control points in the control point survey.

The Tuvalu Continuous GPS Station (TUVA CGPS), which is the primary base station for the GPS control survey in Funafuti and is settled in front of the meteorology office, is part of South Pacific Sea Level and Climate Monitoring Project GPS Network in the Pacific region. The TUVA CGPS coordinates and elevation are as follows;

Latitude : 8° 31′ 31.04910″ S
Longitude : 179° 11′ 47.61932″ E
Elevation : 4.493 meters above Australian Tide Chart Datum

There are a total of one hundred (100) ground control points established on Fongafale and a total of forty seven (47) control points on outer islets, such as Tateiko, Tengasau, Amatuku, Fualifeke, Tepuka, Fualopa, Fuafatu, Vasafua, Fuagea and Tefala. The survey marks on Fongafale islet were placed approximately on the spacing of every hundred meters and they are in line of sight so that origin of bearings for azimuth for future surveys is well defined.

The survey marks were surveyed using the Static GPS techniques together with the local ground control points to compute the horizontal positions (latitude, longitude and elevation) based on the Universal Transverse Mercator (UTM) zone 60 and World Geodetic System (WGS-84).

b) Result of Control Point Survey

The details for the topographic survey results are provided in “Data Book” attached to this report. The contents of the topographic survey in the Data Book are as follows;

① Survey traverse and nature of survey marks
② Ground control points in satellite image
③ Schedule of coordinates for spot height points
④ Cross sectional profiles along ground control points
⑤ Screen shots of cross sectional profiles
⑥ Locality diagrams of ground control points
⑦ Photographs of cross sections and ground control points

The followings describe the overview of the survey results on the control point survey.
Figure 2.12 and Figure 2.13 show the ground control points map all over the Funafuti atoll and Figure 2.14 shows one sample of the detailed ground control points in satellite image as a reference.

Figure 2.12 Ground Control Points Map in Google Earth

Figure 2.13 Ground Control Points Map in Nautical Chart

Figure 2.14 Ground Control Points in Satellite Image (Quick Bird)

As the final results of the control point survey, we can obtain the locations of northing and easting, and heights of the control points. The coordinates and elevations of the main control points used in this survey are shown in Table 2.10.

Table 2.10 Coordinates and Elevations of Ground Control Points

(to be continued)

Point ID	Easting	Northing	Elevation
62b	742198.628	9057747.249	3.283
AMA02	739025.594	9066491.921	3.655
AMU01	738985.822	9066502.017	4.071
BM22	741872.312	9059067.638	4.012
BM23	742014.264	9058616.828	3.926
BM24	742415.177	9057713.679	4.583
BM26	741579.069	9057084.147	3.897
BM27	741676.813	9057021.750	3.003
BM_UoH1	741434.577	9056953.506	3.781
BS20	739318.867	9055368.537	3.058
CENTRE-PT	740159.391	9064934.964	3.366
CS21	739493.458	9055451.601	2.990
CSF14	731067.239	9048578.217	2.701
CSF19	730877.225	9047570.429	2.817
CSF22	730665.065	9046870.149	2.568
CSF23	730690.763	9046682.664	2.601
CSF24	730795.596	9046351.770	2.496
CSF25	730913.926	9046087.500	2.761
CSF33	728392.394	9044872.716	2.466
DS01	742266.439	9058024.174	3.365
FAN01	726754.064	9060899.340	2.610
FAN02	726827.770	9060907.056	2.064
FAR01	731167.286	9045418.589	3.651
FFZ4	739777.115	9065544.330	3.476
FFZ8A	733554.704	9067743.165	4.224
FFZ16	728842.291	9046024.546	2.738
FUA02	724334.756	9058765.336	2.547
FUF01	724396.013	9058741.497	2.928
FUK01	727422.146	9051414.425	4.425
FUK02	727356.668	9051477.398	4.645

Point ID	Easting	Northing	Elevation
FUK03	727308.818	9051554.629	4.465
FUL02	733577.054	9067718.713	4.107
FUN3	740692.569	9063668.055	5.059
FUN4	740750.554	9063455.975	4.860
FUN5	740804.681	9063310.252	4.930
FUN7	741019.590	9062910.528	4.372
FUN8	741155.609	9062661.081	4.495
FUN11	741290.029	9062104.204	4.436
FUN13	741312.206	9061639.764	4.069
FUN16	741325.302	9061145.782	3.854
FUN17	741366.295	9060882.346	4.115
FUN19	741508.347	9060307.507	3.369
FUN23	741681.401	9059585.325	4.461
FUN26	741927.660	9058972.510	4.632
FUN27	741928.462	9058843.297	3.917
FUN30	742172.944	9058226.267	4.753
FUN30a	742221.967	9058049.832	3.620
FUN38	741674.093	9057258.656	4.575
FUN39	741757.687	9057426.088	5.034
FUN40	741895.985	9057616.923	4.366
FUN42	742062.063	9057816.175	4.821
FUN43	742099.760	9057957.560	4.472
FUN48	741181.287	9056443.912	3.715
FUN50	740838.785	9056177.455	4.486
FUN52	740491.284	9055862.288	3.964
FUN100	740420.557	9064379.848	5.093
FUN101	740453.702	9064277.873	4.625
FUN102	740500.134	9064185.487	5.054
FUN103	740541.802	9064054.186	5.021
FUN104	740589.624	9063963.105	5.340
FUN105	740619.673	9063859.805	4.274
FUN106	740658.555	9063767.705	4.662

(to be continued)

Point ID	Easting	Northing	Elevation
FUN107	740711.953	9063572.218	4.699
FUN108	740769.107	9063381.963	4.682
FUN109	740849.128	9063194.834	5.047
FUN110	740903.156	9063095.811	5.107
FUN111	740951.349	9063028.899	5.009
FUN112	741052.001	9062879.168	3.989
FUN113	741115.252	9062763.364	4.314
FUN114	741181.230	9062594.025	4.346
FUN115	741221.184	9062496.989	4.548
FUN116	741261.111	9062407.170	4.143
FUN117	741240.980	9062352.847	4.136
FUN118	741257.371	9062233.755	3.908
FUN119	741298.183	9062022.606	4.026
FUN120	741305.543	9061893.595	4.360
FUN121	741310.290	9061726.333	4.208
FUN122	741314.313	9061509.972	4.183
FUN123	741308.079	9061406.643	4.499
FUN124	741301.114	9061316.771	3.938
FUN125	741320.974	9061210.601	3.942
FUN126	741344.351	9060997.443	3.983
FUN127	741388.281	9060805.940	3.947
FUN128	741405.921	9060711.909	4.263
FUN129	741427.655	9060612.639	3.944
FUN130	741442.029	9060515.578	3.932
FUN131	741469.588	9060407.111	3.397
FUN132	741521.281	9060225.776	3.626
FUN133	741547.118	9060126.321	3.525
FUN134	741565.334	9059991.972	3.367
FUN135	741576.265	9059943.111	3.481
FUN136	741597.491	9059904.907	3.714
FUN137	741598.742	9059835.170	3.905
FUN138	741629.041	9059746.163	3.612
FUN139	741647.928	9059655.367	3.821
FUN140	741734.220	9059497.342	4.257
FUN141	741812.355	9059265.862	4.400
FUN142	741849.604	9059164.413	4.375
FUN143	741877.339	9059069.160	4.640
FUN144	741972.805	9058725.069	3.454
FUN145	742006.283	9058644.673	3.717
FUN146	742046.562	9058525.382	3.402
FUN147	742100.111	9058432.467	3.517
FUN148	742186.550	9058158.175	3.746
FUN149	742189.432	9057939.223	3.450
FUN150	742141.831	9057782.626	3.742
FUN151	742265.206	9057613.631	2.836
FUN152	742146.799	9057490.777	3.048
FUN153	742010.042	9057346.686	2.978
FUN154	741942.120	9057274.374	3.054
FUN155	741652.827	9056935.466	3.152
FUN156	741522.018	9056832.845	3.681
FUN157	741240.747	9056523.450	3.885
FUN158	741108.859	9056367.225	3.531
FUN159	741027.563	9056293.149	3.456
FUN160	740957.000	9056220.853	3.508
FUN161	740907.813	9056186.565	3.541
FUN162	740753.225	9056111.900	4.408
FUN163	740666.804	9056025.349	4.053
FUN164	740593.630	9055957.739	3.798
FUN165	740400.797	9055791.793	4.241
FUN166	740324.883	9055728.762	4.173
FUN167	740231.090	9055663.653	4.095
FUN168	740147.032	9055597.163	4.316
FUN169	740033.406	9055540.960	4.688
FUN170	739937.487	9055488.318	4.197

Point ID	Easting	Northing	Elevation
FUN171	739839.785	9055464.880	3.385
FUN172	739739.658	9055445.090	3.231
FUN173	739674.382	9055466.663	3.519
FUN174	739580.024	9055446.345	3.859
FUN175	739421.636	9055401.485	4.456
FUN176	741726.616	9059519.012	4.383
FUN177	741759.348	9059421.502	3.991
FUN178	741777.951	9059336.851	4.702
FUN200	731159.276	9045476.115	3.455
FUN201	731015.170	9045176.577	2.812
FUN202	730859.715	9044977.716	2.800
FUN203	730668.612	9044873.890	2.302
FUN204	730415.355	9044742.072	2.508
FUN205	730194.053	9044619.313	2.307
FUN206	729567.454	9044191.781	2.436
FUN207	729356.826	9044055.877	2.402
FUN208	728995.208	9043999.191	2.471
FUN209	728422.116	9044487.137	3.364
FUN210	728323.341	9044761.340	2.231
FUN211	728452.291	9045077.947	2.550
FUN212	731122.983	9045768.806	2.651
FUN213	731036.093	9045879.512	2.348
FUN214	730684.301	9047137.540	2.556
FUN215	730737.128	9047301.979	2.581
FUN216	730988.740	9047732.226	5.529
FUN217	731066.077	9047818.839	2.951
FUN218	731134.616	9048185.970	2.632
FUN219	731079.953	9048412.661	2.977
FUN220	731080.701	9048769.994	2.793
LEFT-PT	740164.304	9064926.693	3.432
MAT01	731122.534	9048933.902	3.114
RIGHT-PT	740155.248	9064944.071	3.228

Point ID	Easting	Northing	Elevation
TAF01	727833.882	9049024.687	2.696
TAF02	727801.222	9048974.154	2.764
TEP01	729078.672	9063825.678	4.708
TEP02	729113.839	9063801.870	2.201
TP3A	732751.649	9050727.426	2.951
TUV19A	741623.336	9059469.716	4.358
TUV42	741762.511	9059372.932	4.552
TUV46	742134.870	9058307.628	3.973
TUV69	741772.478	9057093.866	3.004
TUV70	741873.312	9057201.584	3.288
TUV72	742080.335	9057420.575	2.919
TUV73	742180.672	9057526.696	3.087
TUV100	741918.254	9058847.997	3.722
TUVA	741796.294	9056942.260	4.493
TUVA1	741318.521	9056598.008	3.926
TUVA3	741414.902	9056957.851	4.033
TUVA14	741924.263	9057867.685	2.472
TUVA16	740590.204	9055986.872	2.654
UF7	741431.995	9056739.059	3.808
UF12	741722.817	9057201.479	3.816
VAS01	725701.397	9053247.370	2.880
VAS02	725673.326	9053303.470	2.770

(2) Cross Sectional Survey

a) Method of Cross Sectional Survey

The cross sectional survey was conducted on topographic features shallower than the depth of 1.2 meters from the supplementary control points along the survey cross sections from the ocean into the lagoon, The topographic features were measured through indirect leveling using a Total Station at an observation pitch of 10 meters or less and based on topographic feature change points in Fongafale islet. At the same time, surface geological conditions were also recorded.

The cross section lines were set in a direction roughly perpendicular to the coastline at a pitch of 100 meters in Fongafale islet and one line per islet was set on other islets than Fongafale, resulting more than 140 survey lines in the entire atoll of Funafuti.

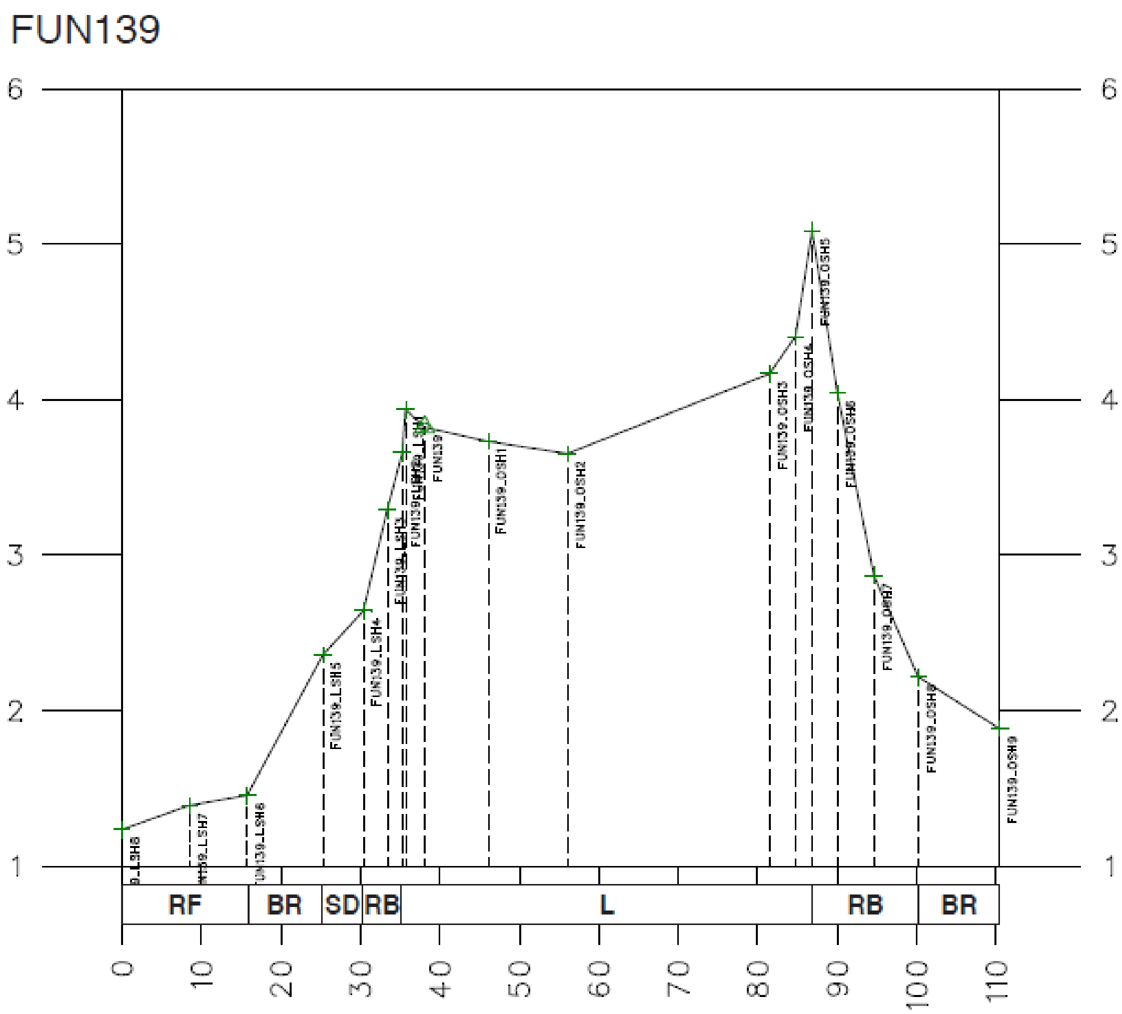
Photo 2.1 Scenes from Cross Sectional Survey using Total Station

b) Result of Cross Sectional Survey

The details for the cross sectional survey results are provided in "Data Book" as "Cross sectional profiles along ground control points" and "Screen shots of cross sectional profiles".

Figure 2.15 and Figure 2.16 show one sample of the detailed cross sectional survey line in satellite image and a cross sectional profile along a ground control point (along the ground control point: FUN-139 near the BP Oil in the north part of Fongafale islet in this case).

Figure 2.15 Cross Sectional Survey Line in Satellite Image (FUN-139 : North Side of BP Oil)



PRINT TO A4

Horizontal Scale 1 : 1000

Vertical Scale 1 : 50

SOPAC

Abbreviation Codes for Funafuti Transect-Sketches

VL	– VEGETATION LINE	BRB	– BEACH ROCK BOULDERS
BF	– BEACH FACE	BRP	– BEACH ROCK PEBBLES
SD	– SAND	BRG	– BEACH ROCK GRAVEL
CR	– CORAL RUBBLE	RB	– RUBBLES
BR	– BEACH ROCK	L	– LAND
CP	– CORAL PATCHES	SP	– SAND PIT
RF	– REEF FLAT	BP	– BORROW PIT

Figure 2.16 Sample of Cross Section (Control Point: FUN-139)