CHAPTER 173

STABILITY AND MANAGEMENT OF AN ARTIFICIAL BEACH

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ABSTRACT

An example of an artificial beach constructed for recreational purposes is presented. The beach stability and its impact on the marine environment is discussed. Also, the beach maintenance and management during almost 20 years is reported.

1. INTRODUCTION

The venue of the 1975 Ocean Expo-75 was in Okinawa, and for this event an artificial beach was constructed to show the "Expo Beach" marine exposition. This was one of the first artificial beaches to be built for recreational purposes in Japan. Since then, the Ocean Expo Commemorative Park Management Foundation has been in charge of management and maintenance for the public beach. In this paper, first the beach characteristics are described, then the impact of the artificial beach on the marine environment, and the stability of the beach are discussed based on measurement campaigns performed at the site, before and after the beach construction. And finally, the beach maintenance and management programs necessary to preserve it as an attractive recreational facility are reported.

2. EXPO BEACH DESCRIPTION

The artificial beach "Expo Beach" is located in the northern part of Okinawa, Japan. It is layed out in a north-south direction above a natural coral reef, with a maximum width of about 1 km at the north of the beach. At the place where the structures were built, the reef width is about 0.5 km, and this gradually decreases to 0.1 km at the southernmost end. The reef elevation around the

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beach structures is D.L. $\pm 0 \sim +0.3$ m, and at the reef edge the elevation is D.L. $+0.5 \sim +1.0$ m. Outside the reef, the slope varies from 1/3 to 1/5 from north to south, the average water depth is 30 m and this goes down to 60 m in some areas. To the north of the beach there are some notorious reef discontinuities; among these, the most pronounced is located about 200 m from the beach north-headland; here the minimum width is at the reef edge, and this gradually expands inside the reef. A sketch of the reef and the beach layout are shown in *Figure 1.*

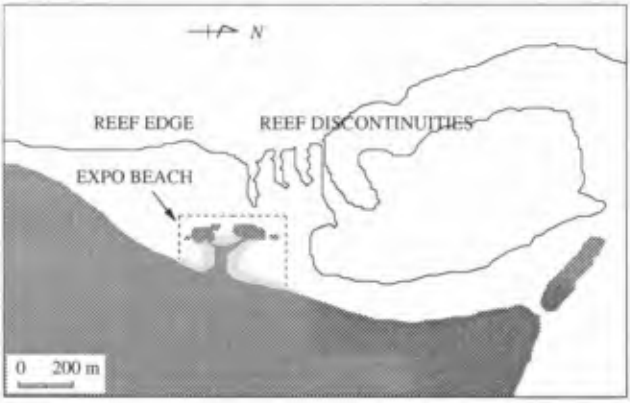

Fig. 1. Beach and reef layout

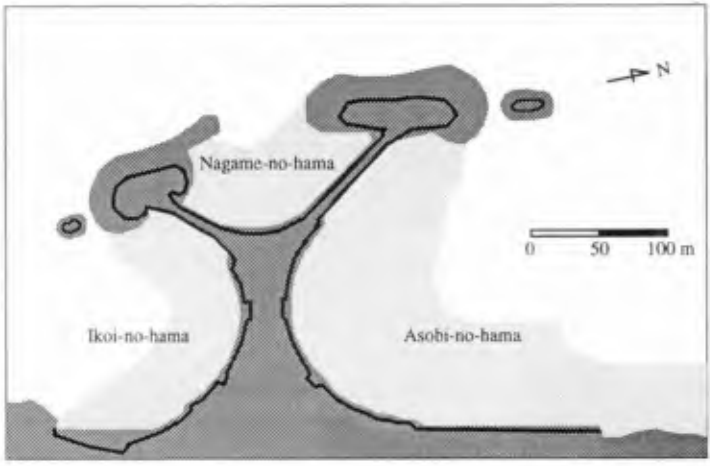

Fig. 2. Plan view of the artificial beach

For the beach design, a length of about 400 m was available, and to make the best use of this, a "Y" shape was selected for the beach layout, as shown in *Figure 2.* Consequently, the total beach length became about 900 m, and this

was then divided accordingly into three beaches named Ikoi-no-hama, Nagame-no-hama and Asobi-no-hama. These are located on the left, top and right sides of the "Y", respectively. The widths of the beaches are approximately 28 m in the Ikoi-no-hama and Nagame-no-hama, and 44 m in Asobi-no-hama.

In *Figure 3* a typical design cross section of the beaches is shown.

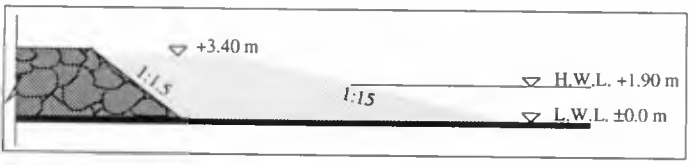

Fig. 3. Typical design cross section of the beach

Each beach was designed to fulfill a different main purpose. That is, Ikoi-no-hama was designed to be safely used by young children who just wanted to play in the water, rather than swim. Nagame-no-hama was designed for those who would like to contemplate the seascape scenery. And, finally, Asobi-no-hama was designed for swimmers.

Relatively shallow water depths were therefore accepted for the Ikoi-no-hama and Nagame-no-hama beaches design; but for the Asobi-no-hama beach, deeper water depths were desired to satisfy the swimmers. For this purpose, the sea bottom material was removed to increase depth by 1.0 m. A sand layer of about 20 cm was then spread over this dredged zone. Hence, 80 cm were added to the water depth here; and for the M.W.L. depths of about 1.9 m were ensured for the swimmers in an area of 10 672 m^2, that is about 9 to 10 times the size of a standard swimming pool. The total volume of extracted rock for this purpose was 14 010 m^3.

Table 1 summarized some of the design characteristics of the artificial

Table 1. Characteristics of the artificial beach

Characteristic	Amount
total beach area	64 000 m^2
stones for protection	36 000 m^3
pedestrian area	7 100 m^2
green area	4 000 m^2
changing rooms and showers	400 m^2
sand nourishment area	42 000 m^2
sand nourishment volume	56 000 m^3
sand mean diameter	0.5 ~ 0.7 mm
sand specific weight	2.8

beach, which have remained unchanged throughout the years. The sand nourishment volume shown in *Table 1* was used to fill the beach during its construction, and no surcharge has been necessary since then.

3. IMPACT ON THE MARINE ENVIRONMENT

Before the artificial beach was constructed, there was no beach development at the site. A comparison of field studies performed at that time, and those done during the almost 20 years thereafter have allowed an assessment of the beaches marine environmental impact. These field studies are mainly related to the velocity field, wave and tide climate, water quality and marine ecology, and are described in this section.

3. 1. Velocity field

Results obtained from field mesurements carried out before and after the artificial beach was constructed are shown in *Table 2*. The measurements of 1973 were performed before the beach construction by taking aerial photographs, at fixed intervals, of buoys deployed in front of the zone destined for the beach. The rest of the results shown in *Table 2* are from measurements taken after the beach construction. The latter results were obtained from measurements at two stations located inside the reef, one at the south of the beach, and the other at its north. The south station was located almost at the same place for all measurement campaigns. The north station, however, was set closer to the beach, outside any notorious reef discontinuity, for the campaigns of 1974 and 1975, and for the campaigns of 1985 and 1986, it was located inside a reef discontinuity. The measurements performed after the beach construction were taken about 50 cm below the water level.

Table 2. Current velocity

Year	Velocity during ebb tide (m/s)	Velocity during flood tide (m/s)	Wind velocity (m/s)
1973	0.30 – 0.40	—	—
1974	0.07 – 0.18	0.06 – 0.17	7.0
1975	0.05 – 0.20	0.02 – 0.12	3.5 – 6.0
1985	0.05 – 0.35	0.03 – 0.55	5.0
1986	0.03 – 0.10	0.02 – 0.50	2.0 – 3.0

Table 2 shows that the respective velocity values are of the same order of magnitude, and that the higher velocities are related to higher wind velocities. It should be noticed, however, that the maximum velocity values were found inside the greatest reef discontinuity, schematized in *Figure 1*. Because during the 1974 and 1975 campaigns the north station was set outside this zone, smaller current velocity values were reported here even though the corresponding wind velocities

were higher, when compared with those values reported from the campaigns of 1985 and 1986.

From measurements taken at other stations, it was found that the maximum velocities reported were obtained at the narrow part of the greatest reef discontinuity. In 1973, velocities ranging from 0.6 to 1.0 m/s during the ebb tide, and in 1986, 0.85 m/s during the flood tide were measured. Relatively high velocities were also found close to the north-headland, where there is another discontinuity; in 1975, velocities of 0.6 m/s were found during both ebb and flood tides, at a station located between the north-headland and the promontory located nearby; and in 1986, velocities of 0.55 m/s during the flood tide were reported to be just in front of this headland.

3. 2. Wave and tide climate

The deep water wave conditions used for the beach design are wave height $H_0 = 7.2$ m, wave period $T = 12.0$ s, with a SW wave direction. The computed significant wave height in front of the beach, at the depth 2.5 m for H.W.L., is $H_{1/3} = 1.5$ m.

The results of wave conditions measured before and after the beach was constructed are summarized in *Table 3.*

Table 3. Wave conditions

Year	Significant wave		Maximum wave		Wave direction
	$H_{1/3}$ (m)	$T_{1/3}$ (s)	H_{max} (m)	T_{max} (s)	
1974	0.21	7.0	0.31	6.8	SW
1985	0.60	6.0	0.65	6.0	NW, SW
1986	0.61	5.1	1.28	2.9	SW

In 1974, the measurements were performed from January to March, and in 1985, during November. In the latter period, two stations were considered, one about 150 m at the SE of the south-headland, and the other about 1 000 m at the NE of the nort-headland. The measurements in 1986 were performed in September, during a typhoon. Two stations were selected, one inside the reef, about 200 m at the SE of the north-headland, and the other outside, about 400 m at the E of the same headland. Outside the reef, the significant wave height during the typhoon was 1.88 m, and its related wave period 9.2 s, and the maximum wave height and related period were 3.08 m and 2.5 s, respectively.

Field observations performed outside and inside the reef show that the wave height inside the reef was significantly decreased from the wave height outside; for instance during the typhoon reported in 1986, the wave height inside the reef was about 30% of the wave height outside.

The wave conditions are influenced by the tide as follows: for H.W.L. waves

of longer period and greater height appear, and of shorter period and smaller height for L.W.L. The tide levels of H.H.W.L., H.W.L., M.W.L. and L.W.L. are +2.40 m, +1.90 m, +1.10 m and ±0.00 respectively.

3. 3. Water quality

Water quality monitoring has shown that the composition of the water inside and outside the reef is similar, so it is presumed that there is enough water circulation inside the reef.

Water quality monitoring is performed twice a year since 1979, once during the Spring time and the other during the Summer. It has been found that the respective average temperatures are about 22 and 28°C. In *Table 4* some results are shown from samples taken before the beach was constructed, in December 1973, and afterwards. In this table, NCB means number of coliform bacteria groups, MPN means most probable number, and the transparency is determined by the secchi disk depth.

Table 4. Water components of the artificial beach

Year	Season	NCB MPN/100 ml	Hexane extracts	COD mg/l	Secchi disk depth
1973	Winter	—	—	0.0 ~ 1.3	≈0.3 m
1980	Spring	17.0	not present	0.7	≈0.3 m
	Summer	25.0	"	0.9	≈0.3 m
1985	Spring	0.2	"	0.7	all depth
	Summer	6.0	"	0.8	all depth
1989	Spring	1.1	"	0.5	≈1.5 m
	Summer	0.3	"	0.9	≈1.5 m
1991	Spring	0.3	"	0.4	≈1.0 m
	Summer	0.8	"	0.3	≈1.0 m
1992	Spring	1.5	"	1.0	≈1.0 m
	Summer	0.0	"	0.8	≈1.0 m
1993	Spring	0.0	"	0.6	all depth
	Summer	2.0	"	0.8	all depth

The Japanese standards for water quality at bathing beaches are shown in *Table 5.*

Comparing the measured values with these standards, it is observed that before 1985 the water quality was good, and thereafter it has improved, and it is now considered to be of very good quality.

Furthermore, in addition to the water quality characteristics shown in *Table 4*, the concentrations of elements such as cadmium, arsenic, chromium, mercury, lead, and phosphorus were analysed, and it was found that the amounts

Table 5. Japanese standards for water quality of bathing beaches

Quality	NCB MPN/100 ml	Hexane extracts	COD mg/l	Secchi disk depth
very good	2	not present	≤2.0	≥1.0 m
good	100	not present	≤2.0	≥1.0 m
moderate	1 000	rarely detected	2.0	<1.0 m
bad	>1 000	always present	–	–

detected in the samples were under the acceptable limits so as to be harmless to humans.

3. 4. Marine ecology

The marine fauna inside the reef consists mainly of deer's horn coral (*Acropora sp.*). During and just after the beach construction was completed, three campaigns to determine the life expectancy of the corals were carried out. The campaigns took place in November 1974, and April and September of 1975. The mortality rates of the corals at seven stations were determined. Results from the April 1975 campaign show values of the coral's mortality rates that lie between those rates measured during the November 1974 and September 1975 campaigns. Results from these two last campaigns are shown in *Figure 4*.

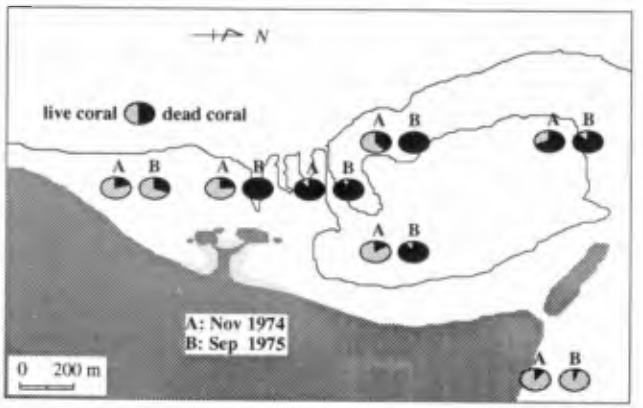

Fig. 4. Coral's mortality rates

In *Figure 4* is observed that particularly for the stations in front of the beach, the mortality rate increased notoriously. One reason for this was indeed the pollutants derived from the beach's construction. The main reason, however, was the sudden proliferation of a marine creature called crown-of-thorns (*Acanthaster*

planci) which feeds on coral. This creature came from a nearby island directly in front of the beach. A campaign to remove part of this species was conducted to preserve the coral reef communities. In 1986, field studies showed that in front of the beach, the coral's mortality rate was less than 30%, and that the prevalent environmental conditions then were also found to be favorable for their steady reproduction.

4. BEACH TOPOGRAPHY CHANGE AND BEACH STABILITY

Nineteen years have passed since the artificial beach was constucted and no renourishment has been necessary.

The initial beach slope was 1/15, and it has presently changed as follows: in Nagame-no-hama it is 1/14, in Asobi-no-hama 1/30 and in Ikoi-no-hama 1/32. The wave and current effects on Nagame-no-hama have been the most significant ones; as expected during the design phase. That is to say, the actual state of the beach is now just as predicted. The wave and current effects on Asobi-no-hama and Ikoi-no-hama are weak and therefore their slopes are mild. These slopes had been established in a couple of years after the beach construction. It is surmised therefore that all the beaches are stable.

Once a year, in February, bed profiles have been measured during the last 10 years and the necessary amount of sand to be moved for the beaches' restoration has been determined. Then, in March, the beaches' configuration is restored. The amount of sand moved for the beaches restoration during five years is shown in *Table 6*. And, in *Table 7* the amount of sand moved for each beach during four years is shown.

Table 6. Amount of sand moved during the beaches restoration

Year	1990	1991	1992	1993	1994
Amount of sand moved (m^3)	3 403	5 611	4 321	3 182	2 242

Table 7. Amount of sand moved for each beach restoration, in m^3

Year	1990	1992	1993	1994
Ikoi-no-hama	1 204	1 198	1 668	436
Nagame-no-hama	362	423	541	528
Asobi-no-hama	1 837	2 700	973	1 278

From *Table 6* it is seen that during the five years shown here, the amount of sand moved for the restoration of the beach configuration represents about 5 to 10% of the sand volume used for the beach nourishment.

From *Table 7* it is seen that only for the Nagame-no-hama beach's restoration the sand volume moved is roughly similar each year, whereas for the Ikoi-no-hama and Asobi-no-hama beaches, the amount of sand moved is more irregular.

Table 8. Amount of sand moved during the beach restoration in 1994

Beach	Removed sand (m^3)	Filled sand (m^3)
Ikoi-no-hama	249	187
Nagame-no-hama	198	330
Asobi-no-hama	674	604

It seems that the amounts of sand moved for these two last beaches are somehow influenced by the volume moved in the previous year.

In *Table 8* the amount of sand removed or used to fill each beach for its restoration in March 1994 is shown; this is schematized in *Figure 5*. In this figure the negative values of thickness refer to the sand removed, and the positive values correspond to the sand filling.

Figure 5 shows that in Ikoi-no-hama there was sand transport from the middle part of the beach to both its ends, but mainly to its closest land end. In the Nagame-no-hama, the sand transport is offshore, so sand should be returned onshore for its restoration. In the Asobi-no-hama, the sand transport is from the beach ends towards the middle part. During its restoration, sand should be therefore removed from the middle and returned to its ends.

The yearly restoration of the beach similar to that shown in *Figure 5* contributes to maintain the beach stability in a functional way.

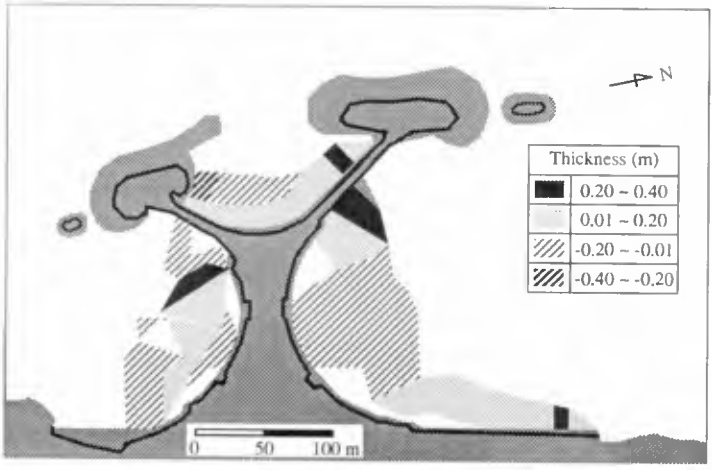

Fig. 5. Sand moved for the beach restoration in 1994

5. BEACH MAINTENANCE AND MANAGEMENT

To protect the environment, the beach is cleaned 250 times each year, and in the water itself, the cleaning is performed 60 times per year. The main problem concerning the environment is the proliferation of seaweeds. The seaweeds that reproduce in the reef are transported to the beach by waves and currents, and since they present an unatractive view to bathers, they are removed periodically.

For the beach restoration, which is performed in March, a bulldozer is used.

The artificial beach is open to the public every year from the first of April to the last day of October. In *Table 9* three year data is shown of the yearly number of vistors to the beach, and from these, the number who used the beach to swim.

Table 9. Visitors and bathers using the beach

Year	1990	1991	1992
Visitors	138 484	154 061	350 921
Bathers	86 620	79 536	132 068

Table 9 reveals that for three consecutive years there has been a continuous increase in the number of visitors and bathers. This may be accredited to the beach maintenance described herein which makes it an attractive recreational facility.

Finally, it may be added that the annual maintenance cost, which includes the beach cleaning and restoration programs, is about fifteen million yen.

6. CONCLUSIONS

It is concluded that after the nearly two decades that the artificial beach "Expo Beach" has existed, the facility has to all extents and purposes retained its natural environment unchanged. Yearly restoration of the beach configuration by using only the sand transported by waves and currents effects, *i.e.* without any sand renourishment, has proved enough to maintain the beach stability in a functional way. This task together with the periodical beach cleaning have preserved this artificial beach as a pleasant recreational facility.

Furthermore, the stated artificial beach was constructed on a coral reef which gave a firm foundation for coastal structures.

The study of the stability, maintenance and management of the artificial beach "Expo Beach" is a good example to consider when similar beach construction projects are planned.

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