

CHAPTER 112

SHORE PROCESS ALONG THE COAST OF IWO-JIMA

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Abstract

Iwo-jima is a small isolated volcanic island located in the Pacific Ocean. Due to the continuous upheaval of the island, foreshore area of this island has been increasing since 1911.

Investigation is made to clarify the variation of the foreshore area of this island by analyzing the various field data obtained during the past three years.

Analyses reveal that the foreshore area is currently increasing at an approximate rate of 180,000 square meters per year due to the unusual upheaval of the island exceeding 45 centimeters per year although seasonal variation of the foreshore area reaches 300,000 square meters.

1. Introduction

Iwo-jima is a small volcanic island located in the Pacific Ocean about 1250 kilometers south of Tokyo ($24^{\circ}45'$ to $24^{\circ}49'N$, $141^{\circ}17'$ to $141^{\circ}21'E$). This island is situated at the southern tip of the Izu-Ogasawara volcanic arc which runs almost parallel to the longitude of $140^{\circ}E$.

Figure 1 shows the present topography of Iwo-jima. To show the beach evolution occurred during the past seven decades, shoreline in 1911 is shown in this figure as a reference. Surface area and shoreline length of this island are currently 23.2 square kilometers and 24.3 kilometers, respectively.

The island is relatively flat with an average of 110 meters except for the area around the Mt. Suribachi. The surface is mostly covered with thick vegetation and there are no rivers on

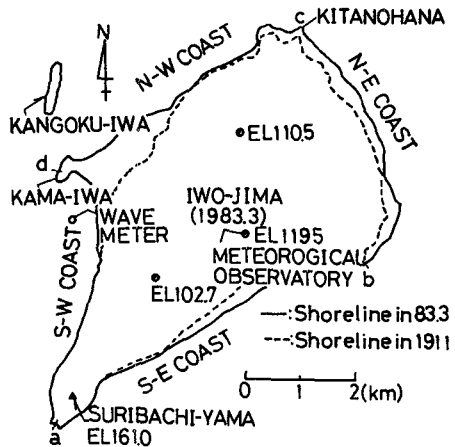


Figure 1. Present topography of Iwo-jima

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this island. Thus, few sources of sediments seem to exist in and around the island. However, most of the coast is rimmed by sandy beach, approximately 200 meters wide. Further, quite surprisingly, the shoreline has been advancing seaward year by year since 1911. The author and his colleagues have analyzed old maps, charts and aerial photographs of Iwo-jima, and found that the shore area has increased roughly 3.2 square kilometers during the past seven decades. They also found that this increase was caused by the unusual upheaval of this island, approximately 30 centimeters per year (Shigemura et al, 1984). These are the characteristics of so called a long term variation of the shore area in Iwo-jima. However, the shore area is varying continuously within shorter period, which is important to know from the engineering point of view.

This paper intends to clarify the characteristics of the short term variation of shore area in Iwo-jima by analyzing various field data obtained during the past three years since 1982.

2. Field measurements

To investigate the short term variation of the shore, the following field surveys have been made during the past three years since 1982:

- (1) Photographing of the shoreline by a helicopter
- (2) Traversing and levelling surveys of the shore
- (3) Measuring of the waves by a supersonic wave meter
- (4) Collection of wind and tidal data

Details of these field surveys will be described in the following sections.

2-1. Photographing of the shoreline by a helicopter

To get the data of the shoreline variation, aerial photographs of entire shoreline have been taken since November 1982, using a helicopter of JMSDF (Japan Maritime Self Defense Force) stationed there. By the end of September 1985, 19 sets of photographs were taken in total, which were taken at an altitude of 2000 meters except for one set of photographs.

2-2. Traversing and levelling of the shore

To get the data of upheaval and variation of the fore-shore area of the island, traversing and levelling surveys have been done on the entire shore of the island since August 1982. These surveys were made at least twice a year, using the 53 measuring points located on the backshore at intervals of roughly 300 meters (figure 2).

2-3. Measurement of the waves by a supersonic wave meter

Wave data has been measured since May 1982 by a supersonic wave meter installed about 450 meters off the west coast

of Iwo-jima at a depth of 12 meters (see figure 1). These data were recorded for 10 minutes every two hours until November 7, 1983 when the typhoon #17 washed the meter away. Thus, waves were measured for 19 months.

2-4. Collection of wind and tidal data

Both wind and tidal data were not measured in each of the field surveys since meteorological data has been measured at the central part of this island since 1968 by JMSDF and tidal data has been recorded at the foot of the Mt. Suribachi since December 1980 by the Japan National Research Center for Disaster Prevention (JNRCDP). These wind data will be used to produce the seasonal wind diagrams covering the period of the field surveys.

Further, the tidal data will be used to refer the elevation of bench mark placed at the foot of the Mt. Suribachi for the levelling survey.

3. Analyses of field data

3-1. Variation of the surface area of Iwo-jima

As mentioned previously, 19 sets of aerial photographs have been taken by a helicopter during the past three years. Table 1 summarizes the details of the photographing.

Unfortunately, most of these photographs were taken with some inclination. Thus, the following procedures were taken to determine the shorelines in each photographed date from these photographs:

- (1) Each set of the film was processed into a series of slides.
- (2) Five reference maps with a scale of 1/4000 were reproduced from the aerial photographs taken in March 10, 1983 (figure 3).
- (3) Each of the reference maps was placed on a special table designed so that it may rotate around three axes, and slides were projected onto it.
- (4) After rotating the table until several points on the map fitted with the corresponding points on the projected slide, the shoreline was drawn successively on the reference map.

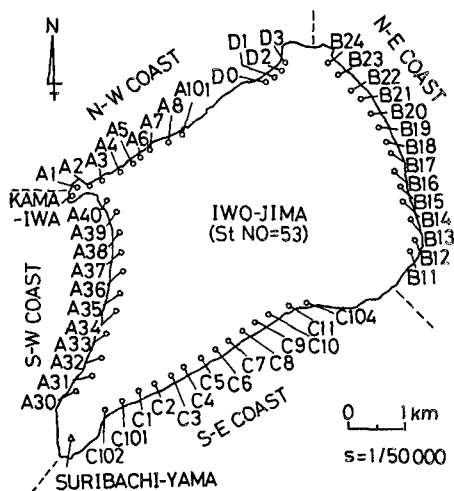


Figure 2. Mesuring points on the backshore of Iwo-jima

Table 1. Details of the photographing of the shoreline

No.	Data	Time	Altitude	Tide	Remarks
1	Nov.25,'82	13:35-14:35	2000 m	84.0 cm	inclined photos
2	Feb.16,'83	13:40-14:40	2000 m	42.0 cm	inclined photos
3	Mar.10,'83	10:00-11:00	6000 m	62.0 cm	vertical photos
4	Apr.08,'83	10:25-11:25	2000 m	59.0 cm	inclined photos
5	Jun.07,'83	10:00-11:00	2000 m	40.0 cm	inclined photos
6	Aug.01,'83	09:10-10:10	2000 m	66.0 cm	inclined photos
7	Oct.01,'83	10:00-11:00	2000 m	50.0 cm	inclined photos
8	Dec.14,'83	09:00-10:00	2000 m	54.0 cm	inclined photos
9	Feb.14,'84	09:00-10:00	2000 m	72.0 cm	inclined photos
10	May 16,'84	13:30-14:30	2000 m	06.0 cm	inclined photos
11	Jun.12,'84	11:00-12:00	2000 m	16.0 cm	inclined photos
12	Jul.11,'84	11:00-12:00	2000 m	20.0 cm	inclined photos
13	Sep.05,'84	09:15-10:15	2000 m	40.0 cm	inclined photos
14	Oct.07,'84	15:30-16:30	2000 m	70.0 cm	inclined photos
15	Nov.16,'84	09:30-10:30	2000 m	56.0 cm	inclined photos
16	Mar.01,'85	09:00-10:00	2000 m	75.0 cm	inclined photos
17	May 27,'85	09:00-10:00	2000 m	76.0 cm	inclined photos
18	Jul.12,'85	09:00-10:00	2000 m	46.0 cm	inclined photos
19	Sep.04,'85	14:30-15:30	2000 m	48.0 cm	inclined photos

Shorelines determined in this way, were processed by a special AD convertor and the position of each shoreline was digitalized every 2 millimeters or 8 meters on the actual spot. Based on this data, the surface area of the island on each photographed date was calculated.

Figure 4 shows the variation of the surface area of Iwo-jima during the past three years.

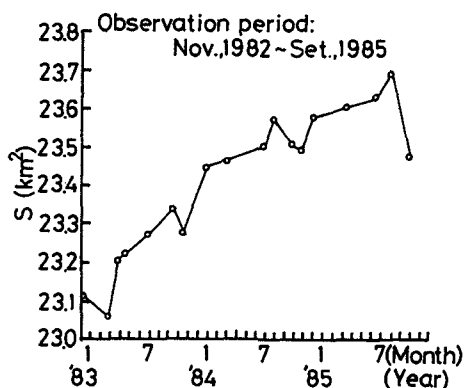
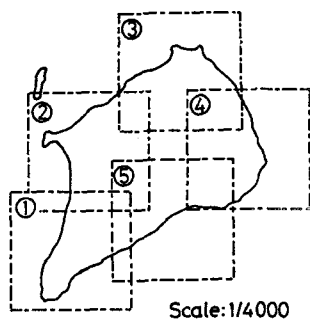


Figure 3. Reference map of Iwo-jima

Figure 4. Variation of the surface area of Iwo-jima

Figure 5 shows the current variation of the surface area together with the one occurred before 1982(Shigemura et al, 1984).

From figure 4 and 5, the following facts can be seen:

- (1) The surface area of Iwo-jima has kept increasing since 1911, although the increasing rate is not constant but varies with time.
- (2) Surface area began to increase drastically in 1952 and kept increasing until 1968 at an approximate rate of 140,000 square meters per year. By the end of 1981, the surface area increased roughly 3.2 square kilometers as compared with the surface area in 1911.
- (3) Surface area is currently increasing at an approximate rate of 180,000 square meters although there is a considerable variation in its magnitude.

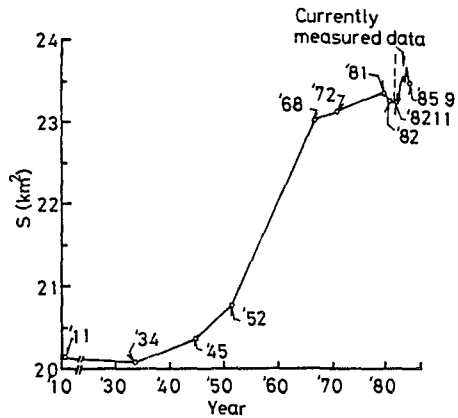


Figure 5. Variation of the surface area of Iwo-jima since 1911

3-2. Upheaval of Iwo-jima

Since August 1982, both traversing and levelling surveys have been made six times along the entire backshore of the island. Table 2 summarizes the periods in which the surveys have been made.

Table 2. Periods in which surveying has been made

No.	Period
1	Jul.23,'82 to Aug.09,'82
2	Jun.08,'83 to Jun.28,'83
3	Feb.09,'84 to Feb.20,'84
4	Nov.16,'84 to Dec.05,'84
5	Mar.09,'85 to Mar.28,'85
6	May 14,'85 to May 31,'85

All of these surveys have been made with the aid of the 101 Topographic Battalion of the Japan Ground Self Defense Force (JGSDF).

Figure 6 shows the variation of the relative upheaval height, ΔH of each measuring point shown in figure 2, which was determined on the basis of its elevation measured in the first survey (August, 1982).

Figure 7 shows the cumulative upheaval height of the backshore of Iwo-jima in the same period which was determined by simply averaging the elevations of the 53 measuring points shown in figure 2. Further, figure 8 shows the cumulative upheaval height of Iwo-jima presented by Kosaka and

his colleagues (Kosaka et al, 1979). They determined the upheaval height by comparing the elevations of several points shown in old maps and charts and by analyzing their own data of levelling which was performed four times during the period between 1968 and 1978.

From figure 6, 7 and 8, the following facts can be observed:

- (1) Upheaval of Iwo-jima is not uniform along the coast but varies considerably in both time and location.
- (2) Iwo-jima upheaved drastically during the period between February 1984 and November 1984 at the rate exceeding 1 meter per year.
- (3) Iwo-jima is currently upheaving at an approximate rate of 45 centimeters per year, which is greater than that observed during the period between 1952 and 1968.

Observation period: Aug., '82-May, '85
Referred elevation: Elevation in Aug., '82

'82 8 ○ '83 6 ● '84 2
△ '84 11 ▲ '85 3 □ '85 5

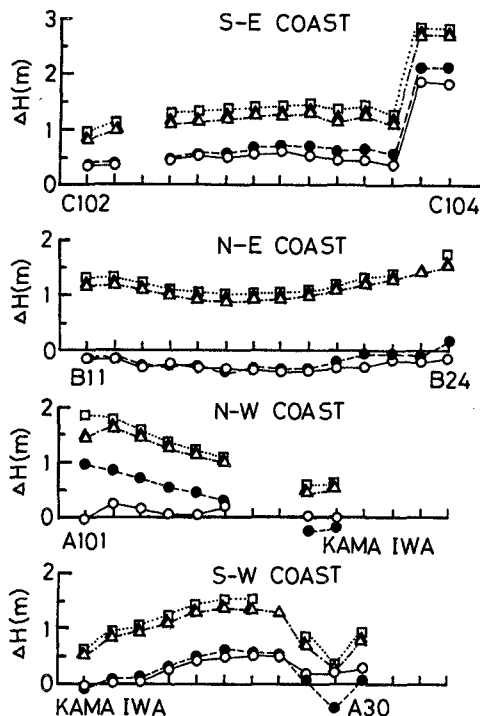


Figure 6. Variation of the relative upheaval height, ΔH of each measuring point

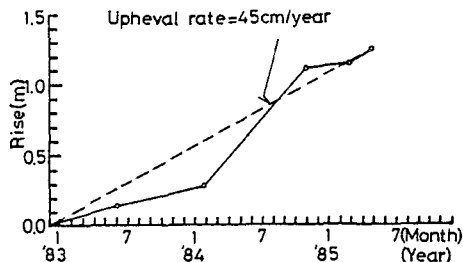


Figure 7. Cumulative upheaval height of Iwo-jima

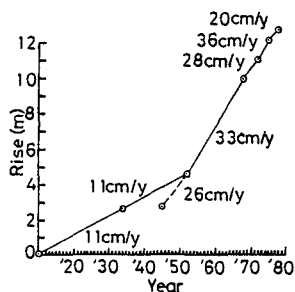


Figure 8. Cumulative upheaval height (After Kosaka et al, 1979)

3-3. Wave characteristics in Iwo-jima

As mentioned in section 2-3, waves were recorded for 19 months after May, 1982. These records were processed at a sampling interval of 0.5 second by an A-D convertor, and wave height and period were determined by applying the zero up crossing method on these processed data.

Table 3 summarizes the seasonal distribution rate of significant waves whose height and period are in the given ranges of their magnitudes.

Table 3. Seasonal distribution rate of the significant waves in Iwo-jima

Season	H 1/3(m)				T 1/3(s)			
	0-1	1-2	2-3	<3	<6	6-8	8-10	<10
Spring	62	36	1	1	29	51	16	4
Summer	70	20	4	6	21	42	21	16
Fall	73	14	7	6	8	43	27	22
Winter	59	35	6	0	31	49	16	4

Table 4 summarizes the maximum height and the significant period of the waves recorded while the typhoons were hitting Iwo-jima.

Table 4. Values of H max and T 1/3 of the waves recorded while typhoons were hitting Iwo-jima

No.	Date	Time	Hmax	T 1/3	Pres.	Location	V	Θ
#4	May 23, '82	0200	8.4m	18.5s	980mb	NNW 150km	27.5m/s	ENE
#5	Jun.26, '82	1000	5.4m	11.1s	975mb	NW 250km	32.5m/s	N
#10	Jul.31, '82	0800	9.2m	19.0s	940mb	WNW 350km	50.0m/s	NNW
#13	Aug.24, '82	2100	lack of data		940mb	W 850km	45.0m/s	NNW
#15	Aug.30, '82	0900	lack of data		945mb	W 300km	45.0m/s	NW
#18	Sep.11, '82	1000	5.3m	12.0s	965mb	WNW 600km	35.0m/s	NW
#19	Sep.19, '82	0000	5.2m	8.3s	940mb	WSW1400km	45.0m/s	WNW
#21	Oct. 7, '82	1600	9.8m	11.5s	920mb	WSW 600km	50.0m/s	NNW
#5	Aug.13, '83	0600	9.8m	13.3s	915mb	WSW1040km	55.5m/s	NNE
#13	Oct.11, '83	1000	2.5m	10.1s	980mb	NNW1050km	25.3m/s	ENE
#17	Nov. 2, '83	0200	lack of data		985mb	NNE1030km	30.0m/s	NNW

In this table, figures in the column of No. indicate the names of typhoons, and the information in the column of location indicates direction and distance to the center of a typhoon from the island. Further, does the letters in column of Θ indicates the advancing direction of each typhoon.

From these tables, the following facts can be seen:

- (1) Dominant waves in Iwo-jima are those whose significant heights are less than 1 meter and whose significant periods are less than 8 seconds through the year.
- (2) High waves whose significant height is greater than 3.0 meters and whose significant period is greater than 10 seconds appear in summer and fall.

(3) Huge swell whose maximum height is roughly 10 meters and whose significant period is greater than 12 seconds will hit Iwo-jima when a typhoon with a central pressure less than 940 millibars pass within a region of 600km far from Iwo-jima.

Huge swells of this size usually hit Iwo-jima several times per year. Characteristics of these waves were also reported at the 19th ICCE(Shigemura et al, 1984)

3-4. Wind characteristics in Iwo-jima

As mentioned in section 2-4, JMSDF has been recording the wind data every three hours, since 1968.

By analyzing the wind data recorded in 1983, 84 and 85, seasonal wind diagrams were produced.

Figure 9 shows the seasonal wind diagrams. From this figure, the following wind characteristics can be observed:

(1) East winds are dominant in spring, summer and fall. South winds are the secondarily dominant in spring and summer.

(2) N-E winds are dominant in fall and winds ranging from NE to N are dominant in winter.

(3) Approximately 3% of the total winds analyzed are the high winds whose velocities exceed 10 meters per second. These winds blow from the direction ranging from SE to SSE in summer although they blow from the direction ranging from NNW to NE in fall and winter.

These results agreed well with the ones obtained by analyzing the wind data recorded in Iwo-jima during the period between 1968 and 1977(Shigemura et al, 1984).

4. Variation of the foreshore area in Iwo-jima

Through the primary analyses, it was found that Iwo-jima was currently increasing its surface area at a rate greater than that occurred before 1982. Further, it was proved that this increase was surely caused by an unusual upheaval of this island.

To see the variation of the surface area more clearly, relative values of the surface area on each photographed date was determined on the basis of the surface area on March 10, 1983. These values will be called ΔS in the following discussion. ΔS may indicate the increase of the foreshore area if the increase of the surface area is caused

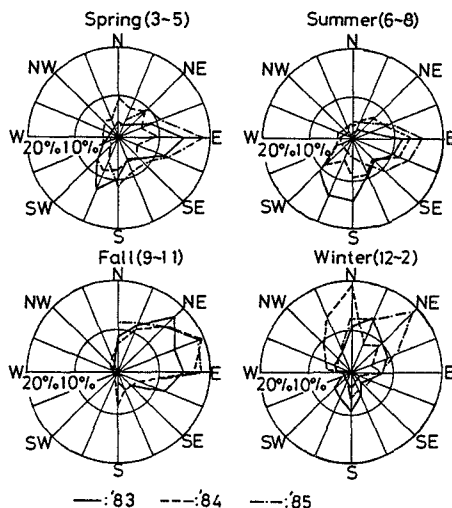


Figure 9. Seasonal wind diagrams in Iwo-jima

by a continuous upheaval of the island.

Regression analysis was made on the data of ΔS over time. Figure 10 shows the variation of ΔS during the past three years. In this figure, the straight line indicates the regression line of ΔS over time and the symbol of square indicates a deviation of ΔS from its corresponding value predicted by the regression line, which will be referred to as dS in the following discussion. Further, the symbol of black circle shows the relative upheaval height, ΔH .

Regression analysis revealed that the foreshore area was currently increasing at an approximate rate of 180,000 square meters per year although dS scatters considerably along the regression line.

Suppose the increasing rate of 180,000 square meters per year was brought by the current upheaval of the island, dS may indicate the variation of the foreshore area caused by the other factors besides upheaval, namely waves and currents. It is difficult to find a definite trend in the variation pattern of dS . However, the following facts can be observed from this figure:

- (1) dS tends to increase from spring to summer and from fall to winter, but to decrease from summer to fall and from winter to spring, respectively.
- (2) The range of the variation of dS is approximately 250,000 square meters per year at most.

These findings are the characteristics of the short term or the seasonal variation at least, of the entire foreshore area of Iwo-jima.

Analysis was further proceeded to examine the local effect on the short term variation of dS . To see the local effect, the coast was divided into four sections as shown in figure 11. These sections were designated S-E coast, N-E coast, N-W coast and S-W coast, respectively.

Similar analysis was made on the data of ΔS in each section. Figure 12 shows the analytical results. In this figure, straight lines indicate the regression lines of ΔS over the time in each coast. Further, the symbol of square indicates the relative upheaval height, ΔH and the symbol of white circle represents ΔS . This figure clearly shows that there is a certain analogy among the variation

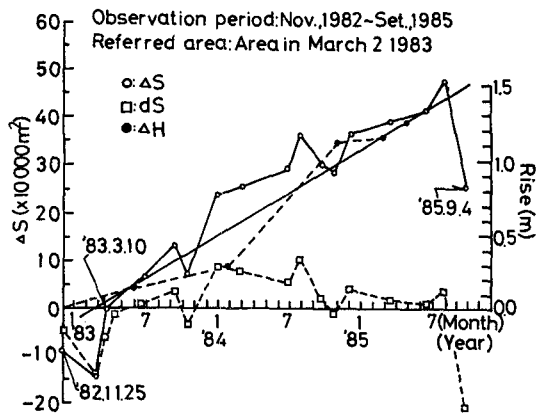


Figure 10. Variation of relative surface area, ΔS in each coast

patterns of ΔS in each coast.

To see this more precisely, variation of dS was checked similarly. Figure 13 shows the short term variation of dS in each coast. From this figure, the following facts were observed:

(1) Variation of dS is generally much greater in both the S-E and N-W coasts compared with that in both the N-E and S-W coasts. Namely, that reaches approximately 300,000 square meters in the former coasts during the period from spring to fall. However, that is usually 150,000 square meters at most in the latter coasts throughout the year.

(2) dS in both the S-E and S-W coasts shows quite similar and rhythmical patterns seasonally. dS in both the N-E and N-W coasts also shows quite similar variation patterns. However, these patterns are not as rhythmical seasonally as they are in the S-E and S-W coasts.

(3) There exist a certain phase lag between the variation patterns of dS in the S-E coast and that in the S-W coast. Similar phase lag is found between the variation patterns of dS in the N-E coast and that in the N-W coast, too.

(4) Variation pattern of dS in the S-E coast is almost opposite to that in the N-W coast.

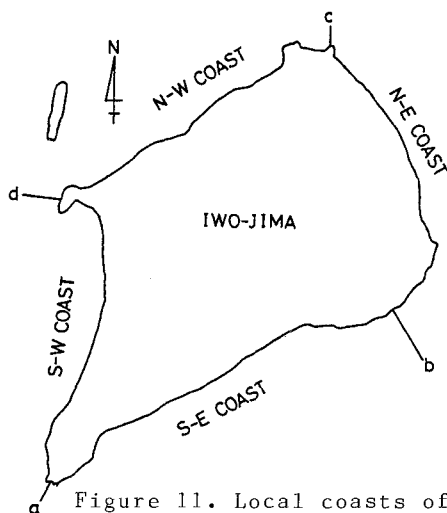


Figure 11. Local coasts of Iwo-jima

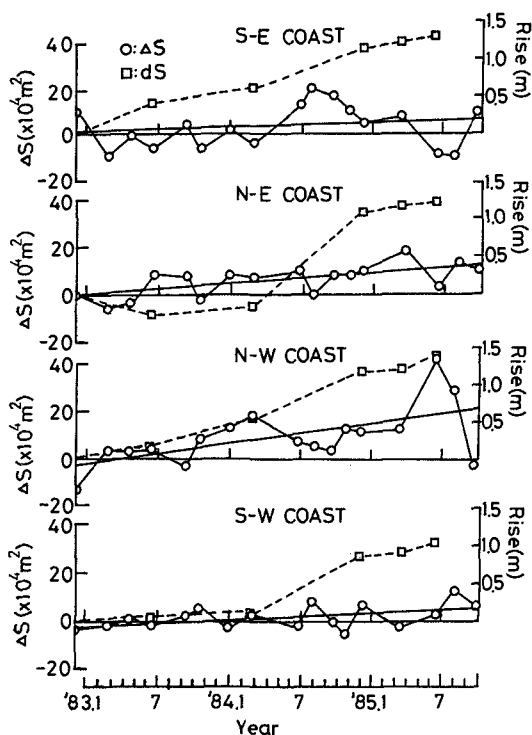


Figure 12. Variation of ΔS in each coast of Iwo-jima

Similarly, variation pattern in the N-E coast is almost opposite to that in the S-E coast.

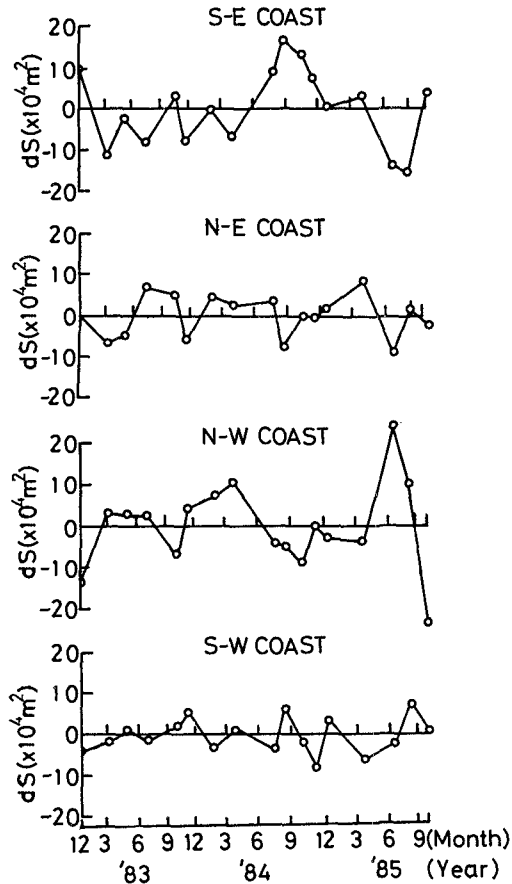


Figure 13. Variation of dS in each coast of Iwo-jima

5. Conclusions

Variation of the foreshore area in Iwo-jima was investigated by analyzing the 19 aerial photographs of the shoreline, land surveying data and wind and wave data which were all obtained through the field surveys performed during the past three years.

As a result, it was found that the foreshore area was currently increasing at an approximate rate of 180,000 square meters per year as a whole, due to the continuous

upheaval of the island exceeding 45 centimeters per year. Further, it was found that two different patterns appeared locally in the variation of the foreshore area and that in S-E and N-W coasts, variation of the foreshore area reached 300,000 square meters seasonally.

Acknowledgement

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