CHAPTER 10

WAVE RUN-UP ON A NATURAL BEACH

Mitsuo Takezawa[1], Masaru Mizuguchi[2]

Shintaro Hotta[3] and Susumu Kubota[4]

ABSTRACT

The swash oscillation, waves and water particle velocity in the surf zone were measured by using 16 mm memo-motion cameras and electromagnetic current meters. It was inferred that incident waves form two-dimensional standing waves with the anti-node in the swash slope. Separation of the incident waves and reflected waves was attempted with good results using small amplitude long wave theory. Reflection coefficient of individual waves ranged between 0.3 and 1.0. The joint distribution of wave heights and periods in the swash oscillation exhibited different distribution from that in and outside the surf zone. This indicates that simple application of wave to wave transformation model fails in the swash zone.

1. INTRODUCTION

The understanding of wave dynamics in the swash zone on natural beaches is important for understanding beach erosion, designing coastal structures, estimating beach deformation after construction of structures, and so on. However, the properties of swash waves are not well understood. Crarification of the wave characteristics is difficult because field observation of waves in the swash zone are diffcult to perform. Only a few measurements are reported (Guza and Thornton, 1982; Mizuguchi, 1984; Holman and Sallenger, 1985).

---

1 Dr. Eng., Professor, Dept. of Civil Eng., College of Science and Technology, Nihon University, Kanda-surugadai 1-8-14, Chiyoda-ku, Tokyo, 101 Japan

2 Dr. Eng., Associate Professor, Dept. of Civil Eng., School of Science and Technology, Chuo University, Kasuga 1-13-27, Bunkyo-ku, Tokyo 112 Japan

3 Dr. Eng., Associate Professor, Dept.of Civil Eng., Nihon University

4 Research Associate, Dept. of Civil Eng., Nihon University

For measurement of waves in the swash zone, the visual method, in which the water surface profile is recorded by camera or video movie camera, and the electrical method, in which resistance-type or capacitance-type wave gages are employed with some modification for the limited use, have been employed (Holman and Guza, 1984). The authors here use both methods for measureing waves in the swash zone, with improvements, and have developed a technique that combines the two method together.

The method developed is an electrical technique utilizing a capacitance-type wave gages, a wave run-up meter, stretched parallel to and about 2 cm above the sand surface, and monitoring of the water surface at maker sticks installed in the swash zone using video-movie cameras or 16mm memo-motion cameras. An advantage of this method is that the record can be supplemented with data form the cameras when the run-up meter malfunctioned.

Field observations were carried out at three different locations Chigasaki, Oarai, and Hasaki Beaches. The field experiment conducted at Chigasaki Beach (facing the Pacific Ocean and located about 50 km southwest of Tokyo) was a preliminary one, and only limited results were obtained as shown in the Conference ABSTRACT. Based on the experience gained in the preliminary experiment, the measuring method was improved and successfully employed in observations at Oarai and Hasaki Beaches. The purpose of present paper is to describe the measuring method, the analysis procedures applied to the data, and their results. More data were obtained than presented in this paper. Only the results fom at Oarai Beach will be described and discussed in this paper. These data were obtained using a remote sensing photographic technique utilizing synchronized 16 mm memo-motion cameras which film the water surface on marker sticks at a fixed time interval.

II FIELD OBSERVATION

Field observation was carried out on July 29, 1987, at Oarai Beach located about 200 km north of Tokyo and facing the Pacific Ocean (Fig. 1). Oarai Beach is bounded by a harbor at its northern end. Groins were constructed for protecting the harbor from contamination by intruding sand from the south. Sand accumulats at the southside of groins and erosion is occuring in an area approximately 2 km south of the largest groin. The observation site was located approximately 1.8 km south of the largest groin (see Fig. 1).

Figure 2 shows the sea bottom topography, and arrangement of instrumentation. In the swash zone vertical target sticks made of iron bar, painted white, were installed normal to the shoreline at an interval of 50 cm (see Fig. 3). A total of 41 sticks were installed covering the entire swash zone.

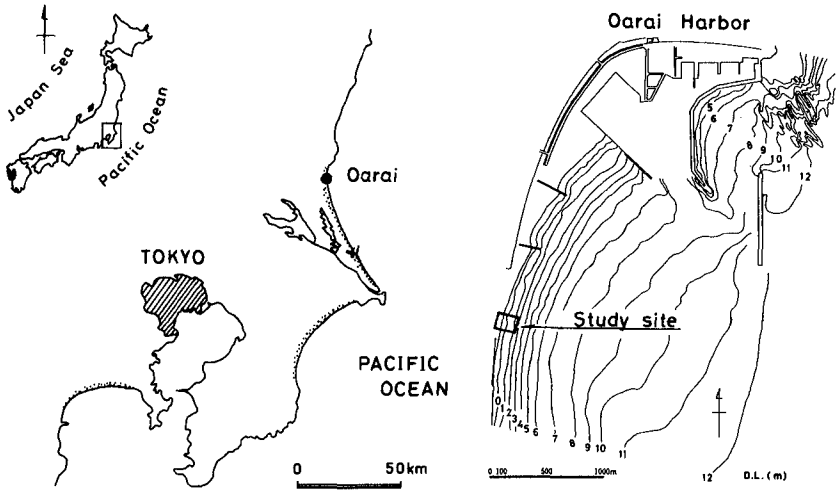

Fig. 1 Location map of field site.

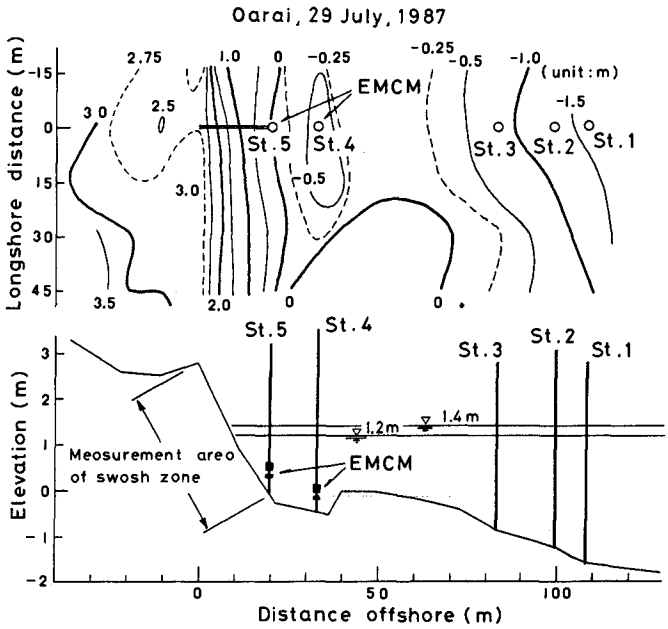

Fig. 2 Beach profile, plan, and arrangement of instrumentation.

A scaffold for photographing waves from the side was erected at the midpoint of the swash zone approximately 40 m south of the stick array. Swash oscillations of the water surface along the array were photographed by two pairs of 16 mm cameras placed on the scaffold. Each camera pair photographed a 10 m section of the swash zone. Five target poles (St. 1 to St. 5 in Fig. 2) were also installed for wave measurement. The sea water surface movement at the poles were recorded by two pairs of cameras mounted on another scaffold constructed on berm. All four pairs of 16 mm cameras were synchronized. The shooting interval was 0.2 s.

A run-up meter was also employed to measure the swash oscillation. The run-up meter was essentially a capacitance-type wave gage, but the measuring range was modified for run-up measurements. The capacitance wire was installed parallel to, and about 50 cm north from, the stick array. The wire was held at a constant height of 2 cm above the sand surface by supporting rods installed at an interval of 2 m. As it was crucial to keep the fixed space of 2 cm during the observation, a couple of man was engaged in for adjusting the height of supporting devices of the capacitance wire. A capacitance-type wave gage and a two-component electromagmetic current meter(EMCM) were attached to filming target poles at St. 4 and St. 5. Photograph 1 shows the stick array and the run-up meter.

The data collection was started at 16:10 and ended at 17:50, giving a 100 min. experiment duration. During the experiment the tide rose about 20 cm. Average breaking wave height and period by visual observation were 1 m and 12 s. Average breaker line was located between Sts. 2 and 3. The type of breaker was plunging and the wave direction was almost normal to the shoreline.

Output of the electrical instrument was recorded on an open-reel digital data recorder. The data sampling interval was 0.2 s. Synchronization between the camera system and data recorder was done by hand. The time lag between both data series was 0.4 s.

Sand in the swash zone was collected at four locations along the array. Sieve analysis indicated the sand was well-sorted with a median diameter of 0.43 to 0.52 mm, sorting coefficients of 1.20 to 1.32, and skewness of 0.92 to 1.11.

III RESULTS AND DISCUSSION

The measuring instruments worked well throughout the experiment except for a capacitance-type wave gage attached to St. 4 which experienced mechanl trouble after installation. The tape was directly loaded onto a main-frame computer and data were transferred to disk for analysis. The data of the 16 mm photographs were first transferred to a personal computer floppy disk using a 16 mm film

analyzer and an ultrasonic digitizer graph pen system. The data were then transferred to compurter disk for convenient analysis. The water edge of the swash zone in the 16mm film was read as the horizontal distance from a reference point. Then the distance was transferred to a vertical distance by assuming the swash zone face was a compound slope consisting of three straight slopes (Fig. 3). The swash oscillation was also measured by the run-up meter. A comparision of data by 16 mm film and by the run-up meter showed the same results as already reported by Halman and Guza(1984). The wave data by 16 mm cameras and by electromagnetic current meters are used in this paper.

3.1 Raw Data

Figure 4 shows a portion of sea water surface records from St. 1 through St. 5 and the swash oscillation. We can easily recognize the crests of primary individual waves (Mizuguchi, 1982) at each measurement point. However, at St. 4 and St. 5, in the surf zone, there small waves appear, which are not observed at St. 1. These waves were generated mainly due to breaking. In addition we could clearly observe small outgoing waves by viewing the film. Some of small waves recorded at St. 4 and St. 5 are these reflected waves.

Figure 5 shows power spectral density functions of the sea water surface variation at St. 1 and St. 5, and the swash oscillation. The main power, which lies in the range from 0.03 Hz to 0.2 Hz($0.03\ \mathrm{Hz} < f < 0.2\ \mathrm{Hz}$, where f is frequency.), decreases considerably from St. 1 to St. 5. However, power in the high frequency range at St.5 increases almost five times that observed at St. 1. This change of power spectral function, which means energy transfer from the peak frequency range to the higher frequency range, is due to the wave breaking. Power in the high frequency range of swash oscillation reduces down to almost the same magnitude of that at St. 1 and power in the frequency range lower than about 0.2 Hz increases greatly. This implies that the low frequency waves form standing waves which have an anti-node in the swash zone. At St. 5, peaks and deep depressions in the power density function alternately appear. However this alternate change of power is not observed in the swash oscillations. Figure 6 shows the cross spectral density function between the sea surface elevation and the on-offshore component of water particle velocity at St. 4. An abrupt fall in coherence and a sudden change in phase function at corresponding frequencies are characteristic features of two-dimensional standing waves (Hotta, Mizuguchi and Isobe, 1981). No significant power was found in the longshore velocity.

The gradient of power density function in the saturated range at the high frequency side of the peak follows -3 power of the frequency (f^{-3}) at the outside of the breaker zone(Sawaragi and Iwata, 1980) and follows -4 power of frequency (f^{-4}) inside the surf zone, as reported by Mizuguchi(1984), and Mase and Iwagaki(1984).

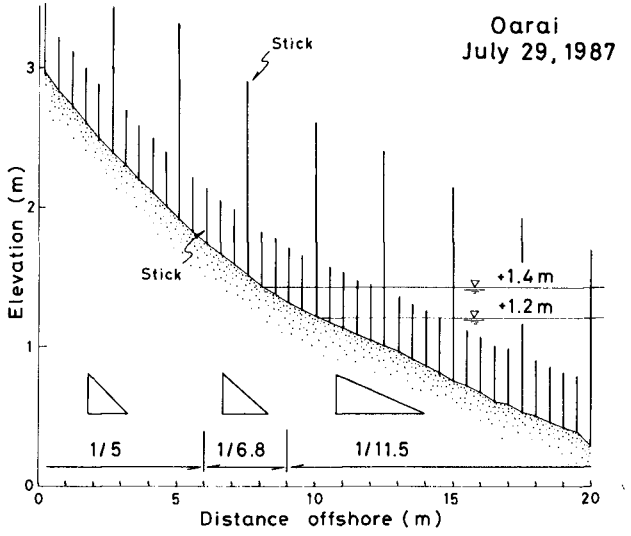

Fig. 3 Assumed compound slope for swash zone.

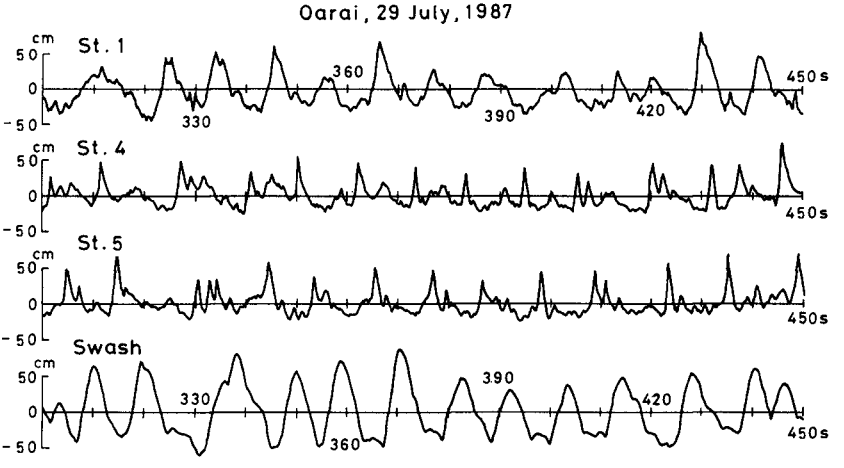

Fig. 4 Example of raw data.

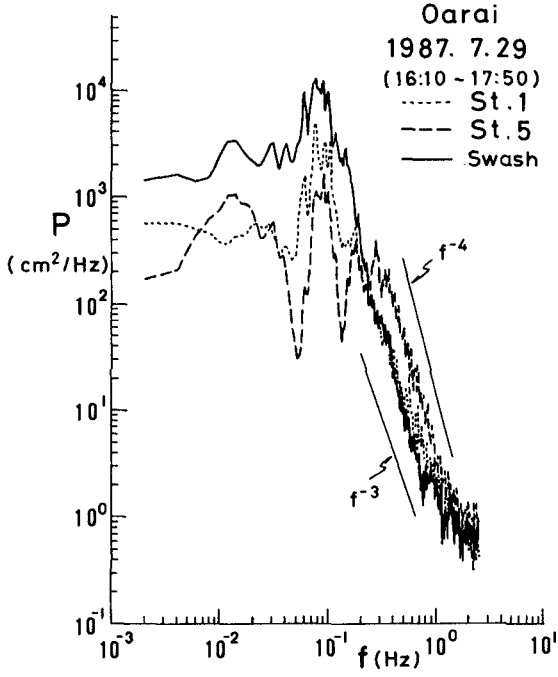

Fig. 5 Power spectral density functions.

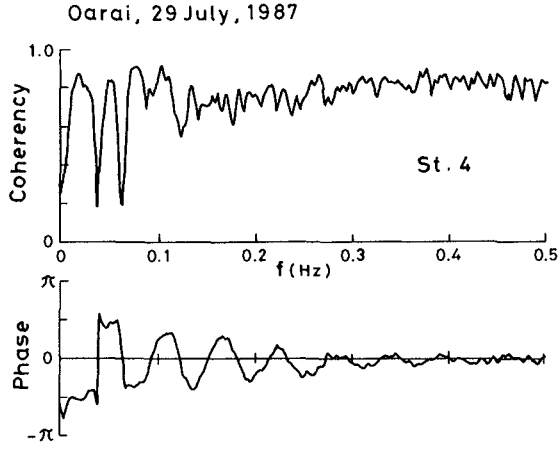

Fig. 6 Cross spectra between surface elevation and on-offshore component of water particle velocity at St. 4.

3.2 Wave Height and Period Distribution

For the study of waves, the wave-to-wave method by zoro-crossing analysis was employed. The zero-crossing method was applied to raw data, data that a mean sea water level trend due to the tide was identified with the assumption of a paraboralic curve, and tide trend was removed(Hereafter referred to as ajusted data), data that were then processed a high pass filter with cut off frequency of 0.045 Hz (Hereafter referred to as filtered data). The filter utilized is given in Fig. 6 of Mizuguchi(1982). Before discussing the results, we note the accuracy of wave data. Wave data obtained by means of 16mm cameras contain error of ± 2 cm in elevation. Therefore, waves lower than 6 cm in height were ignored in analysis (see Hotta and Mizuguchi, 1980).

Figure 7 shows the distributions of wave height and period defined by zero-down crossing method for raw, adjusted, and filtered data at St. 1, St. 4, and the swash oscillation. The number of big waves having large height and long period decreases and the number of small waves having relatively small height and short period increases in order when moving from to raw, adjusted, and filtered data. This can be explained by the effect of the tide and long period fluctuations of the sea water surface on the waves in the nearshore zone. The removal of the tidal trend and the long period fluctuations of sea water surface results in an increase in the number of waves defined by the zero crossing method. Figure 8 compares the wave height distribution of the filtered data by the zero-up and the zero-down crossing methods. Figure 9 shows the joint distribution of wave height and period for the filtered data. Table 1 gives statistically representative waves of the filtered data by zero-down crossing method.

Station 1 is located in the outside of the breaker zone and St. 4 is located in the surf zone. Typical features of wave height and period in the nearshore zone are presented in Figs. 8 and 9. It is seen that the marginal distributions of wave height and period outside of breaker zone is quite similar to the Rayleigh distribution, though the peak shifts to the smaller side. The marginal distributions of the wave height becomes bi-modal and the joint distribution exhibits two maxima in the surf zone. This tendency is particularly strong if waves are defined by the zero-down crossing method(Hotta, Mizuguchi and Isobe, 1982).

It appears that the wave height and period of the swash oscillation is similar to the Gaussian distribution about the mean wave height. However, detailed examination of the joint distribution indicates that the marginal distributions of the wave height and period become bi-modal, and the joint distribution exhibits two maxima if the waves are defined by the zero-up crossing method. This means that big waves often are preceded by relatively small waves in the

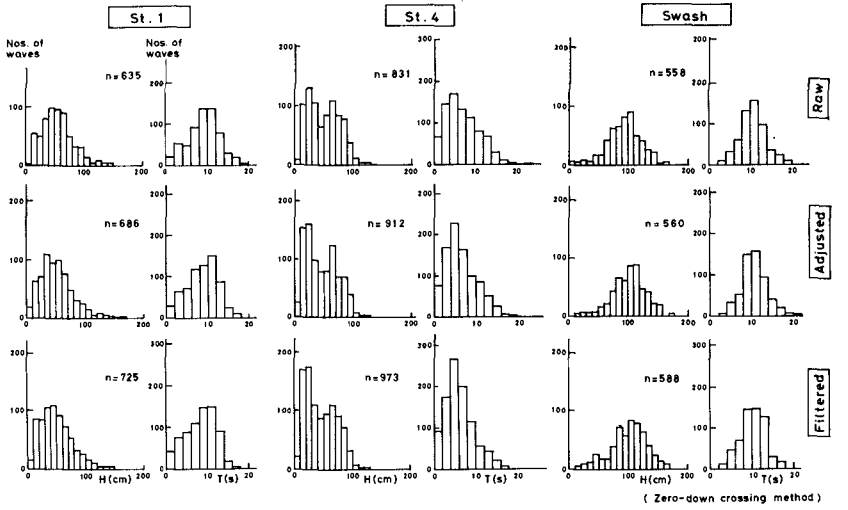

Fig. 7 Wave height and period distribution.

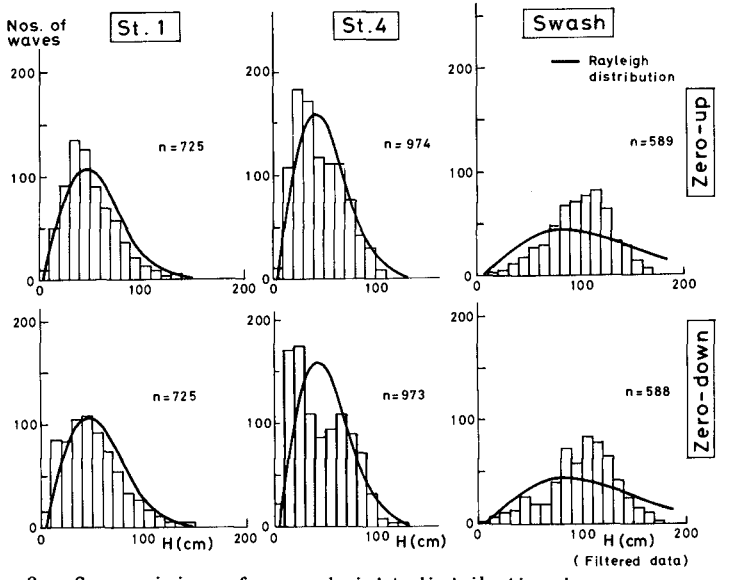

Fig. 8 Comparision of wave height distribution by zero-up and zero-down crossing method.

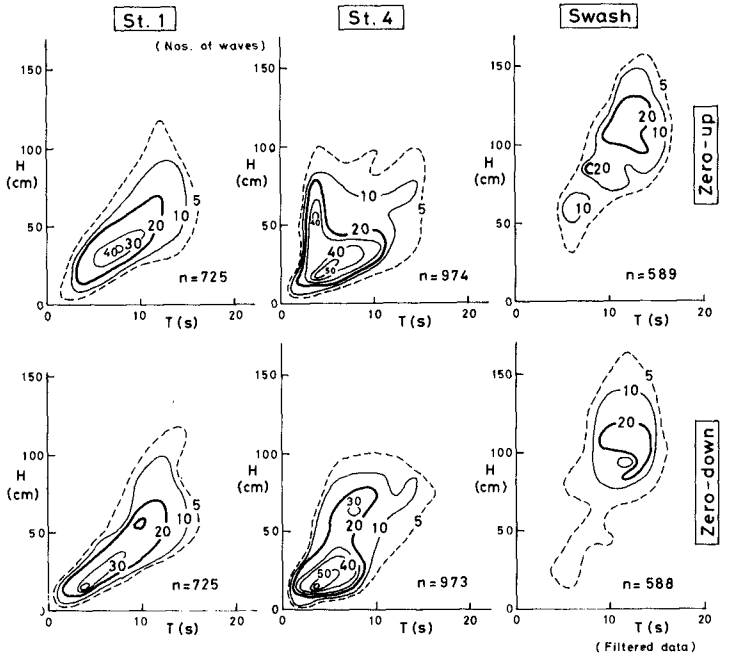

Fig. 9 Joint distribution of wave hight and period. Oarai, 29 July, 1987

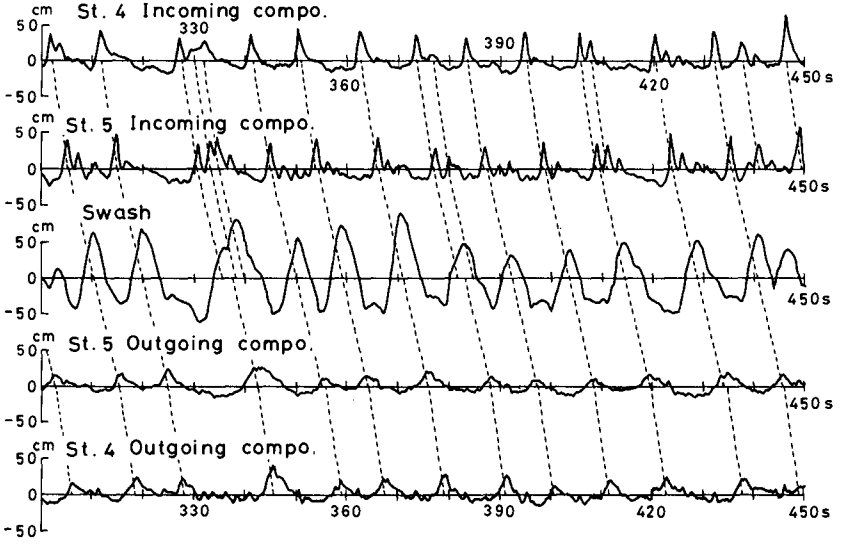

Fig. 10 Example of resolved incident and reflected waves.

swash zone. It is often observed that a larger wave following a smaller preceeding wave travels faster, catches up, and passes the preceeding wave when the wave is running up on the swash slope.

3.3 Reflected Waves

In section 3.1, indications that waves in the inner surf zone form two dimensional standing waves, during this experiment were given. Separation of incident waves and reflected waves was tried. After Guza, Thornton and Holman (1984), the linear small amplitude long wave theory was applied. That is

$$\eta_{IN}(t) = (\eta + \alpha (h/g)^{1/2} u)/2 \quad \cdots\cdots (1)$$

$$\eta_{OUT}(t) = (\eta - \alpha (h/g)^{1/2} u)/2 \quad \cdots\cdots (2)$$

where η_{IN} and η_{OUT} are the water surface elevation of incident and reflected waves, u is the on-offshore component of water particle velocity, g is the acceleration due to gravity, h is the water depth and α is a constant. The constant α thoretically takes the value of unity. However the data contained some experimental error. Therefore using the power value in cross spectral analysis between η and u, the most suitable value of α was selected in order to accomplish the separation.

Figure 10 shows examples of the result. The period of the record shown in Fig. 10 corresponds to that in Fig.4. The upper two plots give the separated incident waves at St. 4 and St. 5. The lower two plots give the reflected waves. The middle plot is the swash oscillations (run-up waves) in the swash zone. The broken lines in Fig.10 identify individual waves. Figure 10 shows that incident and reflected waves propagate with the same celerity between two measuring stations. Figure 11 shows the cross-correlation functions between incident and reflected waves. The maximum correlation coefficients are found at a time lag of 10.2 s at St. 5 and 16.4 s at St. 4. The wave celerity between St. 4 and St. 5 estimated from the above two values agreed well with that calculated from the linear small amplitude long wave theory, taking the average value of water depth between St. 4 and St. 5. Figure 11 also shows that a wave group consisting of two or three individual waves is combined into a single wave in the swash zone and is reflected to the offshore. This is popularly observed at natural beaches.

Finally reflection coeffcient of individual waves, defined by a ratio between reflected wave height and incidient wave height (H_{OUT}/H_{IN}), was examined. Reflection of irregular waves on natural beaches have been dealt with in the frequency domain. However, reflection on a foreshore slope is the result of run-up and run-down of each individual waves. The reflection coefficients in the time

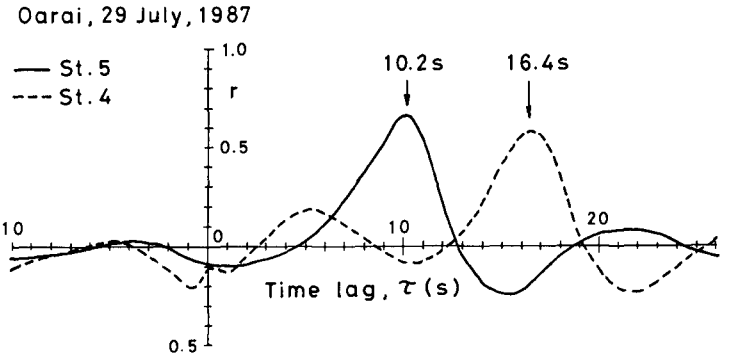

Fig. 11 Cross-correlation function between incident and reflected waves

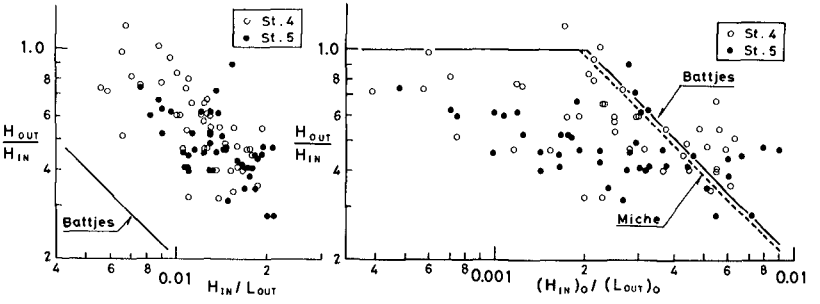

Fig. 12 Relationship between reflection coefficient and wave steepnees.

Fig. 13 Relationship between reflection coefficient and wave steepness in deep water.

Table 1 Statistically representative waves.

Oarai, 29 July, 1987

Station number	Depth h (cm)	Nos. of waves	Wave height					Wave period			
			H_{rms} (cm)	H_{mean} (cm)	H_{max} (cm)	$H_{1/10}$ (cm)	$H_{1/3}$ (cm)	T_{mean} (s)	T_{max} (s)	$T_{1/10}$ (s)	$T_{1/3}$ (s)
St. 1	292	725	59	51	187	114	85	8.3	12.2	11.3	10.9
St. 2	256	762	62	53	207	122	90	7.8	9.1	10.9	10.6
St. 3	220	712	68	57	195	139	98	8.4	10.3	10.8	10.6
St. 4	175	973	53	46	128	93	77	6.2	7.3	9.1	8.5
St. 5	139	1178	50	44	151	91	72	5.1	8.3	8.1	7.3
Swash	0	588	104	99	175	152	133	10.2	10.9	11.3	11.1

(filtered data, zero-down crossing method)

domain is only an artifice, for which it is difficult to attach any physical meaning.

Figure 12 shows a plot of reflection coefficients against the local wave steepness, defined by the ratio between the incident wave height to the shallow water wave length calculated from the reflected wave period. The solid curve in Fig.12 gives the result of reflection coefficient obtained by Battjes (1974) for the regular waves with beach gradient of one-seventh ($\tan \beta = 1/7$). There is a tendency that reflection coefficients are inversely proportional to the local wave steepness as found in the case of regular waves. However values of ratio in irregular waves are much greater than those given by Battjes (1974). This is because the wave height and period were measured in the deeper offshore area in the laboratory experiment, which support Battjes' formula. The reflection coefficients at St. 4 are generally greater than those at St. 5. Physically it is reasonable that the reflection cefficient at St. 5 should be greater than that at St.4 since St. 5 is located nearer to the shoreline. The opposite result in Fig. 12 may result from the fact that the incident waves at St. 5 had sharp peaks due to nonlinear shoaling. The mean reflection coefficient defined by the ratio of rms value of water surface elevations of reflected waves to that of incident waves is 0.67 at St. 4 and 0.93 at St. 5.

Figure 13 shows a plot of reflection coefficients against the deep water wave steepness. The solid curve denotes Battjes' criterion and the broken curve gives Miche's criterion (Miche, 1951, or Horikawa, 1978). Considerable scatter of data makes it difficult to draw conclusions from Fig. 13 except that the magnitude of reflection coefficient of individual waves in irregular waves is comparable to those for corresponding regular waves.

IV CONCLUDING REMARKS

Field data of swash motion of good quality is obtained by a photographic method. Wave data in and outside of the surf zone were measured simultaneously. Analysis in the frequency domain shows that most of the power in the inner surf zone is of standing waves. However wave to wave analysis is better to describe the waves both in the surf zone and in the swash zone.

Zero-crossing methods are applied to define the individual waves. It is revealed that the number of waves changes considerably when waves propagates from outside the surf zone through the surf zone to the swash zone. This indicates that simple wave to wave method fails to describe the transformation of waves.

Joint distribution of height and period of swash oscillation is obtained. Marginal distributions of wave height as well as period is

similar to Gaussian distribution. Physical interpretetion of these facts are left in future. It, however, can be pointed out that nearly constant power in the low frequency range in the swash spectrum might be related to the shape of distribution.

Incident waves and reflected waves are decomposed by using measured surface elevation and cross-shore velocity under the assumption of the linear long wave theory. The decomposed surface elevation profiles show it possible to idntify incident waves (or groups of incident waves) and the corresponding outgoing (reflected) waves. Crude estimate of reflection coefficients of these individual waves is attempted. The values are inversely proportional to the local wave steepness in the inner surf zone, and of the same magnitude as those given by Miche formula for monochromatic waves, though the data scatter is rather large.

Reflected waves can be seen as those generated in the swash zone by the incoming waves. It will be a next problem to find out the relationships among the incoming waves, the swash oscillation and the outgoing waves. The problem would be best treated in the physical time domain.

ACKNOWLEDGEMENT

We would like to express our appreciation to the our university students who supported the field work and digitized the films. Without their help we could not have carried out this field research. We gratefully acknowledge the assistance of Dr. S. A. Hughes of the Coastal Engineering Research Center, WES, in the preparation of the manuscript.

REFERENCES

Battjes, J. A. (1974): Surf similarity, Proc. 14th Coastal Eng. Conf., pp.446-480.

Guza, R. T. and E. B. Thornton(1982): Swash oscillation on a natural beach, J. Geophs. Res., Vol. 87. No. C1, pp.483-491.

Guza, R. T., E. B. Thornton and R. A. Holman(1984): Swash on steep and shallow beaches, Proc. 19th Coastal Eng. Conf., pp.708-723.

Holman, R. A. and R. T. Guza(1984): Measuring runup on natural beaches, Coastal Eng., Vol. 8, pp.129-140.

Holman, R. A. and A. H. Sallenger(1985): Setup and swash on a natural beach, J. Geophs. Res., Vol. 90. No. C1, pp.945-953.

Horikawa, K.(1978): Coastal Engineering---An Introduction to Ocean Engineering---, Univ. of Tokyo Press, Tokyo, 402p.

Hotta, S. and M. Mizuguchi(1980): A field study of waves in the surf zone, Coastal Eng. in Japan, Vol. 23, pp.59-79.

Hotta, S., M. Mizuguchi and M. Isobe(1981): Observations of long period waves in the nearshore zone, Coastal Eng. in Japan,

Hotta, S., M. Mizuguchi and M. Isobe(1982): A field study of waves in the nearshore zone, Proc. 18th Coastal Eng. Conf., pp.38-57.

Mase, H. and Y. Iwagaki(1984): Run-up of random waves on gentle slopes, Proc. 19th Coastal Eng. Conf., pp.593-609.

Miche, R.(1951): le pouvoir reflechissant des ouvrages maritime exposes a laction de la houle, Annales Ponts et Chaussees, 121^{e} Annee, pp.285-319.

Mizuguchi, M.(1982): Individual wave analysis of irregular wave deformation in the nearshore zone, Proc. 18th Coastal Eng. Conf., pp.485-504.

Mizuguchi, M.(1984): Swash on a natural beach, Proc. 19th Coastal Eng. Conf., pp.678-694.

Sawaragi, T. and K. Iwata(1980): Wave power spectrum slope on high frequency range in shallow water surf, Coastal Eng. in Japan, Vol. 23, pp.91-99.

Photo 1 Run-up meter and stick array.