CHAPTER 25

Wave Breaking under Storm Condition

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Abstract

The effects of strong wind on wave breaking were discussed with the field data. At around *U* =23m/s the maximum wave steepness of 0.034 was obtained. At the wind velocity of more than 23m/s, the wave steepness becomes small once because reformed waves which were already broken at the offshore were measured. This corresponds with the changes of the ratio of wave breaking. The relationship between the mean period of SIWEH and significant wave period was made clear. It was found that pulsating behavior of undertow influences wave breaking in a shallow water.

Introduction

In spite of many trials to explain the mechanism of wave transformation and wave breaking, in a shallow water, we have still obscure phenomena in the nearshore zone. For example, under high wind, it is very difficult to predict the location of breaking points of incoming waves. Most of coastal structures have been designed to avoid impulsive shock pressure due to wave breaking, but usually breaker index has been developed on the basis of experimental data conducted under no wind condition. Some coastal disasters have been generated by underestimation or miscalculation of wave forces due to wave breaking.

On a mild sloping beach, high waves under strong wind break two or more times in the crosshore direction. In the shoaling process, we observed frequently that a lower wave just after a higher wave breaks easily. This mechanism was not well understood yet. Moreover, at the wind velocity of more than 20m/s, the applicability of breaker index and plausible maximum wave steepness have not made clear due to lack of field data. Moreover, high wind waves usually come to the shore in accompany with high wind.

The effects of strong wind on wave breaking were discussed with some traditional methods. Firstly, changes of wave steepness and ratio of wave breaking with wind velocity were studied. Secondly, applicability of breaker index was investigated. In order to make clear the effect of undertow on wave breaking, the relationship between the dominant period of SIWEH and significant wave period was also justified. The measurement was conducted on 18 November, 1981 on which developing low pressure moved eastward in the Japan Sea and high wind blew around the coast.

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Field Observation Site and Method

The field experiments were conducted on the Ogata coast which is a straight sandy beach of 20km long facing the Japan Sea. At the measuring site (water depth:7m, bottom slope:1/130, offshore distance:200m), capacitance wave gauges were installed as shown in Fig. 1. Two wave gauges were set respectively in the crosshore direction at the distances of 12.9m landward and 19.6m seaward from the measuring site. A unit of data is each 100 sec in length and 40 units were analyzed as every averaged data. VTR systems focused on sea surface at Ch. 1 Wind characteristics were measured with the anemometer installed at the 35m offshore from Ch. 1 and its height was 15m above mean sea level (tidal range is about 30cm). At the observatory, the anemometer was installed at the height of 10m above ground level. Dominant wave direction was determined through the analysis of directional spectra with the data obtained by eleven wave gauges. The undertow was measured with the ultrasonic type current meters at the height of 1m above the bottom.

Observation Results

Firstly, we analyzed the data with surf similarity parameter ξ to divide into breaking and non-breaking waves. The wave length was calculated with small amplitude wave theory and second-order Stokes wave theory. Figure 2 shows one of the results in which η_d means the distance between mean sea level and wave trough. From this figure, it was found that it is impossible to clarify breaking and non-breaking with the traditional expression. In the similar expression such as η_u / η_d (η_u: distance between mean sea level and wave crest), $H / \eta_d T$ (T : wave period), the combination of and the variables defined here can not express the criterion of breaking and non-breaking. In these relationship, we introduced the wind velocity as the parameter, but we could not get good results to explain wave breaking phenomena.

Effects of High Wind on Wave Breaking

In this chapter, we firstly tried to justify the applicability of breaker index and changes of wave steepness and rate of wave breaking with wind velocity. On the Ogata coast, wind waves develop in accompany with the movement of low pressure and the wave direction changes from west, northwest to east sequentially. It is generally

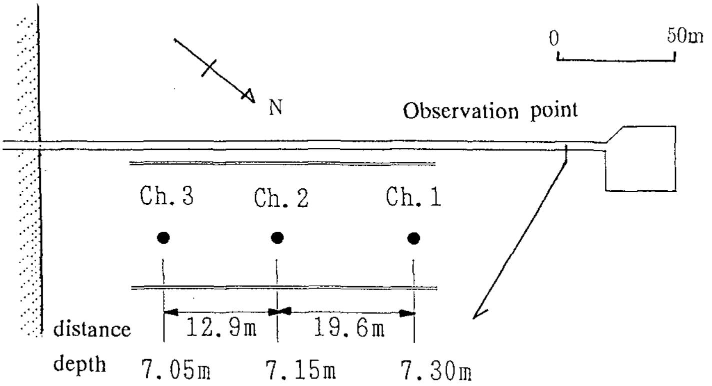


Fig. 1 Observation pier and point on the Ogata coast

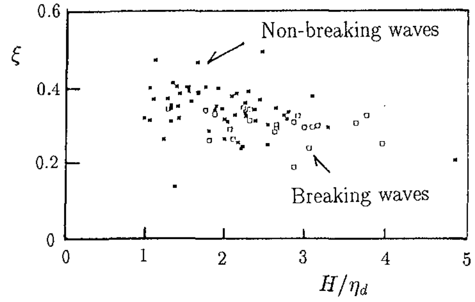


Fig. 2 Relationship between H / η_d and surf similarity parameter

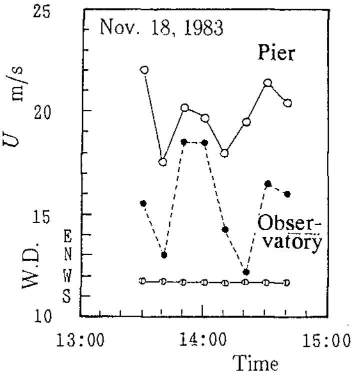
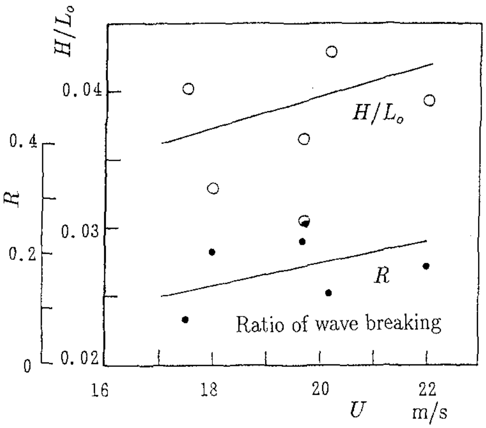


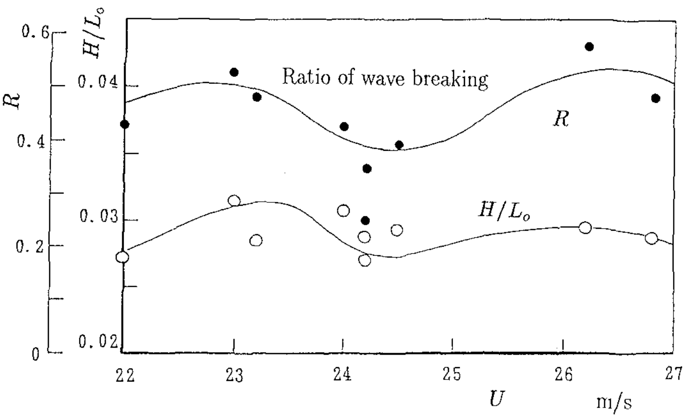
Fig. 3 Changes of wind characteristics

recognized that wave height increases until wave direction becomes northwest. After this stage, waves change to swell.

Figure 3 shows an example of sequential changes of wind characteristics. Every point is 10 min. averaged data. At the pier, we had very high wind and wave breaking with spilling type frequently occurred. Figure 4 shows the changes of the wave steepness H/Lo and ratio of wave breaking R with wind velocity U. Wave steepness was measured at the point of Ch. 3. Individual wave steepness is calculated and averaged in the period of 10 min. The ratio R is defined as the number of wave breaking divided by the total wave number. In the case of (a) (wind direction :WSW) the increase of wave steepness with wind velocity is clear and also the increase of R show same tendency. On the contrary, in the case of (b)(wind direction:WNW), the following results were observed: At around U =23m/s the maximum wave steepness of 0.034 was obtained and at the wind velocity of more than 23m/s, the wave steepness becomes small once because reformed waves which were already broken at the offshore were measured. Furthermore, more than 26m/s, the reformed waves also begin to break. The difference of wind velocity of



(a) wind direction: WSW



(b) wind direction: WNW

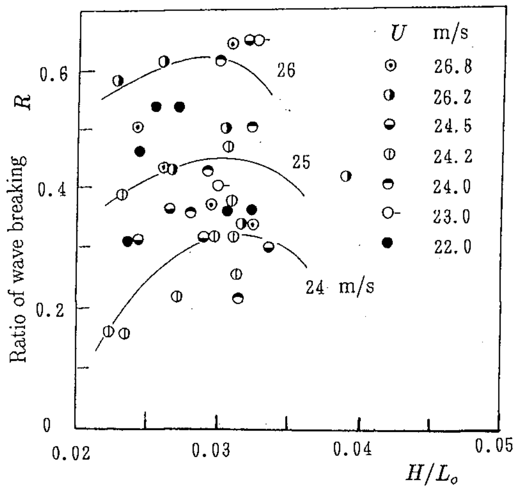
Fig. 4 Changes of wave steepness and ratio of wave breaking with wind velocity

only 3m/s is corresponds to the enlargement of width of breaker zone. The effect of wind direction on the changes of wave steepness is reflected the difference not only fetch and duration of wind waves but also of wave refraction characteristics. For example, the westerly waves changes from long crested to short crested waves due to wave refraction.

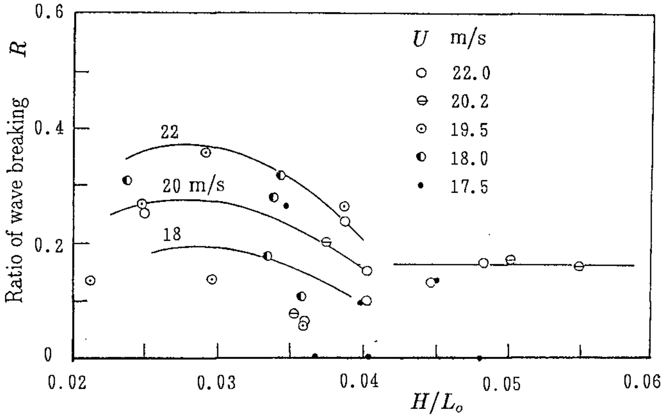
The changes of the rate of wave breaking is similar to that of wave steepness as follows:

a) wind velocity is less than 23m/s, the ratio R increases up to 0.5
b) 23 to 25m/s, R decreases to 0.4.
c) more than 25m/s, $R \approx 0.5$

They correspond well with the changes of wave steepness under high wind conditions.



(a) wind velocity is more than 22m/s



(b) wind velocity is less than 22m/s

Fig. 5 Changes of ratio of wave breaking and wave steepness

Figure 5 shows the relationship between wave steepness and ratio of wave breaking. The following remarks were observed:

a) wind velocity is less than 22m/s, ratio of wave breaking increases with wind velocity. When wave steepness becomes more than 0.04, ratio of wave breaking keeps 0.16.
b) wind velocity ranges from 22 to 24m/s, ratio of wave breaking slightly decreases.
c) more than 24m/s, waves whose steepness is more than 0.04 can not be found.

Figure 6 shows the applicability of breaker index proposed by Goda(1970). The data were recorded at U =26.7m/s and R =0.457. It was found that the breaking height was classified into some groups in each wave age and the breaker index was the upper limit of the field data.

Effect of Undertow on Wave Breaking

In the field, a following lower wave behind a higher wave is sometimes prone to breaking. The following mechanism may be related with the wave breaking phenomena on a mild slope in a shallow water:

a) high waves have low trough level, therefore, following low waves may break.

b) undertow due to high wave breaking promotes breaking of following waves.

Under storm wave condition on the Ogata coast, wave grouping is clearly formed and trough level of carrier waves is almost constant in every storm conditions as shown in Fig. 7. This may be only applicable to the shallow water at the depth of 7m, but the If

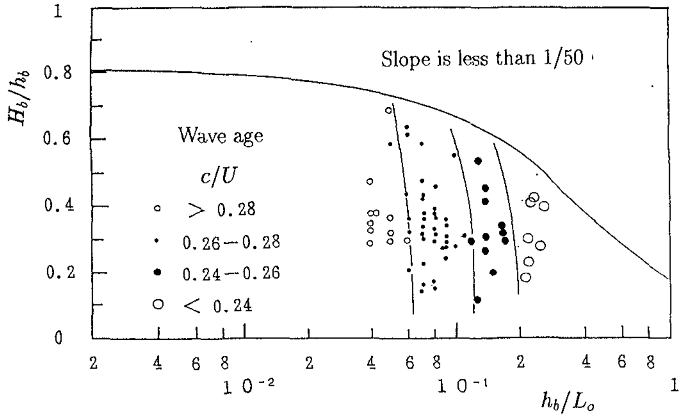


Fig. 6 Applicability of breaker index

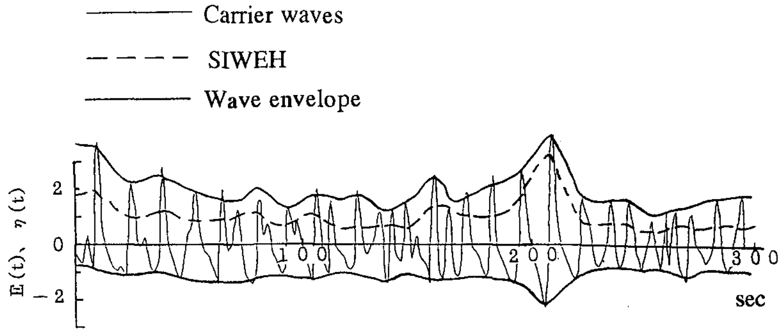


Fig. 7 Wave grouping

hypothesis a) is inadequate. Secondly, we discuss about the plausibility of hypothesis b). If we assume the control volume whose rectangular frame includes one wave length in the crosshore direction and one wave height above the bottom with moving coordinate, the bore model gives undertow due to energy dissipation at the moment of wave breaking. In this case, local water level changes due to changes of radiation stress and its gradient. However, a shoreline is the fixed boundary and flow structure can not be described without consideration about conservation of momentum or energy. Moreover, time scale in the analysis has to be comparable to spatial scale of width of nearshore zone. Therefore, formation of wave grouping and its related phenomena are focused on explanation of wave breaking.

As already pointed out, traditional methods can not predict the wave breaking. The reason of the pulsating occurrence of wave breaking is firstly discussed. If the pulsation exists, the oscillation of wave energy level with nearly same period should be found. Figure 8 shows the changes of wave height along Chs. 1, 2 and 3. The increase of wave height depends on wave transformation or existence of reverse flow. The averaged data show that the increase of wave height is larger than that predicted by wave transformation with small amplitude theory (in the calculation, wave height of 2m and wave period of 8s). In order to make wave height twice, it is necessary to add the reverse flow at the velocity of 2.75m/s. This is very large, but in the field the breaking phenomena is unsteady and the increase of wave height due to breaking also exist, this result suggests that the reverse flow may influence the wave breaking process.

Long Period Fluctuation of Current Velocity

Figure 9 shows the power spectrum of current velocity in the Northwest direction (it is almost in the crosshore direction) at the height of 1m above the bottom (water depth is about 6m)(Tsuchiya et al., 1989). In this figure, the first peak with the frequency of about 0.1Hz responds to that of incoming dominant waves. In the low frequent range, it is found to be some primary peaks.

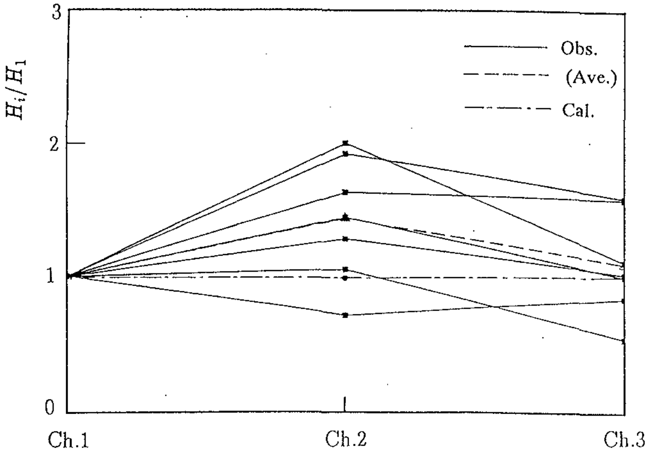


Fig. 8 Changes of wave height in the crosshore direction

Figure 10 shows the long period fluctuation of the current velocity in which the higher frequent component were cut off with the low pass filter of 0.03Hz. The current was recognized with the amplitude of 50cm/s. By this pulsating fluctuation, bursting of the bottom sediment were observed as shown in Fig. 11. The optical suspended sediment sensors are mounted in a vertical steel pipe of 3cm in diameter by 4m long. The lowest sensor was set at the height of 10cm above the bottom.(kawata et al., 1989). This bursting occurred at the moment of the concurrence of undertow and maximum water particle velocity in the offshore direction. The results reveals the importance of undertow to control bottom sediment concentration.

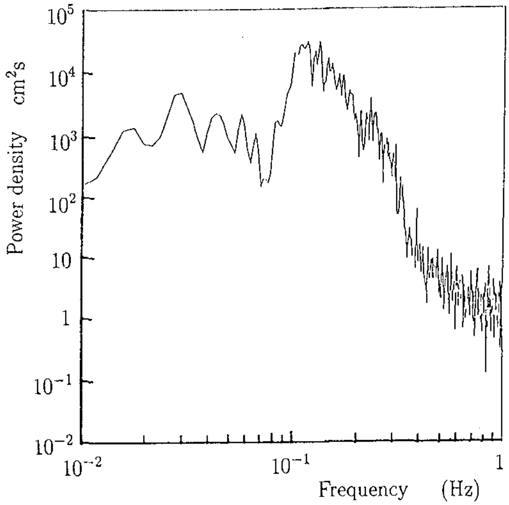


Fig. 9 Power spectrum of current velocity in the crosshore direction

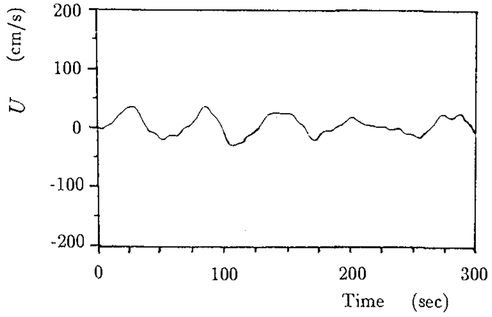


Fig. 10 Long period oscillation of undertow

Correspondence of Undertow and Wave Breaking

It is necessary to make clear the generation mechanism of undertow whose period is several to around ten times of those of incoming waves. Firstly, we checked the wave energy levels of wave grouping on the Ogata coast. Figure 12 shows that the mean period of SIWEH is proportional to that of significant wave period. This figure shows that the increase of wave period well correlate to the long period variation in wave grouping. Secondly, we checked the relationship between the time variation of undertow and the occurrence of wave breaking. The procedure is as follows:

a) In every 200 waves recorded at Chs. 1, 2 and 3, significant wave height and its period are calculated. We get a series of them during 600 waves.
b) In every breaking wave, the period T_{sh} (the period of SIWEH in Fig. 12, given by 5.81 $T_{1/3}$ +1) is shifted behind it and check the certain wave breaking or not.
c) This checking is applied to every individual 30 waves.

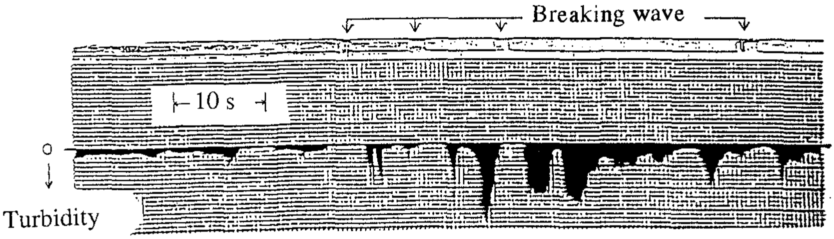


Fig. 11 Suspended sediment bursting due to wave breaking

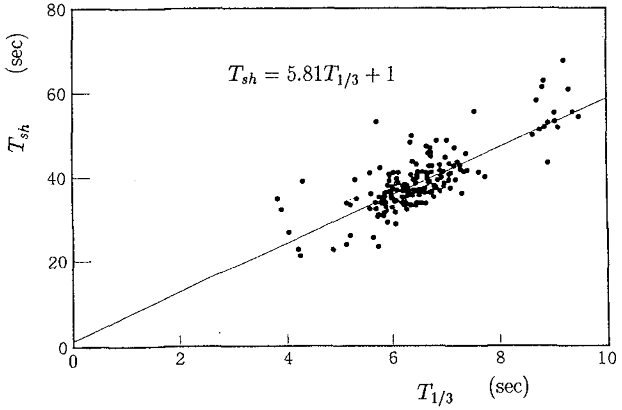


Fig. 12 Relationship between mean period of SIWEH and significant wave period

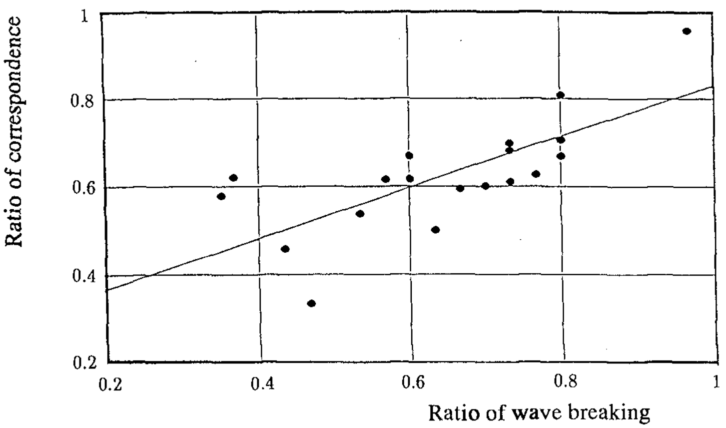


Fig. 13 Changes of ratio of correspondence with ratio of wave breaking

Figure 13 shows the relationship the ratio of correspondence and the ratio of wave breaking. It was found that the increase of the former is roughly predicted by the increase of the latter. Therefore, it was concluded that wave breaking in a shallow water is well depend on the pulsation of the energy level of wave grouping.

Conclusions

The effects of high wind on wave breaking in a shallow water were discussed with the field data. In rough sea state under strong wind, the wave breaking conditions in the nearshore zone can not be predicted with some traditional expressions. At around U =23m/s the maximum wave steepness reaches to 0.034. At the wind velocity of more than 23m/s, the wave steepness becomes small once because reformed waves which were already broken at the offshore site were measured. This corresponds with the changes of the ratio of wave breaking. The relationship between the mean period of variation of SIWEH and significant wave period was made clear. It was found that pulsating behavior of undertow influences wave breaking in a shallow water.

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