CHAPTER 157

Berm Erosion due to Long Period Waves

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Abstract

Breakers in the surf zone are saturated, that is, the wave height at any point is limited by the local water depth. The larger waves in a storm break further offshore making the surf zone wider but leaving the wave height in the inner surf zone the same. Why the beach will erode during the storm? To answer this question, there has recently been considerable interest in the long period waves of one to several minutes in period. The field observation has been carried out for more than one year to acquire the field evidences of berm erosion due to the long period waves. Based on the data obtained, two typical evidences of berm erosion will be shown. A critical level of berm erosion will be discussed, which can be predicted with the mean sea level and the height of long period waves at the shoreline.

1. Introduction

Figure 1 shows the approximate distribution of ocean surface wave energy. The energy in the band of period from 1s to 30s is the largest, which is due to the wind waves. Formerly, the wind waves had been considered to be a main external forces of beach erosion in a storm. The second largest energy is in the band of period from 30s to 5 min. The waves in this frequency band are often called infragravity waves. In this paper, however, they will be referred to as " Long period waves ".

It must be said again that Figure 1 is the approximate

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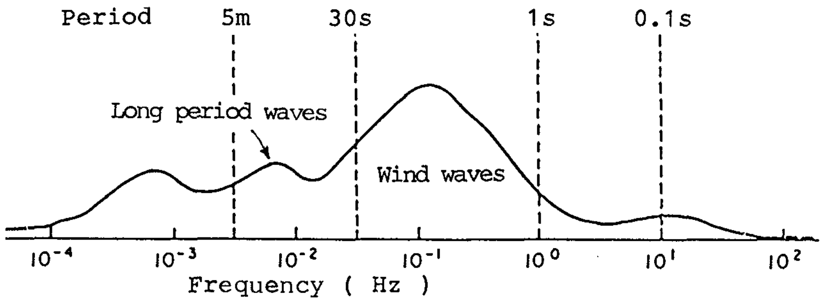

Figure 1 Distribution of ocean surface wave energy

distribution of ocean surface waves, that is to say, in the offshore area. In contrast to the offshore area, for the wave energy in the nearshore, especially in the surf zone, the energy distribution shown in Figure 1 must be modified, since the incident wind waves break and lose their energy in the surf zone. The wave height at any point is limited by the local water depth. The larger waves in a storm break further offshore making the surf zone wider but leaving the wave height in the inner surf zone the same.

On the other hand, the energy in the frequency band of long period waves becomes to be the largest near the shoreline. It has been already known that the amplitude of long period waves at the shoreline becomes larger without breaking in a storm (eg., Bowen and Huntley, 1984).

Therefore, the long period waves of about 1 to several minutes in period have attracted the attentions of researchers as a possible origin of nearshore large scale topographies such as bars. For example, Bowen and Inman (1971) showed theoretically that standing edge waves, which is a kind of the long period waves, can be the origin the formation of crescentic bars. Holman and Bowen (1982) theoretically examined the interaction of two edge waves to predict the three dimensional beach topography such as welded sand bars, and suggested that other three dimensional, complex, rhythmic topographies could also be explained by the same analyses. Katoh (1984) showed with the field data that the two-dimensional multiple longshore bars are formed by the long period standing waves.

Also in the consideration of the mechanism of berm erosion in a storm, it should be very important to take into account not the incident wind waves, but the long period waves, as the external force for the berm erosion. However, we don't have enough field evidences of beach erosion due to the long period waves.

The main purpose of the study is to acquire the field evidences of berm erosion due to the long period waves, and to have a conception for developing a predictive model of abrupt beach erosion in a storm (Katoh et al., 1988).

2. Field observation

The site of field observation is a entirely natural sandy beach, being exposed to the full wave energy of the Pacific Ocean, and is classified as micro-tidal beach with the tide range of about 1.4 meters (see Figure 2). On this beach, Port and Harbour Research Institute has constructed the Hazaki Oceanographical Research Facility (HORF) in 1986 for carrying out the field observation in the surf zone even under sever sea conditions. The research pier is a 427 meters long concrete structures. It is supported by 0.8 meter diameter piles in a single line, at 15 meters interval. The pier deck is 2.5 meters wide and 7 meters above L.W.L. In this facility, the field observation on the relation between the berm erosion and the long period waves had been carried out for more than one year from the 1st of September, 1987 to the 22nd of November, 1988.

Photo. 1 is the side view of the facility, which was taken in a calm wave condition. There is a laboratory at the base of research pier, where two researchers are permanently stationed to measure and observe the many phenomena in the surf zone.

Photo. 2 was taken in a storm condition. Although the facility was isolated in the sea, the two researchers had not any troubles. As a matter of fact, one of them came out from the laboratory to take this picture and went back not by swimming, not by a boat, but on foot with keeping his shoes dry.

Photo. 2 was taken when the crest of the long period waves run up on the beach. After one minute, however, the trough of the long period waves came to the beach and the sandy beach emerged, on which he could go back on foot. Of course, after another one minute the beach was covered with crest again. Then, he had to go bach with quick steps.

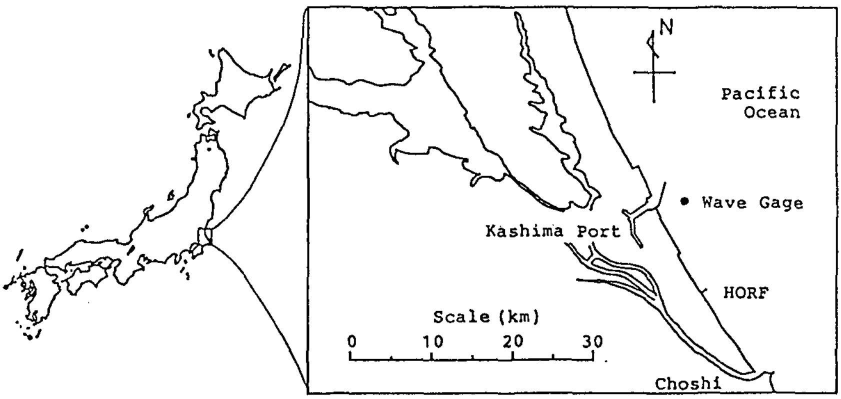

Figure 2 Site of field observation

Photo. 1 Side view of HORF (in a calm condition)

Under this situation, there was a large wave set-up near the shoreline, which has been discussed by Yanagishima and Katoh (1990).

The field observations conducted in conjunction with this study are as follows;

Survey of beach profile

Beach profile along the research pier was surveyed with

Photo. 2 Isolated HORF (in a storm)

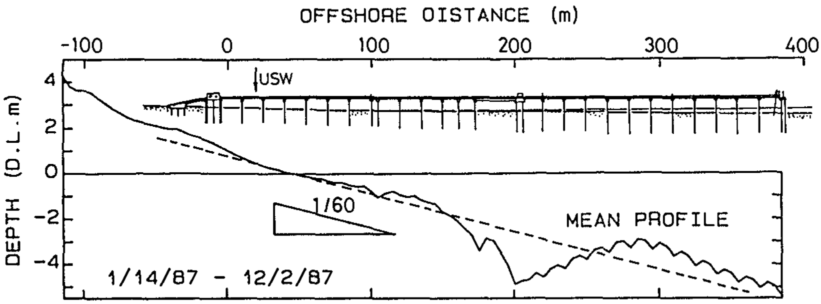

Figure 3 Mean profile and location of observation

a lead from the pier deck. The profile of the backshore and the foreshore was surveyed by using a surveyor's staff and a transit. The cross-shore interval of these measurements was 5 meters. The measurements have been being done, once a day except on Sunday and the national holiday, by the researchers in the HORF. The mean profile during about one year is calculated with these data, and is shown in Figure 3. The foreshore slope is mild, about 1/50 in average, while the mean bottom slope in the surf zone is a little milder, 1/60.

Wave observation near the shoreline

In order to measure the waves near the shoreline, an ultrasonic wave gauge was installed to the pier deck at the reference point of +22m as shown in Figure 3 and 4. The mean grand level at the observation point was 0.3 meter above the datum line. The mean water depth was about 0.4 meter in M.W.L.

The wave measurements were carried out during 20 minutes of every two hours with the sampling time of 0.3 second, which was automatically controlled by using a mini-

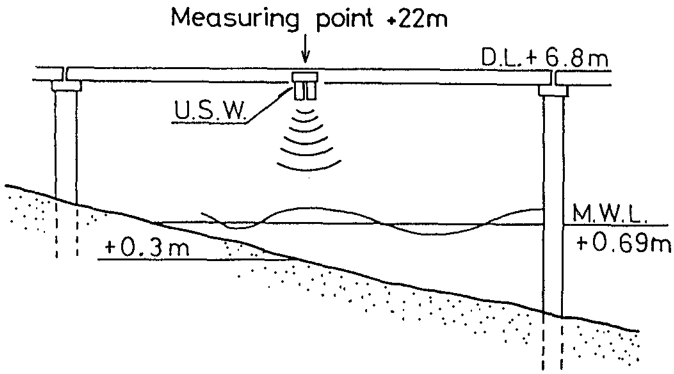

Figure 4 Location of ultrasonic wave gauge

computer in the laboratory at the base of research pier.

By utilizing the wave profile data of 0.3 second interval, the wave heights of incident wind waves and those of long period waves were calculated by the following equations based on the result of spectra analysis;

$$H_S = a \cdot [\int_{f_c}^{\infty} S(f)\,df]^{1/2}, \tag{1}$$

$$H_L = a \cdot [\int_{0}^{f_c} S(f)\,df]^{1/2}, \tag{2}$$

where H_s and H_L are the wave heights of the incident wind waves and the long period waves respectively, f is the frequency, S(f) is the spectral energy density, f_c is the threshold frequency of 0.33Hz, and a is the constant coefficient of 4.0.

For trial, to measure the velocity at the same point as that of wave observation, the two-component type electro-magnetic current meter was set on the sea bottom. It was, however, impossible to obtain the continuous data for a long time because the current meter was buried under the sea bottom due to the sand accumulation in some time or it caught floatage in another time.

Wave observation in the offshore

The offshore waves have been being measured at the mean water depth of 23.4 meters near the Kashima Port (see Figure 1) during also 20 minutes of every two hours.

3. Evidences of berm erosion

Based on the daily beach profile data for more than one year, the evidences of berm erosion have been abstracted. Those are 28 cases in total. To present the concrete participation of the long period waves in the berm erosion, two typical examples, in which there are large time lags between the occurrence of the maximum peak of wind waves and that of long period waves, will be shown.

Berm erosion due to the typhoon No.8713

The upper in Figure 5 shows the changes of the offshore significant waves during the days when the typhoon No.8713 came to near the observation site in September 1987. The significant wave height in the offshore began to be larger on the 11st of September and was larger than 3 meters on the 14th. It decreased a little in the following two days. During these days, the swell had been arriving with the significant period of 12 to 13 seconds. After that, the waves abruptly increased, being the maximum peak of 5.98 meters in the significant wave height at 16 o'clock on the 17th of September, and gradually decreased from this day on. During the latter period, the wind waves with the

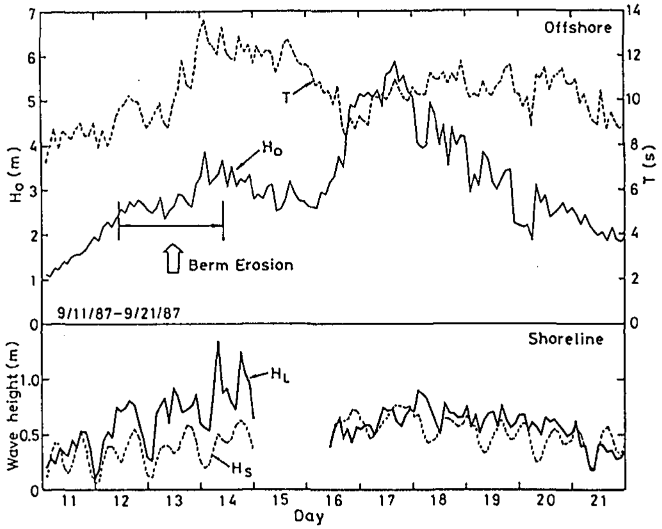

Figure 5 Waves in typhoon No.8713

period of 10 seconds were predominant.

Figure 6 shows the foreshore profiles during the corresponding days. The berm had been formed on the 12th of September, which level was higher than High Water Level. The foreshore profile was not surveyed on 13rd September because it was Sunday unfortunately. We cannot see the berm on the beach profile measured on the 14th of September. This change means that the berm had eroded within two day from the 12th to the 14th of September,

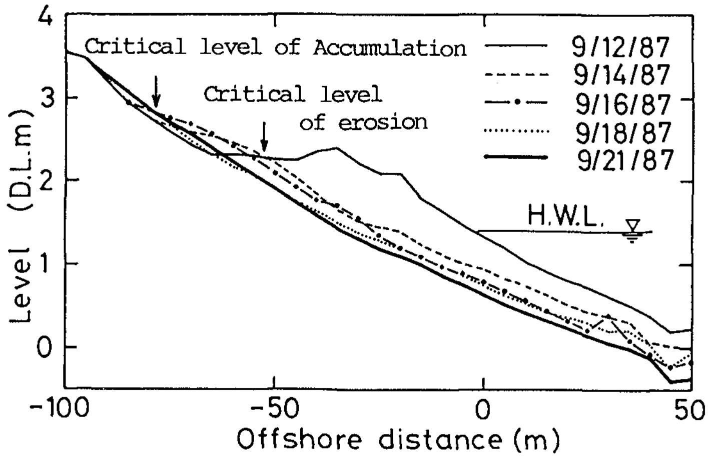

Figure 6 Berm erosion in typhoon No.8713

which is denoted with a blank arrow in Figure 5. It is noticed that the abrupt berm erosion occurred when the swell was coming, being about 4 days before the maximum peak of the offshore waves. When the offshore wave height was maximum, the foreshore also eroded. Its degree, however, was very small as shown in Figure 5. Then, it is rather difficult to obtain the offshore incident waves as the cause of this berm erosion.

The heights of incident waves and the long period waves near the shoreline are shown in the lower in Figure 5. The height of incident waves, H_s, changed periodically, independent on the offshore waves, because the wave height was limited by the shallow water depth which changed with the tide. The detail inspection of Figure 5 reveals that the incident wave height gradually increased with periodical fluctuations during days from the 11st to the 17th of September and also gradually decreased to the end of typhoon. It was due to the sea level rising, including the wave set-up, near the shoreline (Yanagishima and Katoh, 1990). Anyhow, the incident wave heights during the berm erosion were less than 0.5 meter near the shoreline, which was nearly the same values as the incident wave height before the berm erosion, on the 11st of September. Therefore, we cannot decide the incident waves near the shoreline as the cause of berm erosion.

On the other hand, the heights of long period waves, H_L, were nearly 1.0 meter on the 13rd or more on the 14th of September, and were about 0.6 to 0.7 meter when the offshore wave height was maximum on the 17th of September. That is to say, the berm erosion occurred during the days when the heights of long period wave were the largest.

One more notice must be given in Figure 6. There was a interesting paradox that the sand deposited on the greater elevation when the berm eroded, as Bascom (1954) had already pointed out.

Berm erosion due to the typhoon No.8818

The upper in Figure 7 shows the changes of the offshore significant waves during the days when the typhoon No.8818 came to the site in September, 1988. The offshore wave became to be higher since the 14th of September, and had a maximum height on the 16th of September. After that, it decreased with time. The wave period abruptly became to be longer from 6 seconds on the 13rd to 11.9 seconds on the 14th of September. From the 15th on, it fluctuated around 10 seconds.

Figure 8 shows the foreshore profiles during the corresponding days. The berm had been formed on the 13th of September in 1988. Until next day, the 14th of September, this berm had eroded. Since the measurements of beach profile had been carried out just before noon, it can be decided that the initiation of berm erosion occurred before noon on the 14th of September. Also in this case,

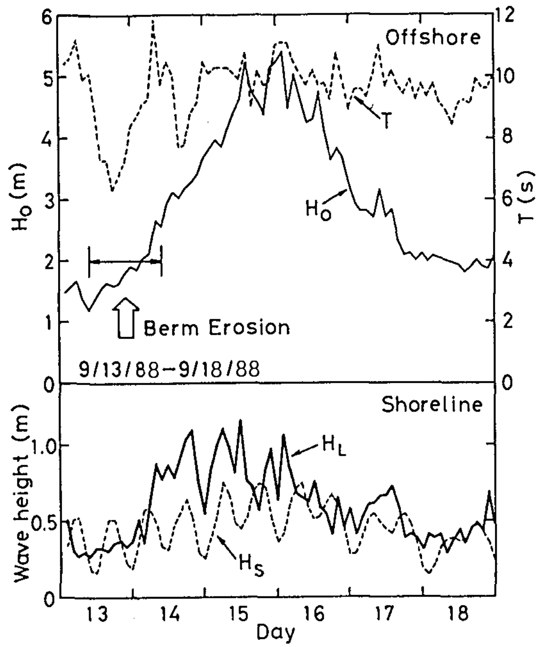

Figure 7 Waves in typhoon No.8818

there was the sand deposition on the greater elevation than the berm crest level. Unfortunately, because it is the national holiday on the 15th of September in Japan, we did not measure the beach profile on that day.

The berm erosion occurred about 3 days ahead of the

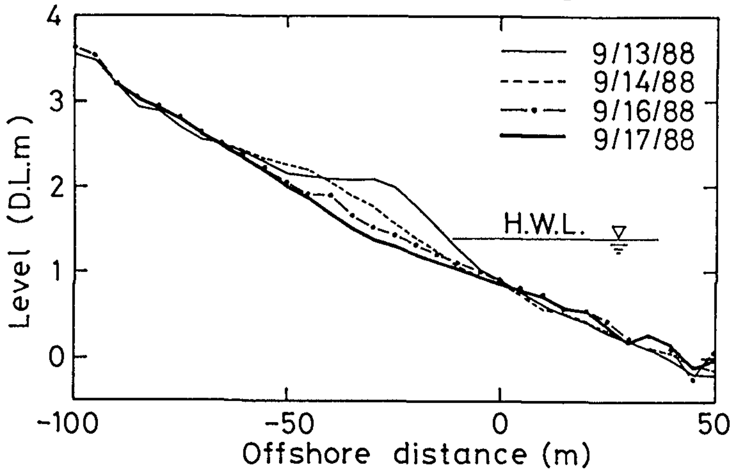

Figure 8 Berm erosion in typhoon No.8818

occurrence of the maximum incident wave height as shown in Figure 7. During the berm erosion, the offshore wave height was less than 2.0 meters. In short, also in this example, it is very hard to explain the berm erosion by taking the offshore incident wave energy into account.

In the lower in Figure 8, the height of incident waves and long period waves near the shoreline are shown. The height of incident waves was less than 0.5 meter during the berm erosion. The height of long period wave became to be larger up to 1 meter in the early morning on the 14th, and was maximum on the 15th of September. Therefore, it can be said that the height of long period waves near the shoreline was large when the berm eroded.

Based on these two examples of berm erosion, we have following tentative conclusions.

(a) When the berm eroded, the height of offshore wave was small. It was 2 to 4 days before the occurrence of the maximum height of offshore waves. This conclusion can be obtained owing to the time lag between the changes of the incident wave height and the long period waves. In the remaining 26 cases, both the offshore wave height and the height of long period waves near the shoreline were maxima on the same day when the berm eroded.

(b) When the berm eroded, the height of incident waves near the shoreline were usually less than those of the long period waves. This consideration is supported by all 28 evidences of berm erosion.

(c) When the berm eroded, the sand accumulated on the greater elevation at the same time. This kind of sand accumulation existed in 23 cases out of 28 evidences of berm erosion.

4. Critical level of berm erosion

It is shown that the waves which have the direct effects on the berm erosion is the long period waves near the shoreline. Then, let's examine the critical level of erosion in the storm, which is shown in Figure 6, in conjunction with the long period waves.

The total wave run-up level on beach will be assumed as

$$R = (\bar{\eta})_0 + R_L + R_S, \tag{3}$$

where R is the total run-up level, $(\bar{\eta})_0$ is the mean sea level, R_L and R_S is the wave run-up due to the long period waves and the incident waves, respectively. These physical values are defined at the shoreline. Since the total wave run-up level is considered to be closely related to the critical level of accumulation, which is also shown in Figure 6, it can be decided in the following manner.

Estimation of mean sea level, $(\bar{\eta})_0$

The mean sea level at the observation point can be calculated by averaging the wave profile data. However, as the observation point was located a little bit offshore side from the shoreline, the calculated mean sea level must be modified to the value at the shoreline. According to the Goda's theory, the rate of wave set-up on this beach increases at the rate of 9% of the decrement in the water depth (Katoh et al., 1989). Then, the mean sea level at the shoreline can be estimated by the following equation:

$$(\bar{\eta})_0 = \bar{\eta}_0 + 0.09h, \tag{4}$$

where $\bar{\eta}_0$ and h are the mean sea level and the actual water depth at the observation point, respevtively.

Estimation of run-up due to the long period waves, R_L

The run-up due to the long period wave is considered to be proportional to its wave height at the shoreline as a first approximation, since it is a standing mode. That is to say,

$$R_L = a\ (H_L)o, \tag{5}$$

where a is a coefficient and $(H_L)o$ is the height of long period waves at the shoreline.

In order to have the height of long period waves at the shoreline, we must modify the value of H_L at the observation point. For this purpose, the Goda's(1975) empirical relation between the offshore significant waves and the height of long period waves at any water depth will be introduced.

Based on the wave data measured both in the surf zone and offshore, Goda (1975) obtained the following relation:

$$\frac{\zeta_{rms}}{(\eta_{rms})_0} = \frac{A}{\left[\dfrac{H_0}{L_0}\cdot\left(1+\dfrac{h}{H_0}\right)\right]^{1/2}}, \tag{6}$$

where ζ_{rms} and $(\eta_{rms})_0$ are the root-mean-square values of the wave profiles of long period waves and offshore waves, respectively, h is the water depth, Lo is the significant wave length in deep water, and A is a coefficient which takes a value of 0.04 in the Goda's relation.

By replacing the left term of Eq.(6) with the following relation

$$\frac{\zeta_{rms}}{(\eta_{rms})_0} = \frac{H_L}{H_0}, \tag{7}$$

the values of Goda's parameter have been calculated and plotted in Figure 9. As seen in Figure 9, almost all data are plotted below the straight line given by Goda. If the Goda's line will be moved parallel downward by employing the value of 0.023 for A, the relatively good approximation to the data will be obtained.

By taking the Goda's parameter into account, we have the transformation equation as

$$(H_L)o = H_L{*}(\ 1+h/Ho\ )^{1/2}, \qquad (8)$$

being independent of the value of A, where Ho is the offshore significant wave height.

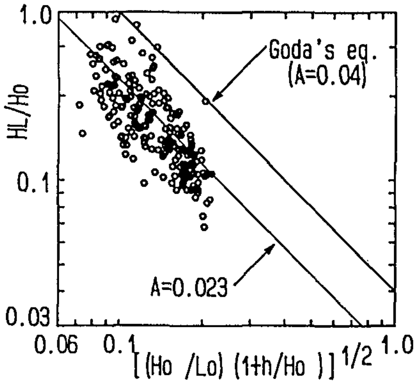

Figure 9 Value of Goda's parameter

Estimation of run-up due to the incident waves, R_s

According to the result of field observation conducted by Guza and Thornton (1982), the swash excursions of the long period components increase with the offshore incident wave height, while those of the incident waves is constant, being independent of the offshore wave conditions. Therefore, we can assume the constant value for R_s,

$$R_s = \text{const.} \qquad (9)$$

By substituting Eq.(5) and (9) into Eq.(3), we have

$$R = (\bar{\eta})_0 + a(H_L)o + \text{const.} \qquad (10)$$

In order to assume that the total run-up level is corresponding to the critical level of accumulation, we must give full consideration to the choice of data. The beach profile had been surveyed once a day, while the mean sea level and the height of long period waves had been observed every two hours. Then, after some consideration, it is decided to choose the data set of the mean sea level and the height of long period waves which summation is maximum among 12 sets of data in 24 hours between the successive surveys of profile. Then, in stead of Eq.(10), we can have

$$A_1 - (\bar{\eta})_0 = a(H_L)o + \text{const.}, \qquad (11)$$

where A_1 is the critical level of accumulation, which value can be obtained by utilizing the beach profile data.

Twenty three sets of data which are estimated with the measured values in the manner described above are plotted in Figure 10. Of course, they are the cases that the sand accumulation have been recognized during the berm erosion. Since the data are plotted close to a solid line which is decided by applying the least squares method to the data, we have

$$R = (\bar{\eta})_0 + 0.96(H_L)o + 0.31.(m), \quad (12)$$

Please pay attention to the replacement that R has been used in place of A_1 in Eq.(12). Equation (12) means that the total run-up level is the sum of mean sea level which contains the tide level and the sea level rising such as the wave set-up, the height of long period waves near the shoreline, and the constant which is the effect of incident wave run-up.

Figure 11 shows a comparison of the total run-up level with the critical levels of accumulation and erosion. On the abscissa in Figure 11, a symbol R_{max} is used since the largest total run-up level in a day during

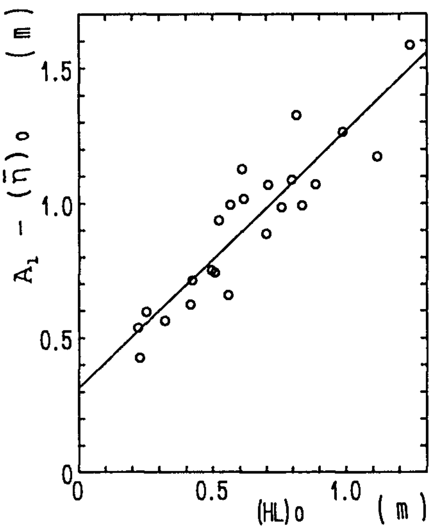

Figure 10 Comparison of wave run-up with the height of long period waves

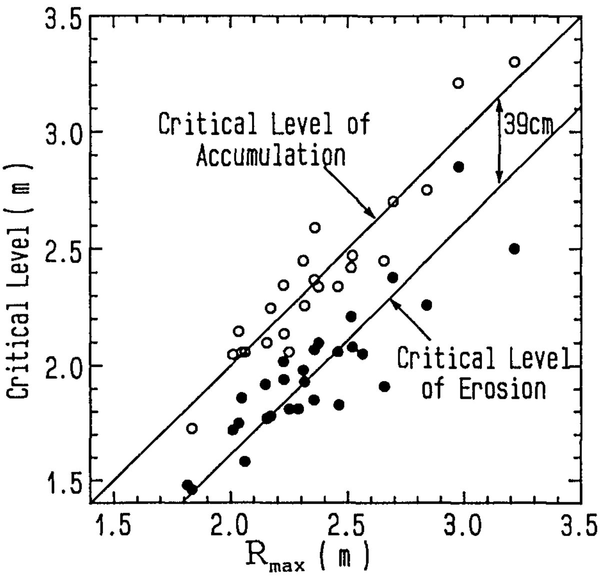

Figure 11 Comparison of critical run-up level of accumulation and erosion with maximum run-up revel

the berm erosion has been chosen. The critical levels of accumulation agree well with R_{max}, while those of erosion are about 40 cm lower than R_{max}.

5. Conclusions

The conclusions obtained in this study are as follows:
(1) When the berm eroded, the height of long period waves near the shoreline was large.
(2) The paradox that the sand accumulates in the greater level when the berm erodes, which have been already pointed out by Bascom (1954), is confirmed with many evidences of field data.
(3) The critical levels of accumulation and the erosion depend not on the incident waves, but on the height of long period wave and the mean sea level at the shoreline.

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