CHAPTER 164

Berm Formation and Berm Erosion

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Abstract

To investigate the mechanism of beach erosion in a storm, a daily survey of beach profile and the measurement of infragravity waves near the shoreline have been carried out in a field during two and half years. Analyses of these data reveal that the infragravity waves and the level rising of water table play a important role in the berm erosion in a storm. The infragravity waves run up beyond the berm crest to the backshore. The swashed water permeates into the beach, which contributes to a high water table. The permeated water rises to the surface of foreshore, where the beach is eroded by the backwash of infragravity waves.

1. Introduction

In a storm, a beach erodes rapidly within one or two days due to the sand transport from the beach to the offshore. Formerly, wind waves had been considered to be a main external forces of beach erosion in a storm. The wind waves, however, lose their energy when they propagate into the surf zone. 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 same. Therefore it is basically difficult to attribute the abrupt beach erosion in a storm to the offshore wind waves.

In contrast to the wind waves, the infragravity waves of about 30 seconds to several minutes in a period well develop in a storm (Guza and Thornton,1982), and do not break in the surf zone, being the largest at the shoreline

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(eg., Bowen and Huntley, 1984; Holman,1984). Based on the field data, Katoh and Yanagishima (1990) showed that the berm, or the beach, abruptly erodes in a storm due to not the wind waves but the infragravity waves. Then, in the consideration of the mechanism of beach profile change, it should be very important to take into account the infragravity waves as the external force.

In this study, paying attention to the changes of berm on the shore and the infragravity waves near the shoreline, a field observation has been carried out every day during two and half years. Evidences of berm erosion and berm formation have been abstracted from the data obtained, being 58 cases and 219 cases respectively. By analyzing these data, the differences of physical condition between the berm formation and berm erosion will be examined, by which the mechanism of berm erosion will be discussed.

2. Field Observation at Hazaki Oceanographical Research Facility (HORF)

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 1). On this beach, Port and Harbour Research Institute, Ministry of Transport, constructed the Hazaki Oceanographical Research Facility (HORF, see Photo.1) in 1986 for carrying out the field observation in the surf zone even under sever sea conditions. The research pier is 427 meters long and supported by concrete-filled steel piles in a single line, at 15 meters interval.

The mean profile during about one year is shown in Figure 2. 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. The mean diameter of sediments on the

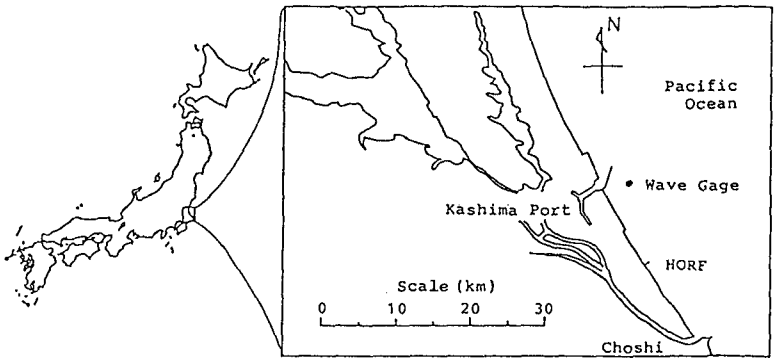

Figure 1 Site of field observation.

Photo. 1 Hazaki Oceanographical Research Facility.

beach is usually 0.18 mm, which changes occasionally in the narrow range between 0.16 mm and 0.20 mm due to the accumulation and the erosion.

On this beach, the field observations on the berm erosion/formation and the infragravity waves had been carried out for about two and half years from August 1987 to January 1990. The observations conducted in conjunction with this study are as follows;

(a) survey of the beach profile,
(b) observation of the infragravity waves near the shoreline,
(c) wave observation in the offshore,
(d) observation of the water table under the beach.

The observation methods related to the items from (a) to (c) and the primary analyses of them have been described by Katoh and Yanagishima (1990). To measure the water table, two pipes of 12.5 centimeters in diameter were sunk into

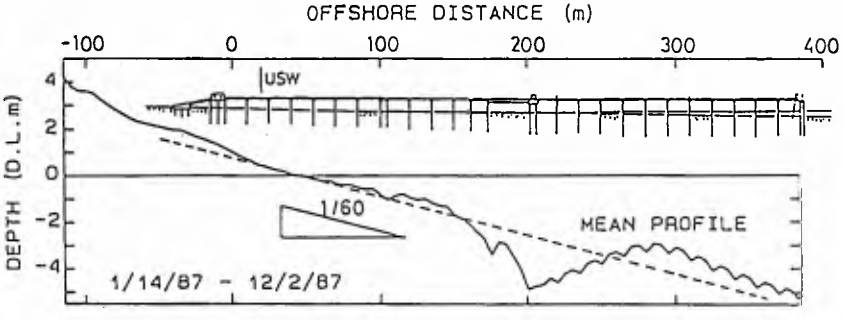

Figure 2 Mean profile of study site.

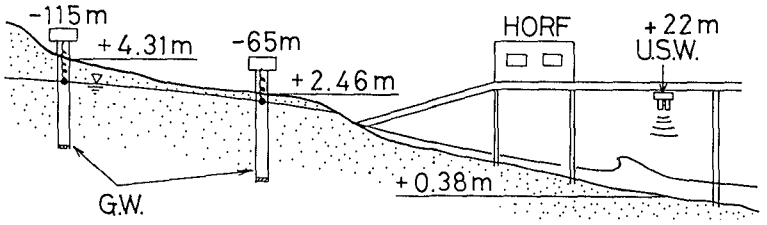

Figure 3 Arrangement of instruments.

the beach at the horizontal reference point of -65m and -115m as shown in Figure 3, and water level meters were installed inside the pipes. The measurement were done during 20 minutes of every hour for about two years from February 1988 to January 1990 including a interruption of about 6 months due to sensor troubles.

3. Level of sand accumulation in the storm

Based on the beach profile data, the evidences of berm erosion have been abstracted. Those are 58 cases in total. Table 1 is the largest ten values of offshore significant wave height in the berm erosions. Two typical examples in the storms have already been reported and discussed by Katoh and Yanagishima (1990) with the data of wind waves and infragravity waves.

Table 1 Large waves in the berm erosions.

Date	$H_{1/3}$ (m)	$T_{1/3}$ (s)
22 Mar.'88	6.51	10.2
17 Sep.'87	5.98	10.9
16 Sep.'88	5.41	11.1
23 May '88	5.00	9.8
23 Jan.'89	4.78	8.7
2 Nov.'89	4.48	12.2
29 Nov.'88	4.29	9.6
12 Oct.'89	4.28	11.2
8 May '88	4.24	8.2
19 Nov.'88	4.02	9.7

Figure 4 shows one of them during the days when the typhoon No.8713 passed near the observation site. The berm had been formed by the 12th of September, but it had eroded within the short term of two days from the 12th to the 14th

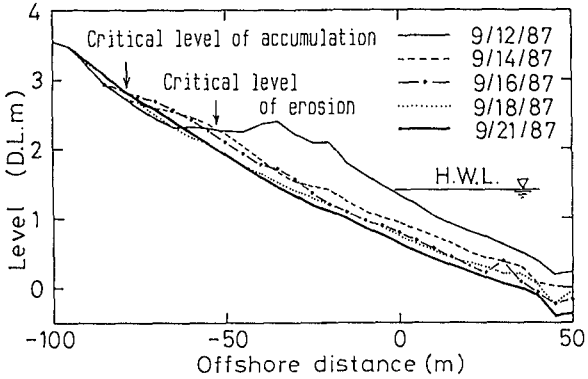

Figure 4 Berm erosion during typhoon No.8713.

of September. One more notice must be given in Figure 4. There was a interesting paradox that the sand deposited on the higher elevation when the berm eroded, as Bascom(1954) had already pointed out. This kind of sand accumulation existed in 48 cases out of 58 evidences of berm erosion.

Katoh and Yanagishima (1990) presented that the critical level of sand accumulation can be predicted by the following equation, which had been empirically obtained with the limited field data,

$$D_L = (\overline{\eta})_0 + 0.96(H_L)_0 + 0.31 \quad (m). \qquad (1)$$

where D_L is the critical level of sand accumulation in a storm, $(\overline{\eta})_0$ is the mean sea level at the shoreline, $(H_L)_0$ is the height of infragravity waves at the shoreline. The third constant term is considered to represent the run-up effect of incident wind waves, because it is independent of the condition of offshore wind waves (Guza and Thornton, 1982).

In Figure 5, the relation between measured values of D_L and values estimated by Eq.(1) with the data of the mean water level and the height of infragravity waves are plotted for 48 cases of the berm erosion. Since the data are plotted close to the solid line, the validity of Eq.(1) is reconfirmed here.

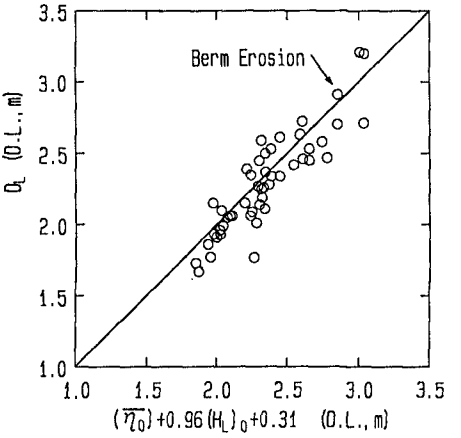

Figure 5 Reconfirmation of Eq.(1).

4. Evidences of the Berm Formation and level of berm crest

Based on the beach profile data, the evidences of successive berm formation for more than several days have been abstracted. Those are 219 cases. Figure 6 shows the typical example of berm formation during the period from the 5th to 15th of August, 1987. The height of offshore wind waves was usually about 1.0 meter with the exception of the short period from the 6th to the 7th when it was 1.8 meters in maximum. The height of infragravity waves at the shoreline was usually smaller than 0.3 meter.

The process of berm formation is characterized as follows;

(a) The berm was formed with the horizontal berm crest.
(b) The foreshore slope became gradually steeper.

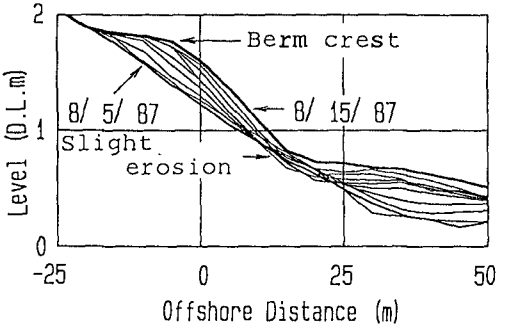

Figure 6 Example of berm formation.

(c) The berm formation was accompanied with a slight erosion at the base of berm.

The features (a) and (b) are recognized in almost all remaining cases. The slight erosions at the base of berm are recognized in 109 cases out of 219 cases. Including the other case that the profile of the base of berm was almost the same as that in the day before, 153 cases are counted in total.

In Figure 7, the relation of the berm crest level, A_L, which is the upper limit level of sand accumulation in the berm formation, and the value estimated by Eq.(1) is plotted with a symbol of triangle. In this figure, the

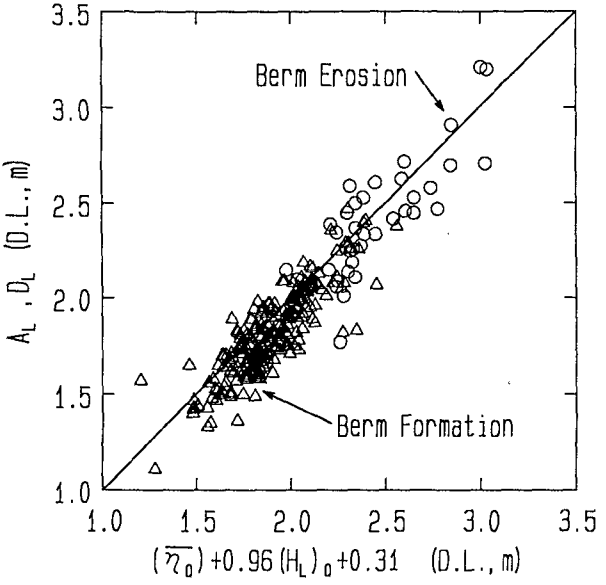

Figure 7 Relation between the berm creat level and the value estimated by Eq.(1).

critical levels of sand accumulation, D_L, are also plotted with a symbol of circle. As almost all of the data agree well with the straight line, the berm crest level in the process of berm formation can be expressed by the same equation as Eq.(1), that is,

$$A_L = (\overline{\eta})_0 + 0.96(H_L)_0 + 0.31 \quad (m). \qquad (2)$$

Although the berm erosion and the formation are the phenomena which are contrary to each other, it has been shown that the critical level of sand accumulation in the berm erosion and the berm crest level in the berm formation can be expressed by the single equation.

5. Difference of Conditions between the Berm Erosion and the Berm Formation

Now, the consideration on the correspondence between two kind levels of sand accumulation, D_L and A_L, and the wave run-up level, R_{MAX}, makes us assume

$$R_{MAX} = (\overline{\eta})_0 + 0.96(H_L)_0 + 0.31, \qquad (3)$$

with the proviso that this assumption changes the physical meaning of R_{MAX} from what is called the run-up level of waves to the upper limit level where the waves may make the significant profile change.

The total value of the second term in the right side of Eq.(3) have been calculated for each event of berm erosion and berm formation, respectively. The total value of the third term which is considered to correspond to the run-up height of incident wind waves have been also calculated for each event. Figure 8 shows the rates of resultant values, by normalizing with the total value of the third term in each event. It may be said that the berm eroded when the run-up height of infragravity waves was relatively large, and the berm was formed when the run-up height of incident wind waves was relatively large.

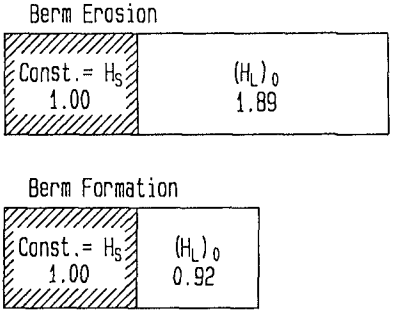

Figure 8 Comparison of run-up heights between the incident wind waves and the infragravity waves in each event.

Next, Figure 9 shows the relation between the wave run-up level, R_{MAX}, and the berm crest level in the previous day, which is denoted by $(A_L)_{FORMER}$. A linear quadratic discriminant analysis has been done to

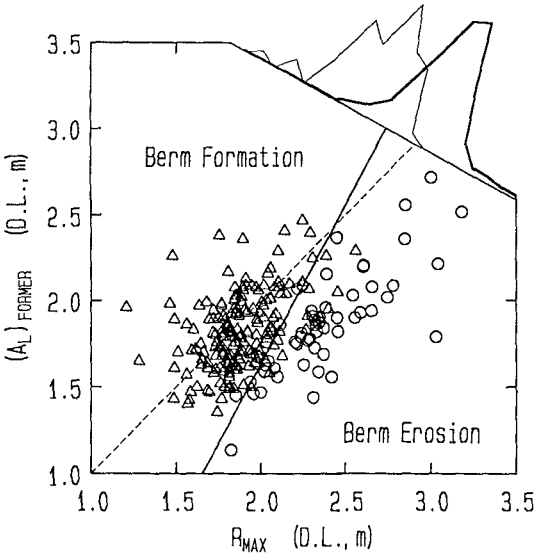

Figure 9 Relation between $(A_L)_{FORMER}$ and R_{MAX}.

classify these data into two groups. The boundary between two groups is drawn with a straight solid line in Figure 9. The occurrence distribution of data in each group is shown in the upper right corner of Figure 9. From this result, we have

$$R_{MAX} > 0.54(A_L)_{FORMER} + 1.11 \quad (m), \qquad (4)$$

as the condition for the berm erosion. In short, the occurrence that the waves run up beyond the existing berm crest to the higher level is a prerequisite for the berm erosion.

Moreover, in Figure 10, the critical level of berm erosion (see Figure 4) and the level of slight erosion in the berm formation (see Figure 6) are plotted against the wave run-up levels, R_{MAX}. The critical level of berm erosion is 0.39 meter lower than R_{MAX}, while the level of slight erosion is about 0.9 meter lower than R_{MAX} with some scattering of data. In short, the critical level of berm erosion is relatively higher than the level of slight erosion.

After all, three conditions are known for the berm erosion. When the berm eroded, (a) the height of infragravity waves at the shoreline was large, (b) the waves run up beyond the berm crest to the higher level, and (c) the critical level of erosion was relatively high.

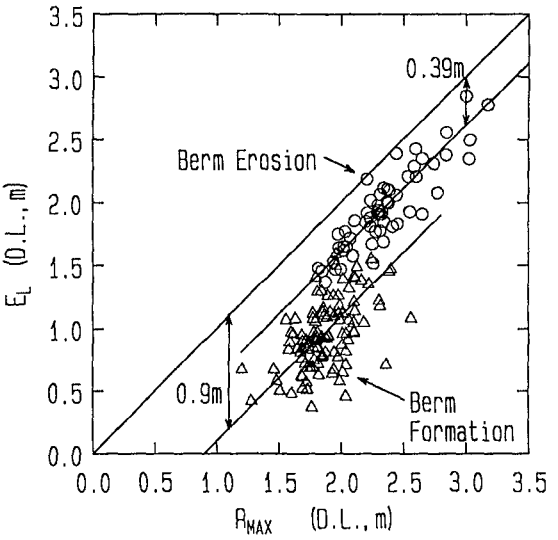

Figure 10 Relation between the erosion level and the wave run-up level.

6. Relation between the Critical Level of Berm Erosion and the Level of Ground Water Table

It have been said for a long time that the position of the water table under the beach has an important bearing on deposition and erosion of the foreshore and backshore. For example, Grant (1948) explained the importance of the wetness or dryness of beach in the changes of beach profile. When the water table under the beach is very high and contiguous with the surface of most of the foreshore, the backwash of the waves is accelerated by addition of water rising to the surface throughout the saturated foreshore. This saturated area is called the effluent zone. The increased volume of backwash by ground water escaping to the surface of the foreshore also dilates the sand and propels the finer grains into the turbulent flow. These enhance the erosion of the foreshore.

The causes of high water table, which have been pointed out up to these days, are;

(a) The water due to the heavy rain storm in the hinterland flows to the backshore (Grant,1948),
(b) As the water table under the beach lags 1 to 3 hours behind the tide, the water table is relatively higher than the tide during the ebb tide (Emery and Foster, 1948; Duncan, 1964),
(c) Hot springs flow out at some beach in Japan (Sato et al., 1982).

All of these, however, are not the causes which take part

Photo. 2 Maximum wave run-down (taken from the rooftop of HORF).

in the berm erosion in a storm. Now, we can add one more cause of high water table which is directly related to the beach erosion in the storm; that is to say, there is a possibility that the water run-up beyond the berm crest penetrates into the beach, which makes the water table high.

In the field observation, it was recognized that the large scale wave run-up beyond the berm crest occurred with a period of 1 to 2 minutes in the storm. Photo. 2 was taken from the rooftop of the laboratory in HORF under the situation of maximum wave run-down. In this picture, the existing berm crest of running in the longshore direction is inspected to be exposed to the air. In the left side, or the land side, the beach was covered with the water which stayed on the backshore for a good while. On the backshore, the authors recognized that air bubbles came out from the ground through the surface of beach, which was due to the replacement with the water penetrated into the ground. As a result, it is not difficult to infer the situation that the level of water table under the beach became higher, and the penetrated water flowed out through the surface of foreshore.

Then, the seepage level, which is the upper limit of the effluent zone, has been determined by the numerical simulation of the finite element method which was developed by Bathe and Khoshgoftaar (1979) for analysis of steady unconfined seepage conditions in two-dimensional case.

The area of simulation is from the reference point of -

115m (see Figure 3) to the offshore in the cross-shore direction, and from the beach surface to the level of -20 meters in the downward direction. The beach profile is approximated by a straight line. In calculation, distorted rectangular elements are made by dividing the area of simulation with the interval of 0.5 meter in the vertical direction, and with the interval of 5 meters, being nearly parallel to the beach slope, in the cross-shore direction. The level of water table measured at the reference point of -115m, which has been confirmed to be usually stable independent of the tide or wave run-up on the beach, is used as the boundary condition at the land side. For the boundary condition at the shoreline, the sum of the mean sea level at the shoreline and the run-up height of incident wind waves, that is $(\overline{\eta})_0 + 0.31$ (m), is utilized. A reason why the run-up of incident waves is taken into consideration is owing to the fact that the incident waves run up repeatedly with the short period of about 8 seconds, which keeps the beach wet. A coefficient of permeability in the beach is employed as 1.14×10^{-2} cm/s, based on the result of permeability test conducted by Zen et al.(1989) with the sand sampled from the study site.

At first, in order to verify the applicability of simulation model, the water tables have been calculated for the calm wave conditions of 74 cases, in which the significant wave heights and the periods in the offshore were less than 1 meter and 8 seconds, respectively. Figure 11 shows the comparison of the observed levels of water

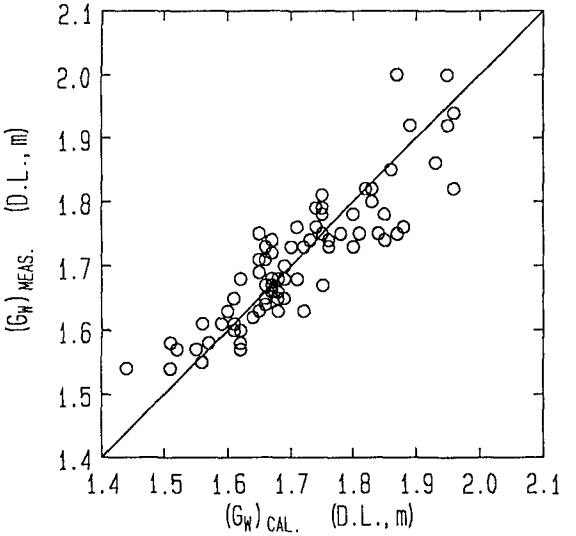

Figure 11 Comparison of observed level of water table with the calculated one.

table, $(G_w)_{MEAS}$, at the reference point of -65m with the calculated ones, $(G_w)_{CAL}$, at the corresponding point. The calculated water tables agree approximately with the observed ones.

Next, the free surfaces of water table have been calculated for the berm erosions in the storms. The calculated levels of water table at the reference point of -65m, however, were lower than measured ones. The difference between them increases with the run-up height of infragravity waves. Therefore, in the calculation of water table in the storm, it is necessary to take into account one more condition that the water on the horizontal portion of the berm penetrates into the beach.

In order to simulate the penetration of water into the beach, the steady discharge of penetration through the beach face has been assumed. The distribution of discharge along the beach surface is set as a triangle, being zero at the wave run-up level, R_{MAX}. The value of discharge has been determined by trial and error so as to coincide the calculated water table at the reference point of -65m with the measured one in the field. The resultant value of discharge is in a range of 0.2 to 0.5 m^3/h per unit longshore length, which has a tendency to increase with the height of infragravity waves.

In this convenient manner, the water table under the

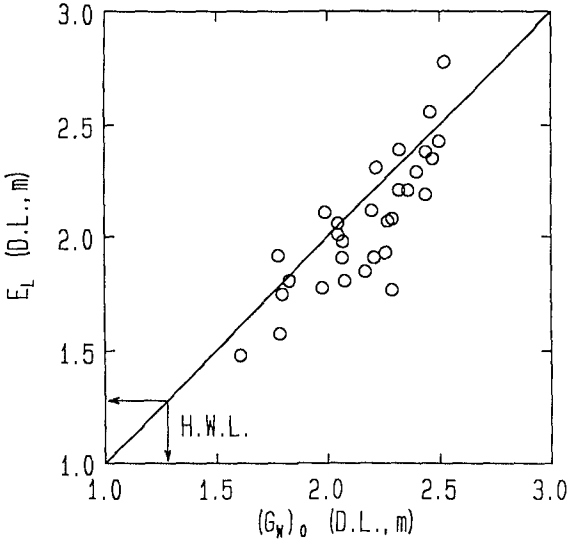

Figure 12 Relation between the critical level of berm erosion and the seepage level of ground water.

beach is calculated for each case of the berm erosion. After that, the seepage level is determined at the intersection of the water table and the foreshore profile, which is denoted by $(G_w)_0$. In Figure 12, the seepage levels are plotted against the critical levels of berm erosion in the storms. The plotted data agree approximately with the straight line; that is to say, the critical level of berm erosion corresponds roughly to the seepage level of water.

Based on this result, we can make another consideration. In the process of berm formation, the run-up level is low and the water goes down immediately along the foreshore slope without staying, which is enhanced by the increase of foreshore slope. As a result, the level of slight erosion in the berm formation is relatively lower in comparison with the run-up level (see Figure 10).

7. Conclusions

The main conclusions reached in this study are as follows;

(1) Both the critical level of sand accumulation in the berm erosion and the berm crest level in the berm formation can be expressed by Eq.(3), which contains the effect of run-up of infragravity waves on the beach.

(2) As the infragravity waves run up beyond the berm crest in the storm, the sea water stays for a good while on the horizontal area of the berm, which accelerates the saturation of water into the beach. As a result, the water table becomes higher, and the water flow out through the surface of foreshore. The seepage level of water corresponds to the critical level of berm erosion.

Acknowledgement

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