CHAPTER 36

BREAKING OF IRREGULAR WAVES ON A SLOPE*

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ABSTRACT

Breaking condition of irregular waves on a slope is studied through a series of labolatory experiment of bichromatic waves. First, breaking condition of individual waves defined by zero-down crossing method is compared with breaking condition of regular waves. An emperical formula is proposed to take into account of the influence of both the depth and width of the following trough. Then it is shown that the breaking condition of regular waves can be applied succesfully when the individual waves are properly defined by paying attention to the nature of the wave crests. Finally these results obtained from the laboratory experiment are tested against the field data with reasonable success.

1. INTRODUCTION

Several studies have been already reported on the breaking of irregular waves on slopes. Goda (1973), Battjes and Janssen (1978), and Thornton and Guza(1983) dealt with probabilistic (and somewhat heuristic) methods to be incorporated into the transformation model of wave height distribution in the nearshore zone. Sugawara and Yamamoto (1978), Mizuguchi and Matsuda (1980), and Mase et al.(1986) constructed an irregular wave transformation model, in which wave breaking condition of individual waves are assumed to be the same as that of monochromatic waves.

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There also have been presented some papers, which directly and experimantally investigated breaking conditions of individual waves in irregular wave trains either in laboratory or in the field (Iwagaki et al.;1977, Isobe et al.;1980, Hotta et al.;1984, Kimura and Seyama;1986, and Mizuguchi et al.;1987). One can summarize these papers as follows.

1) Local wave breaking condition of individual waves (normally defined by zero-down crossing method) shows considerably larger data scatter than that of monochromatic waves.

2) In average, individual waves in irregular wave trains tend to break more easily, that is, to break with smaller wave height compared with regular waves.

3) Adjacent waves, in particular, the depth of the following trough for the waves defined by zero-down crossing method, have some influence on its breaking.

In this paper, first, we look for a possible explanation for the cause of the data scatter as well as the tendency that irregular waves break more easily, taking into account of the influence of the neighbouring waves. In due course, we test the applicability of regular wave breaking criterion to irregular waves, and propose a way to relate the breaking criterions of irregular waves and regular waves. For that purpose, we conducted a series of labolatory experiment, using bichromatic waves, which essentially show a characteristic feature of the irregular waves that the neighbouring waves are not the same as is so for regular waves. An advantage to employ the bichromatic waves is that it is easy to measure the breaking waves by wave gauges, as they have limitted number of fixed breaking points. Finally, we apply our results obtained from the labolatory experiments to the field data and discuss the improvement accomplished and problems remained.

2. LABORATORY EXPERIMENT

Experiment was carried out in a wave flume of 30 cm wide, 20 m long and 45 cm in height with glass side walls. Beach of 1/20 slope with painted plate was installed in one end. Wave maker in the other end was of an absorbing type. Water depth was 35.5 cm in the constant depth area.

Wave generating signal e was chosen as follows.

$$e = a\cos(2\pi t) + qa\cos(\pi t+\epsilon) \quad (1)$$

Here a is the amplitude of the primary waves of period 1 s. Various combinations of bichromatic waves were produced in the wave breaking area by varying the phase difference

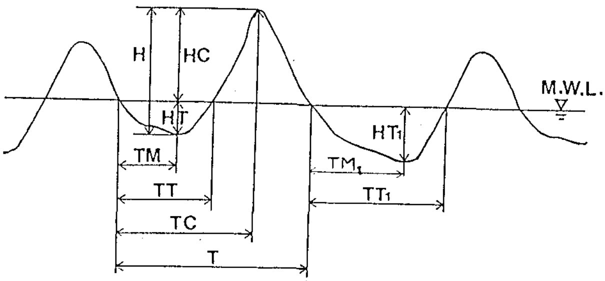


Fig. 1 Typical wave profile in time of two-wave train at one of breaking points.
Various quantities to possibly influence the breaking condition are evaluated.

ϵ and the wave amplitude ratio q. This signal generates two-component waves also in terms of the time series, since the secondary wave has the half frequency of the primary waves. Hereafter we call this wave train as two-wave train. The amplitude a of the primary wave was set to be around 3 or 6 cm in the uniform depth area. The amplitude ratio q was varied as 0.1, 0.2, 0.3, and 0.5. Typical surface profile at a breaking point is shown in Fig. 1. Total of 160 runs of two-wave train experiment were conducted. In addition, 36 runs of regular wave experiment, which can be considered to be of the cases q=0, were also carried out in order to check the validity as well as the values of the experimental constants of the following Goda's breaking criterion (Goda; 1973).

$$H/d = A(L_0/d)[1-exp\{-Bd(1+K\tan^s\beta)\}] + C \qquad (2)$$

where H, d, and L_0 denote wave height, water depth, and deep-water wave length respectively. $\tan\beta$ is the beach slope. A, B, K, s and C are experimental constants and the originally proposed values are 0.17, 1.5, 15, 4/3 and 0 in its order. However, Eq.(2) with the original values of constants gives slightly larger breaking wave height as shown in Fig.2, as was also pointed out by Sugawara and Yamamoto(1978). A=0.158, with original values for other constants, is used in this paper, since it gives the better fitted curve to our regular wave experiment.

In the experiment, first, video-camera was used to determine the breaking points. Then capacitance-type wave gauges were placed at those breaking points (normally two for two-wave trains) to measure the surface profiles. The breaking points were defined visually as the position where significant white foams were observed. If not obvious, then the point of maximum wave height was searched by moving the

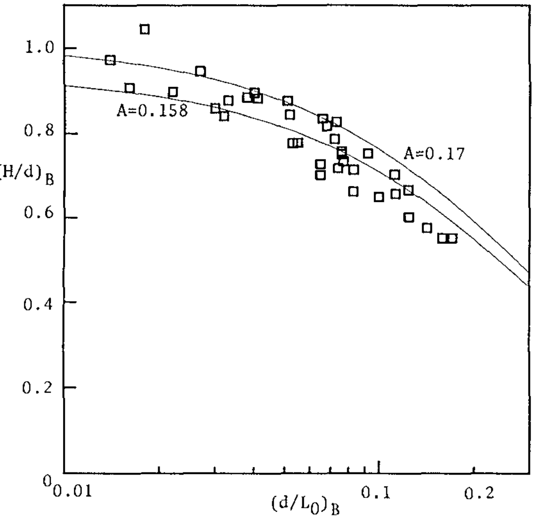


Fig. 2 Local breaking condition of regular waves on a uniform slope.
Solid lines denote the experimental formula by Goda(1973) with specified values of A.

wave gauges in the cross-shore direction. The data was recorded on a digital tape recorder with sampling frequency of 50 Hz for the cases of a ≅ 3 cm and 100 Hz for both cases of a ≅ 6 cm and of regular waves. Data processing as well as signal making were done on a personal computer (Sord M343 SXII).

3. ANALYSIS OF LABORATORY DATA

The obtained data show small fluctuation of period 30 s, which is roughly the period of the first harmonics of the wave flume. The quantities defined for individual waves were averaged over 30 cycles of the primary wave. Positions of wave breaking also fluctuated within the horizontal distance of about 5 cm. This value gives rough estimate for the experimental error.

Zero-down crossing method was employed to define the individual waves, since this method takes the rise from the trough to the crest as the wave height as shown in Fig.1. This height is more appropriate for investigating the wave breaking condition than the fall height from the crest to the trough taken by the zero-up crossing method. As shown in Fig.1, various quantities associated with the defined wave, or more precisely with the shape of the troughs of both sides of the concerned crest, were also calculated in

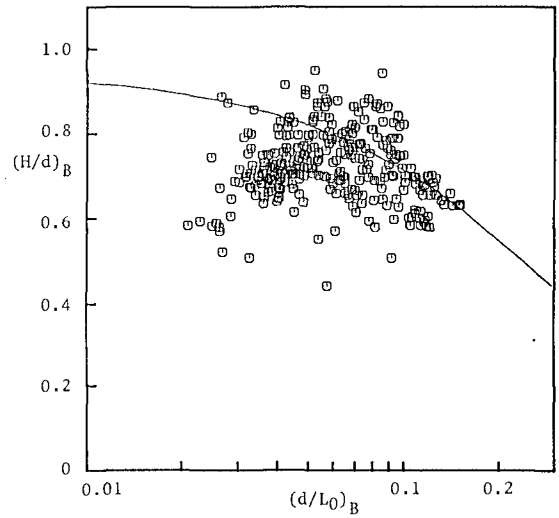


Fig. 3 Breaking condition of two-wave train waves. Goda's experimental formula for regular waves, Eq.(2), is denoted by a solid line.

order to study the influence of the adjacent waves, For the breaking depth, the still water depth at each location is employed. In this stage, a data-base of 196 cases of local wave breaking conditions is obtained.

3.1 Breaking Conditions of Waves Defined by Zero-Down Crossing Method and Regular Waves

Fig. 3 shows the local wave breaking condition in which $(H/d)_B$ is plotted against $(d/L_0)_B$, Subscripts B indicates those evaluated at the breaking point. The distribution of the data is very similar to the case of irregular waves and the data scatter is much larger than that in Fig. 2 for regular waves. For irregular wave results in laboratory experiment, see Fig. 2 in Kimura and Seyama (1986).

Fig. 4 shows direct comparison of measured relative wave height, $(H/d)_E$, against that, $(H/d)_R$, given by Eq.(2). This figure shows that the waves break with wide range of relative wave height, 0.45-0.95, in spite of the expectation from the regular wave formula that they break with narrow range of relative wave height, 0.6-0.85. This may suggest that there are some other hidden parameters to control the breaking of irregular waves and also that the large data scatter in Fig. 3 can be reduced by playing with the definition of the water depth.

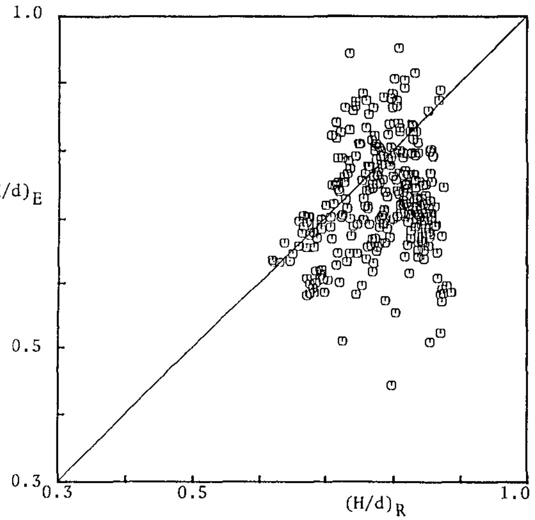
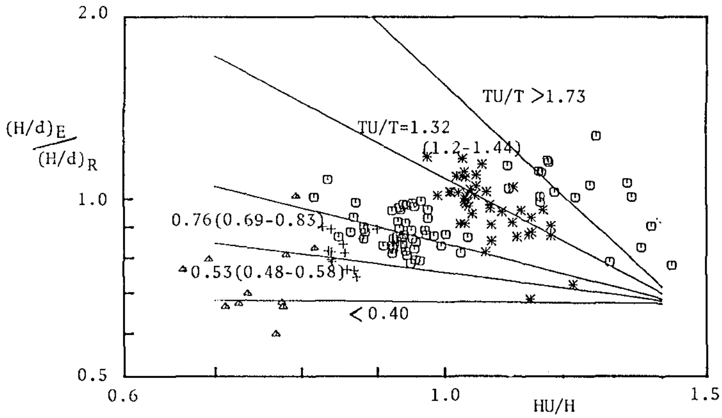


Fig. 4 Direct comparison of breaking wave condition for two-wave train waves with Goda formula.

Kimura and Seyama (1986) succeeded to reduce the data scatter by introducing a modified water depth d_m, that is the depth below the median level of wave crest and trough. However, the reduction may be largely due to the resulting nonlinear scaling in the vertical axis, i.e. H/d_m. Moreover, it is difficult to find physical meaning of d_m for the wave breaking.

Here, first, we assume that the large data scatter is brought in as a result of neglecting the difference of the adjacent waves. We plotted the ratio of measured relative wave height, $(H/d)_E$, to the relative height given by Eq.(2), $(H/d)_R$, against various parameters defined from the quantities shown in Fig.1. Then the ratio shows clear dependency on the following parameters, HU/H (where HU = $H-HT+HT_1$) and TU/T (where TU = $T-TT+TT_1$). HU and TU are, respectively, the wave height and period, defined by the zero-up crossing method for the concerned wave crest. This is very conceivable when one thinks of the fact that it is the wave crest that breaks. In Fig. 5, the ratio of $(H/d)_E/(H/d)_R$ is plotted against HU/H with TU/T as a parameter. The data, as a whole, show monotonical increase, implying the tendency that the larger the HU/H is, i.e., the deeper the following trough is, the higher the breaking wave height is, as was pointed out by Isobe et al.(1980). However, once the length of the following wave trough is taken into account, the data show monotonical decrease, indicating that the waves which are followed by relatively



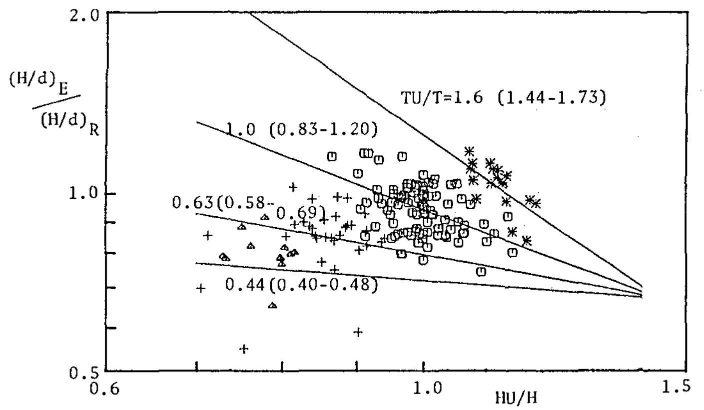


Fig. 5 Effect of the shape of the following trough on in individual wave breaking in two-wave trains. Upper and lower diagrams are for different values of the parameter TU/T.

deeper and shorter trough do break easily or with smaller wave height. In other words, the following deep trough, which is nearer to the wave crest, makes the crest break easily. This is reasonable as the situation means that the wave is sharp-crested and the actual water depth for the crest is shallow. The least square error method was applied to deduce the best-fitted curves, which are plotted with solid lines in Fig.5. They are expressed by the following equation.

$$(H/d)_E/(H/d)_R = 0.58(HU/H)^{-TU/T}exp\{0.48(TU/T)\} \qquad (3)$$

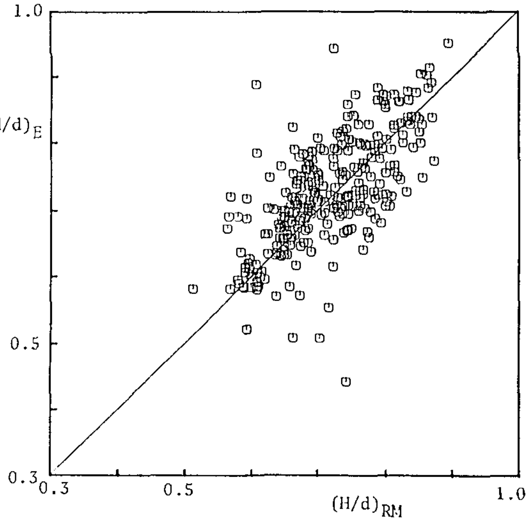


Fig. 6 Comparison of breaking conditions for two-wave trains after modification.

Equation (3) gives value of 0.94 for the ratio when TU/T=1 and HU/H=1, although unit value my be expected as the conditions correspond to the regular waves. The irregular shape of the individual waves may responsible for the easy breaking, although there is a possibility that the difference is within the experimental error. The data in Fig. 5 still show large scatter. In order to reduce the scatter, other parameters like TM_1 to directly desribe the shape of the trough could be better to be used. However we chose HU and TU to introduce the empirical formula, as they are the traditional quantities defined by zero-up crossing method.

Figure 6 shows comparison of measured relative wave height with that given by Eq.(2) with modification after Eq.(3). The improvement is obvious as the average tendency follows that of regular waves. The correlation coefficient in Fig. 6 is 0.68 and much large than the value of 0.15 for Fig. 4. It may be possible to further reduce the the data scatter by introducing another parameter to describe the irregular shape of the waves. However that sort of approach may not be productive.

3.2 Breaking Condition of Individual Wave Crest

In the preceding section a modification of regular wave breaking formula for the individual waves defined by zero-down crossing method was attempted. The results

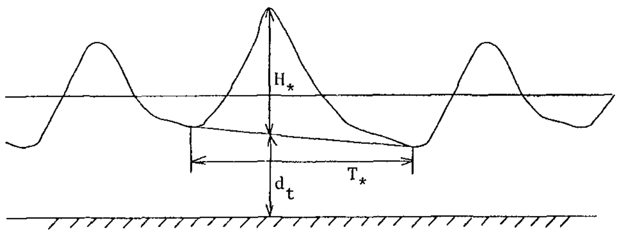


Fig. 7 Properties of an individual wave crest in bichromatic waves.

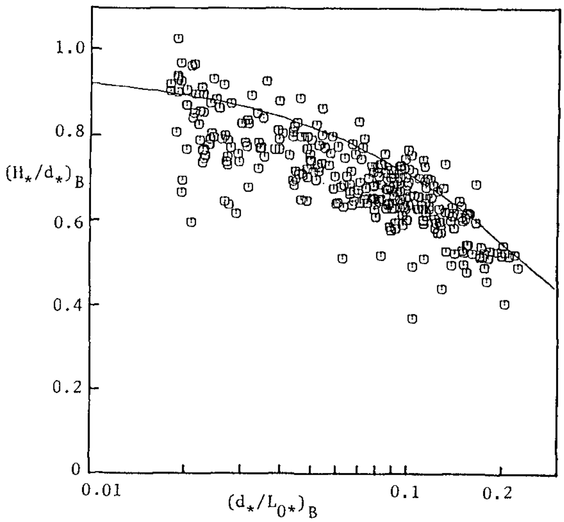


Fig. 8 Breaking condition of individual wave crests in two-wave train waves.

indicates that the properties of the wave crest are important to control the breaking. Now we look into the breaking condition of a wave crest in comparison with regular wave breaking. Here we define an individual waves by trough-to-trough method as shown in Fig. 7. For this individual waves, the height, H_*, is defined as the vertical distance between wave crest and the line drawn from the preceding trough to the following trough. Local water depth d_* is calculated by applying first order cnoidal wave theory (Isobe;1985) as $d_* = d_t$+(mean elevation of cnoidal waves over though level), with H_*, trough-to-trough period, T_*, and trough depth d_t given.

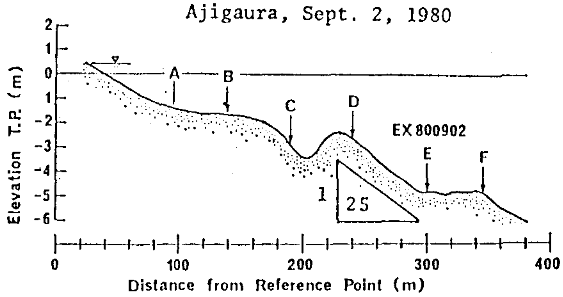


Fig. 9 Bottom topography of field observation site

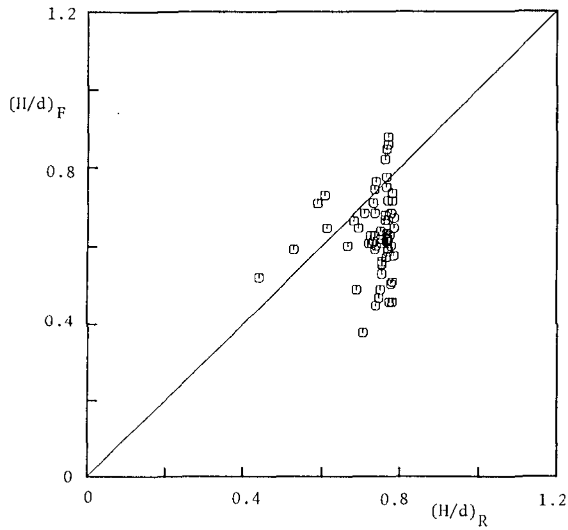


Fig. 10 Comparison of breaking condition of field waves defined by zero-down crossing method and regular waves.

Figure 8 shows local wave breaking condition for the individual wave crests. In contrast to Fig. 2, similarity with regular wave breaking is remarkable. There is still seen large data scatter, some of which may be of experimental error but most of which may be due to an artifice to approximate an individual wave by a regular wave. It is noted that the differences of wave period T_* from the period T defined by zero-down crossing method are large and contribute quite significantly to move the data points in Fig. 7. In Fig. 7, average values of breaking height-depth ratio as well as their standard deviation could be evaluated for a given relative depth, as was done

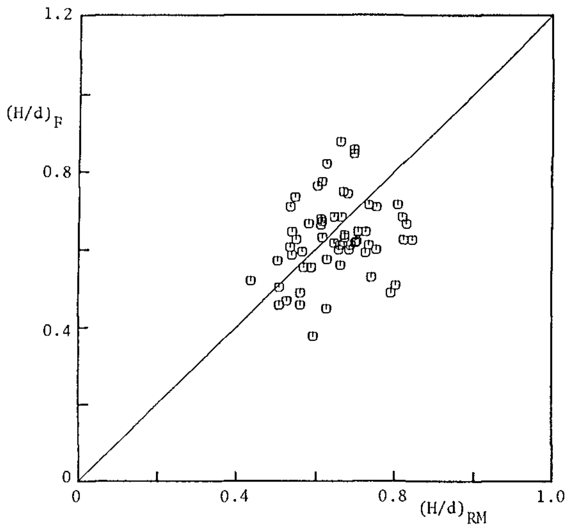


Fig. 11 Comparison of breaking condition of field waves after the modification.

by Kimura and Seyama(1986) for waves defined by zero-down crossing method with their modified depth d_m, yielding experimental formulae for the breaking condition, though not tried here.

4.BREAKING CONDITION OF FIELD WAVES

16 mm camera movies, which shot the target poles in the nearshore zone were used to take out the waves, which are just breaking at the location. This film was already analyzed and the results for the zero-down crossing waves were reported by Mizuguchi et al.(1987). Here we re-analyze the film in the same way as we did for the labaoratory data and calculated the quantities shown in Fig. 1. Fig. 9 shows the cross-shore bottom topography of the site. The data at position D is used. The mean water depth was 2.79 m. Numbers of just breaking waves at position D were 47 out of 1118 waves defined during the observation.

In Fig. 10, relative wave heights at the breaking point for field waves are compared with regular wave formula. For $\tan\beta$, value of 1/25 is used. Figure 10 is very similar to Fig. 4, showing that waves break with wide range of, H/d, values, although Eq.(2) gives narrow range of the values.

Figure 11 shows comparison of relative wave heights for field waves, $(H/d)_F$, with those of the breaking formula

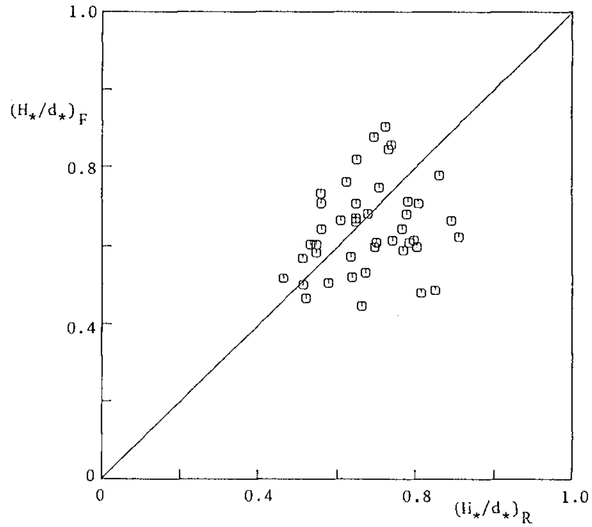


Fig. 12 Comparison of breaking condition of individual waves defined by trough-to-trough method for field waves.

modified with Eq.(3), $(H/d)_{RM}$. Figure 12 shows comparison of breaking condition of the wave crests, $(H_*/d_*)_F$, for field waves and regular waves. Both diagram show a linear trend though large data scatters are still observed. There is no tendency in Fig. 12 that the field values are smaller than those given by regular wave formula, in contrast to the results in Fig. 8. The linear trends proves that the present modifications are in the right direction to establish the wave breaking condition of the individual waves in the field waves. The data scatter may result from various complexities observed in the field, such as three dimensional feature of field waves and non-uniform bottom slope, in addition to the factors possible in laboratory data. Recently, Sato et al.(1990) looked into the effect of long period waves on the irregular wave breaking. Interaction between long period waves and wind waves may be partially responsible for the remaining data scatter.

5. CONCLUSIONS

We can conclude that the individual waves in an irregular wave train do, in average, break in a similar condition to that of the regular waves. However, conventional zero crossing methods may not be suitable to defining the breaking waves, for thus defined waves need the systematic modification as given by Eq.(3). Regular wave breaking condition can be applied reasonably well to the waves defined by the trough-to-trough method.

One can also conclude that the average breaking height-depth ratio of two-wave train is slightly smaller(about 5 %) than that of regular waves, although this tendency is not clear in field waves, and that some data scatter is inevitable when the regular wave formula is used for the individual waves. The irregular shape of the individual waves may be responsible for both of them.

Here only local wave breaking criterion is studied. It is necessary to develop a shoaling model for irregular waves as well as for two-wave trains, which is valid upto breaking point, in order to be able to predict both the breaking depth and wave height.

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