CHAPTER 102

Laboratory experiment on long wave generation by time-varying breakpoint

Satoru Nagase[1] and Masaru Mizuguchi[2]

Abstract

Laboratory experiment is conducted to investigate the long waves generated by time-varying breakpoint. We focus our attention on the variation of plunging point as well as the variation of breaking point. The results show that free long waves (BFLW) are really generated by the variation of the starting point of wave set-up which coincide with the plunging point and that the BFLW observed can be quantitatively evaluated by Mizuguchi(1995) model, which is more direct and realistic model. The generation mechanisms of long waves of other origins, such as bound long waves to wave groups and free long waves generated during shoaling process of wave groups, are also discussed.

1. Introduction

Some lively discussions have been going on concerning the origins of the free long waves (of typical time scale 1 to 3 minutes) observed in the nearshore zone. It is well known that the generation of long waves is closely related with wave groups. However the characteristics of long waves, which may be free or bound, are still not well understood because of the difficulty of detailed measurements. One of the possible mechanism for the generation of free long waves is that the breaking of wave groups generates free long waves.

Longuet-Higgins and Stewart (1962) suggested that the bound long wave to a positive wave group is freed as a set-down wave when the wave group disappears by wave breaking. This concept has been used

[1]Engineer; Taisei corp., Nishi Shinjuku Shinjuku-ku, Tokyo 163-06, JAPAN (Formerly graduate student, Chuo Univ.)

[2]Professor; Dept. of Civil Eng., Chuo Univ., Kasuga, Bunkyo-ku, Tokyo 112, JAPAN

for a long time without any physical or mathematical explanation. In fact, little is known about the behavior of the bound long waves when the primary waves break. Symonds et al.(1982) showed theoretically that time-varying breakpoint generates free long waves by playing a role of time-varying forcing term in the long wave equation. Schaffer(1993) extended their approach by including both the effect of bound long waves to wave groups and the behavior of wave groups in the surf zone. This topic has been studied mainly in a theoretical manner. Most studies have concluded that the model of Symonds et al.(1982) is in qualitative agreement with experimental results. For example, Kostense(1984) in laboratory experiment, Nakamura and Katoh(1992) in field observation. However they have neither measured the variation of breaking point nor the behavior of long waves around the breaker zone. More direct experimental measurements are needed to support or to reject the theoretical modeling.

Here we report a carefully conducted experiment, where the long waves generated by time-varying breakpoint can be quantitatively estimated. Based on the experimental results, we show that the modeling proposed by Symonds et al.(1982) is really valid and the analytical solution for bound long waves by Longuet-Higgins and Stewart (1962) is still correct even in shallow water. Then we show another treatment applicable to non-periodic wave group for the generation of free long waves in the nearshore zone, proposing a simple formula to estimate the magnitude of the free long waves generated by time-varying breakpoint.

2. Experiment

Figure 1 shows our laboratory flume. The wave flume is 20m long and

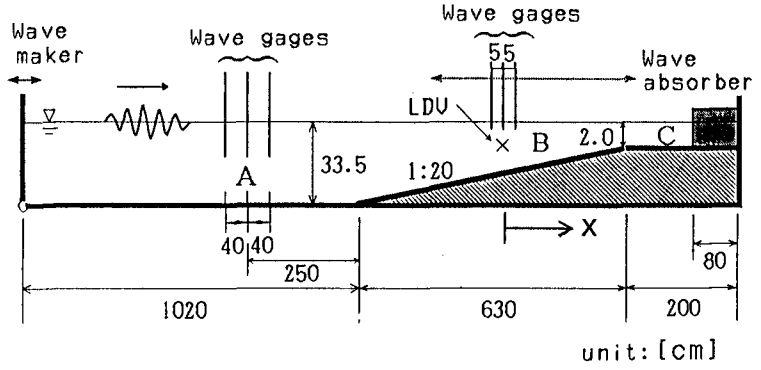


Fig.1 Experimental setup and the origin of x coordinate
The location of water depth 13.5cm is taken to be the origin of x coordinate.

30cm wide. It is equipped with a flap-type wave maker controlled by a personal computer. The slope of 1/20 with a constant depth area in the shoreward is set in a wave flume so that all waves can break on a uniformly sloping beach and then reform on a constant depth area in the shoreward. The wave absorber is installed at the end of the wave flume in order to dissipate the energy of reformed waves. Incomplete absorption of reformed waves at the shore end may cause unstable breakpoint variations due to wave reflection. The water depths at location A in the offshore, location B on a sloping beach and location C on a constant depth area in the shore are 33.5cm, 10.0cm and 2.0cm, respectively. The wave gages and current meter are moved in the nearshore zone so that detailed measurements of the process of long wave generation may be possible.

In order to investigate the simplest case of long wave generation in as much detail as possible, a single hump-type grouping waves are selected. A single wave height variation signal is given by Eq.(1).

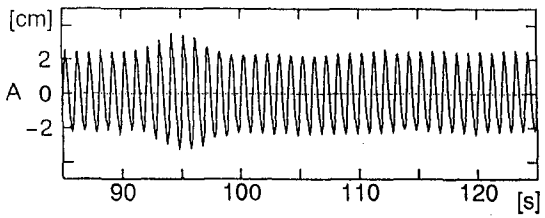
$$H(t)=\begin{cases} H_M(1+\beta(1-\cos(2\pi(t-t_0)/T_g))) & t_0 \leqq t \leqq t_0+T_g \\ H_M & t<t_0,\ t_0+T_g<t \end{cases} \quad (1)$$

where H_M is the steady wave height, T_g is the wave group period and β is the wave height ratio. The experiments are conducted on the following conditions. Both T=1.0s for the wave period of the primary waves and T_g=8.0s are fixed in all cases. The steady wave height at location A in Fig.1, H_M=5.5cm, 4.5cm, 4.2cm, 3.7cm, 2.8cm and the wave height ratio, β=0.2, 0.1, -0.2, -0.1, which introduce the variation of breaking point, are varied. Total of experimental cases are fourteen.

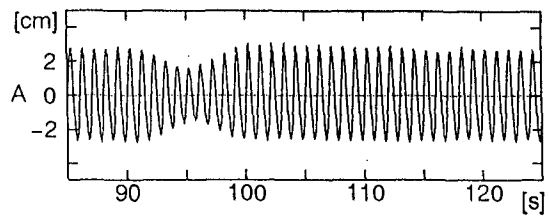
Figure 2 shows examples of a single hump-type grouping waves, a positive wave group and a negative wave group. For generating stable grouping waves, first, the amplitude of the wave maker board is increased very slowly, then the steady uniform waves are maintained for a while (about 40s) and finally a single hump-type grouping waves are added. However, we did not apply the control method either to suppress the generation of the second-order free long waves or to absorb free long waves coming back from the shore. At each location, waves are measured during 180s from the start of wave making with a sampling time of 0.02s.

3. Experimental results

Figure 3 shows the wave height variation of individual waves when a positive single hump-type grouping waves are incident into the surf zone. In this study, individual waves are defined by applying the zero-down crossing method. The breaking point clearly moves offshoreward



(a) A positive wave group (H_M=4.5cm, β=0.2)



(b) A negative wave group (H_M=5.5cm, β=-0.2)

Fig.2 A single hump-type grouping waves (measured at location A)

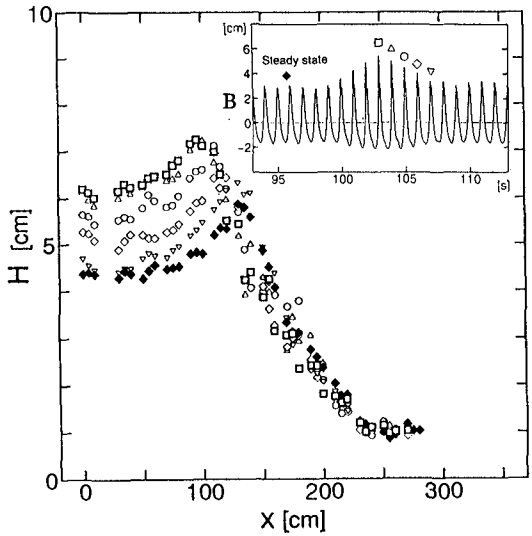


Fig.3 Wave height variation of individual waves in the positive wave group shown in Fig.2(a)

as the wave height increases gradually. As a wave starts to break, its height decreases very rapidly while maintaining an approximately constant ratio of wave height to water depth, in other words, the wave group tends to disappear in the surf zone.

The time variation of the breaking position of individual waves is visually measured using a high-speed video camera. The solid squares in Fig.4 denote the measured variation of breaking position. The variation shows good correspondence with the wave height variation measured outside the breaking zone. Spilling breakers are observed in all cases.

Figure 5 shows the measured wave group structure and the generated long waves for a positive wave group. The long wave components are obtained by applying a numerical filter, by which the short-period components less than 4 second are removed perfectly. The wave group shows stable propagation up to the breaking zone and then disappears or shows slightly negative wave group during the breaking process (between x=90 to 130cm). Low-pass filtered long waves show that the set-down wave propagates at the group velocity of primary waves without significant amplification with a slight delay to the wave group up to the breaking point. Since the wave maker is not controlled to suppress the generation of the second-order free long waves, a free wave (a positive single hump) generated at the wave maker travels just ahead. See the data at location A. As the wave group disappears while breaking, a set-up wave is formed in the surf zone and propagates in the shoreward direction. A set-down wave also appears to be generated and

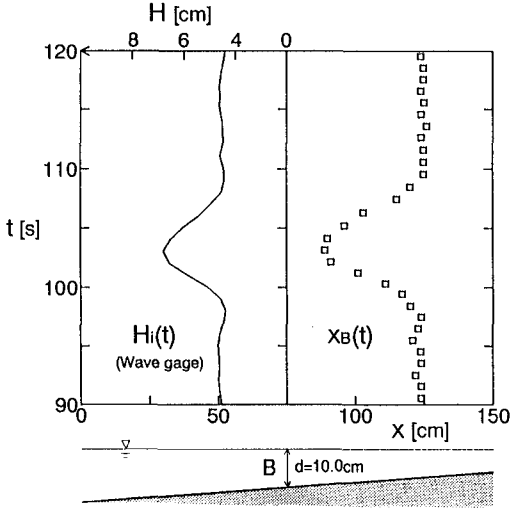


Fig.4 Time variation of breaking position of individual waves in the positive wave group

travel offshoreward outside the breaking zone.

When a negative single hump-type grouping waves is generated, the bound long wave as a set-up wave is observed in the offshore shown in Fig.6. When the primary waves in a negative wave group break, a set-down wave is observed in the surf zone and propagates in the shoreward direction.

These two experimental results are just opposite in the phase of the long waves as are expected. This shows the reliability of the experiment.

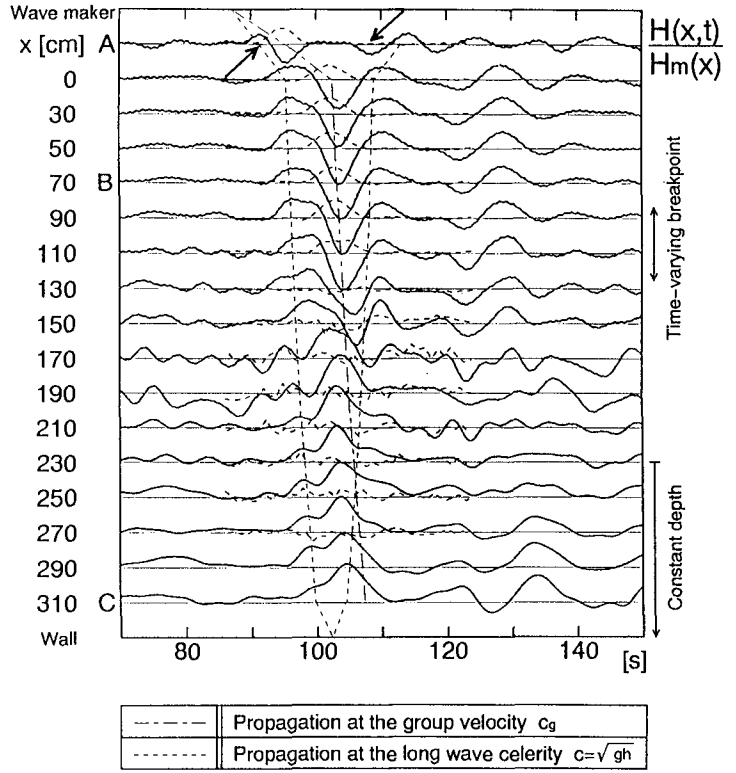


Fig.5 Low pass filtered data (solid line) and time history of wave height (broken line) in the positive wave group

Reference level for long waves is the mean water level of steady state at each location. Wave heights are nondimensionalized by mean wave height of steady state at each location. Scales of vertical axis for long waves and nondimensionalized wave heights are 0.2cm and 1.0, respestively, for an interval of two horizontal lines.

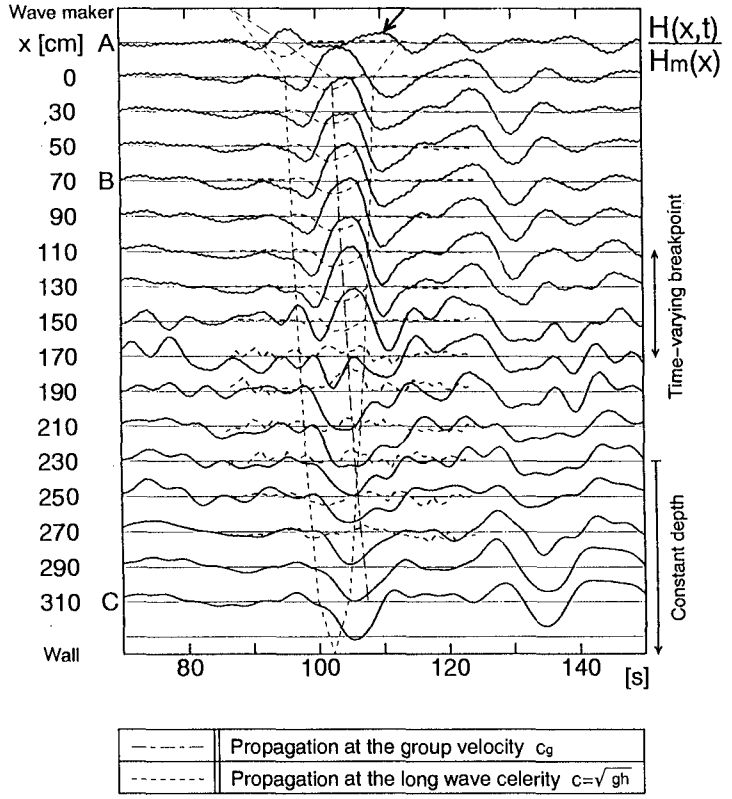


Fig.6 Low pass filtered data (solid line) and time history of wave height (broken line) in the negative wave group shown in Fig.2(b). (See Fig. 5 for explanation.)

4. Discussion

4.1 Generation of long waves

The generation mechanism of long waves in the laboratory experiment may be illustrated schematically as shown in Fig.7.

Long waves in this experiment consist of, ① free long waves generated at the wave maker, ② bound long waves to wave group, ②′ bound long waves being freed at the breaking point, ③ free long waves generated during the shoaling process of wave group and ④ time-varying breakpoint forced (free) long waves (BFLW). Wave groups are assumed to disappear after their breaking.

Free waves generated at the wave maker (①) can be identified as the leading positive hump on a sloping beach. Then a point to be noted is

that the transforming wave group due to wave shoaling does accompany free long waves (③) in addition to the bound long waves (②). Any change of wave group may result in the generation of free long waves, simply because the new bounded solution is different from the old one and free waves are needed to satisfy the old condition. This free waves have the opposite sign to the bound waves and travel only a little faster as schematically illustrated in Fig.7(b). This is the reason why in shallow water the long waves appear to lag behind the wave group, as is also pointed out by List(1992) and Van Leewen(1992), and why its magnitude is not so large as the analytical solution by Longuet-Higgins and Stewart (1962).

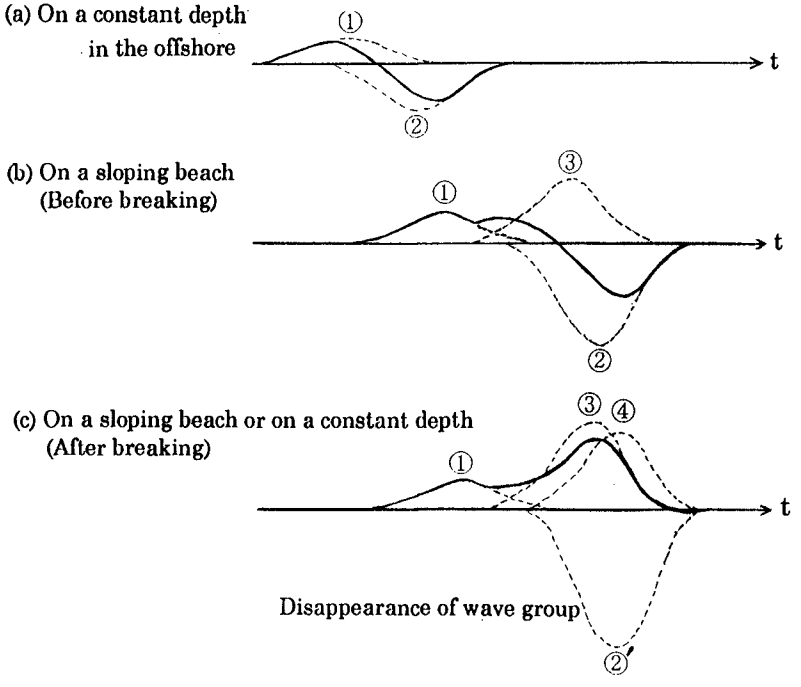


Fig.7 Schematic illustration of generation and propagation of long waves(time profile) in the positive wave group

Solid lines denote the observed long waves, which can be resolved into,

① Free long waves generated at the wave maker
② Bound long waves to wave group
②′ Bound long waves being freed at the breaking point
③ Free long waves generated during the shoaling process of wave group
④ Time-varying breakpoint forced (free) long waves (BFLW)

It has been quoted in various studies that the LHS solution predict unreasonably large wave heights in shallow water and cannot be applied in the nearshore. The fact is that the LHS solution is a particular solution and the physical situation must include general solutions, which nearly cancel the particular solution. For more detailed discussion, see Mizuguchi and Toita(1996). In addition to these long waves, free outgoing long waves (set-down waves) generated by time-varying breakpoint may have an effect on both the phase and the magnitude of long waves observed in the offshore. However this free waves were difficult to evaluate separately and are neglected in Fig.7.

At the breaking point, bound long wave (②′) to a positive wave group is freed as a set-down wave due to sudden disappearance of the wave group, and the free wave generated while shoaling (③) continues to propagate as a free wave. In addition to these waves, the BFLW is generated. The shoreward propagating BFLW has the same phase with the wave group, that is, a positive wave group produces a set-up wave.

4.2 Magnitude of the BFLW

We discuss the generation mechanism of the BFLW, trying to evaluate its magnitude. First, in Fig.8 we plot the change of mean water level of individual waves in the nearshore zone when the positive wave group is generated. Figure 8 shows the starting points of the rise of mean water level, that is, the plunging points of individual waves move offshoreward corresponding to the offshoreward movement of the breaking points. The mean water level rises in the shoreward region with approximately constant gradient. This is what the generation of the BFLW really is. Thus the variation of the plunging point is essential. In Fig.8 the theoretical results (Bowen et al.,1968) on wave set-down and wave set-up for regular waves are also shown. The value of the wave height to water depth ratio, γ, is typically taken to be 0.8. Here the gradients of mean water level of individual waves in the transition region between the breaking point and the plunging point are neglected. The gradient of the measured set-up shows good agreement with the predicted value. As mentioned later, the vertical difference shown in Fig.8 is taken to be the magnitude of the BFLW traveling shoreward measured just after breaking.

Symonds et al.(1982) first proposed the model for the long waves generated by time-varying breakpoint. Figure 8 supports their modeling. However their approach assumes the periodicity in time of the breaking point variation and cannot be applied to a single hump-type grouping waves employed with this experiment. Recently, Mizuguchi(1995) shows more direct and realistic modeling with much simpler solution in the time domain. The modeling may be illustrated as shown in Fig.9.

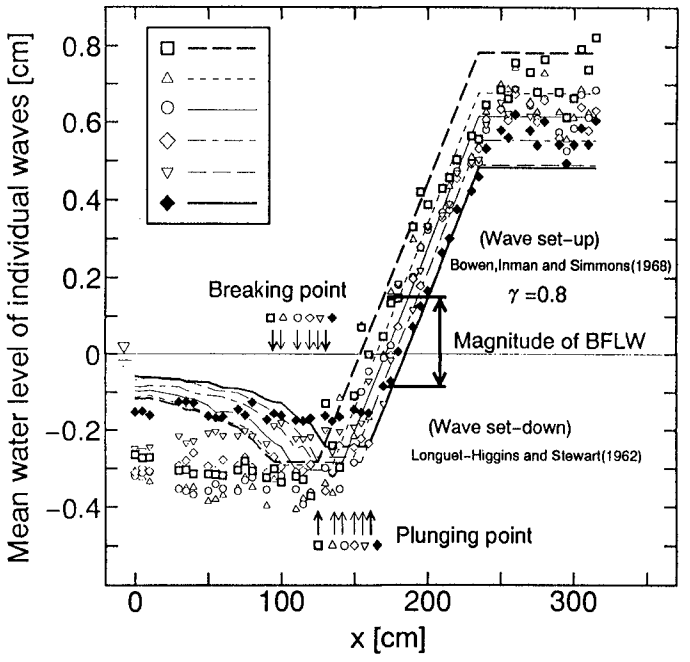


Fig.8 Change of mean water level of individual waves in the positive wave group

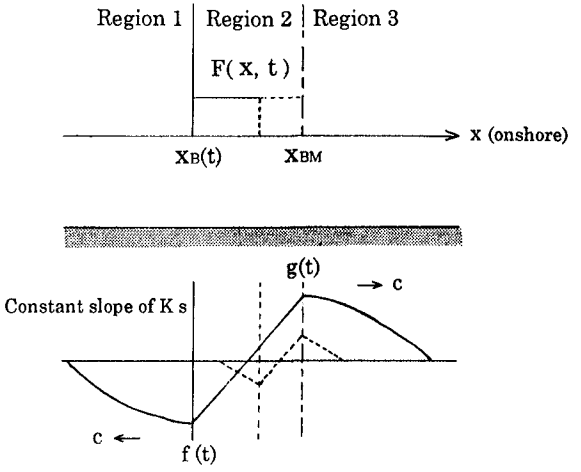


Fig.9 Schematic illustration of forcing term (top) and local profiles of long waves (bottom) after Mizuguchi(1995)

The well-known linear long wave equation with a forcing term is solved analytically on the following assumptions. First, the water depth around the breaking point is taken to be constant as far as the long waves are concerned. Second, a bounded solution for region 2 may be given by the steady version of the momentum equation, as is observed in this experiment.

The solutions obtained are so simple as shown in Eq.(2).

$$\begin{aligned} g(t) &= K\, s(x_{BM} - x_B(t))/2 \\ & \qquad\qquad \text{at } x = x_{BM} \\ f(t) &= -K\, s(x_{BM} - x_B(t))/2 \end{aligned} \tag{2}$$

where g(t) and f(t) are the functional form of the long waves propagating toward the shore and that propagating toward the offshore, respectively, $x_B(t)$ is the time-varying breaking point, x_{BM} is the mean (or steady) breaking point, K is the constant given by γ, wave height-water depth ratio in the surf zone (Bowen et al.,1968) and s is the local bottom slope around the breaking point. Therefore, the magnitude of the BFLW, which radiate both shoreward and offshoreward, can be expressed as follows.

$$\Delta \overline{\eta} = K\, s\, \Delta\, x_B / 2 \tag{3}$$

where $\Delta\, x_B$ is the width of breaking variation.

In order to evaluate the magnitude of the BFLW with Eq.(3), it is necessary to estimate the variation of breaking points. Here a very crude model for the variation of breaking points is employed. That is, by assuming that the structure of wave group incident on a shallow water region can be expressed by Eq.(1), and by applying Green's formula for shoaling up to wave breaking, $\Delta\, x_B$, is simply given by Eq.(4).

$$\Delta\, x_B = 1.6\, \beta\, h_{BM} / s \tag{4}$$

where h_{BM} is the mean (or steady) breaking depth. In Eq.(4) $\beta \ll 1$ is assumed.

Figure 10 shows the comparison of the width of breaking point variation predicted by Eq.(4) with that measured. In spite of a crude approximation, the model predicts the width of breaking point variation reasonably well. The measured width of plunging point variation are also compared in Fig.11. The measured values show surprisingly good agreement with the predicted ones.

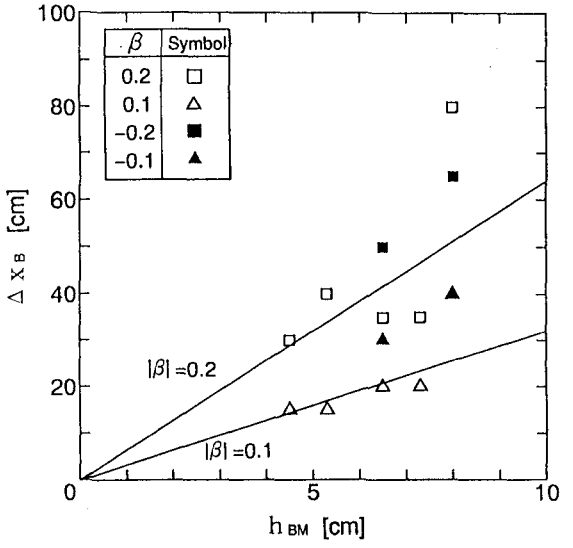


Fig.10 Comparison of width of breaking point variation predicted with that measured

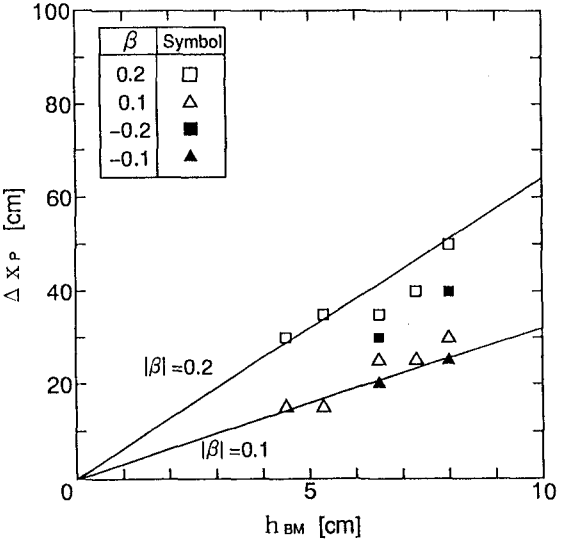


Fig.11 Comparison of width of plunging point variation predicted with that measured

As was already discussed using illustration in Fig.7, one needs cares to evaluate the BFLW separately. Here, as marked in Fig.8, the maximum height of long waves measured just after breaking is simply assumed to correspond to the magnitude of the BFLW. Because, around the breaking zone, the new free waves due to wave shoaling(③)and the new bound waves being freed(②′) may cancel each other and may not exceed the old bound waves in the offshore(②), which may be negligible compared to the BFLW, as shown in Fig.7. Thus evaluated magnitude of the long waves traveling shoreward is plotted in Fig.12 with solid lines which denote Mizuguchi(1995) model. Good quantitative agreement between the experimental values and theoretical ones is observed. The experimental values show linear dependency on the mean breaking depth, h_{BM}, and the wave height ratio, β, as is also predicted by the model.

The quantitative discussions on free long waves in the offshore direction is rather difficult as the separation between the incoming bound waves and the outgoing free waves was not possible in the nearshore area. However the data at location A in Fig.5 and 6 shows long period motion with the opposite sign for the first motion of reflected mode, supporting the results in Eq.(2) at least qualitatively.

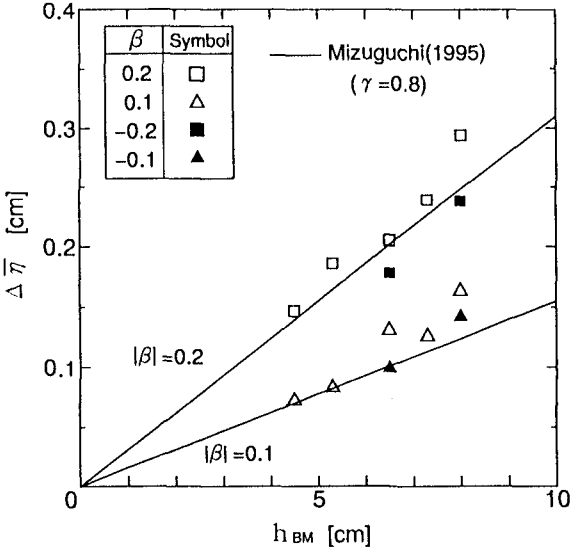


Fig.12 Magnitude of the BFLW traveling shoreward

5. Conclusions

In this study the main conclusions are as follows.

(1) Careful experiments with both detailed measurements and elaborate data analysis reveal that free long waves, which radiate both shoreward and offshoreward, are really generated by time varying breakpoint.

(2) The generation of the BFLW result from the variation of the starting point of wave set-up which coincide with the plunging point.

(3) The BFLW observed in this experiments can be quantitatively evaluated by Mizuguchi(1995) model, although the measured data may be contaminated with long waves of other origins.

References

Bowen, A. J. , D. L. Inman and V. P. Simmons (1968), Wave set-down and set-up, JGR, Vol.73, 8, pp.2569-2577.

Kostense, J. K. (1984), Measurements of surf beat and set-down beneath wave groups, Proc.19th ICCE, Houston, pp.724-740.

List, J. H. (1992), A model for the generation of two-dimensional surf beat, JGR, Vol.97, C4, pp.5623-5635.

Longuet-Higgins, M.S. and R.W. Stewart (1962), Radiation stress and mass transport in gravity waves, with application to " surf beat ", JFM, Vol.13, pp.481-504.

Mizuguchi, M. (1995), A simple analysis of long wave generation by time-varying breakpoint, Coastal Eng. In Japan, JSCE, Vol.38, pp.105-109.

Mizuguchi, M. and Toita, H. (1996), Generation of second-order long waves by a wave group in a laboratory flume and its control, Proc.25rd ICCE, Orlando (in press)

Nakamura, S. and K. Katoh (1992), Generation of infragravity waves in breaking process of wave groups, Proc.23rd ICCE, Venice, pp.990-1003.

Schaffer, H. A. (1993), Infragravity waves induced by short-wave groups, JFM, Vol.247, pp.551-588.

Symonds, G. , D, A. Huntley and A. J. Bowen (1982), Two-dimentional surf beat : long wave generation by a Time-varying breakpoint, JGR, Vol.87, C1, pp.492-498.

Van Leeuwen, P. J. (1992), Low-frequency wave generation due to breaking wind waves, Communications on hydraulic and geotechnical engineering, Delft University of Technology, 151pp.