CHAPTER 36

NEARSHORE CURRENT ON A GENTLY SLOPING BEACH

By

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ABSTRACT

The authors developed a new field observation system called STEREO-BACS by which simultaneous measurements of a spacial distribution on waves and currents in the nearshore environment can be obtained. This system was applyed on Ajigaura Beach, Japan, and several analyzed results are presented. Also field observations of infragravity low mode edge waves to support the Infragravity Domain Hypothesis on nearshore currents concerning a gently sloping beach [Sasaki(1974,1975), Sasaki and Horikawa (1975)] are introduced.

INTRODUCTION

Extensive studies on nearshore currents have been made over the last several years. As a result, numerous theories on nearshore currents especially on rip current generation have been proposed by Bowen (1967), Bowen and Inman(1969), Sonu(1972), Noda(1972), Hino(1973), Hashimoto and Uda(1974), Noda et al.(1974), Sasaki(1974,1975), Sasaki and Horikawa(1975), Liu and Mei(1974,1976), Birkemeier and Dalrymple(1975), Dalrymple(1975), Iwata (1976), Mizuguchi (1976), Mizuguchi and Horikawa(1976), Horikawa and Maruyama(1976).

However, the validity of these theories have been not clarified in detail due to the lack of precise field data[Sasaki and Horikawa(1975)]. The major difficulties in observing nearshore currents are due to 1) the spatial distribution of their phenomena, 2) multiplicity of affecting factors involved, 3) rough waves and currents in the surf zone, and 4) time dependency. To overcome these difficulties, the authors have been making numerous efforts over the last 6 years.

The best solution conceivable for overcoming these obstacles is to apply the principle of photogrammetry by using a pair of helicopters and/or blimps to secure observation platforms in the air. The authors have once tried utilizing a pair of helicopters called SIHELS [Fig. 1,

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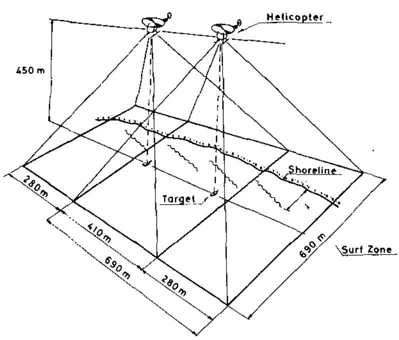

Fig. 1 Schematic diagram of SIHELS. (Horikawa and Sasaki, 1972)

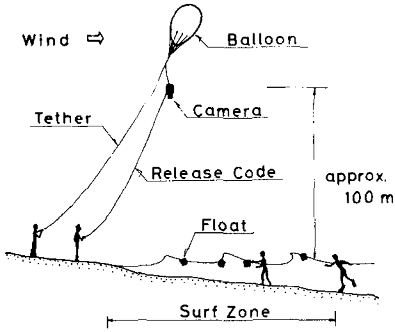

Fig. 2 Schematic diagram of BACS. (Horikawa and Sasaki, 1972)

SImultaneous HELicopter System, Horikawa and Sasaki(1972)], and realized that the obtained accuracy in mapping the wave height distribution was very satisfactory. However the cost was prohibitive, so that this system could only be utilized one time.

In place of the SIHELS, the authors developed a balloon borne camera system called BACS [Fig. 2, Horikawa and Sasaki(1972)]. By this system, the spatial flow field can be easily obtained by tracing floats in successive pictures [Sasaki(1974,1975), Sasaki and Horikawa(1975)]. This system is a very simple and convenient one, however, the wave height field cannot be obtained due to the fact that only a single balloon is used.

Last year, the authors further developed a new system, which consists of a pair of balloons called STEREO-BACS. The aim of this system is to achieve simultaneous measurements of spatial distributions of nearshore waves and currents over a relatively broad area.

In the present paper, the authors first introduce this new system, secondly present an outline of the results obtained from observations made in December, 1976 on Ajigaura Beach, Japan, and lastly show several results to support the Infragravity Domain Hypothesis on a gently sloping beach.

STEREO-BACS

An idea of STEREO-BACS appeared in 1893 by C. B. Adams for terrestrial mapping[Thompson(1966)]. For the application of this idea to unsteady phenomena in the surf zone, the development of a motor-driven camera is required.

Sonu(1969) utilized a Nikon motor-driven camera(35mm) for the study of nearshore current patterns and mixing [Sonu(1972a,1976)]. The Hasselblad 500EL motor-driven camera(70mm) was applied for the first time by Horikawa and Sasaki(1972) to obtain further accuracy in mapping the quantitative flow field in the surf zone.

Figure 3 shows a schematic representation of the STEREO-BACS. Two balloons are lifted about 150 m apart at an altitude of around 300 m. The volume of helium gas necessary to fill a balloon is 33 m^3. The effective bouyancy is about 25 kg without tethers or a camera capsule. Two cameras are triggered simultaneously by a radio transmitter. A super-wide angle lense, Zeiss Distagon 40 mm, has been adopted to take wide coverage. About 30 to 50 floats are introduced around the surf zone by divers and from a pier. The floats are made of polyurethene foam coated by red or orange coloured polyvinylchloride sheet and equipped with a drogue.

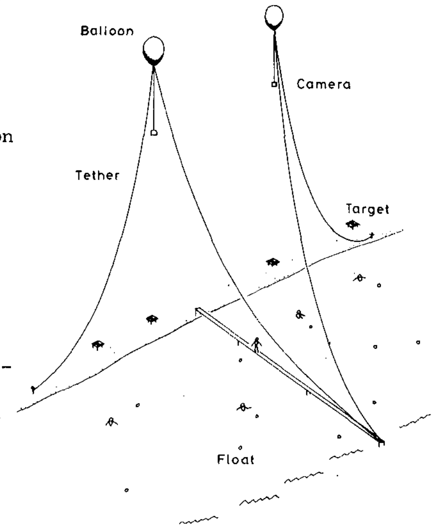

Fig. 3 Schematic diagrm of STEREO-BACS.

The pier was 100 m long (presently extended to 200 m), and was constructed by the Public Works Research Institute, Ministry of Construction for research use. Piers play an essential role in operating the STEREO-BACS. Most importantly, they act as a target for absolute orientation of the stereoscopic pairs in onshore-offshore direction. A second role is to secure a foothold for distributing many floats into the surf zone. And a third role is to give a stay for mooring balloons under onshore wind or windless conditions. Two tethers are employed, and the camera is suspended by a single rope from the balloon.

DESCRIPTION OF THE SITE OBSERVED

Field observations by this system were made on Ajigaura Beach. This beach is located 100 km northward from Tokyo and faces the Pacific Ocean (Fig. 4). About 1 km south of the pier, the beach is bounded by a headland. Figure 5 is a overview of the pier. Several rip currents can be sean in this picture.

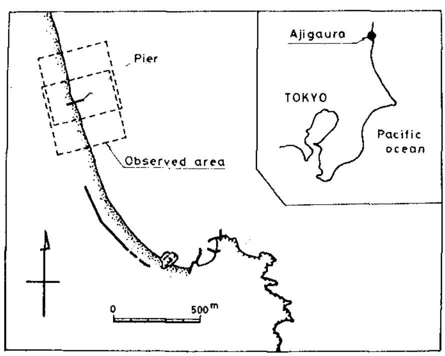

Fig. 4 Location map of Ajigaura Beach.

Fig. 5 Overview of Ajigaura Beach.

The beach slope is 1/40 to 1/70, and classified as a gentle beach. Strictly speaking, this beach is in Infragravity Domain[Sasaki(1975)] under a relatively rough sea, while under a calm sea it is in Instability Domain.

FIELD OBSERVATION USING THE STEREO-BACS

Wave Climate

Simultaneous measurements of a spatial distribution on waves including infragravity waves, currents, and mean water surface using the STEREO-BACS were carried out in December, 1975.

Figure 6 is a mosaicked picture made from the stereoscopic pairs obtained on December 18, 1975. Because two cameras were used, the long-shore coverage of this picture became very wide compared to that using a single camera (BACS). It is estimated at about 400 m by comparing with the 100 m long pier.

The breaker height and period were around 1.2 m and 13 sec respectively. The wave direction was 2 degrees shifted leftward at the tip of the pier. It was almost windless, and the wave climate was classified as very calm for this coastal region.

Velocity Field

Figure 7 shows the velocity vector field obtained during a quarter

Fig. 6 An example of pictures taken by the STEREO-BACS (December, 1975).

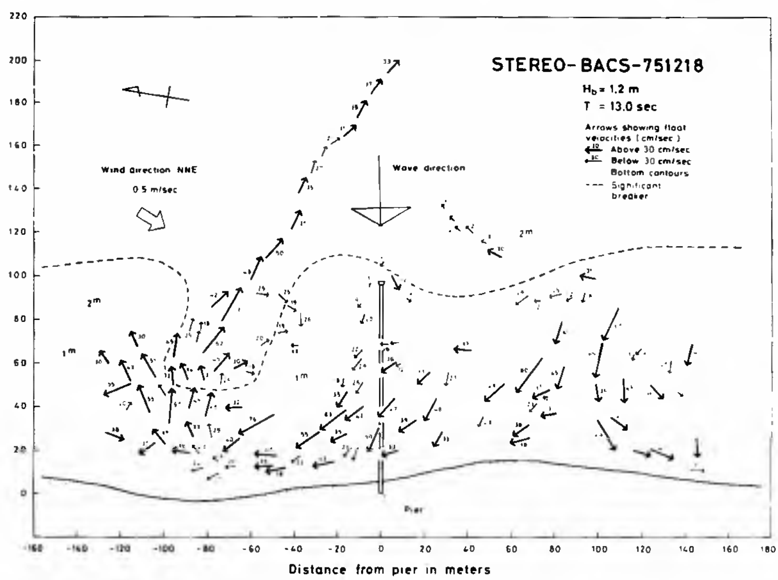

Fig. 7 Velocity vector field (December, 1975).

hour observation. The thick dotted line indicates a significant breaker line, and the thick arrows indicate velocity vectors exceeding 30 cm/sec. The vectors were compiled from interpreting the position of each float in successive pictures taken every 15 sec. Alongshore coverage for the velocity distribution was somewhat limited about 300 m due to the small number of divers in the surf zone available for introducing floats.

On the lefthand side of the pier, a rip current flows out with a maximum velocity exceeding 70 cm/sec. Only one float could overcome the attack of the incoming waves and was able to leave from the surf zone. On the righthand side of the pier, an inflow of offshore water can be seen. This was the first time we were able to catch an entire circulation process of this kind. This is simply due to the combination of the higher altitude of the balloons lifted and the utilization of a pair of balloons. The longshore dimension of the cell was about 200 m.

Figure 8 shows a current speed contour map derived from Fig. 7. By tracing the 40 cm/sec contour line, the shape of the current can be seen vividly. On the shoal located on the righthand side, the inflow is separated into right and left directions. And on the lefthand side, two longshore currents from opposite directions meet to form the rip current at around one half of the surf zone width from the shoreline.

The maximum velocity of the longshore current across the surf zone takes place very close to the shoreline. This fact does not agree with the result based on the theory of Longuet-Higgins(1970) for a plane beach, in which the lateral mixing parameter, P, generally takes a value between 0.1 and 0.4, derived from laboratory data, as pointed out by Sasaki and Horikawa(1975).

Transport Stream Function

Figure 9 is the transport stream function[Arthur(1962)] derived from the longshore compornent of the observed velocities. The maximum discharge exceeds 20 m^3/sec.

Figure 10 is a simulated transport stream line using the numerical model originally developed by Noda(1972). However, the treatment of bottom friction was modified with Jonsson's(1966) wave friction factors in the present computation. The roughness length for the bottom was calibrated by the observed velocity field [Sasaki (1975)]. The general current pattern and velocity agree well with observations except near the rip current. The disagreement in the vicinity of the rip current may be the result of the neglection of a lateral mixing and a convective term.

Wave Height Field

Figure 11 shows the maximum wave crest height distribution corresponding to a wave height field. This was made from 5 different instantaneous stereoscopic pairs of water surface configurations. For this, the Hasselblad 500EL motor driven camera, instead of a photogrammetric one, was used, so that the expected accuracy in this mapping might not be so high. However, the characteristic features of the wave height distribution is considered to be significant.

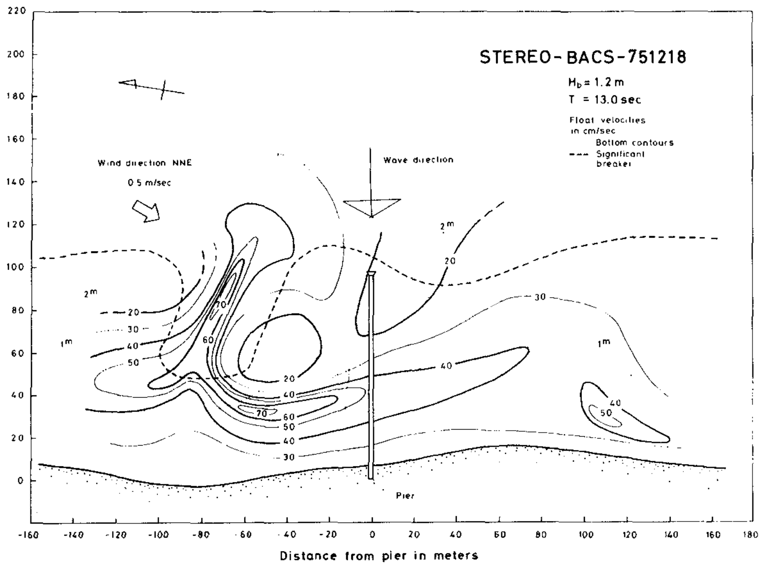

Fig. 8 Current speed contour (December, 1975).

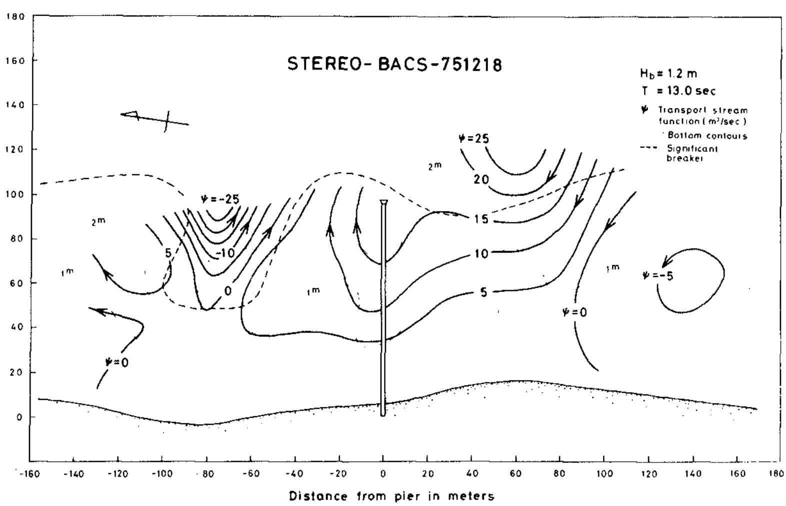

Fig. 9 Observed transport stream function (December, 1975).

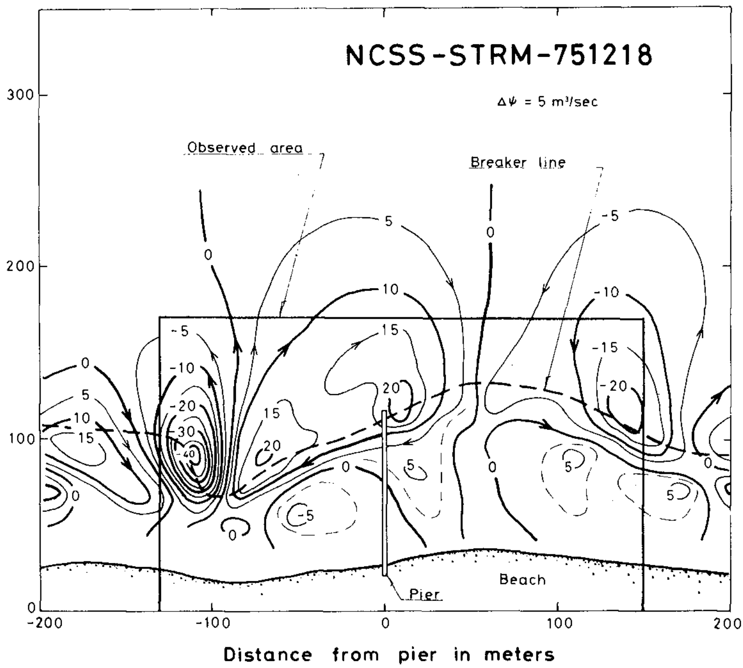

Fig. 10 Simulated transport stream function.

On both sides of the rip current, the maximum wave height appears, and on the lee side of the rip current, wave breaking takes place very close to the shoreline. The main stream of the circulation selects its path where the wave height is lower in the surf zone. A similar phenomena was also observed in the laboratory at the University of Tokyo [Mizuguchi and Horikawa(1976)].

Mean Water Surface

Figure 12 shows a simulated mean water surface elevation of a wave set-up and set-down. The maximum set-up is about 20 cm on a shoal, and the maximum set-down is about 5 cm at the intersection between the breaker line and the rip current. The maximum water surface gradients are seen at a root of the rip current, and are estimated to be approximately 1/200.

Figure 13 is the mean water surface observed by using the hydraulic filter originally designed by Sonu(1972a). The maximum difference of the water surface elevation is 40 cm, and the maximum water surface arises on a shoal. The longshore current flows from high to low zone like a river. The longshore gradient of the surface is about 1/350 that is fairly larger than simulated value of 1/200. Remarkable difference between obseved and simulated in water surface distribution is the location where the maximum set-up appears. In the field data, maximum appears somewhat apart from the

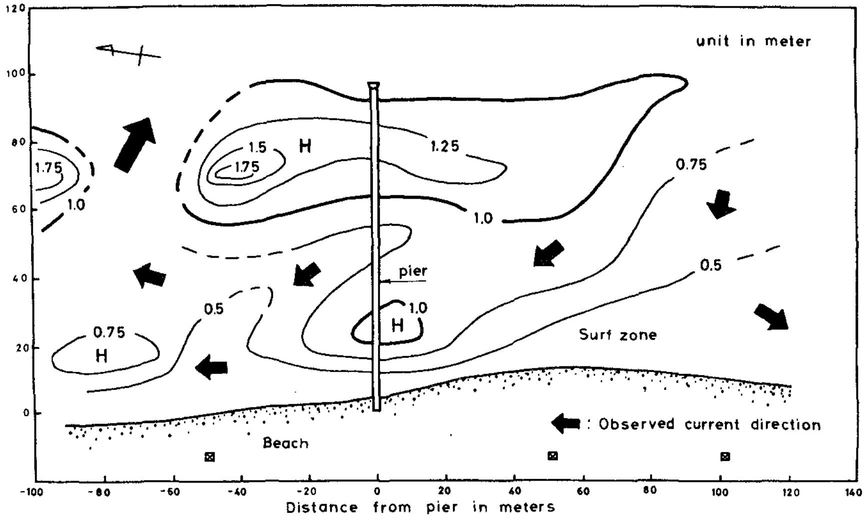

Fig. 11 Observed maximum wave crest height distribution (December, 1975)

shoreline. One of the explanations for this is due to the effect of a percolation in the swash zone.

Estimate of a Convective Term

Noda(1972) and Noda et al.(1974) neglected convective terms in simulating the nearshore current. Based on the above field data, the authors tried to estimate the relative significance of a pressure term with a convective term in the equations of motion. The magnitude of each terms are estimated at every 10 m grid point. Figure 14 shows a comparison of longshore terms(y-axis). Upper diagram is the pressure term, and the lower is the convective term. Near the rip current, convective terms have the magnitudes of 1/3 to 1/5 of the pressure terms. Whereas in the other area, pressure terms have 20 to 30 times larger than convective terms. Therefore, it can be said that near the rip current convective terms may be effective in this case.

FIELD OBSERVATION OF INFRAGRAVITY LOW MODE EDGE WAVES

Infragravity Domain

As for the spacing of rip currents, two theories have been presented [Bowen and Inman(1969) and Hino(1973)]. However, there is some confusion concerning their applicability for the actual phenomena[Sonu(1972b)].

Sasaki(1974,1975) found the existence of three domains on nearshore currents by applying the Iribarren No., I_r, [surf similarity parameter, Battjes (1974)] and the concept of infragravity waves[Suhayda(1974)] and clarified that the previous two theories can only be applied to two of the

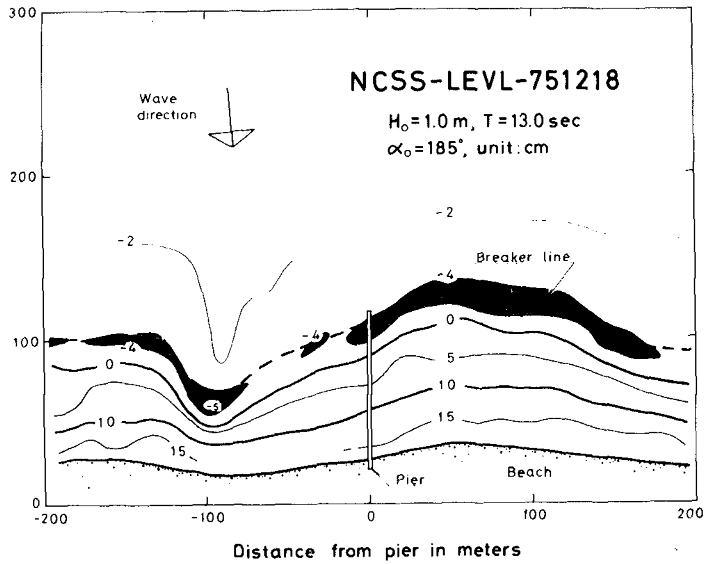

Fig. 12 Simulated mean water surface elevation.

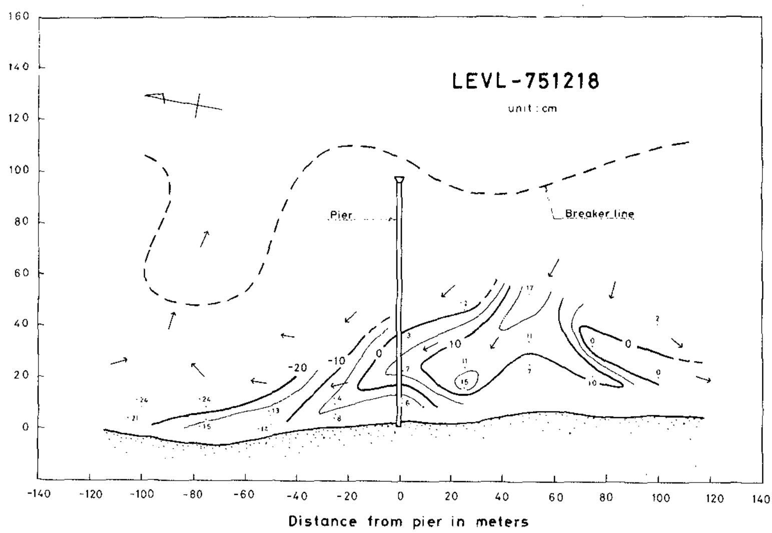

Fig. 13 Observed mean water surface elevation (December, 1975).

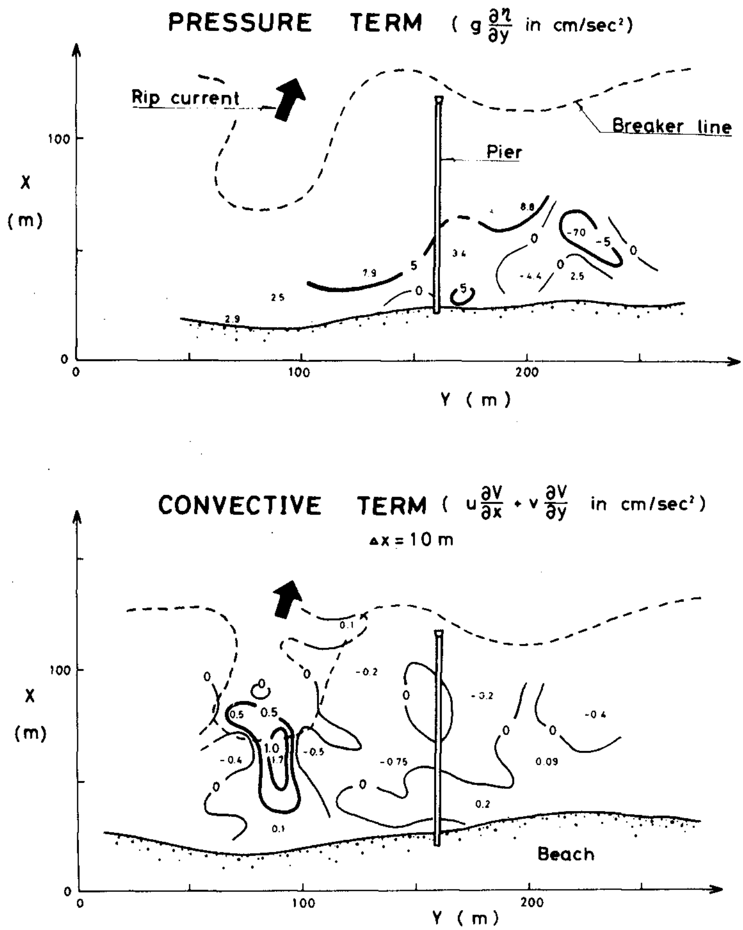

Fig. 14 Pressure term and convective term (December, 1975).

three domains for steep and medium beaches, respectively. For the additional domain, an Infragravity Domain Hypothesis has been proposed for a gently sloping beach [Sasaki(1974, 1975) and, Sasaki and Horikawa(1975)].

Here, the authors review this Hypothesis briefly, and show several observational results to support this. Figure 15 illustrates the concept of the three domains on nearshore currents. The top shows the Infragravity Domain [Sasaki(1974,1975)], the middle is the Instability Domain [Hino (1973)], and the bottom is the Edge Wave Domain [Bowen and Inman(1969)]. These three domains correspond to gentle, medium, and steep beaches, respectively. As shown in Fig. 15, it is easy to understand the concept of these domains using the number of waves in the surf zone [Battjies(1974)].

The Edge Wave Domain arises when the number of waves in the surf zone is less than 1, and has surging/collapsing or plunging breakers. This domain includes "the reflective system" [Guza and Inman(1975)]. The Instability Domain has 1 to 3 waves in the surf zone, and plunging or spilling breakers. On the contrary, the Infragravity Domain has more than 3 waves in the surf zone, and always has spilling breakers. This domain typically appears when relatively steep waves like wind waves attack a gently sloping beach. For this domain, Sasaki(1974,1975) presented the next equation for the spacing of rip currents;

$$Y_r^* = 157\ I_r^2 \tag{1}$$

where, Y_r^* is a nondimensional spacing of rip currents defined by Eq.(2);

$$Y_r^* = Y_r / X_b \tag{2}$$

I_r is the Iribarren No. [Battjes(1974)] defined by Eq.(3);

$$I_r = \tan\beta/(H/L)_o^{1/2} \tag{3}$$

In Eqs. (2) and (3), Y_r, X_b, $\tan\beta$, H, and L are spacing of rip currents, width of the surf zone, beach slope, wave height, and wave period, respectively. Subscript, o, denotes the value in deep water.

Figure 16 shows the relationship between Y_r^* and I_r for all three domains. The theory of Bowen and Inman corresponds for large values of I_r ($I_r > 1$), and Hino's theory can well be applied for medium values of I_r ($1 > I_r > 0.23$). In the Infragravity Domain ($0.23 > I_r$), Eq.(1) suggests the presence of low mode infragravity edge waves with significant amplitudes. Gravity waves having periods less than 20 sec have negligible reflection from the beach in this domain, while infragravity waves have fairly large reflectivity. So infragravity edge waves can be generated and are able to control nearshore circulation through bottom perturbation. Because the data on infragravity waves are very few, the authors have been trying to detect these waves on numerous occasions.

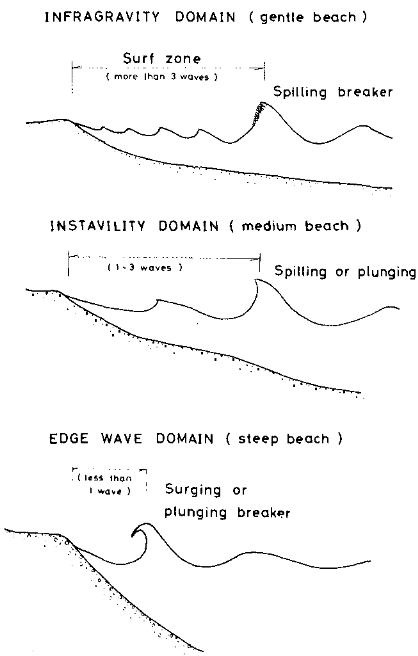

Fig. 15 Concept of three domains. (Sasaki, 1974)

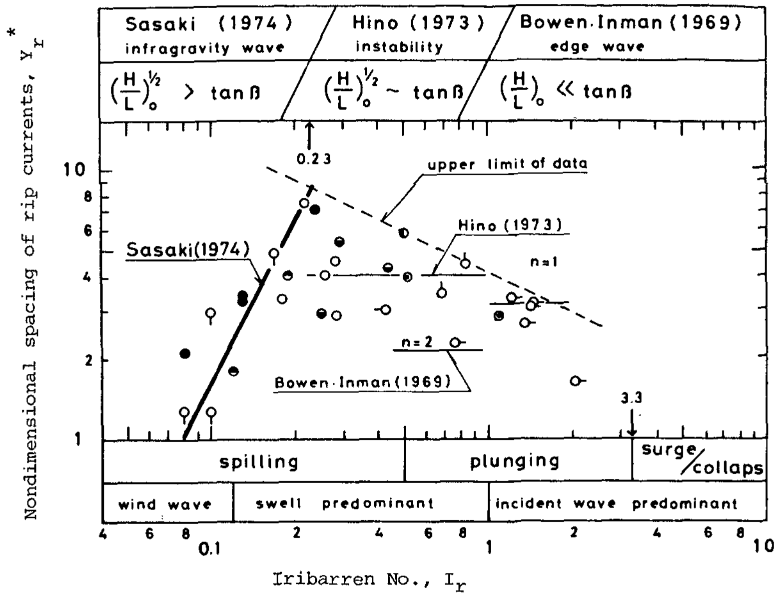

Fig. 16 Y_r^* and I_r (Sasaki, 1974).

Infragravity Low Mode Edge Waves

Figure 17 shows an example of infragravity wave spectrum in the surf zone observed in March, 1976 on Ajigaura Beach. The breaker height at that time was around 3 m. As the width of the surf zone was very wide over 300 m, the 6 wave staffs which were used were all placed in the surf zone. The water surface fluctuations were measured by using 16 mm memomotion cine-cameras.

These three spectra show the results from offshore arrangement of sensors along a pier. There are two dominant peaks. The right peak shows an incident wave peak of 13 sec. The other one is an infragravity wave peak of around 50 sec. In the swash zone(C), the gravity wave peak disappears, and only the infragravity wave peak can be seen. The result of a cross-spectrum analysis by BMD-02T reveals the existence of a nodal line parallel to the shore between B and C sensors.

Figure 18 shows the results from a longshore arrangement of sensors at the same time. In this case, 4 alongshore sensors were located close to the shoreline, so the gravity wave peaks are lower than infragravity wave peaks. The energy levels are somewhat larger than those offshore, and a secondary low frequency peak is found at around 2 min wave period. In each of 6 spectra, the wave height of the infragravity waves is 40 cm to 60 cm.

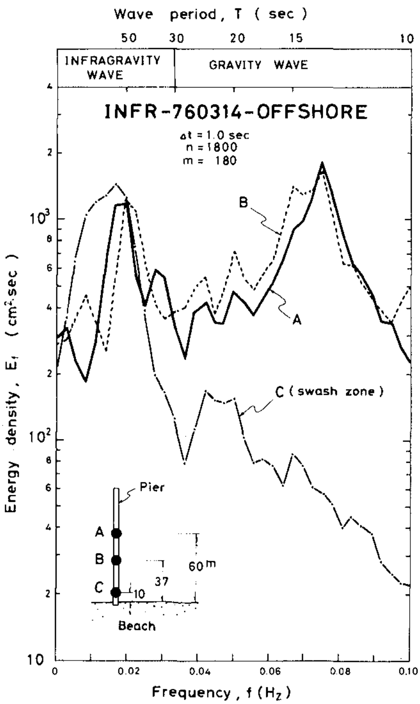

Fig. 17 On-offshore infragravity wave spectrum (March,1976).

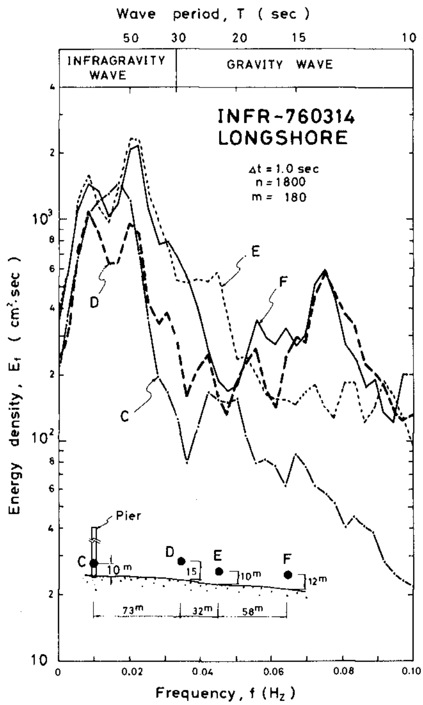

Fig. 18 Longshore infragravity wave spectrum (March,1976).

An offshore profile of a relative wave height is shown in Fig. 19. The thick solid curve indicates the infragravity low mode edge waves [Eckart (1951)] with an offshore modal number, n = 1. Similar result was obtained also on December 18, 1975 (Fig. 20) when the STEREO-BACS was carried out. The short length of the pier prevented us from detecting a perfect envelope of a wave height profile. The case in which a nodal line perpendicular to the shoreline was observed has been reported by Sasaki and Horikawa(1975).

It is very difficult to measure the perfect configuration of edge waves in the field, because numerous wave sensors or flow meters are required to detect it. However, most of our observations carried out on a gently sloping beach show an existence of low mode(n = 1 and/or 2) edge waves with infragravity wave frequencies.

Similar results have been shown by Inman and Guza(1976) on the Scripps Beach behind the La Jolla Canyon, and their periods were 70 to 80 sec. Guza and Bowen(1975) and Guza and Inman(1975) introduced Gallagher's(1971) work on surf beat generation; that is incident gravity wave frequency and directional spectra allow infragravity edge wave (30 to 150 sec) excitation through the interaction of different gravity wave components. As for the

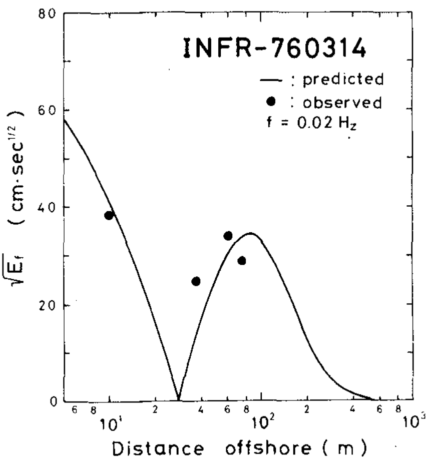

Fig. 19 Infragravity low mode edge wave profile (March,1976).

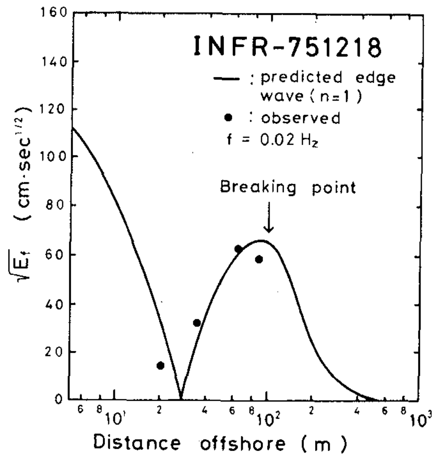

Fig. 20 Infragravity low mode edge wave profile (Dec.,1975).

cause by nonlinear interactions through different wave frequencies, Yoshida (1950) also derived the generation of 1 to 3 min infragravity waves. As pointed out by Isaacs et al.(1951), surf beats might be, in fact, infragravity low mode edge waves, if some condition [Carrier and Greenspan (1958)] that can be also expressed by Iribarren No. I_r, is satisfied.

Regarding amplitudes of infragravity waves (surf beats), with those periods larger than 20 sec, Goda(1975) has shown several observational results in the surf zone, and revealed that the amplitude of infragravity waves may amount to 40 % of that of offshore waves. This value of 40 % is fairly large compared to that of Tucker(1950) obtained outside the surf zone. This difference may be due to the infragravity edge wave resonances in the surf zone.

The above mentioned several works on infragravity waves, though not fully organized, suggest the validity of the Infragravity Domain Hypothesis, however, further research is needed concerning precise coupling mechanism between nearshore currents, infragravity waves and nearshore topographies on a gently sloping beach.

SUMMARY AND CONCLUSION

1) The authors developed a new field observation system called STEREO-BACS based on a principle of stereophotogrammetry by which simultaneous measurements of a spatial distribution on waves and currents in the nearshore zone can be obtained. Also a broader coverage is achieved compared to the previous system [BACS, Horikawa and Sasaki(1972)].

2) The STEREO-BACS was applied on Ajigaura Beach, Japan, facing the

Pacific Ocean in December, 1975, and observations including infragravity waves and mean water surface elevations were carried out. In this obsevation, the authors succeeded in catching an entire process of one circulation for the first time.

3) The obtained wave height distribution in the surf zone shows that the rip current flows out at the location where the breaker height is minimum on the breaker line, and the main stream of nearshore currents selects its path where the wave height is lower in the surf zone.

4) Concerning a mean water surface elevation, it is observed that the maximum difference in water surface reached about 40 cm, and longshore currents flow like a river in the surf zone.

5) Based on the above observation, an estimate of a relative significance of a pressure term with a convective term could be made quantitatively, and it was found that the convective term has a magnitude of from 1/3 to 1/5 of the pressure term near the rip current.

6) Our numerous field observations, Goda's(1975) observation, and Gallagher 's(1971) work on infragravity waves suggest the existence of infragravity low mode edge waves with significant amplitudes which can cause nearshore circulations through bottom perturbation, and thus support the Infragravity Domain Hypothesis on a gently sloping beach [Sasaki(1974,1975), Sasaki and Horikawa (1975)]. The typical periods of infragravity waves observed are around 1 min.

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