OBSERVATION OF NEARSHORE CURRENT AND EDGE WAVES

by

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ABSTRACT

Nodal lines normal to the shoreline of infragravity low mode edge waves in the nearshore zone were observed with eleven wave staffs simultaneously with the nearshore current spatial velocity field on a gently sloping beach. About five peaks were found in the energy spectrum and their frequencies agreed well with cut-off mode edge waves [Huntley(1976)]. Based on the above observation, conceptual models of nearshore current patterns for the infragravity domain are proposed and general current patterns for the three domains are discussed by combining the horizontal patterns of Harris(1969) and the vertical patterns of Sasaki et al.(1976).

INTRODUCTION

Since the publication of the rip current theories of Bowen(1967) and Harris(1967) which attribute the generation mechanism of rip currents to the interaction between incoming waves and gravity edge waves, numerous theories on rip current generation have been proposed regarding causes of longshore perturbations: these are wave perturbations due to synchronous edge waves [Harris(1967), Bowen(1967)], bottom perturbations [Bowen(1969), Sonu(1972), Noda(1972), Sasaki(1975), Birkemeier and Dalrymple(1975)], cross waves [Dalrymple(1975), Maruyama(1976)], infragravity low mode edge waves [Sasaki(1974), Sasaki and Horikawa(1975), Sasaki et al.(1976), Horikawa(1978a)], surf beats [Bowen and Inman(1969)], wave diffraction [Liu and Mei(1974), Hashimoto and Uda(1974)], an instability mechanism [Hino(1973)], Mizuguchi(1976), Dalrymple(1978)], and wave-current interaction [Dalrymple(1978)]. The numerousness of such generation theories implies the complexity of the phenomena, and multiple causes would be possible simultaneously.

Through use of the Battjes'(1974) surf simularity parameter, Sasaki (1974) pointed out that Bowen and Inman's(1969) gravity edge wave mechanism is applicable to steep beaches where synchronous and subharmonic edge waves are excited [Guza and Inman(1975)] and proposed the Infragravity Domain Hypothesis for gentle beaches where infragravity low mode edge waves should control rip current spacing.

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Recently, more dynamical and comprehensive models have been proposed by Chappel and Wright(1978), Wright, Thom, and Chappel(1978), and Short(1975, 1978) regarding the interaction between incident wave spectrum, currents, and beach morphology, and they uncovered the role of infragravity waves on the morphodynamics of dissipative beaches [Guza and Inman(1975)], or in the authors' terminology, beaches in the infragravity domain. Also, several researchers have shown that the previously termed surf beats are in fact infragravity low mode edge waves [Sasaki, Horikawa, and Hotta(1976), Meadows(1976), Huntley(1976), Sasaki, Horikawa, and Kubota(1977), Fujinawa, Okada, and Watabe(1977), Huntley, Guza, and Bowen(1977), Bowen and Guza(1978), Holman, Huntley, and Bowen(1978), Nakamura et al.(1978)].

In the present paper the authors deal with the simultaneous obserbation of the spatial nearshore current field and infragravity low mode edge waves, carried out in the end of August, 1976, on Ajigaura Beach, Japan. Also, the unsteady current pattern change was observed with a newly adopted Hasselbrad 100 ft magazine in place of the previously used smaller 15 ft magazine. Based on these observations a conceptual model of nearshore current patterns is proposed in considering infragravity low mode edge waves.

Figure 1. Overview of Ajigaura Beach(1:30 p.m., 21st October, 1976).

STUDY SITE

The field observation was carried out on Ajigaura Beach which faces the Pacific Ocean(Fig. 1), and which is located 100 km north-east from Tokyo. On this beach is sited a sediment research pier 200 m long(Fig. 1), built by the Public Works Research Institute, Ministry of Construction [Hashimoto and Uda(1976)]. A headland is located about 1 km from the pier, as shown in the Figure. The beach slope is 1/40 ∿ 1/70. Under ordinary wave conditions, the pier head extends outside of the surf zone.

Figures 2 and 3 show the results of a previous current spacing survey taken on February, 1973 [Sasaki and Horikawa(1975)]. The current speed and direction were measured at midsurf by divers with a tethered float, at a wading depth of about 1 m. In this example, rip currents were equally spaced at 400 m intervals. Figure 3 shows the longshore distribution of longshore components of measured current speeds. The location of rip currents can be defined where the curve crosses the horizontal axis. With close examination of the velocities between rip currents, several seemingly periodic fluctuations can be observed. The authors felt this fluctuation could be due to the coexistence of multiple edge waves existing at that time. Concerning spatial longshore current velocity fluctuations as in this case, Meadows(1976) also presented time dependent fluctuations recorded with flowmeters, attributed to low mode edge waves.

Figure 4 shows a photograph taken with a balloon-borne camera system, BACS [Sasaki et al.(1976)], launched from the pier seen at the center of the photograph, on the 29th August, 1976. This day is the last Sunday of the Japanese school summer vacation. A surfing contest was being held on the right-hand side of the pier, and many cars were parked on the beach. Unfortunately STEREO-BACS to obtain wave height fields [Sasaki et al.(1976)] was failed.

The breaker height and period were 1.2 m and 13 sec respectively, and the wind speed was 3m/s from the south-east. The width of the surf zone was about 100 m, and two waves were observed in the surf zone. Because the pier is 200 m long, the size of the coverage is about 400 m alongshore by 250 m offshore. Eleven letters, from A to K, give the locations of wave staffs, and all of them except "I" on the pier are in the surf zone. The staff array is distributed in an area that coveres 200 m alongshore and 140 m offshore. There are 4 staffs attached to the pier piles(K, G, H, and I) in the offshore direction. The water surface fluctuations were filmed with 16 mm memo-motion movie cameras, Bolex H16-SBM, at one second intervals.

The surf zone beach topography up to 3 m depth(Fig. 5) was measured just after the current and wave measurements. No clear rip channels could be defined but the 1 m depth contour-line showed a depression around the pier. The average beach slope up to 2 m was about 1/60. The depth of the furthest offshore wave staff "I" was about 2.5 m.

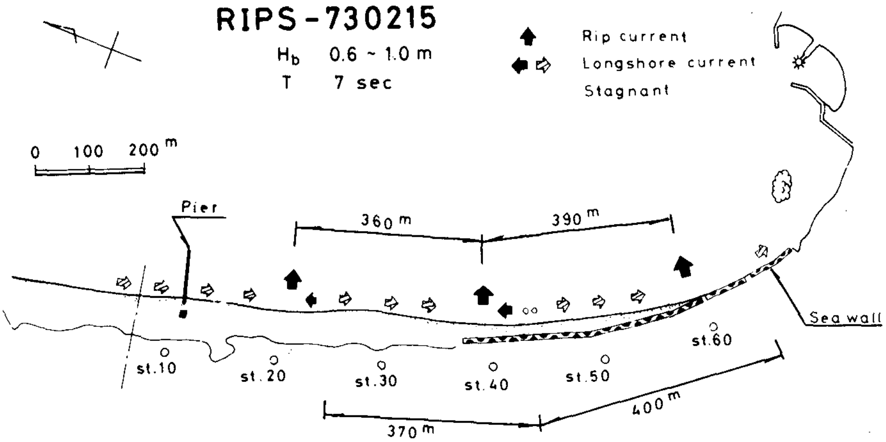

Figure 2. Evenly spaced rip currents on Ajigaura Beach(RIPS-730215), (Sasaki and Horikawa(1975)).

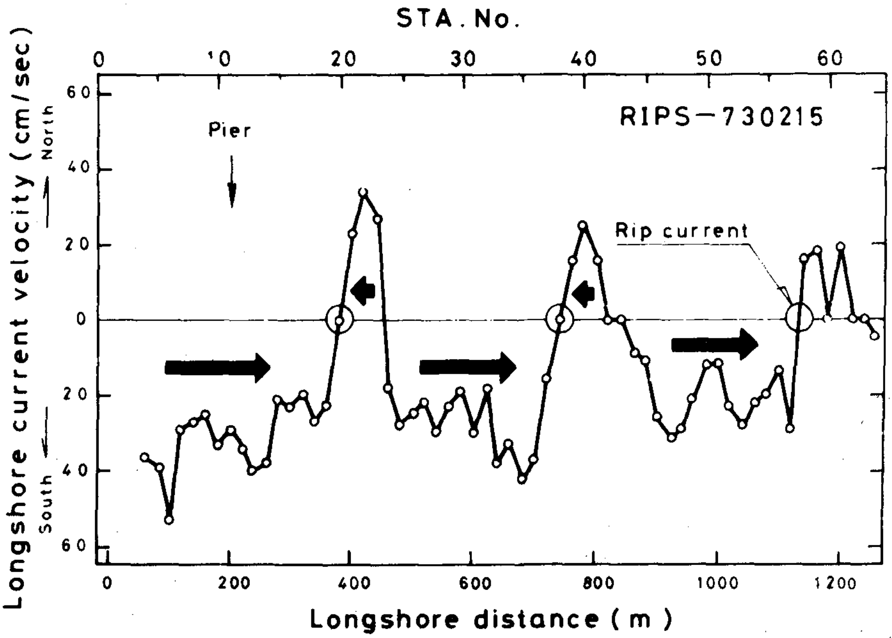

Figure 3. Alongshore distribution of longshore current velocities (RIPS-730215), Sasaki and Horikawa(1975).

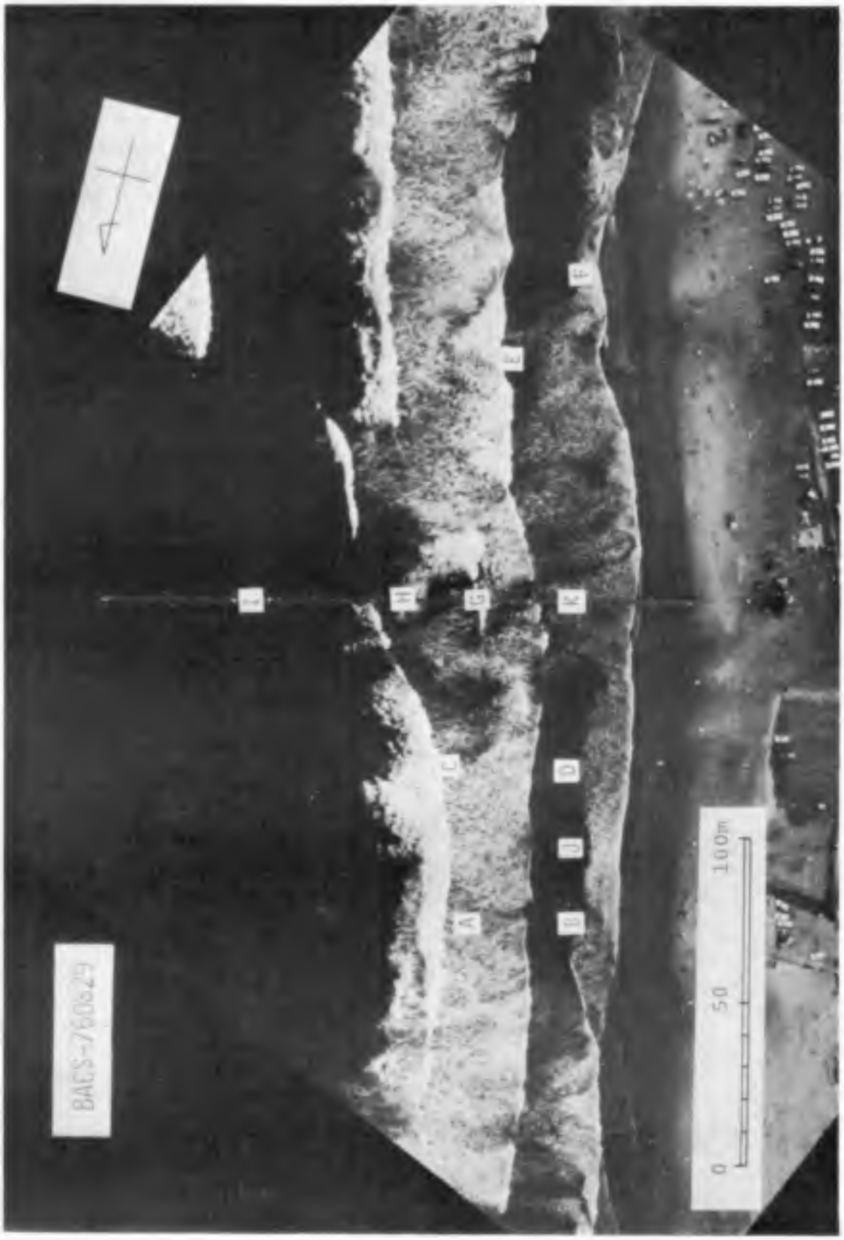

Figure 4. Observation area and instrument locations, August 29, 1976, Ajigaura Beach.

NEARSHORE CURRENT PATTERN FLUCTUATION

Up to 1975, the authors had used a Hasselblad 15 ft magazine which permitted only 70 frames. Because the shutter interval adopted is close to the wave period, i.e., 10 s to 15 s, the observation time was therefore limited to a synoptic measurement of only 10 min to 15 min. However, a longer observation period became possible by utilyzing a newly developed 100 ft magazine which allows 480 frames. This enabled a 37 minite continuous measurement at 15 s intervals at on altitude of 240 m. The resultant 150 frames were split into 3 stages, each consisting of 50 frames, and the nearshore current pattern change during these 3 stages over 37 minutes was analyzed.

Figure 6 shows float velocity vectors for the 3 stages. The water enters the surf zone from the left-hand side of the pier, and branches off to the left and to the right forming longshore currents. A part of the latter longshore current enters a small rip current around the pier, and the remaining longshore current moves away furtehr to the right. The maximum longshore current velocity is about 70 cm/s and the average velocity range is 40 to 50 cm/s. The sparse distribution of floats at Stage III is due to diver fatigue from the strenuous work maintained over half an hour.

There is no major rip current or well defined rip channel in this coverage. The rip current seen around the pier is weak and not a major

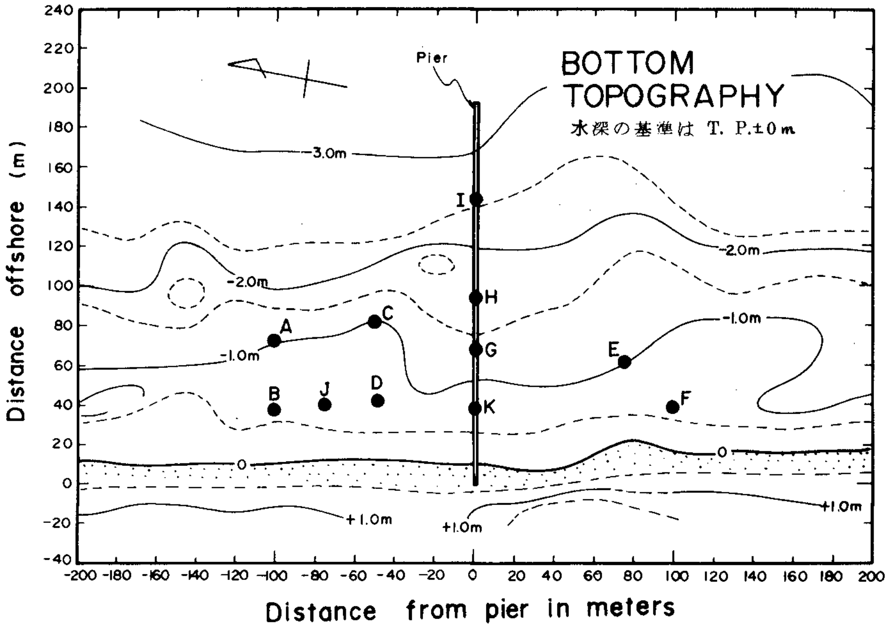

Figure 5. Surf zone topography surveyed on 29th August, 1976.

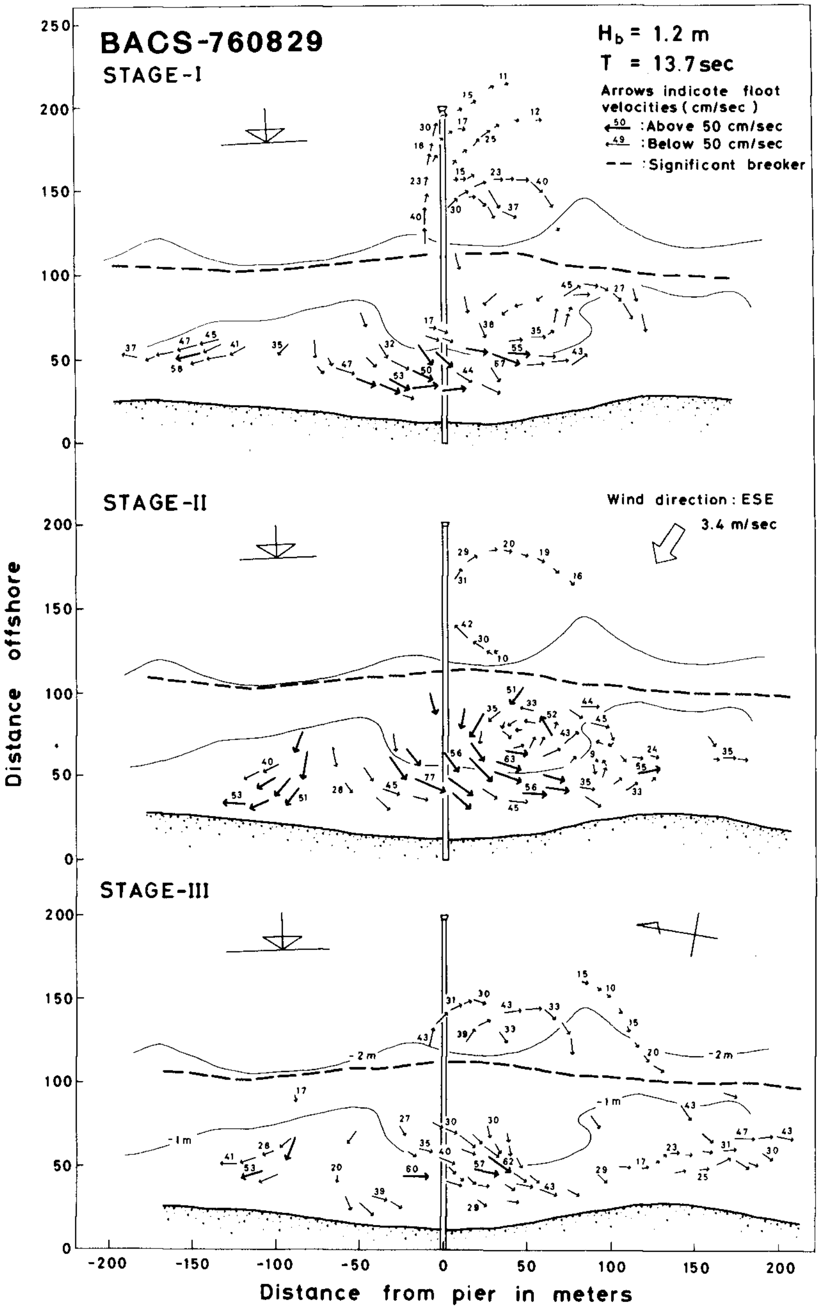

Figure 6. Float velocity vectors for the three 12 min. observation.

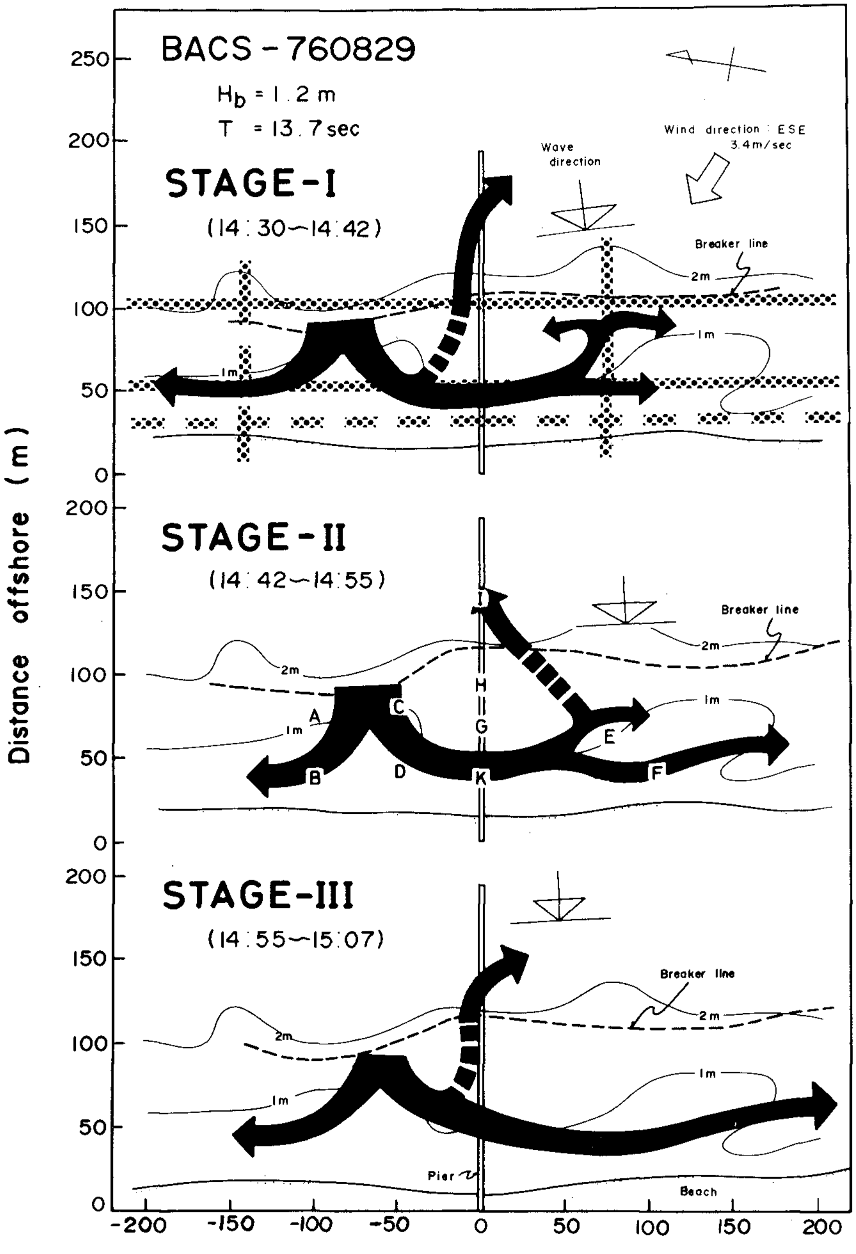

Figure 7. Nearshore current pattern change and associated nodal lines.

one; the current path also seems to be very unstable and unsteady. The maximum velocity is about 40 cm/s.

Figure 7 shows the current pattern change. The longshore current is strong and steady throughout the 3 stages. The reason that the weak rip current is very unsteady may be due to absence of a clear rip channel. A rather wider embayment is formed as seen on the 1 m depth contour line at both sides of the pier. The width of the bottom depression in the surf zone makes the small rip current fluctuate.

The thatched lines in the top diagram indicate the observed nodal lines of edge waves to be mentioned later. The shore parallel nodal line nearest to the shoreline should lie in the swash zone("swash node"), the second one appears to correspond to the main stream of the longshore current("longshore current node"), and the third one appears to coincide with the breaker line("breaker node").

OBSERVATION OF INFRAGRAVITY LOW MODE EDGE WAVES

Observation of the water surface fluctuations was carried out simultaneously with that of the nearshore current. The data obtained from the eleven wave staffs were digitized and analyzed by BMD-02T, i.e., cross-spectrum analysis with $\Delta t = 1$ s.

Figure 8 shows the spectra of input waves around the breaker line "H" and swash zone "K". In the breaker wave spectrum of "H", a broad peak from 6 to 14 s is seen, which, when closely examined, reveals three peaks at 7, 9, and 13 s. In contrast to the input waves, a maximum peak appears in the infragravity wave region, that is, around 40-50 s. Then, to increase the resolution for infragravity waves, data were resampled with $\Delta t = 3$ s after smoothing, and a cross-spectrum analysis was applied.

The power spectra, coherence squared, and phase angle, respectively, for the 11 wave staffs are shown in Figure 9. The left-hand diagram shows the onshore-offshore array attached to the pier, and the middle and the right-hand diagrams are the results from the longshore array. The middle one is the result from the array arranged about 50 m from the shoreline(A, C, G, and E), and the right side is from the array 15-20 m from the shore(B, J, D, and F). In the left-hand diagram,

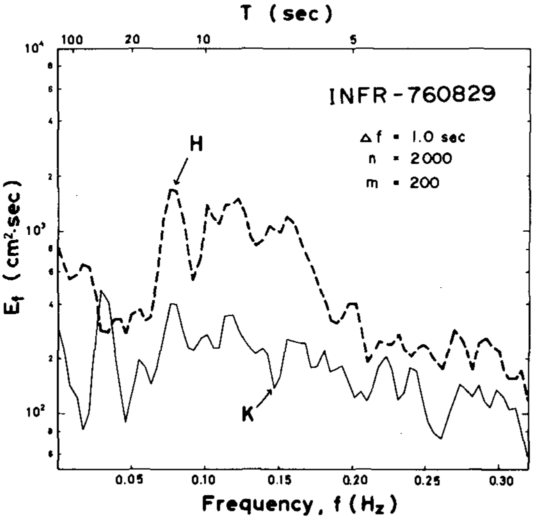

Figure 8. Input wave(H) and swash wave (K) spectra.

Table 1. Nodal lines parallel to the shoreline(INFR-760829).

Peak frequency (Hz)	Wave period T(sec)	Distance of nodal line from shoreline, x(m)			
		n = 1	n = 2	n = 3	n = 4
0.010 (n = 1)	100	90			
0.020 (n = 2)	50	20	100		
0.030 (n = 3)	33	(10)	50	130	
0.039 (n = 4)	26	(6)	30	80	(150)

tanβ = 1/40, n: offshore modal number, ( ): inferred.

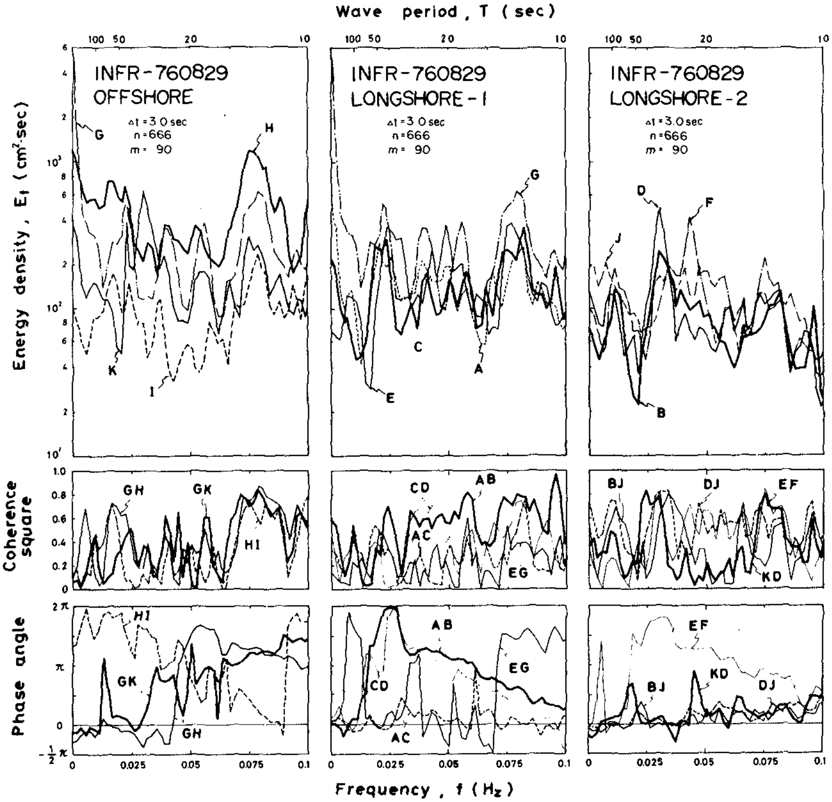

Figure 9. Wave energy density, coherence squared and phase angles for 11 wave staffs.

i.e., the spectrum along the pier, "I" is located the furthest offshore and distant from the surf zone, while "K" is located nearest to the shoreline.

From phase angles, the characteristics of standing waves appear in those waves longer than about 20 s(0.05 Hz). The lowest oscillation occurs in the "G" spectra, which is located along the pier at the mid-surf position. In the power spectrum, about five peaks around 0.01, 0.02, 0.03, 0.04, and 0.05 Hz can be found.

From the phase angles, it is interpreted that each peak is associated with one or two nodal lines parallel to the shore as shown in Table 1. The distance from the shoreline is evaluated from Eckert's (1951) edge wave theory by using a beach slope of tanβ = 1/40. The distances in parenthesis in the Table indicate inferred nodal lines which could not be confirmed due to the wave staff arrangement. The quantity "n" is an offshore modal number, and each peak frequency corresponds to n = 1, 2, 3 and so forth, respectively.

Regarding the nodal lines normal to the shore, proof of edge wave existence can be found in the 0.04 Hz and 0.05 Hz peaks. For lower frequency waves, nodal lines normal to the shore could not be detected due to the narrow distribution of the wave staffs. Huntley(1976) presented the excitation of cut-off low mode edge waves by applying Ball's (1967) edge wave theory for concave beach profile to his field observation. Ball gave a solution for the exponential bottom profile defined as

$$h/h_\infty = 1 - e^{-\alpha x} \qquad (1)$$

where h is the water depth, x is the distance offshore, and h_∞ and α are constants determined form the bottom profile. When x tends to infinity, αh_∞ tends to tanβ, the beach slope. Defining ν as a peak frequency, ν is simply given as a function of n and bottom profile, that is α and h_∞, as shown by Huntley(1976)

$$\nu = \frac{\alpha\sqrt{gh_\infty}}{2\pi}\sqrt{n(n+1)} \qquad (2)$$

Here, n and g are the offshore modal number and acceleration due to gravity, respectively. Equation (2) was derived from a critical condition of Ball's edge wave excitation, that is, the cut-off mode edge waves. This expression means that if the bottom profile or topogra-

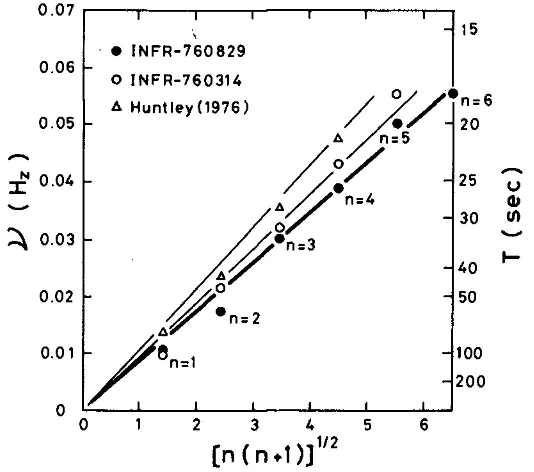

Figure 10. Peak frequency ν verses edge wave modal number n.

graphy were given, the peak frequency of edge waves could be obtained, and also suggests a coexsitence of multiple modes of edge waves as suggested in Figure 3.

Figure 10 is a plot of ν and n. Also shown in this figure are the infragravity low mode edge waves observed on March, 1976 [Sasaki et al. (1976)] on Ajigaura Beach, as well as Huntley's(1976) results. These results agree well with the empirical fact that in many of our field observations, we have found several minor rip currents between two neighboring major rip currents or, in other words, rip currents are strengthened selectively by the super-position of multiple mode infragravity low mode edge waves. Figure 11 is an example from a 1972 observation on Kujuukuri Coast, east of Tokyo. Very large rip currents developed evenly with a 600 m spacing in the middle part of the stretch, and between them, several minor rip currents are seen.

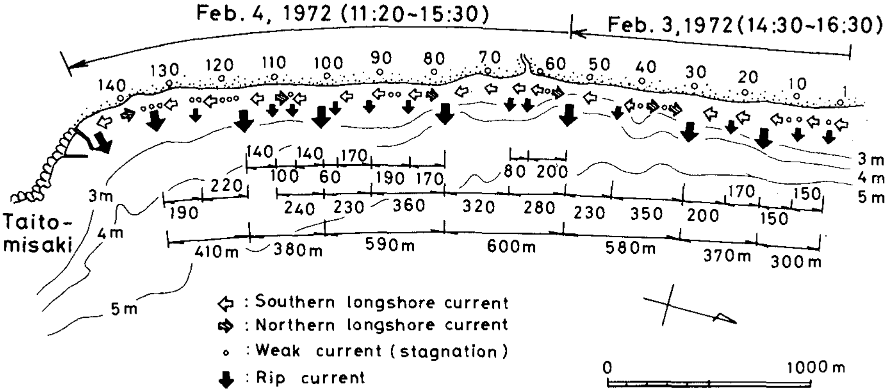

Figure 11. Rip current spacing distribution observed on February, 1972, on southern end of Kujuukuri Coast, Horikawa, Sasaki and Igarashi(1972), Horikawa(1978b).

TRANSFORMATION OF POWER SPECTRUM ACROSS THE SURF ZONE

In the morning of the same day as the above described current and edge wave observation, observation of the onshore-offshore transformation of the power spectrum across the surf zone was performed using 4 wave staffs along the pier, to study the behavior of such infragravity low mode edge waves near the surf zone. Power spectra from 4 wave staffs arranged along the pier, that is, "E", "G", "H", and "I" and plotted in Figure 12. Only "I" is located outside the surf zone, and "E" is located in the swash zone. A very wide spectrum exists outside the surf zone, but in the surf zone higher frequency waves above 0.2 Hz(5 s) are attenuated due to breaking; further, only waves lower than 0.05 Hz(20 s) exist in the swash zone. In contrast with these, waves below 0.05 Hz are not seen outside the surf zone. These infragravity waves are believed to be

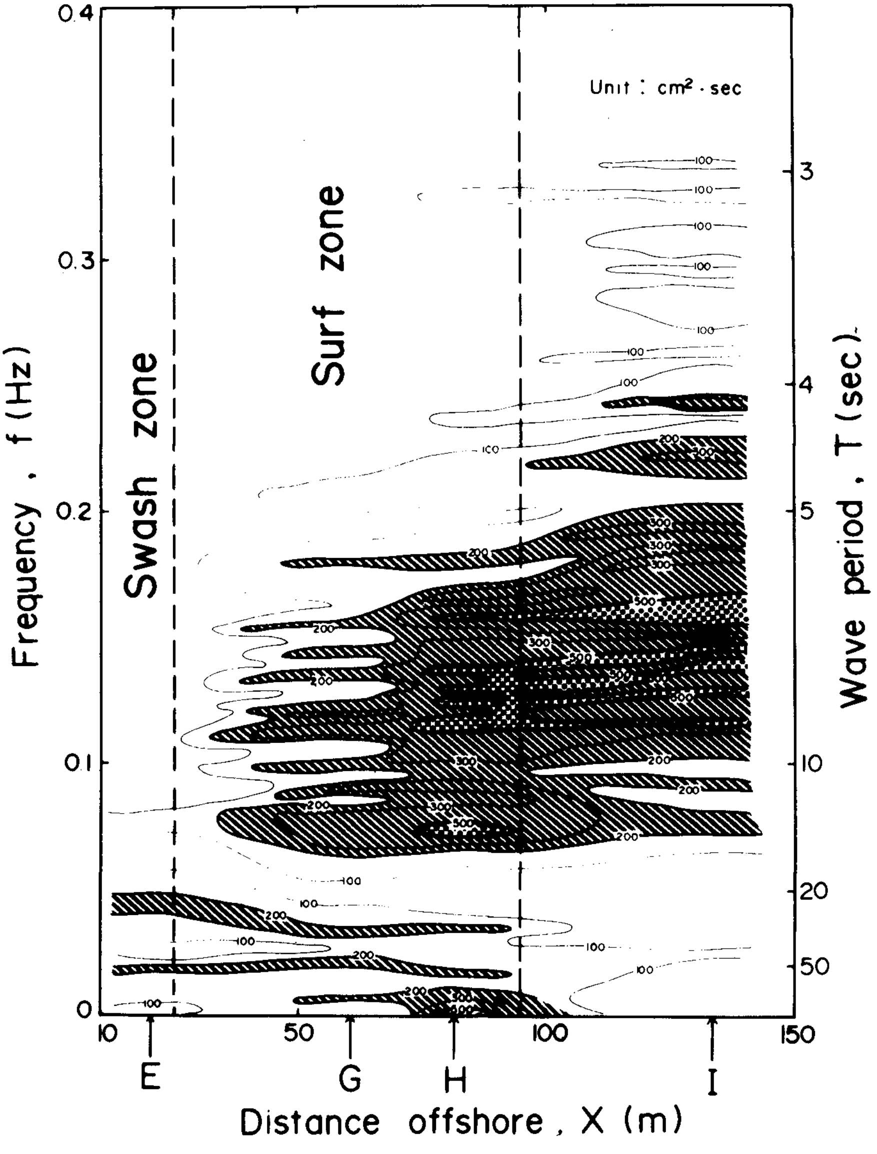

Figure 12. Onshore-offshore wave energy density transformation along the pier.

excited in the surf zone by receiving energy from the gravity waves outside of the surf zone.

CONCEPTUAL MODEL OF THE NEARSHORE CURRENT PATTERN

In conclusion, a conceptual sketch of the nearshore current pattern in the infragravity domain is presented(Fig. 13). Firstly, assuming the existence of multiple mode infragravity edge waves, it is possible to explain in the super-position of major and minor rip currents. Here, a "major" and a "minor" rip current are defined respectively as one which penetrates the breaker line from the surf zone and one which is totaly confined to the surf zone. The shapes of the corresponding rip heads differ as illustrated. The number of minor rip currents contained between neighboring major rip currents depends on the frequency of the modes. The major three nodal lines parallel to the shore could be termed as

1) "breaker node"
2) "longshore current node", and
3) "swash node"

since the breaker node appears around the breaker line, the longshore current node appears to correspond to the location of the main stream of the longshore current and the swash node appears to be located in the swash zone.

In our experience, waves break close to the shoreline in the lee of a rip current, because the rip channel is deep and does not satisfy breaking criteria under ordinary wave conditions. Thus the plan shape of a shoreline behind a rip channel is somewhat enbayed and has a steep foreshore slope. Two longshore currents from opposite directions meet almost midway in the surf zone resulting in a rip current, and behind this a stagnant zone is produced as shown in the Figure.

Figure 14 gives a more general conceptual model of nearshore current patterns for the three domains [Sasaki(1974), and Sasaki and Horikawa (1975)] combined with the plan view of Harris(1969) and the cross sectional view of the surf zone of Sasaki, Horikawa and Hotta(1976). These three conceptual models can be connected in a probabilistic sense. However, the model proposed here appears to be rather static. From the recent morphodynamic results of Wright, Thom, and Chappel(1978), and Short(1978), various dynamical transition patterns are suggested for the instability domain or asymmetrical cellular circulation system between two typical current patterns, i.e., the infragravity domain and the edge wave domain.

Both domains can be connected with their beach types or stages as in Table 2. To link with the beach type evolution models of Wright et al. (1978) and Short(1978) and to clarify current field associated with them would produce fruitful understanding of the precise coupling mechanism between edge waves, currents and beach topography.

Table 2. Comparison of terminology on wave, current and beach types

Sasaki(1974)	Guza and Inman (1975)	Wright et al. (1978)	Short(1978)
Infragravity domain	Dissipative system	Type 1	Stage 6
Edge wave domain	reflective system	Type 6	Stage 1

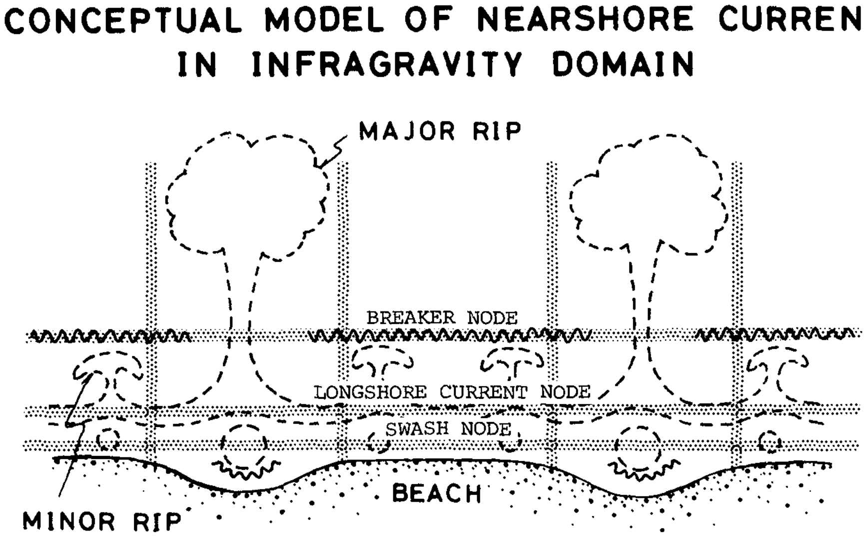

Figure 13. Conceptual model of nearshore current in infragravity domain.

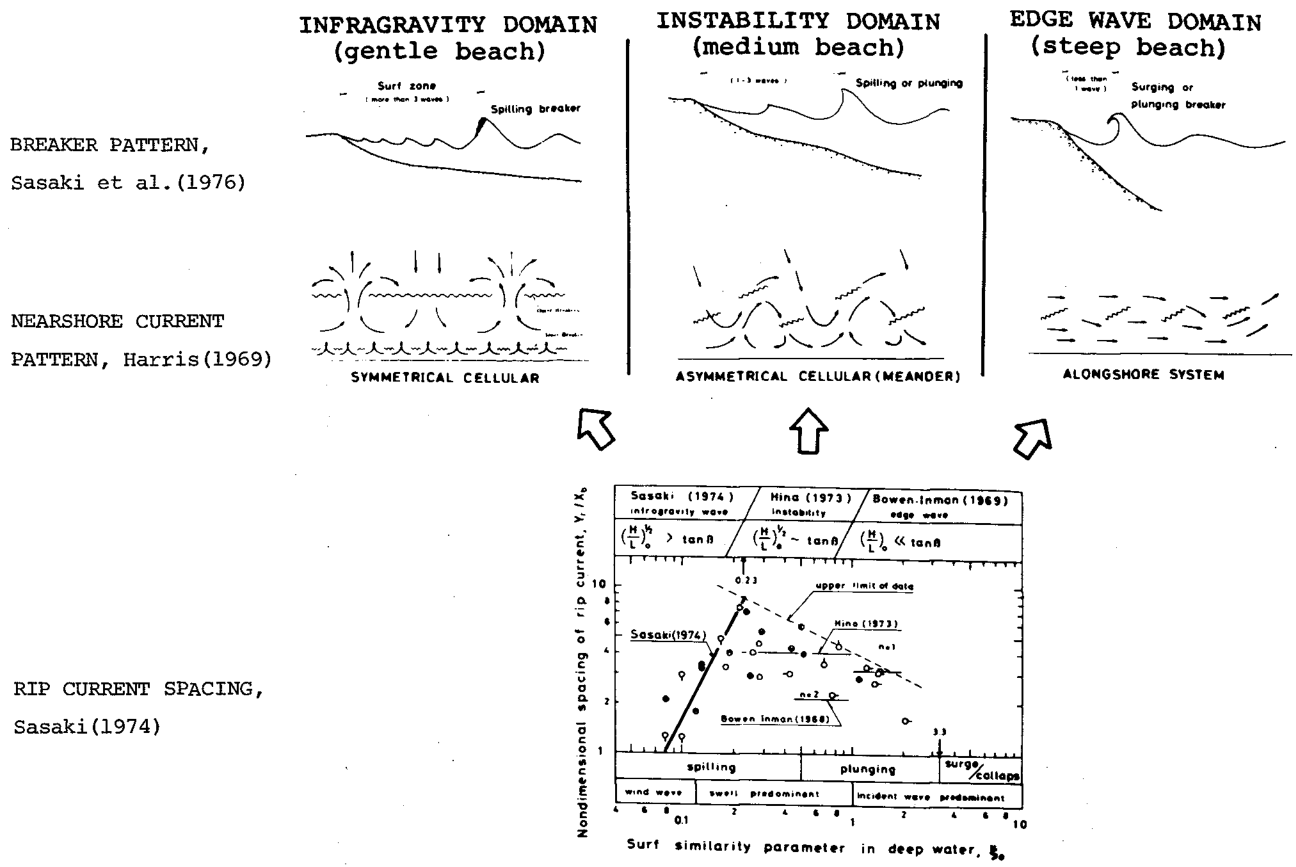

Figure 14. Conceptual model of three typical nearshore current patterns

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