CHAPTER 60

Field Observation of Surf Beats Outside the Surf Zone

Tsunehiro Sekimoto[1], Takuzo Shimizu[2] , Kosuke Kondo[2]
and
Yasuhiro Kubo[3]

Abstract

Field observations of waves were conducted inside and outside a harbor in order to study the behavior of surf beats. From the observations, it is confirmed that surf beats propagate as bounded long waves at depths of 13 to 15m, whereas they behave as free waves in the harbor. It is found that the amplitude of bounded long waves become 20% of the ordinary-wave amplitude when the ordinary-waves height is 5 m.

1. Introduction

Since the surf beats, which are water surface fluctuations with long periods of 1 to 5 minutes, were first observed by Munk (1949) and Tucker (1950), their characteristics have been investigated by means of field measurements and laboratory experiments by many researchers, e.g. Hotta et al. (1981), Kimura (1984), Kostence (1984), List (1988), Mansard and Barthel (1984), Ottesen-Hansen (1978), Ottesen-Hansen et al. (1980), Sand (1982), Sharma and Dean (1979), Symonds et al. (1982), Symonds and Bowen (1984). It is pointed out that surf beat plays an important role in the sediment transport in the surf zone, the slow drift oscillation of a moored vessel, the resonant edge wave growth and the harbor resonance.

[1]Penta-Ocean Construction Co. Ltd., 1-11-25 Higashiohi, Shinagawa-Ku, Tokyo 140, Japan.
[2]Penta-Ocean Construction Co. Ltd., 2-2-8 Koraku, Bunkyo-Ku, Tokyo 112, Japan.
[3]Tokyo Electric Power Co. Inc., 1-1-3 Uchisaiwaicho,Chiyoda-Ku, Tokyo 100, Japan.

Outside the surf zone, it is suggested that surf beat exists as a bounded long wave (Longuet-Higgins and Stewart, 1962). However, few field data, which show that surf beats are bounded and how much the magnitude of bounded long wave is, have been observed. Moreover the behavior of the surf beat in an actual harbor is still unclear.

The aim of this study is to explain the characteristics of surf beat in the nearshore non-breaking zone and its propagation into the harbor on the basis of the field measurement data.

In this study the term of surf beat means long period fluctuation of mean sea level with 1 to 5 minutes periods irrespective of water depth.

2. Field investigations

Field investigations were conducted at two sites. One site was the port of Kashiwazaki-Kariwa nuclear power plant, Niigata prefecture, Japan, which is facing the Sea of Japan. This power plant was constructed in both Kashiwazaki city and Kariwa town, so we call it shortly Kashiwazaki-Kariwa. Another site was the port of Oharai, Ibaraki Prefecture, which is located at the Pacific Ocean side of Japan. The locations of these sites are shown in Figure 1.

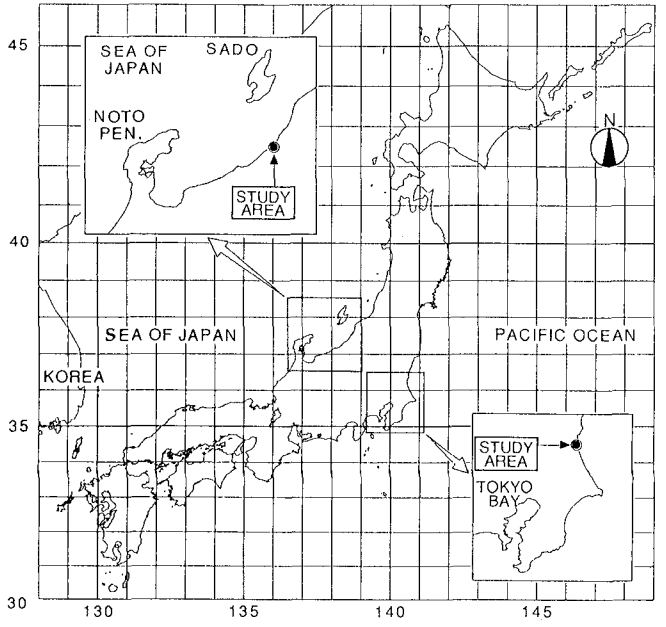

Figure 1. The location of the investigation site.

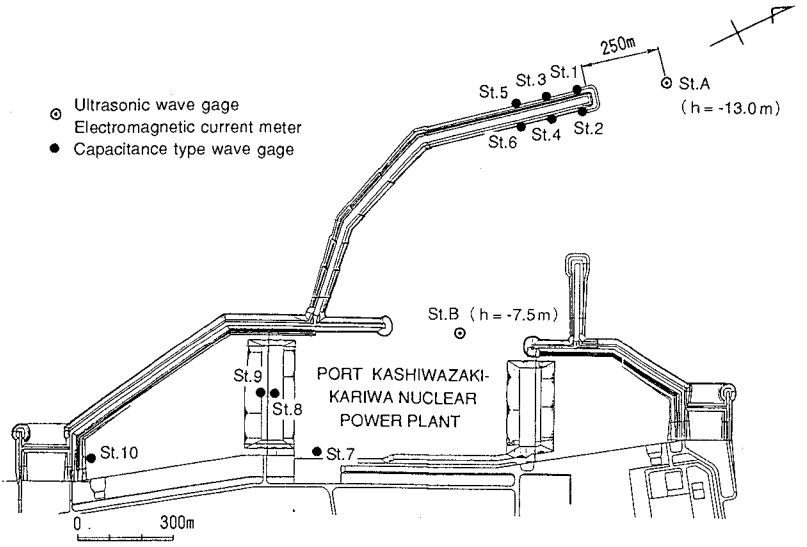

Figure 2. Location of observation points
(Port of Kashiwazaki-Kariwa Nuclear Power Plant).

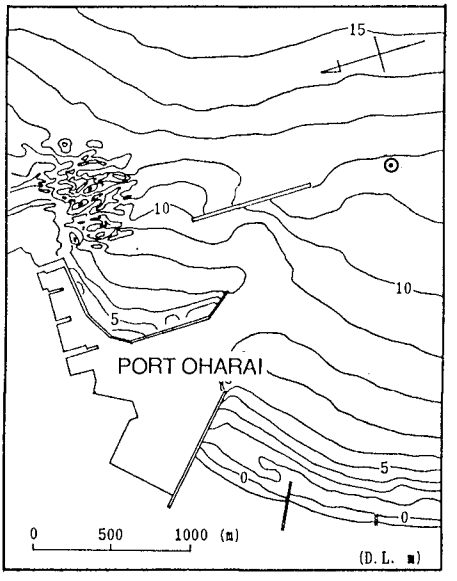

Figure 3. The location of observation point
(Port of Oharai).

At Kashiwazaki-Kariwa site, field measurements were carried out inside and outside harbor from January through March of 1989. Figure 2 shows the port of Kashiwazaki-Kariwa nuclear power plant. The tip of main breakwater is located at 13m depth. The locations of measurement instruments are shown in this figure. At St. A and St. B the water surface elevation and two components of horizontal current velocity were measured using both ultrasonic wave gage and electromagnetic current meter. The water depths of St. A and St. B are 13.0m and 7.5m, respectively. At St. 1 through St. 10, the water surface elevation was measured by capacitance type wave gages. Since the waves higher than 2m were observed only a few times at Kashiwazaki-Kariwa during this observation, the wave data obtained in January and March of 1987 which are a part of a long term study by Tokyo Electric Power Co. Inc. were also analyzed. In this long term observation, ultrasonic wave gage is laid 1.5 km from the shore line.

At Oharai site, field observations were carried out outside the harbor, from November through December of 1990. Figure 3 is the general view of the Oharai port. The locations of measurement instruments are shown in this figure. An ultrasonic wave gage and an electromagnetic current meter with pressure gage were set at a point of 500 m away from the end of offshore breakwater.

The fluctuations of water surface level, and of pressure and two components of horizontal orbital velocities at the bottom were measured. At both sites, wave data were sampled at 0.5 second intervals and more than 300 records of time series of 20 minutes long and 150 records of 40 minutes long were obtained. The profiles of surf beat were extracted from

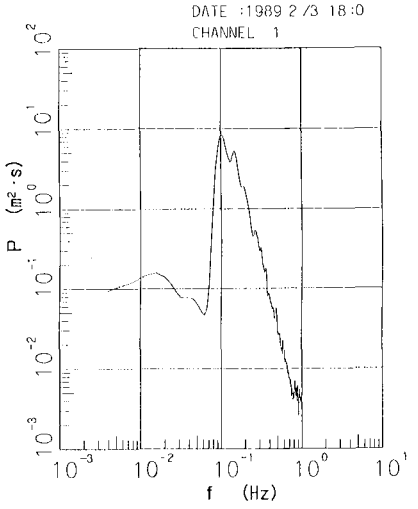

Figure 4. Typical wave spectrum at Kashiwazaki-Kariwa site.

those of water surface elevation and pressure by means of numerical filter. The cut off frequencies of numerical filter were 0.05 Hz for the data of Kashiwazaki-Kariwa and 0.04 Hz for the Oharai data which were determined from the results of power spectrum analysis. The extracted surf beats were used for various analyses. Typical wave spectrum at Kashiwazaki-Kariwa site is shown in figure 4. It is found that the peak frequency of ordinary-wave is about 0.1 Hz and the long wave energy is 2 orders below the peak energy of ordinary-wave.

3. Surf beats outside the harbor

Figure 5 shows the relationship between the significant wave height of ordinary-wave and that of surf beats at St. A. Under the condition of significant wave height higher than 1.5m, at the water depths of 13m the significant wave height of surf beats is proportional to the square of that of ordinary-waves. In this figure the calculation results estimated by unidirectional non-linear interaction theory (Ottesen-Hansen, 1978) and empirical relation proposed by Goda (1975) are also drawn.

The calculation by non-linear interaction theory is the average of 75 simulations of surf beat which are calculated from 75 simulated ordinary-waves using the procedure proposed by Sand (1982). In this calculation, the difference of the directions of ordinary-wave components is set to zero. The simulated 75 ordinary-waves were calculated from 3

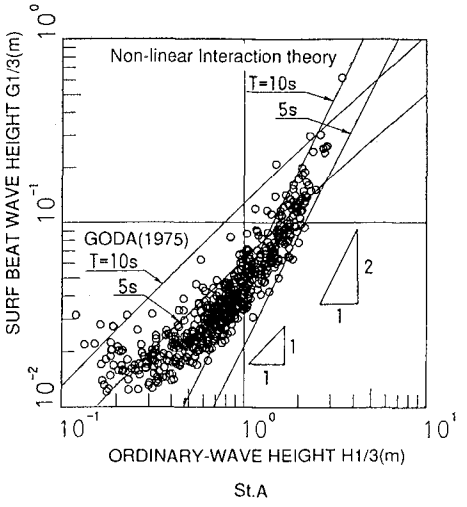

Figure 5. The relationship between the wave height of surf beat and that of the ordinary–wave height (St.A).

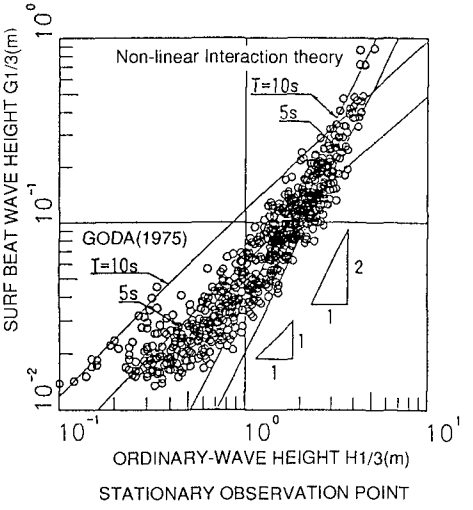

Figure 6. The relationship between the wave height of surf beat and that of the ordinary–wave height (Stationary observation point).

types of energy spectrum and 25 sets of phase angles of component wave. The calculation results estimated by non-linear interaction theories fit the field measurements very well. Figure 6 shows the relationship between the surf beat and the ordinary-wave height of long term observation by Tokyo Electric Power Co., Inc. It is confirmed that the relationship between surf beat and ordinary-wave is the same as the relationship which was found in figure 5.

The surf beat profile was simulated on the basis of the non-linear interaction wave theory proposed by Sand (1982) by using the observed ordinary-wave profile in the condition of approximately unidirectional wave. That is the difference of the directions of ordinary-wave components is set to zero.

$$\zeta = \sum_{i-j=1}^{\infty} \sum_{j=1}^{\infty} \sum_{m_j=1}^{\infty} \sum_{n_j=1}^{\infty} \xi_{ij}, \tag{1}$$

where

$$\xi_{ij} = a_i a_j G_{\eta\xi} \cos\left(\psi_i - \psi_j\right), \tag{2}$$

$$G_{\eta\xi} = \frac{1}{2h}\left[\frac{G' - k_i h \cdot k_j h \cos\theta_{m_i n_j} - 16\pi^4 D_i^2 D_j^2}{4\pi^4 D_i^2 D_j^2} + 4\pi^2\left(D_i^2 + D_j^2\right)\right], \tag{3}$$

$$G' = \left\{\left(D_i - D_j\right)\left[D_j\left(k_i^2 h - 16\pi^4 D_i^4\right) - D_i\left(k_j^2 h - 16\pi^4 D_j^4\right)\right]\right.$$
$$\left. +2\left(D_i - D_j\right)^2\left[k_i h \cdot k_j h \cos\theta_{m_i n_j} + 16\pi^4 D_i^2 D_j^2\right]\right\} / \tag{4}$$
$$\left\{\left(D_i - D_j\right)^2 \bar{k_{ij}} h \tanh \bar{k_{ij}} h\right\}$$

$$\psi_i = \mathbf{k}_i \cdot \mathbf{x} - \sigma_i t + \varepsilon_i, \tag{5}$$

$$D_i = \sqrt{\frac{h}{g}}\frac{\sigma_i}{2\pi}, \tag{6}$$

$$\theta_{m_i n_j} = \theta_{m_i} - \theta_{n_j}, \tag{7}$$

$$\bar{k_{ij}} = \left|\mathbf{k}_i - \mathbf{k}_j\right| \tag{8}$$

$$\mathbf{k}_i = \left(k_i \cos\theta_{m_i}, k_i \sin\theta_{m_i}\right), \tag{9}$$

and k_i and σ_i are the wave number and frequency respectively.

Figure 7 shows the directional spectra of wave which is used in surf beat simulation. It is seen that the directional spectrum is very narrow.

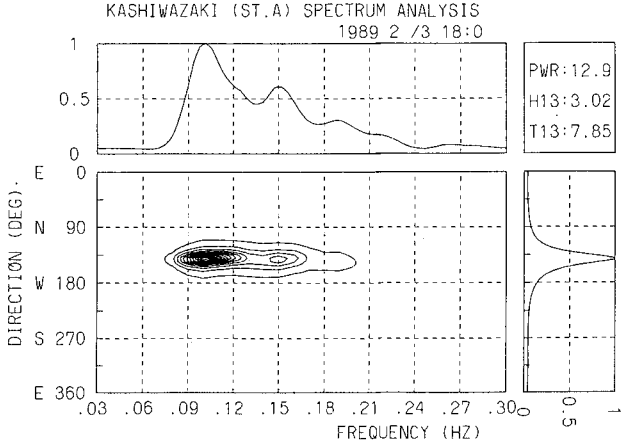

Figure 7. The directional spectra of wave which is used in surfbeat simulation.

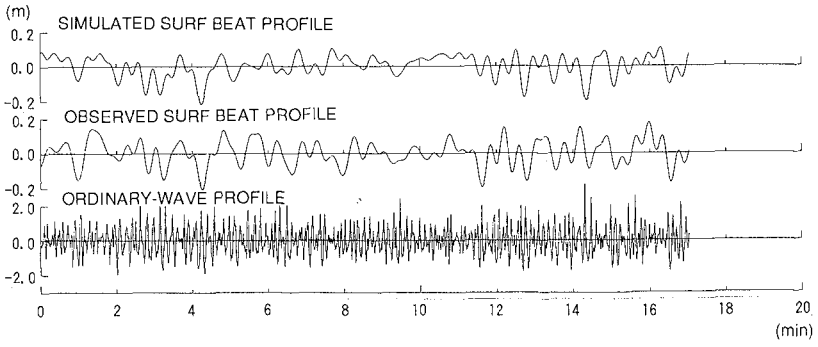

Figure 8. The comparison of the observed results with simulated surfbeat profile by non-linear interaction theory.

The comparison of observed surf beat with simulated surf beat is shown in figure 8. The observed surf beat profiles present a typical bounded long wave profile which is depressed beneath a group of high waves. The simulated profile shows good agreement with the observed one.

In order to investigate the correlation between the observed and simulated surf beat, cross-spectral analysis of these profiles was conducted. Figure 9 is the results of cross-spectral analysis. The figures are the phase function, square-root of ratio of powers, and coherence squared, respectively from top to bottom. Although the coherence squared is less

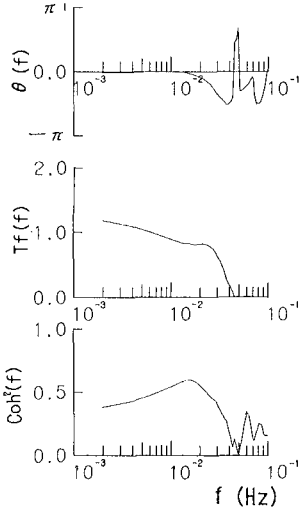

Figure 9. The results of cross-spectra (Phase function,square-root of ratio of power and coherence squared).

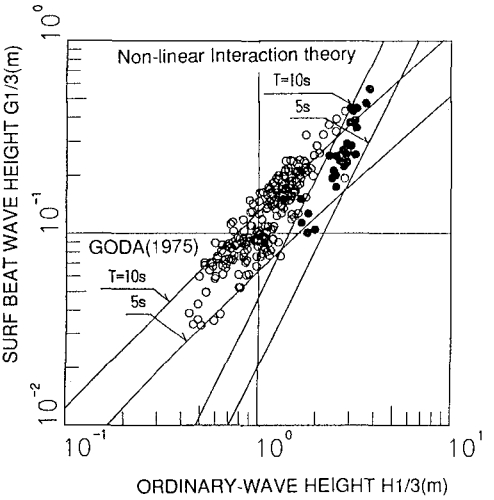

Figure 10. The relationship between the wave height of surf beat and the ordinary-wave height of Oharai wave data.

than unity but the phase function is nearly zero and transfer function is close to one. Considering that the coherence function is strongly affected by the fluctuation of phase difference in each component, it is concluded that the correlation is high and the observed surf beat is bounded.

Figure 10 shows the relationship between the wave height of surf

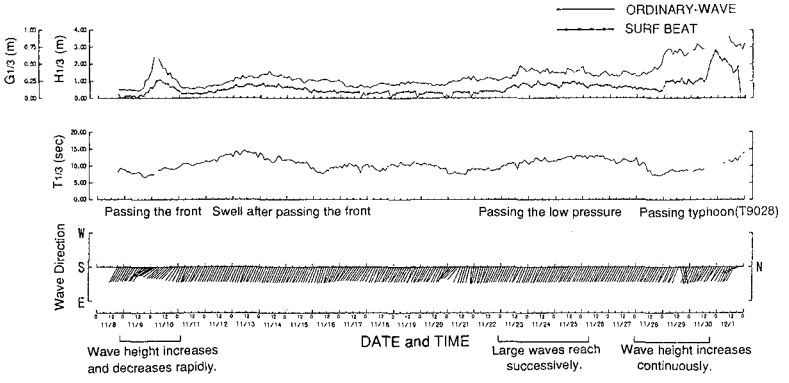

Figure 11. The variation of the ordinary-wave height and period and surfbeat wave height with the time.

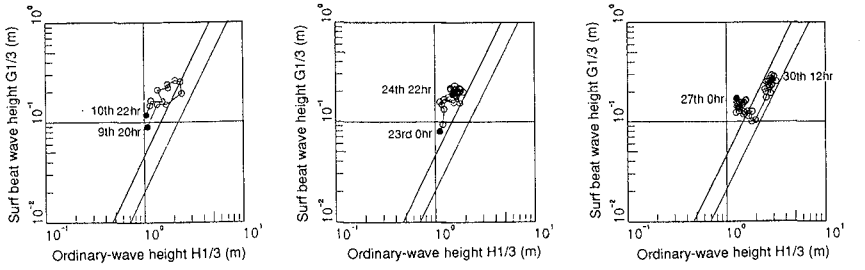

Figure 12. The relationship between the wave height of surf beat and the ordinary–wave height.

beat and the ordinary-wave height of Oharai wave data. In this figure, the relationship seems not the same as previous relation. In order to study the cause of this difference, we investigate this relation in detail.

Figure 11 is the variations of the ordinary-wave height and period, and the surf beat wave height with the time. Three intervals of typical sea state were selected for analysis. The first of these is the period of rapid wave height increase and decrease. The second is the interval which large waves arrive successively. The last is the period of continuous increase of wave height. Figure 12 is the plot of the relationships between the surf beat height and the ordinary-wave height corresponding to the above three periods of typical sea state. In this figure, black symbols indicate the start and end of plot.

Figure 12(1) is in the period of rapid wave height increase and decrease. In this period when the waves increase in height, surf beats fit the nonlinear interaction theory. In the period of the decay, however, surf beat wave heights decrease with relatively higher energy level than that of the increasing time.

Figure 12(2) is in the period of arriving large wave successively. The surf beat wave heights have a relatively large energy level. So, an energy other than that of bounded long waves may also exist in surf beat in this case. Because of the shape of the port, wave energy may trap by Oharai port.

Figure 12(3) is in the period of continuous increase of wave height This figure shows that the increase of surf beat due to nonlinear interaction is preceded by a decrease in the surf beat wave height because of the decrease in the ordinary-wave period. Therefore, it is found that in the condition that wave height increase from calm, surf beats exist as bounded long waves.

In figure 10, the black symbols show the condition that wave height

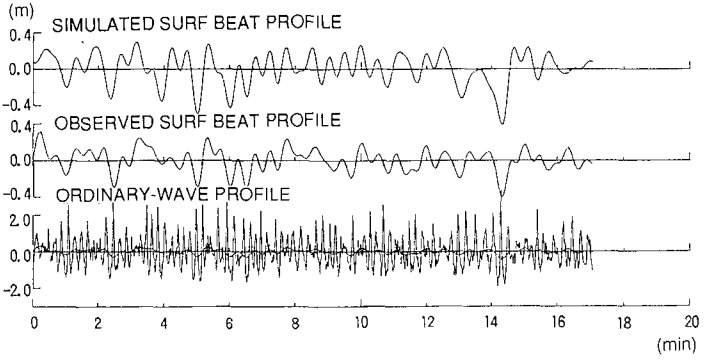

Figure 13. The comparison of the observed surfbeat with simulated surfbeat in the condition that wave height increase from calm.

increase from calm. It is seen that these fit the nonlinear interaction theory.

Figure 13 is the comparison of observed surf beat with simulated surf beat in the condition that wave height increase from calm. The simulated profile shows good agreement with the observed one. Thus it is concluded that the surf beats at the point of 13 m depth exist as bounded waves. According to both measurements and calculations, when the significant wave height of ordinary-waves is 5m, the wave height of surf beat is approximately 1m. This water surface fluctuation is not negligible to the design of maritime structures, because such a large long period fluctuation causes an increase in both hydrostatic pressure and buoyancy of the breakwater.

4. Surf beats inside the harbor

Bowers (1977) investigated the long period wave behavior through theoretical and experimental study and concluded that the bounded long waves became free waves in a harbor. The surf beat behavior inside the harbor is investigated by using the field observation data. For this, wave data in Kashiwazaki-Kariwa are used. At the three points behind the breakwater, St. 2, St. 4 and St. 6, water surface elevations were measured along the direction of wave propagation. Figure 14 shows the result of cross spectral analysis between each two wave data. In figure 14, the solid curve means the phase difference which is calculated from the linear wave theory of progressive waves. From these results, it is confirmed that

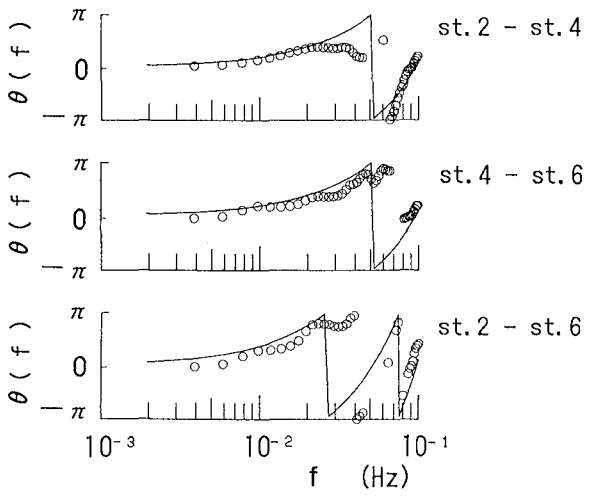

Figure 14. The results of cross spectra analysis between points of behind breakwater.

surf beats in the harbor propagate as free waves.

Figure 15 shows the relationship between the significant wave height of ordinary-wave and that of surf beats at St. B. In the harbor the

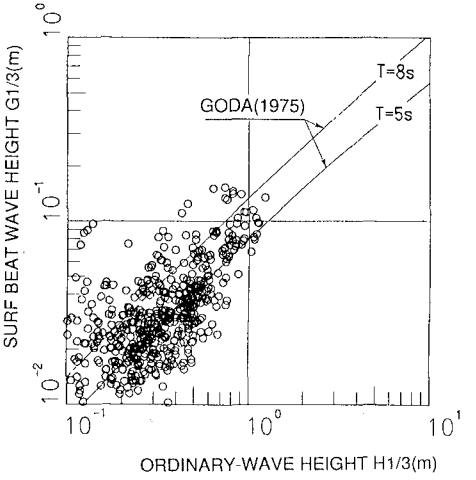

Figure 15. The relationship between the wave height of surfbeat and the ordinary-wave height (St.B).

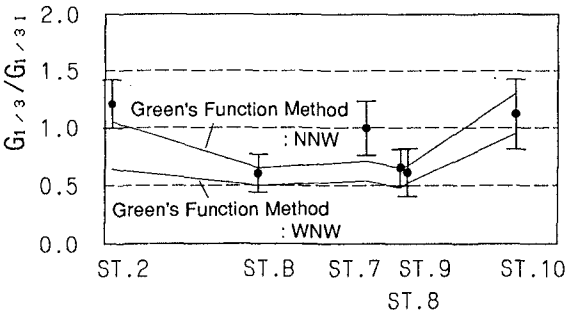

Figure 16. The comparison of the observation results with calculation results for wave height distribution inside the harbor by Green's function method.

clear relationship between the significant wave height of ordinary-wave and that of surf beats is not found because the degree of deformation of both depends on the wave direction and the wave period.

As the surf beats inside the harbor seem to be free waves, the wave height distribution of surf beat may be calculated by the method for ordinary-wave height. The wave height distribution of surf beat in the harbor was calculated, using Green's function method for ordinary-waves. The result of the comparison between the calculation and the observations is shown in figure 16. In this figure, the wave height ratio of surf beat is plotted for each observation point. Relatively good agreement was obtained between the calculation and the observation results except for St. 2 and St. 7. It is considered that the reason for these deviations are that the boundary condition of incident wave is not satisfied completely at St. 2 and the modeling of the shape of sea wall around the St. 7 is inadequate

5. Conclusions

Field observations of surf beat inside and outside a harbor were conducted and the characteristics of surf beat in the nearshore non-breaking zone were investigated. It was found that the surf beats exist as bounded waves outside the harbor. In the condition that wave height increase from calm, the height of surf beats may reach 20 % of ordinary-wave heights when the ordinary-wave height is 5m at the depth of 13 m. It was also confirmed that the surf beats exist as free waves inside the

harbor and the wave height distribution of surf beat inside the harbor may be calculated by the same method as that for ordinary-waves.

References

Bowers,E.C. (1977): Harbour resonance due to set-down beneath wave group, J. Fluid Mech., Vol.79, part 1, pp.71-92.

Hotta,S., M.Mizuguchi and M.Isobe (1981): Observations of long period waves in the surf zone, Coastal Engineering Japan, Vol.24, pp.41-76.

Goda,Y. (1985): Randome seas and design of maritime structure, University of Tokyo press, 323p.

Kimura,A. (1984): Averaged two-dimensional low-frequency wave spectrum of wind waves, Comm. on Hydraulics, Dept. of Civil Engg. Delft Univ. of Tech., Report No.84-3, 54p.

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

List,J.H. (1988): Wave groupiness as a source of nearshore long waves, Proc. of 21st ICCE, pp.497-551.

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

Mansard,E.P.D. and V.Barthel (1984): Shoaling properties of bounded long waves, Proc. of 19th ICCE, pp.798-814.

Munk,W.H. (1949): Surf beats, Trans. Amer. Geophys. Un 30(6), pp.849-653.

Ottesen-Hansen,N.-E. (1978): Long period waves in natural wave trains. Inst. Hydrodyn. and Hydraulic Engrg., Tech. Univ. Denmark, Prog. Rep. 46, pp.13-24.

Ottesen-Hansen,N.-E., S.E.Sand, S.E.Lundgren, T.Sorensen and H.Gravesen(1980): Correct reproduction of group-induced long waves, Proc. 17th Int. Conf. Coastal Eng., pp.784-800.

Sand,S.E. (1982): Long waves in directional seas, Coastal Engineering, Vol.6, pp.195-208.

Sharma,J.N. and R.G.Dean (1979): Development and evaluation of a procedure for simulating a random directional second order sea surface and associated wave force, Ocean Engg. Rept. No.20, Dept. Civil Engg., Univ. of Delawere, 139p.

Symonds, G.,D.A.Huntley and A.J.Bowen (1982): Two-dimensional surf beat: long wave generated by a time-varying break point, J. Geophys. Res., Vol.87, No.C1, pp.492-498.

Symonds,G. and A.J. Bowen (1984): Interaction of near shore bars with incoming wave groups, J. Geophys. Res., Vol.89, No.C2, pp.1953-1977.

Tucker,M.J. (1950): Surf beats: sea waves of 1 to 5 min. period,Proc. Roy. Soc. London, Ser. A, 207, pp.565-573.