

CHAPTER 22

Generation Characteristics of Wave Sounds as a Factor of Beach Amenity

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Abstract

This study deals with the comfortableness of wave sounds from physiological and psychological aspects. Firstly, the difference of wave sound generation mechanism between plunging and spilling breakers is discussed on basis of the variation characteristics of sound pressure level and the volume of air bubbles in water. Secondly, the comfortableness of wave sounds is investigated based on the generation characteristics of the brain wave and the result of questionnaire surveys of auditory test.

Introduction

Many artificially nourished beaches have been created as part of the improvement works related to coastal environment. The visual, auditory and olfactory factors are considered important factors of beach amenities.

Recently, much importance has been attached to the roles of desirable sounds in environment. The term "Sound Scape" named by R.M.Schafer(1977) has been used in much the same way as the term "Land Scape". More attention must be paid to the sound environment of the coastal zone.

As a matter of fact, the sensory tests on psychological responses to wave sound

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have shown that the auditory factor such as breaking wave sounds is one of the most important factors affecting the amenities of the beach environment just as much as visual and olfactory factors(Nadaoka et al,1991a,b. Murakami et al, 1991). Authors have also investigated the characteristics of breaking wave sounds in laboratory tests and field observations(Murakami et al,1993). However, the exact physical mechanism of sound generation due to wave breaking remains under debate.

The purpose of this study is to investigate fundamental characteristics of the wave sound generation and to examine the difference of the sound generation mechanism in two types of wave breaking, the plunging and spilling breakers. Furthermore, the relationship between wave sound and its comfortableness is discussed from physiological and psychological aspects.

Characteristics of Wave Sound Generation of Air Bubbles in Wave Breaking

1) Experimental Methods

A wave tank with a pendulum-type wave generator at one end, which was 30m long, 1m wide and 0.9m deep, was used as shown in Fig.1. The bottom slopes θ were 1/10 and 1/15, and 45 kinds of waves which had different surf similarity parameters ξ_0 were induced.

Wave sounds were recorded by a sound level meter at the upper point 30cm from still water surface. The video pictures of breaking

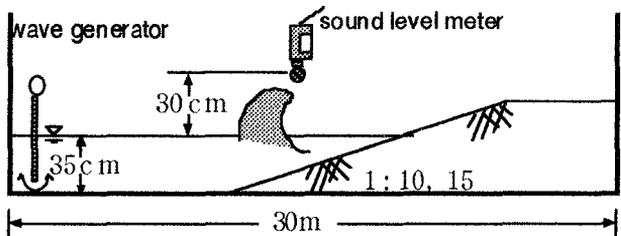


Fig.1 Experimental Apparatus

Table 1 Experimental Conditions

beach slope $\tan\theta$	wave period T (sec)	equivalent deepwater waveheight H_0' (cm)	surf similarity parameter ξ_0
1/10	0.8~2.0	1.8~13.4	0.397~2.045
1/15	0.8~2.0	2.9~13.3	0.214~0.894

waves were taken simultaneously at the distance of 1.5m from the side wall of wave tank to observe air bubbles in water induced by wave breaking. The water depth h was kept at a constant of 35 cm. The wave period T was changed from 0.8 to 2.0 sec.

Experimental conditions of wave breaking were shown in Table 1.

The surf similarity parameter ξ_0 as a breaker type index is defined as follows(Battjes,1974):

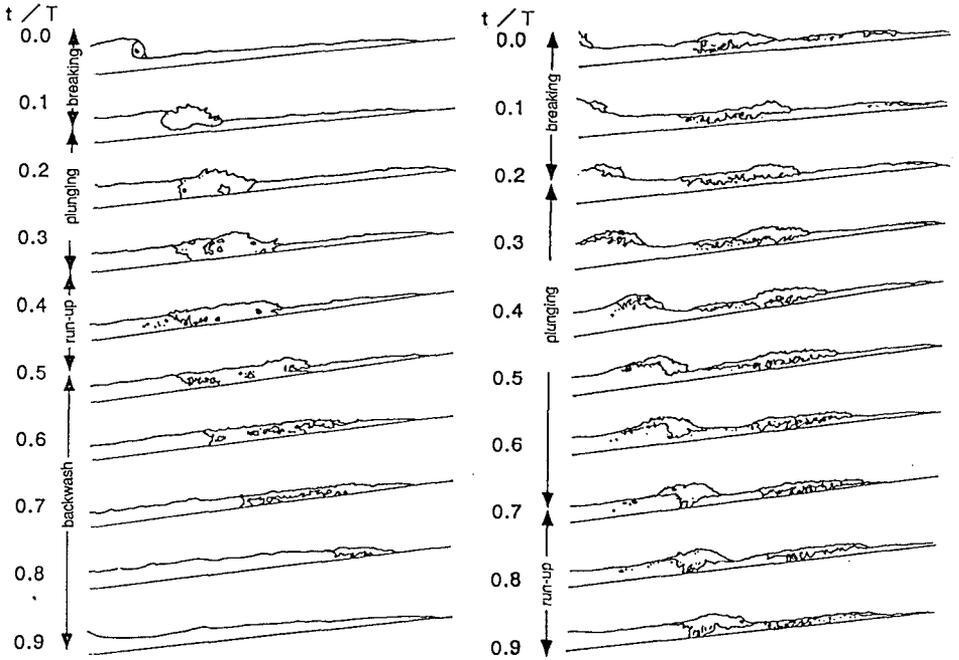
$$\xi_0 = \tan \theta / \sqrt{H_0'/L_0}$$

Spilling breaker, if $\xi_0 < 0.5$. Plunging breaker, if $0.5 < \xi_0 < 3.3$. Surging breaker, if $\xi_0 > 3.3$. In which, H_0' ; equivalent deepwater wave height, L_0 ; deepwater wave length. ξ_0 in this study are in the range of 0.2-2.0 . This means the experiments include both spilling and plunging breakers.

2) Characteristics of Generation of Air Bubbles and Wave Sounds

Fig.2 shows an example of the wave breaking process and air bubble generation during a wave period for the plunging and spilling breaker, respectively. Nondimensional phase $t/T=0$ means the onset of wave breaking. Generally, the behavior of wave breaking is divided into the following four phases; breaking , plunging, run-up and backwash.

For the plunging breaker, the wave begins to break and folds over air at the breaking phase. At the plunging phase, a large quantity of air bubbles are generated.



(1) plunging breaker

($H_0'/L_0=0.01, \tan \theta =1/15$)

(2) spilling breaker

($H_0'/L_0=0.12, \tan \theta =1/15$)

Fig.2 Breaking Process and Air Bubble Generation

Subsequently air entrainment occurs and the air bubble cloud reaches the sea bottom. After that, the air bubble cloud spreads out gradually to create the patch of foam at the run-up and backwash phases.

On the other hand, for the spilling breaker, the air bubble cloud induced by the former wave breaking remains without appearance over a wide area, even when a new wave begins to break at the wave crest in the breaking phase. The air bubble cloud near the wave crest spreads radially in every direction at the breaking and plunging phases. Finally, it combines with the former air bubble cloud.

From this experiment, the difference of generation and disappearance mechanism of air bubbles for the two types of wave breaking was revealed to

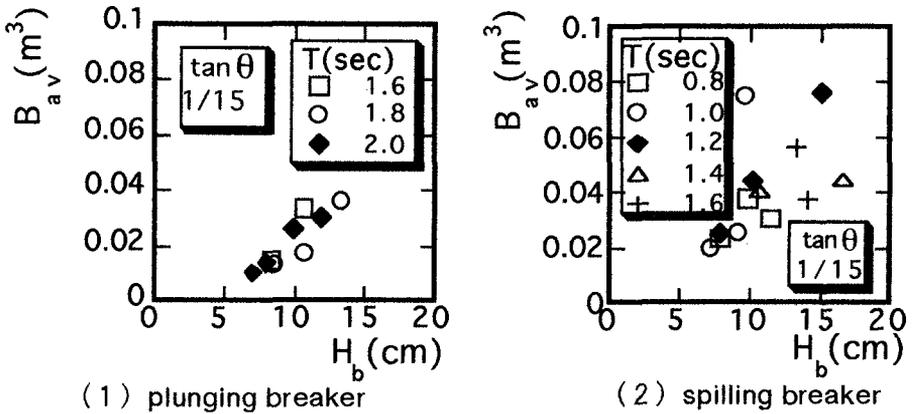


Fig.3 Relationship between B_{av} and H_b

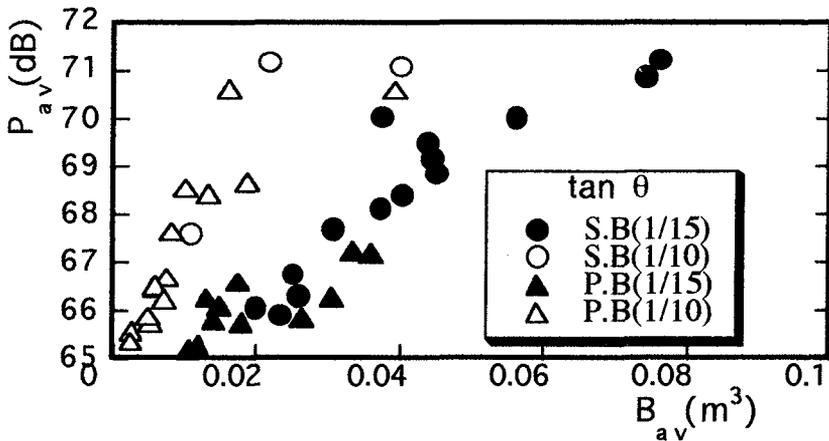


Fig.4 Relationship between P_{av} and B_{av}

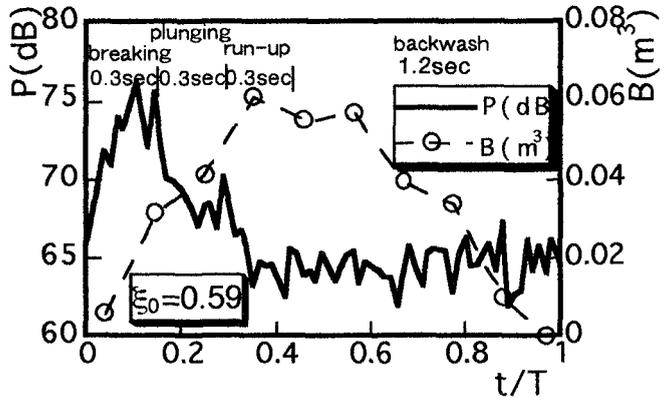
some degree. The volume of air bubbles, however, depends on the breaking wave height. In addition, the wave sound must be related to the volume of air bubbles.

Fig.3 shows the relationship between the average volume of air bubbles per one wave B_{av} and a breaking wave height H_b in the case of the bottom slope 1/15. It is difficult to measure directly a volume of air bubbles. The volume of air bubbles B at an arbitrary phase of wave is conveniently defined so that B can be obtained by multiplying a bubble cloud cross section area projected on the glass wall of wave tank with a wave tank width. An average volume of air bubbles B_{av} was obtained from the average value at the 5 different wave phases in a one wave period.

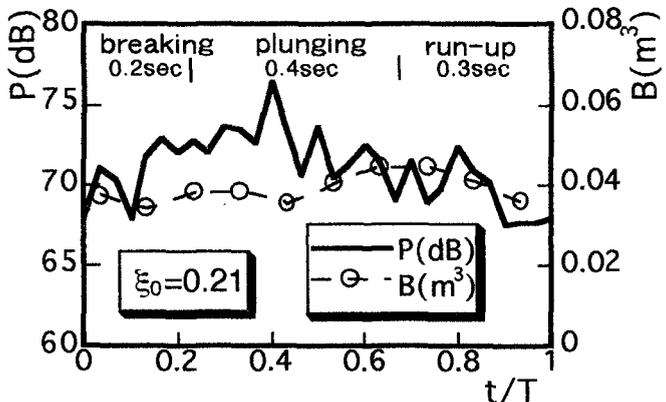
It can be seen that B_{av} increases with an increase of H_b . However, it shows a partially opposite tendency in the spilling breaker's long period wave. The relationship between an average sound pressure level P_{av} and B_{av} is shown in Fig.4. P_{av} increases with an increase of B_{av} regardless of the breaking type. The rate of increase of P_{av} , however, is more distinct with a steeper bottom slope.

The sound pressure level is also closely related to the volume of air bubbles.

Furthermore, let us consider the correlation between



(1) plunging breaker ($H'_0/L_0 = 0.01, \tan\theta = 1/15$)



(2) spilling breaker ($H'_0/L_0 = 0.12, \tan\theta = 1/15$)

Fig.5 Temporal fluctuation of P and B

the variation of sound pressure level P and the volume of air bubbles B in time in order to clarify the sound generation mechanism .

Fig.5 shows the temporal fluctuations of P and B for two types of wave breakers. Let us first consider the variation characteristics of P for the plunging breaker. P takes the maximum value in the middle of breaking and plunging phases. P decreases rapidly at the run-up and backwash phases. On the other hand, B takes the maximum value in the middle of run-up and backwash phases. It is significant that the maximum sound is not generated when the volume of air bubbles is at a maximum . It means a dominant sound is generated only in the short time when a water wave plunges on to the water surface, however, air bubbles are only slightly generated. Subsequently, even if the volume of air bubbles increases gradually after breaking, these bubbles are not an important factor in the generation of dominant sounds.

Secondly, let us consider the characteristics of the spilling breaker. P does not fluctuate so noticeably, though it increases slightly at the breaking phase in comparison with other phases. The fluctuation of B is smaller than that of P . It can be recognized that the mechanism of wave sound generation for the spilling breaker is attributed to the strong turbulence and bursting of air bubbles in the vicinity of the water surface.

Comfortableness of Wave Sounds due to Auditory Tests

1) Experimental Methods

In order to investigate the comfortableness of wave sounds, the brain wave test and questionnaire surveys were carried out simultaneously with 8 students of the University of Tokushima being the subjects.

Fig.6 shows an outline of brain wave measurement . First of all, a subject listened to various kinds of recording tapes of wave sounds on the headphones. The brain waves at the central zone C_z and occipital one O_z were measured and recorded in the FM data recorder whilst the subject's eyes were open for 3-6 min. The brain

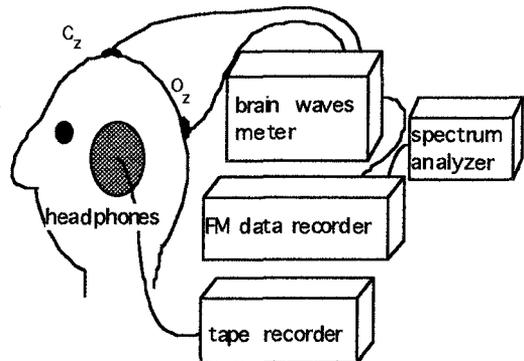


Fig.6 Outline of Brain Wave Measurement

Table 2 Experimental Conditions of Auditory Tests

sound factor	wave sound		subject
	kind	condition	
strength	field observation sounds	$P_{av}(dB)$ 54,62,74	students male4,female1
wave period	artificial sound	$T(sec)$ 4,6,8,10,12	male7
sound tone	field observation sounds	$f^{-1/2}, f^{-1}$	male8

wave spectrum was obtained by a spectrum analyzer. In addition, the questionnaire surveys were conducted to find the most desirable sound by the same subjects.

The experimental conditions used in the brain wave tests and questionnaire surveys are shown in Table 2. Field observation wave sounds and artificial sounds made from white noise by FM radio were used as wave sounds in the tests. The effects of sound strength, sound wave period and sound tone as physical sound factors on the comfortableness of wave sounds were examined. The sound tone spectra at the backwash phase used here is shown in Fig.7. One is having minus 1/2 power of frequency f at the higher frequency region. The other is having minus 1st power of frequency f .

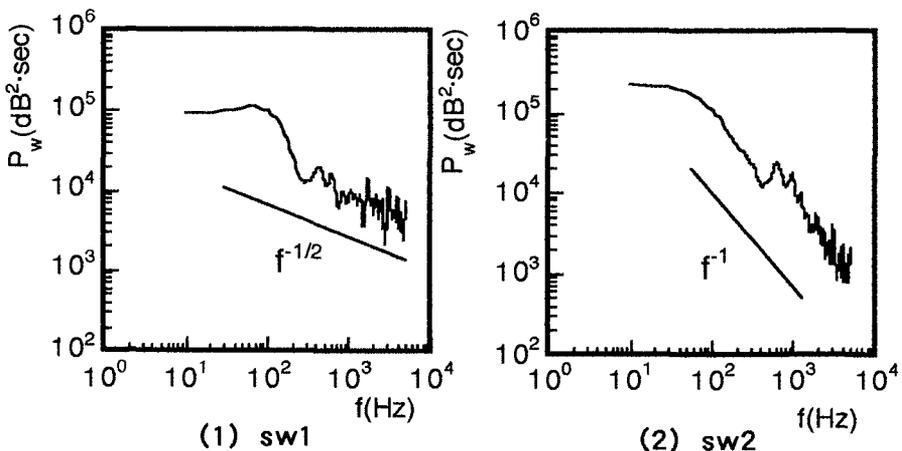


Fig.7 Sound Tone Spectra at Backwash Phase

2) Effects of Wave Sound Strength on Comfortableness

Fig.8 shows the relationship between the average power of α -wave(8-13Hz) P_w and an average sound pressure level SP_{av} over 6 min. Sign N in the transverse axis means non-sound. P_w decreases slightly with an increase of SP_{av} at the central zone Cz. On the other hand, P_w at the occipital zone Oz has the maximum value for the 62 dB sound. Especially, it should be noted that the power of α -wave for the 74 dB sound is smaller than that for the two others.

Fig.9 shows the result of a questionnaire survey on the relationship between the

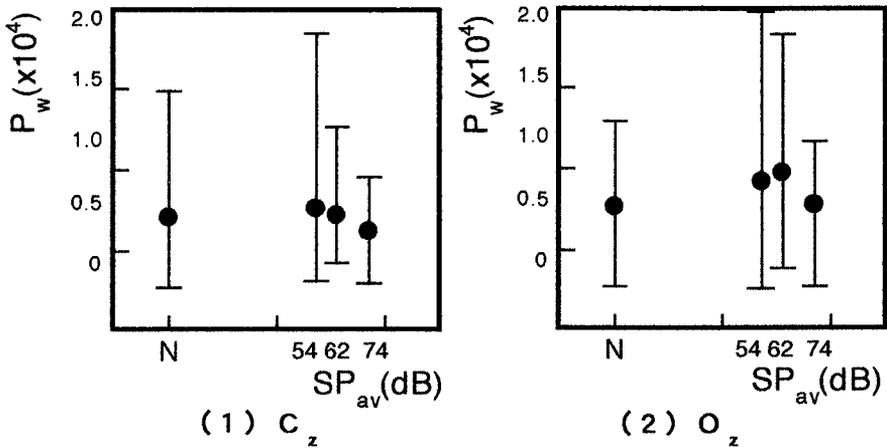


Fig.8 Relationship between P_w and SP_{av}

comfortableness and the average sound pressure level P_{av} . The vertical axis indicates the number of persons, who gave the most suggestive response from the three sounds. From this test, the 62dB sound is the most comfortable of the three which corresponds to as the tendency of the brain wave tests at Oz. No one felt any comfortableness from on the 74dB sound to the subjects. The 74dB sound seemed to be felt as if it were stormy sea.

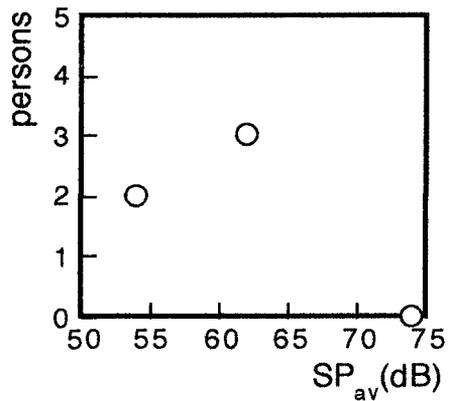


Fig.9 Effect of SP_{av} on Comfortableness

3) Effects of Sound Wave Period on Comfortableness

The authors have already pointed out from the questionnaire survey of the 67 students that the subjects feel the comfortableness for 6-8 sec of the sound wave period, but do not feel the comfortableness under 6 sec of the wave period. It has been pointed out this desirable value is nearly equivalent to the period of our breathing(Murakami et al,1992).

Fig.10 shows the effect of the sound wave period on the brain wave. The power of α -wave P_w has the muxmum value in 8 -10 sec of wave period in both figures. In the case of the wave period being under 6 sec, P_w has less than the power at non-sound.

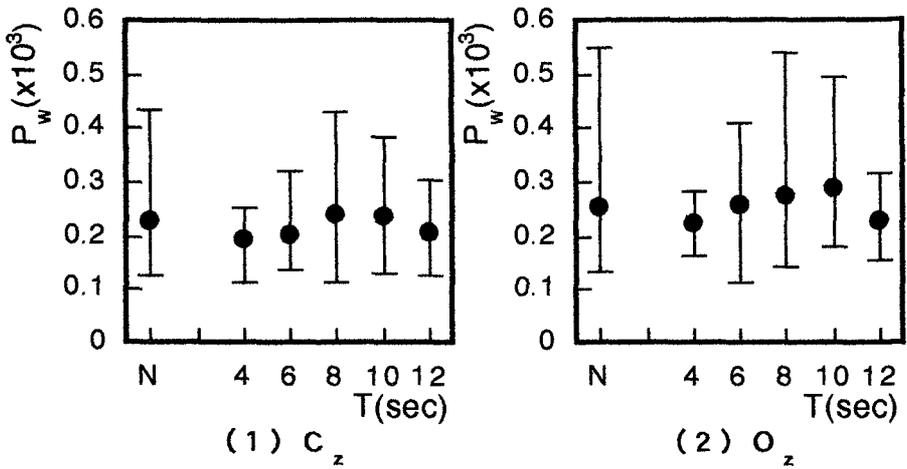


Fig.10 Relationship between P_w and T

Fig.11 shows the results of the points obtained from the questionnaire survey of the five grade estimations with a score of 5 to 1 points for each wave period. The tendency in this figure is similar to the result of brain wave tests, though the tendency of the two in 12 sec of the wave period is different.

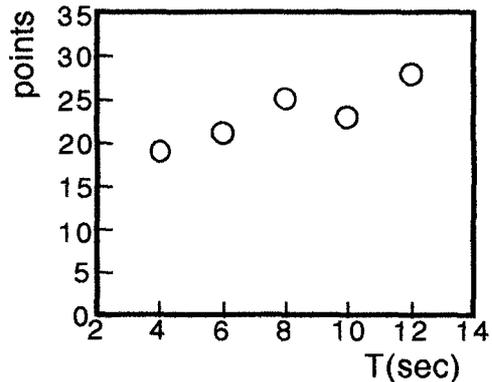


Fig.11 Effect of T on Comfortableness

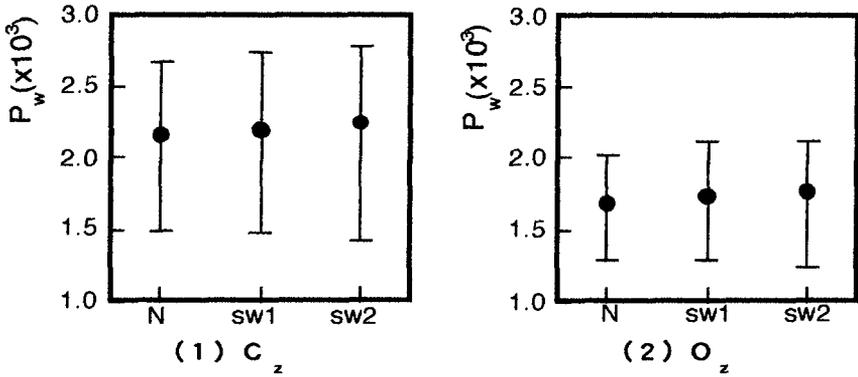


Fig.12 Effect of Power Spectrum Shape on Comfortableness

4) Effects of Sound Tone on Comfortableness

The subjects listened to wave sounds which had two kinds of sound tone spectra as shown in Fig.7.

Fig.12 shows the effects of wave sound tone on the α -wave power. As a result, it can be seen that the power on sw2 is only slightly bigger than that on sw1. It is widely noted the α -wave power increases in the case of sound tone with the minus 1st power of frequency at a higher frequency region.

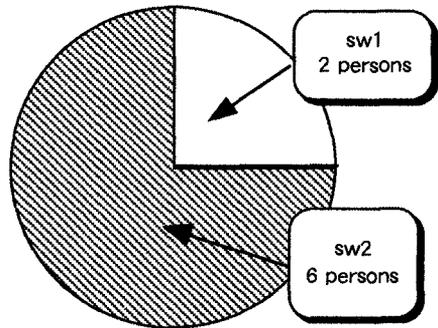


Fig.13 Comfortableness of Sound Tone

Fig.13 shows the comparison of the comfortableness of two kinds of sound tone on the basis of the questionnaire survey. The sound tones with sw2 and sw1 are in the ratio 6:2. This is the same tendency as the result of the brain wave test.

Conclusion

The generation mechanism of wave sound for two types of wave breakers was discussed on the basis of measurement of sound pressure level and volume of air bubbles. The effects of sound factors on comfortableness were examined from the physiological and psychological aspects. As a result, the wave sounds should be emphasised as being one of the most important factors of beach amenities. The

results are summarized as follows.

1) The difference of the sound generation mechanism between the plunging and spilling breakers was clarified. It was confirmed the behavior of air bubbles generated by wave breaking was closely connected with the characteristics of wave sounds.

2) It was proved that the comfortableness of wave sounds was affected by the factors of sound pressure level, sound wave period and sound tone and so on through the power of α -wave in the brain wave test and questionnaire surveys.

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