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# Recovery of sound quality of singing sand by sediment renourishment

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**ABSTRACT**

It was shown that ignition loss (organic matter adhered to singing sand) could be new index related to reduction of sound quality in ‘singing sand’. Ignition loss for the Kotobiki Beach was found to be about 0.5%. To recover the quality of the sound producing property of singing sand, wave action, bottom profile and sediment renourishment were investigated. For optimum sound recovery of the beach, it was found that the ideal injection point was near the offshore bar under erosive wave action conditions.

**ADDITIONALINDEXWORDS:** *Singing sand, placing sand method, sediment transport*

## INTRODUCTION

Sandy beaches composed of sound producing sand grains or ‘singing sand’can be found at Ogunquit Beach in Maine State, USA, the Bay of Laig, Isle of Eigg in Scotland and Kokobiki Beach in Japan amongst other isolated sites world wide. About twenty beaches composed of singing sands exist in Japan. Site locations of singing sand relatively are rare and the sound producing properties depend largely on the change of season at the site. More recently it has been shown that the quality of the sound producing property has begun to decrease or halt altogether by local environmental changes. The singing properties of the sand are very sensitive to air or water pollution, in that they can act as a sensor to it. Therefore, the quality of the sound producing properties of singing sand on the beach is environmental indicator of quality of the coastal environment. It has been reported that the sound producing properties of singing sand are related to grain size, mineral composition and contamination adhering to the sediment population. However, a satisfactory explanation of the sound producing properties is still unavailable. It is also reported that the quality of the sound producing property reduces from summer to fall and revives from winter to spring again.

In this paper, ignition loss as a means of quantifying contamination adhering to sand grains and its effects on the quality of the sound producing properties of singing sand is examined. A method for reviving the sound producing properties of sand using wave action will be proposed. Nearshore profile changes using this revival method are simulated by a numerical method based on Bussinesq’s wave equation and Bailard’s sediment equations.

## PREVIOUS STUDIES ON ‘SINGING’ SAND

### Morphological characteristic of singing beach sand

Singing sand beaches can be found over Hokkaido to Kyushu in the Japan Sea and Sanriku region (Pacific Ocean side). The length of coastline that contains sand with acoustic properties amounts to less 2000m and its profile is similar to a pocket beach. The ratio of width at the bay mouth and a distance from the bay mouth to its head is about 0.3. Onshore – offshore sediment transport is generally prominent at these sites. Singing grains are generally contained within the system.

### Characteristics of singing sand

The physical properties of singing sand are almost the same as normal sand grains For example, specific weight is 2.65, maximum density from 1.6 to 1.65 , mean diameter from 0.3 to 0.4mm, and sorting coefficient from 1.4 to 1.6. The major difference however singing sand and normal sand is the content ratio of quartz, whose value normally exceeds a value of more than 60 percentages for singing sand.

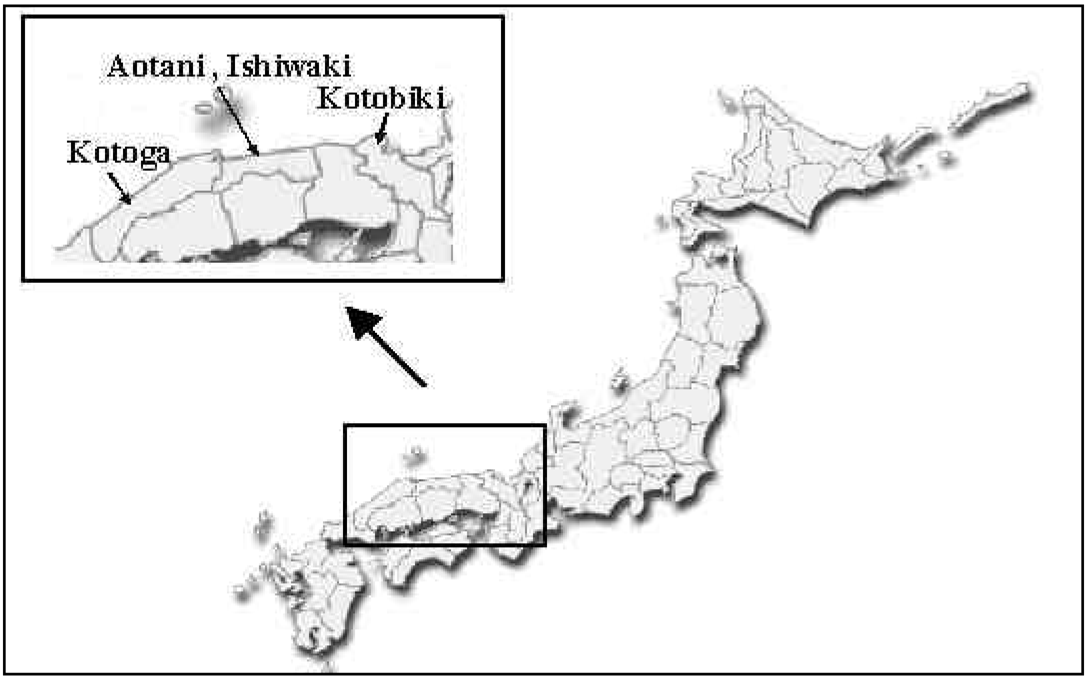

Figure 1. Map of singing sand beaches .

**Mechanism and factors necessary for sound production**

One of factors, which affect the sound producing property, is contamination by fine-grained sediment such as dust or chalk powder. As little as 0.1 % contamination into a singing sand population halts sound production altogether. Singing sand needs a highly polished granular surface to produce sound and any contamination may increase make its surface roughness (Kawamura *et al.*, 1995). However there is still little insight into the relationship between contamination and sound_producing properties of the grains.

Earlier studies (Bagnold, 1954) suggested that the sound is produced by a piezo electronic effect i.e.; the production of electrical currents by quartz grains under mechanical stress. Recently it has been shown that the sound is produced by the internal shearing of sand grains during avalanches down a slope with overriding of super adjacent layers of sand grains providing the energy of sound production (Bagnold, 1966).

## FIELD OBSERVATION

The field site is at Kotobiki Beach is a natural sandy beach with no artificial hard engineering coastal structures present. Water quality monitoring, sediment sampling of the singing sand and interviews with the local resident population were all carried out at the site. Sound producing properties of singing sand at the Kotobiki Beach were compared to other ‘acoustic’beaches at the Ishiwaki Beach, the Aotani Beach and the Kotogahama Beach (shown in figure 1). Organic matter content of the local sediment population of these beaches was examined as part of the study into why the acoustical properties appeared to be diminishing in recent years. The sound producing properties were analyzed into Fourier coefficients.

Figure 2 and 3 show the sound producing properties before and after removal of organic matter. It should be noted that there is no peak in the analyzed results, which are similar to the sound profile of white noise. On the other hand, a couple of peak values are seen around 1000HZ, 2000HZ and 3000HZ. Such sound profiles reassemble that typically produced by musical instruments, and is called the harmonic structure. This is the most important characteristic of sound production. The weight ratio of removing organic matter for singing sand and not singing sand are 0.47 % and 0.5 %, respectively. This ratio expresses ignition loss. Through the experimental results, it was found that both difference for ignition loss was very small._ The value of 0.5 % is very small, in comparison to the values of ignition loss at other sandy beaches which are typically generally from 2 to 5 %( Tsujimoto *et al.*, 1999).

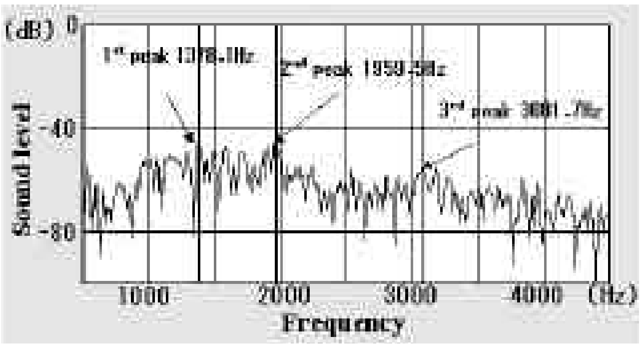

Figure 2. Sound producing properties before removal of organic matter.

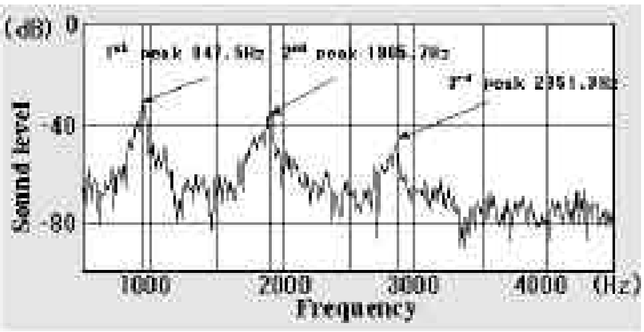

Figure 3. Sound producing properties after removal of organic matter.

## BEACH BOTTOM PROFILE OF SOUND PRODUCING BEACHES

### Experimental method

It was found through field observations that the sound producing properties of the beach sediment was usually excellent in spring, declining as the season progressed. Experiments then focused on how the nearshore profile at the site related to this phenomena.

Observations were made in the wave flume of Kobe City College of Technology. The facility is 0.6m wide, 16m in length and wit a 0.4m water depth. Experiments showed that beach slope was maintained at 1:5 with singing sand without any production of sound. Sand grains used in the experiments were 0.5mm in diameter, with 6.7cm/s settling velocity and 0.5% weight ratio of ignition loss. Depositional or erosive waves were generated for a couple of hours until the initial beach profile reached equilibrium. The bottom profile and the weight of ignition loss over the equilibrium beach profile in an onshore-offshore direction were measured. The sound producing properties of the sediment was analyzed using Fourier coefficients.

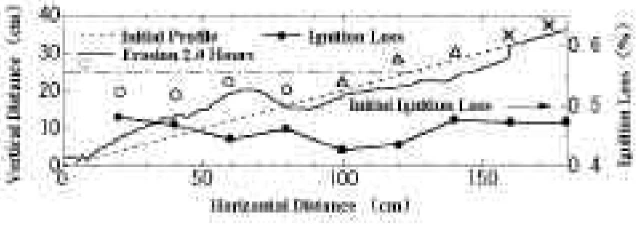

Figure 4. Sound producing properties and ignition loss over onshore-offshore cross section under erosive wave action.

### Experimental results

Figure 4 shows the equilibrium beach profile under erosive waves for two hours (wave period 0.9sec, wave height 10cm and water depth 25cm) and Figure 4 under depositional wave (wave period 1.6sec, wave height 6cm and water depth 25cm) for two hours, where the onshore-offshore distribution on the sound producing property and the value of ignition loss were shown. In order to express the sound producing property easily, the follow marks were used; _: clear sound, _: small sound , and _: no sound.

As shown in Figure 4, the values of ignition loss were changed from 0.5 to 0.4% after erosive wave action, and singing sand that had already lost its sound producing qualities produced the sound again. The values of ignition loss near the wave breaking point decreased markedly. However, the sound producing properties of singing sand deposited near the shoreline could not be recovered well.

Under depositional wave action as shown in figure 5, the values of ignition loss near the shoreline could be increased to about 0.6% from the initial value 0.5% and the sound producing property could not be increased to a ‘good’level. This infers that depositional waves do not have enough energy to remove the organic matter.

Figure 6 shows the experimental results under both erosive and depositional wave action environments. As shown in figure 4, the sound producing property of singing sand cannot be recovered near the shoreline. However, the values of ignition loss decreased to less than 0.4% and the potential for sound producing properties existed over all measured points. These experimental results may demonstrate that in the field that singing sand would be washed and its sound producing properties recovered under erosive wave action in the winter, being transported toward the onshore direction and deposited near the shoreline in the spring.

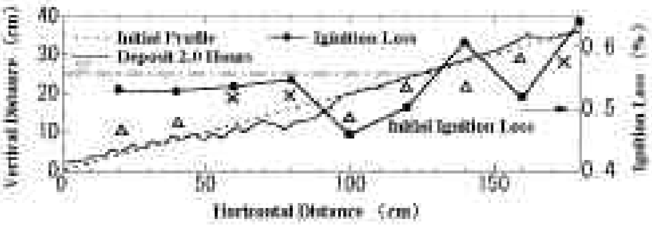

Figure 5. Sound producing properties and ignition loss over onshore-offshore cross section under depositional wave action

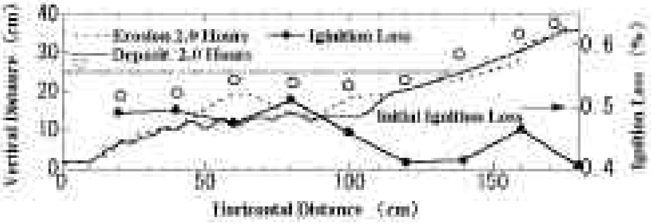

Figure 6. Sound producing properties and ignition loss over onshore-offshore cross section under both erosive and depositional wave action.

## RECOVERY OF SOUND PRODUCING QUALITY

### Changes in bottom profile by the renourishment of the nearshore

Attempts to recover the quality of sound production have been conducted by Kawamura (1995), who washed or boiled the sediment. However, these methods are not realistic in the field. In the current study a method making use of natural wave action is proposed.

A movable sediment bed with a 1 : 10 slope, 5m in length and 0.6 m in width is used in the experiment. An erosive wave (wave period 1.1sec, water depth 0.4m and wave height 0.14m) was generated for about one hour until an equilibrium beach profile was established. This beach profile is used as the initial beach conditions. Placing sand grains at three points over the initial beach, both erosive and depositional wave were then generated.

20 kilograms of sand grains were placed near the wave breaking point. The resulting bottom profile after the erosive waves were ran against it for one hour is shown in Figure 7. In Comparison to the initial bottom profile, a sand bar was moved toward the offshore direction slightly and grew in size. Since the wave breaking point is stable just after sand was released, wave breaking readily picks up the sand grains placed on the onshore side of the bar. They are transported toward the offshore side, and deposited on the offshore side of the initial bar, increasing the elevation of sea bottom. With time, the wave breaking point moves gradually towards the offshore side and a new bar is formed. Offshore sediment transport is also prominent near the newly formed bar. The development and movement of the bar occurs over a relatively short time.

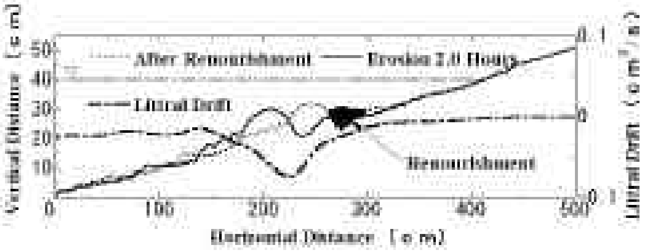

Figure 7. Sand renourishment method near the wave breaking point.

Other scenarios of releasing the sediment near the swash zone are shown in Figure 8 and 9, respectively. Waves after the wave breaking point do not have enough energy to transport or move sand grains much further. As a results, little difference in morphology between the ‘before’and the ‘after’ the application of erosive waves is seen in both figures, i.e., the sand grains initially placed near the swash zone and near the shoreline are deposited only in front and behind a bar on average. Comparing the rate of sediment transport with figure 6, the value was negligible.

### Beach cross-section changes

It was found through the last experiment that when renourishment was implemented near the bar, the rate of sediment transport would be increased. Therefore experiments were conducted to recover the quality of sound production using the bar profile and wave action. The experimental procedures are as follows; firstly, erosive waves are generated for one hour as the last experiment and the equilibrium beach formed. Secondly sand grains deposited from 200 to 300cm in onshore-offshore direction as shown in figure 9 are replaced with non-singing sand grains which the value of ignition loss is more than 0.5%. Thirdly, renourishment takes place with non- singing sand grains near the bar. Finally erosive waves are generated for one hour and depositional waves for two and half hours. The sound producing qualities and the values of ignition loss for singing sand grains were then measured.

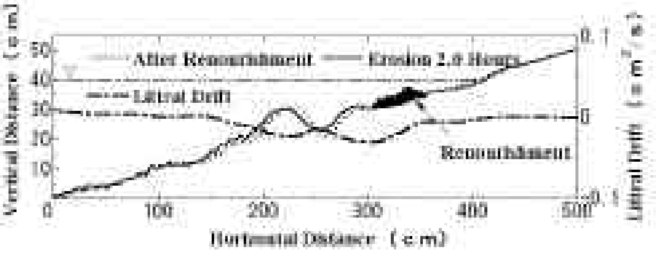

Figure 8. Sand renourishment method near the swash zone.

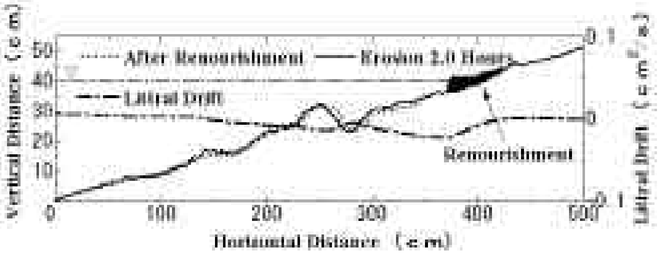

Figure 9. Sand renourishment method near the shore line.

As shown in figure 10, the values of ignition loss from the offshore to the onshore side have been decreased especially so behind of the bar. Also the sound producing properties are recovered at all measured points.

## NUMERICALAPPROACH

### Calculation method

It was found through experimental approaches that by using the renourishment method, above singing sand recovered its sound producing properties with new sediment being transported near the shoreline. In this section, the bottom profile changes associated with this were examined by numerical simulation.

The basic equations are based on Bousinessq's (Pergrine 1967) equation and sediment transport equation by Bailard (1981).

$$\partial\eta/\partial t+\partial\left[(h+\eta)u\right]/\partial x=0$$

$$\partial u/\partial t+g\,\partial\eta/\partial x+u\,\partial u/\partial x=\frac{h}{2}\frac{\partial}{\partial x}\left[\frac{\partial}{\partial x}\left(h\frac{\partial u}{\partial t}\right)\right] \qquad \textbf{(1)}$$

$$-\frac{h^2}{6}\frac{\partial^3 u}{\partial x^2\partial t}-D_{loss}$$

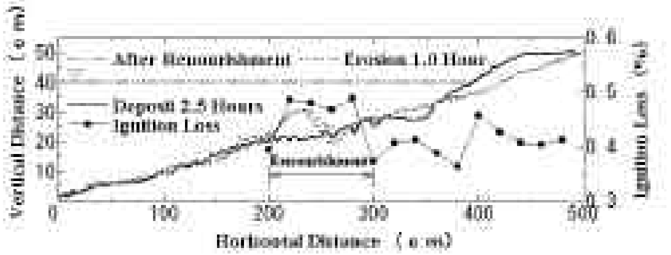

Figure 10. Bottom profile changes and ignition loss after renourishment near the breaking wave point.

Where η is the surface water elevation, *h* is the water depth, *u* is the depth-averaged velocity, *g* is the gravitational acceleration. The equations include weakly nonlinear terms ($\partial(\eta\cdot u)/\partial x, u\partial u/\partial x$) and frequency dispersion terms of the form $\partial^3u/\partial^2x\partial t$. Also $D_{loss}$ is the wave energy dissipation rate by the wave breaking, being written is as follows (Sawaragi, 1984);

$$D_{loss}=\frac{\partial}{\partial x}\left[\kappa(\eta+h)^2\left(\frac{u}{h}\right)^2\right] \qquad \textbf{(2)}$$

where κ is the experimental constant. The equations were discretised by using a staggered, and horizontal mesh interval of $\Delta_x$=5cm and the time interval $\Delta_t$=0.01sec. The boundary conditions at the offshore side are given from velocity and surface elevation of small amplitude wave theory. Also the moving boundary condition is applied at the onshore side. The breaking wave point was defined as where the horizontal velocity is more than 0.5 or 0.6 times the wave celerity of long waves. The rate of onshore-offshore sediment transport was calculated by the values of velocity through equation (1) and (2). Here the equations proposed by Bailard(1981) were applied.

$$q(t)=q_b(t)+q_s(t)$$

$$q_b(t)=\frac{\rho c_f\varepsilon_b}{(\rho_s-\rho\ )g\tan\phi}\left[u|u|^2-a\frac{\tan\phi}{\tan\beta}|u|^3\right] \qquad \textbf{(3)}$$

$$q_b(t)=\frac{\rho c_f\varepsilon_s}{(\rho_s-\rho)g\omega_s}\left[u|u|^3-a\frac{\varepsilon_s}{\omega_s}\tan\beta\,|u|^5\right]$$

Where $q_b$ and $q_s$ is the rate of bed load and suspended sediment, ρ and $\rho_s$ are density of water and the sediment, $c_f$ is drag coefficient of the bed, $\varepsilon_b$is the bed load efficiency factor, ∅ is internal angle of friction of sediment, is the bed slope, is the suspended load efficiency factor, tan β is the fall velocity of the sediment, is instantaneous near bottom fluid velocity. In the present study, values of 0.1 for and 0.7 for are selected. The net rate of sediment transport is obtained from equation (3). By using the rate of local sediment transport, the bottom profile was calculated with equation (4) that is taken into account the effect of bottom slope.

$$\frac{\partial h}{\partial t} = \frac{1}{1-\lambda} \frac{\partial}{\partial x} \left( q - \varepsilon |q| \frac{\partial h}{\partial x} \right) \tag{4}$$

Where  is the sand porosity and  is the local slope coefficient (=0.5). Also the angle of local would not exceed the angle of repose in the calculation.

The wave field over an initial bottom profile by eq. (1) and (2) and the changes of bottom profile by eq. (3) and (4) have been calculated, respectively. The changed bottom profiles must be taken into account during the wave field calculation, so that the time step of eq. (4) is set at 120 seconds.

The bed profile formed after erosive waves had been generated for one hour was set as the initial bottom profile. A total of 10 kilograms singing sand grains have been placed on the onshore side of a bar and depositional waves were generated for two hours.

It is important that sand grains with acoustic potential are accumulated and deposited near the shoreline, therefore the depositional waves have been focused at this point. The bar that moved a little towards the offshore side from its initial position disappeared early in the experiment, but this was predicted a little slower in the simulated results. However, it should be noted that the scale of the calculated bar is a little larger than that in the experiment. However the agreement of bottom profile changes near the shoreline is good (show in figure 11).

## CONCLUSIONS

This study has presented the characteristics of sound producing sand and examined a remedial approach to beach that have since lost this quality in their sediments The following conclusions have been reached:

(1) A significant factor in lowering the sound producing properties of beach sand is the presence of organic matter adhering to grains. Ignition loss therefore can be suggested as a new index in characterizing reduction of acoustic quality. For the Kotobiki Beach site ignition loss is about 0.5% and anything above this will prevent acoustic or singing sand from occurring.

(2) Depositional waves do not have enough energy to remove organic matter from contaminated singing sand with no improvement in acoustic properties of the grains taking place. Depleted acoustical sand grains did however recover their sound producing qualities and are deposited near the shoreline by using both depositional and erosive wave environments together.

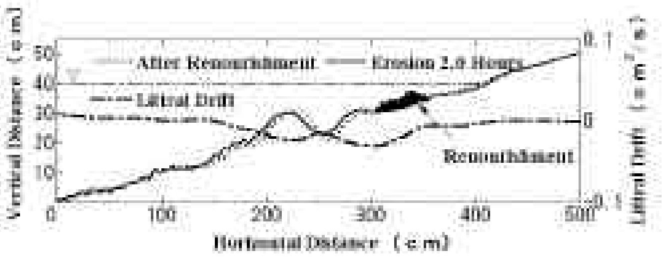

Figure 11. Comparison between experimental data and numerical predictions of bottom profile changes

(3) This may explain why Spring conditions induce higher quality 'singing sand'events.

(4) Sediment renourishment using 'non-clean' sand and released at selected points in the breaker zone proved a very effective remedial technique.

(5) The numerical simulation should good predictions in terms of changes in nearshore bottom profile after renourishment.

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