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AN EFFICIENT VOLUME REDUCTION APPROACH FOR WATER DREDGED SOIL BY ULTRASONIC WAVE

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Dredged soil caused by dredging work has brought the limits of the capacity of sediment disposal facilities in Japan. One way to solve this problem is considered to efficiently reduce the dredged soil and secure the capacity of the sediment disposal facilities. As a method of volume reduction, the technique utilizing ultrasonic vibration for compacting of soil particles has been studied so far. There are two purposes of this study. One is to clarify the volume reduction characteristic of water dredged soil by ultrasonic wave irradiation by changing the frequency or output voltage. The other is to take aim at 30% of the volume reduction. In the experimental method, the slurry of either sand or silt, its moisture content adjusted to 150%, was poured into each container. Ultrasonic wave was irradiated from the horizontal direction. After the experiment, the mass of the sample was measured. Relative density and volume reduction ratio were calculated through wet density, dry density, and void ratio. As a result, the highest volume reduction ratio of 27% was obtained when the ultrasonic wave of frequency 28kHz with output voltage 200V were irradiated in the silt. In conclusion, although we did not reach the target volume reduction of 30%, we were able to confirm the increase in density and the decrease in volume.

Keywords: Sediment disposal, Ultrasonic wave irradiation, Ultrasonic vibration, Dredging.

1 INTRODUCTION

Dredging is one of the most important work for constructing anchorages, channels, and underwater structures. Dredging work generates a lot of earth and sand. Part of one is used for landfill materials on the sea, but the rest is carried to sediment disposal facilities. In recent year, the limit of the capacity of sediment disposal facilities is near with the increase of dredged soil in Japan. Hence, we must reduce the volume of the dredged soil efficiently and secure the capacity of the sediment disposal facilities.

As a method of volume reduction, the technique utilizing ultrasonic vibration 20kHz for compacting of soil particles has been studied so far. Ouchi *et al*. (2016) conducted an experiment to irradiate the ultrasonic wave from the vertical direction to the soil tank of Toyoura sand. Thereby, they succeed in densification of the soil tank. However, this method cannot be applied to *fines* such as silt or clay. Fines are extremely small and light, so if ultrasonic wave are irradiated from above, fines will be blown up. This is called *convection phenomenon*.

In this study, ultrasonic wave is irradiated not from the vertical direction but from the horizontal direction of the soil tank. And we set two goals. One is to clarify the volume reduction characteristic of soil particles by ultrasonic wave irradiation by changing the frequency or output voltage. The other is to take aim at 30% of the volume reduction.

2 CONCEPT OF DENSIFICATION OF FINES BY ULTRASONIC WAVE

Figure 1 illustrates concepts of the behavior of fines which is irradiated ultrasonic wave from the horizontal direction. Focusing on the shape of the ultrasonic wave, there are two places where the wave is high and where the wave crosses at the center. The former is called an *anti-node*, and the latter is called a *node*. An anti-node has the effect of dispersing the fines, and a node has the effect of flocculating the fines. Therefore, fines move from an anti-node to a node and flocculate at a node, and densification of fines is promoted because of increasing self-weight of the fines.

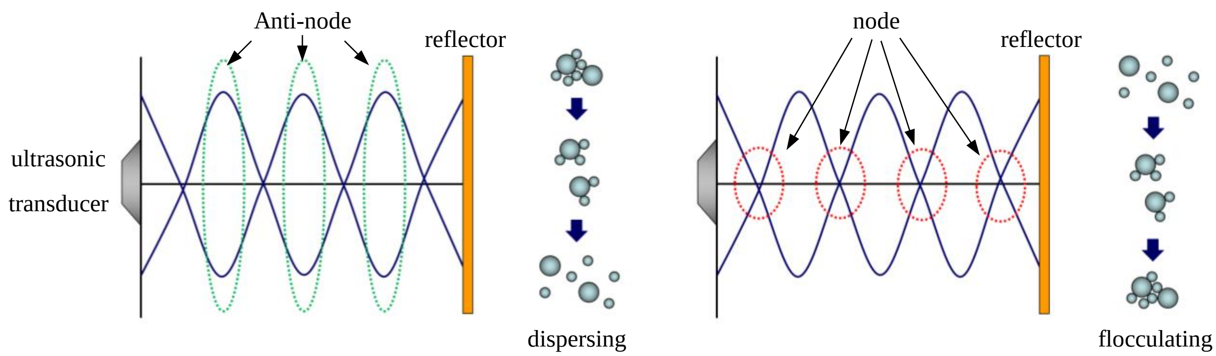

Figure 1. Mechanism of dispersion and flocculation of fines.

3 MATERIALS AND METHODS

3.1 Materials

In order to examine the relationship between the particle diameter and the volume reduction characteristics, the experiments were conducted with three kinds of samples. The samples, Toyoura sand, No.7 silica sand, and Silica powder, were used, all of which were mined in Yamaguchi Prefecture in Japan. Figure 2 shows their grading curves and photos, and Table 1 shows their physical properties.

Figure 2. Particle size distribution curves and images of experimental materials.

Table 1. Physical properties for experimental materials.

	Toyoura sand	No.7 silica sand	Silica powder
Specific gravity, G_s	2.637	2.604	2.590
Maximum void ratio, e_{max}	0.960	1.163	1.502
Minimum void ratio, e_{min}	0.640	0.655	0.668
D_{30} (mm)	0.2	0.1	0.006

3.2 Equipment

The equipment used in the experiment is as follows: ultrasonic transducer, container, ultrasonic transmitter, and digital oscilloscope. The ultrasonic wave is generated with the vibration of the piezoelectric ceramics in the ultrasonic transducer. An ultrasonic transmitter and an oscilloscope are connected to the ultrasonic transducer. The former is modified to output voltage and the latter is displayed the waveform. The frequencies used in the experiment are 28kHz, 40kHz and 60kHz, and the container size is designed to match each wavelength. Figure 3 shows the experimental equipment and detail of the ultrasonic transducer.

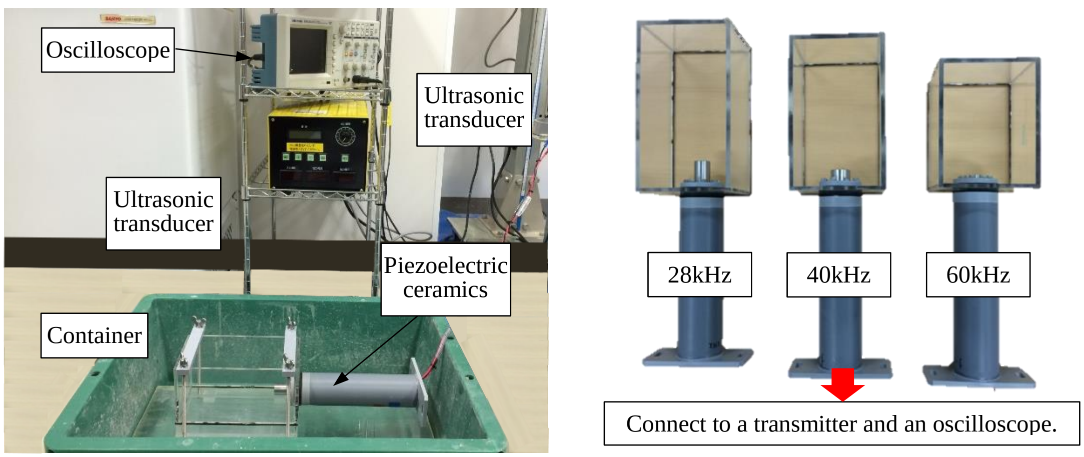

Figure 3. Construction of the experimental equipment and detail of the ultrasonic transducer.

3.3 Methods

The experimental conditions are listed in Table 2. The experiment was conducted three times under each condition. For comparison, we also conducted an unirradiated experiment.

Table 2. List for experimental conditions.

Frequency (kHz)	Output voltage (V)	Time to irradiate (min)	Number of experiments
0	0		
28	100		
	200		
	300		
40	100	30	3
	200		
	300		
60	100		
	200		
	300		

The experimental procedures are described below:

(1) the sample, its moisture content adjusted to 150%, is thoroughly stirred and then poured into a container.
(2) voltage is outputted by an ultrasonic transmitter, and the ultrasonic wave is directly irradiated to the sample for 30 minutes.
(3) after 30 minutes, the ultrasonic transmitter is stopped and the wet mass of the deposited sample, m, is measured.
(4) The sample is dried and then the dry mass, m_s, is measured.
(5) Wet density, ρ_t, dry density, ρ_d, and void ratio, e, are calculated.
(6) The relative density, D_r, and the volume reduction ratio, D_v, are calculated. The relative density is the compactness of a soil relative to that same soil under highly compacted and very uncompacted conditions. We defined the volume reduction ratio as the proportion of volume decrease by irradiating the ultrasonic wave. The relative density and the volume reduction ratio can be determined by the following equations:

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100(\%) \tag{1}$$

$$D_v = \frac{e_0 - e}{1 + e_0} \times 100(\%) \tag{2}$$

Where e_{max} is the void ratio for the very loose (uncompacted) condition and e_{min} is the void ratio for the highly compacted condition. e_{max} and e_{min} are determined from the maximum density and minimum density tests. In addition, e_0 is the void ratio when the ultrasonic wave is unirradiated.

4 RESULTS AND DISCUSSION

We organized the values obtained in the experiment for each sample. Figure 4 to Figure 6 show the relationship between the output voltage and the relative density or the volume reduction ratio. The horizontal axis represents the output voltage, the vertical axis represents the values of the relative density or the volume reduction ratio. In addition, Figure 7 shows the relationship the particle size and the relative density or the volume reduction ratio. The horizontal axis represents the 30% cumulative average particle diameter of the samples, the vertical axis represents the values of the relative density or the volume reduction ratio. Graphs were color-coding these values under each frequency.

4.1 Toyoura Sand

Figure 4 shows the results in Toyoura sand. The relative density exceeds 70% at any frequency. This is a relatively high value, and the compaction using the ultrasonic wave can be said to be effective. On the other hand, the volume reduction ratio is almost the same as the unirradiated graph. It seems to be a low level. These results could be attributed to the particle size. We supposed that Toyoura sand has been already relatively tight before irradiating the ultrasonic wave. Hence the relative density becomes high and the volume reduction ratio becomes low.

4.2 No.7 Silica Sand

Figure 5 shows the results in No.7 silica sand. Comparison with Toyoura sand, the relative density was low and the volume reduction ratio was high. The volume reduction ratio peaked at frequency 28kHz with output voltage 200V.

4.3 Silica Powder

Figure 6 shows the results in Silica powder. The volume reduction ratio peaked at frequency 28kHz with output voltage 200V, and its value was 27.3%. There are many voids in Silica powder before irradiating the ultrasonic wave. Hence the volume reduction ratio of Silica powder becomes high.

4.4 Comparison In the 30% Cumulative Average Particle Diameter

Figure 7 shows the relationship between the 30% cumulative average particle diameter of samples and the relative density or volume reduction ratio, respectively. Regarding the horizontal axis, 0.2mm corresponds to Toyoura sand, 0.1mm corresponds to No.7 silica sand and 0.006mm corresponds to Silica powder. The relative density graphs are rising to the right and the volume reduction ratio graphs are dropping to the right, approximately. These trends are evident regarding the physical properties of the experimental materials. When the particle size decreases, the difference between the maximum void ratio and the minimum void ratio increases; That is, the results depend on the particle size. However, this study has not been clarified the behavior in the sample which the particle size is mixed. Therefore, it is necessary to conduct experiments and clarify the behavior of an actual dredged soil. These are challenges for the future.

Focusing on the frequency of the ultrasonic wave, when the frequency is 28kHz, the relative density and the volume reduction ratio is peaked overall. Hence, the frequency does not relate to the value of the relative density and the volume reduction ratio.

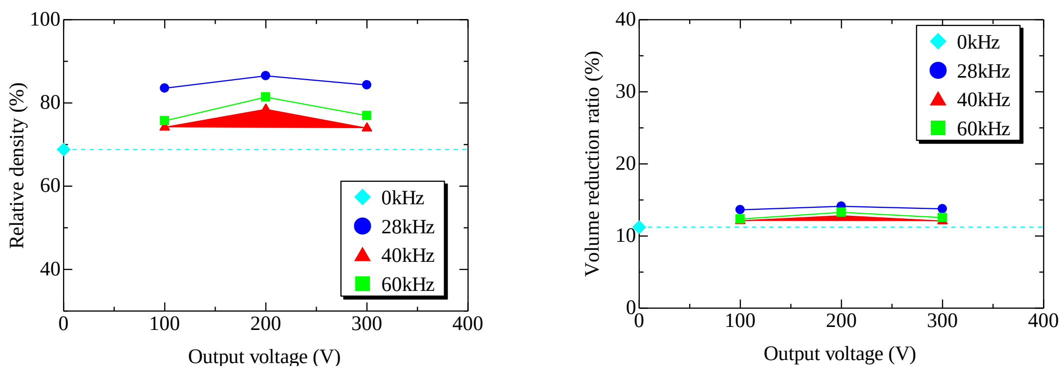

Figure 4. Experimental results in Toyoura sand.

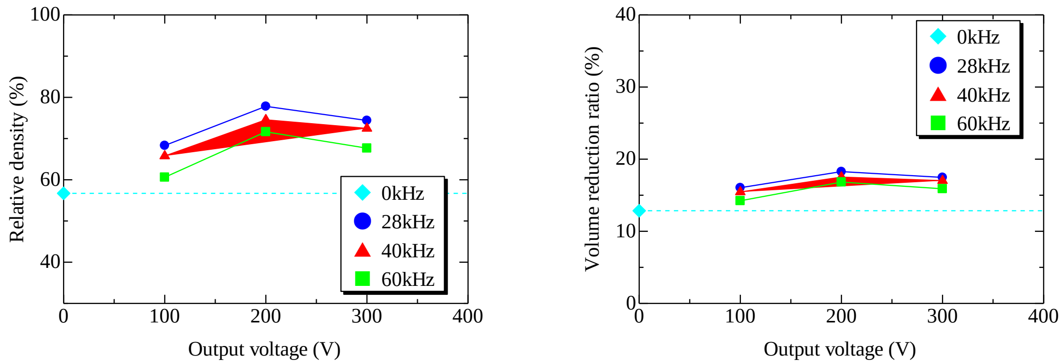

Figure 5. Experimental results in No.7 silica sand.

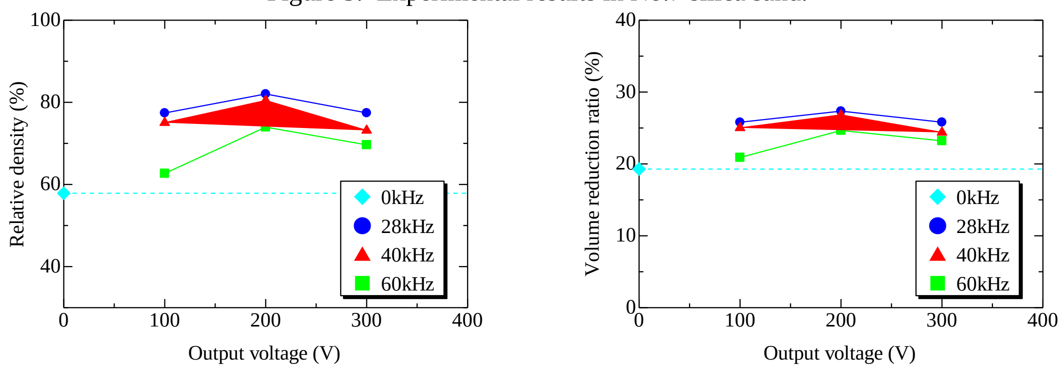

Figure 6. Experimental results in Silica powder.

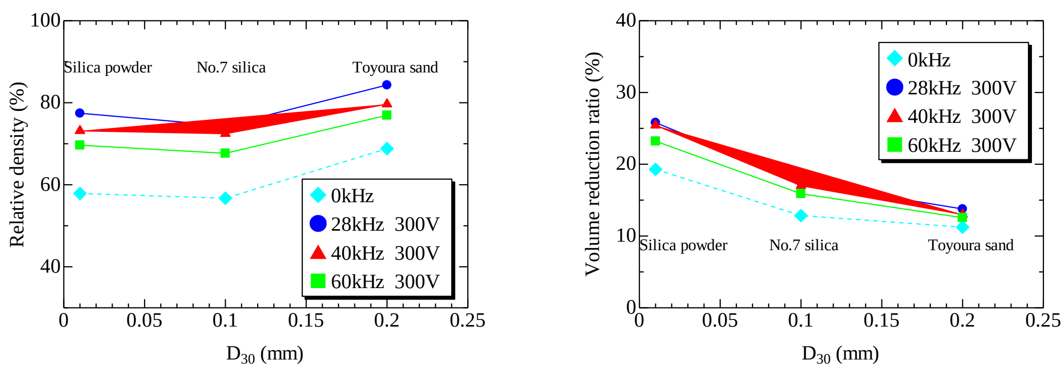

Figure 7. Comparison of the relationship between the 30% cumulative average particle diameter of samples and the relative density or volume reduction ratio.

5 CONCLUSIONS

The object of this study was to establish an efficient volume reduction method for sediment disposal facilities. From the results of the experiment on three kinds of samples with the ultrasonic wave, the following conclusions were derived:

- Irradiation of the ultrasonic wave from the horizontal direction was effective for increasing the density of fines.

- The results were extremely related to the particle size of the sample. The smaller the particle size was, the smaller the relative density was and the larger the volume reduction ratio was.
- In any of the samples, the volume reduction ratio was maximized at the ultrasonic wave of frequency 28kHz with output voltage 200V. Consequently, we couldn't find out a correlation between the particle size and the frequency.

References

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