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VERIFICATION OF AN EFFECT OF SOIL DENSIFICATION APPLYING GRAVEL DRAIN SYSTEM USING SURFACE-WAVE METHOD AND DEM SIMULATION

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Abstract

In this research, the validity of soil densification applying gravel drain system was inspected, by practicing a small-scale experiment and a distinct element method simulation. Soil densification applying gravel drain system that was developed by MARUJUN Corporation is one of the effective ways of preventing liquefaction. Because of the peculiarity of the motor, it is possible to hold down the cost, scale and the term of construction compared to conventional methods. Effect of compaction can be expected too, from applying pressure when injecting aggregate from the top. The effect of compaction was verified using surface-wave method. Surface-wave method has been applied to both engineering and earth science problems to image the S-wave velocity of the earth. Surface-wave method can estimate S-wave velocity models that are extremely valuable in geotechnical work. Therefore, surface-wave method has been increasingly used in various civil engineering and environmental investigations. To decide a diameter of auger, distinct element method (DEM) Simulation was performed. DEM is suitable for the simulation of deformation behavior of a discontinuous model. It assumes that an analysis object is a set of small elements. By solving the equations of motion for each element, behavior of the analysis object is observed.

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INTRODUCTION

Gravel drain system is one of liquefaction prevention methods. In this construction method, gravels are stuffed in column-shaped drain. Because of gravels' drainage effect, excess hydrostatic pressure, which come in when earthquake occur is dissipated. So, liquefaction can be prevented [1][2]. Gravel drain system using rotator motor can make gravel drain at a lower cost and more speedy because of its particularity of motor. By pressing gravels when drain is made, it is expected that an effect of soil densification as well as liquefaction prevention.

In this research, surface-wave method is used for verification of an effect of soil densification applying gravel drain system. Surface-wave method can estimate S-wave velocity models of ground easily. Therefore, the surface-wave method has been increasingly applied in various civil engineering and environmental investigations [3]. Small-scale experiment for verification of an effect of soil densification applying gravel drain system using surface-wave method is conducted on loamy layer of the Kanto Plain.

. On development of gravel drain system using rotator motor, distinct element method (DEM) Simulation is performed to decide a diameter of auger.

GRAVEL DRAIN SYSTEM USING ROTATOR MOTOR

Gravel drain system using rotator motor is suitable for construction in urban area and near existing building because it can construct gravel drains with low-noise and without applying vibration to vicinity of the construction site. By pressing gravels when they are injected into drain, gravel drain applies pressure to ground around it. Therefore, soil densification is expected as well as liquefaction prevention. Figure 1 shows Gravel drain system using rotator motor and figure 2 shows structures of a rotator motor and a guide for drill shaft inserted into drain.

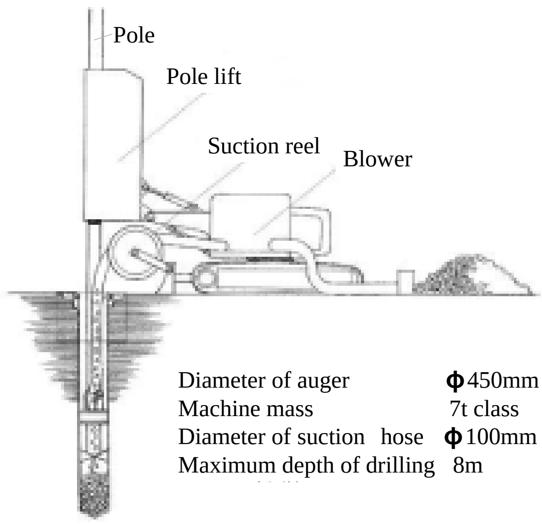

Figure 1 - Gravel drain system using rotator motor

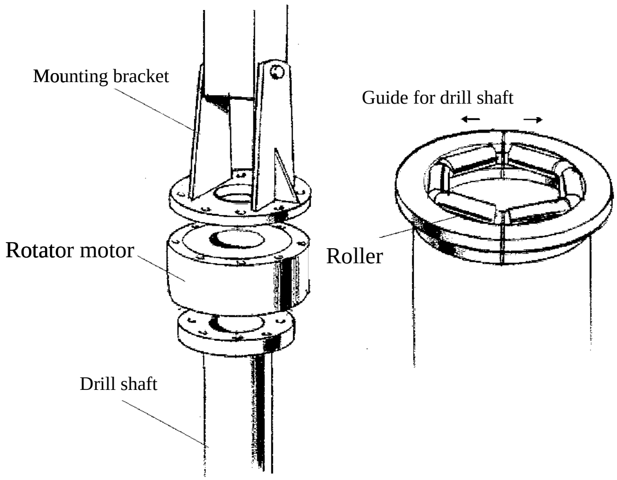

Figure 2 - Structures of a rotator motor and a guide for drill shaft inserted into drain

Comparing gravel drain system using rotator motor and one that does not, the former using rotator motor has three non-conventional characteristics. First, it is the position of motor. Conventional motor is fixed on the upper part of a pole, therefore drilling pole can't keep stability and qualities of made-up drains are not constant. But rotator motor developed by MARUJUN Corporation can be fixed to the lower part of a pole, so the center of gravity of drilling pole is seated lower and constant quality gravel drain can be constructed. Secondly, the rotator motor is torus-shape and gravels can be injected into drain through the rotator motor and pole. Conventionally, gravels are injected outside of pole. So, there is need to guard wall surface of drain. But there is no need to take that procedure in gravel drain system using rotator motor. Thirdly, the heavy machine in figure 1 can construct gravel drains by itself, without any other heavy machine. So cost comes down lower and space, which is needed for construction comes smaller.

SURFACE-WAVE METHOD

Surface-wave method is technique of estimating S-wave velocity models by measuring and analysing the Rayleigh-wave, which is one characteristic of surface-waves. Phase velocity of surface-wave is sensitive to the S-wave velocity. Phase velocity of surface-wave is 0.9 to 0.95 times that of S-wave. Surface-wave is extremely valuable in geotechnical works and it is easy to survey two-dimensional information of ground's hardness. Figure 3 shows the basic concept of surface-wave. By hammering the ground, elastic waves propagate surface and subsurface ground. Rayleigh-wave with short wavelength propagates through shoal ground and one with longer wavelength propagates through deeper ground. Generally, hardness of ground is different in its depth. So difference of wavelength causes the difference of survey depth. S-wave velocity model is obtained through the inversion of dispersion curve, which is the graph of phase velocity represented with frequency and velocity.

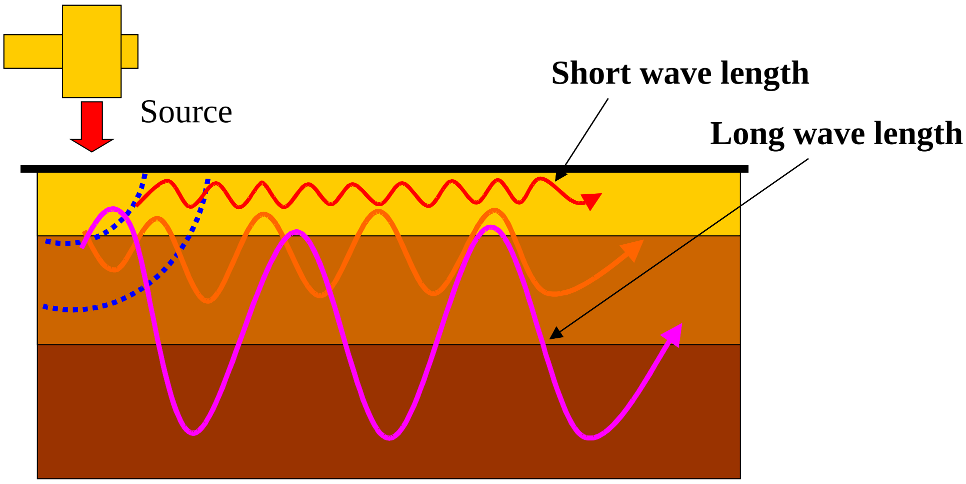

Figure 3 - Basic concept of S-wave method

THE SMALL-SCALE EXPERIMENT

Small-scale experiment is conducted on loamy layer of the Kanto Plain to image S-wave velocity model of the ground.

Experimental Set Up

Figure 4 shows experimental set up. The source and eight receivers were arranged linearly. The source was stroke by wooden hammer and receivers were geophones of which natural frequency is 4.5Hz. At first, receivers were placed from 0m to 10.5m on the survey line with 1.5m intervals. The source was at the interval of 5m from first receiver. After every stroke and measurement, source and receivers were moved 1.5m on survey line. The waveforms received by receivers were analyzed on PC. Sampling frequency was 2kHz and measurement time was 4s.

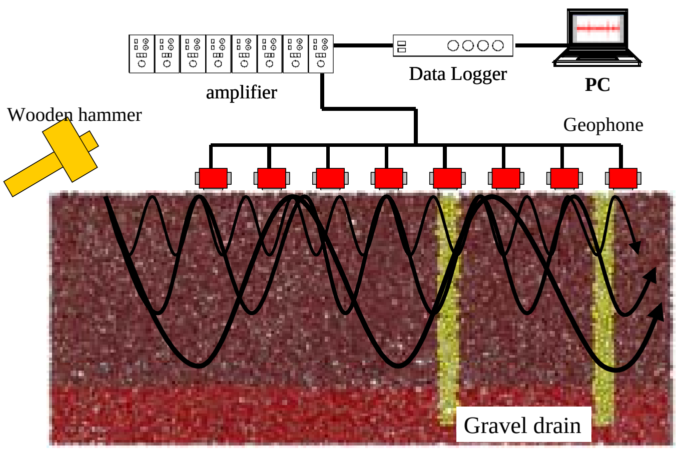

Figure 4 - Experimental set up

Table 1 shows experimental cases. Gravel drains we constructed were 80mm in diameter and 1.5m in length. Size of gravels which compose drains were from 5mm to 13mm. In order to apply pressure to gravel, pile driving was given when gravel was being injected. Pile was 60mm in diameter, whose front edge was cone-shaped and was made from plastic. These strokes were given based on results Ito(1992) showed. Figure 5 shows arrangement plan of gravel drains and geophones in each experimental cases.

Table 1 – Experimental cases

case (a)	Ground that any gravel drains have not constructed
case (b)	Ground that 6 gravel drains have constructed but not applied pressure
case (c)	Ground that 18 Gravel drains have constructed but applied pressure

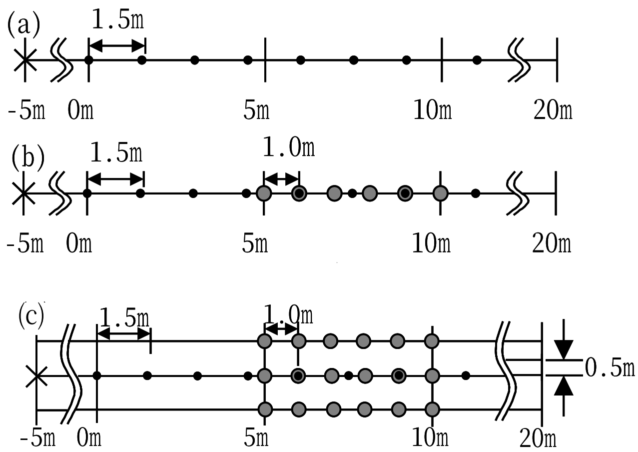

Figure 5 - Arrangement plan of gravel drains and geophones in each experimental case

Experimental Result

Figure 6 shows the waveforms collected from the receivers when the source was placed at distance –5m in case(a). Figure 7 shows an example of dispersion curve image calculated from each shot gather through CMP analysis. Figure 8 shows one dimension S-wave velocity structure obtained from phase velocity curve. Dark gray zone in the S-wave velocity structure is an area in which degree of confidence is sufficient.

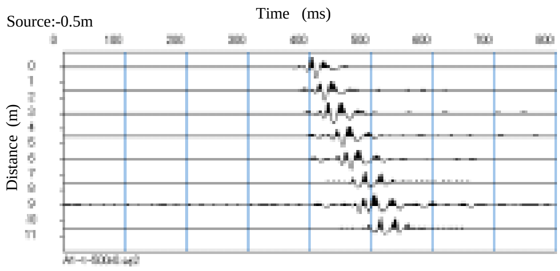

Figure 6 - Waveforms collected from the receivers

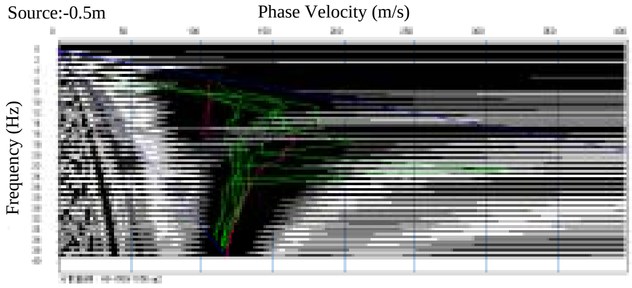

Figure 7 - Example of dispersion curve image

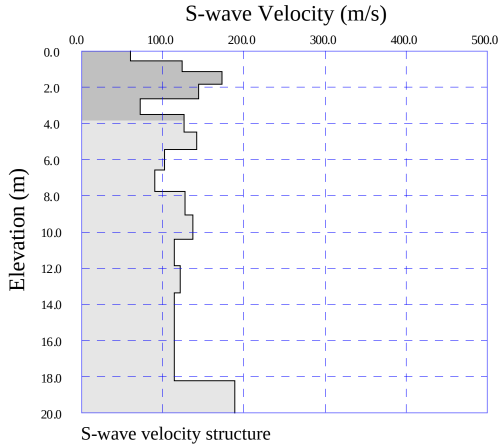

Figure 8 - One dimension S-wave velocity structure

Figure 9 shows the S-wave velocity structure in experimental case (a) and figure 10 shows the S-wave velocity structure in experimental case (b). In experimental case (a), gravel drains had not been constructed yet. While in experimental case (b), gravel drains had been constructed however, pressure on the gravels had not been applied. These S-wave velocity structures show cut plane from 1m to 19m on the survey line. Comparing figure 9 and figure 10, S-wave velocities are almost identical. In figure 10, the region in which S-wave velocity is faster than the other region does not exist where the region gravel drains were constructed.

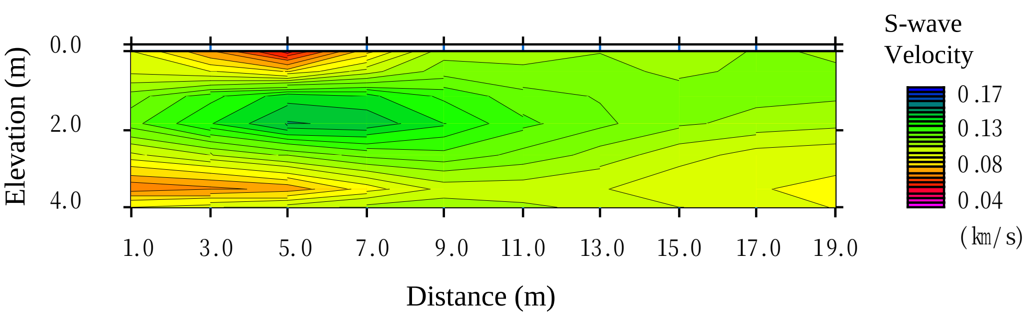

Figure 9 - S-wave velocity structure in experimental case (a)

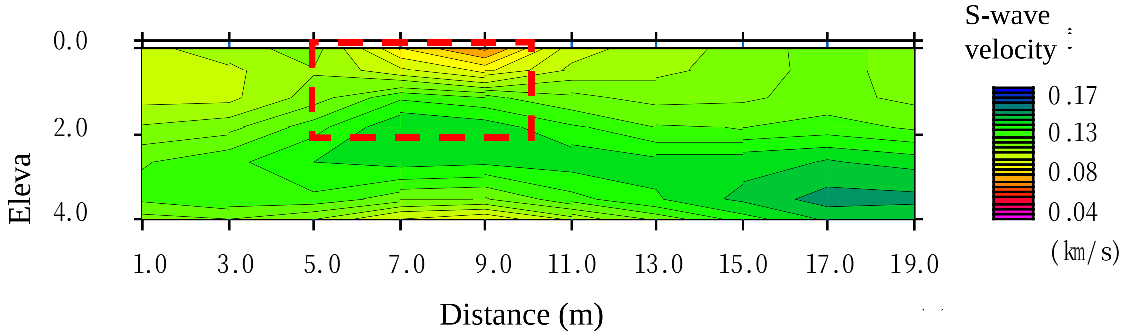

Figure 10 - S-wave velocity structure in experimental case (b)

Figure 11 shows the S-wave velocity structure in experimental case (c). In case (c), 18 gravel drains were constructed and pressure was applied. In figure 11, S-wave velocity is faster in the region at the horizontal distance of 5m to 10m and at the depth of 0m to 1.5m than the other region. Gravel drains were constructed in this region. From here onwards, the soil densification was caused by pressure applied to the gravel drains.

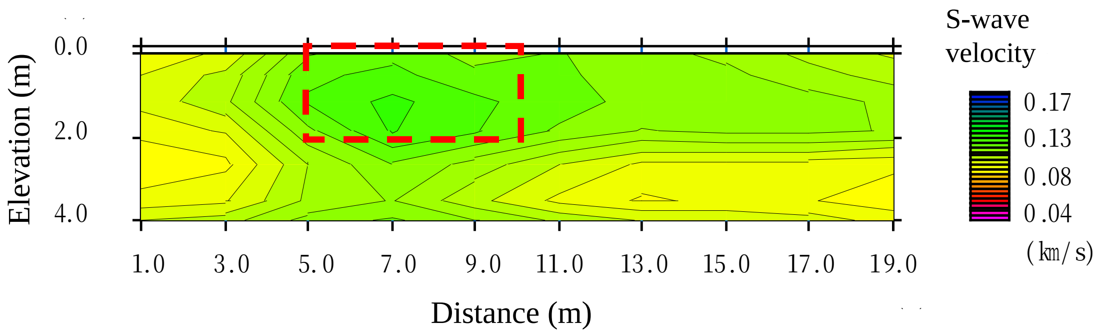

Figure 11 – S-wave velocity structure in experimental case (c)

DEM SIMULATION

On development of gravel drain system using rotator motor, it was necessary to decide a diameter of auger. DEM simulation was performed in order to reveal the optimal diameter of gravel drain between 400mm and 500mm to be used by the gravel drain system using rotator motor. Two models with each having three gravel drains were constructed. Figure 12 shows each model. In the former model, diameter of gravel drain is 400mm. And in the latter one, diameter of gravel drain is 500mm. Seismic wave was applied to these models. Figure 13 shows x-coordinate of two particle of each model. One is on the surface in the region gravel drains were constructed; the other is on the surface in the region gravel drains were not constructed. Comparing (a) and (b), each particle on the surface where the region gravel drains were constructed acted similarly.

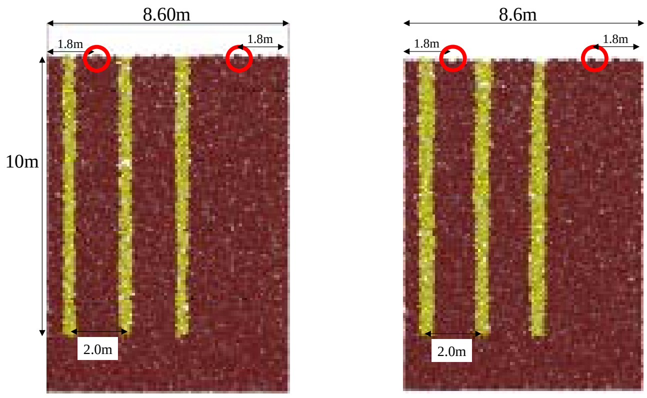

Figure 12 – DEM models

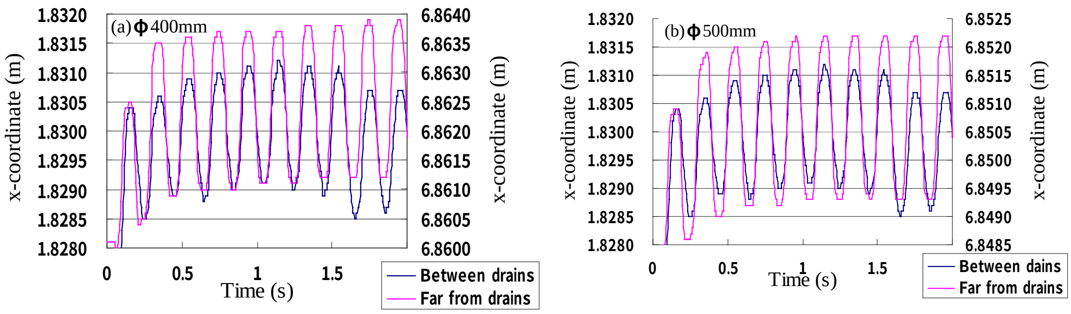

Figure 13 - X-coordinate of particles of each model

CONCLUSION

In this research, small-scale experiments were conducted to verify the effectiveness of soil densification applying gravel drain system. From the results, the following conclusions were obtained.

- The S-wave velocity models were estimated from surface-wave method.
- S-wave came faster in the region where gravel drains were constructed and pressure was applied on top of them.

Also from the results of DEM simulation, it was identified that drain's diameter whether it was 400mm or 500mm had no effect on the outcome of this system.

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