Experimental research on soft ground improvement incorporating vertical drains with heating

Beom Jun Kim & Chan-Young Yune
Gangneung-Wonju National University, Korea

ABSTRACT: In order to investigate the ground improvement of soft ground with heat injection, we developed a testing device to simulate a vertical drain with heat injection. Using the device, we performed a laboratory test according to the existence of heat injection and a varying diameter of the vertical drain. Based on the test results, the temperature distribution and the consolidation behavior of the soft ground were analyzed. Test results showed that heat injection of soft ground increased the final settlement.

Keywords: Heat injection, vertical drain, temperature distribution, ground improvement, final settlement

1 INTRODUCTION

Temperature change affects the consolidation behavior of soft soils. Heat injection into vertical drains installed in a soft ground generates excess pore pressure in surrounding soil, and decreases the volume and the void ratio after the dissipation of the excess pore pressure. High temperature also reduces the viscosity of water, and accordingly accelerates the consolidation rate. Therefore, if heating is used with vertical drains and a pre-loading method, the improvement of soft ground can be achieved in an expeditious and efficient manner. Abuel-Naga et al. (2006) and Bergado et al. (2007) studied the consolidation behavior with a heat exchanger in a prefabricated vertical drain on soft ground. Park et al. (2012) performed the study of ultimate bearing capacity and trafficability on soft ground using a vertical drain with heat injection, and then estimated a range of ground improvement and strength variation. However, previous research has focused on the consolidation characteristics due to the temperature change of soft ground. The consolidation behavior with temperature change can be significantly varied according to the diameter of a vertical drain, because the increase of the drain diameter increases the affected area by heating. The temperature change according to the diameter of a vertical drain has a greater effect on compressibility and permeability of soft ground. Subsequently, these effects can increase consolidation settlement and decrease the consolidation rate of soft ground. Therefore, the study of consolidation behavior on soft ground using vertical drains with heat injection is needed.

In this study, to investigate the effect of heat injection with a vertical drain on the ground improvement of soft ground, a testing device to simulate heat injection was developed. Using the testing device, a consolidation test was performed considering heat injection and the varying diameter of a vertical drain. During consolidation, vertical settlement and temperature at various locations in the specimen were measured. Based on the test results, the temperature distribution and the consolidation behavior of soft ground were analyzed.

2 LABORATORY TEST

2.1 *Developed testing apparatus*

Figures 1 and 2 show the schematic illustration of the testing device for the consolidation of soft ground by vertical loading accompanied with heating. The consolidation chamber has an inside diameter of 300 mm and a height of 485 mm. A rigid plate is placed on the top of the specimen to transmit air pressure controlled by a regulator as a vertical load upon the specimen. An electric heating rod located at the center of a sand drain is used to inject heating during the consolidation of the specimen. The electric heating rod is 300 mm in height and 20 mm in diameter. The vertical sand drain is installed by an open-end mandrel made as a thin-wall tube to minimize smear around the sand drain. Two sizes of mandrel (40 mm and 60 mm in outside diameter) were manufactured to simulate various sizes of sand drain. During consolidation of the specimen under constant load, the temperature of the heating rod was also maintained constant by a temperature controller. Temperature sensors were used at several locations to measure the temperature inside the specimen during consolidation. Vertical displacement was measured by an LVDT.

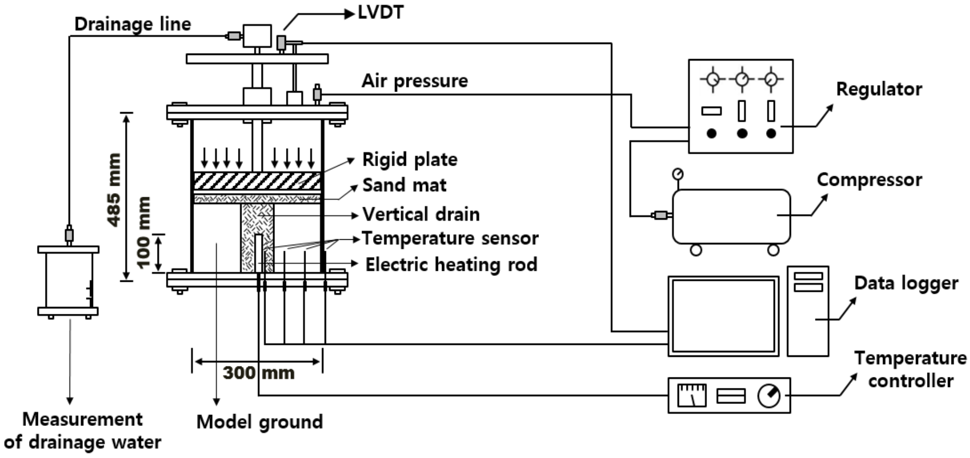


Figure 1. Schematic diagram of test setup.

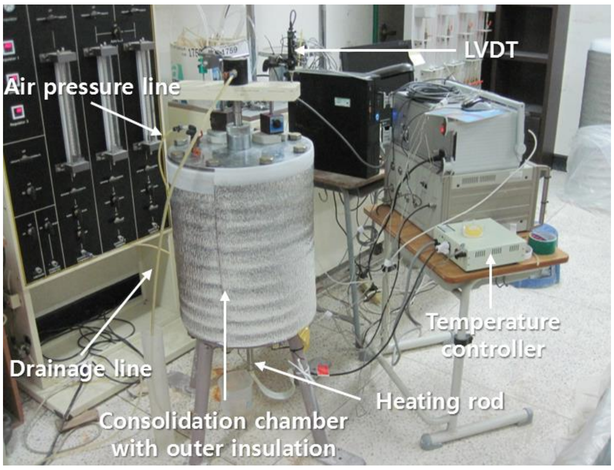


Figure 2. Testing device.

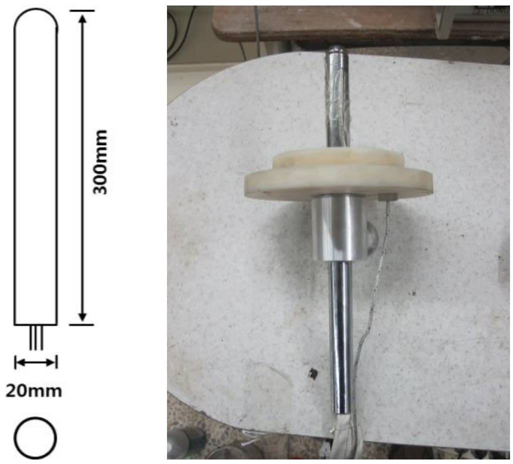


Figure 3. Electric heating rod.

2.2 *Test procedure and condition*

Reconstituted kaolin was used to simulate soft ground. The index properties of kaolin are summarized in Table 1. For the reconstitution of a specimen, kaolin powder was placed in a mixing chamber with a water content of 110%, more than twice the liquid limit of kaolin. Then, the kaolin slurry was stirred constantly by a mixing blade for about 24 hours. During the mixing, a vacuum was applied to remove air bubbles trapped in the slurry. Once the mixing under the vacuum was completed, the kaolin slurry was placed into the consolidation chamber, and then 40 kPa of pre-consolidation pressure was applied for approximately 10 days. After the reconstitution of the specimen, the consolidation chamber was located at the center of a mandrel-inserting device. After that, the mandrel was pushed into the center of the specimen to make a central hole for the vertical drain. After the insertion of a heating rod through the bottom plate of the chamber, sand was poured into the central hole and the top of the specimen to make the vertical sand drain and the sand mat. Temperature sensors were installed at intervals of 50mm from the heating rod. The heat injection of the specimen was injected by the heating rod. The temperature of the heating rod was maintained at 53°C for the consolidation. The specimen was consolidated by increasing the vertical load incrementally in two stages (100 kPa and 200 kPa). During the consolidation, temperature, settlement, and the amount of drainage water were measured. Five tests were performed according to the heat injection and the varying diameter of the sand drain. Test conditions are summarized in Table 2.

Table 1. Index properties of kaolin.

	LL(%)	PL(%)	PI(%)	Gs	Passing ratio (#200)	U.S.C.S.
EPK kaolin	55.60	18.93	36.67	2.51	99.46	MH

Table 2. Test conditions.

Test conditions			Designation
Drainage direction	Diameter of sand drain (mm)	Heating condition	
Vertical	-	Without heating	V
Vertical and Radially inward	40	Without heating	R-40
	60	Without heating	R-60
	40	With heating (53°C)	RH-40
	60	With heating (53°C)	RH-60

2.3 *Temperature change*

Figure 4 shows the temperature change in the soft ground according to the heating time. The temperature in the soft ground was measured at 50 mm, 100 mm, and 150 mm from the heating rod. After the heat injection, the temperature increased and stabilized after 10,000 minutes until the end of the subsequent consolidation test. The increasing diameter of the sand drain also increased the temperature of the specimen. Figure 5 shows the spatial distribution of temperature in the specimen as radial distance from the center. In order to investigate the changing behavior of the temperature according to time, the temperature distribution was plotted with varying time (1, 10, 100, 1,000, and 10,000 minutes). The temperature of two specimens with drain diameter of 40 and 60 mm shows similar distribution before 100 minutes and then the temperature in RH-60 increases by 1.04 times higher than RH-40 because of high thermal conductivity of the sand drain as shown in Figure 5 (a) and (b).

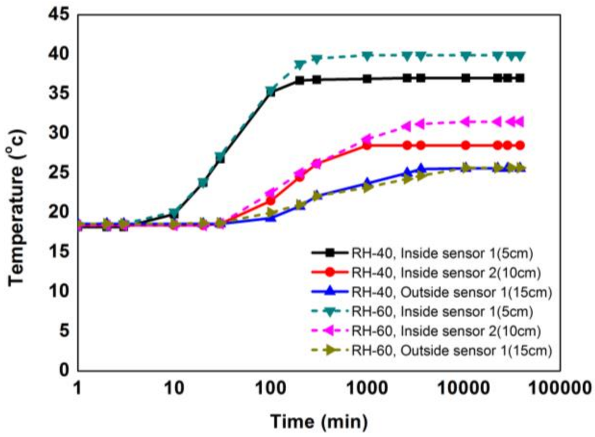
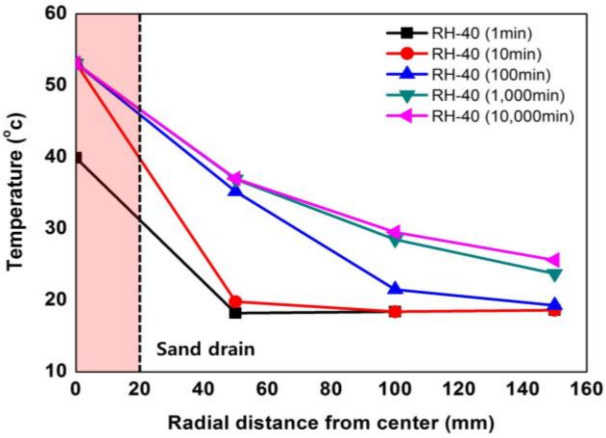


Figure 4. Temperature in the soft ground sample.

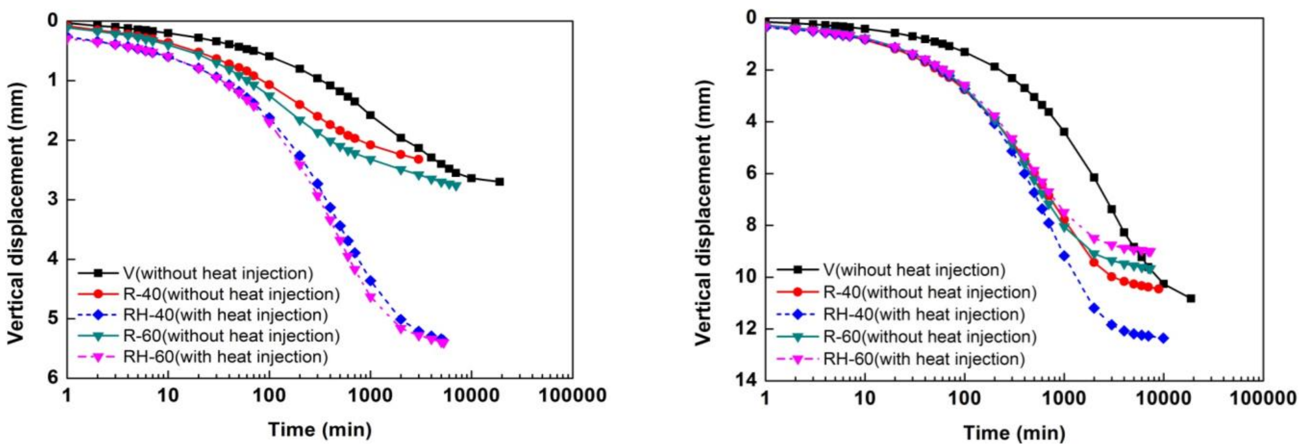


(a) RH-40 (b) RH-60

Figure 5. Temperature distribution in specimen

2.4 *Consolidation settlement*

Figure 6 shows the consolidation settlement measured in two stages of loading (100 kPa and 200 kPa). Based on the settlement data, the final settlement in each test condition was estimated at 95% of the consolidation ratio by hyperbolic method. In Figure 6, the sand drain accelerated the consolidation rate, and the heat injection increased the final settlement. Table 3 summarizes the final settlement for all tests to compare the results quantitatively. At the loading stage of 100 kPa, the vertical drain accelerated the consolidation rate, but had a negligible effect on consolidation settlement. On the other hand, heat injection clearly increased the final settlement about 85%. At the loading stage of 200 kPa, heat injection did not affect the consolidation settlement, while the vertical drain accelerated the consolidation rate.



(a) 100 kPa loading (OC state) (b) 200 kPa loading (NC state)

Figure 6. Consolidation settlement.

Table 3. Comparison of final settlement.

Test	100 kPa loading		200 kPa loading	
	Total settlement (mm)	Settlement ratio	Total settlement (mm)	Settlement ratio
V	2.91	1.00	10.82	1.00
R-40	2.35	0.81	10.45	0.97
R-60	2.76	0.95	9.66	0.89
RH-40	5.36	1.84	12.35	1.14
RH-60	5.40	1.86	9.00	0.83

3. CONCLUSION

In this study, to investigate soft ground improvement with heat injection, a testing device to simulate soft ground with heat injection was developed. Using the testing device, a series of consolidation tests with heat injection and a sand drain were conducted. Based on the test results, the temperature distribution and the consolidation behavior of soft ground were analyzed. The test results showed that heat injection increased the final settlement. Furthermore, the increasing diameter of the sand drain increased the temperature of the specimen.

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REFERENCES

Abuel-Naga, H.M., Bergado, D.T., and Chaiprakaikeow, S. 2006. Innovative thermal technique for enhancing the performance of prefabricated vertical drain during the preloading process, *Journal of International Geosynthetics Society*, Vol. 24(6), pp. 359–370.

Bergado, D.T., Shin, E.C., and Park, J.J. 2007, Improvement of consolidation characteristics around PVD using the thermal method, *Journal of Korean Geotechnical Society*, Vol. 23(10), pp. 5–11.

Park, M.C., Im, E.S., Lee, K.S., and Han, H.S. 2012. Experimental study for consolidation by electric heating system, *Journal of Korean Geoenvironmental Society*, Vol. 13(10), pp. 43–53.