Field application and numerical analysis of Suction Vertical Drain Method
Champ de l'Application et de l'Analyse Numérique de la Méthode de la Succion de l'Egout Vertical

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ABSTRACT

In this study, field application test for Suction Drain Method, which can improve the soft ground without surcharge loading or sealing sheet was performed to find out the construction period and improvement degree with suction pressure stage. Also, the analysis program for optimized finite elements with Suction Drain Method was developed, and compare and analyze with analysis results of commercial program and field test construction. As a result, settlement data from existed program was larger than actual field test data. On the contrary, analysis results of Suction-CAIN program were similar to field test results.

RÉSUMÉ

Dans cette étude, le test de l'application du champ pour la Méthode de la Succion de l'Egout, qui peut améliorer le sol doux sans supplément de charge ou sans feuille de cachetage etait exécuté pour déterminer la durée de la construction et le degré de l'amélioration avec l'étape de la pression de la succion. Ainsi, le programme de l'analyse pour les éléments optimisés et finis avec la Méthode de la Succion de l'Egout etait développé, et compare et analyse avec les résultats des analyses du programme commercial et la construction du test du champ. Par conséquent, la donnée de l'accord du programme ancien était plus grande que celle du test du champ actuel. Au contraire, les résultats des analyses du programme de Succion-CAIN étaient semblables aux résultats du test du champ.

Keywords : Suction Drain Method, Suction-CAIN, PVD, Vacuum Pressure

1 INTRODUCTION

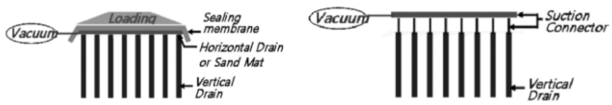
The Vertical Drain Method is used in construction that accelerating consolidated settlement by placing permeable layers vertically under the ground and shortening distance of drain. However, taking effect of the vertical drain depends on loading pressure, and the soil embankment loading is necessary for this method. So, Vertical Drain Method causes a lot of problems such as matters of securing sand and differential settlement, causing large shearing stress in soft layers around end of loading place which is in the foundation ground receiving partial loading, and not occurring of effective consolidation caused by considerable shape shifting with the beginning of loading.

For these reasons, the Suction Drain Method, which has excellent soil improvement effect and can be easily constructed, was suggested to resolve the problems of consolidation acceleration method. Recently, the influence factors of Suction Drain Method were clarified through various indoor experiments by Kim et al.(2006, 2008) and Han et al.(2008).

This study shows performance of consecutive field test construction for examining field application of Suction Drain method, based on the influence factors derived from the laboratory tests at soft ground of reclaimed land nearby Hwaseong-si, Gyeonggi-do, Korea. The construction was performed with 2 sections using 2 types of drain boards selected through laboratory test. And improvement efficiency of each section was compared and analyzed by measuring settlement, horizontal displacement, vacuum pressure, pore water pressure. Also, the analysis program for optimized finite elements with Suction Drain Method was developed, and compare and analyze with analysis results of commercial program and field test construction..

2 PRINCIPLES OF SUCTION DRAIN METHOD

The Vertical Drain Method is the method using a principle of consolidation progress through dissipation of excess pore water pressure, which is revealed by loading pressure. On the contrary, Suction Drain Method is the method using a principle of consolidation progress, caused by increase of effective stress due to discharging pore water pressure at fixed total stress with installing a vertical drain board in the ground and giving vacuum pressure directly. This method could overcome the defects of existing vacuum consolidation method and surcharge loading method by improving the ground using vacuum pressure without surcharge or sealing sheet. It also could adjust the thickness of Sealing layer by adjusting the installing depth of drain board and connecting vacuum pump to drain board directly. Hence, it could maximize vacuum efficiency, apply equal vacuum pressure to the ground, and prevent the shear failure and differential settlement in the ground. In figure 1, it shows the comparison between vacuum consolidation method by Kjellman(1948) and suction drain method.



(a) vacuum consolidation method (b) suction vertlcal drain method

Figure 1. Comparison between vacuum consolidation method and suction vertical drain method

3 FIELD TEST

on the result of the earlier soil investigation of site(figure 3). The Vertical Drain Method is the method using a principle of consolidation progress through dissipation of excess pore water pressure, which is revealed

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3.1 *Test Construction Site*

Most of the soft ground in Korea consists of filled ground by dredging and reclaimed land with marine deposit near the coast. Therefore, this study considered reclaimed land near the coast as the object to improve, and decided reclaimed land in the site of OO sea wall as the target ground. The thickness of the soft ground in the target area was around 10m, so the object depth of this study was fixed within 10m.

3.2 *Test Methods and Conditions*

The laboratory test indicated that the efficiency of 2 types of drain boards — spiral-core circular type and double-core harmonica type which are commonly used in domestic construction was relatively high. Accordingly, this field test tried to understand the efficiency of method with those 2 types of drain boards. Also, vacuum press was given in 4 stages at intervals of –0.2kg/cm², from –0.2kg/cm² to –0.8kg/cm², based on the result of the laboratory test(table 1). The size of the target site was fixed at width 70m, height 20m, and depth 10m (30m×10m×2 section, at intervals of 10m) (figure 2). The test period and the gap between drain boards was fixed based

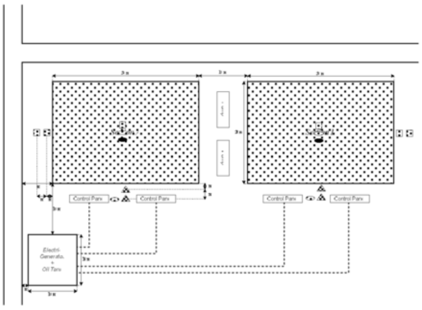
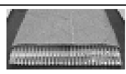
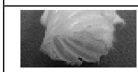


Figure 2. Schematic diagram of target field

Figure 3. Installing vertical drains

Table 1. Field test conditions

Case	Arrang-ement of rains	Filter Type	Drain Shape	Suction Pressure	Shape of Drain
Section A	Square	Pocket	Plate	0.2→0.4→ 0.6→0.8 (-kg/cm²)	
Section B			Circu-lar		

3.3 *Result of Field Test*

3.3.1 *Settlement and Horizontal Displacement*

In figure 4 and 5, it shows the distribution of settlement of section A and B, according to the time elapsed. The ground of section A had the settlement 8cm less than the ground of section B. The reason that the improvement efficiency of the spiral-core circular drain board was better than the double core flat drain board, is the actual air way, which is able to apply the vacuum pressure, of circular core shape was larger than the flat core. During 3 days after the cumulative conduct period, the power of generator was cut off and the operation of the pump was stopped, due to heavy rain and thunderbolt. In the period, there was slight a little bit of the settlement delay, but almost no swelling. And the settlement was very similar to the tendency of the earlier result after reoperation of the pump.

Total settlement of each step of vacuum pressure was compared, and the tendency appeared that total settlement decreased when there was higher stage of the vacuum pressure. It is because permeability was decreased by dense space of soil particles with decrease in void ratio of the ground when there was consistent consolidation at the stage of low vacuum pressure. These effects suggested the tendency of decrease in the efficiency of vacuum pressure, which was given through the pump, in inside of the drain board according to the time elapsed. The figure 6 and 7 are the graphs showing the horizontal displacement distribution in each depth, measured at the boundary point of improved area in section A and section B. The horizontal displacement of the section A, measured at the surface of the ground, was 3.8cm utmost, and 5.3cm utmost for the section B. In the case of the suction drain method, horizontal displacement was occured in the inside direction of the improvement area, which is opposed to the general soil loading method. And the unimproved area was pushed into improvement area due to given vacuum pressure in the ground.

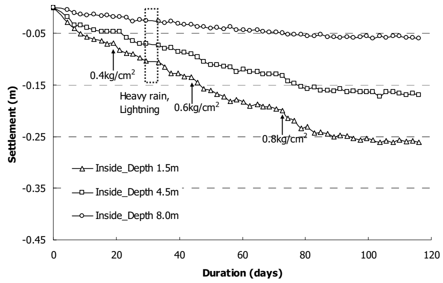


Figure 4. Distribution of settlement by elapsed time (Section A)

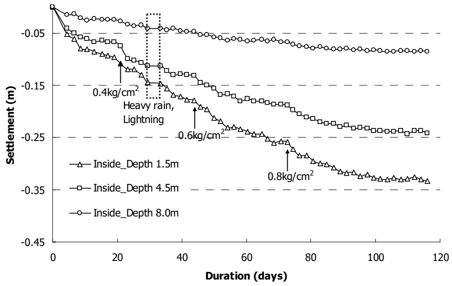


Figure 5. Distribution of settlement by elapsed time (Section B)

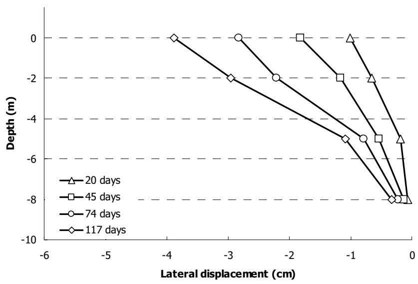


Figure 6. Horizontal displacement by elapsed time (Section A)

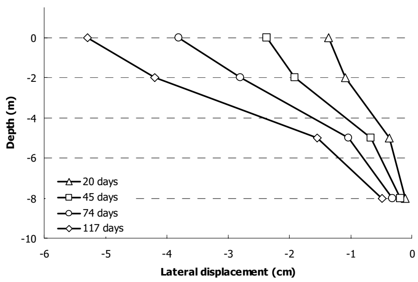


Figure 7. Horizontal displacement by elapsed time (Section B)

3.3.2 *Distribution of Vacuum Pressure*

The efficiency of the creation of vacuum pressure in each stage is shown in the figure 8 and 9. The efficiency of vacuum pressure in the section A was 85% average in the depth of 1.5m and decreased to 48% average in the depth of 9.5m. In the case of the section B, the efficiency was 90% average in the depth of 1.5m and 70% average in the depth of 9.5m. It suggests that the circular drain board is more efficient related to the vacuum pressure, than the flat drain board. The flat drain board is complicated to connect the hoses to the board, which causes the problem of sustaining the vacuum pressure, different than the circular drain board that can be connected to hoses directly. The vacuum pressure measured after the interruption of the system due to heavy rain, was increased and recovered the original status. The vacuum pressure efficiency was 98% utmost in the depth of 1.5m at the section B, indicated the tendency to decrease little by little when the pressure was getting larger.

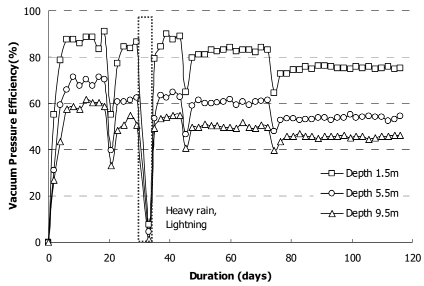


Figure 8. Efficiency of vacuum pressure by elapsed time (Section A)

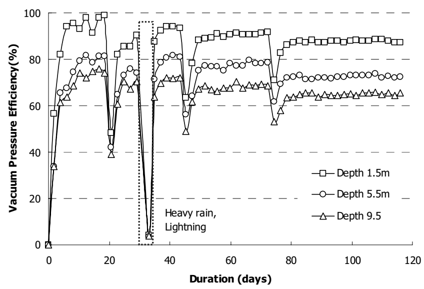


Figure 9. Efficiency of vacuum pressure by elapsed time (Section B)

The loss of the pressure almost didn't exist in the depth of 1.5m, and it is because the sealing layer was completely sealed and it was very close to the vacuum pump. The pressure efficiency was 74% utmost in the depth of 9.5m, and the efficiency decreased by 24% when the depth increased by 8m except for sealing layer and soil layer. In the case of flat drain board, the average efficiency of the vacuum pressure measured in the depth of 1.5m was about 85%, which was lower than the circular drain board by 9%. The difference between circular and flat board was getting larger as much as the depth getting deeper. The efficiency of the vacuum pressure was around 47% in the depth of 9.0m and decreased by 38% when the depth increased by 8m..

4 APPLICATION OF THE SUCTION-CAIN PROGRAM

4.1 *Suction-CAIN program*

The Suction-CAIN program is 2D finite element analysis program which offers various function including automatic element division with the Drainage Element, automatic measuring of permeability and converted equivalent sectional area using suggesting type by Hird (1992), automatic detecting of maximum settlement and maximum horizontal displacement location, reverse analysis of input parameter, and the functions that provided by the general finite element program. The program was developed as the exclusive program for suction drain method to apply to the vacuum pressure to the drain board directly.

4.2 *Analyzed Section and Boundary Condition*

The exclusive program for suction drain, Suction-CAIN, was performed the analysis of the same section as the test construction site to examine the application ability, and performed comparative analysis with existed program (Sage CRISP) and the result of field test construction. The analyzed section was fixed at the same condition as the site, which is 1m thickness of sealing layer, 9m thickness of the improved layer, and the square arrangement of the drain board. Also, the properties of the ground installed with drain board were corrected and inputted automatically, through the measuring equation of Hird. Only the single drain to the top was allowed, the intervals of the drain board were the same as the site condition. The finite element nets created by the analysis are shown in figure 10 and 11. The period of analysis for each stage performed the same as the site with each stage of the vacuum pressure. The vacuum pressure given to the drain board was inputted the same as the site based on the pressure measured at field test construction, with consideration of each stage and the efficiency of each depth.

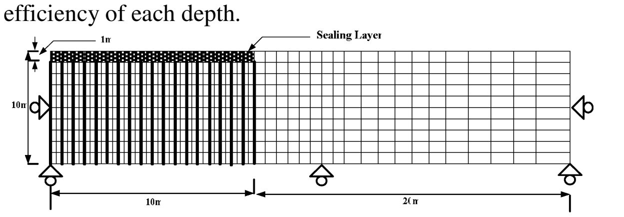


Figure 10. Boundary condition and finite element mesh(Sage Crisp)

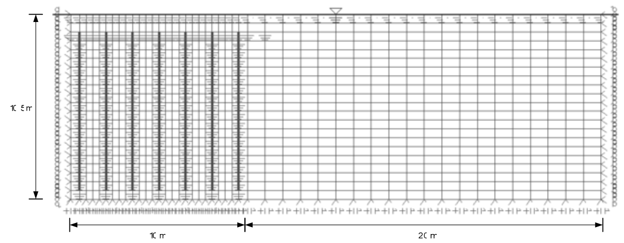


Figure 11. Boundary condition and finite element mesh(Suction-CAIN)

4.3 *Result and Analysis*

4.3.1 *Settlement and Horizontal Displacement*

The figure 12 shows the field data comparison which was applied with circular drain board at each depth and settlement aspect of suction drain method created from the center of the improved area according to the changes in stage of vacuum pressure. The final settlement, predicted by Suction-CAIN program, was similar to the actual measures of settlement. The settlement of each stage of vacuum pressure was large at the low stage. And the increase in the stage caused the behavior of decrease in the settlement due to the consolidation of the previous stage, and those matched with actual field data. The figure 13 shows the values of field measuring and the total settlement predicted by existing program (Sage CRISP) and Suction-CAIN. The existing program couldn't consider the permeability decline section by hardening zone and vacuum pressure efficiency. It caused relatively large values of settlement, and created the result of remarkably different values of settlement behavior in each vacuum pressure stage. However, it was possible to get closer value to the actual measurement through consideration process of each loading stage, pressure efficiency of each depth, hardening area, and equivalent permeability using Hird's law, which was more accurate than the CRISP program. The Application ability of suction drain was examined through those results.

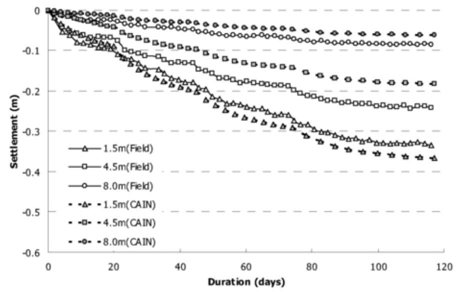


Figure 12. Comparison of measured settlement and predicted value by Suction-CAIN program

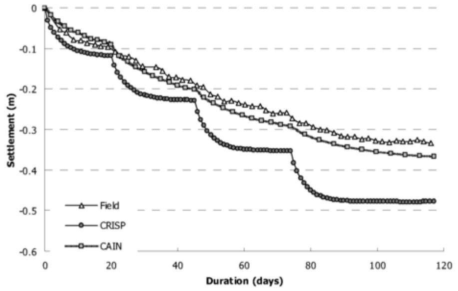


Figure 13. Comparison of measured settlement, result of sage crisp and Suction-CAIN program

The figure 14 shows the distribution of the final horizontal displacement from the analysis result of Suction-CAIN and existing program, and the measurement from the construction site. As the result, the predicted amount of displacement was a little different than actual measure, and the difference (4cm utmost) was very little. However, the displacement behavior predicted by existing program was quite different than the actual site behavior. The Suction-CAIN program could analyze the ground behavior similarly to actual site, because it adjusts the size of vacuum pressure as linear or nonlinear at each depth. It was possible to predict the relatively exact behavior through copying the tendency of vacuum pressure decline according to the depths created in the actual ground.

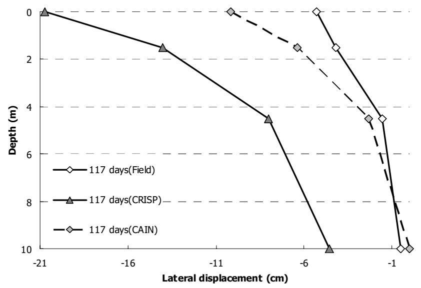


Figure 14 Comparison of measured maximum horizontal displacement, result of sage crisp and Suction-CAIN program

4.3.2 *Distribution of Vacuum Pressure*

The figure 15 is the graph of comparison between measurement analysis and actual site measurement of distribution of vacuum pressure according to the depths. In the case of field measurement, the efficiency decreased in accordance with the depths, and the vacuum pressure was decreased. The distribution of vacuum pressure of drain board was the same as the actual site. It is because that the vacuum pressure was inputted, which was considered by the efficiency of each loading stage, and each depth. On the contrary, the existing program indicated the constant values, because it couldn't reflect the decline effect of vacuum pressure according to the depths. The result was a key factor that creates the larger values of every data than the actual measurement and Suction-CAIN program after the analysis process of existing program.

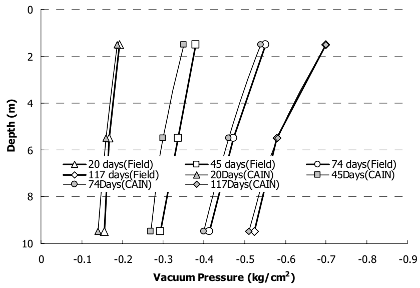


Figure 15 Comparison of measured vacuum pressure and result of Suction-CAIN program by depth

5 CONCLUSION

In this study, the behavior of settlement, vacuum pressure, horizontal displacement and pore water pressure were measured through field test construction of suction drain method, according to the types of drain board. And the consolidation behavior and the deformation aspect within the ground was derived from those results. Also, the test result was compared to the analysis of Suction-CAIN program, and the conclusion is suggested as follows.

1) The result of the field test indicated around 26cm and 34 cm settlement for flat and circular drain board each, because the vacuum pressure efficiency of circular drain board within the ground is average of 20% larger than the flat drain board.
2) The general PBD method usually indicates the direction of displacement is created from improved area to unimproved area when it comes to the side displacement. On the contrary, the suction drain method indicated the displacement within the improved area. By application of the suction drain method, increase in stress was created, and affected to the ground with isotropy.
3) The distribution of the vacuum pressure indicated that average of 94% and 85% of the efficiency in the depth of 1.5m, and decreased average of 70% and 47% in depth of 9.5m, where the flat and circular drain boards were installed, and the flat drain board had a larger decreased efficiency. The vacuum pressure measured inside of the ground, was given to the drain board at approximately 50~58%.
4) The result of the field test was compared and examined to review the application ability of Suction-CAIN program. It was almost the same as the actual measurement in horizontal / vertical displacement, vacuum pressure, and behavior of pore water pressure tests. The result indicates that the program was possible copying the relatively similar condition of the actual site, and considered the decrease in the vacuum pressure according to the length of drain board and the decline ratio of permeability. Therefore, it will be possible to predict more accurate behavior of the ground, where the suction drain method is actually applied, using the Suction-CAIN program developed by this study.

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