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Vacuum consolidation method applied to underwater mud improvement

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ABSTRACT: Vacuum consolidation is an effective ground improvement method for very soft ground. It has been used to improve sedimentary layers in rivers. This has shortened the construction period compared to the conventional method of removing sedimentary mud. This method is also good for the environment not only for the above reason but also because it reduces construction noise.

As a result, the effectiveness of the vacuum consolidation method applied to underwater mud improvement in a marsh was confirmed. Various investigations and the measurements showed that vibration and noise during construction were minimized, and construction was finished with little impact on the local environment.

1 INTRODUCTION

Vacuum consolidation is a ground improvement method for very soft ground (Kjellman, W. 1952). In this method, airtight seats are spread on very soft ground surfaces, and then vacuum pressure is applied as a surcharge load. To improve soft clay ground, an embankment surcharge method is usually applied. However, this method requires a long construction period because large deformations may occur with rapid embankment construction. The vacuum consolidation method has the advantage that it enables high stability during the improvement process, because it requires no embankment construction.

Sometimes a short construction period is required for improvement work that enlarges the cross sections of rivers or lakes by compressing the sedimentary mud at the site. On-site consolidation of sedimentary mud is effective in ensuring large river or lake capacity without the need to excavate and dispose of sedimentary mud.

The vacuum consolidation method has been applied to improve sedimentary layers in rivers. This has shortened the construction period compared to the conventional method of removing sedimentary mud. This method is also good for the environment not only for the above reason but also because it reduces construction noise.

This paper presents applications of the vacuum consolidation method for volume reduction of bottom mud, and the effect of the improvement.

2 APPLICATION OF VACUUM CONSOLIDATION METHOD UNDER WATER SURFACE

2.1 *Outline of typical ground improvement construction and advance*

This ground improvement construction involves dredging to increase the depth of the Sugao Marsh in Ibaragi Pref. Japan to improve the flood control function. During construction, it was necessary to preserve the environment of plants and animals, because the locale was specified as a natural environmental preservation district and a bird and beast sanctuary, and very severe restrictions had been placed on it. Thus, the use of large construction machines was limited.

Therefore, the vacuum consolidation method under the water surface was applied as a method of securing depth without the need to excavate mud.

Figure 1 shows an image of the vacuum consolidation method applied to underwater mud improvement. The vacuum consolidation method is characterized in its processing of the bottom mud without dredging it. An airtight seat is placed over the marsh mud. The vacuum pressure obtained by the vacuum pump and airtight seat are applied to the soft clay. Mud is consolidated by the obtained vacuum pressure. As a result, the depth of the marsh is secured. This settlement can achieve the same effect as dredging.

This ground improvement method lays the edge in an airtight seat underground. Traditionally, to secure

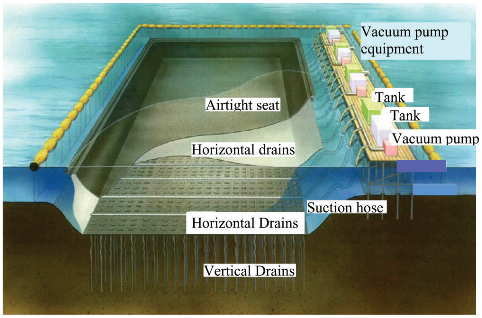

Figure 1. Image chart of vacuum consolidation method under water surface.

airtightness of the ground, sheet piles are constructed as an interception wall. However, because a large-scale construction machine cannot be used in the locale because of the environmental protection requirements, no interception wall could be constructed. Therefore, the above method was adopted. Cost should also be reduced with this simplified method.

Moreover, because the cross-sectional areas of the horizontal drain material are decreased by the vacuum pressure, a horizontal drain material that provides resisting pressure was adopted.

2.2 *Ground condition and ground improvement construction*

Figure 2 shows a cross section of the ground improvement. In the surface part, there is a soft clay layer 10 m thick. To achieve ground improvement, plastic board drains were driven 10 m deep from the ground surface where there is 0.3 m depth of water. After that, horizontal drains were placed in the soft ground. The area of this improvement was 100 m square.

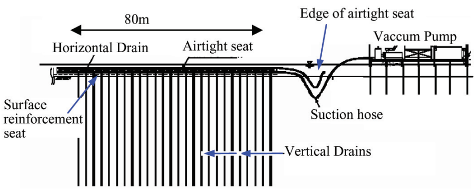

Figure 2 Cross section of field.

Figure 3 shows the construction procedure. Table 1 shows properties of geosynthetics that used in this site. Photo 1 shows a horizontal drain.

This construction work was done in 0.3 m depth of water.

Most of the construction work, such as expanding seats and backfilling of the seat edge, was done manually in consideration of the environment.

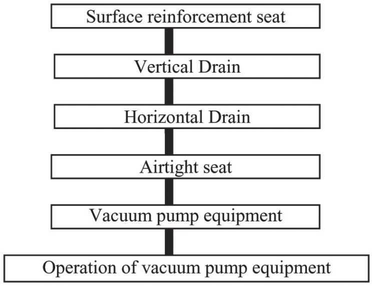

Figure 3. Construction flow.

Table 1. Geosynthetics used in this construction.

Kind of geosynthetics	Specifications
Surface reinforcement seat	Geogrid
Vertical Drains	Plastic board drains (PVD) PVD were set at 0.5 m intervals and were driven 10 m depth in a 12 m-deep soft clay layer.
Horizontal Drains	Geocomposite This geocomposite has function of horizontal drain and airtight seat. Horizontal drains are 10 mm thickness.
Airtight seats	Airtight seats are 1 mm thickness and are made of vulcanized rubber.

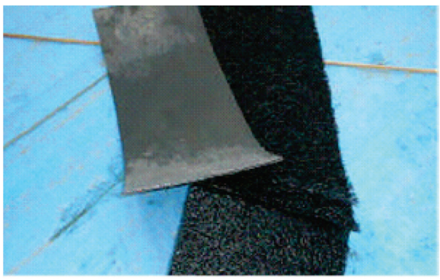

Photo 1. Geocomposite that have function of horizontal drain and airtight seat.

2.3 *Consideration on effect of edge of airtight seat by trial calculations of a model ground*

The effect of the edge of the airtight seat was considered by means of FEM consolidation analysis using the modified Cam-clay model.

The effective area of the vacuum pressure is more indefinite than that in the surcharge method.

In many FEM analyses, it is assumed that vacuum pressure acts only in the area of vertical drains (for example Matsumoto, K, et al,1998).

Figure 4 shows the analytical conditions. Vertical drains were set at 1 m intervals. They were driven excluding 1 m to the bottom of a 10 m-deep clay

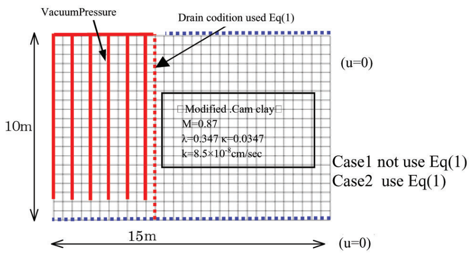

Figure 4. Condition on FEM analysis.

layer. The airtight seat was spread on the ground surface. In the analysis, 50 kPa vacuum pressure was applied to the area where veridical drains were driven and the airtight seat was placed. For Case 2, in addition to the above condition, another drain boundary condition was set 0.5 m away from the vertical drains. This distance was required from the Sichhardt Equation (Leonalds, G.A.1962). The Sichhardt Equation is used to evaluate the boundary conditions of the seepage problem where a well is used to decrease ground water level. The Sichhardt equation is shown in Equation (1).

$$R = 3000\sqrt{k} \quad (1)$$

R : radius of influence area (m)
s : maximum water level decrease (m)
k : coefficient of permeability (m/sec)

Figure 5 shows the distribution of pore pressure when consolidation is complete. Case 1 shows a broader area than Case 2.

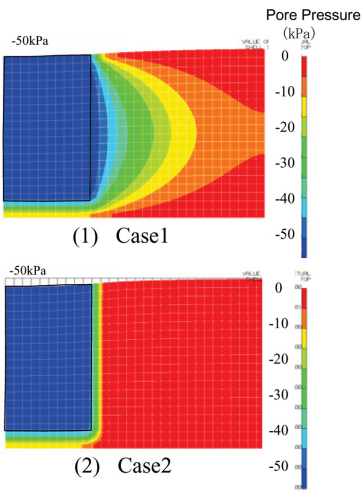

Figure 5. Distributions of pore pressure.

Figure 6 shows the settlement distribution at the ground surface. In the area adjoining the improved ground, settlement was also recognized. The settlement of Case 2 was smaller than that of Case 1. Actually, settlement occurred in the area surrounding that where vacuum pressure was applied. An analytical result of Case 2 shows an actual feature well compared with Case 1.

From these analytical results, it is obtain that a improvement method laying the edge in an airtight seat underground is effective to improve the soft ground using vacuum pressure as well as interception with sheet piles.

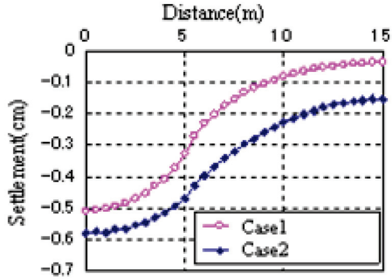

Figure 6. Distributions of settlement.

3 EFFECT OF GROUND IMPROVEMENT

3.1 *Settlement curves*

Figure 7 shows the relation between the vacuum pressure and settlement. The settlement increases with vacuum pressure. The obtained vacuum pressure was about 60%. This is almost equal to that obtained in a traditional land construction site. During this construction period, three big typhoons came and the water height of the marsh rose. During each of these times, the vacuum pumps had to be stopped. As a result, vacuum pressure decrease and rebound appeared, and these phenomena are confirmed in this figure. Although it was a severe natural condition, settlement of about 160 cm, enough for the target, was obtained in three months.

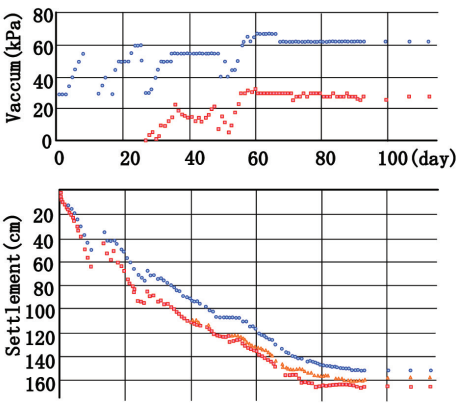

Figure 7. Settlement curves.

3.2 *Settlement distributions*

Figure 8 shows the settlement distribution. In the every improved area, the settlement amounts are almost same. Maximum settlement was observed at the center of the improved area and was about 1.9 m. It is possible to confirm that almost the same vacuum pressure had been applied in this improved area without decrease at the edge.

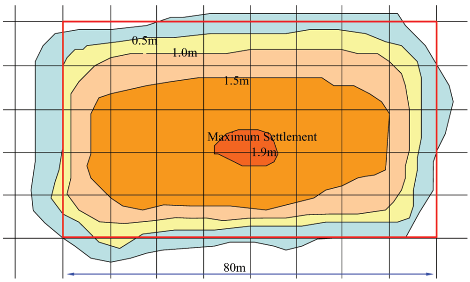

Figure 8. Distributions of settlement.

3.3 *Surrounding environmental impact*

Various investigations and measurements showed that vibration and noise during construction were minimized. Furthermore, construction was finished with little impact on the local environment.

Photo 2. Swans near construction site.

The quality of pumping water was investigated to manage the influence of this vacuum consolidation method, and it was confirmed that the water quality and turbidity met the environmental standard criteria.

A lot of winter birds such as swans return to the construction area every year. It was confirmed that they nested and passed the winter there during the construction period just as usual, thus showing that this industrial method was gentle on the natural environment.

4 CONCLUSION

The vacuum consolidation method was applied under the water surface as bottom mud processing construction of marsh.

The main results obtained from this study are as follows.

(1) The effectiveness of the vacuum consolidation method applied to underwater mud improvement in the marsh was confirmed.

(2) Various investigations and measurements showed that vibration and noise during construction were minimized, and construction was finished with little impact on the local environment.

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