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CONTENTS

Air-Water Separation System for the Vacuum Consolidation Method 1

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Air-Water Separation System for the Vacuum Consolidation Method

Maintaining vacuum pressure at a high level during soft ground improvement using the vacuum consolidation method with air-water separation system

1. Introduction

The Vacuum Consolidation Technology Association was established in 2000 comprising consultants and contractors, with the aim to develop soft ground improvement by means of the vacuum consolidation method, which is used to accelerate consolidation progress to promote ground settlement and increase ground stability during construction.

Kjellman (1952) was the first person who introduced this method. The basic components are vertical drains, a filter drainage layer, an airtight sheet and a vacuum pump. By means of a vacuum pump, a reduced pressure is created inside the improved area and distributed through the vertical drains installed in the soft ground. The airtight sheet acts as a barrier to separate the atmospheric pressure between the inside and outside of the improved area. The difference in atmospheric pressure is a loading force to consolidate the soft soil.

Vacuum pressure is the key to success in the vacuum consolidation method. The quality of ground improvement work can be assured by carefully checking and maintaining vacuum pressure under the airtight sheet.

Practically, the vacuum pressure measured under the airtight sheet will be around 60~80 kPa at the beginning of vacuum operation. However, it was found that the vacuum pressure measured under the airtight sheet gradually decreased during vacuum pumping operation. Therefore, the performance of this method was considered not to meet the design load level.

This document presents case histories of ground improvement projects in Japan using the vacuum consolidation method, the problem of vacuum pressure decrease with its case studies, and the concept of the air-water separation system, which was developed to solve the above-mentioned problem.

2. Loss of vacuum pressure

The schematic of the vacuum consolidation method developed in Japan shown in Figure-1 is based on the original system proposed by Kjellman (1952). According to the field observation data obtained from several projects in Japan, it was found that the vacuum pressure measured under the airtight sheet was gradually decreasing during vacuum operation process.

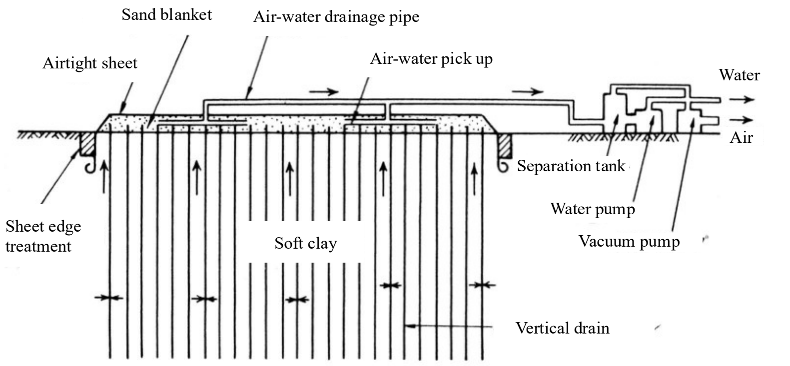

Figure-1 Conventional vacuum consolidation system in Japan

Two of the case studies from different locations in Japan during years 2000-2003 were selected to be presented: One in Kushiro and the other in Noshiro.

Kushiro, located in Hokkaido, Japan, is where National Highway No. 38 was constructed over a soft ground area. Figure-2 shows the field monitoring data from Kushiro. The vacuum pressure measured at the pump was about 85~92 kPa during vacuum operation. The vacuum pressures measured at two different points under the airtight sheet were low at the beginning of operation and gradually increased to 50~60 kPa prior to the start of embankment operation, as shown in Figure-2(c). The consolidation settlement induced by vacuum pressure and embankment loads was about 241 cm.

It was found that the decrease in vacuum pressure somehow relates with the quantity of ground settlement. Figure-2(d) shows the vacuum pressure difference between at the pump and under the airtight sheet. The change in vacuum pressure based on the elevation head loss calculated from the settlement data, is also plotted in Figure-2(d) for comparison. It was found some agreement in this case.

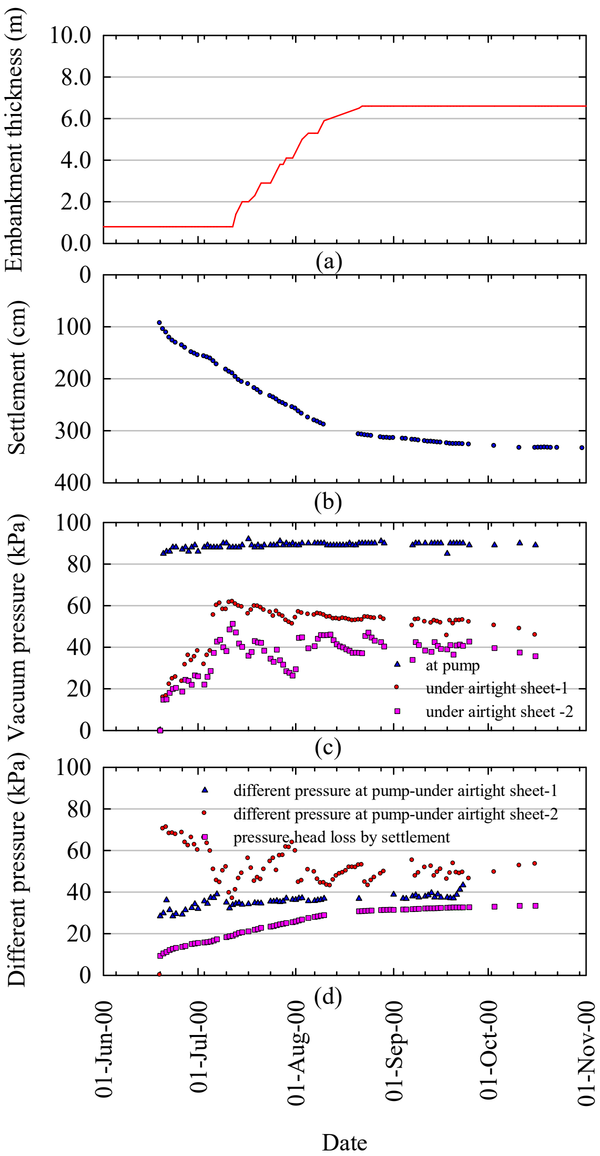

Figure-2 Field monitoring data from Kushiro

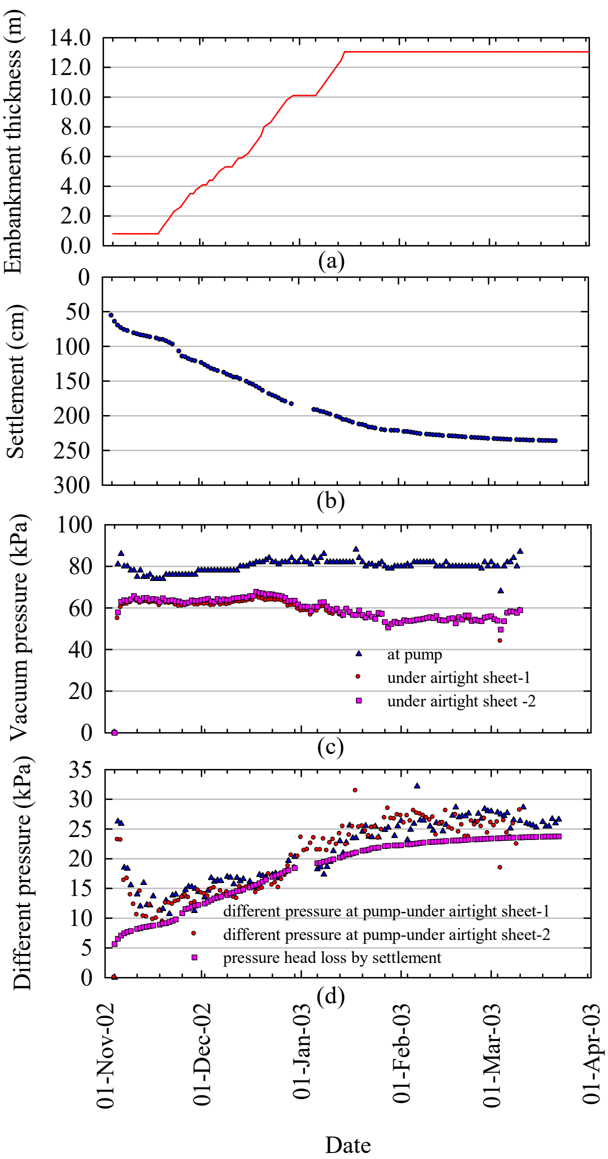

Figure-3 Field monitoring data from Noshiro

However, it can be seen that the vacuum pressure difference was smaller than the elevation head loss. This is probably due to some leakage of vacuum pressure through intermediated sand layers existing under the subsoil.

Noshiro is located in Akita, Japan. The project is a highway bypass construction over a soft ground area in the city. Figure-3 shows the field monitoring data from Noshiro. As shown in Figure-3(c), the vacuum pressure measured at the pump was about 68~88 kPa during vacuum operation. On the other hand, the average vacuum pressures measured at two different points under the airtight sheet were about 60 kPa at the beginning of operation. The vacuum pressure at the pump slightly decreased during backfilling embankments up to 6 m and then gradually returned to over 80 kPa. The consolidation settlement induced by vacuum pressure and embankment loads was about 237 cm.

Figure-3 (b) and (d) shows the vacuum pressure difference between at the pump and under the airtight sheet, and the elevation head loss due to consolidation settlement. It can be clearly seen that the difference between the vacuum pressure difference and the elevation head loss is smaller than in the case of Kushiro.This could be considered that the loss of vacuum pressure at this site was less than at Kushiro due to the absence of intermediated sand layers.

3. Air-Water Separation System

Based on the aforementioned problem, the concept of vacuum consolidation was revised and analyzed.

Figure-4 shows the basic pore pressure profile during depressurization of atmospheric pressure in the vacuum consolidation system. Imai (2005) described the use of a vacuum pump and its limitations based on the use of hydraulic fluid.

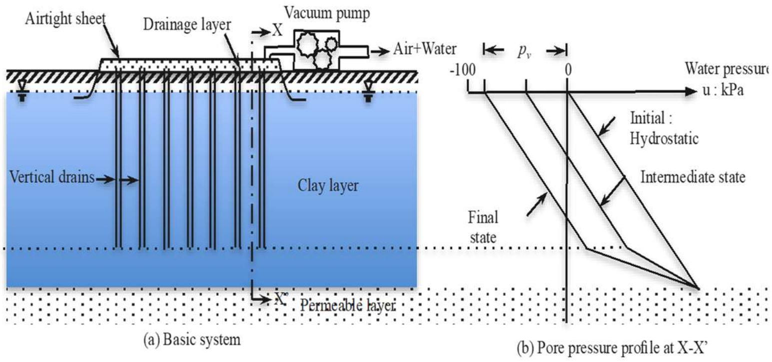

Figure-4 Basic vacuum consolidation system and water pressure profile (Imai, 2005)

Figure-5 (a) shows the simple schematic of using a vacuum pump to lift up water and Figure-5 (b) shows the pressure diagram corresponding to the schematic in Figure-5(a), where pa and pv are atmospheric pressure and vacuum pressure, respectively. At point A and point D, the pressure is equal to atmospheric pressure. At point B, the absolute pressure is equal to pa-pv.

From point B to point C, there is only air, therefore, the pressures at point B and point C are equal when the head loss in the pipe is ignored. From point C to point D, the absolute pressure linearly increases to atmospheric pressure. Therefore, the maximum height of water lifted up by means of the vacuum pump is equal to the value in the following inequality.

$$H = \frac{P_v}{\gamma_w} \leq \frac{P_a}{\gamma_w} \qquad (1)$$

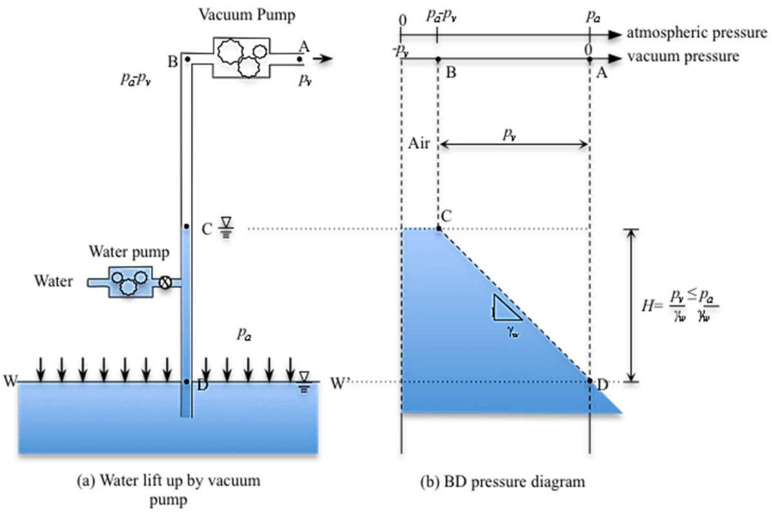

Figure-5 Reason and limitation of water lift-up by vacuum pump (Imai, 2005)

Hence, water cannot be discharged through the vacuum pump if the elevation head at B-D is higher than H. This limitation can be solved by discharging water below point C by the water pump, as shown in Figure-5 (a).

Based on the this principle, the conventional vacuum consolidation system was modified to be equipped with air-water separation system embedded under the airtight sheet.

Figure-6 shows the pressure diagram comparison for the vacuum consolidation system without and with air-water separation system. In a static condition, the hydrostatic pressure is equal to Line 2. After atmospheric pressure is depressurized, the hydrostatic line will change to Line 1 or Line 3 for the vacuum consolidation system without and with air-water separation system, respectively.

It can be seen that the vacuum pressure at the vacuum pump to the water pump is the same, no matter how much is the elevation head difference between the vacuum pump and the improved area.

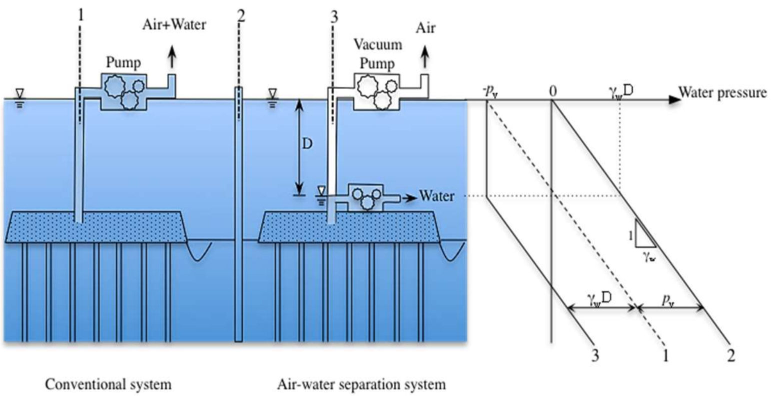

Figure-6 Water pressure diagram for vacuum consolidation with air-water separation system (Imai, 2005)

4. Implementation of Air-Water Separation System

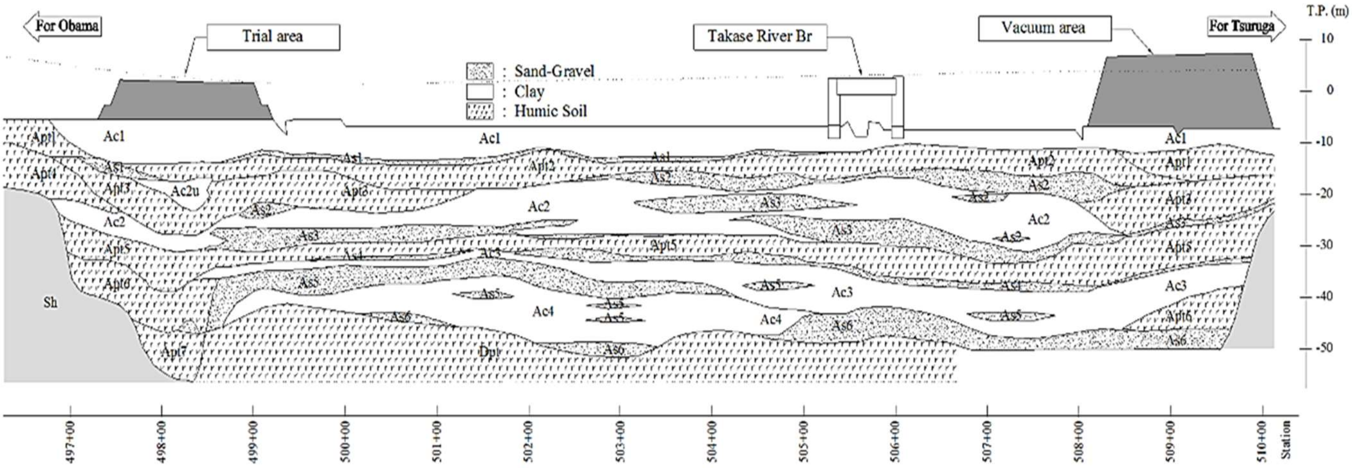

Figure-7 Tsuruga soil profile

The Maizuru-Wakasa Expressway diverges from the Chugoku Expressway at Yokawa JCT and passes Fukuchiyama, Maizuru, Obama City and ends at Tsuruga JCT, connecting to the Hokuriku Expressway, with a total distance of about 162 km. Soft ground is distributed along the construction area with a distance of 50 km from Obama-Nishi to Tsuruga.

Wakasa Bay has a kind of irregular submerged coastline called ria and many drowned valleys exist around Mikata-goko lakes.

The Mukasa area is a typical drowned valley. As a geological feature, the valley is partially covered with humic and sandy soils. At both ends of the valley, humic soil predominates with the depth of 30 to 40 meters.

Tsuruga's soil profile is shown in Figure-7. Humic soils and cohesive soils are found to be formed in alternate layers. Cohesive soils predominate at the center part of Tsuruga's soil profile.

Originally, prefabricated vertical drains (PVDs) with the surcharge method were selected for ground improvement work. PVDs were installed up to 34 m deep. In this method, the embankment construction rate was limited to 3 cm per day by the design criteria.

Later on, it was found that the construction time would be limited. Increasing the rate of embankment construction was required to accelerate the construction process. Therefore, the vacuum consolidation method was selected to apply because it can provide a higher stability during construction, resulting in increasing the embankment construction rate.

Moreover, vacuum pressure was also used as a surcharge load in place of the surcharge load created by embankment material. Therefore, the vacuum consolidation system with air-water separation system (CVC) was selected to replace PVDs with the surcharge method.

The schematic of the CVC system is illustrated in Figure-8.

To construct the CVC system, PVDs (7 mm thick) were installed up to 20 m deep between the existing PVDs (3 mm thick), which were previously installed up to 34 m deep, in a square grid pattern of 1.2 m x 1.2 m.

It should be noted in advance that the top of the existing PVDs (3 mm) were not directly connected to the CVC system.

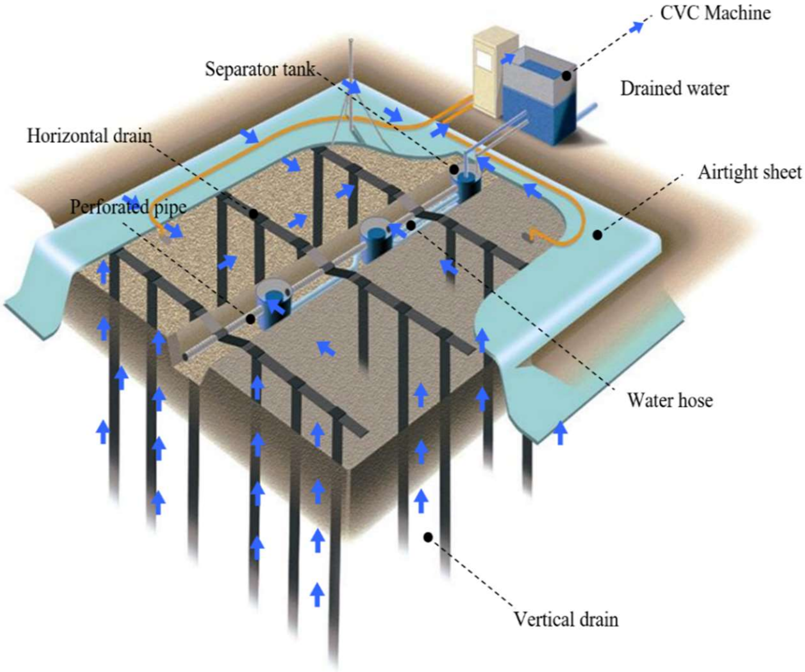

Figure-8 CVC System

The constructed improvement area was about 9,000 m^2, as shown in Figure-9.

The embankment height including surcharged backfill was designed to be 14 m high.

Figure-10 shows the completion of the embankment.

Figure-9 Vacuum Consolidation Area

Figure-10 Completion of Embankment

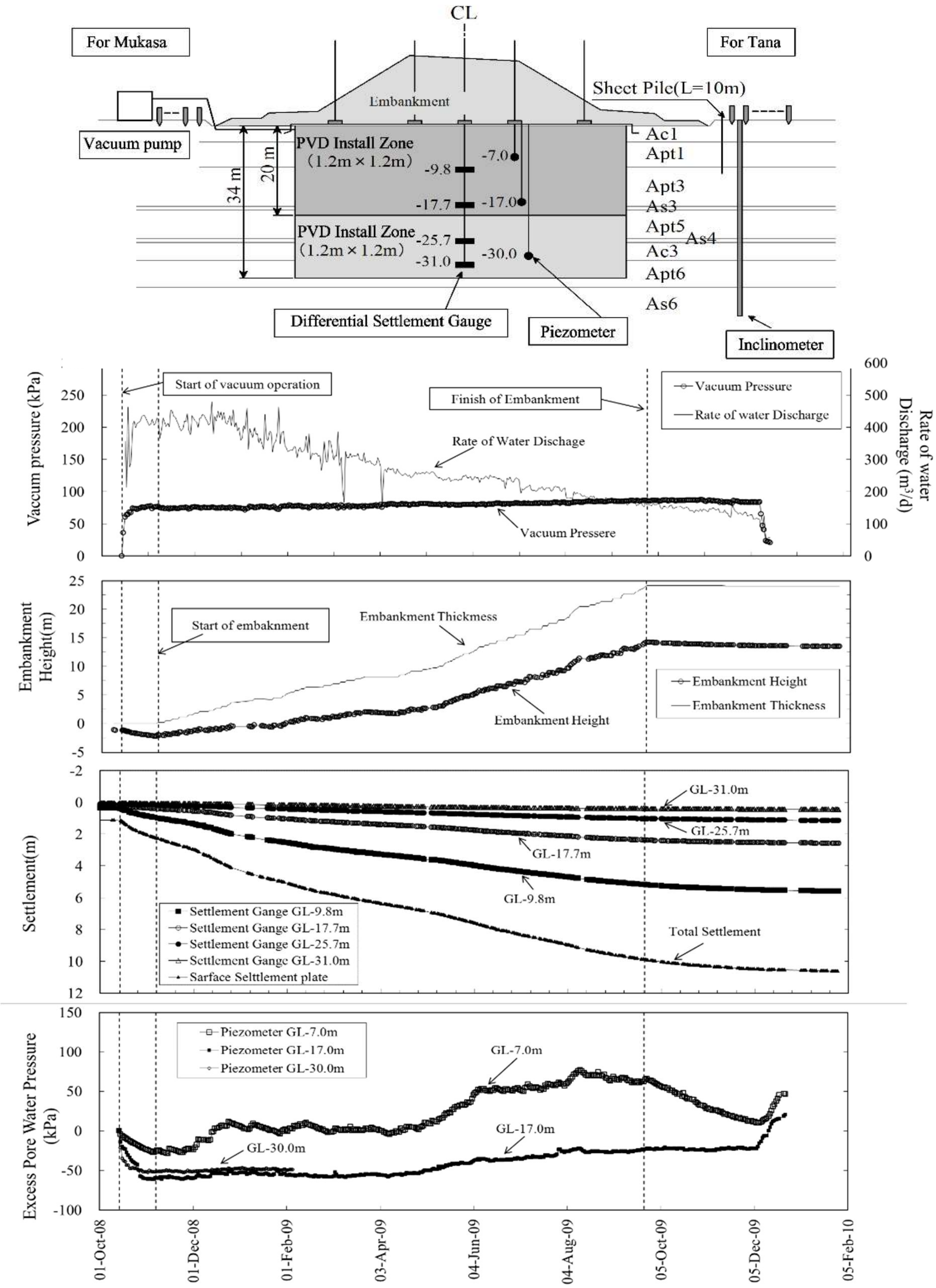

Figure-11 Field monitoring data from Tsuruga

5. Monitoring Results

The field monitoring instruments are shown in Figure-11. According to the results, the amount of consolidation settlement during construction was extraordinary about 11 m. Vacuum pressure measured under the airtight sheet was maintained constantly at about 80 kPa along with consolidation settlement.

By using the air-water separation system, it is clearly seen that vacuum pressure measured under the airtight sheet does not gradually decrease along with consolidation settlement unlike the conventional vacuum consolidation system, where vacuum pressure decreases by 10 kPa for every 1 m of consolidation settlement. This result confirms the effectiveness of the vacuum consolidation system equipped with an air-water separating tank in the CVC system.

6. Conclusion

The Vacuum consolidation method is a technique for soft ground improvement by utilizing the difference in atmospheric pressure. The conventional vacuum consolidation system had a limitation to preserve the vacuum pressure inside the improved area during consolidation settlement.

To resolve this problem, the concept of vacuum consolidation was analyzed in order to investigate the cause of the problem. It was found that the decrease in vacuum pressure during consolidation settlement was related to the elevation head difference between the vacuum pump and the improved area.

The concept of air-water separation was proposed to resolve the problem and developed to be used in practice. The vacuum consolidation system equipped with air-water separation system has been successfully utilized in many ground improvement projects in Japan as well as overseas.

7. Contact Information

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