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Technical Note

Settlement analysis considerng sand mat induced initial settlement in soft ground improved by pbd

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Abstract

The ground improvement using Plastic Board Drain (PBD) in soft soil was undertaken by sand mat formation, PBD installation, preloading surcharge, and removal of surcharge. During this procedure, the sand mat formation induced an initial settlement. However, it was very difficult to estimate that settlement due to PBD installation, which frequently destroyed the instruments installed in the ground. Consequently, the initial settlement was not properly included in total settlement. In this study, the initial settlement was estimated using ground level measurement and cone penetration test. Both predicted almost the same amount of initial settlement. The initial settlement is linearly increased with the depth of the sand mat. The degree of consolidation and the time of surcharge removal were estimated using the settlement included the initial settlement. Correct estimation of initial settlement is very important because it is a critical factor, which affects total settlement and the time of surcharge removal. If the initial settlement is not considered, the preloading surcharge may be overloaded or the time of surcharge removal may be predicted incorrectly. Consequently, the prediction of settlement, which requires to management of construction procedure of the project, may be wrong

Keywords: *Initial settlement, Sand mat, Prediction settlement, Time of surcharge removal, Plastic board drain (PBD).*

1. Introduction

Many different types of vertical drain methods have been developed to increase the shear strength of the soil, to reduce the soil compressibility, to reduce the permeability of the soil prior to construction and placement of the final construction load, and to prevent large and/or differential settlements and potential damages to the structures. One of them is plastic board drain (PBD) which is commonly used in many countries. Like other vertical drain methods, the PBD method can accelerate consolidation of soft clay deposits and thus decrease the required time for consolidation [1, 2, 3]. Many researches related to PBD method have been studied experimentally and theoretically regarding the factors of smear zone, well resistance, installation pattern, discharge capacity, material properties, and permeability, etc. [4, 5, 6, 7, 8, 9, 10, 11, 12]. These previous researches provided an understanding of PBD performance and the factors affecting their function. Additionally, some studies have been done on the ground improvement effect due to PBD [13, 14, 15]. The ground improvement effect of PBDs in soft soil was examined using crucial factors such as ground settlement or undrained shear strength.

Settlement analysis is a typical method to check ground improvement. Theoretically, the dissipation of excess pore water pressure can induce settlement of the ground and the same degree of consolidation could be estimated from pore water pressure and settlement gauges. However, the degree of consolidation obtained by pore water pressure and settlement gauges may be different compared to the induced real settlement. Since the pore water pressure gauge does not show consistent results due to nonhomogeneity of ground, sensor correction for depth due to settlement and variation of ground water level, the degree of consolidation with depth based on the pore water pressure gauges may not be correct. Therefore, the estimation of the degree of consolidation using pore water pressure gauge is not recommended. However, it is reasonable to use the degree of consolidation predicted by the pore water pressure gauge for reference. This paper is especially focused on the ground settlement.

In general, the ground improvement using PBD is undertaken by following procedures; sand mat formation, PBD installation, preloading surcharge, removal of surcharge (Fig. 1). During this procedure, to estimate an initial settlement due to sand mat formation, typically, the settlement and pore water pressure gauges were used.

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However, due to installation of PBDs, these instruments were destroyed frequently. Therefore, before and after PBDs installation, it was very difficult to estimate the initial ground settlement. Estimation of initial settlement is very important because it is a critical factor, which affects total settlement and the time of surcharge removal. The surcharge load was removed when the ground reached a required degree of consolidation or residual settlement, such as 90 % of degree of consolidation or 10 cm residual settlement. If the initial settlement is not considered, therefore, preloading surcharge may be overloaded or the time of surcharge removal may be delayed.

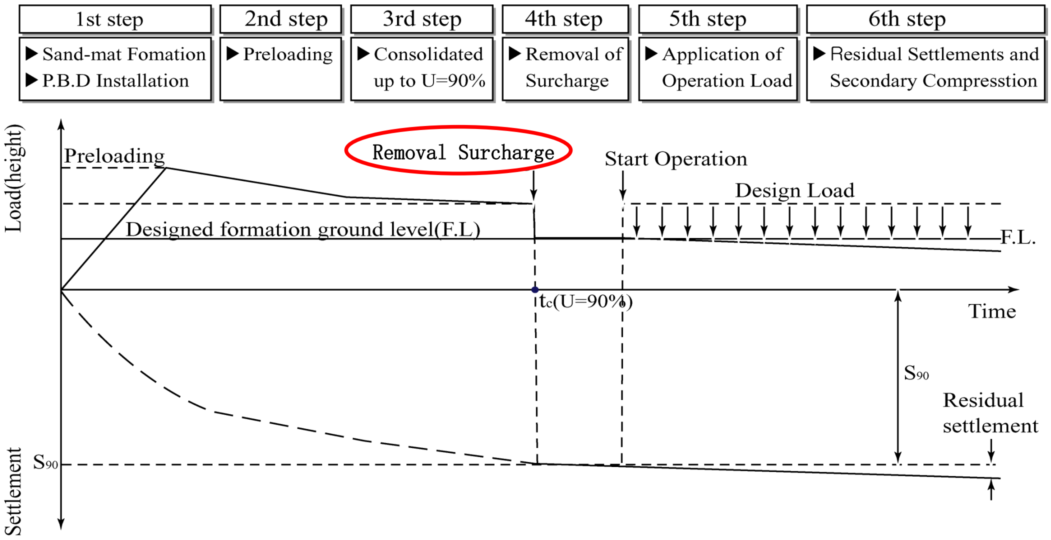


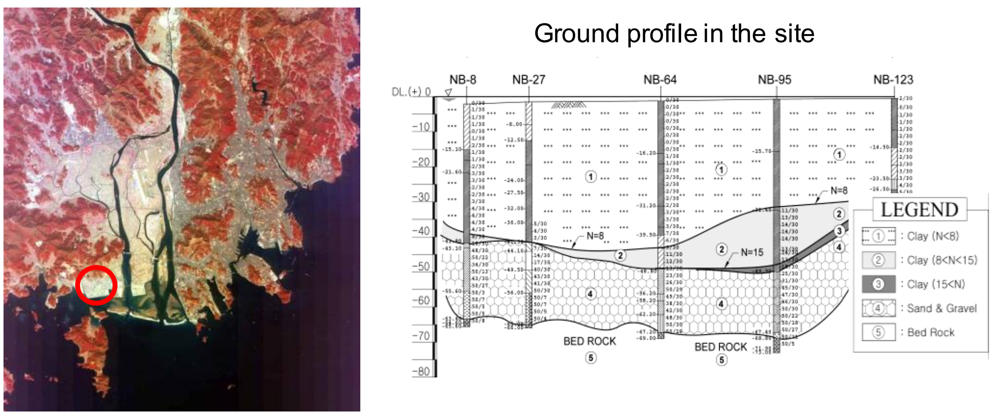
Fig. 1 Flow of ground improvement with PBDs

In this paper, the initial settlement was estimated using ground level measurement and cone penetration test. The effect of initial settlement on settlement behavior of the soft ground improved by PBDs was analyzed by comparison between two settlement data, one is included the initial settlement and the other is not. The degree of consolidation and the time of surcharge removal were estimated using the ground settlement that incorporated the initial settlement.

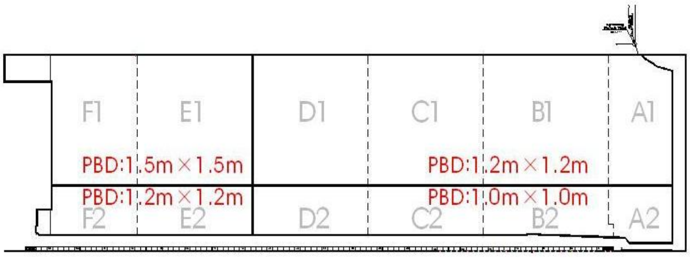
2. Site Description

The site is located west of Busan city and corresponds to the lower delta in the Nakdong River delta. A thick deposit covers the river delta. The deposit consist of silty sand (upper layer), thick soft clay, sand, and gravel on the bedrock. The soft clay layer in some area reaches over 70 m in thickness. Thus, this area was considered unsuitable land for development in the past. However, many construction activities including port development, road and rail road construction, residual and industrial land development have been going in this area last 20 years. The soft soil deposited in this area has a low bearing capacity and exhibit large settlements when subjected to loading. It is therefore necessary to treat soft soil deposits prior to construction activities in order to prevent differential settlements and consequently potential damage to structures. Figure 2(a) shows the location of site and a typical ground condition. A clay ground depth is from DL.(-)30 to DL(-)50 m. The improved depth was at N-value 8 depth DL.(-) 30 ~ 40 m. N value was obtained from Standard Penetration Test (SPT). The N-value is total number of blows to drive sampler 30 cm.

To improve soft ground, PBDs method was applied in this site. Three different installation spaces of 1.0m, 1.2m, and 1.5m with square arrangement were used (Fig. 2(b)). This study used the data obtained from three blocks C2, D1, and E1.



(a) Site location and ground profile

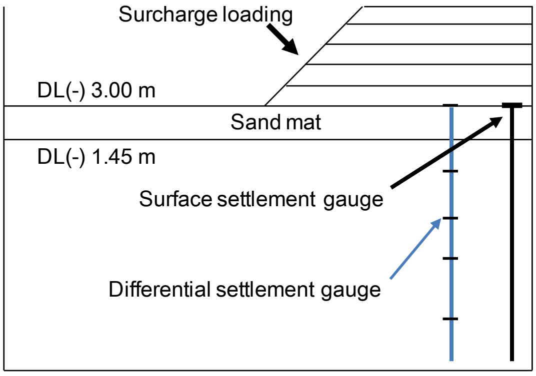


(b) Plan view of PBD installation

Fig. 2 Site description: (a) Site location and ground profile and (b) Plan view of PBD installation

3. Initial Settlement Analysis

Figure 3(a) shows the side view of sand mat and surcharge loading in the site. The sand mat typically was placed in range of 4 ~ 5 m before PBD installation. The placed sand mat was adjusted to the target level and the position for PBD installation was marked as shown in Fig. 3(b).



(a)

(b)

Fig. 3 (a) Sand mat depth and (b) leveled sand mat with position marking for PBD installation

3.1. Ground level measurement

The following two methods were applied to estimate an initial settlement: 1) ground level measurement and 2) cone penetration tests. The ground level was measured after sand mat formation and PBD installation at the same locations where measurement gauges were installed. In Fig. 4, the initial settlement occurs in range of 0.4 m ~ 1.0 m between the sand mat formation and the PBD installation. The average settlement is about 0.6 m and it is almost constant over the elapsed time between sand mat formation and PBD installation. In addition, the initial settlement is linearly increased with the depth of the sand mat (Fig. 5). This is directly related to excess pore water pressure in soft ground. The magnitude of excess pore water pressures is totally depending on the overburden surcharge load.

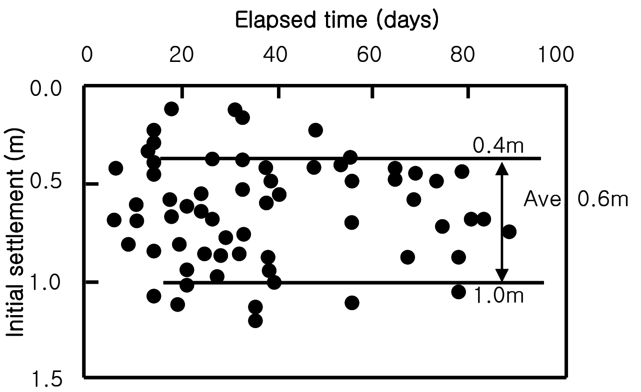


Fig. 4 Results of the measured ground level during the time between sand mat formation and PBD installation

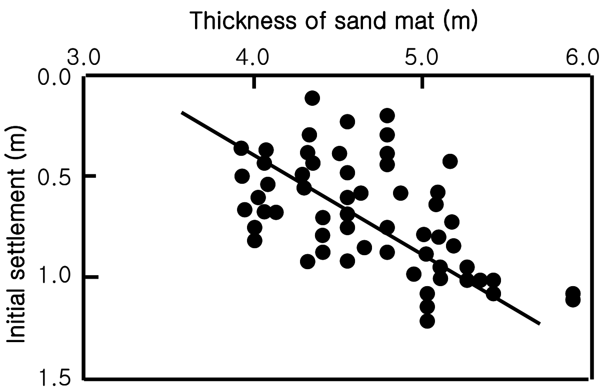


Fig. 5 Relationship between the initial settlement and the thickness of sand mat

3.2. Cone penetration test

An initial settlement was also estimated by the cone penetration test. The border between the sand mat and the soft ground was clearly detected when CPTs were conducted, because the resistance of ground was very different between sand mat and soft ground. Figure 6 shows an initial settlement obtained from cone resistance, q_t (Eq. 1) [16], from CPT, before and after PBD installation.

$$q_t = q_c + (1-a)u_{bt} \qquad (1)$$

where q_t = Corrected cone resistance, q_c = Cone resistance, a = net area ratio, and u_{bt} = pore water pressure.

In Fig. 6, the variation of the ground height is the same as that of the height of soft ground underneath sand mat. It is evident that the ground settlement when the sand mat was formed was occurred due to the consolidation of the original soft ground. This initial settlement is about 0.6 m. Thus, it should be considered in total consolidation settlement for the estimation of time to remove the surcharge load. In addition, as shown by the CPT result, the sand mat layer itself did not compress.

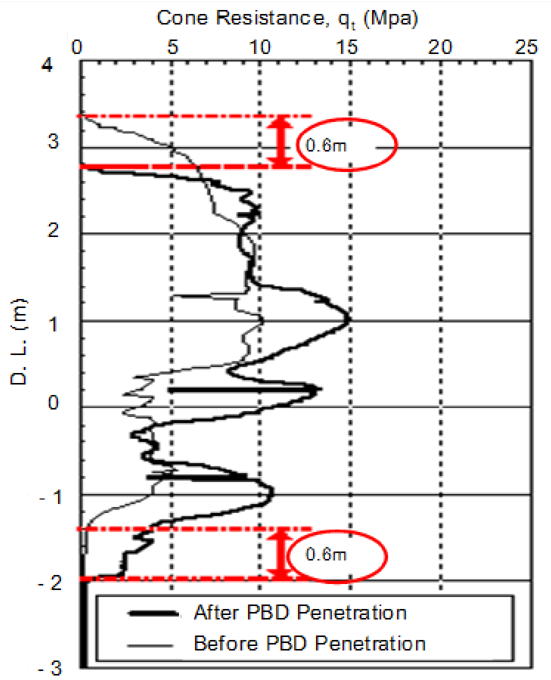


Fig. 6 CPT results before and after PBD installation on the soft ground with reclaimed sand mat

4. Settlement Analysis Including Initial Settlement

Figure 7 clearly shows the effect of initial settlement of 0.6 m on settlement behavior of the soft ground improved by PBDs. By comparison between the two sets settlement data, the extra time needed to reach the desired settlement state when the initial 0.6 m settlement is not considered can be directly obtained as shown in Fig. 8. For instance, if without the initial settlement, it takes 1 month for 1 m of settlement. For completing 4 m of settlement, it takes more than 3 months. The time needed for the desired settlement increases as the amount of desired settlement increases. This is related to the permeability property of compressible soil, which gradually decreases during the consolidation process. Based on Figs. 7 and 8, if the initial settlement is not considered, surcharge should be overloaded until the desired settlement induces. Consequently, the prediction of settlement which requires to management of construction procedure of the project may be wrong.

The degree of consolidation or the time of surcharge removal is estimated using the ground settlement. Table 1 shows the back analysis results predicted by TCON program (TAGA Engineering Ltd.) considering construction background history. TCON program (a Finite Difference Method) was developed based on Terzaghi's one dimensional theory for consolidation. This program calculates consolidation settlement and rate of settlement. It allows radial as well as vertical drainage providing the capability to simulate sand or wick drains. To do back analysis, first, the input data such as unit weight, water content, compression index, consolidation velocity, and coefficient of consolidation were determined for each location where measurement gauges were placed. Then, soil properties were estimated, especially coefficient of consolidation by trial and error and by comparison with the measured data. The time of surcharge removal corresponding to over a 90% of degrees of consolidation was also estimated.

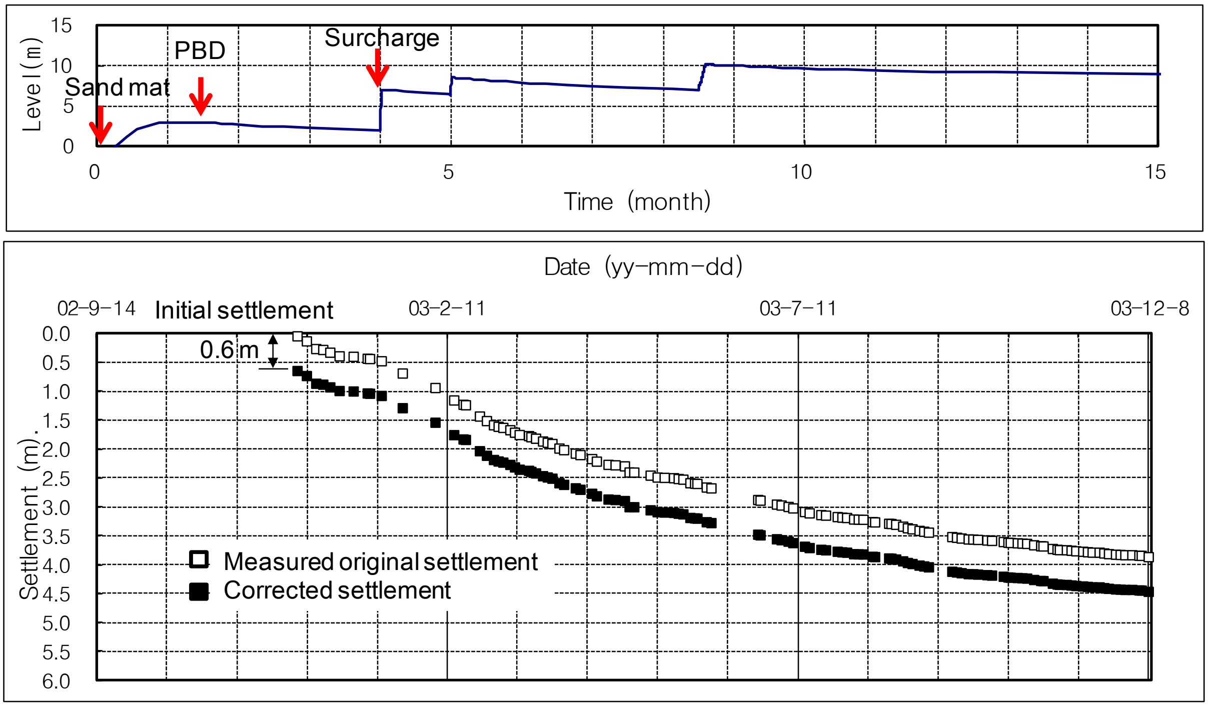


Fig. 7 Measured and predicted settlement history of the soft ground improved by PBDs with considering initial settlement due to sand mat formation in D-1 block

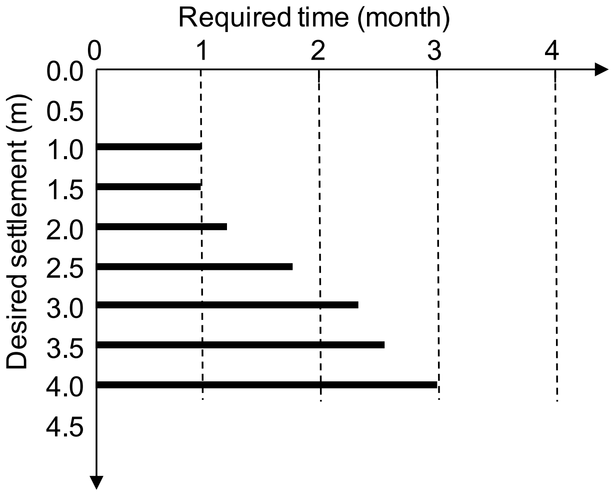


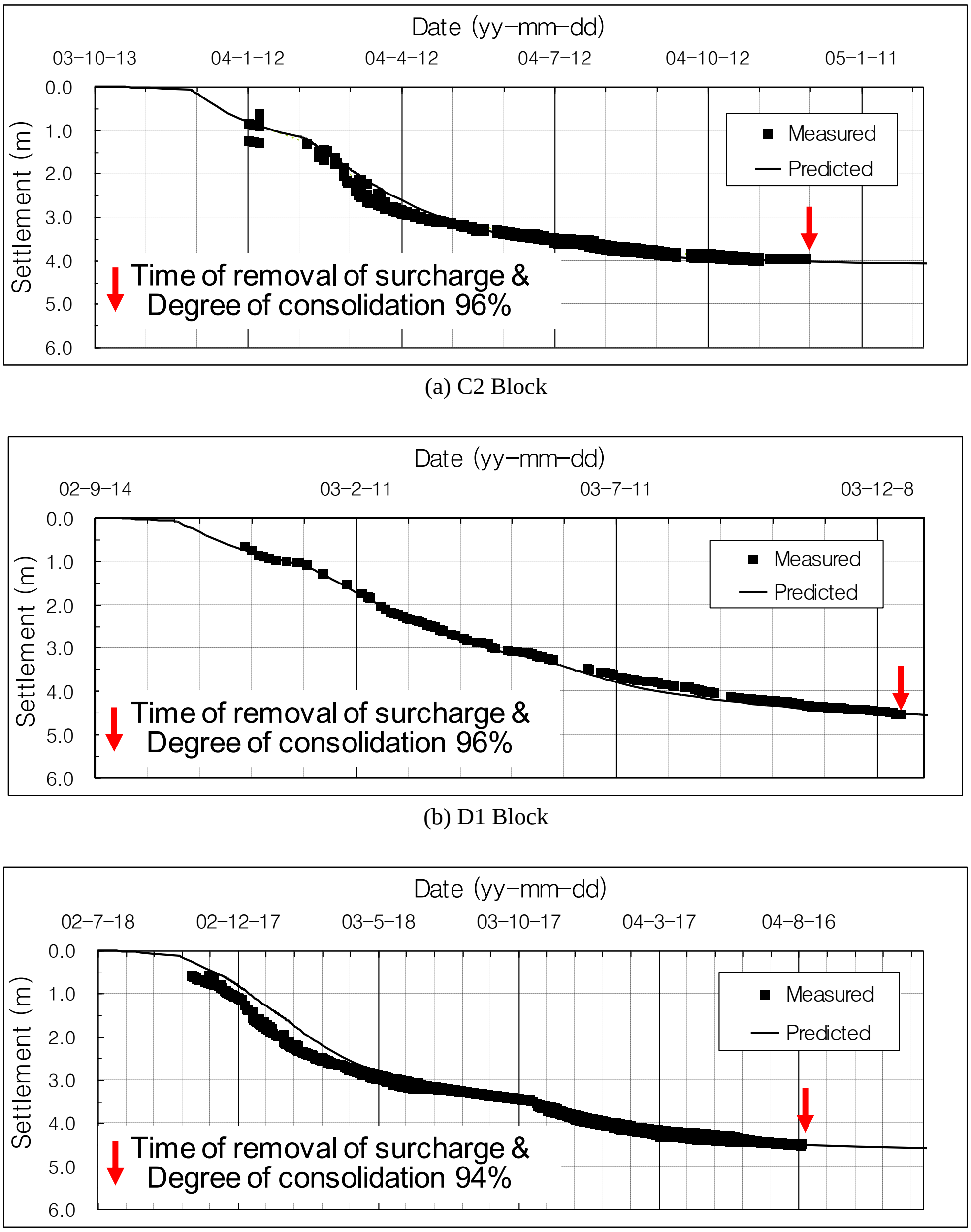
Fig. 8 Extra required time to reach the desired settlement if not considered the initial settlement

Table 1 Back analysis results predicted by TCON program

Location	Space of PBD (m)	Back analysis result from TCON (Settlement, m)			Degree of consolidation (%)	C_h/C_v
		Removal of surcharge (Measured)	Final (Predicted)	Operating load (Predicted)		
C2	1.0×1.0	3.968	4.114	3.903	96.5	3.2
D1	1.2×1.2	4.620	4.785	4.556	96.6	2.3 ~ 3.4
E1	1.5×1.5	5.393	5.734	5.339	94.1	3.1

In Table 1, at the time the surcharge load was removed, the degree of consolidation had reached over 94% for all block areas. This degree of consolidation satisfied the design criterion, over 90% degree of consolidation. In design, the coefficient of horizontal consolidation is assumed as two times the coefficient of vertical consolidation, $C_h = 2C_v$. In back analysis, the predicted settlement is closed to the measured one if the coefficient of horizontal consolidation is assumed as 2.3 ~ 3.5 times of the coefficient of vertical consolidation.

The measured and predicted settlement history at C2, D1, and E1 blocks are shown in Fig. 9. These results are included the initial settlement shown in Fig. 7. As expected, the predicted results well matched measured results. The time of surcharge removal corresponding to over a 90% of degrees of consolidation was also estimated. blocks C2, D1, and E1.



(a) C2 Block

(b) D1 Block

(c) E1 Block

Fig. 9 Measured and predicted settlement history including the initial settlement

5. Conclusion

Correct estimation of the sand mat induced initial settlement in soft ground improved by PBDs is very important because it is a critical factor affecting total settlement and the time of surcharge removal. The initial settlement due to sand mat formation was estimated using ground level measurement and cone penetration test. The ground level was measured after sand mat formation. The average initial settlement recorded about 0.6 m and it increased linearly with the depth of the sand mat. The initial settlement was also estimated by cone penetration test. The border between sand mat and soft ground was clearly detected when CPTs were conducted. CPTs showed the same amount of initial settlement as the ground level measurement. The effect of initial settlement on settlement behavior of the soft ground improved by PBDs was analyzed by comparison between two settlement data, one with and one without the initial settlement. When the 0.6 m initial settlement is not considered, it takes extra time to reach the desired settlement. For completing 4 m of settlement, it takes more than 3 months. The time needed for the desired settlement increases as desired settlement increases. The degree of consolidation and the time of surcharge removal were estimated using the ground settlement with the initial settlement considered.

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