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Long-Term Settlement Prediction of Ground Reinforcement Foundation Using a Deep Cement Mixing Method in Reclaimed Land

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Abstract: The greenhouse foundation method requires a lower allowable bearing capacity compared to general buildings, but the high-spec and expensive prestressed high-strength concrete (PHC) pile reinforcement method is mainly applied. Therefore, the deep cement mixing (DCM) method, which is one of the ground reinforcement foundations that replaces the PHC piles and secures structural safety suitable for the greenhouse foundation, was considered. To verify the structural safety of the DCM method, a geotechnical survey and soil test were conducted, and a long-term settlement monitoring system was established. The specifications of the DCM foundation were designed to be 0.8 m in diameter, 3 m × 3 m in width and length, and 3 m in depth. Based on the settlement monitoring data, long-term settlement was predicted considering the greenhouse durability of 15 years. For long-term settlement prediction, the Log S–T, hyperbolic, Asaoka method, Schmertmann theory, and the finite element method (FEM) analysis were performed. In the case of the Log S–T, hyperbolic, and Asaoka method based on actual measurement data, the settlement amount was predicted to be 12.18~20.43 mm, and in the case of the Schmertmann empirical formula, it was predicted to be 19.66 m. The FEM analysis result was 8.89 mm. As the most conservative result, the DCM foundation method designed in this paper had an allowable bearing capacity of 310 kN/m^2 and a long-term settlement of 20.43 mm. This is the result of satisfying both the allowable bearing capacity of 100 kN/m^2 and the allowable settlement range of 25.4 mm as a foundation. Through this study, it was proven that long-term structural safety can be sufficiently secured when the DCM foundation is constructed on a soft ground through a design that considers the required service life and allowable bearing capacity of the structure. In addition, it was confirmed that the Hyperbolic, Asaoka, and FEM analysis method adopted in this paper can be applied to the long-term settlement behavior analysis of the DCM foundation method.

Keywords: deep cement mixing method; soft ground; greenhouse foundation; reclaimed land; long-term settlement; finite element method

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1. Introduction

The reclaimed land within the management of the republic of Korea government is approximately 30,000 hectares. To overcome the food crisis, it is planning to cultivate crops and eco-friendly livestock, produce bioenergy, and create a horticultural complex. Among them, the size of the horticultural complex where vegetables can be grown all year round is about 5800 ha, accounting for 20% of the total construction plan [1]. Reclaimed land in Korea, including Saemangeum, the subject of this study, has the characteristics of soft ground created through embankment. Since the strength of the ground is weak, it is necessary to apply the soft ground reinforcement method for the structural stability of large structures, such as horticultural complexes and sites, and precise ground investigation is required for accurate information required for construction [2,3].

The high-spec prestressed high-strength concrete (PHC) pile reinforcement method is mainly applied to the ground foundation of large-scale horticultural complexes [4]. In the case of PHC piles, the foundation can be stably reinforced, but expensive construction costs are required. In order to reduce the construction cost [5] and provide high construction convenience for construction requiring low bearing capacity [6], various construction methods, such as the soil cement mixing method, timber piles, and helical piles for reinforcing soft ground, have been proposed [7,8]. Since it is difficult to apply the compaction method to a thick buried layer such as a reclaimed land, this paper reviewed the structural safety of the deep cement mixing (DCM) method, which is one of the ground reinforcement methods for the construction of large-scale horticultural facilities [4,9].

The DCM method reviewed in this study is being constructed by various construction companies such as Menard [10] and Keller [5] and is widely applied to roads and multi-purpose service buildings. In terms of research, the most representative studies are to verify the mechanical properties according to the cement content and the type and combination of the reinforcement [11] and matrix [5] to improve performance. In addition, structural safety verification studies were conducted through load tests, and an analysis of the DCM foundations with additional precast reinforced core pile was applied [12,13]. However, studies on the effect of the DCM reinforcement method on the amount of settlement that can occur during the service life of a building according to the creep load are very limited [14].

In this study, the actual settlement of the DCM foundation method according to the creep load was measured, and long-term structural safety was reviewed through the analysis based on the measured data. The purpose of this study is to review the feasibility of the DCM method as a greenhouse foundation method that can sufficiently secure structural safety. The dimensions of the DCM columns applied in this study were designed based on the allowable bearing capacity and settlement of the greenhouse foundation to be applied. The diameter of the column was 0.8 m, and the width and depth were 3 m, which is a relatively low specification foundation compared to the general DCM method. For long-term settlement prediction, a Log S–T graph, the hyperbolic method, Asaoka method, Schmertmann theory, and a finite element method (FEM) analysis were performed. The hyperbolic and Asaoka method are variously applied models to predict the long-term settlement of soft ground [15], and Schmertmann (1978) theory is an empirical formula that provides high-level prediction of long-term settlement [16]. The Mohr–Coulomb model applied to the FEM analysis has been used by various researchers, including in the analysis of the settlement mechanism [14] and creep behavior [17] of DCM columns.

2. Materials and Methods

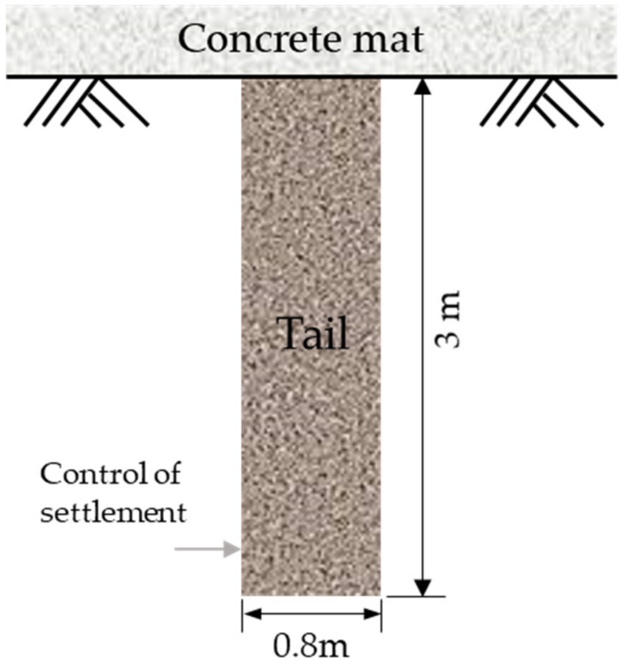
The test site was near Gwanghwal-myeon, Gimje-si, Jeollabuk-do, and the specification of the DCM foundation was determined through geotechnical surveys and soil tests. Based on the determined specifications, a DCM reinforcement foundation was built, and long-term settlement was predicted based on actual measurement data. To this end, the amount of settlement was predicted through theoretical equations and a long-term settlement prediction model, and the predicted values were compared with the results of finite element analysis. The test methods and procedures were as follows.

(1) The description of the DCM method and the configuration diagram of the settlement monitoring system will be described.
(2) Ground investigation and indoor soil test methods were explained, and the physical properties applied to the design were defined.
(3) The theoretical formula and numerical analysis model for calculating the allowable bearing capacity and settlement amount of the DCM method were defined.
(4) The hyperbolic method and the Asaoka model were explained to predict long-term settlement considering the durability.
(5) Finally, the finite element analysis model was introduced.

2.1. Deep Cement Mixing (DCM) Method

The DCM foundation is a construction method that forms an improved composite column and secures bearing capacity by injecting cement-based stabilizer into the soft ground and mixing it with the original ground for the construction of lightweight structures. It has various physical properties depending on the type, properties, and mixing ratio of the stabilizer, and it affects the allowable bearing capacity range [18]. The stirring process of the DCM method and the base configuration are shown in Figure 1a,b. The diameter of the DCM method was determined based on 0.8 m, which is mostly applied in the field. The position of the improved composite column was composed of a 2 × 2 arrangement based on the center.

(a)



(b)

Figure 1. Stirring process and cross-section view of the DCM method. (**a**) Stirring process of the DCM method. (**b**) Layout of the DCM reinforcement method [9].

2.2. Settlement Monitoring System

Figure 2 is a block diagram of the long-term settlement monitoring system. In order to measure the amount of vertical settlement for creep load, a lead cable was connected to the soft rock layer before construction, and a vertical settlement gauge was installed so that it was exposed on the top of the concrete. Systems such as power supplies and modems were included for real-time data reception. The data logger used for the measurement was CR-1000X, the mux for analog data input was AM16/32, and the measurement displacement meter was a CDP-50 of Tokyo Sokki Co., Ltd., Tokyo, Japan. A solar panel was installed for power supply.

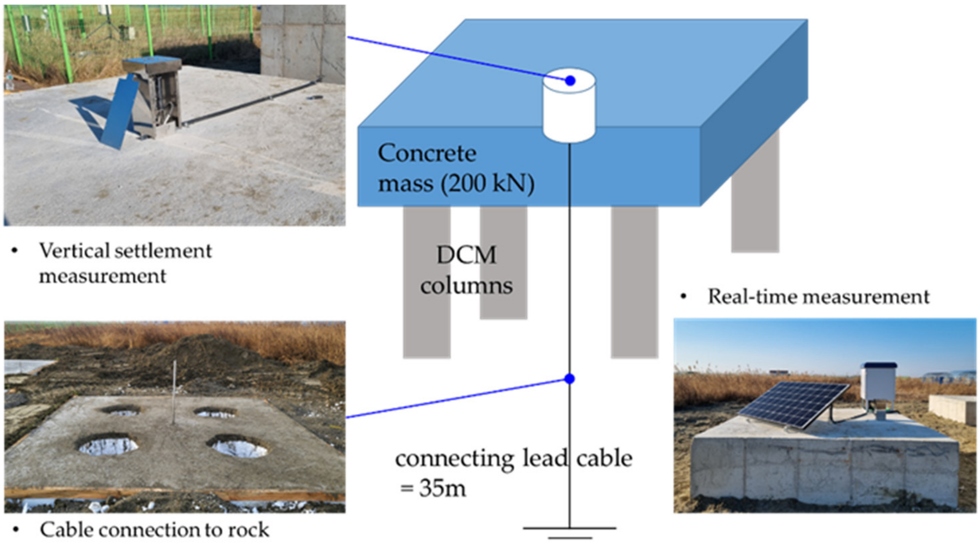


Figure 2. Settlement monitoring system.

2.3. Geotechnical Survey and Evaluation of Soil Properties

As shown in Figure 3, the test location is reclaimed land on the west coast of the republic of Korea. The surface elevation is about 4 m, and the geographic coordinates are 126° 41′ 21′′ east longitudes and 35° 49′ 40″ north latitudes. As test evaluation items, groundwater level and N-values according to the standard penetration test (SPT), borehole load test, borehole shear test, consolidated undrained test (CU), and indoor soil test were conducted. In the case of SPT, the penetration depth was measured by free-falling from a drop height of 76 cm with a standard hammer (64 kg) in accordance with ASTM D 1586 standards, and the number of blows required to penetrate the sample by 30 cm was recorded as the N value [19].

Figure 3. Site of the geotechnical survey and settlement monitoring system construction.

In order to derive the physical properties required for numerical analysis, such as specific weight, soil cohesion, internal friction angle, elastic modulus, and Poisson's ratio, these was reviewed through tests and empirical formulas. In the process of selecting the soil cohesion (C) and the internal friction angle (ø), the empirical equations of Dunham [20], Terzaghi-Peck [21], and Ohsaki [22] were reviewed. Equations (1) to (4) are equations for calculating the soil cohesion, and they are set based on the clay soil when the friction angle is 0° [23]. *N* is the value derived from the SPT test, and q_u is the compressive strength.

$$C = q_u \times 5\ (\text{kPa}) \tag{1}$$

$$\text{Dunham (1954), } q_u = N/0.77 \tag{2}$$

$$\text{Terzaghi-Peck (1948), } q_u = N/0.82 \tag{3}$$

$$\text{Ohsaki (1962), } q_u = N/0.82 \tag{4}$$

Equations (5) to (7) are empirical formulas for estimating the internal friction angle of the soil. The elastic modulus of the soil is based on the road traffic standard (1996) and the empirical formula of Schmertmann [24] and Hisatake [25], and the Poisson's ratio (υ) is based on the formula of Bowles [26] and Das [27].

$$\text{Dunham (1954), } ø = \sqrt{12\,N} + 15 \tag{5}$$

$$\text{Terzaghi-Peck (1948), } ø = 0.3\,N + 27 \tag{6}$$

$$\text{Ohsaki (1962), } ø = \sqrt{20\,N} + 15 \tag{7}$$

2.4. Formula for Allowable Bearing Capacity and Settlement

The allowable bearing capacity was derived from Terzaghi, Meyerhof, and Hansen's formula, and the settlement amount was applied to the Schmertmann theory. The allowable bearing capacity of the greenhouse foundation was 100 kN/m^2 [9], and the allowable settlement was set at 25.4 mm according to Terzaghi and Peck (1943) [28]. Terzaghi's bearing capacity calculation formula is as shown in Equation (8) [29].

$$Q_{ult} = \alpha \cdot C \cdot N_c + \gamma_2 \cdot D_f \times N_q + \beta \cdot \gamma_1 \cdot B \cdot N_r \tag{8}$$

where Q_{ult} is the ultimate bearing capacity (kN/m^2), C is the cohesion of the soil below the load surface of the foundation (kN/m^2), B is the minimum width of the foundation, and D_f is the rooting depth of the foundation (m). N_c, N_q, and N_r represent the coefficients of bearing capacity. γ_1 is the unit weight of the soil below the bottom of the foundation (kN/m^3), γ_2 is the unit weight of the soil above the bottom of the foundation (kN/m^3), and α and β are the shape factors of the foundation (1.3 and 0.4 for a square, respectively). Meyerhof's bearing capacity calculation formula is as shown in Equation (9) [30].

$$Q_{ult} = C \cdot N_c \cdot S_c \cdot d_c \cdot i_c + q \cdot N_q \cdot S_q \cdot d_q \cdot i_q + 0.5 \cdot \gamma_1 \cdot B \cdot N_r \cdot S_r \cdot d_r \cdot i_r \tag{9}$$

where N_c, N_q, and N_r are the coefficients of bearing capacity. S_c, S_q, and S_r are the shape coefficients of the foundation. d_c, d_q, d_r are the depth coefficients of the foundation. i_c, i_q, and i_r are the inclination coefficients of the foundation. The Hansen's bearing capacity calculation formula is as shown in Equation (10) [31].

$$Q_{ult} = C \cdot N_c \cdot s_c \cdot d_c \cdot i_c \cdot b_c \cdot g_c + q \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot b_q \cdot g_q + 0.5 \cdot \gamma_1 \cdot B \cdot N_r \cdot s_r \cdot d_r \cdot i_r \cdot b_r \cdot g_r \tag{10}$$

where b_c, b_q, and b_r are the linear coefficients of the slope. g_c, g_q, g_r are the grounding coefficients of the slope. The ultimate bearing capacity was calculated by applying three theoretical formulas, and the allowable bearing capacity was calculated by considering the safety factor of 3.0.

$$S = C_1 \cdot C_2 \cdot \triangle P \times \Sigma(I_z/E) \cdot \triangle Z \tag{11}$$

where C_1 is the correction factor of foundation depth, C_2 is the correction factor of ground creep, ΔP is the net load acting on the foundation (kN/m^2), ΔZ is the thickness of each soil layer (m), I_Z is the deformation influence factor, and E represents the modulus of elasticity (kN/m^2).

2.5. Long-Term Settlement Prediction Model

Long-term settlement is a phenomenon in which the ground gradually sinks over a long period of time. These phenomena, including differential settlement, can lead to structural cracking, overturning, deterioration, and functional problems [32]. In the case of reclaimed land on the west coast of republic of Korea, it is built as a landfill, so there is a large variation in ground characteristics and a lot of soft ground is distributed. Therefore, it was attempted to predict the amount of long-term settlement through a model mainly applied to soft ground analysis. In general, various methods, such as Terzaghi consolidation theory, Barron, Skempton-Bjerrum, Mikasa (1965), and Gibson (1967), are applied, but large deviations from reality occur mostly due to problems such as parameter uncertainty.

To compensate for these problems, a method of predicting the amount of settlement using field measurements is being used. Various methods, such as the hyperbolic method, Asaoka method, and Hosino method have been proposed by many researchers [33,34]. In this study, the hyperbolic stress–strain method and the Asaoka method were applied to analyze the long-term settlement [35].

The hyperbolic stress–strain relationship [36] is a method proposed under the assumption that the average settlement velocity changes in a hyperbolic form with time. The relationship between the settlement amount (S) and time (t) is the same as Equation (12), The Asoka (1978) method draws a straight line at internals of 30 to 100 days using the settlement points, and the point where the straight line intersects the 45 degree line is the ultimate settlement (S_∞).

$$S = t/(\alpha+\beta t) \text{ or } t/S = \alpha+\beta t \tag{12}$$

$$\lim S = \lim S \times 1/(\alpha/t+\beta)\ (t\to\infty) \tag{13}$$

2.6. Finite Element Analysis Model

MIDAS GTX was used as a finite element analysis program for numerical analysis. In order to consider the nonlinearity of the soil, it was defined by the Mohr–Coulomb failure model [37]. Figure 4 shows the boundary condition, load condition, and groundwater level as a model applied to the analysis. The CEB-FIP model (1990) code and the time-dependent elastoplastic constitutive equation code were applied as the creep shrinkage function used for analysis [38,39].

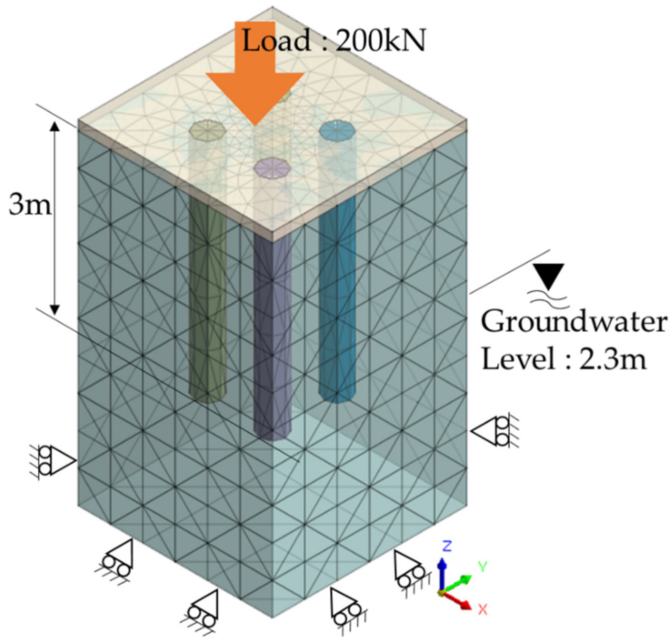


Figure 4. Boundary conditions of FEM analysis [9].

In the case of creep load for long-term settlement monitoring, a safety factor of 2.0 was set, and a load of 200 kN/m^2 was applied [40]. The dimensions of the base mat considering the specific gravity of concrete were $3 \times 3 \times 0.89$ m. The depth of ground improvement was set to 3.0 m in consideration of the allowable bearing capacity and the amount of settlement in consideration of the existing research [9].

3. Results

3.1. Geotechnical Survey

The groundwater (GL) was 2.3 m, and the strata consisted of the topsoil(buried) layer, deposit layer, accumulation layer, weathered rock, and soft rock in that order. The topsoil layer is distributed at a thickness of 0.5 m from the top, and the deposit layer is an artificially buried stratum and is distributed from the top to a depth of 19.9 to 20.1 m. The topsoil layer and the deposit layer are classified as ML (silt of medium plastic) according to the Unified soil classification system (U.S.C.S), and the sedimentary layer is distributed at a depth of 20.1–34 m and is classified as CL (clay of low plastic) [41]. The weathering zone of this layer is distributed at a depth of 34.5 m and a thickness of 0.5 m. Soft rock layers were identified at a depth of 35.0 m. The N value of the buried and deposit layers were 6/30~25/30 (count/cm), and the level of the accumulation layer was 4/30~33/30 (count/cm). Figure 5 shows the standard penetration test results.

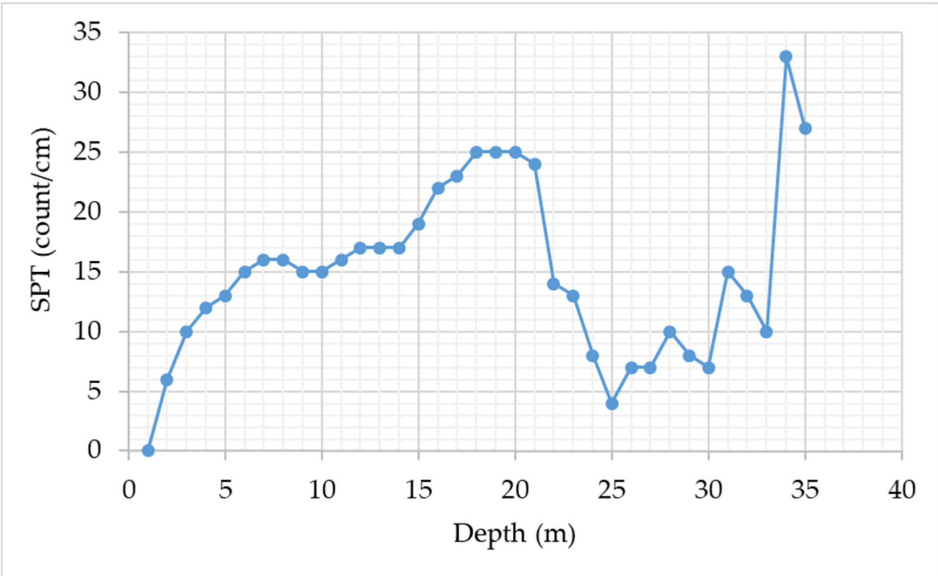


Figure 5. Standard penetration test results [9].

As can be seen in Table 1, the borehole load test was performed twice. The elastic modulus can be calculated from the pressure–strain curve [42]. The cohesion (C) and internal friction angle (ø) of the soil were calculated through the borehole shear test (BST) and the consolidation non-drainage test performed in accordance with ASTM D4767 standards [43]. The soil cohesion and friction angle can be calculated from the measured normal stress and shear stress, and the measurement results are shown in Table 2. Test measurements were carried out at depths of 1, 4, 24, and 29 m, and in the case of depths of 1 m and 4 m, the test was conducted in the field due to the difficulty in securing undisturbed specimens. At 24 m and 29 m, the consolidated–undrained tests were performed through continuous undisturbed specimens.

Table 1. Results of lateral load test (borehole test).

Depth (m)	Soil Stratum	N Value	Coefficient of Ground Reaction Force (K_m, MPa)	Modulus of Elasticity (E_p, MPa)	Poisson's Ratio
1.0	Buried layer	6/30	1.02	8.2	0.40
2.0	Buried layer	10/30	1.46	9.2	0.35

Table 2. Result of borehole shear and consolidated undrained test.

Depth (m)	Soil Stratum	N Value	Internal Friction Angle (ø)	Cohesion (kPa)
1	Buried layer	6/30	25.0	2.7
4	Deposit layer	13/30	28.7	9
24	Accumulation layer	4/30	23.9	13
29	Accumulation layer	7/30	23.7	15

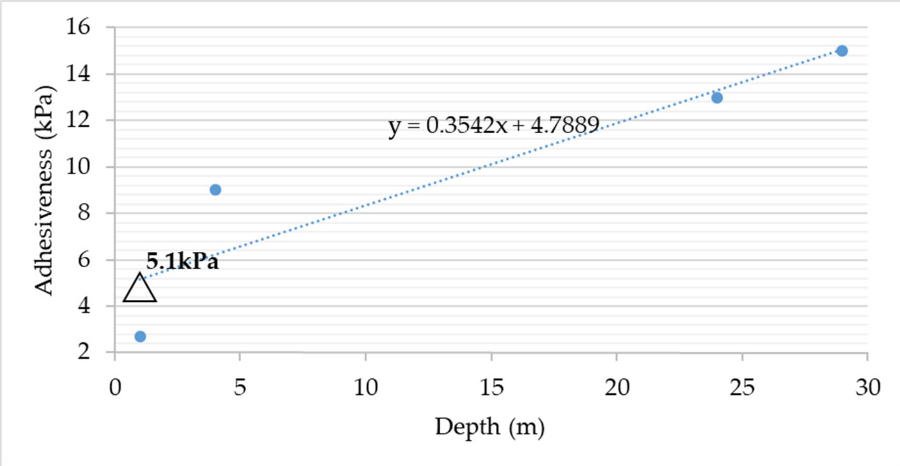
In the 1–4 m section, the internal friction angle was 25–28.7°, and the soil cohesion was 2.7–9.0 kPa. In the 24–29 m section, the internal friction angle was 23.7–23.89° and the soil cohesion was 13–15 kPa. As the depth increased, the soil cohesion increased, while the friction angle tended to decrease. Figure 6 plots the trend line through the obtained test results and shows the friction angle of 26.9° and the soil cohesion of 5.1 kPa at a depth of 1.0 m. The design properties selected by considering the empirical formula and the test result can be confirmed in Table 3. Table 4 shows the physical properties of the composite column formed by the DCM method.

Table 3. Estimated values of physical properties of the ground.

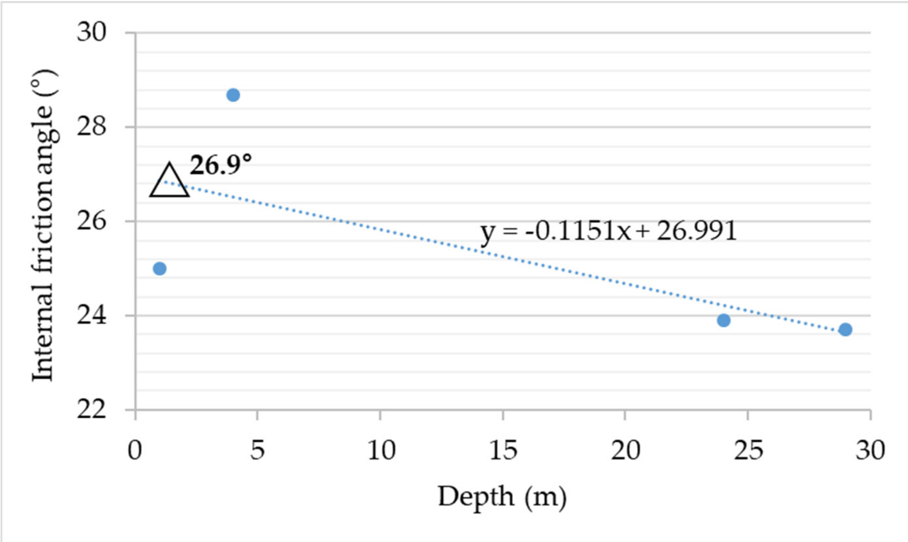
Classification	**Representative N Values**	**Dunham**	**Terzaghi-Peck**	**Ohsaki**	**Calculated Value (Avg.)**	**Measured Value**	**Applied Properties**
Specific weight (kN/m^3)	5	-	-	-		16.0	16.0
Cohesion (c, kPa)	5	39.0	36.6	19.0	31.5	5.1	5.1
Internal friction angle (∅, °)	5	24.5	28.8	26.0	26.1	26.9	26.1
Classification	**Representative N Values**	**Schmertmann**	**Hisatake**	**Road Traffic Specifications**	**Calculated Value (Avg.)**	**Measured Value**	**Applied Properties**
Modulus of elasticity (MPa)	5	2.4	37	16.8	18.7	8.7	8.7
Classification	Representative N values	Bowles	Das	-	Calculated value (Avg.)	Measured value	Applied properties
Poisson's ratio	5	0.2~0.3	0.2~0.5	-	-	0.35–0.4	0.35

Table 4. Physical properties of the DCM composite column [44].

Uniaxial Compressive Strength (MPa)	Allowable Compressive Strength (MPa)	Specific Weight (kN/m^3)	Cohesion (c, kPa)	Modulus of Elasticity (MPa)	Poisson's Ratio
2	0.4	1.90	30	300	0.35



(**a**)



(**b**)

Figure 6. Test results of cohesion and friction angle through the shear and tri-axial compression test. (**a**) Cohesion according to depth; (**b**) internal friction angle according to depth.

3.2. Calculation Result of Allowable Bearing Capacity and Long-Term Settlement

Table 5 shows the calculation results of the allowable bearing capacity and settlement amount of a DCM foundation method with a diameter of 0.8 m and width and length of 3.0 m. When the width and length were 3 m, the construction interval was 1.5 m, and the replacement rate was 22.4%. The allowable bearing capacity was satisfied based on the Hansen theoretical solution, which showed the lowest value in all conditions, and the settlement amount was 19.66 mm, which was within the standard limit of 25.4 mm.

Table 5. Specification of the DCM foundation method (Allowable bearing capacity and settlement).

Allowable Bearing Capacity (kN/m^2)			Settlement (mm)	Replacement Ratio (%)
Terzaghi	Meyerhof	Hansen	Schmertmann	
378	436	310	19.66	22.4

3.3. Prediction Result of Long-Term Settlement Amount

Figure 7 is a log S–T (settlement–time) graph based on the settlement data measured by the monitoring system. Through the trend line, the long-term settlement was derived as 14.17 mm for 10 years, 20.43 mm for 15 years, and 26.49 mm for 20 years. Considering the glass greenhouse durability standard of 15 years (Korea rural community Corporation, 1999), the settlement amount was 20.43 mm, which is satisfactory with the allowable settlement range of 25.4 mm.

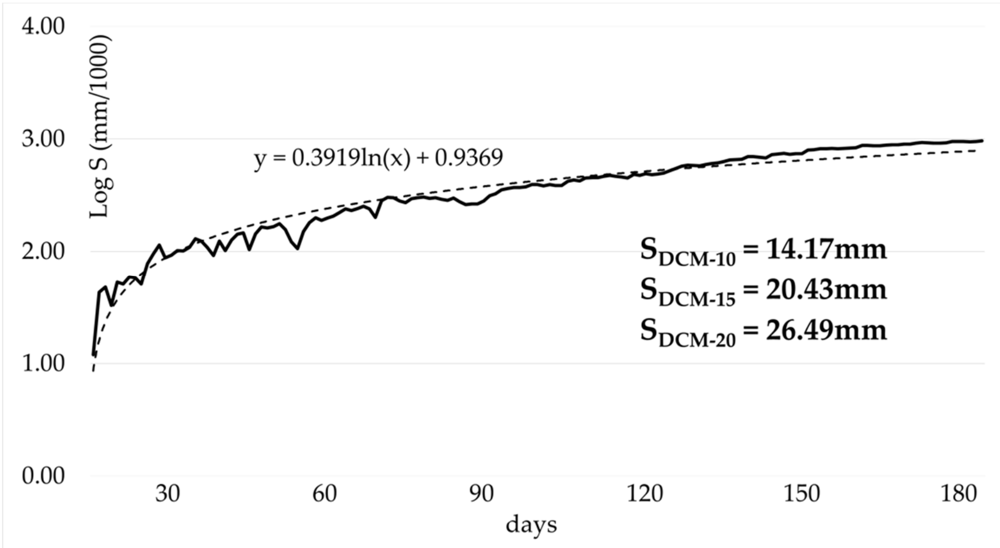


Figure 7. Long-term settlement predicted by the Log S–T curve.

Figure 8 is a graph of long-term settlement predicted by the hyperbolic method. In the initial section, the graph did not converge and showed a tendency to diverge with a negative (−) slope, and the data after 150 days showed a partial rebound. When the amount of settlement was calculated based on the β value derived from this of 0.0821, S_∞ was found to be at the level of 12.18 mm. Figure 9 is a graph of long-term settlement predicted by the Asaoka method. S_∞ is $\beta_0\ /(1 - \beta_1)$, and the maximum settlement amount was 13.9 mm.

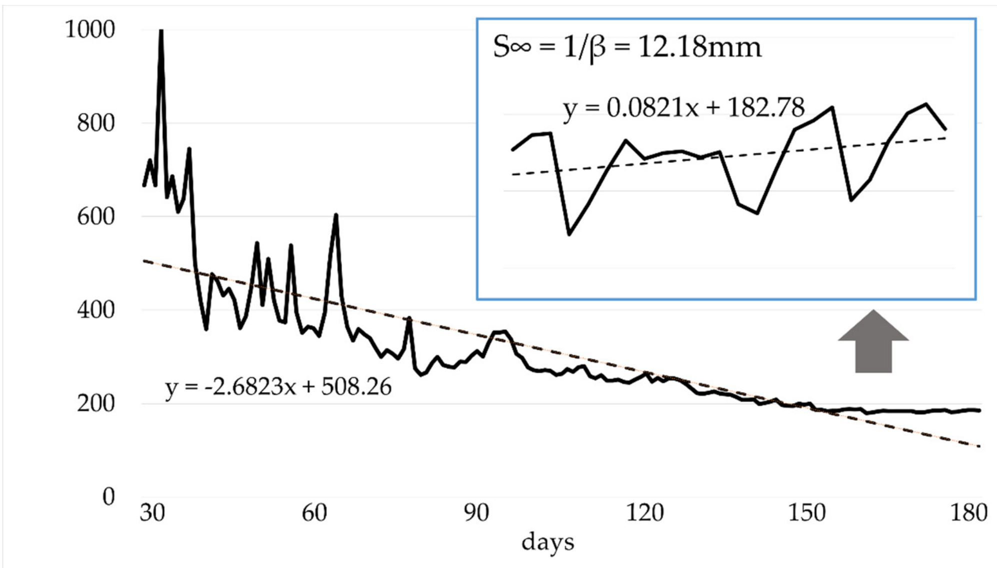


Figure 8. Long-term settlement predicted by the hyperbolic method.

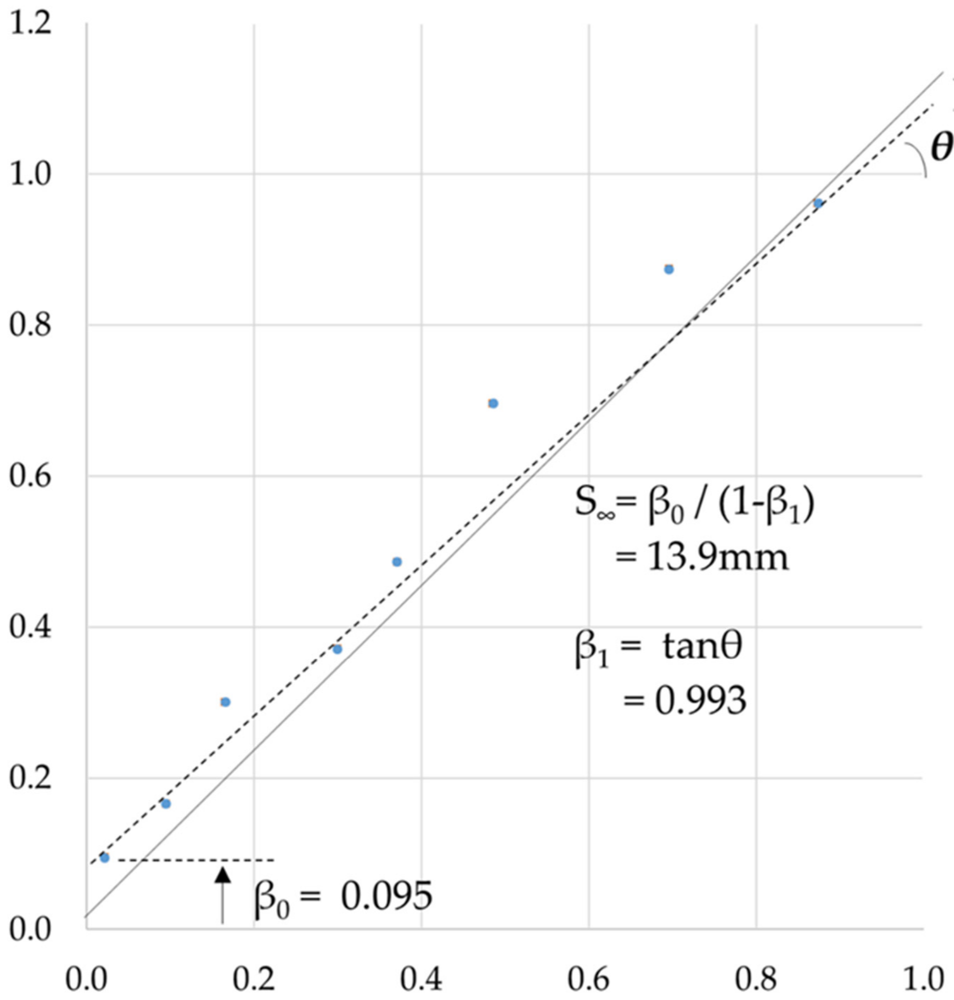


Figure 9. Long-term settlement predicted by Asaoka method [45].

3.4. Numerical Analysis Result

Tables 4 and 5 show the physical properties of the soil and reinforcement used in the analysis. The physical properties of the soil were derived through the experimental test results and empirical formulas, and related data were applied for the DCM composite column [44]. Figure 10 is the result of a finite element analysis, applying the Mohr–Coulomb failure model and creep theory, and it was found to be 8.89 mm in 15 years and 11.26 mm in 20 years. Aa result of the analysis, it showed a tendency lower than the theoretical value, and the settlement amount was within the allowable settlement range of 25.4 mm.

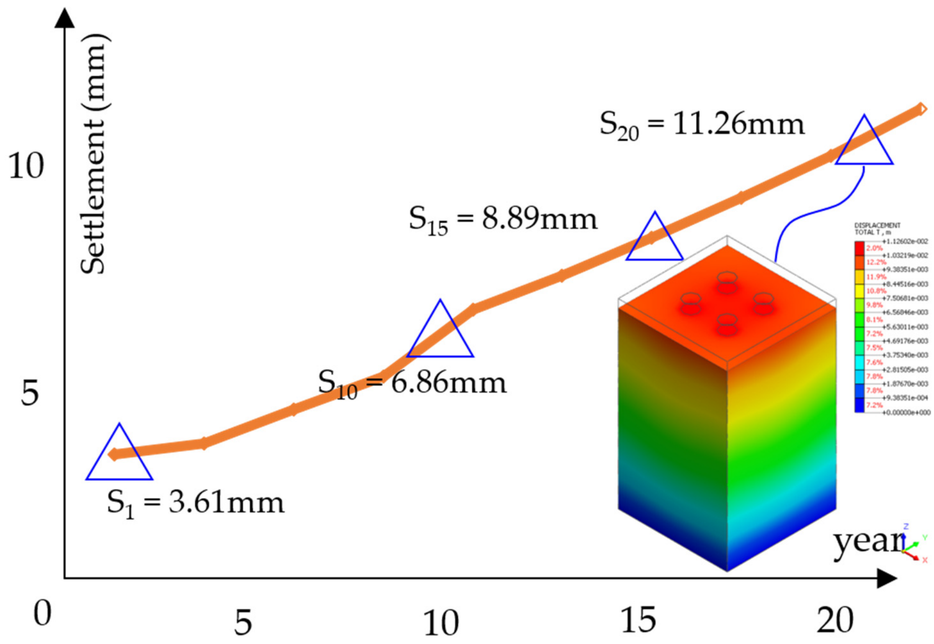


Figure 10. Long-term settlement predicted by FEM analysis.

4. Discussion

In this study, structural safety was evaluated by applying the DCM foundation method, which is one of the ground reinforcement methods for economical and safe construction necessary for the construction of large-scale horticultural complexes. To consider the structural safety of the DCM method, a geotechnical survey, soil test, and a long-term settlement monitoring system were established. Based on the settlement monitoring data, long-term settlement was predicted considering the greenhouse durability. For long-term settlement prediction, the Log S–T, hyperbolic, and Asaoka method; Schmertmann theory; and finite element method (FEM) analysis were performed.

Table 6 and Figure 11 summarizes the long-term settlement. In the case of the Log S–T, hyperbolic, and Asaoka method based on actual measurement data, the settlement was predicted to be 12.18~20.43 mm, and in the case of the Schmertmann empirical formula, it was predicted to be 19.66 m. The FEM analysis result was 8.89 mm, which was considered to be the lowest level of long-term settlement. Relatively, the FEM results showed the lowest value, and the prediction results based on empirical formula and measurement data showed a high degree of agreement of around 20 mm. As the most conservative result, the DCM foundation method designed in this paper has an allowable bearing capacity of 310 kN/m^2 and a long-term settlement of 20.43 mm. This is the result of satisfying both the allowable bearing capacity of 100 kN/m^2 and the allowable settlement range of 25.4 mm as a greenhouse foundation. If the service life is considered to be 20 years, the method of suppressing settlement by increasing the depth of the column may be considered. Through this study, it was proved that long-term structural safety can be sufficiently secured when the DCM foundation is constructed on a soft ground through a design that considers the required service life and allowable bearing capacity of the structure. In addition, it was confirmed that the Hyperbolic, Asaoka, and FEM analysis method adopted in this paper can be applied to the long-term settlement analysis of the DCM foundation method.

Table 6. Summary of long-term settlement analysis results of the DCM foundation method.

Settlement (mm, Duration of 15 Years)				
Log S–T	**Hyperbolic**	**Asaoka**	**Schmertmann**	**FEM Analysis**
20.43	12.18	13.9	19.66	8.89

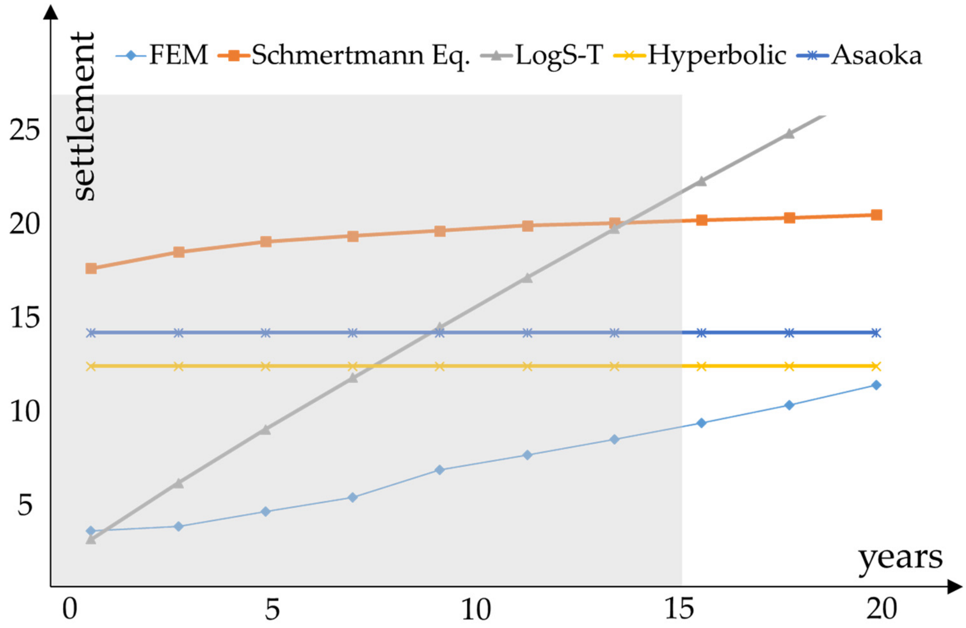


Figure 11. Long-term settlement predicted by FEM analysis.

One of the limitations of this paper is that it is necessary to obtain additional settlement data to apply the hyperbolic model. The trend line for the first 150 days showed a tendency to diverge with a negative slope, and a rebound trend line appeared after 150 days. In this regard, when the hyperbolic method is applied, it is necessary to verify it from a long-term perspective through additional long-term settlement monitoring. In addition, there is a limit in constructing the entire area under the same design conditions, because the soil of the reclaimed land has large variations in physical properties.

As mentioned above, although not covered in this study, additional research is needed to review the design range of the DCM reinforcement foundation, considering the variation in the physical properties of the reclaimed land soil. In terms of settlement behavior, it is necessary to additionally examine the lateral displacement and differential settlement that may occur in soft ground separately from the vertical settlement reviewed in this study.

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