

Study on Stress Distribution in Soft Ground Consolidated with Deep Cement Mixing Columns under Road Embankment

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Abstract Soil consolidation using deep mixing method (DMM) is commonly used to protect soft ground in alluvial stratum in deltas such as Mekong Delta. In this study, the finite element method (FEM) using PLAXIS software is adopted to analyze the stress distribution on columns and ground base of the deep cement mixing (DCM) columns system combined with geotextiles in the consolidation of soft ground under road embankment in Tien Giang Province. With this method, the behavior of the DCM columns in soft ground treatment is examined by the distribution of stress and settlement of the DCM columns and soft soil layers. Simultaneously, the settlement of road base construction is monitored. The stress distribution on DCM columns and their settlement are also given from the analysis of FEM. The FEM models simulating the soft ground consolidated with DCM columns combined with geotextile under the road embankment in Tien Giang with the DCM columns of 0.6 m diameter, 11.2 m length and 1.0m center-to-center spacing show the largest settlement of 0.120 m and the stability coefficient of 1.679.

Keywords Montmorillonite, DCM, Soft Ground, Mekong Delta, Numerical Simulation

1. Introduction

The Mekong Delta has young tectonics of which over 90% of the area is soft soil. The regional economic development over recent years has promoted the integration of civil engineering technology to meet the economic needs. With the policy of developing infrastructure for the region, many traffic works, dams, warehouses and factories have been built. However, the constructions on soft ground often face a wide range of problems such as stability and subsidence compensation. A normal practice to solve this problem is to replace soft soil layer with a new one and make subsidence compensation [1]. Because the resources are limited and non-renewable, scientific, technological and engineering integration over recent years has brought new solutions to handle this problem with the goal of treating the foundation for a long-term stability, shortening treatment duration and reducing the amount of resources to compensate future subsidence.

Today, two popular DMMs are wet mixing method and dry mixing method. The principle of this method is to use a specialized device as a twist drill to direct its tip to the intended depth and at the same time, the soil is loosened and mixed with consolidation substances in downward or upward directions or both directions. Then a consolidated soil column is the product of the mixing of soft soil and

consolidation substances [6].

The modern technology can help make DCM columns in various sizes. Deep mixers typically contain 1 to 4 mixing shafts. For multi-shaft mixer, these shafts are attached to rotating blades that rotate in opposite directions when mixing soil with cement to produce good quality columns. Column diameters may vary from 0.5 m to 2.0 m. Recently, Japan has introduced big mixers with a number of mixing shafts up to 8 and is able to create columns with various areas of 1.0 m², 2.2 m² and 5.7 m² [4].

In Vietnam, lime-cement columns were introduced in early 80's with Swedish technology. Then this technology has been applied in civil engineering to treat soft ground for constructions of water tanks, oil tanks and the irrigation works adopting technology of wet grouting for repair, crack proof and waterproof of drain bases, etc.

Japanese soft ground consolidation technology with DCM has been introduced and applied in transport industry during recent years. The most notable project was Can Tho airport in 2004, which adopted effectively DCM columns of 60 cm in diameter, 6 m in depth and 1 m at interval; the amount of cement accounted for 230 kg per m³ soft soil. Since then, this construction technology has been used regularly in Vietnam to protect soft ground for traffic works such as Ho Chi Minh City- Trung Luong Expressway, Thang Long Avenue and 5B National Highway, etc. [9].

Farouk and Shahien (2013) launched an experimental study using DCM columns to protect soft ground. The study results showed that the compressive strength of the cement-soil samples increased even when cement content was very low and the settlement of the footing was reduced by 80% depending on the quantity and length of the DCM columns [2].

Hormdeel and Jirawattana (2020) studied the load-bearing capacity and compressibility of the loess consolidated by compaction method and cement mortar mixture, the purpose of this study was to consider the load-bearing capacity and subsidence of Khon Kaen loess when it was compressed with and without cement. The lab and field test results showed that the tightness of the soil consolidated with cement increased by 95% against natural soil. This was because of the influence of density, initial moisture, added cement content and the curing time of the sample. The test results also stated that where the water content increased, the compressive strength of the sample decreased significantly and the compressibility of the sample increased sharply. For high cement content, the settlement decreased and the compressive strength of the sample increased critically [5].

Yemi Kehinde Ariye et al. (2020) carried out an experimental study for the consolidation of the road embankment by DCM columns from Papalanto to Sagamu about 43 km long in Ogun state, Nigeria. It was the road that was always in difficult conditions because of heavy trucks causing damage and subsidence. The solution was to

use 5% of cement mixed with soil to increase the load capacity of the road embankment [24].

Moayed and Azini (2020) carried out a field load test to evaluate the results of the numerical model of shotcrete. The purpose of this study is to assess the results of the numerical model based on field static load test. The study result showed that the field test and modeling results were acceptable. It also stated that it was possible to use numerical models to study soft soil consolidation [20].

With current industrial revolution 4.0, Nguyen et al. (2020) also conducted a research on integrating information and communication into soft soil treatment with DCM columns. This research showed that when the DCM columns were applied into the ground, they were not able to be observed directly for their engineering process situations. The result was that inappropriate management of construction data and quality of DCM columns was experienced. By combining information and communication technology, a visualization system for the construction of DCM columns was developed, "3D Pile Viewer". The system consists of two functions: positioning guidance and visualization of construction information by using global positioning system, total station and inclinometer. Then, a 3D model of all information in the construction process such as depth, electrical current value, amount of mud, speed of rotation, etc., can be created and shared via internet [8].

The redistribution of stress on columns and ground depends on mutual impact between columns, soil, embankments, geotextiles and reinforcement layers (if applicable). The above-mentioned complicated impact is mainly due to the phenomenon of "Arching effect" in the ground. The determination of stress distribution in and below the ground consolidated with DCM columns is very important in the design of road embankments on soft ground. "The Arching effect is found to be the most common in soil both from laboratory and field tests" according to Terzaghi (1943) [23]. The results of field monitoring revealed that vertical load acting on column tips increased over time and it was the result of the arching effect on columns. The arching level is a function of the parameters of diameter, columns spacing, embankment height, and column over soft soil hardness ratio. The factors determining arching effect include height of embankment, column layout, shear strength of soil embankment and stiffness of column [15].

The studies on DCM columns in Vietnam first started in late 1980s. Typically, the research and application of scientific and technological progress 26-03-03-07 for DCM columns was led by Nguyen (1985), however such research was mainly conducted in laboratory and its results were only orientation [14].

In 2012, the Ministry of Science and Technology issued the National Standard for soft ground consolidation by the method of DCM columns [22]. This standard specifies technical requirements for surveying, testing, designing,

constructing and accepting the DCM columns used to protect soft ground in the construction of light-load buildings and structures, embankments and protective slopes.

There have been so far a number of research topics and dissertations done at the Universities of Irrigation, Architecture, Construction, Transport, etc. Notable studies are described below:

The study by Tho (2011) on ensuring the stability of embankment on soft ground with the support of DCM columns [10] determines whether DCM column has similar structure to the hard bored pile surrounded by elastic ground and its tip on hard ground (vertical force acting on the pile is all transmitted to the hard ground) and Mindlin's theory of stress is used to (applied to the effect of force in the elastic space) build f_s correlation with the force exerted in the soil around the column.

An (2012) studied some factors affecting the load-bearing capacity of DCM columns to protect soft ground [19]. The author believes that the settlement of the pile foundation is a complicated problem because there is a turbulence. Stress distribution upon availability of column is not known and load transmission mechanism in the column is not understood correctly. Therefore, the displacement of the load transmission mechanism is only approximately determined by semi-empirical, empirical method and compressive test methods.

The study by Dat (2013) applied chemical grouting technology to protect the dyke in Ha Nam Province. The study covered many new treatment technologies where they took in account high-pressure jet grouting technology that grouted cement in the soil to enhance the waterproofing effect of the dyke [12].

Hung (2014) from the University of Transport studied solutions to improve the effectiveness of soft soil treatment with DCM columns in the construction of embankments on soft ground. The software Plaxis V8.2 allows investigating on numerical model regarding variation of deformation (settlement) in various geological conditions, soft soil thickness and column sizes [16].

The study by Thang (2017) titled "Influence of Montmorillonite mineral on compressive strength of DCM columns" focused on analyzing the effect of MMT content on the compressive strength of soil-cement samples by unidirectional confined compressive test in combination with X-ray analysis method. The samples were cured in freshwater medium with curing duration of 7, 14 and 28 days. The test was performed on the samples of soil-cement made from Kaolinite clay with 20% cement, 80% moisture and the MMT content varying from 0%, 3.3%, and 6.5% to 9.8% [11].

Generally, the authors have the same study subjects but different approaches and methods. This study has certain contributions to computational theories.

2. Materials and Methods

For deep mixing treatment designed to satisfy the feasible, economic and long-term requirements and withstand the impacts and influences during construction and operation, which means that it meets the conditions of extreme and the limit states of use, its design is normally made in iterative approach, in which the results of multiple test methods are an important aspect. The preliminary design is based on laboratory sample results. The correlation of unconfined compressive strength between the field column sample and laboratory sample can be chosen empirically from 0.2 to 0.5 depending on soil type and mixing ratio.

The method used is to study theories about the solution of consolidation with DCM columns in combination with the geotextiles under elevated embankment. These theories cover stress distribution and deformation in soft ground reinforced with DCM columns that are combined with geotextiles [13, 18].

Based on geotechnical data, loads, theoretical basis and related references [3], the author used Plaxis V8.2 software to analyze and assess the case of the DCM column group under the pressure of the upper embankment.

The failure model of the system is the soft ground (causing subsidence to the tip of the column or sliding to the soft ground around the DCM column). In practice, DCM columns are usually arranged in groups and in most of cases, the behavior of a single column is different from that of a group of columns, but it is often allowed to calculate the load which a single column carries. Evaluation of stability of the column according to limit state 1: the calculated load is determined based on an investigation of either shear failure or settlement failure (the minimum value of the limit load divided by the safety coefficient and the load corresponding to allowable settlement of the ground under the column). For the column under the impact of vertical loads, because the column is hard, the limit load Q_{gh} thereof is determined by the limit resistance force of the column tip Q_p (determined when the ground under the column fails) and lateral friction Q_f (determined when sliding occurs between the ground and the column).

It should be noted that the determination of the ultimate limit value taking into account the failure of the soil under the column tip is calculated as the limit problem of shallow foundation. Determination of the shear friction force f_s is calculated from the Coulomb soil sliding failure conditions. The determination of the soil-column strength c_a, ϕ_a and the horizontal pressure of the soil acting on the column are complicated and there are many different points of view.

2.1. Materials

2.1.1. Geological conditions

In general, the ground surface is characterized by new alluvial to be rich in clay mud and organics, so it is

relatively low in respect of topography and poorly load-resistant in respect of geology, which requires much compaction and protection in process of construction.

To obtain data on the properties of natural soils, a 30 m borehole was prepared in Chau Thanh district, Tien Giang province, Vietnam [7]. The testing results to determine the physical-mechanical properties of the soil layers are shown in Table 1.

The analysis and generalization of physical-mechanical properties from the data obtained from the borehole showed the strata of the boring position are divided into the following layers:

Layer 1: Clay mixed with little sand of dark gray-brown color, flowing state, medium plasticity; 9.8 m thick.

Layer 2: Clay mixed with a little sand of white-spotted gray-brown color, hard plasticity state, medium plasticity; 7.5 m thick.

Layer 3: Fine-grained sand in yellow-gray color, poorly tight condition; 2.6m thick.

Layer 4: Clay mixed with a little sand of gray-yellow and white-gray color, semi-hard state, medium plasticity; 8.7 m thick.

2.1.2. Calculation model in plaxis

The calculation model is a road embankment with soft soil layers: The ground has 4 layers of soils including 11.2 m of soft clay, 7.5 m of sandy clay, 2.6 m of fine sand and 8.7 m of tight clay; above the soil layers, the road of 5m high embankment is located as shown in the Fig.1.

When an analysis of two-dimensional finite element is made, it is possible to use plane strain model and axial symmetry model at the same time. In this study, the road embankment located on soft ground can be considered as a strap footing for calculation, so the road embankment will be simulated according to the plane strain model.

To simulate the soil layers, a triangular 6-node or 15-node element is used to create a plane model for calculation. The 6-node triangular element is the default option for a 2-dimensional analysis. It provides an interpolation as two for displacement. The element hardness matrix is estimated by the integration of the sum of the three Gauss stress points. Whereas, the 15-node triangular element has sequential interpolation and it is estimated by the integration of the sum of 12 stress points.

Table 1. Physical-mechanical properties of soil layers

Physical-mechanical properties	Layer 1	Layer 2	Layer 3	Layer 4
Water content, W(%)	71.24	30.14	25.65	26.53
Wet unit weight, γ_w (kN/m ³)	15.62	19.12	19.35	19.63
Dry unit weight, γ_d (kN/m ³)	9.12	14.69	15.40	15.51
Initial void ratio, e_0	1.901	0.832	0.729	0.736
Liquid Limit, LL (%)	64.04	43.25	-	44.40
Plastic Limit, PL (%)	30.82	22.83	-	23.28
Liquidity index, IL(%)	1.22	0.36	-	0.15
Total deformation module, E_{01-2} (kN/m ²)	508	2402	8278	2713
Cohesive, c (kN/m ²)	8.8	11	8.8	38.2
Friction angle, ϕ	3°14'	5°58'	27°35'	15°15'
%particle accumulation				
< 4.75mm (%)	100%	100%	100%	100%
< 2.00mm (%)	100%	100%	100%	100%
< 0.425mm (%)	100%	100%	95.5%	100%
< 0.075mm (%)	100%	94.5%	34.2%	95.8%
< 0.002mm (%)	44.1%	32.1%	6.0%	33.6%

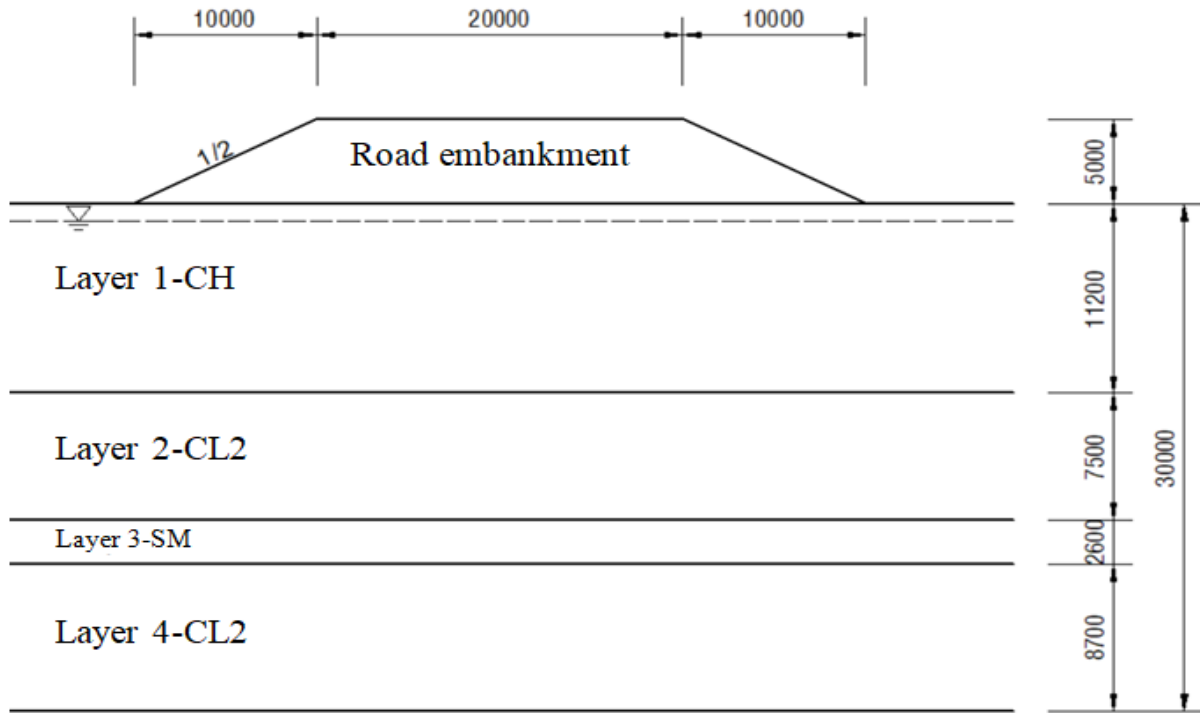


Figure 1. Cross section of road embankment on soft ground

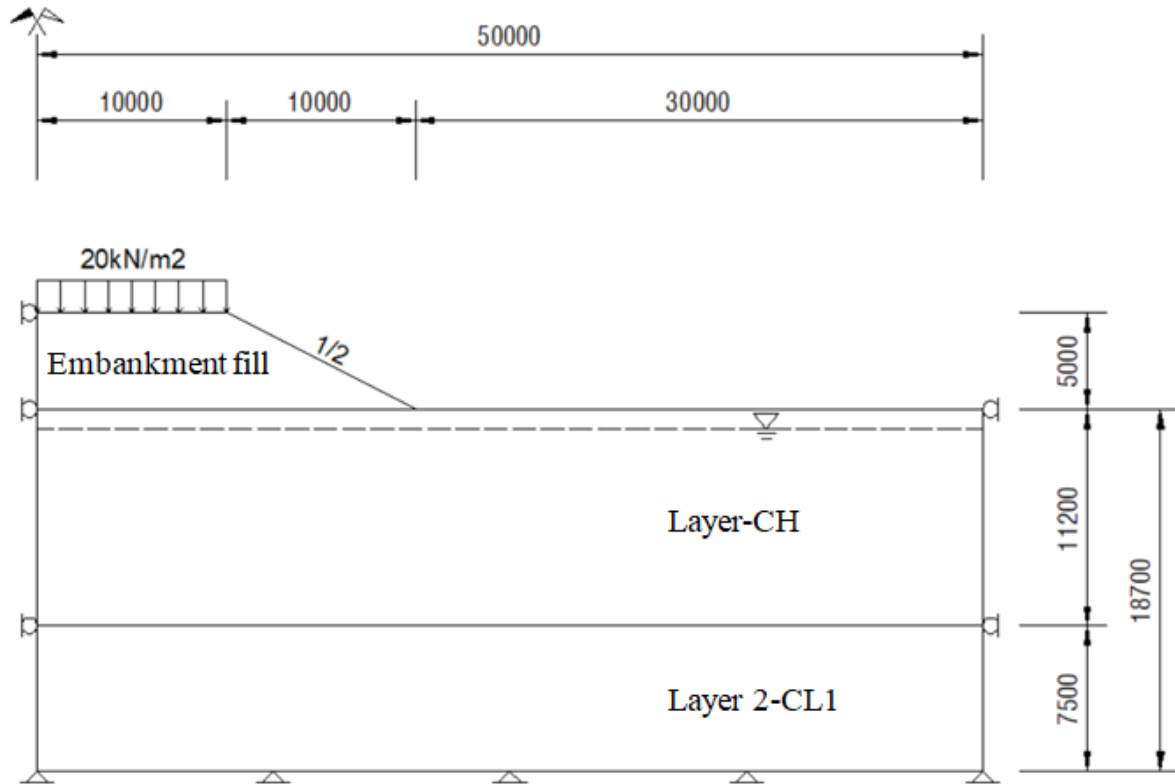


Figure 2. The soft ground is not consolidated

2.1.3. The case where the ground is not consolidated

The case where the ground is not consolidated is simulated in Figs. 2 and 3. The model of the finite element problem is simulated in Plaxis as shown in Figure 3, which contains untreated soft soil layers and the embankment of the roadbed.

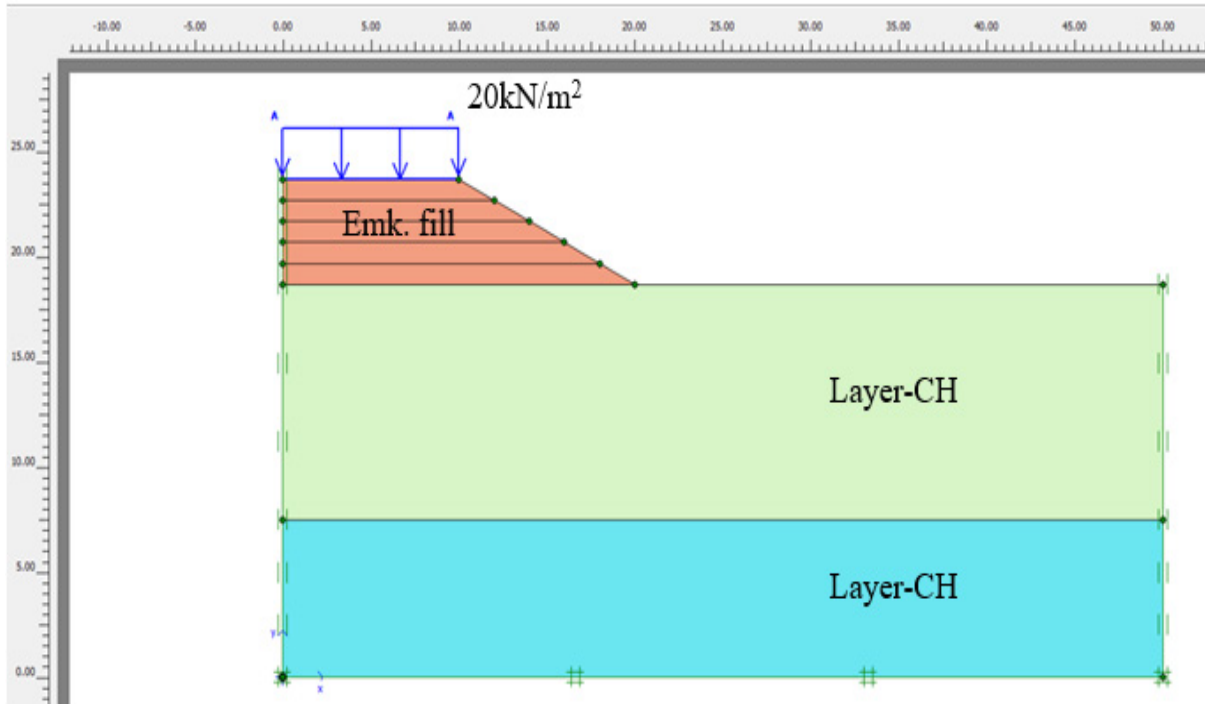


Figure 3. The model of finite element of the un-consolidated soft ground

2.1.4. The case where the soft ground is consolidated with DCM columns combined with geotextiles

The soft ground which is consolidated with DCM columns of 0.6 m in diameter, 11.2 m in length and 1.0 m in center to center spacing combined with geotextiles is simulated in Figs. 4 and 5. The roadbed is filled in layers in accordance with construction schedule, followed by the loads of vehicle operations.

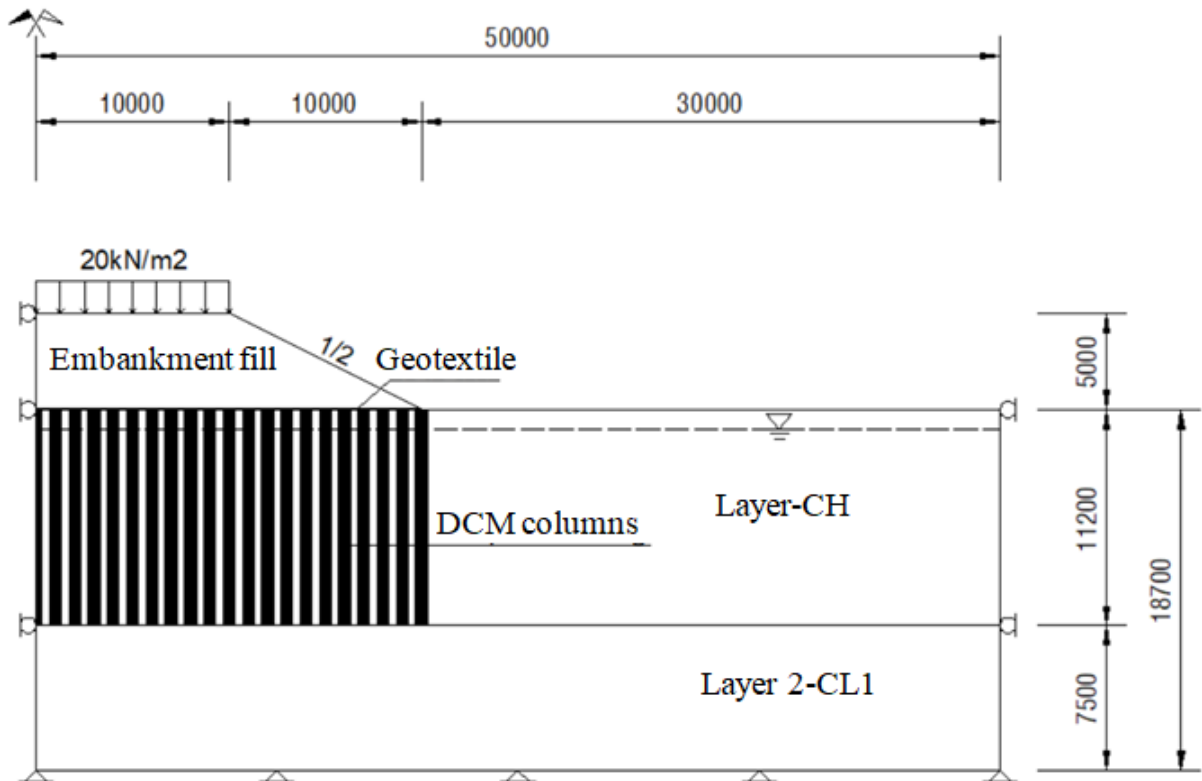


Figure 4. The soft ground is consolidated with DCM columns combined with geotextile

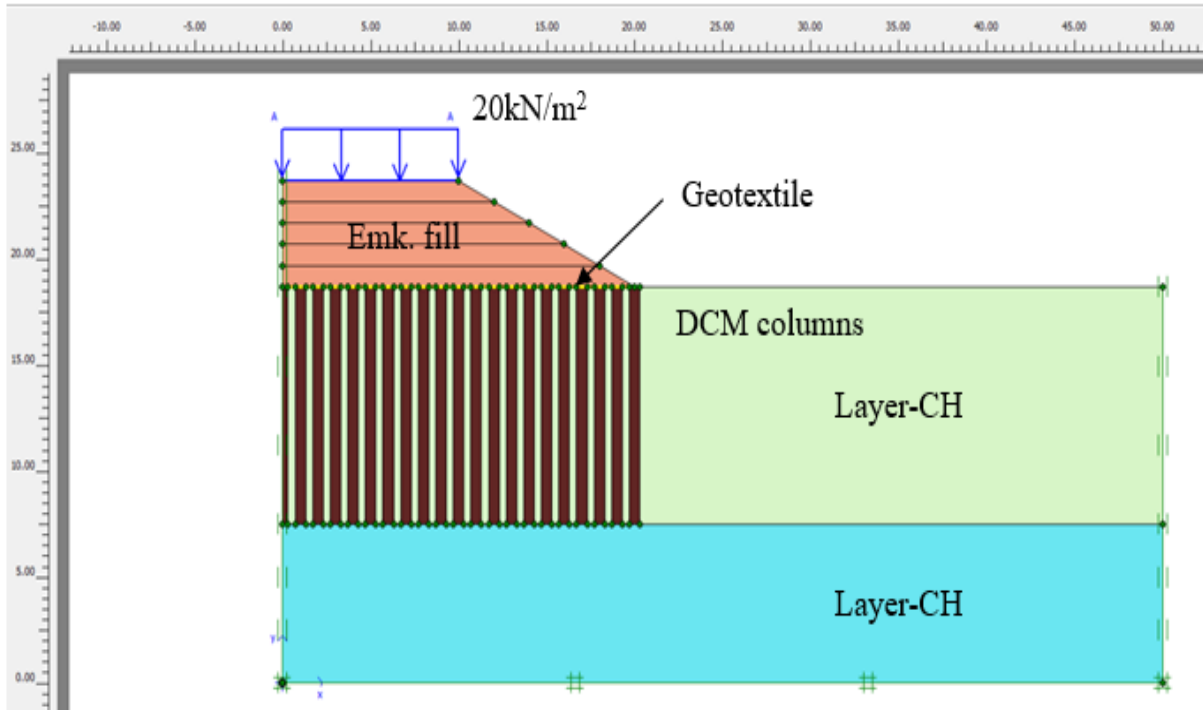


Figure 5. The model of finite element of the soft ground consolidated with DCM columns combined with geotextiles

2.1.5. Boundary conditions

Standard fixities format is utilized to register boundary conditions. Create limit conditions: Click the corresponding Standard fixities button on the toolbar. Plaxis automatically affects a set of common boundary conditions in the geometry model. These conditions are the following generated rules:

The vertical structures where the x coordinate is equal to the lowest or highest value in the model obtain a horizontal restraining ($u_x = 0$).

The horizontal structures where the y coordinate is equal to the lowest or highest value in the model obtain a full restraining ($u_x = u_y = 0$).

The standard restraining is used as a convenience and the fastest choice.

2.1.6. Material characteristics registration

Plaxis accepts soil models including Linear Elastic model (LE), Mohr-Coulomb model (MC), Hardening Soil model (HS), Soft Soil Creep model (SSC) and User - Defined model (UD).

Among all the above models, the Mohr - Coulomb model is chosen to describe the actual properties of the soil and the computational applicability of Version 8.2. This is the ideal plastic-elastic model with 5 basic soil parameters: Young's modulus (E), Poisson's ratio (ν), Cohesion (c), Frictional angle (ϕ) and Dilatancy angle (ψ). Normally, all model parameters simulate the effective stress state of the soil. An important property of soil is the existence of pore water pressure. The effects of pore water pressure are divided into 3 types of behaviors in the software: drained behavior, un-drained behavior and non - porous behavior.

The parameters of soil layers are shown in Table 2.

Table 2. Parameters of soil layers in Plaxis model

Parameters	Layer 1	Layer 1	Emb. fill
Material model	Mohr - Coulomb	Mohr - Coulomb	Mohr - Coulomb
Type of behavior	Un-drained	Un-drained	Drained
Unit weight γ_{unsat} (kN/m ³)	15.62	19.12	18.00
Saturated unit weight γ_{sat} (kN/m ³)	15.67	19.23	20.00
Horizontal permeability k_x (m/day)	10 ⁻⁶	10 ⁻⁵	10 ⁻³
Vertical permeability k_v (m/day)	10 ⁻⁶	10 ⁻⁵	10 ⁻³
Young's modulus, E (kN/m ²)	508	2402	20000
Poisson's ratio ν	0.352	0.331	0.330
Cohesion c_{ref} (kN/m ²)	8.8	11.0	10
Friction angle (ϕ)	3°14'	5°58'	25°
Dilatancy angle (ψ)	0	0	0

The properties of the DCM columns are tested from the q_u determination test and references to the documents regarding the properties of DCM columns: CDIT (2002) [4] shows that specific weight of the soil mixed with cement increases from 3% to 15%. From sample compression tests, Young's modulus are taken as $E_{50} = (50 \div 63)q_u$. Poisson's ratio according to Niina et al. (1977) [17] is proposed from 0.15 to 0.35. The resulted parameters are shown in Table 3.

Geotextile is simulated by Geogrid element with $EA=2500$ kN/m.

Table 3. Parameters of DCM columns

Parameters	Value
<i>Material model</i>	<i>Mohr-Coulomb</i>
Type of behavior	Un-drained
Unit weight γ_{unsat} (kN/m ³)	11.15
Saturated unit weight γ_{sat} (kN/m ³)	18.40
Horizontal permeability, k_x (m/day)	10 ⁻⁷
Vertical permeability, k_y (m/day)	10 ⁻⁷
Young's modules, E (kN/m ²)	100000
Poisson's ratio ν	0.333
Cohesion c_{ref} (kN/m ²)	175
Friction angle ($^\circ$)	30
Dilatancy angle ($^\circ$)	0

Table 4. Calculation phases

Phase	Item	Cal. type	Loading input	Time
Initial	N/A	N/A	N/A	0 day
1	Construction of DCM columns	Plastic	Staged construction Click DCM columns	5 days
2	Construction of geotextile	Plastic	Staged construction Click geotextile	5 days
3	Construction of road emb. fill 1 of 1.0 m thickness	Consolidation	Staged construction Click road emb.fill 1	5 days
4	For consolidation	Consolidation	Staged construction	15 days
5	Stability, FS4	Phi/c reduction	Incremental multipliers	0 day
6	Construction of road emb. fill 2 of 1.0 m thickness	Consolidation	Staged construction Click road emb.fill 2	5 days
7	For consolidation	Consolidation	Staged construction	15 days
8	Stability, FS7	Phi/c reduction	Incremental multipliers	0 day
9	Construction of road emb. fill 3 of 1.0 m thickness	Consolidation	Staged construction Click road emb. fill 3	5 days
10	For consolidation	Consolidation	Staged construction	15 days
11	Stability, FS10	Phi/c reduction	Incremental multipliers	0 days
12	Construction of road emb. fill 4 of 1.0 m thickness	Consolidation	Staged construction Click road emb.fill 4	5 days
13	For consolidation	Consolidation	Staged construction	15 days
14	Stability, FS13	Phi/c reduction	Incremental multipliers	0 day
15	Construction of road emb. fill 5 of 1.0 m thickness	Consolidation	Staged construction Click road emb. fill 5	5 days
16	For consolidation	Consolidation	Staged construction	15 days
17	Stability, FS16	Phi/c reduction	Incremental multipliers	0 day
18	Loading 20kN/m ²	Plastic	Staged construction Click loading	5 days
19	Stability, FS18	Phi/c reduction	Incremental multipliers	0 day
Total				115 days

2.2. Calculation

Each model is analyzed in various phases: Construction of DCM columns, construction of geotextiles, road embankment fill and loading as shown in Table 4.

Plastic calculation is used to compute elastic-plastic

deformation. It is used when analyzing the destructivity and stability of a to-be-analyzed object. The plastic calculation does not take into account the time factor when the pore water pressure is released, and is therefore not suitable for settlement analysis of the ground of low permeability.

Consolidation Analysis: Saturated soil must be drained when settlement increases. For the low permeability soil such as clay, this process takes a long time and is very important to be considered when analyzing settlement. That is the main phenomenon in consolidation calculation. This calculation is therefore suitable for the analysis of settlement over time for water- saturated soils and low permeability soils.

Safety Analysis (ϕ reduction): For safety analysis, Plaxis included a type of calculation called PHI-C reduction. This is a calculation of plasticity, in which the soil strength parameters and interface are gradually reduced until failure. Safety coefficient for an object is calculated by dividing the transient strength by the failure strength.

Phreatic level is located at the depth of -1.0m. Closed consolidation boundary is registered for the left and right

boundaries of the problem. Generation of water pressures is made by selecting generate water pressures based on Phreatic level.

2.3. Results

The calculation results are shown in Figs 6-15.

Figure 6 shows that the ground fails to bear the load of the first embankment (total displacement is 508.45 mm). However, when the soft ground consolidated with DCM columns combined with geotextiles total displacement is 120.18 mm under the 5th embankment and with the loads of vehicles (Figure 7), the maximum horizontal displacement is 95.65 mm (Figure 8) and the maximum vertical displacement at the center of the roadbed is 120.18 mm (Figure 9).

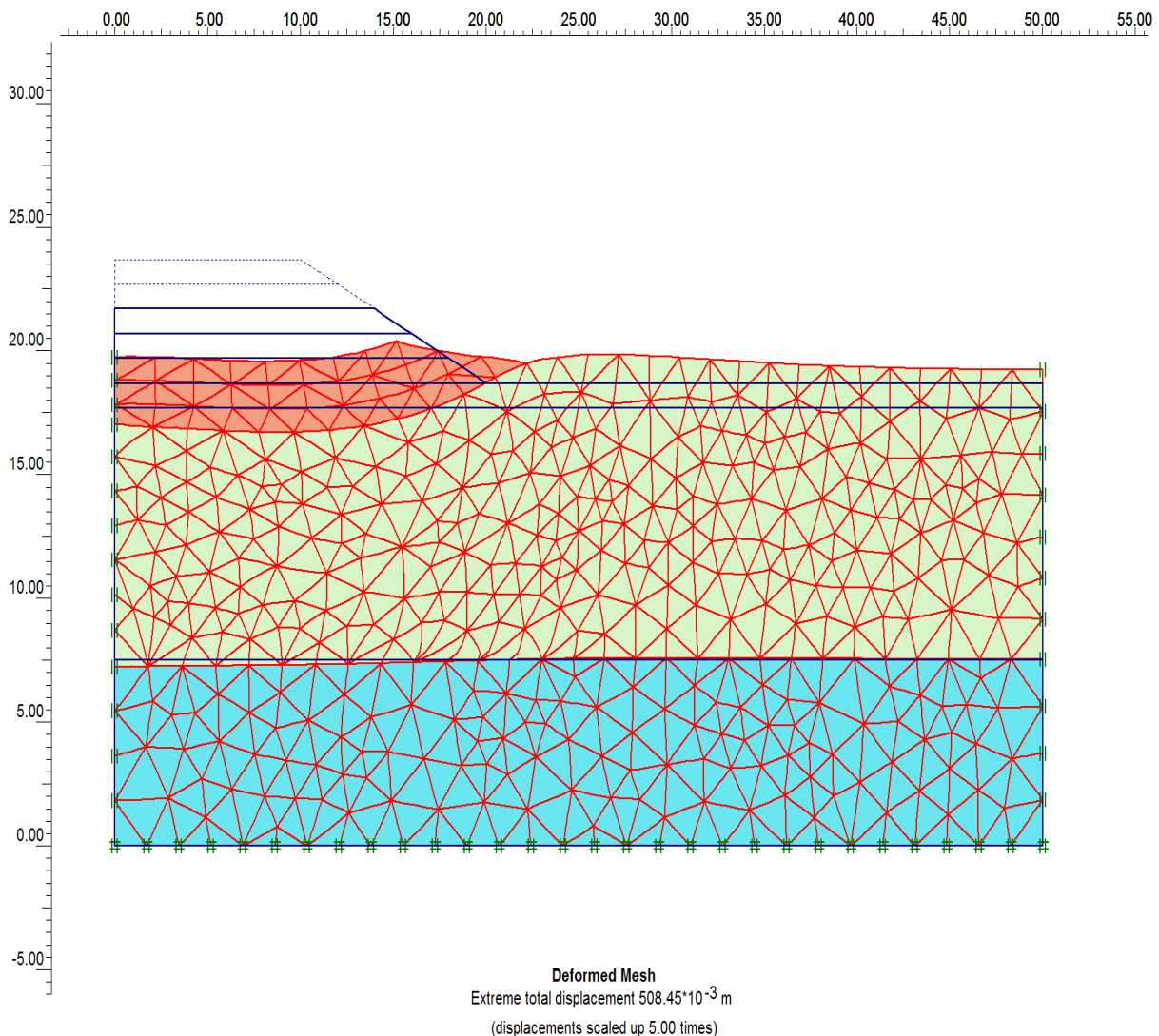


Figure 6. The displacement of the soft ground without consolidation

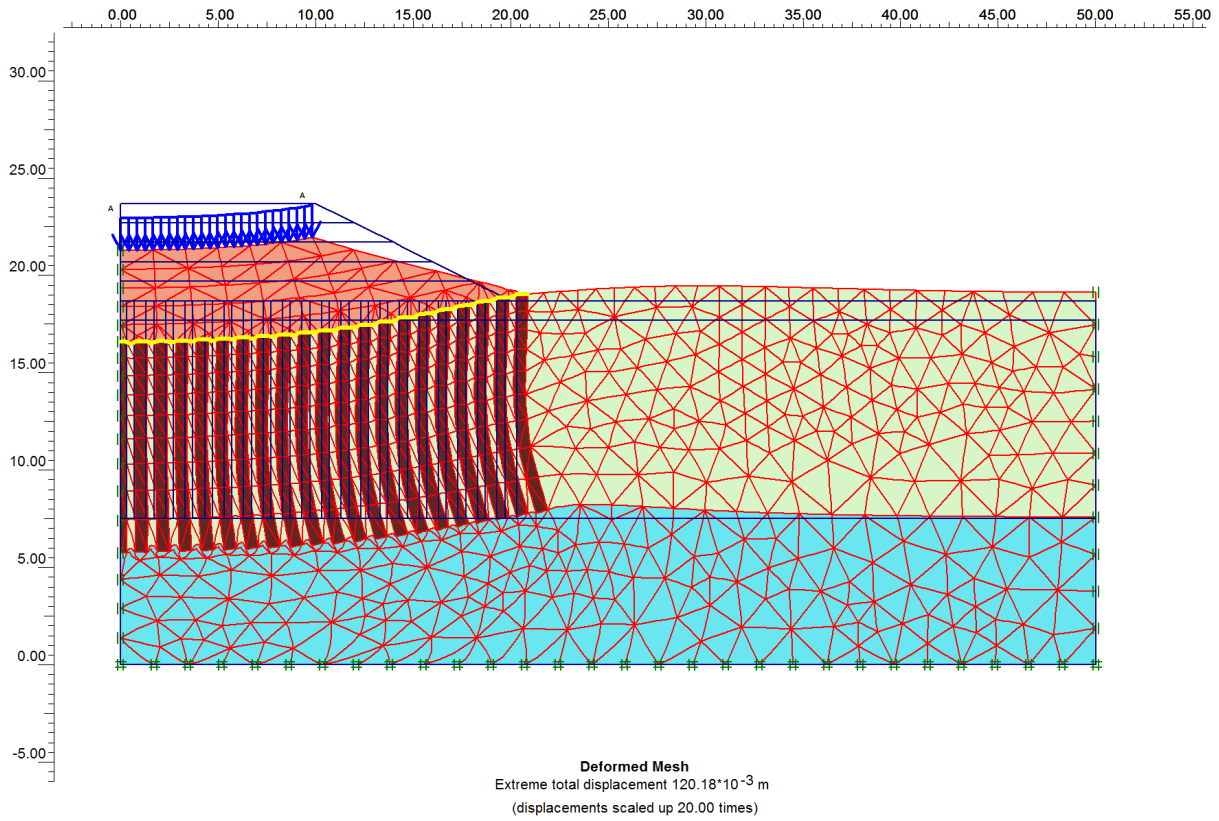


Figure 7. The soft ground displacement with consolidation after 115 days

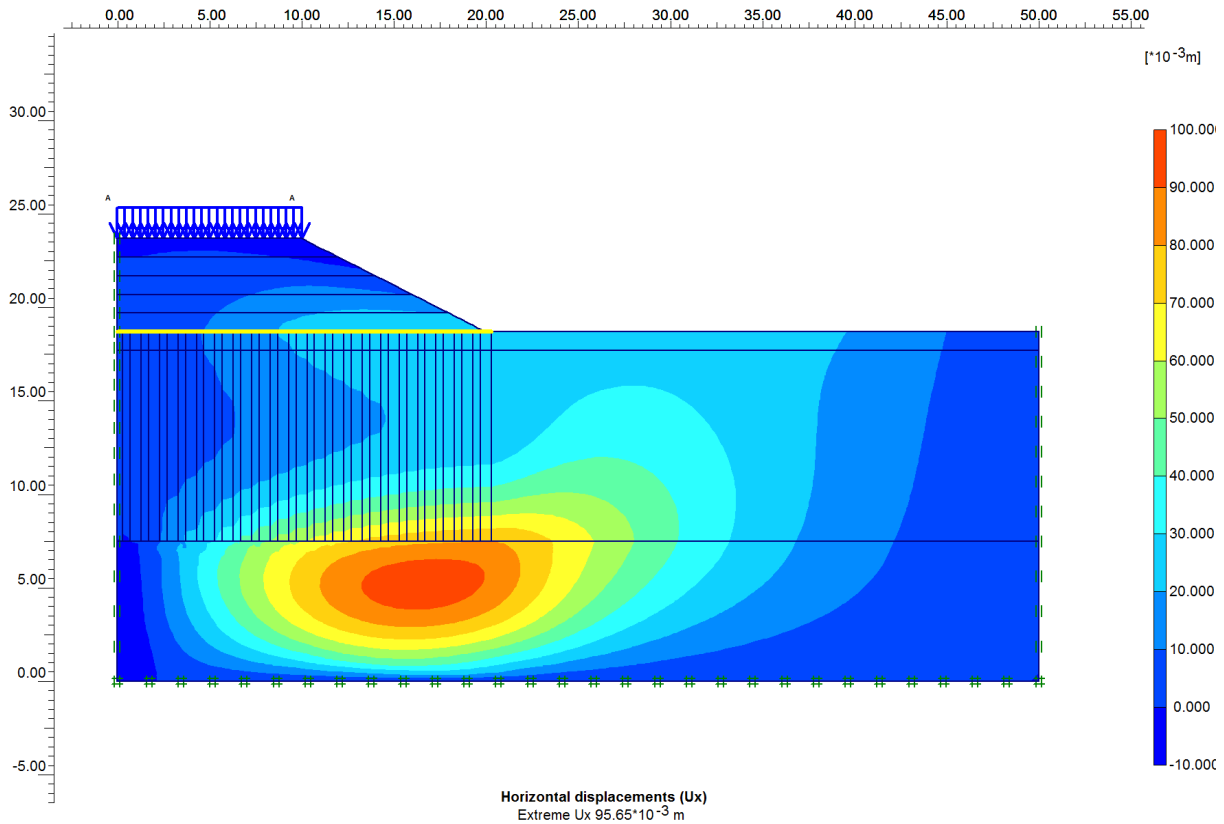


Figure 8. Horizontal displacement of the soft ground with consolidation

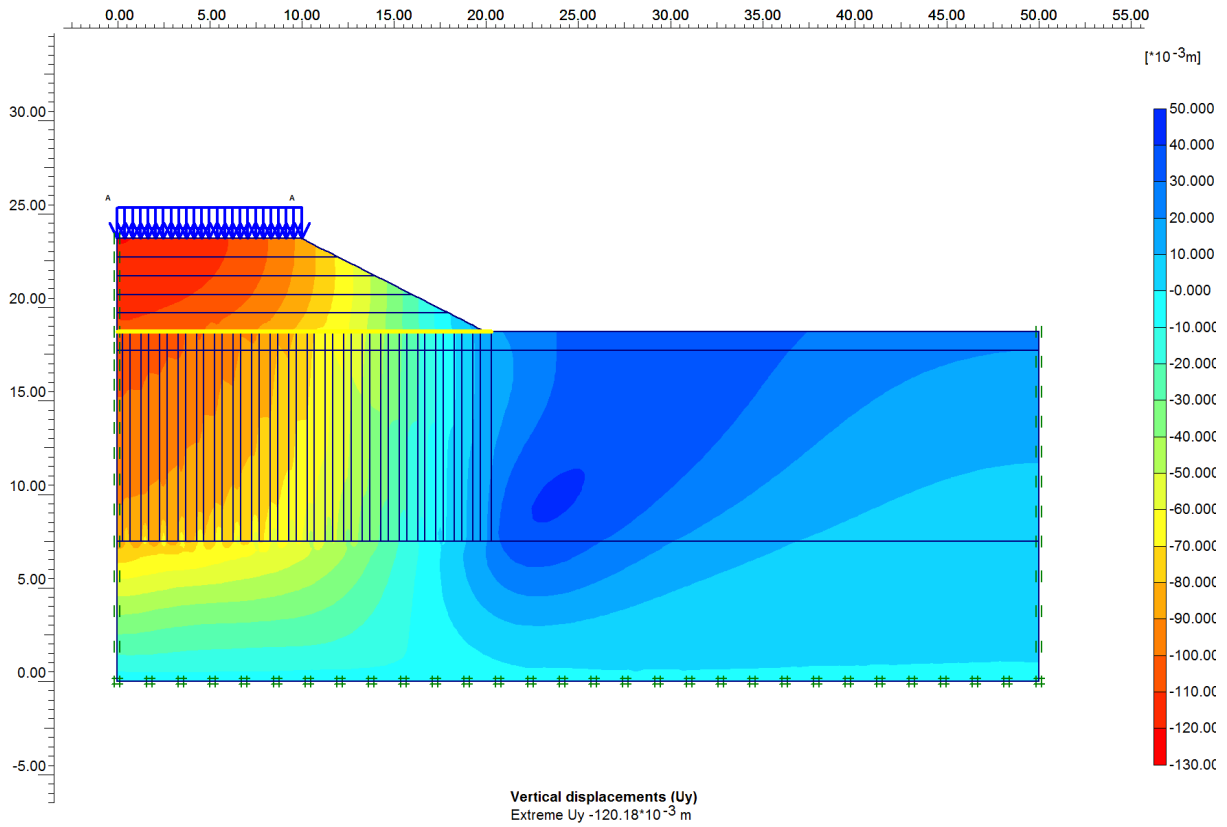


Figure 9. Vertical displacement of the soft ground with consolidation

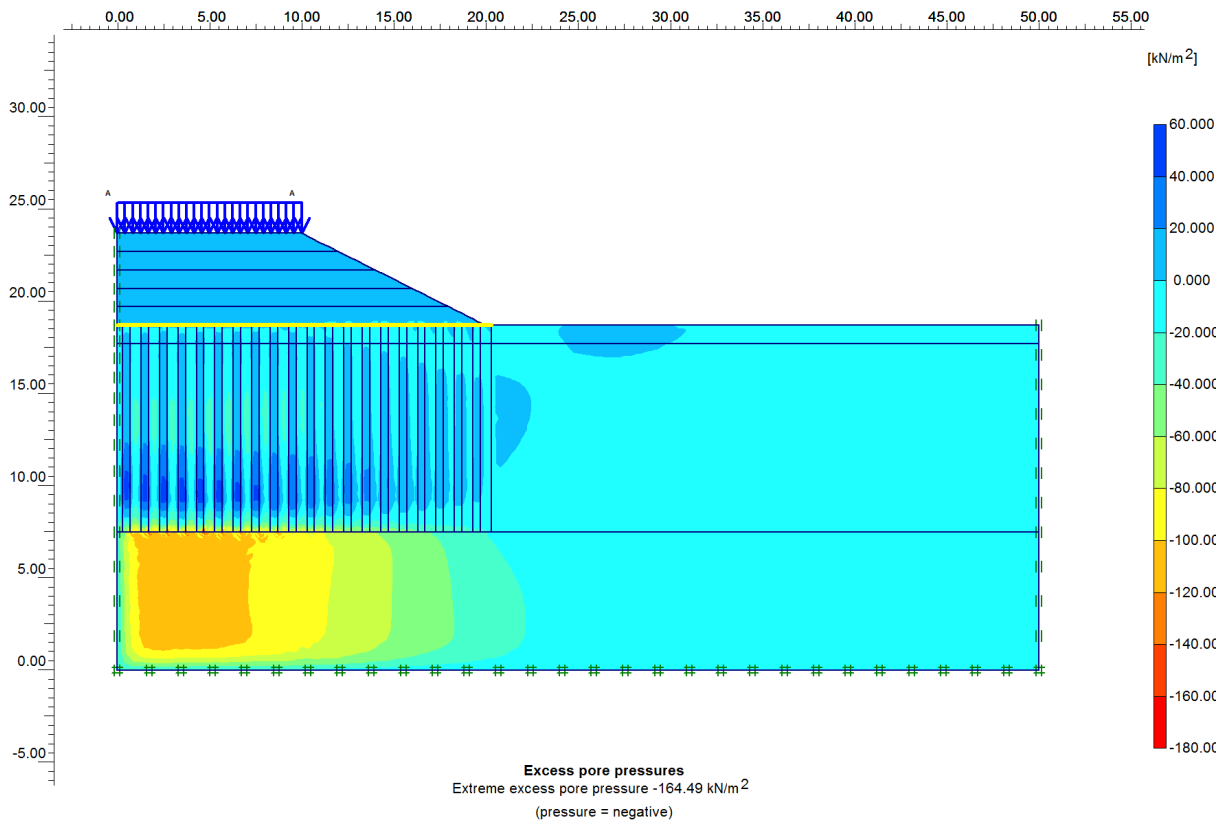


Figure 10. Residual pore water pressure

When simulating the soft ground consolidated with DCM columns and geotextiles, the surplus pore water pressure is also taken into account and the surplus pore water pressure of this study reaches 164.49 kN / m² (Figure 10).

Figures 11 and 12 show the distribution of the effective and total stresses on the DCM columns and on the soft ground composing such columns. The maximum effective stress (200.063 kN/m²) is twice less than the maximum total stress (402.73 kN / m²).

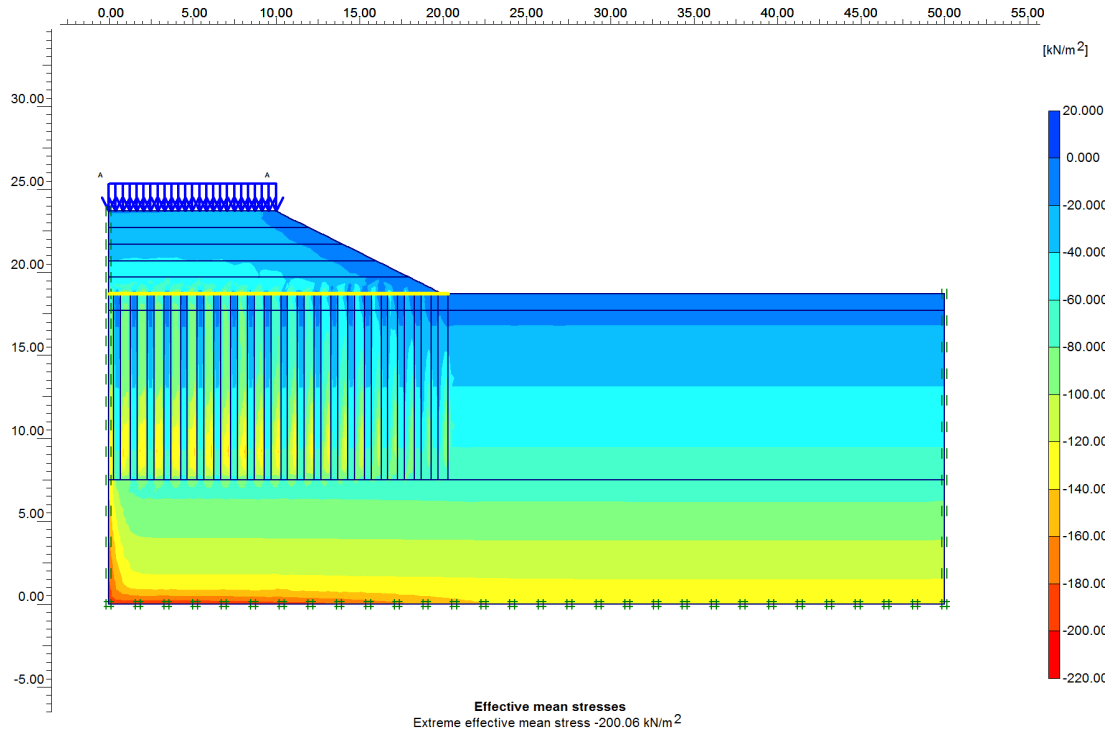


Figure 11. Effective stress distribution in the consolidated soft ground

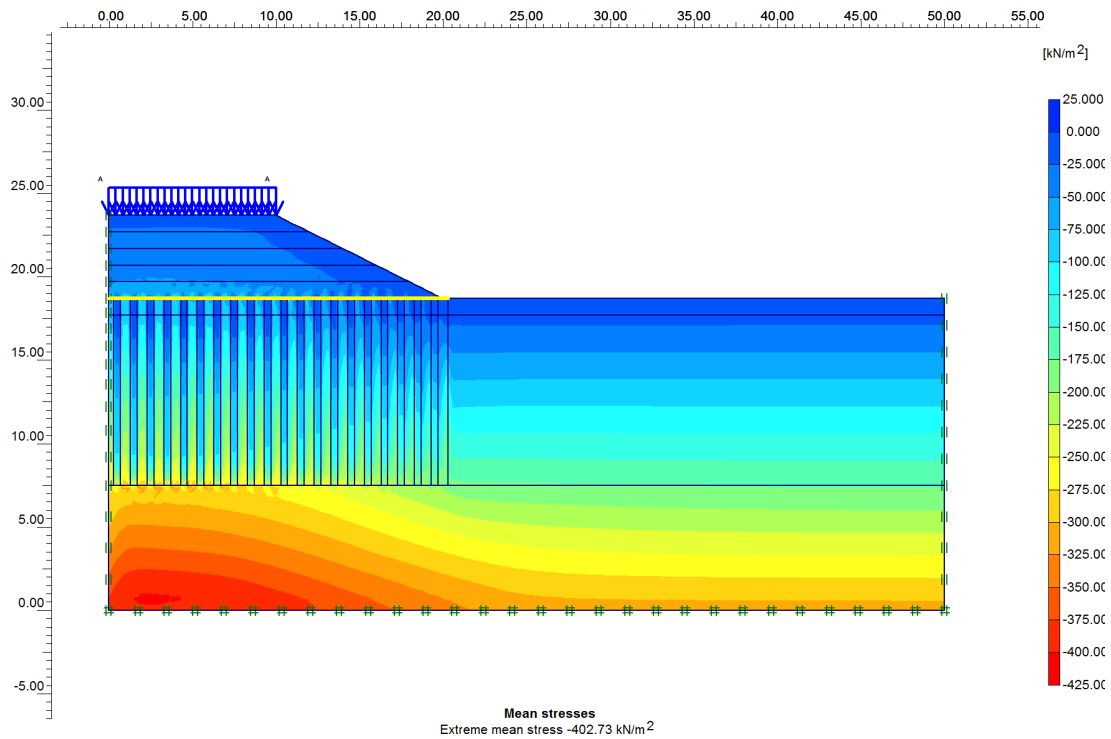


Figure 12. Total stress distribution in the consolidated soft ground

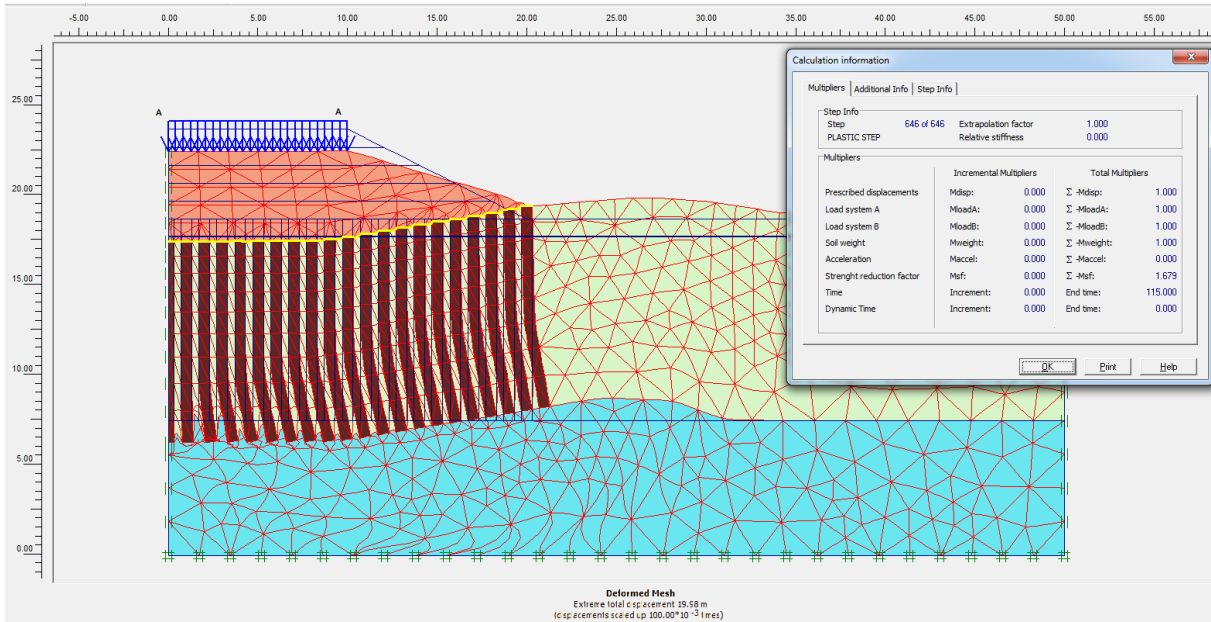


Figure 13. Stability coefficient of the consolidated soft ground

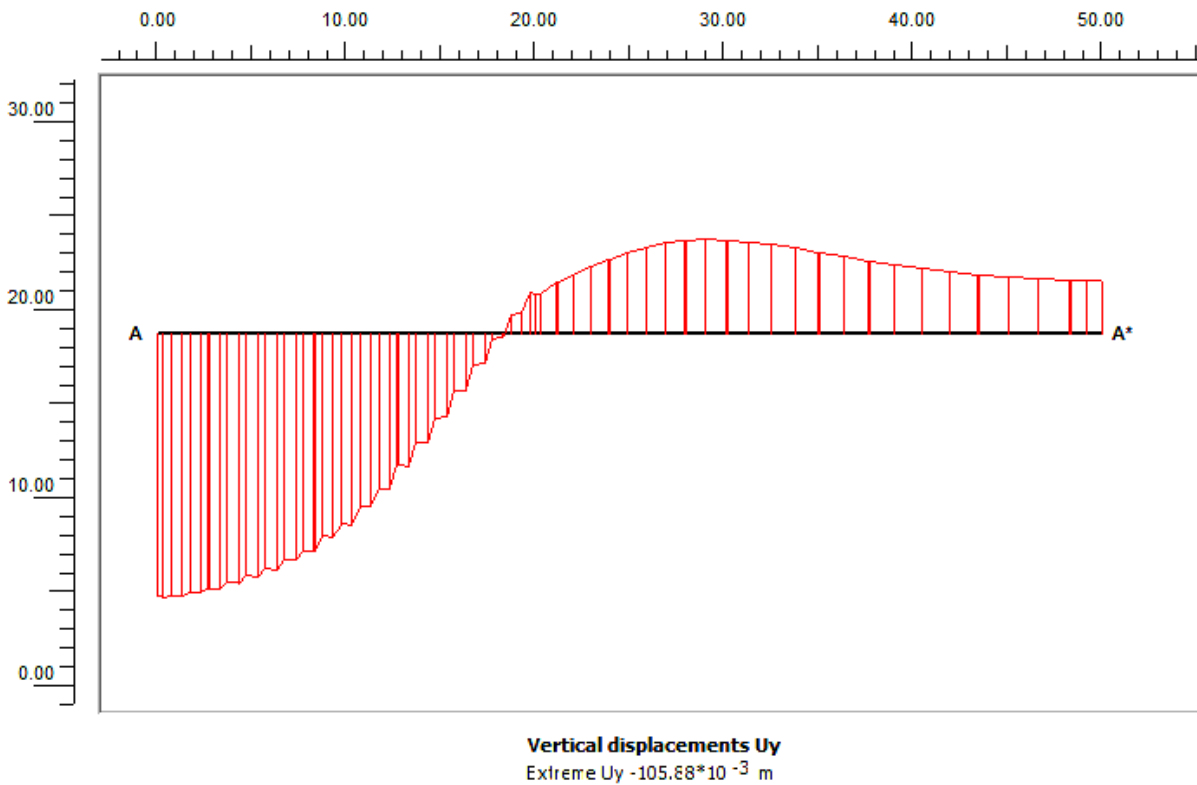


Figure 14. Vertical displacement at the tip of DCM columns

Figure 13 shows that the resultant parameters of the Plaxis software and the simulation results give the coefficient of stability of $\Sigma\text{-Mfs} = 1.679$ that is greater than 1, indicating that the soft ground is in stable condition and has enough load bearing capacity after consolidation.

The soil cement columns near the road center experience the greatest displacements, the ones far from the center experience smaller displacements, and they tend to uplift (Figure 14). Figure 15 shows that the stress distribution at the tips of DCM column is greater than that at the ground around the column.

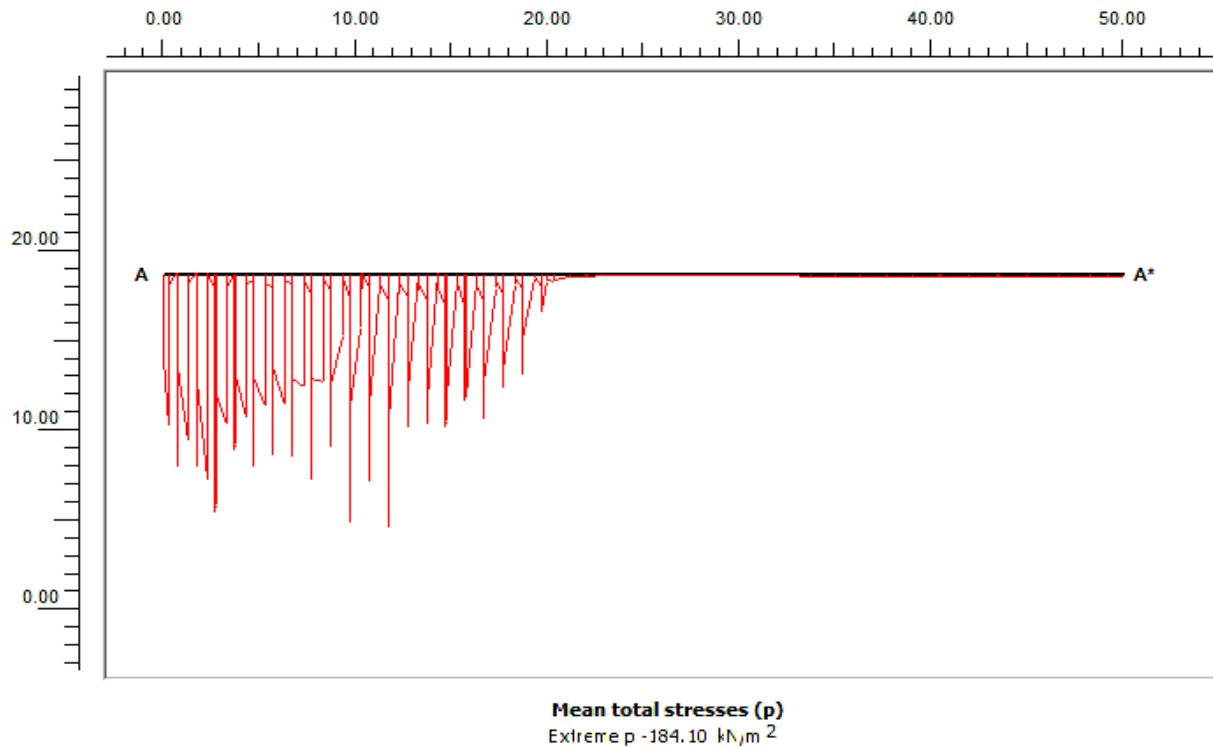


Figure 15. Stress distribution at the tip of DCM columns

2.4. Discussion

When the ground is not consolidated, it will fail when the 3rd embankment is built with the settlement of 0.508 m. When the ground is consolidated with DCM columns of 0.6 m diameter, 11.2m length and 1.0 m center-to-center spacing, the settlement is only 0.120 m and the stability coefficient becomes 1.679.

Stress concentration factor according to the simulation model is $n = 5.2$.

With finite element method, it is possible to simulate the problem of consolidating soft ground with DCM columns.

The calculation method is suitable for estimating the load concentrated on the column tip and the load distributed on the soft ground between the DCM columns with geotextiles in soft soil of Mekong Delta. The addition of the reinforcement layer on the tip of the column has a significant effect to reduce the stress to soft soil. According to the results obtained from the above analysis, the SRR is reduced where the reinforcement layer is added on the tip of the column. The survey can evaluate the reduction rate of settlement of the ground surface before and after consolidation in respect to elastic parameters of soils, columns and the sizes of columns.

3. Conclusions

The finite element method can simulate the problem of the soft ground consolidated with DCM columns. This

method can allow researchers to calculate the residual stress and pore pressure at any point on the ground.

The DCM column technology is effectively applied for the treatment of the embankments on soft ground and the works with short-time construction, remaining small settlement and rapid soil consolidation. Calculation results help prepare the suitable design for soft soil reinforced with DCM columns combined with geotextiles in Tien Giang.

After the soft ground is reinforced with DCM columns, the settlement of the ground surface is reduced by 4.2 times (76%).

Simulation results show that there is stress concentration phenomenon at the tips of columns in the geological conditions of the Mekong Delta.

There are many technical solutions for treatment of soft ground under road embankment and each solution has its own advantages and disadvantages. Applying which solution should depend on the conditions such as geological structure of the ground and the acting loads. The solution in this study is only given from the technical aspect not from the economical one. The solution of soft ground consolidation with DCM columns combined with geotextiles is found to be effective for the geological conditions of the Mekong Delta and the regions with similar properties.

Recommendations

It is recommended to apply problem model to study the

consolidation of soft ground by DCM columns, determine the stress state, limit stress and calculate the transient settlement of the consolidated surface.

Consolidating soft ground with DCM columns is a technical solution, which depends on many factors, so its approaches are very various such as research on reinforcing materials, technological equipment, etc. Simulation results of the study show that the improvement of the practicality of the study may be obtained by additional studies on the effects of the buffer layer, the on-column embankments and the stiffness of the column on the stress variation in the ground-column system.

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