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CEMENT DEEP MIXING FOR SOFT SOIL IMPROVEMENT IN VIETNAM

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Аннотация. Cement Deep Mixing (CDM) method is a technique to chemically solidify and strengthen soft soils by in-situ mixing of the soil with cement slurry. For many years, this high quality, environment friendly, low cost ground improvement technique has become the most popular ground improvement method in Vietnam. The CDM method is often superior to other methods in a wide range of ground improvement applications such as prevention of embankment in stability and settlement, improving ground stability for construction projects, countermeasures against liquefaction, and reinforcement of ground to improve earthquake-response of superstructures. In this paper, the CDM is analyzed by FEM model with support of Plaxis software to estimate the effective mean stress, horizontal and vertical displacement when diameter of column is 0.8 m; length of column changed from 9m to 11m and column spacing changed from 1.8m to 3.0 m when improve soft soil for a road in Quang Ninh province of Vietnam. The research results show that with diameter of CDM column is 0.8m, column length of 11m, column spacing of 2.2m, and cement content of 300kg/m3 are suitable CDM parameters in soft soil improvement for this road.

Ключевые слова: Cement Deep Mixing (CDM), Stability, Displacement, Plaxis, FEM model.

Annotation. Cement Deep Mixing (CDM) method is a technique to chemically solidify and strengthen soft soils by in-situ mixing of the soil with cement slurry. For many years, this high quality, environment friendly, low cost ground improvement technique has become the most popular ground improvement method in Vietnam. The CDM method is often superior to other methods in a wide range of ground improvement applications such as prevention of embankment in stability and settlement, improving ground stability for construction projects, countermeasures against liquefaction, and reinforcement of ground to improve earthquake-response of superstructures. In this paper, the CDM is analyzed by FEM model with support of Plaxis software to estimate the effective mean stress, horizontal and vertical displacement when diameter of column is 0.8 m; length of column changed from 9m to 11m and column spacing changed from 1.8m to 3.0 m when improve soft soil for a road in Quang Ninh province of Vietnam. The research results show that with diameter of CDM column is 0.8m, column length of 11m, column spacing of 2.2m, and cement content of 300kg/m3 are suitable CDM parameters in soft soil improvement for this road.

Keywords: Cement Deep Mixing (CDM), Stability, Displacement, Plaxis, FEM model.

NTRODUCTION

Cement Deep Mixing Method (CDM) was derived from Sweden and Japan in 1960s. Dry mixing method application using lime powder and wet mixing cement has been used in Japan since the 1970s, during the same time as lime column was also introduced in Sweden [5]. This method is popular all around the world. Recently there are some more kinds of new material, such as cement-mixing, lime with gypsum, flyash or slag, introduced with advanced mixing equipment. The method is also applied in many countries to solve environmental problems such as preventing and treating pollution areas. Compared with a number of previous improvement methods, CDM technology can be processed at a depth of 50m under tight conditions, reduced of construction time for other items. Especially, with Japanese technology, it can be processed proximately 70m depth in offshore soil conditions.

In Viet Nam, CDM method was first introduced the 1980s under support constructed equipment by Swedish Geotechnical Institute (SGI). Up to now, this method has been applied in some constructions, and there are many limitations in the design, calculation and construction. In the design, CDM is calculated in terms of equivalent ground under the TCXDVN 385: 2006 standard developed by Vietnam Institute for Building Science and Technology in 2016. From 2013 to 2016, the quality of CDM was constructed in Viet Nam about 10.4 million meter with different items such as Road foundation of 59 %. According to the prediction of BOT data project, there will be increase in the number of CDM by 7.2 million meter between 2016 and 2018.

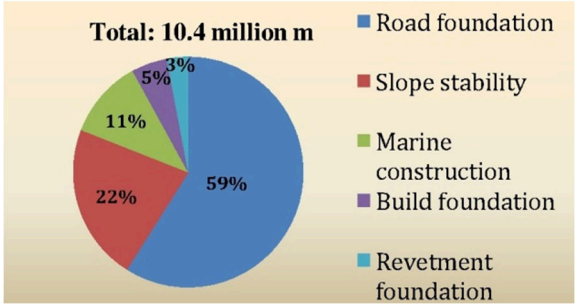


Figure 1 – The number of CDM used in Vietnam from 2013 to 2016 [10]

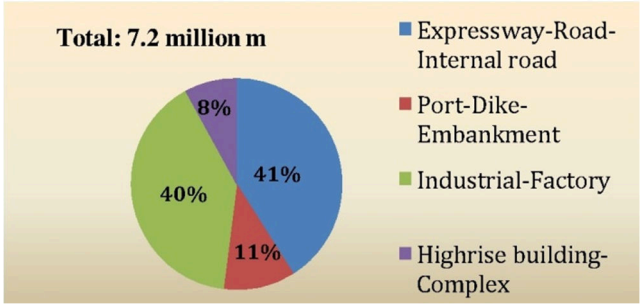


Figure 2 – Prediction of CDM quantity in Vietnam from 2016 to 2018 [10]

METHODOLOGY

Cement Deep Mixing (CDM) is a method for improving the ground to a prescribed strength by mixing cement slurry with the soft soil in situ. Generally, the cement used is either ordinary portland cement or a mixture of portland cement and blast-furnace slag. The cement alone creates cementitious materials through hydration, although the reaction differs with the soil type, the calcium hydroxide liberated from the cement also undergoes a pozzolanic reaction with the soil to create cementitious materials. As the mixture ages, these cementitious materials gradually fill the void space between the soil particles, which results in higher strength and lower volume compressibility of soil.

There are number of theory analysis to estimate settlement of cement deep mixing. According to TCXDVN 385: 2006 “Stabilization of Soft Soil by the Soil Cement Column Method” of Vietnam [1], the settlement of CDM column is calculate pursuant to ground equivalent method which is taken the average of modulus, shear strength value between ground and column. On the other hand, according to Asian Institute of Technology (AIT), the bearing capacity of single cement pile in weak clay is determined by surrounding the weak clay resistance (failure earth) or the shear strength resistance of the cement column (failure column), as documented by D.T. Bergado [5].

$$S_1 = \frac{q.H}{E_{tb}} = \frac{q.H}{a.E_c + (1-a)E_s}$$

q: Loading of construction tranfer to improvement stratum;
H: Layer thickness;
Ec: Modulus of column material,
Ec = (50÷100).Cc;
Es: Elastic Modulus of soil between each column,
Es = 250.Cu.

According to TCVN 9403-2012, ground equivalent method

$$Q_{ult.soil} = (\pi.d.L + \frac{9\pi.d^2}{4}).C_{u.soil}$$

d: Cement column diameter;
L: Length of cement colum;
Cu.soil: average undraige shear strength of surrounding soft soil (Determined by in-situ test, such as vane shear test (VST), cone penetration test (CPT));

$$Q_{ult.col} = (3.5C_{col} + K_{boh}).A_{col}$$

Kboth : Passive pressure.

According to Asian Institute of Technology (AIT)

In this paper, Finite element method (FEM) is applied to compute the settlement of the ground at several selected positions with the support of PLAXIS sofware. Both Plane Strain and Axisymmetric Models were used for CDM structures. A plane strain model is used for geometries with a (more or less) uniform cross-section and corresponding stress state and loading cheme over a certain length perpendicular to the cross section (Z-direction). Displacements and strains in Z-direction are assumed to be zero. However, normal stress in Z-direction are fully taken into account. An Axisymmetric model is used for circular structures with a (more or less) uniform radial cross section and loading scheme around the central axis, where the deformation and stress state are assumed to be identical in any radial direction [11].

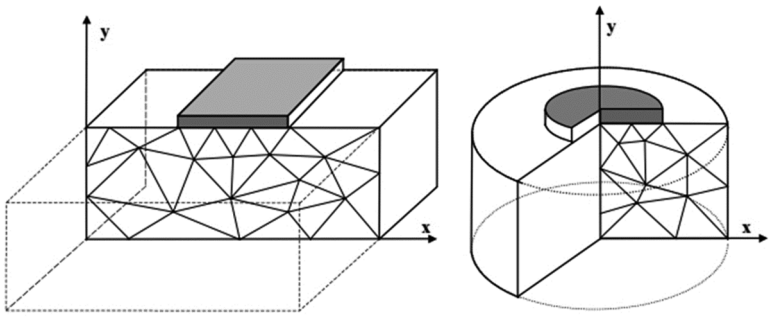
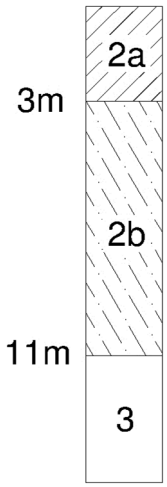


Figure 3 – Plane strain and Axisymmetric model [11]

DESIGN AND ANALYSIS

Geotechnical Condition

Ha Long Cement Plant is one of the three large-scale cement projects of Quang Ninh Province, it was designed and provided equipment by F.L.Smindth of Denmark and was invested by Ha Long Cement Joint Stock Company. The factory is built on an area of 60.5ha, with a total investment of more than 3.984 billion VND. The access road from berth to the factory is more than 3km long, 26m wide, and 4m high designed over soft soils with the average thickness of 11m.



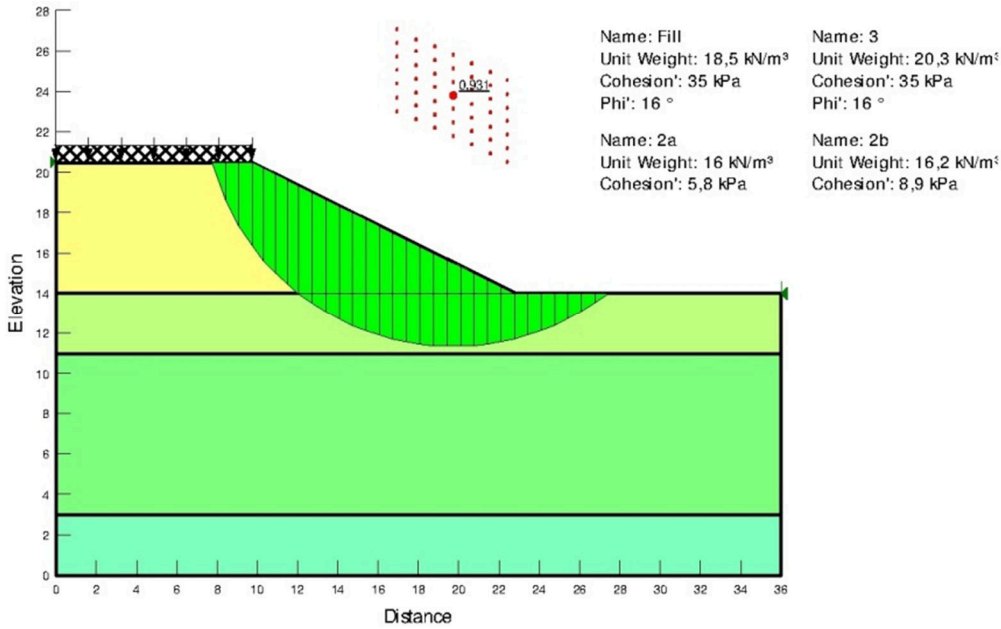


Figure 4 – Geological strata

Figure 5 – Overall stability of embankment calculated by Geoslope software

The geotechnical condition beneath of access road to Ha Long Cement Plant is rather complicated with the presence of soft soil layers of 2a, 2b. According to estimate preadsheet and Geo-slope sofware, the settlement is about 1.6m and overall stability coefficient (K_{min}) = 0.93.

Tab. 1 – Geotechnical data

Name	Symbol	Fill Soil	Silt Clay (layer 2a)	Clay (layer 2b)	Sandy Clay (layer 3)	Unit
Unit Weight Natural	γ	18.5	15.8	16	19.5	kN/m^3
Plastic Limit	PL	-	54.94	54.41	29.15	%
Liquid Limit	LL	-	26.36	25.22	15.32	%
Plastic index	PI	-	28.58	29.18	13.84	%
Water content	W	-	64.46	61.89	22.2	%
Permeability Vertical	K_y	1 (m)	0.25	0.30	0.41	10^{-4}m/day
Permeability Horizontal	K_x	1(m)	0.75	0.91	1.24	10^{-4}m/day
Void Ratio	e_0	-	1.766	1.687	0.614	-
Compression index	C_c	-	0.55	0.44	0.10	-
Cohesion	c	35	5.8	8.9	35.0	kN/m^2
Internal friction angle	φ	16	2	2	16	Degree
Young's Modulus	E_{ref}	10000	1450	2200	8750	kN/m^2
Poison's ratio	ν	0.2	0.35	0.35	0.3	-

Tab. 2 – Estimate settlement pursuant to the nondimensional time factor

Time	Nondimensional time factor	Consolidation	Total Settlment	Estimate Settlement
Year	Tv	U	S (cm)	S(t) (cm)
0.5	0.0017	3.3%	160	5.31
1	0.0033	6.7%	160	**10.63**
5	0.0166	14.5%	160	23.20
10	0.0333	20.5%	160	32.81
15	0.0499	25.2%	160	**40.17**
25	0.0832	32.5%	160	51.82
50	0.1664	46.0%	160	73.45

Cement Deep Mixing Dimensions and Properties

Based on calculation, the settlement will be about 1.6m and K_{min} is 0.93, so that ground improvement is necessary to ensure safety and smoothly during operation time. The soft soil improvement method chosen is CDM.

With live load (LL) = 15.15 kN/m^2, the length of column (L) of 9 to 11m and spacing between columns (S) of 1.8m to 3.0m will be researched for selection.

Tab. 3 – CDM dimensions and Properties

Name	Model	Length (m)	Diameter (m)	Spacing (m)	Unconifined compressive strength (kN/m^2)	Undrained Shear Strength (kN/m^2)	Young's Modulus (kN/m^2)	Poison's ratio
CDM	Axisymmetric	9	0.8	1.8÷3.0	600	300	150000	0.2
		10		1.8÷3.0				
		11		1.8÷3.0				
	Plane Strain	11		2.2				

Designed Result Analysis

According to Axisymmetric model, there are simulations of cement deep mixing from 9m to 11m in length with a variety of spacing between 1.8m to 3.0m. The figures from 6 to 10 show vertical displacement distribution increased slightly in the number of column for spacing go up and reach a peak at 29.8cm for L = 9m, S = 3m. It is sharp fall by over 10cm for rise of CDM's length from 9m to 11m. For effective mean stresses, the stresses are distributed to both of column's tip and soil surrounding for kind of CDM friction. However, the major of stress tranfers from embankment to layer 3 throught column so there are hugh of stress at the tip of CDM, it is about 479.5 kN/m^2 for 11m of length and spacing 3m.

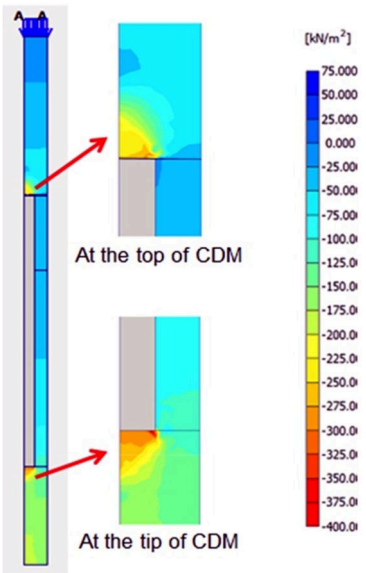


Figure 6 – Effective mean stresses

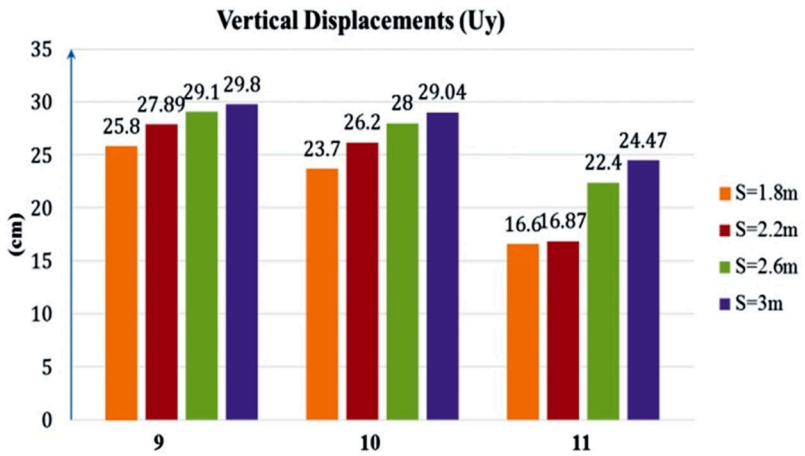


Figure 7 – Comparison of vertical displacements

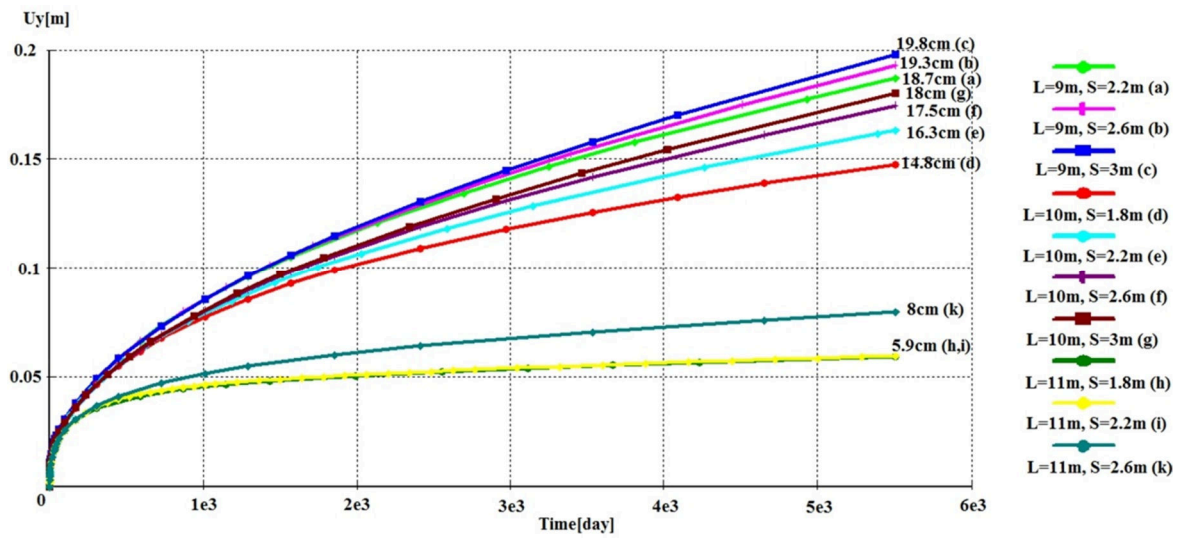


Figure 8 – Vertical displacements at the tip of each column

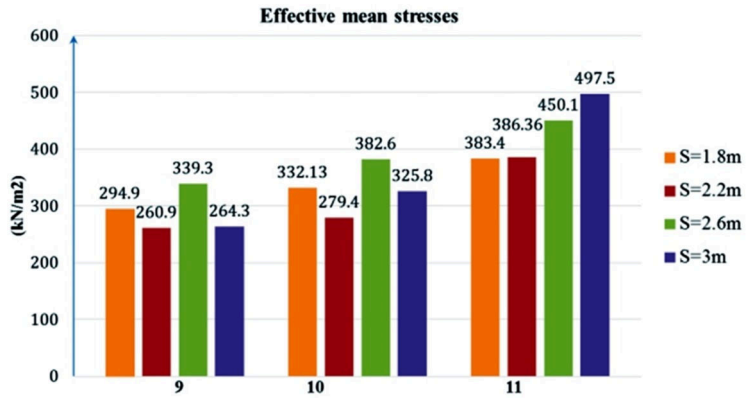


Figure 9 – Effective mean stresses comparison

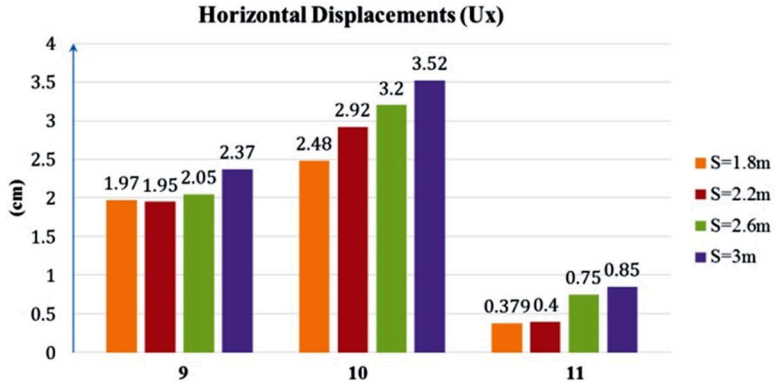


Figure 10 – Horizontal displacements comparison

According to Plane strain model, the CDM is designed with 19 columns with 11m in length and spacing of 2.2m. With the support of Plaxis software, the results show that vertical displacement and effective mean stress has a different in the number of each column. For example, column in the center of embankment, the settlement at the tip of column is proximately 5.5cm but it is 2cm for column near the toe of the embankment. Specially, this model can check the stability of embankment thought each stage of construction. It is peak at 2.1 for the last of the construction time and sastisfy requirement on safety (overall stability coefficient should be greater than 1.4).

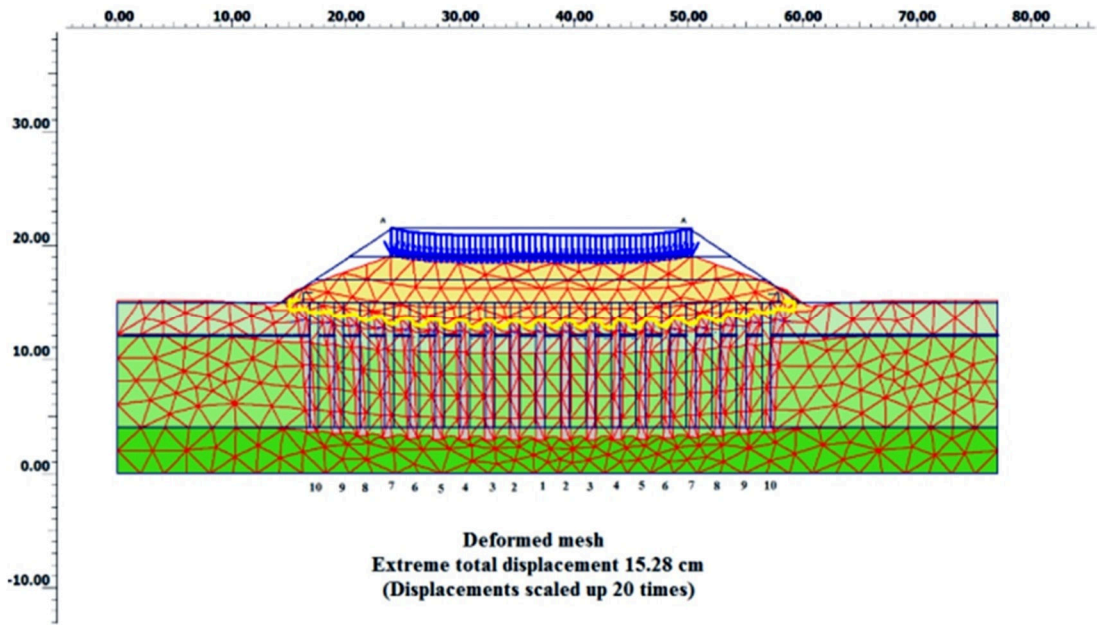


Figure 11 – Deformed mesh with scaled up 20 times

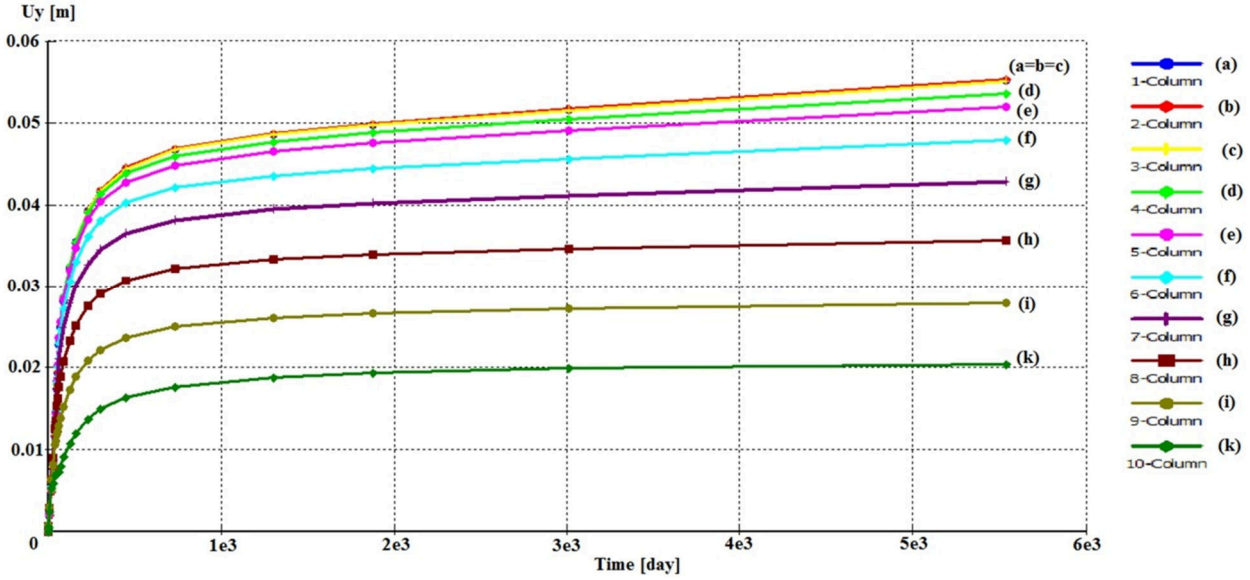


Figure 12 – Settlement of CDM for each column location

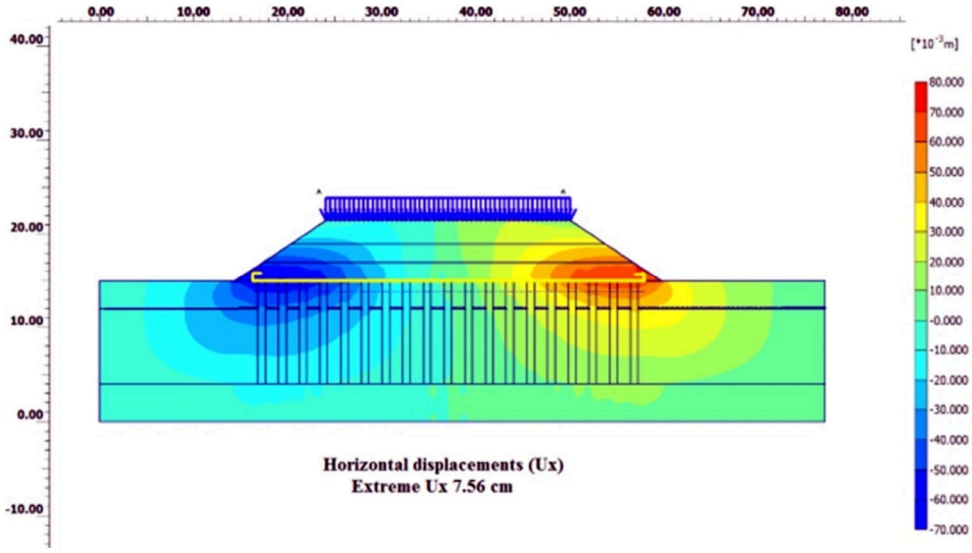


Figure 13 – Horizontal displacement (Ux) of CDM

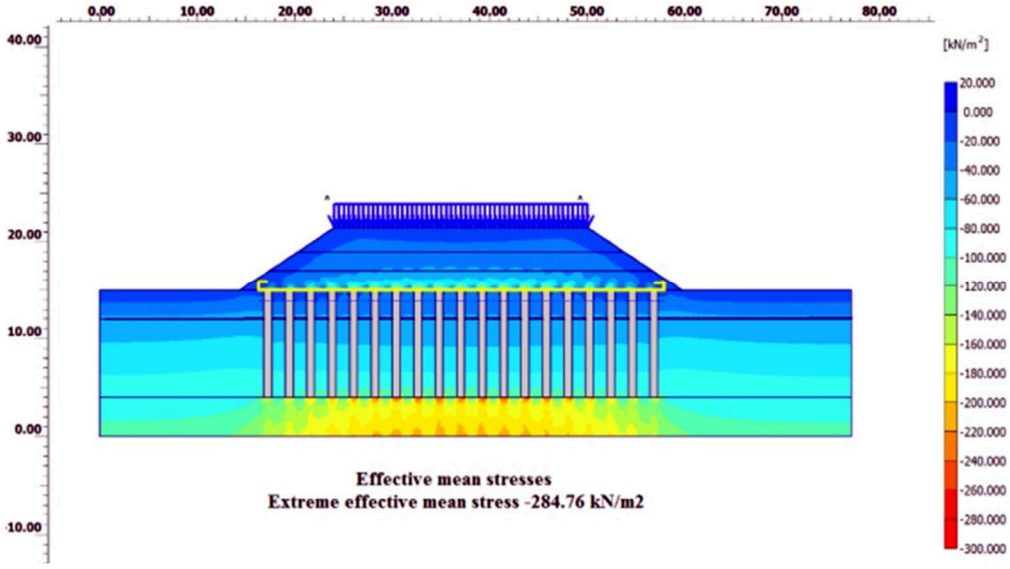


Figure 14 – Effective mean stresses of CDM

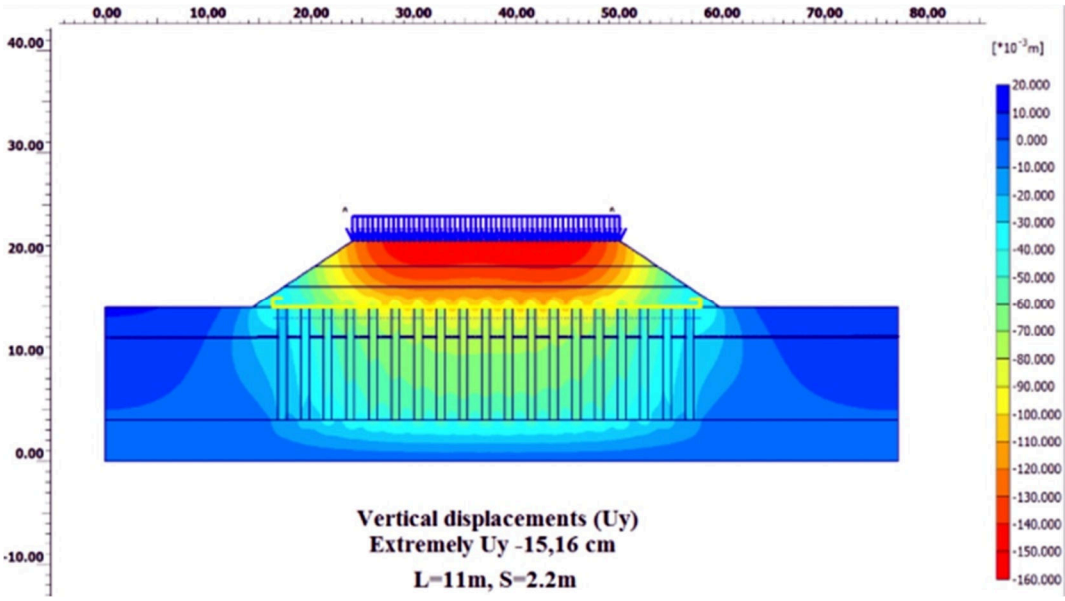


Figure 15 – Vertical displacements (Uy) of CDM

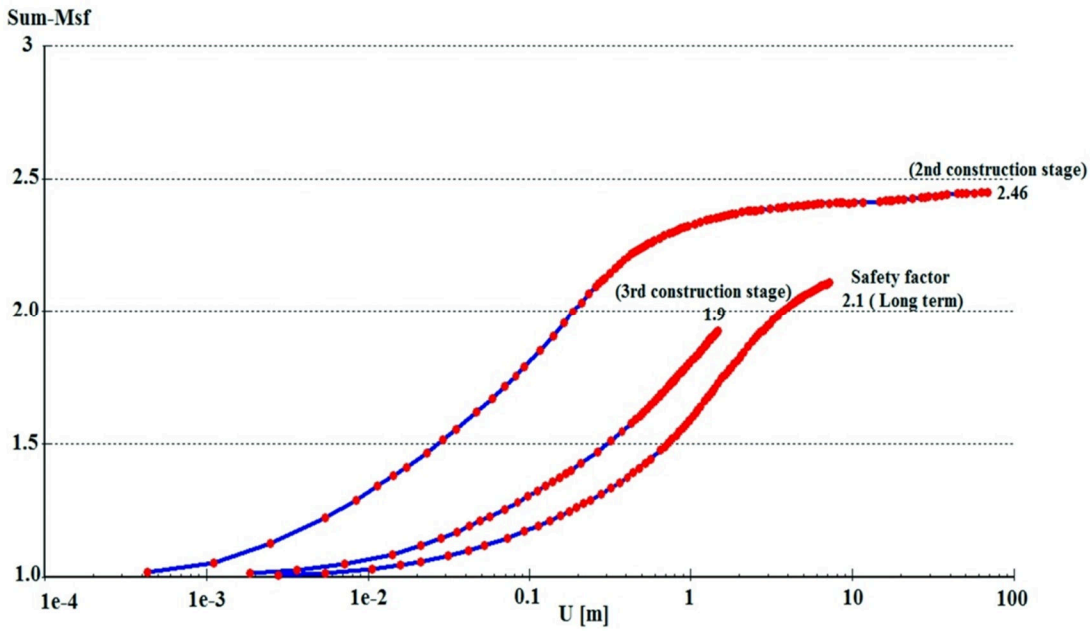


Figure 16 – Overall stability factor for construction stages

CONCLUSION

Application of CDM in soft soil improvement is aim to reduce the time of construction, reduce settlement and increase the stability of road embankment. This method is suitable for clay and high embankment.

CDM with diameter of 0.8m, length of 11m, spacing of 2.2m is proposed for soft soil improvement for the access road of Ha Long Cement Plant.

Special reinforcement for CDMs at the center of the embankment should be applied because positions at center line of embankment have the largest settlement.

The length of CDM column should be smaller than 20m and spacing between columns should not greater than 2.2m.

Load and stress are considered all directions around column in the axis symmetry model. Howerver, the only one side was analyzed in the plane strain model.

The plane strain mode shows the work of all the piles as group column while the axissymmetry model only considers one column for all of them.

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