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SLOPE STABILITY ANALYSIS AND SETTLEMENT OF EMBANKMENT REINGORCED BY DEEP MIXING COLUMN

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Abstract - Deep mixing columns are being used to improve the stability and settlement of embankments constructed over soft soils. The column into the soft soils acts as reinforcing element that increases the bearing capacity reduces the settlement of the soil and also increases the stability of the embankments. The purpose of this study is to analyze the slope stability of embankment, determine the factor safety of embankment, and compute the settlement of embankment using numerical methods. There factors that influence both the slope stability and settlement of embankment like the strength deep mixing column, space of the column and replacement ratio in settlement analysis. In slope stability analysis, Limit equilibrium method was used in Geo-slope software program and finite element method was used in PLAXIS software and also the settlement analysis numerical solution was modeled getting horizontal deformation and vertical deformation of embankment within 160 days of stage construction settlement.

Keywords: **Deep mixing columns, Embankment, Stability, settlement, PLAXIS, Geo-slope**

I. INTRODUCTION

When embankments are constructed over thick soft soils, the soft soils often do not have sufficient bearing capacities to support embankment. Under such a condition, columns can be used to increase the bearing capacity and reduce the settlement of the soft foundation. One of the most common methods used for soil improvement is the dry/wet deep mixing (DM) method. Deep mixing is a general name of different methods used for soil improvement, which is a mechanical mixing process, that mixes a binding agent mostly lime or cement with soil. In the Scandinavian countries, this method has different names such as "lime-cement column", "deep improvement", "dry jet mixing method" or "column improvement" Larsson (2003)Improvement of soil using the lime/cement column (LCC) is a widely applicable in Sweden and Finland to improve the stability of a road and railway embankments constructed on soft soil Kivelö et al (1999). This method is often more economical compared with other conventional methods such as excavation and replacement and embankment piles. Han et al (2005) Studied Factors of Safety against Deep-Seated Failure of Embankments over, mentioning that the calculated factors of safety using Bishop's simplified method are higher than those calculated using the numerical method.

Deep Mixed Columns When assessing the slope stability of DM column-supported embankment over soft soils, the reliability of calculation for factor of safety needs to be verified. Navin et al (2006), Indicated that the factor of safety by plane strain analysis was conservative as compared with that by three-dimensional (3-D) analyses. Limit equilibrium methods can be used to analyze slope stability embankment improve by deep mixing columns Bishop, (1955), with shear failure Bishop's simplified method only accounts for the shear strengths of the soil and the DM columns along the slip surface. Liu et al (2012) used the field performance of T- Shaped Deep mixing soil cement column- supported by embankment over soft ground, three test sites (A–C) were contiguously planned in the middle of Husuzhe Highway. Each site was 50 m wide and 100m long. The height of the embankment was approximately 4 m. Both in situ and laboratory tests were conducted for site characterization studies before installation of the TDM/DM columns. Abusharar et al (2009) investigated Finite element modeling of the consolidation behavior of multi-column supported road embankment. Yao et al (2016) , studied Settlement evaluation of soft ground reinforced by deep mixed columns, conducting the effect of column length, area replacement ratio and surcharge load on foundation settlement was investigated. The column length was varied from 40 cm to 100 cm while the area replacement ratio was changed from 0.023 to 0.093. Test results show that the foundation settlement will decrease with the increase of column length when area replacement ratio and surcharge load are certain. Jiang et al (2013), investigated on numerical analysis for consolidation of soft soil, which is improved by a fully penetrated deep mixed column, the study mainly focused on the analysis of the effect of different parameters on the consolidation process of soft soils results in a settlement.

However, the deep mixing process is not simply concerning the chemical reactions between the binder and the soil. It is very complex and will contain different phases that influence the results and the properties of the improved soil Larsson (2003). The uncertainties in settlements calculation and how the settlements develop with time have been rather significant. Using a simplified method of analysis for the calculation may result in a moderately conservative Baker (2000.).

The objective of this paper is to assess the slope stability and settlement of DM column-supported embankment over soft soil based on the limit equilibrium method and numerical method.

II. METHODS, MATERIAL AND PARAMETERS

2.1 Limit equilibrium Method.

Two reports were published and encapsulate the current topic knows as the embankment of soft soils improve by DMM columns, and how these reports were used In the practical field, CDIT) (2002), EuroSoilStab (2002), these two reports Illustrates slope stability methods that are based on limit equilibrium. The stability of ground improved with deep mixing-methods columns is often analyzed by using a short term, UN-drained analysis because the shear strength of the column and the soil between columns generally increase with time. Embankment stability is typically analyzed assuming a circular shear surface as shown in figure 1.

Slope stability analysis should be study to determine the critical failure surface and corresponding factor of safety. It is suggest that Spencer's and bishop's methods are used to compute FS values because they satisfies all conditions of equilibrium and results in more realistic factor of safety values than some of the more simplified methods of slope stability analysis.

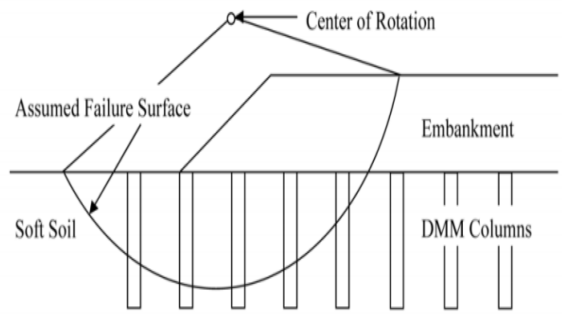

Figure 1 Circular sliding surface (after Broms and Boman 1979)

2.2 Numerical method:

Geo-technical engineers use finite element methods to analyze the stability of slopes and embankment and calculate the factor of safety, in the same way as that used in limit equilibrium analysis Griffiths at aL (1999) . Commercial programs that perform this type of analysis include PLAXIS and SIGMA/W (Geo-Slope. PLAXIS provides six different soil models to simulate soil behavior. The Mohr Coulomb model was adopted as recommended for situations where soil parameters are estimated. This model requires; Young's Modulus (E) and Poisson's Ratio (v) for elasticity, Dilatancy Angle (ψ), Permeability (k), Dry Unit Weight (γd) and Saturated Unit Weight (γs).

Stability Failure Modes for Embankments Supported on Deep Mixed Columns, the four failures below are the failures of stability of the embankment as shown in Figure 2. In this study we try to get the shear failure of embankment under deep mixing columns.

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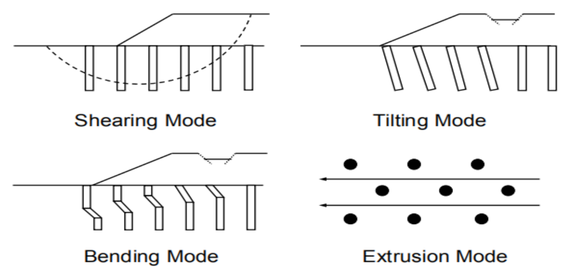

Figure 2 Stability Failure Modes for Embankments Supported on Deep Mixed Columns.

2.3 LEM and NUMERICAL Modeling
The geometry model shown in figure 3 is an embankment model reinforced by DM columns, the PLAXIS and GEOSTUDIO software's was used to establish the numerical and limit equilibrium model. In this study the embankment has a height of 3m, unit weight of 18kn/m^3 below the embankment fill layer there soft clay and sand soils, With a unit weight of 14kn/m^3 and 18 KN/m^3, the deep mixing column installed in study has 500 mm in diameter and 10 m length with a space of 1.5 and 2 m. In which the area of replacement was calculated in table 3. The embankment has traffic surcharge of 12kpa.The bottom boundary was fixed in both horizontal and vertical directions; the two side boundaries were fixed in the horizontal direction but allowed to move freely in the vertical direction
Zhang et al (2018). Water is at the ground surface. Materials properties are summarized in Table 1 and 2 below

Table1. Material properties subgrade soil layers

Parameters	**Soft cay**	**Sand**
Unit weight γ(kN/m3)	14	18
Young's modulus, E (MPa)	2.4	5
Poisson's ratio, υ	0.3	0.3
Effective cohesion, c' (kPa)	1	0
Effective friction angle, φ' (°)	23	30
Permeability coefficient, k (m/day)	5*10^{-5}	1

Table2. Input Soil Parameters (Embankment and Columns)

parameters	**Embankment Fill**	**DMC**
Unit weight γ(kN/m3)	18	16
Young's modulus (MPa)	3	30
Poisson's ratio, υ	0.3	0.2
Effective cohesion ,c' (kPa)	0	100
Effective friction angle ,φ' (°)	32	0
Permeability coefficient ,k (m/day)	1	3.88 x 10-5

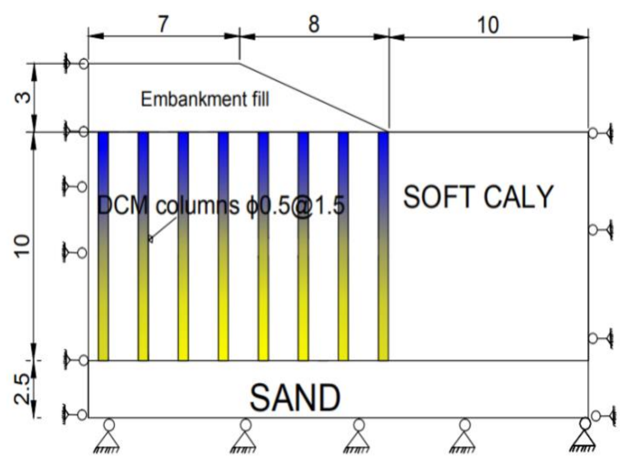

Figure3. Geometry model of embankment improve by DCM columns

2.4 Settlement
In deep mixing improved soil, the settlement and its change in time mainly depend on the modulus of compressibility and the permeability of both the improved and unimproved soil (Baker, 2000.) There are factors that influence the settlement foundations improve by deep mixing columns, it includes, area of replacement, length and diameter of the column and space between the DM columns. In this study the settlement of embankment is model within 160 days stage consolidation settlement, the effect of short and long columns might increase or decrease the settlement of soft soils, the column length of this study is 10m, also the effect of area of replacement on soft soil will influence the settlement of embankment improve with columns.

The area of replacement ratio can be calculated in accordance with Bergado et al, (1996).

$$a_s = \frac{\pi}{4}\left(\frac{D}{S}\right)^2 \qquad [1]$$

D= Diameter of DMC

S= the center to center column spacing.

Table 3: Area Replacement Ratios for varied Centre to Centre Spacing's

	Area of replacement	
Diameter	**Spacing=1.5**	**Spacing=2**
0.5	0.087	0.049

III. RESULTS AND DISCUSSION

3.1 Stability analysis of slope embankment

There are factor that affect the slope stability of embankment reinforced by deep mixing column, in shear failure of the embankment. The factors investigated in this study include the strength, spacing and size of DM columns, cohesion soft soil and height of embankment fill. The effect of each factor on the FS is presented below.

3.1.1 Critical slip surface

The slip surface can be evaluated based on the contours of shear strain rate from the PLAXIS and SLOPE/W analysis. The high shear strain rate contours imply the potential failure zone. Figure 4 a and b presents the contours of shear strain rate for the embankment over soft soil without Deep Mixing columns, which clearly show a circular slip surface as assumed by numerical and Bishop's method. The numerical method has a factor of safety 1.442 and bishop's limit equilibrium method has FS of 1.412.

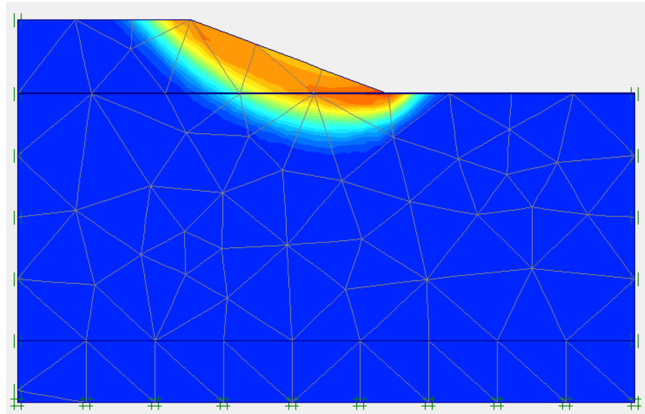

Figure.4 a PLAXIS Contours slip surface of Shear Strain Rate for the Embankment over Soft Soil without DM columns.

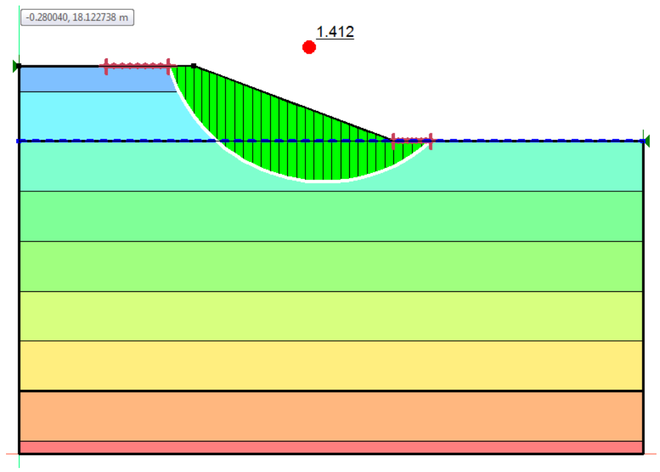

Figure 4, b. Slope/w Contours slip surface of Shear Strain Rate for the Embankment over Soft Soil without DM columns.

The slip shear surface of the embankment over soft soil with DM columns is shown in Figure5.a, b and bending failure of the columns in figure 5 c. The contours of slip surface are small in this case with the existence of DM columns, when the cohesion strength of DM column is high obviously there is bending failure developed in the treated area with columns. The factor of safety of bishops method FS= 1.676 and numerical method FS= 1.594, in this case bishop's method have higher factor of safety than the numerical method Han et al (2005).

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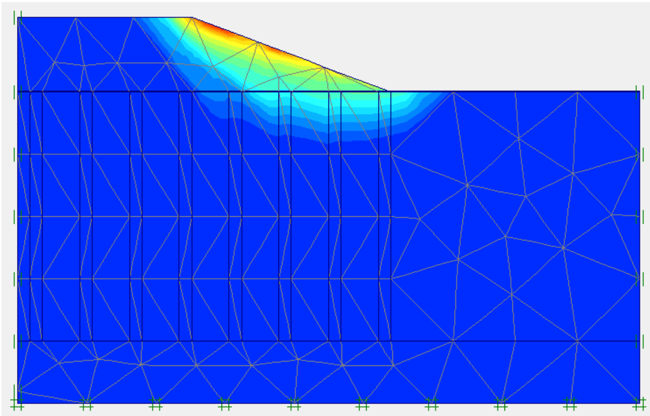

Figure 5.a slip shear surface of embankment over soft soil with DM columns having Cohesion of 100kPa.

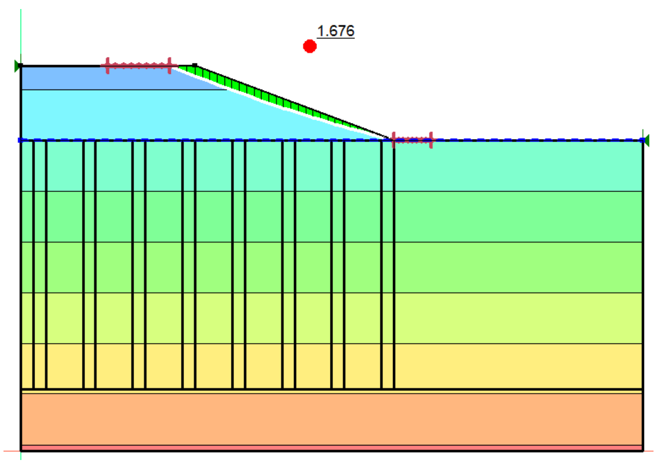

Figure 5.b Slope/w Contours slip surface of Shear Strain Rate for the Embankment over Soft Soil with DM columns.

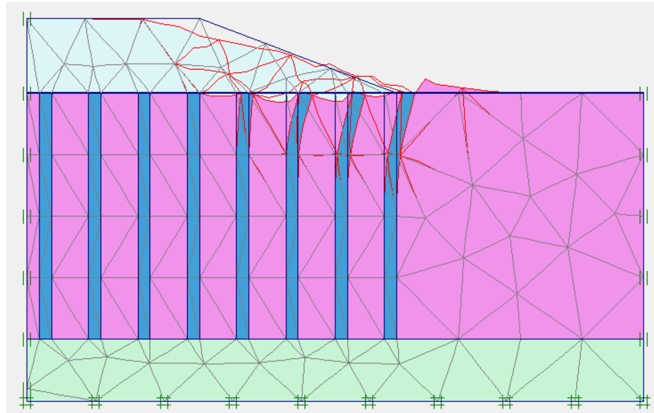

Figure 5.c Bending failure of DM column c=100kpa

3.1.2. Strength of DM Columns c=100

The influence of shear strength of embankment over soft soil reinforced by deep mixing columns is shown in figure 6. When the cohesion of the columns is less 10 kPa, the same as that of the soft soil, it represents an untreated layer. The results from the numerical method and Bishop's simplified method both show that the factors of safety increase with an increase of the cohesion of the DM columns. When the cohesion of the DM columns is less than 100kPa, the two methods have almost similar FS results. When the cohesion of the DM columns is greater than 100kPa, when the cohesion of the DM columns is greater than 100kPa, however, the FS values computed by the numerical method are lower than those by the Bishop's method Han et al (2005).

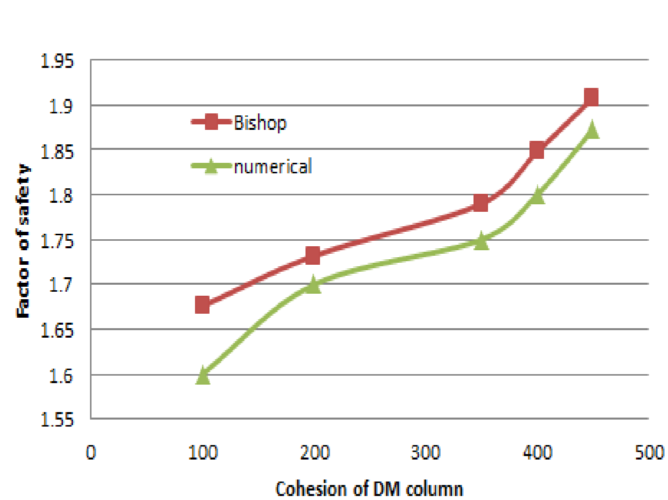

Figure 6.Influence of undrained shear strength of DM Column

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3.1.3 Space of DM column
The effect of the spacing of DM columns on FS values is shown in Fig. 7. It is shown that as the space of DM column increase the FS decreases.

3.1.4. Size of DM column
The influence of the size of DM columns on the factor of safety is shown in Figure 8. It is shown that an increase of the thickness of the DM columns increases the FS value of the embankment system. The thickness range of DM column from 0.5m to 1.5m corresponds to the improvement ratio of 20% to 60%.

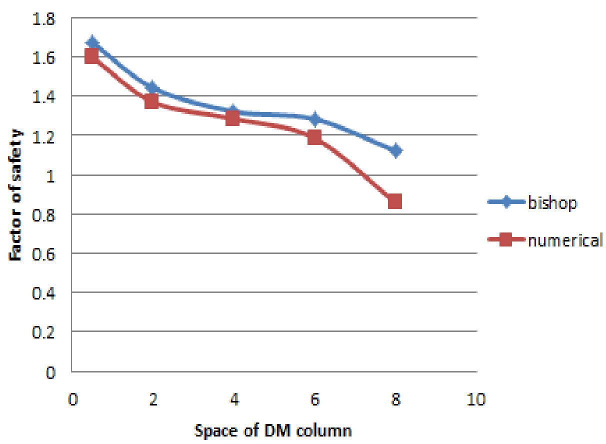

Figure.7 Influence of spacing of stone column.

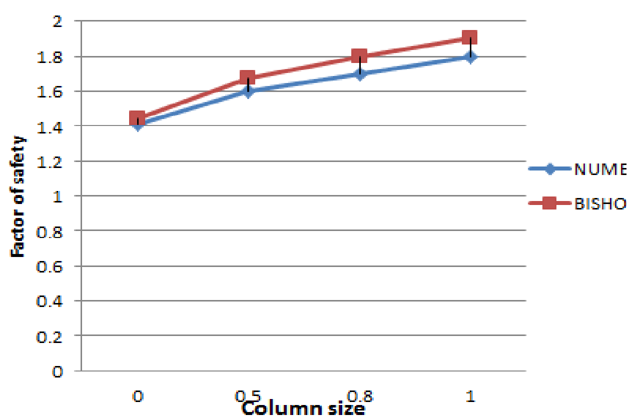

Figure 8.The influence of the size of DM columns

3.1.5. Cohesion of soft soil
The influence of the cohesion of the soft soil on the factors of safety is shown in Figure 9. An increase of the undrained cohesion of the soft soil increases the FS value of the embankment over DM columns based on both the numerical and Bishop's methods. The numerical analysis yields lower FS values than Bishop's method (Han, 2005).

3.1.6. Influence height of embankment fill
Figure 10 shows the influence of the embankment height on the safety factor of the embankment supported by DM columns. Factor of safety reduces as the height increases. The increase of the embankment height increases the loading to the foundation of soft soils and thus, which leads unstable slope.

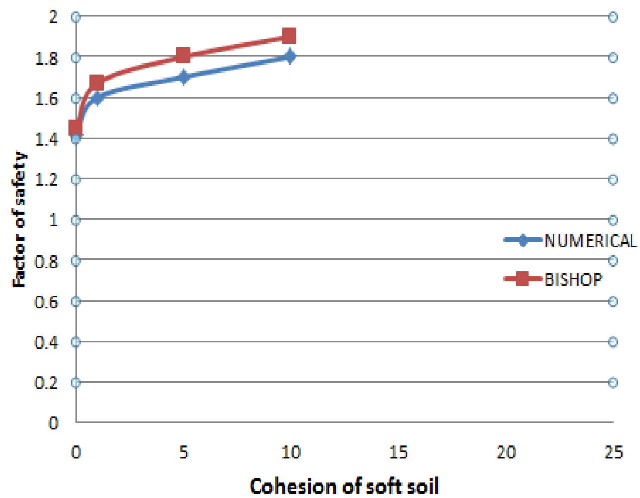

Figure 10 Influence of cohesion of soft soil

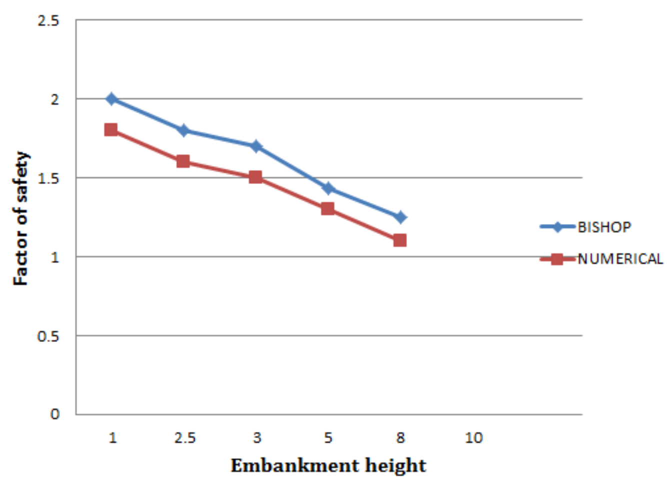

Figure11. Influence of Height of Embankment

3.2 Settlement analysis
Figure 11 shows the result numerical modeling of settlement of embankment reinforced with Deep Mixing column with area of replacement of 0.087 the total

displacement is 44 mm and the vertical displacement is 24.73 mm

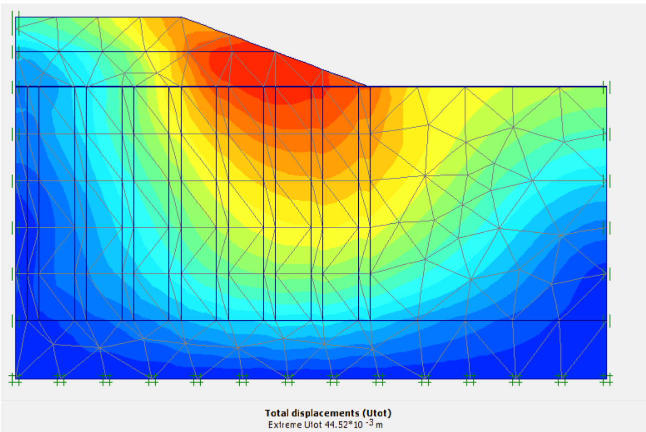

Figure.11 a. Total displacement with area of replacement of 0.087

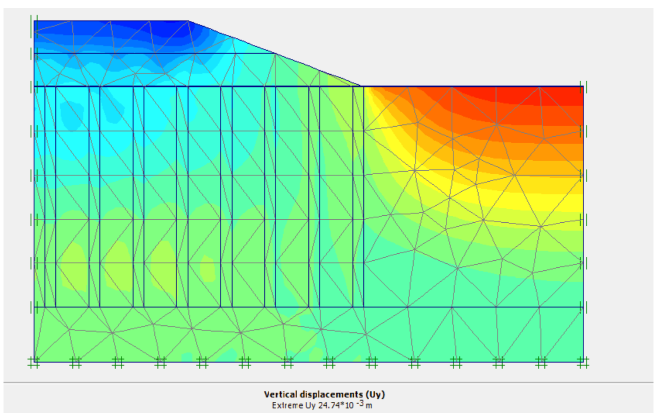

Figure 11.b. Vertical displacement of an embankment reinforced with Deep Mixing column (space 1.5 m)

Figure.12. a and b show result of when column spacing is 2 m center to center the settlement increase as the column space increases with area of replacement of 0.049. The total displacement is 46 mm and vertical displacement 34 mm. It could also be seen that the embankment settlement will increase with decrease of area replacement ratio from 0.087 to 0.049 with certain column length and time.

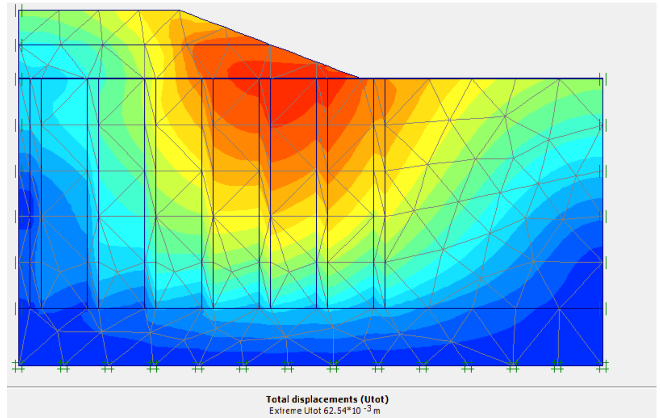

Figure.12 a. Total displacement with area of replacement of 0.049 (space= 2m)

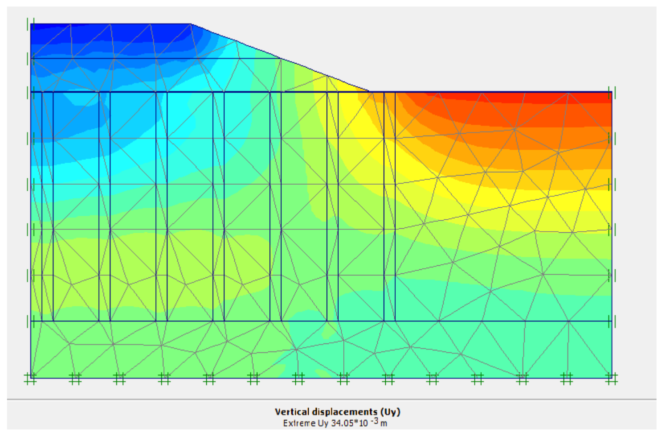

Figure 12.b. Vertical displacement of an embankment reinforced with Deep Mixing column (space 2 m).

Figure 13 shows the total consolidation settlement of embankment reinforcement with deep mixing column considering different area of replacement.

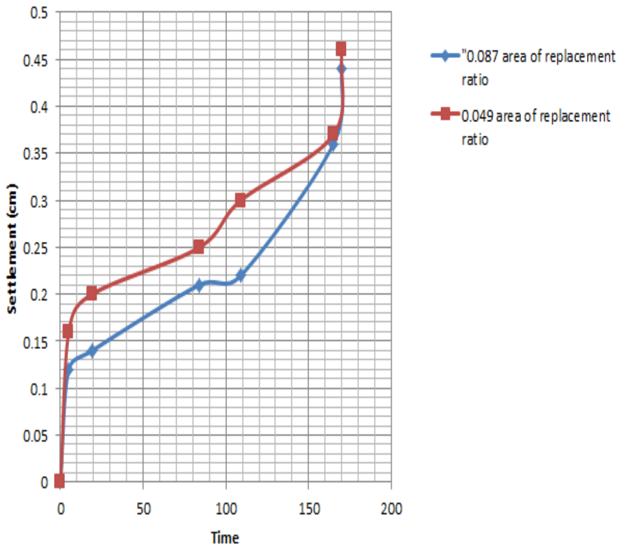

Figure.13.settlement of embankment reinforced with deep mixing column

IV. CONCLUSIONS

In paper the conclusions is as follow:

1. In slope stability analysis of embankment, Strength, column spacing, and size of deep mixed columns, the cohesion and thickness of soft soil, angle and height of embankment fill all influence the FS where limit equilibrium method has more FS than the numerical method. The modes of failure for deep mixed columns include shearing, bending, or rotation, tension failure, or a combination of these four modes depending on soil conditions, column strength.

2. The settlement of embankment reinforced by deep mixing columns, the area of replacement influence the total deformation as settlement increasing the area of replacement decreases.

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