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Analysing Foundation on Port Said Soft Clay Stabilized by Deep Mixed Columns

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Abstract

Port Said is characterized by the presence of thick layers of soft clay. Particularly inSouth of Port Said, soft clay strata extend from the ground surface to few tens of meters making it not possible to use conventional ground improvement methods, as soil replacement. Deep Mixing Method(DMM) is an alternativemethod with relative advantage as it does not require full soil replacement and can be used when soft soil layers extend deeply up to 40 m.

This paper aims to study the effectiveness of using deep mixed columns (DMC) to improve the bearing capacity and to reduce settlements below embankments and light structures in South of Port Said. Numerical analyses on hypothetic embankment and raft foundation models were performed using finite element packages PLAXIS. A parametric study was performed to assess the influences of different parameters on DMCeffectiveness.

The study showed that the installation of DMC is very effective in reducing settlement and lateral movement of South of Port Said deep soft clay strata particularly for low area ratios of DMC. On the other side, DMC installation generates zones of shear and effective stress concentration. From the studied parameters it was noticed that DMC effectiveness to reduce settlement increases linearly with DMC depth and with stiffness ratio between DMC and soil. 10% area ratio was found optimum for settlement reduction while16 meter DMC depth was optimum for lateral movement reduction.

Keywords: Plaxis 2D,FEM, Deep Mixing ColumnsDMC, Soft Soil, Port Said

1 INTRODUCTION

South of Port Said is characterized by soft soil layers extend tens of meters wheresoil improvement by conventional methods, such as soil replacement, is not feasible. Accordingly, alternativeground improvementmethodsare neededto enable construction over such strata. Deep mixing method (DMM) is a ground improvement technology where deep mixing columns (DMC) are installed below road embankments and foundations of structures to improve bearing capacity and reduce settlements and increase overall stability. According to Krenn &Karstunen [1], DMM is often more economical than traditional methods, as soil replacement and small diameter piles. According to Bruce [2], DMM has relative advantage as it doesn't require full soil replacement and can be used up to 40 m.

Conventionally the analysis and design of DMM presented by Broms [3] based on an assumption of equal strains in both columns and surrounding soil. Further empirical design guidelines were outlined in the other references as EuroSoilStab [4].Finite element method (FEM) is an alternative to conventional methods where true geometry, complex stress-strain behaviour and interaction between soil, columns and structure are considered. In the present study PLAXIS [5], FEM software packages, is used to analyse DMC.

FEM has been used in several studies to analyse the behaviour of soft soils stabilized by DMC. Han [6] studied the factors influence the deep-seated stability of column-supported embankments as columns strength, spacing, and size, soft soil cohesion and thickness, and friction angle and height of the embankment fill.

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DMC analysis was the subject of many previous researches. Jinchun [7] studied the methods for predicting consolidation settlements of floating deep mixed columns, DMC. He concluded that the behaviour of floating DMC behaviour differs from the end bearing DMC.

During the consolidation process with floating DCM, relative penetration of the columns into the underlying soft soil occurs. As a result, the stress concentration ratio (between stresses in DMC and surrounding soft soil) changes with time and depth.

Chai [8] reported thatthis relative penetration is influenced by area replacement ratio, DMC depth, loading intensity and soft soil strength and stiffness.

Krishna [9] provided numerical solution using PLAXIS to evaluate the behaviour of the embankment constructed on soft soil stabilized by lime column. The predicted excess pore pressure, settlements, and lateral displacement using PLAXIS has been compared with actual field results and found in good match.

Krenn and Karstunen [10]UtilizedPlaxis 3D to investigatecolumn spacing influence on surface settlements and columns and soil stresses. It has been shown that the assumption of equal strain, as adopted in the conventional design, is only appropriate for small column spacing. For the cases considered the increase in vertical stress in the column is on average 6 to 7 times the increase in vertical stress in the soil. The columns below the crest of the embankment bear,in average, the same load but the predicted load gradually decreases in the columns below the slope of the embankment.

Chai [11] proposed method to calculate consolidation settlement of soft subsoil improved by floating DMC–slab system subjected to embankment loading. This method is performed by treating improved layer as an equivalent an unimproved layer and calculating its compression. Theresults were compared with the used methods used by the Japanese Institute of Construction Engineering (JICE) for three case histories in Fukuoka, Japan. Comparing the calculated results with the field values shows that the proposed method yielded much better predictions than that of the JICE method.

Ali [12] utilizedPLAXIS 3D to evaluate settlement of soft peat stabilised by floating and end- bearing DMC. A mat foundation was considered as a three-dimensional problem. DMC was modelled as a pile while soft soil, peat, was modelled by soft soil creepmodel. In the case of floating columns settlement results from thesoftware were compared to Brom's analytical methods. The results indicated that the settlementspredicted by the software were close to those obtained analytically.

As a continuation to the efforts of Sharoubim et al [13] ,the present study aims to investigate the effectiveness of utilizing floating DMC to stabilize Port Said soft soil.In the present study, road embankment model and raft foundation model are analysed using PLAXIS 2D. A parametric study is performed where the influence of area replacement ratio, depth of DMC, column to soil stiffness ratio, column cohesion and friction angle are studied on DMC effectiveness is investigated. The criteria of the studied parameters include settlement, lateral displacement, shear and effective stress and consolidation time. The parametric study performed, results and discussions and conclusion are presented in next sections of this paper.

2 PARAMETRIC STUDY

The present study proposed two different hypothetic models both represent constructions on deep soft soil stabilized by DMC. The first model represents road embankment while the other one is raft foundation model. Both models have been analysed by PLAXIS where parametric study was performed for each model separately. The description of each model and the applied parameters are presented afterwards.

2.1 Embankment model

A hypothetic embankment is assumed asestablished on a soft clay stratastabilized byDMC installed in single rectangular pattern. The material propertiesand soil profile were selected to correspond with the soil strata and soil properties of South Port Said in its natural and mixed state.The model geometry was selected close to the model proposed andanalysed by Krenn [14] and Ekarut[15].

a) Geometry and boundary conditions

Cross-section and subsurface profile of the embankment model passing through the installed columns is shown in figure (1). Plaxis 2D is used to study the embankment model where the area ratio was used instead of column diameter. According to Rahman [16] the area replacement ratio is calculated using the formula $a_s = \frac{A_{col}}{A_{col} + A_{soil}}$ where A_{col} and A_{soil} are are the area of column and area of soil surrounding columns, respectively.In the analyses the diameter of the columns was taken as 0.6 m, the most common diameter in industry, with 1.05 meter column to column spacing to correspond with 25% area ratio.In 2D analysis this was modelled as 1 meter spacing with 0.25 meter equivalent extended element. The embankment height is 3 m from ground surface with side slope of 1V:2H. The embankment is constructed on layered soft clay with very soft layer with thickness of 4 meters underlain by deep layer of soft soil.Holtz and Kovacs [17] have developed empirical chart and tables for calculating vertical stress under a very long embankment. Based on the geometry of the hypothetic model, the depth considered underneath the embankment was taken as 20 meters where load intensity reaches 0.2 of the surface load. Accordingly 16 meters thickness of the extended layer is considered. The columns are assumed to extend from the ground surface with20 meter depth. The water table is assumed on the ground surface with drainage allowed only from top. The model has been assumed with full fixity at the base and roller condition at the vertical sides

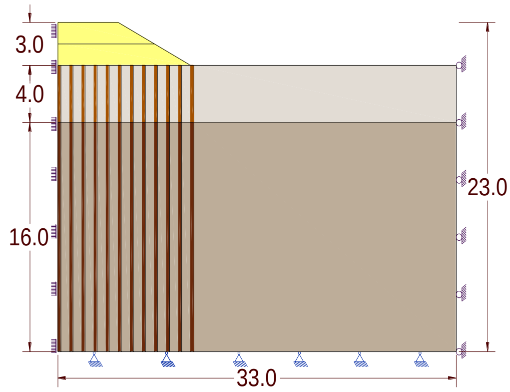

Figure (1) Hypothetic Embankment Model

b) Material modelling

The model includes three different materials:

- Two layers of soft soil with different properties, with given names soil1 and soil2.
- Two layers of mixed soil or DMC material with different properties,with given names DMC1 and DMC2.
- Fill material with given name Fill.

The input parameters for soil in its natural and mixed state were selected to correspond withSouth of Port Said soft clay as reported bySharoubim et al [13].

The materials modelling and the software input parameters as summarized below.

Soft Soil Material Modelling

Soft soil is characterized by two main features, its high degree of compressibility and linear stress-dependency of soil stiffness. In the present study, soft soil is modelledby Soft Soil Creep model, one of the standard soil models in PLAXIS-2D software. This model was developed by Vermeer& Neher [18]. According to Brinkgreve [19], when constructing embankments on soft soil, large primary settlement is usually followed by substantial creep. In such cases it is desirable to estimate the creep from FEM- computations with creep model (SSC).Gustafsson [20] evaluated the performances of three different material models to describe the soft soil creep effect. The results of the study demonstrated that SSC model was capable of simulating the small-scale laboratory tests results as well as the full-scale field test. In the present study, SSC model is selected to model the soft soil material.The input parameters used to feed PLAXIS-2D software are presented in the following table.

Table (1) Soft soil parameters

Property	Sym.	Unit	Soil1	Soil2
Material model	-	-	SSC	SSC
Material type	-	-	Undr.	Undr
Unsaturated unit weight	γ_{unsat}	kN/m^3	14.9	15.8
Saturated unit weight	γ_{sat}	kN/m^3	15.9	16.8
Permeability	k_x, k_y	m/day	0.0001	0.00005
Modified compression index	λ^*	-	0.120	0.128
Modified swelling index	k^*	-	0.012	0.013
Modified creep index	μ^*	-	0.00414	0.0044
Compression index	C_c	-	0.7710	0.7040
Recompression index	C_s	-	0.0393	0.0364
Creep index	C_α	-	0.0267	0.0245
Initial void ratio	e_{int}	-	1.8	1.4
Cohesion	c	kN/m^2	8	15
Friction angle	φ	^{o}	7	9
Dilatancy angle	Ψ	^{o}	0	0
Unload/reload Poisson's ratio	ν_{ur}	-	0.15	0.15
Lateral earth pressure (Normal consolidation)	k_0^{nc}	-	0.976	0.960
Over consolidated ratio	OCR	-	1.5	1.5
Interface ratio	R_{inter}	-	1	1

Note: Undr. Refers to undrained behavior

DMCMaterial Modelling

Krenn [13] performed model simulations for Vanttila claystabilized by deep mixedby applying drained triaxial tests.Krenn aimed to establish whether Mohr Coulomb model (MC) or Hardening Soil model both standard models in the PLAXIS can realistically represent the observed non-linear stress-strain behaviour. Krenn concluded that only HS model matches closely the observed non-linear behaviour.

Krenn &Karstunen [10]utilized FEM PLAXIS-3D package to simulate embankment on DMC. It was shown that the observed non-linear stress-strain behaviour of the deep mixed columns can be represented by Hardening Soil model (HS),In addition, HS model was found to account for stress dependent stiffness via a hyperbolic stress-strain relationship and there is a distinction between primary loading and unloading/reloading. Accordingly, HS model was selected in the present study to model DMC material.

Brandl [21] indicates that an increase inpermeability of deep mixed columns, when only lime is used, by one or two orders of magnitude is possible. Bengtsson and Holm [22] found that with lime column permeability was about 100 permeability of the unstabilized soil. Pramborg and Albertsson [23] reported that the in situ permeability of lime/cement columns has been 200 times the permeability of the unstabilized clay. Rogbeck and Trank [24]found for lime/cement columns that the permeability was about 750 to 1000 times the initial permeability. The permeability of cement columns is low. As reported by Okumura, 1996 in some cases the permeability of cement columnshas even been lower than the permeability of the unstabilized soil.

In this paper, the permeability of DMC is assumed as 100 time the permeability of the unstabilized soil.

Table (2) DMCparameters

Property	Sym.	Unit	DMC1	DMC2
Material model	-	-	HS	HS
Material type	-	-	Undr	Undr
Unsaturated unit weight	γ_{unsat}	kN/m^3	16	17
Saturated unit weight	γ_{sat}	kN/m^3	17	18
Permeability	k_x, k_y	m/day	0.01	0.005
Secant modulus	E_{50}^{ref}	kN/m^2	21000	26000
Odom. modulus	E_{oed}^{ref}	kN/m^2	16800	20800
Unload/reload modulus	μ^*	kN/m^2	63000	78000
Power of stress level	m	-	0.5	0.5
Compression index	C_c	-	0.0383	0.0265
Recompression index	C_s	-	0.0092	0.0064
Initial void ratio	e_{int}	-	1.8	1.4
cohesion	c	kN/m^2	180	220
Friction angle	φ	^{o}	36	38
Dilatancy angle	Ψ	^{o}	0	0
Unload/reload Poisson's	ν_{ur}	-	0.2	0.2
Lateral earth pressure (Normal consolidation)	k_0^{nc}	-	0.412	0.384
Reference stress	p^{ref}	kN/m^2	100	100
Over consolidated ratio	OCR	-	1.5	1.5
Interface ratio	R_{inter}	-	1	1

FillMaterial Modelling

The fill material has been modelled using the elastic perfectly plastic PLAXIS constitutive model Mohr Coulomb (MC).The input parameters are given in table (3) below:

Table (3) Fill material properties

Input Parameter	Sym.	Unit	Soil1
Material model	-	-	MC
Material type	-	-	Drained
Unsaturated unit weight	γ_{unsat}	kN/m^3	17
Saturated unit weight	γ_{sat}	kN/m^3	19
Permeability	k_x, k_y	m/day	1
Initial void ratio	e_{int}	-	0.5
Modulus of elasticity	E_{ref}	kN/m^2	15 000
Unload/reload Poisson's ratio	ν(un)	-	0.3
cohesion	c_{ref}	kN/m^2	1
Friction angle	φ	^{o}	30
Dilatancy angle	Ψ	^{o}	0
Interface ratio	R_{inter}	-	1

c) Discretization and mesh generation

Fully automatic mesh generation of finite element mesh is generated by PLAXIS-2D using plane strain 15-node triangular element. Medium coarseness option is used for the discretization for the mesh generation.The relation between stress increments and strain increments is usually non-linear. Consequently global iterative procedure is needed to satisfy equilibrium conditions for integration of stresses. Vermeer [25] has shown that the selection of implicit integration has major advantages, as it overcomes the requirements to update the stress in transition from elastic to elastoplastic behaviour and its positive influence on iterative procedures. Due to these advantages, implicit integration is selected for time integration.

d) Loads and phases

A distributed load of 10 kN/m^2 is assumed as a traffic load. The phases of loading are considered after the installation of DMC. The three meters fill are constructed in two equal stages each is constructed in 15 days followed by 50 day proposed consolidation period. Then the traffic load is applied in 15 days followed by consolidation period long enough for pore water pressureto dissipatetill less than 1 kN/m^2.

e) Initial condition

The initial stress-state was calculated with the K0-procedure and the initial water condition was calculated by the direct method.

f) Studied parameters

To investigate the different parameters that mayaffect behaviour of embankment constructed on deep soft soil stratain South of Port Said; a parametric study has been performed.Different codeshave been used to refer to each studied parameter where the codes and the selected values for the each parameter are shown briefly below:

Table (4) Studied parameters for embankment model

Property	*Sym.*	Values
Deep Mixed Column to soil area ratio	*AR*	5%, 10%, 20%, 25%, 30%, 40% and 50%
Column Depth	*DP*	6, 8, 10, 12, 14, 16, 18, 20 m
Deep Mixed Column stiffness (Secant modulus)	*ST*	5250, 10500, 15750, 21000, 26250and 31500 kN/m^2
Deep Mixed Columncohesion strength	*CH*	50, 100, 150, 200, 250 and 300kN/m^2
Soft soil friction angle	φ_{DSM}	20, 24, 28, 32, 36, 40 and 44° (degree)

2.2 Raft foundation model

A hypothetic squareraft foundation is assumed as established on soft clay strata stabilized by deep mixed columns. The arrangement of the columns was assumed in single rectangular pattern. Similar to the embankment model, the material properties and soil profile were selected to correspond with the soil profile and properties of South Port Said.The raft foundation is analysed by PLAXIS-2D software.

The method used to analyse the hypothetic model of raft constructed on DMC is selected close to the method presented by Andre [26]

The hypothetic modelsdetails and the input parameters are presented as follows.

2.2.1 Raft foundationmodel

a)Geometry and boundary conditions

The geometry of the model is presented in figure (2).

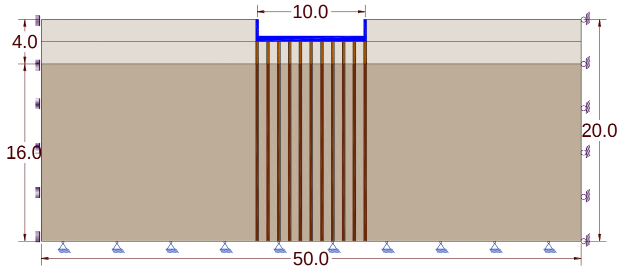

Figure (2) Hypothetic raft Model

b) Material modelling

The input parameters for different materials are considered. For soft soil and mixed soil, the nput parameters are given in table 1 & 2.

For the raft the input parameters are assumed as presented in the below table:

Table (5) Raft material properties

Input Parameter	Symp	Unit	Raft.	Wall
Material type	-	-	Elastic	Elastic
Normal stiffness	*EI*	kN/m	$1.75x10^7$	$1.05x10^7$
Flexural rigidity		kNm^2/m	$3.65x10^5$	$7.88x10^4$
depth	*d*	m	0.5	0.3
Weight	*w*	kN/m/m	12.5	7.5
Poisson's ratio	*v*	-	0.2	0.2

c) Discretization and mesh generation

Automatic mesh generation using plane strain 15-node triangular element withmedium coarseness option is selected. Implicit integration is selected for time integration.

d) Loads and phases

The phases are assumed to start after the DMC installation and the excavation for raft installation. The phases start by one phase for the installation of raft followed by phase for 5 stories installation represented by 50 kN/m^{2}distributed load.This load was considered to reflect the recommendation of constructing light structures in such very soft soil area. Then followed by consolidation period long enough for pore water pressure to dissipatetill less than 1 kN/m^2

f)Studied parameters

The behaviour of raft constructed on deep soft soil has been studied by PLAXIS considering two parameters as shown in the below table.

Table (6) Studied parameters for PLAXIS raft model

Property	*Sym.*	Values
Column to soil area ratio	*AR*	10%, 20%, 25%, 30%, 40% and 50%
Over consolidation ratio	*OCR*	1, 1.5, 2 and 2.5

3 RESULTS AND DISCUSSION

3.1 Results and discussions of embankment model

3.1.1 Area Ratio Effect

The effect on settlement and lateral movement

The effect of area replacement ratio on settlement reduction is shown in figure 3

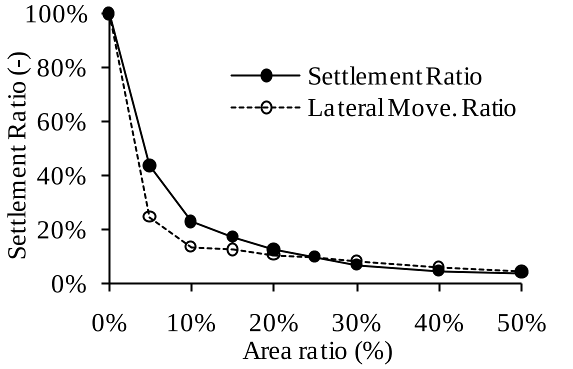

Figure (3) DMC effect on settlement with different ARs

In the figure, a range of area ratios of 05%, 10 %, 15%, 20%, 25%, 30%, 40% and 50% is analyzed to corresponding to columns spacing of 2.4, 1.6, 1.4, 1.2, 1.05, 0.95, 0.85 and 0.75 m, respectively.The change in settlement due to DMC installation is expressed as a ratio between settlement prior to DMC installation and settlements with different area ratios.

From the figure it can be concluded that DMC largely reduces the settlement and lateral movement. The reduced values of settlement ranged from 44% with 5% AR till 4% with 50% area ratio. It can be concluded that this effectiveness is higher with lower area ratios, as shown in the steep part of the two curves in the figure,and then decreases with increasing the area ratio AR.

In figure (4), settlement for 10 years after embankment construction is shown.The results showed thatthe construction of embankment without DMC installation results in soil profile collapse. The installation of DMC enables the construction of the embankment where the settlement value is calculated to be around 0.5 m in the first 10 years for area ratio of 10% as shown in figure (4). The increase of AR to 50% reduces the settlement to less than 0.07 m within the first 10 years.

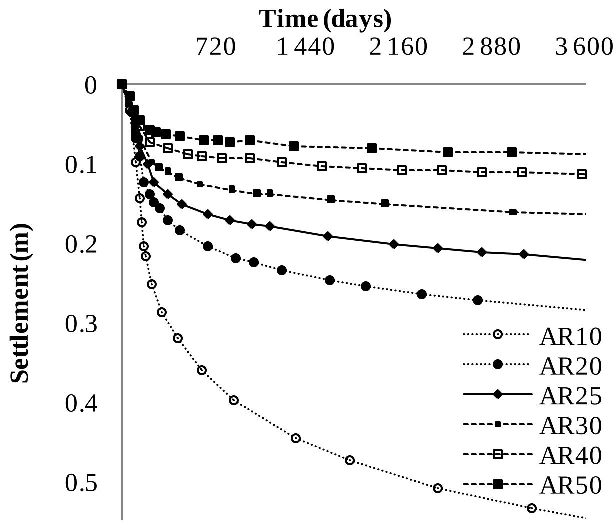

Figure (4) The effect of A R on 10 years consolidation

The effect on stresses

In figure (5) the change in shear and effective stress due to DMC is expressed as ratio between stress before and after DMC installation.

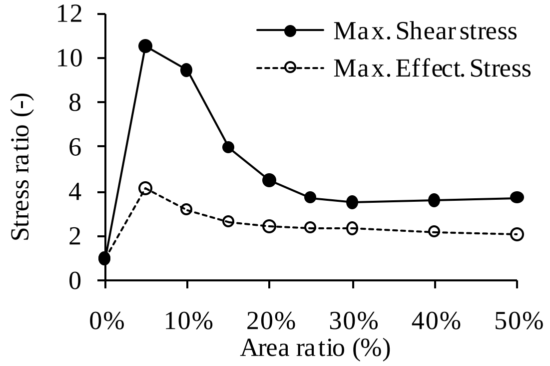

Figure (5) DMC effect on stresses with different ARs

From figure (5) it can be noticed that the installation of DMC with 5% area ratio increases maximum shear stress from 15 kN/m^{2}to 155 kN/m^2 (10 times) and increases maximum effective stresses from 125 kN/m^2 to 525 kN/m^2 (4 times)

3.1.2 DMC depth ratio

DMC depth is expressed in the form of depth ratio (Dr) between DMC depth and soft soil depth. In the studied model, 20 meters of soft soil depth was considered. In the analysis, DMC with different depths (from 6 meters up to 20 meters)was considered. These DMC depths correspond with depth ratios from 0.3 to 1.

The effect on settlement

As shown in figure (6), for all studied area ratios, the reduction effect of DMC increases almost linearly with the increase in DMC depth ratio

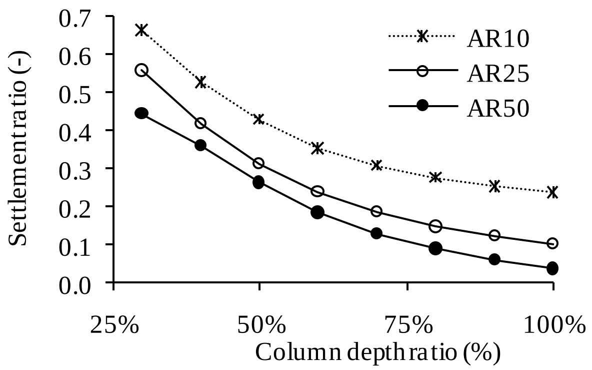

Figure (6) DMC effect on settlement with different ARs

The effect on lateral movement

As shown in figure (7) the increase in depth ratio considerably reduces lateral movement up to 75% depth ratio for all tried area ratios. After 75% depth ratio lateral movement starts to increase with the increase of depth ratio this could be related to the effect of stress concentration.

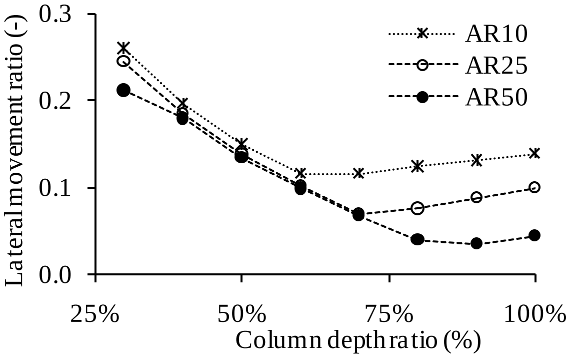

Figure (7) DMC depth effect on lateral move

The effect on stresses

In general and as shown in figure (8), increasing depth ratio slightly increases the concentration ofshear stress and raises maximum values of shear stress values. For low area ratios and for middle values of depth ratio the increase in maximum shear stressbecomes high particularly for depth ratios between 40% and 70%.

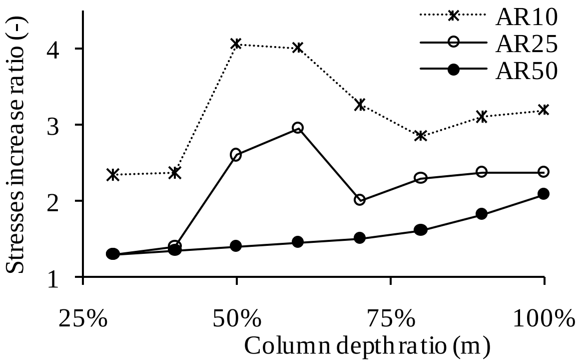

Figure (8) DMC depth effect on shear stresses

3.1.3 DMC stiffness ratio

The influence of DMC stiffness is expressed as stiffness ratio between DMC and surrounding soil.

DMC stiffness is represented in DMC secant modulus of elasticity E50. The applied values in the present study included6500, 13000, 19500, 26000, 32500 and 39000 kN/m^2. These values correspond to stiffness ratio between DMC and soil of 40, 80, 120, 160, 200 and 240. These stiffness ratios were applied considering two different area ratios, 25% and 50%.

The effect on settlement and lateral movement

As shown in figure (9), settlement decreases almost linearly with the increase in DMC stiffness ratio with slightly higher effect with lower stiffness ratio.

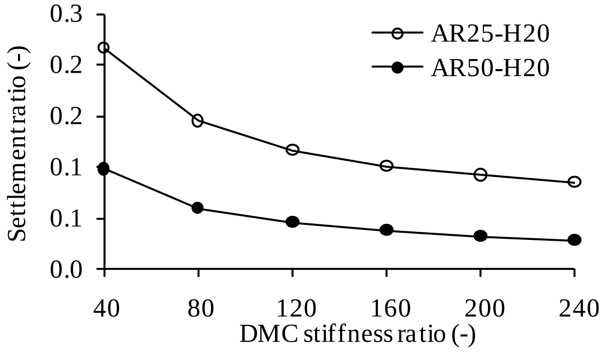

Figure (9) DMC Stiffness effect on settlement

The same reduction effect of DMC stiffness ratio is noticed also with lateral movement as shown in figure (10) but withless value.

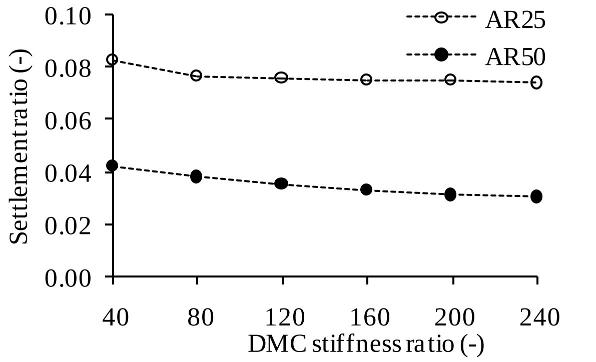

Figure (10) DMC Stiffness effect on lateral movement

The effect on shear and effective stress

On the other hand and as shown in figure (11,12), the increase in DMC stiffness ratio and surrounding soilleads to increasing the maximum values of shear stresses and effective stresses.

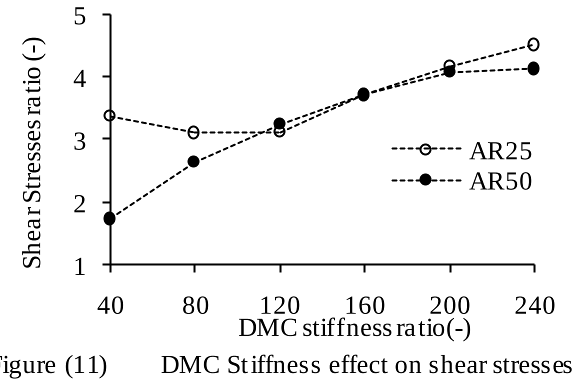

Figure (11) DMC Stiffness effect on shear stresses

This is related to the increase in stresses concentration due to the increase instiffness difference between DMC and surrounding soil

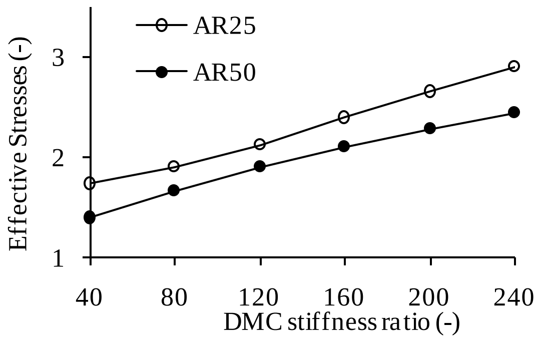

Figure (12) DMC Stiffness effect on effective stresses

3.1.4 DMC Cohesion Strength

The influence of DMC cohesion strength on DMC effectivenessis investigated in the present study by applying cohesion strength values ranged from 50 to 300 kN/m^2. These values are equivalent to cohesion strength ratio betweenDMC and surrounding soil of 7, 14, 21, 28, 35 and 42.

The effect on settlement

As shown in figure (13), the installation of DMC is more effective in reducing settlement with lower values of cohesion strength ratio. When such ratio exceeds 14 the effectiveness of DMC settlement reduction effect becomes independent of cohesion strength ratio

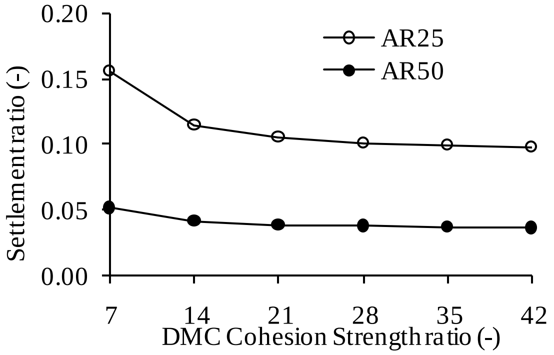

Figure (13) DMC cohesion ratio effect on settlement

On the other side DMC cohesion strength ratio has no influence on DMC effect on lateral movement.

The effect on settlement

As shown in figure (14), increasing DMC cohesion strength ratio has very slight increase effect on maximum shear stresses. This can be related to the increase in the gap between cohesion strength of DMC and soft soil surrounding the DMC.This increases the shear stressesconcentration effect due to DMC installation.

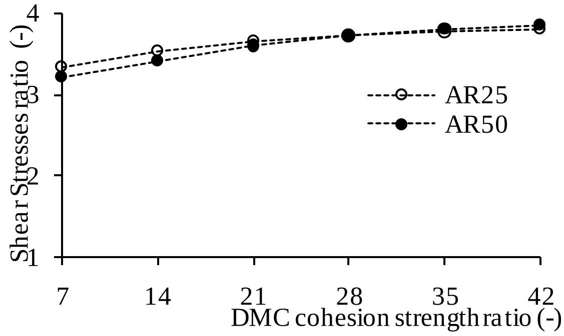

Figure (14) Cohesion ratio effect on settlement

3.1.5 DMC internal friction angle ratio

In the present study, the internal friction angle is expressed in the form of ratio between DMC and surrounding soil internal friction angle. DMC internal friction angle values ranged from 20 to 44^{o} are selected to correspond with friction angle ratios of 2.4 to 4.8.

The effect on settlement and lateral movement

As shown in figure (15), the increase in internal friction angle ratioremarkably reduces settlement particularly with lower area ratios.

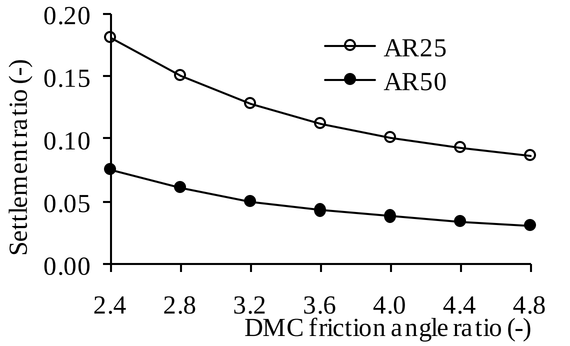

Figure (15) Friction angle ratio effect on settlement

On the other side and as shown in figure (16) the influence offriction angle ratioon lateral movement is very slight and can be neglected.

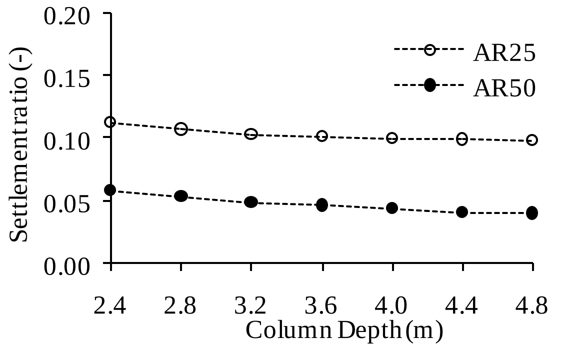

Figure (16) DMC Stiffness effect on settlement

The effect on stress

On the other side and similar to the effect of DMC cohesion strength, the increase in friction angle ratioincreases shear stress concentration effect due to DMC installation as shown in figure (17)

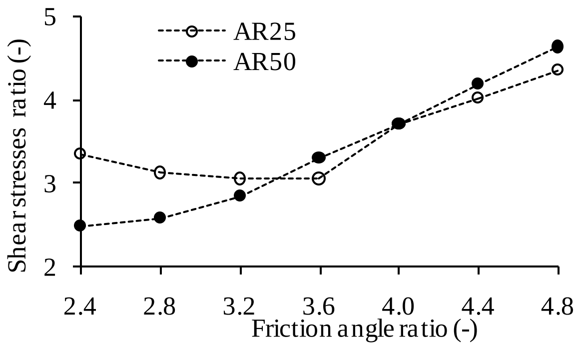

Figure (17) Friction angle effect on shear stress

3.2 Results and discussions of raft model

In the analysis of the raft model by PLAXIS, the effect of two parameters has been studied, area ratio and over consolidation ratio. The results of studying the two parameters are presented as below.

The effect on settlement and lateral movement

The effect is expressed as the settlements ratio between different area ratios to settlement with no DMC

As shown in figure (19, 20), the increase in area ratio considerably reduces settlement ratio. The reduction rate is higher with lower values of area ratio especially for low over consolidation ratio. The mutual effect of increasing area ratio and increasing over consolidation ratio results in lower rates of settlement reduction.

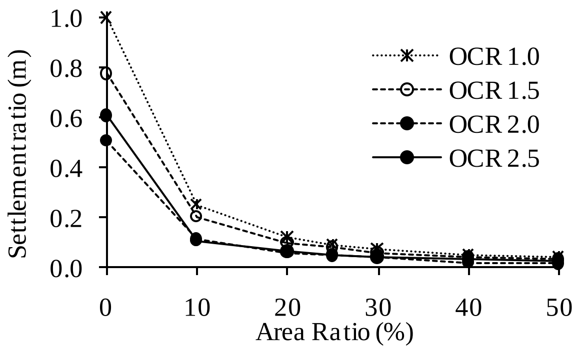

Figure (18) Midpoint Settlement reduction by DMC

Figure (19) shows the effect of area ratio on maximum settlement for different over consolidation ratios.

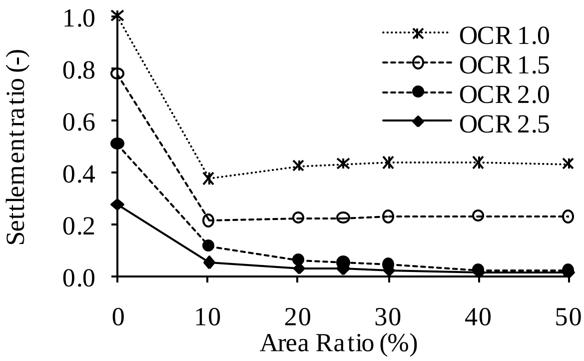

Figure (19) Maximum Settlement reduction by DMC

From the difference between figure (18) and (19), it can be concluded that the reduction effect of DMC on both maximum and mid-point settlement is similar for low area ratios. With the increase in area ratio, the reduction effect continues with mid-point settlement while vanishes with maximum settlement.

From figure (20) it can be concluded that the increase of area ratio results in increasing lateral movement particularly for normally consolidated clay

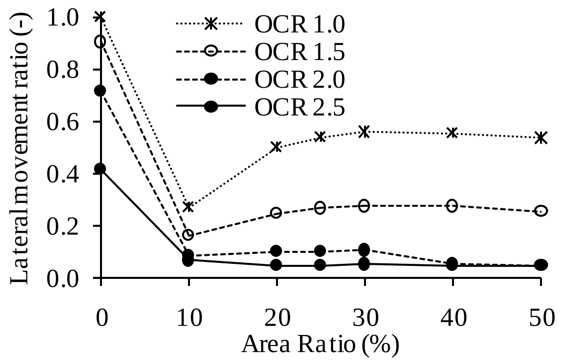

Figure (20) Area ratio effect on lateral movement

The effect on shear and effective stress

For shear stress and as shown in figure (21), the installation of DMC results in stress concentration and high increase in shear stress particularly for low area ratio. Then the effect becomes neutral with area ratios higher than 10% for different values of OCR.

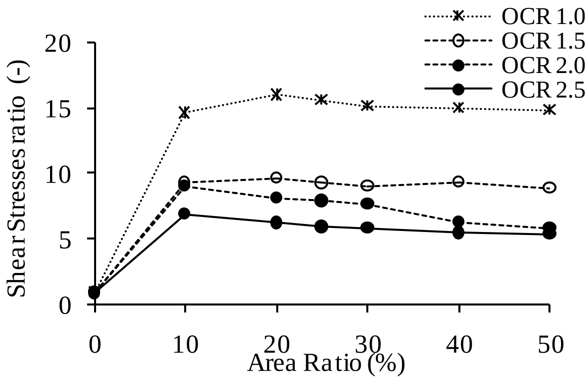

Figure (21) Area ratio effect on shear stress

For effective stress the effect of DMC is almost similar to the effect on shear stress. As shown in figure (22), large increase in effective stress takes place due to DMC installation with 10% area ratio. Then the effective stress starts to decrease slightly with the increase of area ratio.

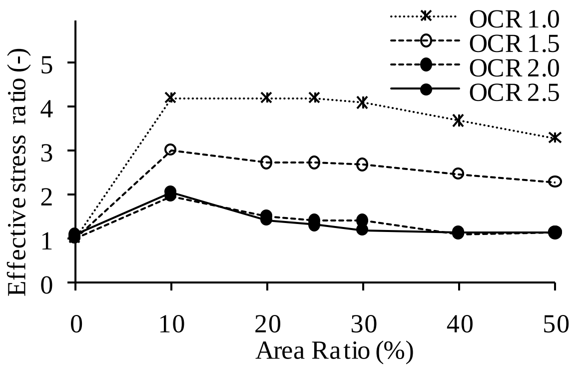

Figure (22) Area ratio effect on effective stress

4 CONCLUSION

In the present study the effectiveness of using DMC to improve thick layers of soft clay below embankments and light structures in the South of Port Said is performed. Numerical analyses on hypothetic embankment and raft foundation models were analysed using finite element packages PLAXIS. The results of parametric study performed to assess the influences of different parameters on the effectiveness of DMC on long term settlement, horizontal displacement, shear and effective stress and consolidation time. The results showed that:

- The installation of DMC is effective in reducing settlement and lateral movement for South of Port Said deep soft clay strata.
- The effectiveness of settlement reduction is very high with low Area ratio then decreases considerably with the increase of DMC area ratio.The optimum area ratio for DMC effectiveness with settlement reduction was found to be 10%.
- The installation of DMC causes stresses concentration and increases maximum values of shear and effective stresses.
- Stresses concentration is higher with low area ratios and decreases with area ratio increase.
- The increase in DMC depth ratio increases DMC effectiveness to reduce settlement and lateral movement almost linearly without affecting the shear or effective stresses. The optimum DMC depth ratio for lateral movement reduction is found to be 80%of the considered soil layer thickness.
- The increase in stiffness ratio between DMC and surrounding soil increases the effectiveness of DMC to reduce settlement and lateral movement.
- On the other side increasing stiffness ratio increases concentration of both shear and effective stress.
- The increase in cohesionstrength ratio betweenDMC and surrounding soil slightly increases DMC effectiveness to reduce settlement while considerably increases stress concentration. Similar effect is found also for internal friction angle ratio between DMC and surrounding soil.
- From the results of raft model, it was found that DMC is more effective in reducing settlement with normally consolidated clay. However such clay suffers more stress concentration due to DMC installation.

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