International Journal of GEOMATE, Oct., 2017, Vol.13, Issue 38, pp.09-15
Geotec., Const. Mat. & Env., ISSN:2186-2990, Japan, DOI: http://dx.doi.org/10.21660/2017.38.6527

THE ESTIMATION OF BEARING CAPACITY AND SWELL POTENTIAL OF DEEP SOIL MIXING ON EXPANSIVE SOIL BY SMALL SCALE MODEL TEST

*Yulvi Zaika[1] and Arief Rachmansyah[2]

[1,2] Engineering Faculty, Brawijaya University, Indonesia

*Corresponding Author, Received: 14 June 2017, Revised: 13 July 2016, Accepted: 16 Feb. 2017

ABSTRACT: Deep Soil Mixing (DSM) is a ground modification technique to improve soil characteristic. This paper explain the result of laboratory experiment of deep soil mixing (DSM) in small scale. The model have been constructed to estimate field condition. The important properties of expansive soil such as the strength and swelling were investigated. The fly ash was used as binder material to enhance strength and mitigate swell potential. However optimum binder dosage, water – binder ratio and geometrical column (length, diameter and spacing) influenced performance of DSM. Variation of length and spacing of column could be established by considering active zone and the area ratio in the single square arrangement. The required treatment area are determined based on tolerable swelling and allowable bearing capacity. The small scale of DSM construction showed significant improvement of swell and strength properties compare with untreated soil. The empirical model are presented in this research provided reasonable predictions of strength and swelling for in situ condition.

Keywords: Expansive, Strength, Swelling, Improvement, Deep Mixing

1. INTRODUCTION

One of geotechnical problems encountered in the construction of transportation infrastructure in the north part of East Java is wide spread expansive clayey soil (Fig.1). In this region it is founded two types of clayey soil.

Fig.1 Map of the spread of soft soil and expansive soil in the northern part of East Java, Indonesia and transportation infrastructure (Rachmansyah, 2014).

The first type is the sediment soil that as the product of sedimentation materials carried by the river Bengawan Solo and sedimentation in wetlands (Qa). This soil is generally fine-grained, and contains a lot of organic matter. The thickness of young soft sediment soil can reach 40 m depth (Wesley, 2010). The second type of clayey soil is the product of weathering process of mudstone (residual soil) of the Lidah Formation. The Lidah Formation (TQs) composed by blue grey mudstone with lenses of carbonates sandstones and limestone. This geological formation is formed in a shallow marine environment during the Pliocene - Pleistocene (Ratman, et al., 1998). This residual soil type has generally high shrink-swell characteristics (known as high expansive soil), because of its high contents of montmorilonite minerals. Bojonegoro district is one of area in this formation. The expansive characteristics of the clayey soil can cause cracks in the floor of building and the road, and prone the landslide (Fig. 2).

Fig. 2 Typical cracks of the pavement that were built on the residual soil of Lidah Formation in the North East Java

Some additive materials such as cement, lime, fly ash, silica and various chemical compound were applied to improve the soil properties that is shrink swell characteristics. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants. Because of it contains such as silica (SiO_2), iron oxide (Fe_2O3), aluminium oxide (Al_2O_3), and calcium oxide (CaO), fly ash can be categorized as pozzolanic materials.

Considering the successful and rapid nature of chemical based DSM in stabilizing soft soil, the same technology was considered to expansive soil. The purpose of this study was to explore the change of strength and swell potential of improvement with DSM in different geometric parameters (length, diameter and spacing of columns) in small scale laboratory experiment. Laboratory result on field cores indicated that both field stiffness and strength are about 20% to 40% less than the corresponding laboratory prepared soil samples (Madhyannapu et al, 2010). Some of numerical studies have been carried out to understand the behavior column-supported embankment system, assuming linear elastic or linear elastic perfectly plastic but Yapage et al. (2014) obtained strain softening constitutive behavior for cement stabilized clay for DSM column. Application and evaluation of DSM was developed by Madhyannapu at al. (2014) to propose the stepwise design methodology.

2. DEEP SOIL MIXING METHOD

The use of the soil mixing to improve the engineering properties of soft soil and contaminated soil is very well known for a long time. In this method soils are mixed in situ with stabilized binders. The stabilized material will produce the higher strength, lower permeability, and lower compressibility and lower swell potential than native soil. The improvement becomes possible by action exchange at the surface clay minerals, bounding of soil particles and/or filling of void by chemical reaction product. The widely used binder are cement and lime, gypsum, fly ash and secondary products are also used.

The soil mixing can be divided into two general methods: the deep soil mixing and shallow soil mixing. The DSM is an applied for in situ stabilization of soil to minimum depth of 1.5 m (depend on mass stabilization). Generally DSM can be performed in two techniques of mixing, dry mixing and wet mixing. In the wet mixing, the soil is mixed with additives in binder slurry, while the dry mixing soil mixed with additives in binder powder.

2.1 The Heave of Expansive Soil and Composite Ground

The model for predicting the heave of expansive subsoil was based on the variation of swell pressures with depth and is presented in the following equation (Fredlund and Rahardjo, 1993):

$$\Delta \boldsymbol{h} = \sum_{i=1}^{n} \frac{C_{s,i} h_i}{1+e_{0,i}} \log \frac{p'_{f,i}}{p'_{s,i}} \quad \textbf{(1)}$$

Where:
$C_{s,i}$: swell index
$e_{o,i}$: initial void ratio
$p'_{f,i}$: final stress (overburden ± any change of total stress)
$p'_{s,i}$: initial swell pressure (suction).
h_i : thickness of each layer

According to Rao at. al. (1988) in unsaturated expansive soil the initial swell pressure could be measured as the corrected swell pressure, $p'_{s,i}$ from the constant volume type oedometer test. The final stress state, $p'_{f,i}$, accounts for the overburden stress, as well as any net change in total stress from either excavation or surcharge type loading. The Eq. (1) was modified into Eq. (2).

$$\Delta \boldsymbol{h} = \sum_{i=1}^{n} \frac{C_{s,comp,i} h_i}{1+e_{0.i}^{comp}} \log \frac{p'_{f,comp,i}}{p'_{s,comp,i}} \quad (2)$$

Where the parameter $\boldsymbol{C_{s,comp,i}}$, $\boldsymbol{e_{0.i}^{comp}}$, $\boldsymbol{p'_{f,comp,i}}$ and $\boldsymbol{p'_{s,comp,i}}$ are composite properties of layer i in the treated ground. The parameter could be estimated as shown following:

$$\boldsymbol{C_{s,comp,i} = C_{s,col}.\, a_r + C_{s,soil}.\,(1 - a_r)} \quad (3)$$

$$\boldsymbol{p'_{s,comp,i} = p'_{s,col}.\, a_r + p'_{s,soil}.\,(1 - a_r)} \quad (4)$$

Where subscript soil= untreated soil properties subscript col = treated soil, a_r = replacement volume ratio.

Because of initial void ratio and bulk unit weight for treated and untreated are the same and constant with depth and the composite properties $\boldsymbol{C_{s,comp,i}}$, $\boldsymbol{p'_{s,comp,i}}$ were also constant with depth, the Eq.(2) became more simple:

$$\Delta \boldsymbol{h} = \sum_{i=1}^{n} \frac{C_{s,comp,i} h_i}{1+e_{0.}} \log \frac{p'_{f,,i}}{p'_{s,comp,i}} \quad (5)$$

2.2 Bearing Capacity of Composite Ground

The improvement bearing capacity of expansive soil also important in application of DSM. Some methods to calculate bearing capacity of composite ground (end bearing column) are expressed:

(1) Weighted method

$$q_u = c_{uc}\alpha + (1 - \alpha)c_{us} \quad (6)$$

(2) Broms (2000); Bouassida and Porbaha (2004) Method

$$q_u = 0.7q_{uc}\alpha + \lambda(1-\alpha)c_{us} \qquad (7)$$

Where:
c_{uc}: undrained shear strength of column
c_{us}: undrained shear strength of soil(untreated)
q_{uc}: unconfined compressive strength of column
α : replacement area ratio
λ : 5.5 (Bergado at al., 1994)

2.3 Replacement Volume Ratio

Estimate the stabilized volume ratio (if the treatment was not end bearing column) is required to reduce overall swelling to tolerable swelling (heave).

The diameter of DSM column depend on the availability of local DSM rigs. The area ratio of square arrangement could be calculate based on Eq. 8.

$$\boldsymbol{a_r = \frac{a_{col}}{a_{soil}+a_{col}} = \frac{\pi d_{col}^2/4}{s_{cc}.s_{cc}}} \qquad \textbf{(8)}$$

Where a_{col} = area of column DSM, d_{col} = diameter of column DSM and s_{cc} is space between 2 columns.

3. BEARING CAPACITY IMPROVEMENT

The improvement soil characteristic is well understood by using Bearing Capacity Ratio or *Bearing Capacity Improvement* (BCI) that can be determined based on ultimate bearing capacity and bearing capacity of treated soil (DSM). Formulation of BCI can be written as

$$\boldsymbol{BCI = \frac{P(I)}{P_u}} \qquad (9)$$

Where:
Pu (I): ultimate bearing capacity with DSM
Pu : ultimate bearing capacity native soil

4. SWELL POTENTIAL

Determination of swell potential is quite important in design of foundations on expansive soils. The swelling tendencies of expansive soils are quantified by the swelling potential and/or free swell. Swell potential or volume change is defined as the ratio of increase in height to the initial height of the soil sample compacted at optimum moisture content in a consolidation ring and soaked under a surcharge of 6.9 kPa (1 psi) , Seed et al. (1962).

$$\boldsymbol{SP = \frac{H_i - H_f}{H_i}\, x100\%} \qquad (10)$$

Where, H_i : initial height of sample, H_f : final height

Swell potential was percentage of swell under 1-psi surcharge of sample compacted at optimum water content to maximum density in Standard AASTHO Compaction Test. Set the swell gauge to zero and record the time of the start of test. The test will be stopped when the swell terminated.

5. MATERIAL AND METHOD

5.1. Soil Properties

The characteristics of expansive soil in this study are shown Table 1.

Table **1**. Characteristics of expansive soil

Characteristics	Value
Liquid Limit (LL)	73.9%
Plastic Limit(PL)	30.4%
Shrinkage Limit(SL)	2.8%
Plasticity Index (PI)	43.1%
USCS	CH

Based on specification of PI and LL was proposed by Horz and Gibbs (1956), Raman, V (1967), Chen (1988) and Snethen at.al (1977) the degree expansion of soil is height**.**

5.2 Box Model and Soil Preparation of Loading Test

Prime element that used is box, made of fiber glass with length 100 cm, width 50 cm and height 30 cm. The box use L profile as the frame and it made to be rigid enough. Fiberglass used as box to make observation easier in laboratory (Fig.3).

The loading test performed on the untreated soil with 27.9 % moisture content and dry unit weight 12.88 kN/m^3 and treated soil in 25.8% water content and 15% fly ash (based on previous research). Compaction is controlled from weight of soil that is loaded into the box with a volume that is required. The fly ash and soil are mix in dry condition.

The holes in treated soil test are made by using a steel pipe of the same size with a diameter of DSM column (2cm). In this experiment attempted to vary spacing and depth to the composition of a single square pattern (Fig.4)

Treated soil is inserted into the hole with several layers. Each layer was compacted. The number of collisions is done by way of a preliminary study to obtain desirable density. The DSM construction are cured in 3 days.

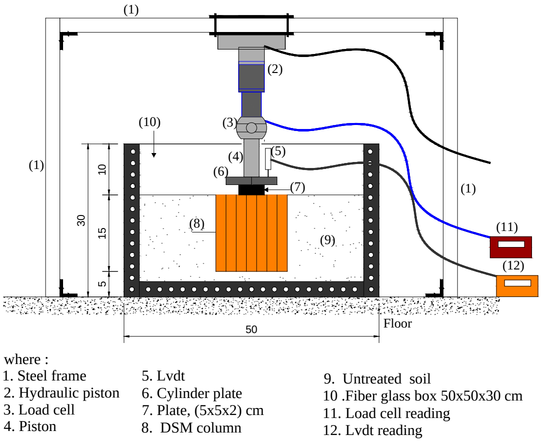

Fig. 3 Box experiment and loading test

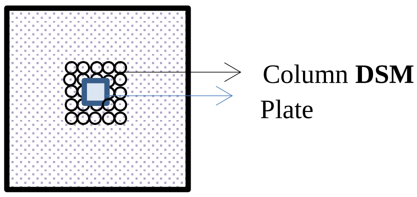

Fig. 4 Single square model

Variation of length and spacing of columns can be seen in Table 2. **T**here are two variations of the floating column and an end bearing column.

Table 2 Column Length and Spacing

Parameters	cm
Length (L)	B, 2B, 3B
Spacing(S)	D,1.25D, 1.5D

Where: B= width of loading plate (square) = 5 cm, D= diameter of column=2 cm.

5.3 Soil Preparation and Swelling Test

Swelling tests were applied for untreated and treated soil in the same condition (water content, dry density, cure time) in CBR mold. There are some variation of columns are made in CBR mold for swelling test. The amount of column established different replacement volume ratio. The test is conducted to obtain relationship between replacement volume ratio of soil and swell potential. The relation will be used to estimate swell potential in small scale model.

5.4 Unconfined Compressive Strength Test

Unconfined compressive strength tests was applied to investigate the change of undrained shear strength (qu) before and after improvement. The parameter of shear strength, cu is obtained in this test.

6. RESULTS AND DISCUSTION

6.1 Strength of soil improvement

Clay soil performances significant increasing of strength when mixed with fly ash. The Table 3 shows cu or cohesion of undrained shear strength in undisturbed, compact untreated and treated soil sample.

Table 3 Undrained shear strength of such condition expansive soil

Sample	Water content (%)	cu (kN/m^2)
Undisturbed	49.46	25.3
Compacted soil	27.8 (omc)	64.3
Treated soil	25.8 (omc)	98.1

The strength of expansive soil increases 155%, 289% by compaction method and mixed by fly ash in optimum content respectively.

6.2 Spacing and Length Column Effect to Strength and Settlement

One the most important analyses of DSM is control of settlement of soil. Fig. 5 shown the relation between stress and settlement of soil. The untreated soil reached ultimate stress at 380 kPa. At the same stress, the treated soil by DSM column underwent small settlement. It made sense the treated soil was stiffer than untreated one.

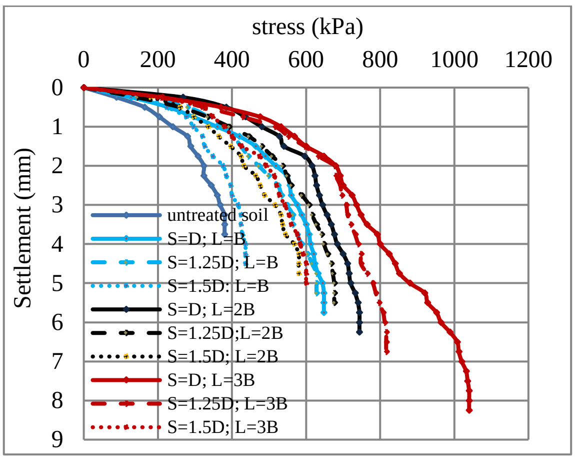

Fig.5 Relation between stress and settlement with variation of length and column spacing

The longest and closest column reached peak load value. The result showed linear elastic perfectly plastic behavior of DSM columns. Based on Euro

Soil Stab (2012), the curve is linear up to the long term strength (creep strength) and then the exceeded load is assumed to be constant as shown in Fig.6.

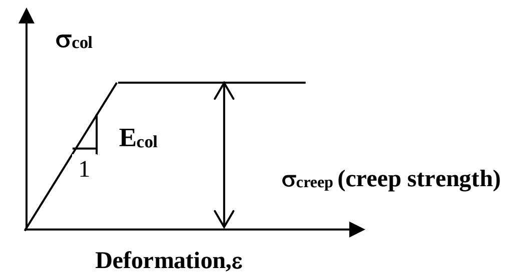

Fig. 6 Stress and deformation in column stabilized soil (Euro Soil Stab)

6.3 Bearing Capacity Improvement (BCI)

BCI is a measure that indicates the effect of treatment on the bearing capacity of soil. Based on 3 variations of spacing and length of column, relation between Bearing Capacity Improvement and the parameters could be analyzed. The experiment result gives the highest BCI is 2.73 for the longest and nearest column spacing and the lowest one is 1.147 for the shortest and widest space column (Fig.7).

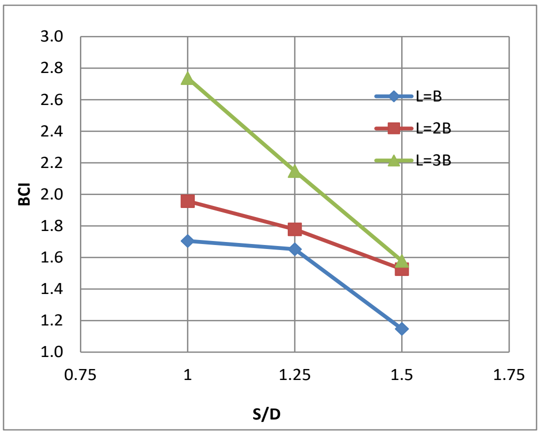

Fig. 7 BCI of soil for different spacing and length of DSM columns

Length and spacing of columns arrangement have effect to the replacement volume ratio than these give impact to increase of the bearing capacity of the soil as shown in Fig.8. In this study the relation between replacement volume ratio and bearing capacity is nonlinear. But based on Eq. 6 and 7, the relations is linear for end bearing column. But Bouassida, M. (2016) suggest prediction for the bearing capacity of treated soil by the DSM method with wide range of cohesion ratio and replacement area used limit analysis method. It will considered more valid and reliable than the previous method.

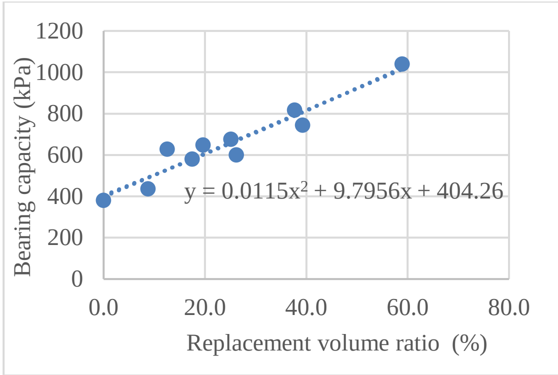

Fig. 8 Influence replacement volume ratio to bearing capacity

6.4 The Swell Potential of Improved Soil

The observation of swell potential for DSM method was done by variation of number of column soil improvement. In this case a lot number of column will give height the volume of treated soil.

The relationship between replacement volume ratio and swell potential is shown in Fig. 9.

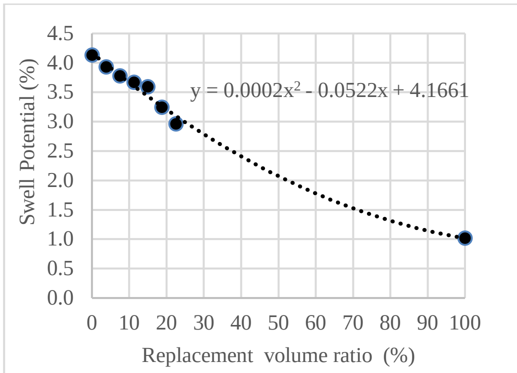

Fig. 8 Improvement of replacement volume ratio to swell potential

The regression analysis was applied to the relationship and gave the formulation as follows:

$$y = 0.0002x^2 - 0.0522x + 4.1661 \quad (11)$$

Where x = replacement volume ratio and y = swell potential. The equation could be used to estimate swell potential of DSM in small scale model. The increasing of replacement volume ratio will decrease swell potential. There are some factors that influence swell potential such as characteristic expansive soil, type of binder, water content, curing time and mixing methodology.

The estimation of swell potential of DSM at single square arrangement could be read in Table 4.

Table 4 Swell potential of single square arrangement of DSM

Spacing of column	Length of column	Ratio of Replacement volume	Eq.11
untreated soil		0.00	4.08
D	B	19.63	3.74
2D	B	12.57	3.54
3D	B	8.73	3.73
D	2B	39.27	2.42
2D	2B	25.13	2.98
3D	2B	17.45	3.32
D	3B	58.90	1.79
2D	3B	37.70	2.48
3D	3B	26.18	2.94

The tolerable heave for flexible pavement is generally on the order of 12 mm. The swell potential of untreated soil is 4.08% in Bojonegoro district. The depth of expansive soil (active layer) is 1m = 1000 mm with the result the maximum swell potential is 1.2%. Based on Eq.11 the replacement volume ratio is estimated around 85%.

7. SUMMARY AND CONCLUSION

This study is a small scale experiment to evaluate DSM construction for stabilizing expansive soil to predict the condition in actual field. Prior to DSM construction, laboratory mix design need to conduct such as swelling and strength untreated and treated soil in optimum dosage of binder.

The variation of spacing and depth of column are directly influenced to ratio of stabilized soil. The relation between strength or swell potential and replacement volume are not linear function.

It is needed to further study intensively about swell potential, binder content and also water content in situ to choose geometric parameter such as diameter and depth in installation pattern (square, triangular),

REFERENCES

[1] Asano, J, Ban, K and Azuma, K," Deep mixing method of soil stabilization using coal ash", Proc. The second international conference on grouting improvement geosystem, Balkema Rotterdam, 1996, pp.392-398.

[2] Bergado, D.T, Chai, J.C, Alfaro, M.C and Balasubramaniam, A.S," Improvement techniques of soft ground in subsiding and lowland environment", 1994, Balkema, Retterdam, 1-220.

[3] Bouassida, M," Rational Design of foundation on soil reinforcement by column", Review Article, Innov.Infrastruct. Solut.(2016) 1:13, DOI 10.1007/s41062-016-0038-3.

[4] Bouassida, M, Porbaha,"Ultimate bearing capacity of soft clays reinforces by a group of column application to a deep mixing technique", Soils and foundations, 2004, vol.44, No.3, pp. 91-101.

[5] Broms, B.B," Lime and lime/columns, summary and visions, Proceeding 4th international conference on ground improvement geo-system, 2000, vol. 1, 43.

[6] Chen, F.H." The use of piers to prevent the uplifting of lightly loaded structure founded on expansive soil", Concluding Proc. Eng. Effects of moisture change in soils, Int. Res. Eng. Conf. expansive clay soil, 1965, Texas A&M Press, pp.152-171.

[7] Euro Soil Stab," Development of design and construction methods to stabilize soft organic soil" Design guide soft soil stabilization, (2012), CT97-0351, Project no.BE-3177

[8] Fredlund, D G, Raharjo, H," Overview of unsaturated soil behavior", Proc. Unsaturated soil, 1993, ASCE, pp. 1-31.

[9] Holtz, W.G and Gibbs, "Engineering properties of expansive clays", Transaction ASCE, 1956, Vol.121, Issue 1, pp. 641-677.

[10] Madhyannapu, RS and Puppala, AJ, Nazarian, S, Yuan, D ,"Quality assessment and quality control of deep soil mixing construction for stabilizing expansive sub soils ", J. Geotechnic & Geo-environment Engineering, 10.1061/(ASCE) GT.1943-5606.0000188, 2010, pp. 119 – 128.

[11] Madhyannapu, RS and Puppala, AJ," Design and construction guidelines for deep soil mixing to stabilize expansive soil", J. Geotech. Geoenviron. Eng., 10.1061/ (ASCE) GT.1943-5606.0001149, 2014, Pp. 04014051-1-04014051-14.

[12] Rahmansyah,A," Improvement of expansive soil of east java, Indonesia by using industrial solid waste", Proc. Int. Conf. on unsaturated soil UNSAT, 2014, Sydney, Australia.

[13] Raman,V," Identification of expansive soils from plasticity index and the shrinkage index data", Indian Eng., 1967, Calcuta 11(1), pp. 17-22.

[14] Ratman, N, Suwarti, T, and Samodra, H, "Peta Geologi Indonesia, Lembar Surabaya, skala 1:1000.000, Pusat Penelitian dan

Pengembangan Geologi, 1998, Bandung (indonesia version)

[15] Rao, R.R, Rahardjo,H, Fredlund, D.G," Closed form heave solutions for expansive soils", Journal Geotecnical Engineering, 1988, Vol.114, No.5, Pp. 573-588.

[16] Snethen, D.R, Johnson,L.D and Patrick,D.M," An evaluation of expedient methodology for identification of potentially expansive soil, soil and pavement lab.", US Army Eng.,1977, Waterway Exp.Sta, Vicksburg, MS,Rep. No. FHWA-RE-77-94,NTIS, PB-289-164.

[17] Seed,H.B, Woodward. R.J and Lundgren, R," Prediction of swelling pontential for compected clay", Journal ASCE, Soil Mechanics and Foundation Division, 1962,Vol. 88, Issue 3, pp. 53-88.

[18] Wesley, L D, " Fundamental of Soil Mechanics for Sedimentary and Residual Soils, 2010,John Wiley and Sons

[19] Yapage, N.N.S, Liyanapathirana, DS, Kelly, RB, Poulos, HG, Leo, CJ," Numerical Modeling of an Embankment over soft ground improved with deep cement mixed column: case story", Journal Geotech. Geoenviron Eng. 10.1061/ (ASCE) GT.1943-5606.0001165, 2014, pp. 04014062-1-04014062-10.