RELATIONSHIP OF AREA RATIO TO DISPLACEMENT ON SUBGRADE STABILIZED BY DEEP SOIL MIXING

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ABSTRACT

Expansive clay soil has high potential of swelling due to minerals content which bind water, therefore, soil improvement is required to stabilize the swelling behavior by add binder additive such as lime in deep soil mixing method (DSM). In this study, Finite Element model approach was performed with embankment provided on the top of expansive clay layer to provide bearing layer for road construction. As the deep soil mixing is applied on the subgrade (expansive clay layer), some model variation is performed such as diameter variation with 0.4m; 0.6m; 0.8m, depth variation with 5m; 6.5m; 8m and space variation 0.8 m;1.2m;1.6m; 2.4m. Area ratio parameter also used for ease understanding of deep soil mixing behavior with so many model variations provided. Analysis results shows that higher area ratio of deep soil mixing will provide lower displacement value either immediate displacement or consolidation displacement. Moreover, plot result of area ratio shows that area ratio of 0.393 provide effective value regarding consolidation displacement and duration.

Keyword : area ratio, consolidation, finite element method, deep soil mixing, settlement, soil improvement, expansive soil

1. INTRODUCTION

Structural construction such as building, retaining wall, storage tank and road embankment which lay on expansive soil are several of geotechnical engineering challenge. Expansive soil has high potential swelling-ability due to change of water content inside the soil, that could make the soil highly stiff on dry season, and turn to soft soil layer during rainy season. [1]. During dry condition, high rate of shrink make the soil cracks but provide high internal shear strength. However, in saturated condition, the soil tends to swell with high decrease of shear strength. Therefore, the soil properties are needed to be improved to avoid any damage on the upper structure.

In general, soil improvement work is performed to provide higher strength properties, reduce compressibility, and improving soil permeability. Today's research has provided wide range of expansive soil improvement. One of common method is performing soil stabilization by mixing soil with chemical binder such as lime, cement and or fly ash which expected to provide increases of strength soil parameters [2]. As some soil mixing improvement are performed on top layer with open cut method, other soil mixing method is performed in form of deep soil mixing (DSM) which was developed on Japan and Sweden in 1970's by using soil mixing equipment to develop deep cemented soil column as shown in Figure 1 [3]. Later, many new technologies involving soil mixing equipment which capable to perform soil mixing with wide range of chemical binder in to certain required depth.

According to previous study [4], soil stabilization by using lime has been conducted on soil embankment structure with the expansive soil subgrade in study case soil condition from Ngasem, Kabupaten (district) Ngawi, East Java Province. During dry season, there are many cracks with crack wide up to 5 centimeters. In the other hand, the soil turned softer with high plasticity during rainy season. Later, the soil embankment is stabilized using lime to gain mixed soil [4].

Objective of this study is to observe road embankment structure-subgrade behavior as deep soil mixing (DSM) using lime stabilized soil parameter is provided on subgrade layer, and higher embankment will be applied. Soil parameter and basic subgrade model will be in accordance to previous study reference [4].

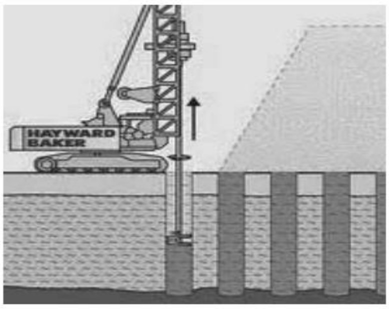

Figure 1. *Deep soil mixing column works*

2. LITERATURE REVIEW

2.1 Effect of lime as stabilization material

Several researches has been done to reduce swelling potential of expansive soil by using lime [5] [6] and resulting that lime could prevent swelling behavior in expansive soil significantly. Pozzolanic reaction in mixed soil causing increasing of soil strength with resulting to higher CBR (California bearing ratio), lower plasticity index (PI) and reduce swelling behavior [7]. Other research shows increasing of cohesion value (*Cu*) and compression strength (*qu*) and spreading of soil cementing reaction throughout column area [2]. Other field observation [8] shows more comprehensive regarding deep mixing column strength and characteristic with more binder variation, area ratio and other soil parameters.

2.2 Effect of deep soil mixing (DSM) in expansive and soft soil.

In principal, during deep mixing soil application, soil stabilization is performed with binder in dry or liquid form injected to the soil depth and provided with mixing equipment to ensure uniform cemented soil along the column [9]. In wet form, binder to be used is such cement (portland cement) combined with water, while dry form of binder material are such lime and fly-ash injected by pneumatic deep mixing equipment.

There are some pattern commonly applied in deep soil mixing method such as triangular patter, square pattern, panels, blocks and grid pattern as shown in Figure 2.

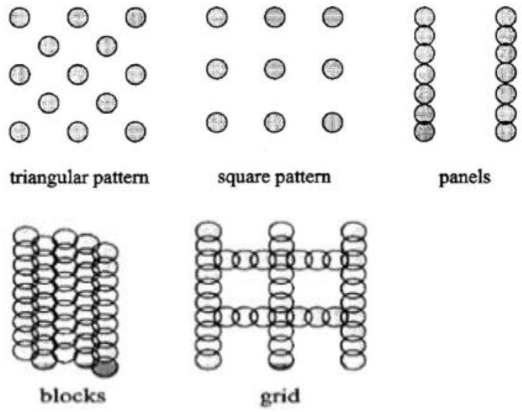

Figure 2. Deep soil mixing pattern types

A study of soil improvement using deep soil mixing with triangular pattern has been conducted by using soil cement [10]. The case study is also added with prefabricated vertical drain (PVD) to accelerate consolidation phase. In the study, excess pore-water pressure is observed as settlement process due to embankment load.

Other observation shows deep soil mixing increase rate of consolidation process than foundation subgrade without treatment [11]. According to performed numerical analysis, higher area ration will decrease consolidation value with indication of curvature change in particular value of area ratio, as shown on Figure 3.

2.3 Parameter of area ratio (a_r) on *deep soil mixing* (DSM) analysis

One of important parameter to understand affectivity of deep soil mixing design is *area ratio* (a_r). *area ratio (a_r)* defined as sum of deep soil mixing area divided by sum of all treated area [12] [13] which can be written as equation 1. On the other hand, *area ratio* could also be defined as sum of deep soil mixing cross section area is divided by total cross section of treated area [14], however the last definition is not used in this study.

In design process or study related to deep soil mixing, it is important to understand an effective or suitable value of area ratio. Thus, not only affect construction project cost, but also determine settlement magnitude of the constructed structure. In order to determine *area ratio* in the project, several variation of column dimension and spacing need to be made.

$$a_r = \frac{A_c}{A} = \frac{A_c}{A_c + A_s} \quad (1)$$

Where a_r is *area ratio*, A_c is area of cemented column, A is total area, A_s is untreated area.

The analysis of numerical method is commonly performed using 2D Finite Element Model (FEM) software, which also be used in this numerical study. In this study, Mohr-Coulomb is used as material model for embankment and construction road (base). Generally, Mohr-Coulomb method is used to analyze soil model to generate common soil behavior such as embankment, slope stability, etc. in the soil model, soil parameter used are Young Modulus (E), Poisson's ratio (v), friction angle, and cohesion. During calculation analysis, soil is modeled as elastic material until a certain strain value which transformed as non-linear which representing elasto-plastic behavior of general soil characteristic.

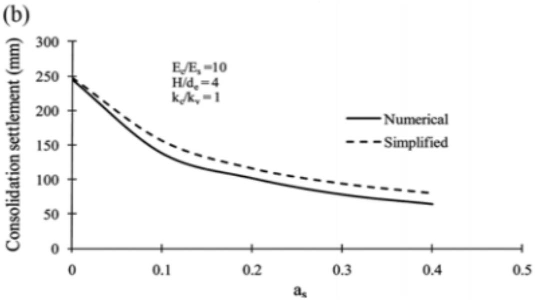

Figure 3. Area ratio to consolidation magnitude [11]

Other soil model used are soft soil model, which commonly used for soft soil analysis with soil condition such as normally consolidated clay, peat and other soft organic soil [15]. The soft soil model shows better approach for soil model that mostly experience compressed treatment or compressible soil layer.

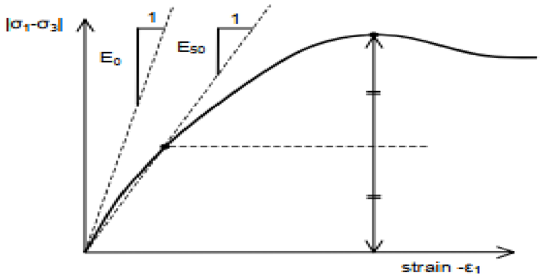

Figure 4. Elasticity curve in Mohr-Column model [15]

3. RESEARCH METHOD

3.1 Material and Soil Parameter

Soil parameter used in this study is subgrade layer which is soft expansive layer, road pavement or base, embankment soil, and deep soil mixing. The deep soil mixing soil parameters is based on laboratory testing data of lime treated soil from Ngasem, Kabupaten Ngawi, East Java Province. The data is provided by previous study [4]. The material has Liquid Limit value > 60 with IP >35 which can be considered as soil with high plasticity index. In this study, lime treated mixed soil then applied as deep soil mixing column as stabilization alternative method than direct mixing method provided in the previous study.

The lime mixed soil data was obtained by laboratory testing with lime content is 8% to volume of treated soil. From previous study [16], this lime content provided optimum value for treated soil with highest CBR soaked and unsoaked value. Furthermore, relationship between stress and strain of the lime treat soil provide better material behavior as the soil is neither to be too brittle nor too soft. Soil parameter has been provided on Table 1.

Considering that swelling-ability of the soil has been stabilized with lime binder [4] [7] [5] [2], therefore, this study will focused on interaction and soil behavior of the embankment and expansive soil which will be applied by deep soil mixing method (DSM).

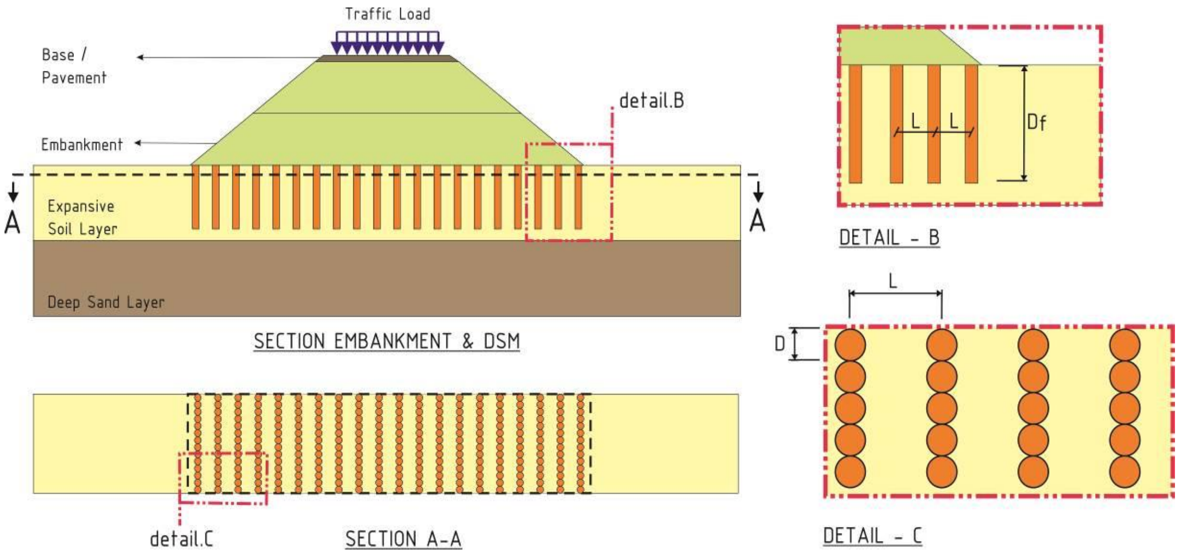

Figure 5. Case study of embankment, construction road, and deep soil mixing column

Table 1. Soil parameter data [4]

Parameter Tanah		Unit	Base	Embankment (Timbunan)	Subgrade (Expansive Soil)	Deep Mixing Soil (DSM)	Deep Sand (Tambahan)
Material Model			MC	MC	SS	MC	MC
Material Type			Non Porous	Drained	Undrained	Undrained	Drained
Thickness		m	0.5	9	8	8/6.5/5	8
Young Modulus	E	kN/m^2	140000	22000	5000	8000	120000
Poisson Ratio	v		0.35	0.3	-	0.25	0.3
Unit Weight	γ_{unsat}	kN/m^3	20	17	16	16	17
	γ_{sat}	kN/m^3	22	20	17.4	17.5	21
Cohesion	c	kN/m^2	5	10	40	126	1
Friction Angel	φ	^{0}	40	30	8	20	33
Dilatation Angel	ψ	^{0}	13	-	-	6	3
Compression Index	c_c	-	-	-	1.034	-	-
Swelling Index	c_s	-	-	-	0.21	-	-
Void Ratio	e_{init}	-	-	-	0.5	-	-
kx		m/day	-	1	0.0008	0.1	0.5
ky		m/day	-	1	0.0008	0.1	0.5

3.2 *Numerical modeling*

Geometrical model of embankment is provided as high as 9 meters with 0.5 meters thick of pavement layer on the top of embankment. Soft soil layer has depth 8 meters, and deep sand underneath the soft expansive soil layer is provided as depth as 8m beneath the expansive soil. The arrangement of geometrical model is shown on Figure 5. As the FEM 2D software capable to run symmetrical model, therefore model in the FEM 2D software is performed with half symmetric geometric model as shown on Figure 8. This modeling will lessen computation analysis duration with lower number of meshes to be calculated. The embankment is divided by two construction stages to simulate construction phase as commonly performed on field.

Given load on the model is distributed load with magnitude 15 kPa in accordance to SNI 8460-2017 Requirement of Geotechnical Design [17], which is minimum distributed load to be applied for traffic load for Class-1 road. This assumption is according to actual road utilization of high frequency uses of heavy tank truck by Government owned Oil-Gas Company.

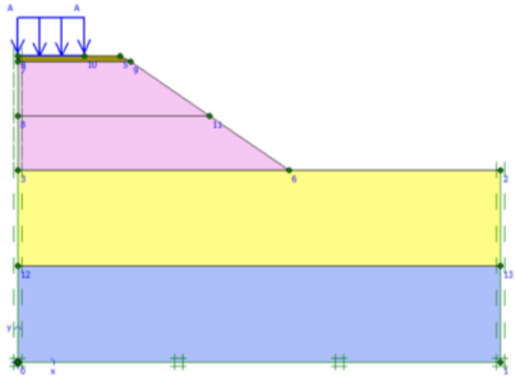

Figure 6. Geometrical model with road construction embankment without deep soil mixing treatment (for control model)

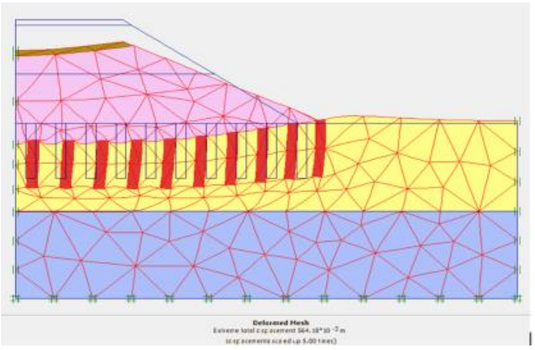

Figure 7. Mesh deformation on variation with diameter 0.8 meters, 2.4 meters space and 5 meters deep soil mixing depth.

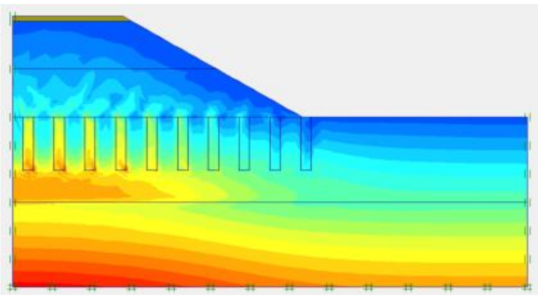

Figure 8. Total stress shading for variation with 0.8 meters diameter, 2.4 meters space and 5 meters depth of the deep soil mixing.

In the study, overall model which generated are 45 models with variation of column diameter, column space along the cross section and depth of the column. The variations of diameter are 0.4 m; 0.6 m; and 0.8 m. For column depth, there are 3 variation such as 5 m; 6.5 m; and 8 m, and for space of column along the section are 0.8 m; 1.2 m; 1.6 m; 1.8 m and 2.4 m.

3.3 Boundary Conditions

Plain strain model is used in this study in coherence with model of deep soil mixing which uses panel pattern type column. The plain strain model considered to be suitable with this study as on the panel type, the cross section of the column panel will act as wall along the assumed direction of road construction. This condition is in accordance with the plain strain modeling concept.

In this study, plain strain model will use mesh element with 15 nodal points. Every geometrical edge, such as right and left hand side edge of the geometrical model, as well as bottom edge, is generated with boundary condition. To avoid uncontrolled displacement along the boundary, each nodal of the boundary need to be assigned for certain value of deformation, and in this case the value is set to 0 (zero) or standard fixities as provided on the software. Moreover, to avoid error and zero displacement to the toe of the soil mixing column, especially for column depth variation of 8 meter, beneath the expansive layer is provided with deep sand layer which representing hard stratum of the soil layer.

When generating process of mesh, each soil cluster will be divided by triangular elements as shown in Figure 9. Coarseness of the mesh is set up as medium setting considering that the setting will provide enough detailed calculation in the other hand will shorten computing process of the model. Mesh generation is indicated on **Figure 7**.

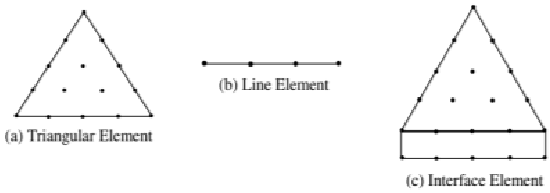

Figure 9. Basic element model for application of mesh generating in the FEM 2D software.

Several construction stage/phases are defined on the software analysis to representing actual construction stage on the field. The construction stage of two divided embankment is set up as 7 days and 15 days, which construction time of base or pavement structure is included the second embankment duration. Consolidation stage for first embankment is added before construction embankment with consolidation duration is 10 days. After completion of embankment and road construction stage, final consolidation stage is analyzed until reach excess pore pressure as low as 1 kPa. Last provided steps are phi-reduction analysis to obtain Safety Factor (SF) value for embankment with given traffic load, and Safety Factor value for embankment construction after final consolidation. However, in this paper, discussion regarding the obtained Safety Factor is not provided.

4. RESULTS AND DISCUSSION

4.1 Effect of deep soil mixing treatment to immediate displacement.

Result for the FEM 2D software analysis shows significant improvement to the soil immediate displacement due to embankment and traffic load. As shown in the graphic on Figure 10, the model shows maximum displacement value of the embankment as high as 1.2 meters. On the other hand, displacement result with expansive soil treated with deep mixing soil obtained lower displacement value from 0.2 meters to 0.6 meters. Defined variation of the graph is variation group with 0.6 meter diameter and 6.5 meters of column depth. Displacement value shows similar trend with other variation group with column depth of 5 meters and 8 meters.

Total stress shading of the structure which demonstrated by Figure 8 show that higher stress is occurs along the DSM column than surrounding subgrade soil. This condition indicating that DSM columns which has higher modulus and soil strength, support the embankment structure and transfer it to bottom layer. Higher stress contour straight to the column bottom is also indicating that stress of the column is transferred to the bottom subgrade layer.

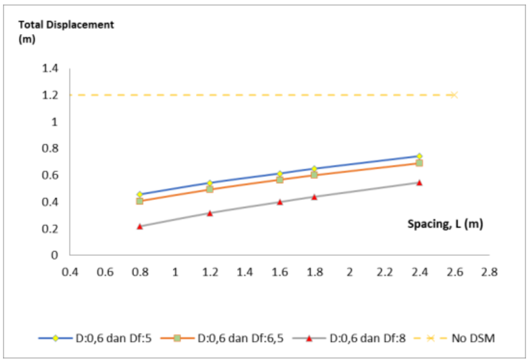

Figure 10. Immediate displacement to DSM spacing (L) of 0.6 meters diameter variation

4.2 Effects of *area ratio* (a_r) long term displacement (consolidation) and immediate displacement.

The uses of area ratio will give ease observation to researcher to understand behavior of deep soil mixing, where several different dimension and space variation can be represented by one parameter. In this study, *area ratio* for each variation is obtained by variation of diameter and length/space between soil mixing column panels as shown on Table 2. According to the table, increasing volume of column and total treated area are linearly correlated with increase of *area ratio* value.

Table 2. *area ratio* of each variation on *deep soil mixing (DSM)*

Variasi DSM	Area Ratio (a_r)
D:0,4 m L:0,8 m	0.393
D:0,4 m L:1,2 m	0.262
D:0,4 m L:1,6 m	0.196
D:0,4 m L:1,8 m	0.174
D:0,4 m L:2,4 m	0.131
D:0,6 m L:0,8 m	0.589
D:0,6 m L:1,2 m	0.393
D:0,6 m L:1,6 m	0.294
D:0,6 m L:1,8 m	0.262
D:0,6 m L:2,4 m	0.196
D:0,8 m L:0,8 m	0.785
D:0,8 m L:1,2 m	0.523
D:0,8 m L:1,6 m	0.393
D:0,8 m L:1,8 m	0.349
D:0,8 m L:2,4 m	0.262

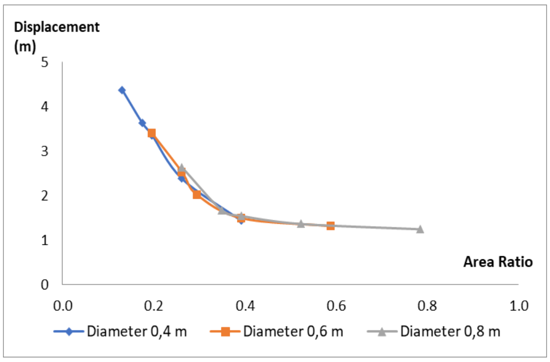

Figure 11. Area ratio to consolidation displacement of deep soil mixing column with 5 meters depth

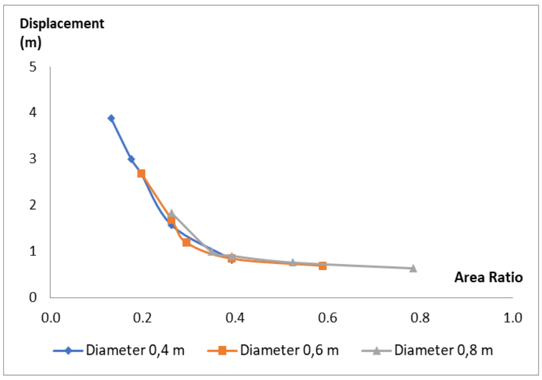

Figure 12. Area ratio to consolidation displacement of deep soil mixing column with 6.5 meters depth

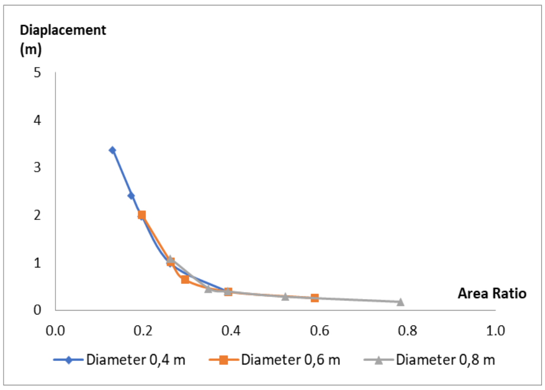

Figure 13. Area ratio to consolidation displacement of deep soil mixing column with 8 meters depth

The FEM 2D software analysis result on Figure 11, Figure 12, and Figure 13 shown decrease pattern of displacement value due to consolidation process for each *area ratio* value. Displacement value with for deep soil mixing (DSM) with depth 8 meters show lower maximum displacement than displacement of depth variation 5 meters. This result proved that more deep of the treated column will provide lower maximum consolidation displacement. This result supports the previous study as shown as on **Figure 3.**

According to the result, variations of deep soil mixing column that have same or close value, will have same or close will resulting on similar displacement value. For example, both of variation of D:0.4 m;L:0.8 m;Df:6.5m and variation of D:0.6 m;L:1.2m; Df:6.5m have area ratio value as 0.262. as the result, two variations obtain displacement value 1.57 m and 1.69 m respectively. As a conclusion, the uses of area ratio will provide better approach for deep soil mixing design or study observation for its behavior.

Furthermore, graph of Figure 11, Figure 12, Figure 13, and Figure 15 of area ratio show change of curvature significantly in area ratio 0.393. According to the graphs, decreasing rate of displacement from 0.131 m to 0.393 m has steep decreasing line, while decreasing rate of displacement between 0.393 m to 0.785 m has more sloping line, which indicated that area ratio beyond 0.393 have insignificant decreasing displacement and consolidation duration. This result could visualize the efficacy of certain area ratio to the long term displacement and achievement duration of consolidation time. Therefore, the most effective deep soil mixing variation in this study is provided by variation of D:0.4 m; L:0.8 m; D:0.6 m; L:1.2 m and D:0.8 m; L:1.6 m with the three provide area ratio of 0.393.

However, during analysis of immediate displacement by embankment and traffic load as shown on Figure 14, line curvature does not change significantly along the rate of decreasing settlement. Therefore, this behavior of area ratio to short term displacement shall be subject to be observed for next study and discussion forward.

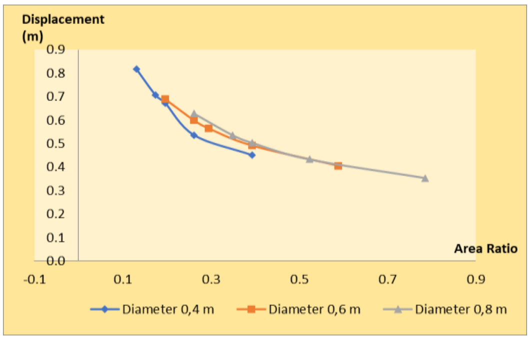

Figure 14. Area ratio to immediate displacement of deep soil mixing column with 6,5 meters depth

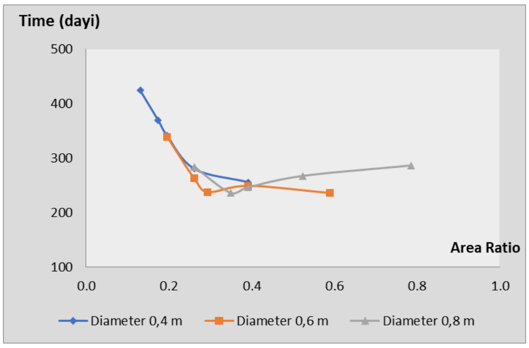

Figure 15. Area ratio to total consolidation time of deep soil mixing with 6.5 meters depth

5. CONCLUSION

1. Application of lime as soil binder in soil improvement of expansive soil using deep soil mixing method (DSM) could provide increasing of soil bearing capacity and better subgrade behavior to embankment and traffic loading.
2. Increasing of treated area of deep soil mixing which could be represented by increasing of area ratio could provide decreasing of displacement value of road embankment structure. Therefore increasing of road capacity and its serviceability could be achieved.
3. Uses of area ratio could provide ease observation of the researchers to understand deep soil mixing behavior, as well as determine an effective or optimum area ratio value for every deep soil mixing dimension and spacing variation.

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