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IMPROVEMENT OF EXPANSIVE SUBGRADE USING COLUMN TECHNIQUE OF CARBIDE LIME AND RICE HUSK ASH MIXTURES

Agus Setyo Muntohar [1]

ABSTRACT: Pavement deficiencies on expansive clay have been found as the result of the heave and shrink effect of the expansive soil during seasonal period. This paper paper presents a result of the utilization of carbide lime and rice husk ash mixture for improving performance of expansive soil. The carbide lime and rice husk ash was mixed to form SiCC columns in expansive soil. Application of the SiCC column supported flexible pavement was investigated numerically using finite element method. Two column shapes that are conventional (O-Shape) and enlarged column cap (T-Shape) were investigated in axi-symmetric model. The soil was modeled to have about 5% swelling, while 80 kN standard axle load was applied on pavement surface. The results show that the T-Shaped column can improve the settlement stability of soil between columns remarkably, while narrowing column spacing can reduce the settlement of soil effectively. A columns spacing of 3D to 5D is reasonable to reduce maximum settlement of the pavement due to heave and vehicle load.

Keywords: expansive soil, flexible pavement, SiCC column, finite element, heave.

INTRODUCTION

Expansive soils are the soils which swell significantly when come in contact with water and shrink when the water squeezes out. The severity of damages done by expansive soil has been well documented in literature worldwide (Chen, 1988; Nelson and Miller, 1992; Gourley et al., 1993). Expansive soils are frequently encountered in the Indonesia lowland in areas where favorable environments exist. Muntohar (2006) found the deterioration of a road section at Sta. 8 + 127 of the Purworejo-Wates road which is a national highway at south-path. Pavement deficiency on expansive clay was also found in Cikampek highway (Abadi, 2007). Some traditional methods using lime, fly ash, cement, and any other chemical materials have been introduced to stabilized the expansive soil to enhance the strength and reduce the expansiveness. An innovation method using Cakar Ayam Modifikasi (CAM) has been investigated by Hardiyatmo and Suhendro (2010) as an monolithic continuous reinforced rigid pavement and short pile system on expansive soil.

Lime-column or lime pile and lime/cement column reinforced expansive soil has been studied by Swamy (2000), Tonoz et al., (2003), Muntohar (2003), Rao and Thyagaraj (2003). The technique was adopted from mini pile foundation to control the heave and deformation (Hewayde et al. (2005). The application of the lime-column can be extended to reinforce flexible pavement system on expansive soil. However, use of lime, that produces from calcinations and hydration of calcium carbonate, needs a huge amount of limestone quarry. Excavation the limestone can trigger environment decay. Utilization industrial waste enriched lime e.g. carbide waste is a benefit for environment and construction. Abundant of another solid waste such as rice husk ash, can be mixed with carbide lime to form a cementitious materials. The shear strength properties of the carbide lime and rice husk mixture to improve expansive clay has been studied intensively by Diana et al. (2012) and Muntohar et al. (2014).

Based on the previous results, this paper presents a result of the utilization of carbide lime and rice husk ash mixture for improving performance of expansive soil. The carbide lime and rice husk ash was mixed to form SiCC columns in expansive soil. Application of the SiCC column supported flexible pavement was

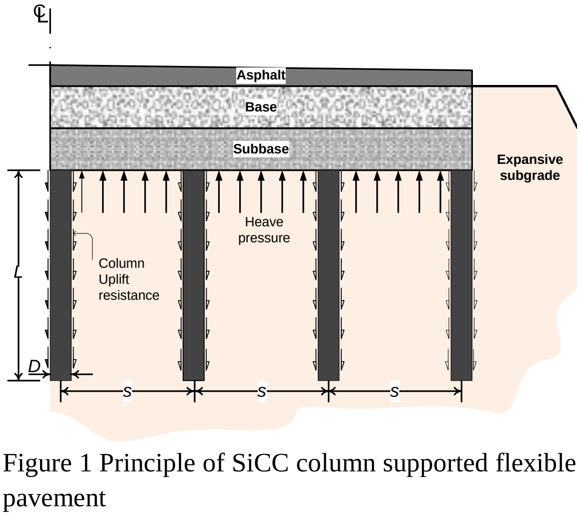

Figure 1 Principle of SiCC column supported flexible pavement

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investigated numerically using finite element method. The main objective of the study is to investigate the deformation of the SiCC column system reinforced flexible pavement due to heave of expansive soil and to obtain an optimum column size and spacing column to column. The principle of SiCC column supported flexible pavement is illustrated in Figure 1.

NUMERICAL ANALYSIS

Soil Models and Parameters

The behavior of a subgrade reinforced with either a group of SiCC column was investigated in this paper using numerical analyses. The case was analyzed as an axi-symmetric problem using PLAXIS 2D software. The model is shown in Figure 2. Two column shapes that are O-Shape and T-Shape models were investigated in the numerical simulation. The O-Shape column is a circular column with diameter of 0.15 m (Figure 2a). The T-Shape column is a circular column of 0.15 m in diameter (D) and enlarged column cap of 0.3 m in diameter. The length of enlarged column cap is 0.3 m (Figure 2b). The total length of the column was 1 m. The center to center columns spacing was varied into 3D, 5D, 6D, 9D, and 13D.

The expansive clay, the column and pavement materials (subbase, base, and asphalt layer) were modeled using the hardening soil model (HS) in PLAXIS (Schanz et al., 1999). The material properties used in the finite element analyses is presented in Table 1. The pavement subjected to standard axle load 80 kN that is equivalent to 400 kPa pressures at each wheels. The load configuration is shown in Figure 2.

Modeling Soil Heave

Heave of the expansive clay was modeled by applying a volumetric strain to the reactive clay layer. For simplicity, in the analyses presented herein, the 5% volumetric strain was applied uniformly across the full thickness of the clay layer. However in reality, the swelling rate of expansive clay would normally expand depends on the location from the source of moisture and magnitude of overburden pressure. For comparison the heave effect, the pavement model without columns was also simulated in this study. The variation of heave is observed at three locations that are at column tip (A), column cap (B), and pavement surface (C).

RESULTS AND DISCUSSION

In this research the effect of heave is discussed in two conditions (1) without load, and (2) with load. The first condition refers to a condition before opening the traffic, while the last represents a condition with traffic.

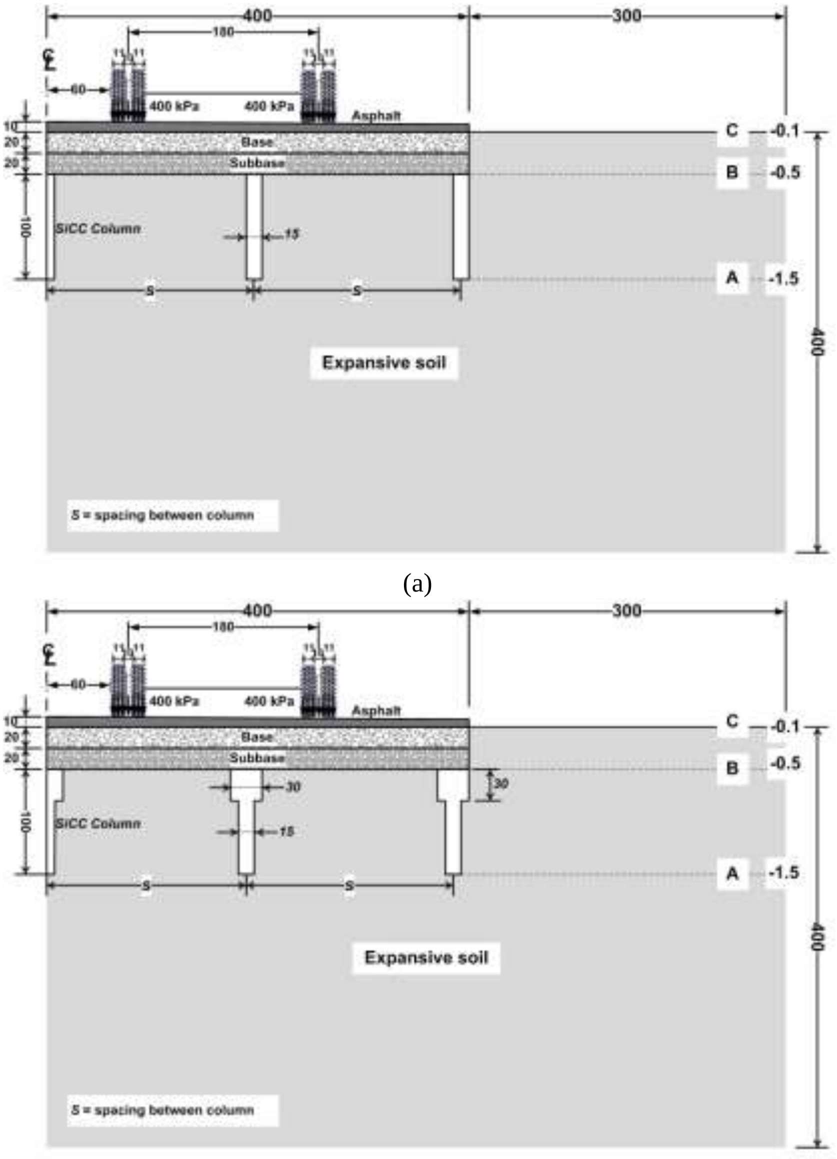
Behavior Due To Heave

The behavior of the SiCC column reinforced pavement system due to heave before applying vehicle load (condition 1) is illustrated in Figure 3. In general, the highest heave occur at pavement surface, and decreases with depth. The pavement without columns experiences to have maximum uplift deformation at the edge side. The uplift deformation at centerline of roadway is about 0.11 m to 0.16 m and increases to about 0.12 m to 0.17 m at the edge side of pavement. Installing SiCC columns reduces the heave at subgrade. Reverse arching pattern was observed at subsoil as shown in Figure 3a and 3b. At the columns tip, the heave is greater than the heave without columns support. But, the heave of soil between columns decreases. For this case, the SiCC column was not installed into passive

Table 1. Material properties used in the finite element analyses

Parameter	Expansive Soil	SiCC Column	Subbase layer	Base layer	Asphalt
γ_{unsat} (kN/m^3)	17	17	22	21	25
γ_{sat} (kN/m^3)	20	20	24	23	25
E_{50}^{ref} (MPa)	0.718	3.317	200	400	4×10^3
E_{oed}^{ref} (MPa)	0.575	2.653	220	440	4.4×10^3
E_{ur}^{ref} (MPa)	3	4	1×10^3	2×10^3	2×10^4
υ_{ur}	0,495	0,495	0.35	0.45	0.4
m	1	0.5	0.5	0.5	0.5
c' (kPa)	57	43	20	30	30
ϕ' (degree)	15	46	40	40	40

Note: E_{50}^{ref} is the deformation modulus at 50% of strength at reference pressure p$^{(ref)}$; E_{ur}^{ref} is the unload-reload deformation modulus at reference pressure; E_{oed}^{ref} is the incremental constrained modulus at reference pressure; υ_{ur} is the unload-reload Poisson's ratio; m defines dependency of stiffness on lateral effective stress



(a)

(b)

Figure 2 The model of SiCC columns supported flexible pavement on expansive soil, (a) circular shape column (O - Shape), and (b) circular shape with enlargement of column head (T-Shape).

zone, hence the columns behave as floating pile. As the result, the columns experience to move vertically. However in general, this behavior illustrates that the SiCC columns supported flexible pavement can prevent the soil to experience extreme heave.

As mentioned previously, at the pavement surface, the deformation due to heave increase to the edge side of pavement. The SiCC lime columns reduced the deformation from 0.17 m to 0.15 m at the near edge side (Figure 3c). But, the deformation at the centerline of roadway increase from 0.16 m to 0.165 m. This result indicates that modeling heave effect of columns supported flexible pavement was a complex soil-structure interaction problem. A similar behavior was observed for piled embankment on soft soil as studied in Satibi (2009) and Poulos (2007).

Behavior Due To Heave and Vehicle Load

Figure 4 shows the deformation of SiCC supported flexible pavement due to heave and vehicle load. In general, the pavement goes to settle from the centerline of roadway to a distance of 3 m and the upward deformation was observed at the rest section. Without the SiCC column, the pavement structure experiences an extreme settlement and upward movement under the applied load. Installing the SiCC column can reduce and maintain the settlement of subsoil (Figure 4a and 4b) and pavement surface (Figure 4c). It should be noted that extreme upward deformation at the edge side because of the combination of heave and loading that depends on the soil model and parameter. The higher the soil strength parameters and soil stiffness the lower the

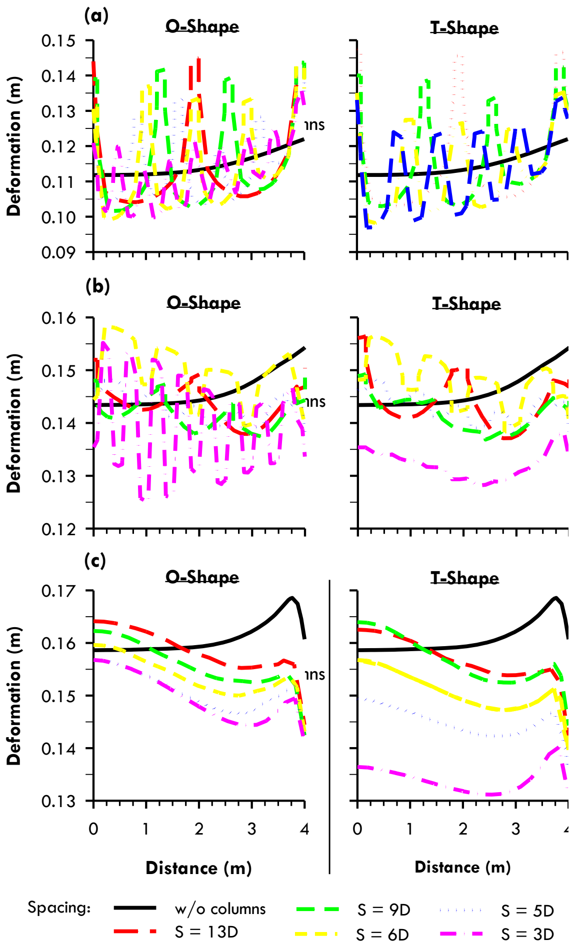


Figure 3 Heave simulated from FEM (a) at depth -1.5 m (column tip), (b) depth -0.5 (column cap) and (c) pavement surface.

maximum and differential settlement at the subsoil and pavement surface (Jenck et al., 2007).

Effect of Column Spacing

Figure 5 shows relationship between the spacing and heave of subgrade (location B) and pavement surface (location C) at centerline of roadway. Results show that narrowing column distance can reduce the heave at the pavement (Figure 5a) and subgrade (Figure 5b). It was found that heave reduces as column spacing reduces. Column spacing of 5D is reasonable in terms of heaving control and economic purposes. Narrowing columns distance can reduce the heave of soil effectively. A closer spacing results in arching effect at subgrade. Zhang et al. (2010) mentioned that horizontal displacement on neighboring piles induced the deformation of soil between the piles. In this study, arching heave effect was found when the spacing is smaller than six times of the column diameter (6D) as shown in Figure 4b and 5b.

Figure 6 shows the effect of columns spacing on the settlement of pavement at the centerline of roadway due

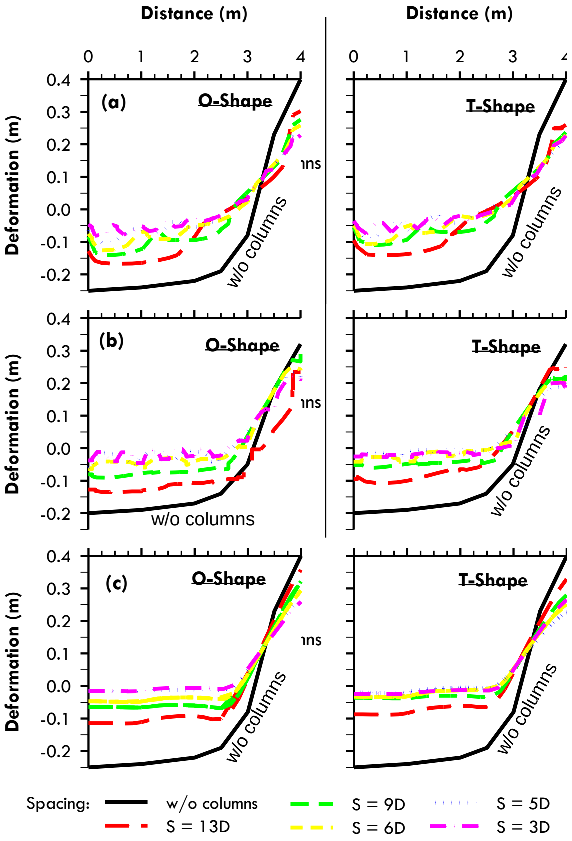


Figure 4 Deformation simulated from FEM (a) at depth -1.5 m (column tip), (b) depth -0.5 (column cap) and (c) pavement surface.

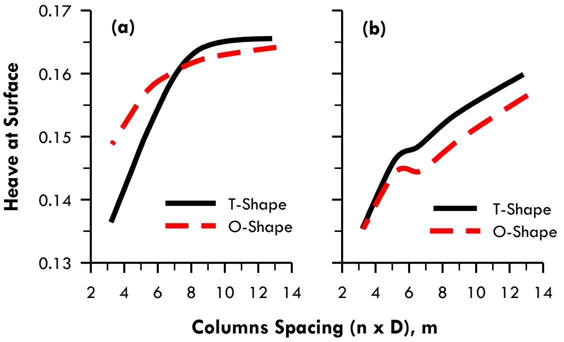


Figure 5 Relationship between the spacing and heave (a) at pavement surface, (b) at subgrade surface.

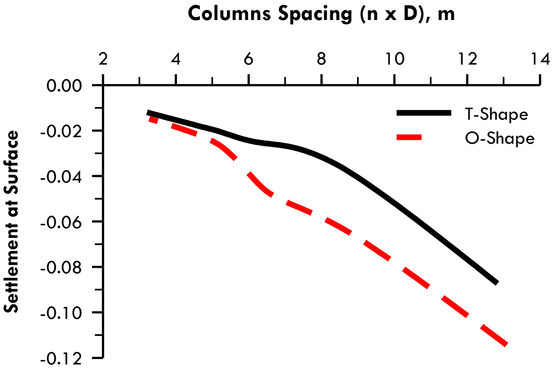


Figure 6 Relationship between the spacing and settlement of pavement surface due to heave and vehicle load.

to heave and vehicle load. Increasing column spacing obviously decreases the pavement load transferred to the columns. This leads to the decrease of efficacy and the increase of maximum and differential settlements and soil arching ratio of a column supported flexible pavement. A columns spacing of 3D is reasonable to reduce maximum settlement of the pavement due to heave and vehicle load as shown in Figure 6.

Effect of Enlarged Column Cap

Results in Figure 5 and 6 shows that enlarging the diameter of column cap (T-Shape column) can minimize heaving of expansive soils and improve the settlement stability of soil between columns remarkably. As shown in Figure 6, the settlement at the pavement surface reduces by double for T-Shape column if compare to conventional columns (O-Shape). The T-Shape column reduces significantly the settlement of the pavement due to the applied load. The effect of the enlarged column cap of the SiCC column is similar to the effect of increasing the percentage coverage of pile caps in rigid pile–supported embankments, which can increase pile efficacy and suppress differential settlement of ground surface (Han and Gabr, 2002), Liu et al. (2012). In this study, the column percentage coverage or the column area replacement ratio (a_s) of the T-Shape column is double of the O-Shape column.

CONCLUSIONS

The results of a series of axi-symmetric FE analyses to investigate the heave and settlement of flexible pavement supported by SiCC columns over a expansive subsoil have been reported. The analyses demonstrated that the centre-to-centre column spacing (S) is a key parameter to control heave and settlement. Increasing column spacing obviously decreases the pavement load transferred to the columns. This leads to the decrease of efficacy and the increase of maximum and differential settlements and soil arching ratio of a column supported flexible pavement. Enlarged column cap (T-Shape column) reduced significantly the settlement of the pavement due to the applied load. Narrowing columns spacing can reduce the settlement of soil effectively. A columns spacing of 3D to 5D is reasonable to reduce maximum settlement of the pavement due to heave and vehicle load.

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