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Study of Reinforced Soil Embankment Supported on StoneColumn Improved Ground

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Abstract: In the present paper, a parametric study with the help of numerical modeling is carried out to understand the effect of basal reinforcement using uni-axial geogrid on stone column supported embankment. A comparative study was also performed to understand the embankment behavior with and w/o basal reinforcement (BR). The governing factors such as basal reinforcement tensile stiffness, stone column spacing, soil stratum thickness, soil shear strength parameter and embankment height are considered for analysis. The Two-Dimensional (2-D) plane strain numerical modeling is carried out with the finite element software Plaxis 2D. Stone column modeling with the gravel trench method and homogenizing method is carried out. From the study, it was found that the influence of stresses acting on stone columns and surrounding soil, settlement profile along the embankment base, stability of the embankment, and horizontal soil deformation beneath the embankment toe are affected by basal reinforcement presence.

Keywords: Basal reinforcement; stone column; Plaxis2D, embankment, geogrid

1 Introduction

Embankment construction on soft soil is a challenging task. To cater to the needs of industrial expansion, transportation plays a key role in the economic development of any country. Due to the development of railways and highways, which many times require construction at a higher grade level than the existing natural level on soft soil, their settlement and bearing requirements need to be satisfied to ensure safe and economic transportation. Various field and numerical studies have been conducted for stone column supported embankments (Murugesan & Rajagopal, 2006), (Ambily & Gandhi, 2012). Based on available literature for embankments on soft soil, basal reinforcement has been extensively used in the construction of embankments on soft clays (Han and gabber, Bathurst & Naftchali, 2021, Zheng 2020 et. al.). The piled embankment with basal reinforcement has been widely used in the construction of roadways and highway embankments in Europe.

It was found that a handful of studies have been observed on stone column supported geosynthetic reinforced embankments resting over soft soil. (Deb & Mohapatra, 2013). A basal geosynthetic reinforcement can aid in resisting the earth pressure within the embankment and prevent lateral deformation of its foundation, thereby increasing bearing capacity and stability. (Yoo & Kim, 2009). The application of geosynthetic reinforcement helps to transfer stresses from the soft soil to the columns (Rowe & Li, 2002). The application of stone columns fulfils the combined benefit of stability and increased bearing capacity of embankment supported on the soft clay foundation (Jayapal & Rajagopal, 2020).

In this paper, 2D plane strain modeling of stone columns with geosynthetic reinforced embankment is carried out following the gravel trench (G) and homogenization (H) approach. In the present parametric analysis, embankment stability and deformation behavior were studied considering multiple factors such as basal reinforcement tensile strength, stone column material stiffness, spacing and length, soil strata thickness and shear strength parameters, and embankment height. The homogenization method consists of replacing the stone column and soft soil with an equivalent homogeneous soil with improved properties (Castro, 2017). The ratio of the amount of soft soil replaced by the stone column is called the area replacement ratio (as). By varying the area replacement ratio (as) and material parameter and without making a change in geometry, various combinations of different parameters can be analyzed at the design stage. Especially when the geometry is complex (Gupta 2022 et al.). For the gravel trench method, Tan et al. (2008) proposed two different methods to convert the geometry of a single stone column in 2D plane strain from a three-dimensional model. In the first method, soil permeability is changed while maintaining the column diameter constant while in the second method column diameter is changed by maintaining the soil permeability constant. After field validation he found the second method to be more reliable than the first one. For the present parametric study second approach is employed for analysis.

2 Numerical Modeling

2.1 Model Validation

In order to validate the modelling of the stone column supported embankment, the solution of (Abusharar & Han, 2011) is selected. The dimension of geometry is provided as follows: the width of column is 0.8m, the column length is 10m, the c/c column spacing is 4.0m, the embankment crest width is 20, the height of embankment is 5m and the angle of side slope is 2(H):1(V). The material parameters are shown in Table 1. The finite element software Plaxis 2D is used to validate the model. The location of the critical slip surface generated in both methods is observed and found reasonably similar. Figure 1 shows the critical failure pattern observed in cases with and without water table.

Table 1. Soil property considered in the present parametric study (after Abusharar & Han, 2011)

Parameter	Unit	Embankment fill	Clay	Sand	Stone column	Equivalent area
Thickness	m	5	10	2	10	10

Unsaturated unit weight	kN/m^3	18	16	18	17	16.2
Porosity	-	0.25	0.25	0.25	0.25	0.25
Cohesion	kPa	0	0	0	0	16
Friction angle	°	32	30	30	38	8.9

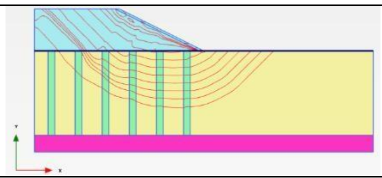	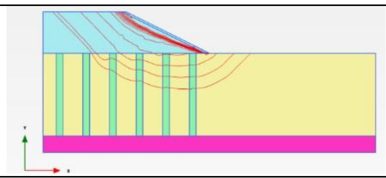
Case a) Individual column considering water table	Case b) Individual column without considering water table

Figure 1: Embankment stability with gravel trench method (Case a) with considering water table and (Case b) without considering water table

Table 2. Factor of safety (after Abusharar & Han, 2011)

Ground water condition	**Modified after Abusharar & Han, 2011**		**Current FEM model**	
	Individual column	Equivalent area method	Individual column	Equivalent area method
With water table	1.49	1.6	1.485	1.464
Without water table	1.53	1.69	1.531	1.48

Table 2 shows the factor of safety derived with the gravel trench method and homogenization method with the current FEM based model and existing Finite difference method-based software by Abusharar & Han, 2011. The result derived from current model shows good agreement with that of model used for validation purpose for both homogenisation and gravel trench method.

2.2 Present Parametric Study

For the present study plane strain configuration is adopted for modeling stone column supported basal reinforced embankment. The governing parameter such as basal reinforcement tensile stiffness (J), stone column spacing (S), soil stratum thickness, soil shear strength parameter and embankment height are considered for analysis.

In the study, the stone column termination is considered in two different soils. In ground model A, the stone column is terminated in soft soil. While in ground model B, the stone column is terminated in medium dense sand. For model A, soft clay layer depth is taken as 14.0m, while for model B, it is considered as 10.0m. Thereafter medium-dense sand is considered for both models. The stone column length and column diameter is kept constant for both the models. For each combination, modeling is carried out with gravel trench method and homogenization method. The embankment is constructed in 2.0m lift. It is assumed that excess pore pressure is dissipated while construction.

Table 3. Soil properties considered in present parametric study

Material property	Embankment Fill	Stone column	Soft clay	Medium Dense Sand
Unit weight, kN/m^3	20	20	19.45	18.5
Friction angle, °	30	34	-	30
Undrained cohesion, kPa	5	-	25	-
Poison ratio	0.3	0.3	0.4	0.3
Modulus of elasticity, kPa	20000	65000	5500	22000
Material behavior	Drained	Drained	Undrained	Drained

The parameters adopted for ground modeling are in the range recommended by manuals and various available literature. (Ambily & Gandhi, 2012, Zheng 2020). Table 3 shows the material parameter used for modeling the ground profile. The uniaxial geogrid as basal reinforcement with tensile stiffness (J1) of 3000 (kN/m) at 5% strain is considered for analysis. The stone column spacing variation is kept at 1.5m (S1) and 1.8m (S2) c/c. Figure 2 shows the embankment geometry adopted for the analysis. One row of columns is extended from outer edge of the embankment to maintain the confinement. Here (J0) indicates the absence of basal reinforcement.

Table 4. Parametric study combination for stone column supported basal reinforced ground

Method of analysis	Combination	Height of Embankment (m)	Method of analysis	Combination	Height of Embankment (m)
Ground Model A- Gravel trench method	AG_6m	6	Ground Model B- Gravel trench method	BG_6m	6
	AG_8m	8		BG_8m	8
	AG-S1-J0_6m	6		BG-S1-J0_6m	6
	AG-S1-J0_8m	8		BG-S1-J0_8m	8
	AG-S1-J1_6m	6		BG-S1-J1_6m	6
	AG-S1-J1_8m	8		BG-S1-J1_8m	8
	AG-S2-J0_6m	6		BG-S2-J0_6m	6
	AG-S2-J0_8m	8		BG-S2-J0_8m	8
	AG-S2-J1_6m	6		BG-S2-J1_6m	6
	AG-S2-J1_8m	8		BG-S2-J1_8m	8
Ground Model A- Homogenization method	AH-S1-J0_6m	6	Ground Model B- Homogenization method	BH-S1-J0_6m	6
	AH-S1-J0_8m	8		BH-S1-J0_8m	8
	AH-S1-J1_6m	6		BH-S1-J1_6m	6
	AH-S1-J1_8m	8		BH-S1-J1_8m	8
	AH-S2-J0_6m	6		BH-S2-J0_6m	6
	AH-S2-J0_8m	8		BH-S2-J0_8m	8
	AH-S2-J1_6m	6		BH-S2-J1_6m	6
	AH-S2-J1_8m	8		BH-S2-J1_8m	8

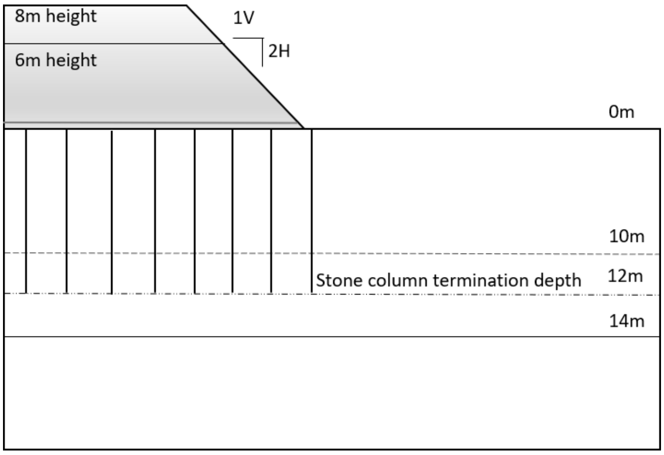

Figure 2: Numerical Model Adopted for Parametric Study

3 Result and Discussion

The main objective of this present study is to understand the deformation and stability behavior of stone column supported embankments with basal reinforcement. The settlement profile along the embankment base, stability of embankment and horizontal soil deformation beneath the embankment toe are affected by basal reinforcement presence. Two ground models are studied with respect to stone column termination depth.

As shown in Figure 3 and Figure 4 uneven settlement was observed at the ground surface due to stiffness difference between the column and surrounding soil. The same is not reflected in Figure 5 showing the base settlement with homogenization method. Upheaving deformations of soft soil foundation was noticed outside of the embankment. Maximum upheaval was observed in the ground with minimum area replacement ratio. The upheaval was observed at a distance from embankment edge. Settlement is measured at 0.1m below from ground level.

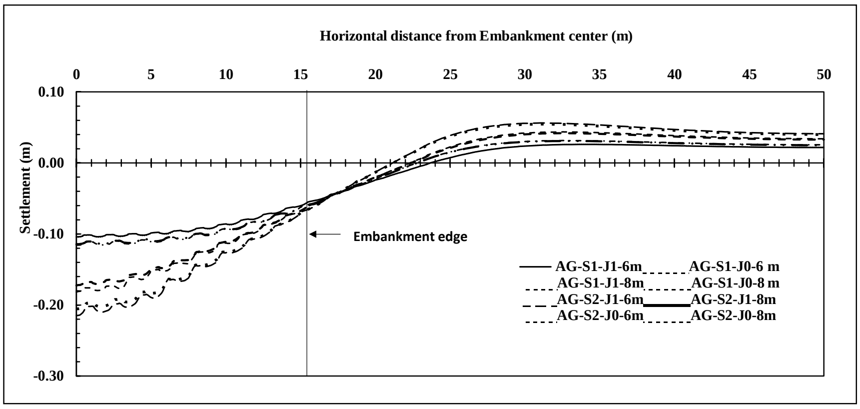

Figure 3: Base settlement for Ground model A

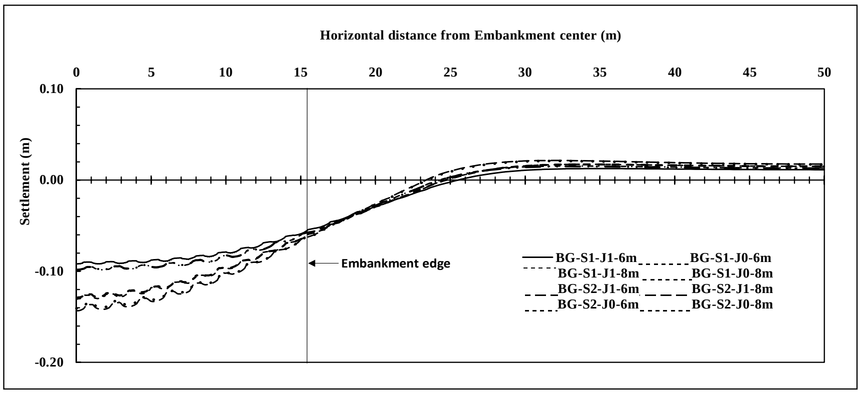

Figure 4: Base settlement for Ground model B

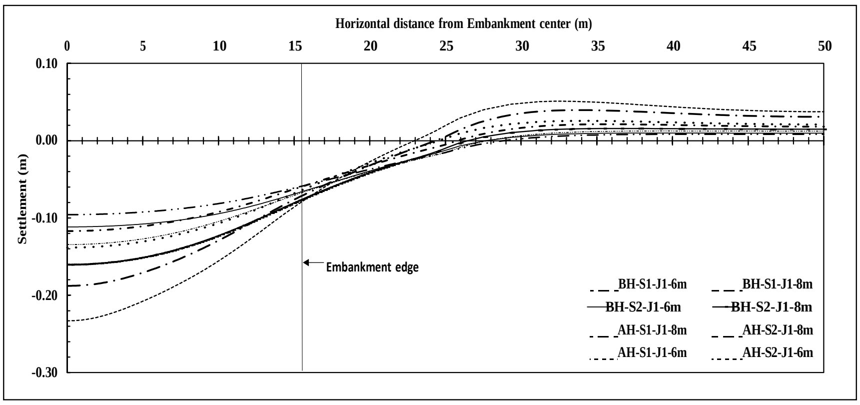

Figure 5: Base settlement with Homogenization method for Ground models A and B

The lateral deformation of column at 1m inside the embankment toe is shown in Figure 6 and Figure 7 for both the ground condition with stone column c/c spacing of 1.5m and 1.8m for embankment height of 6.0 and 8.0m. Lateral deformation observed with stone column terminating in ground condition with model A has significantly more deformation when compared to ground model B. i.e. stone column terminating in soft ground has significantly more deformation at top and bottom compared to column terminating in stiff soil with and without the basal reinforcement. Lateral deformation at top, middle and bottom in stone column for a 6m high embankment with columns terminating in medium dense sand has 25%, 36% and 51 % variation compared to columns terminating in soft clay at respective levels for both the spacing condition. While for an 8m high embankment it is 33%,46% and 65 % variation at top, middle and bottom levels in stone column for both spacing. Nearly similar behavior is observed in cases without basal reinforcement.

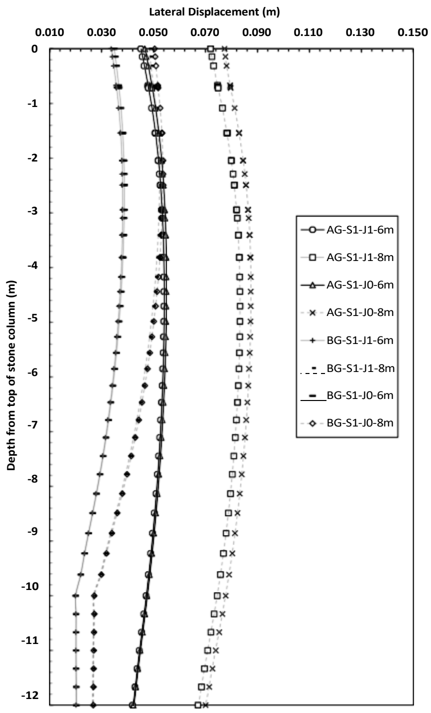

Figure 6: Effect of basal reinforcement of lateral deformation of column near embankment toe for 1.5m c/c stone column spacing with Case A and Case B ground condition

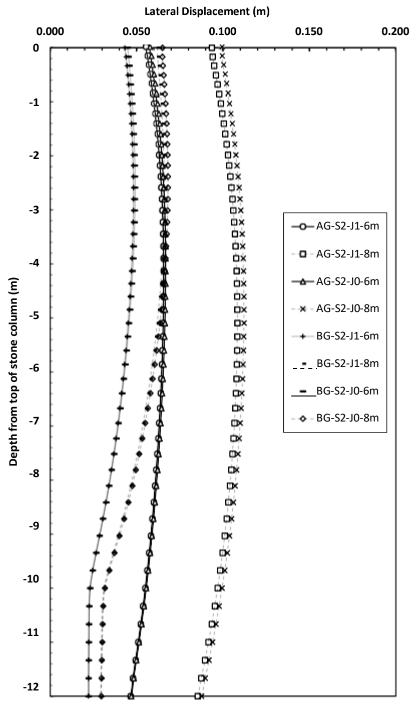

Figure 7: Effect of basal reinforcement of lateral deformation of column near embankment toe for 1.8m c/c stone column spacing with Case A and Case B ground condition

Stability analysis for embankment is conducted for ground condition with all the parametric combinations shown in Table 4. Figure 8 and Figure 9 shows the factor of safety for 6.0 m and 8.0m embankment height for all reinforced and unreinforced ground combination with gravel trench and homogenization method. There is a 4% to 6% variation in the factor of safety in absence of basal reinforcement for ground model A. With ground model B it is observed to be 9% to 12 % in absence of basal reinforcement for both the column spacing.

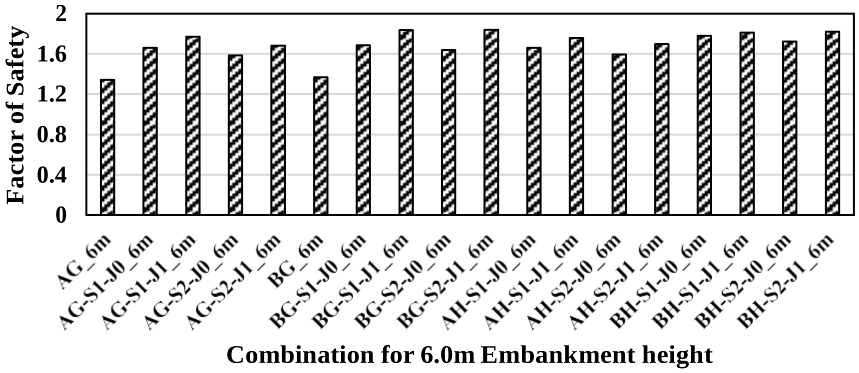

Figure 8: Factor of Safety with Ground Model A for different reinforcement and stone column spacing condition

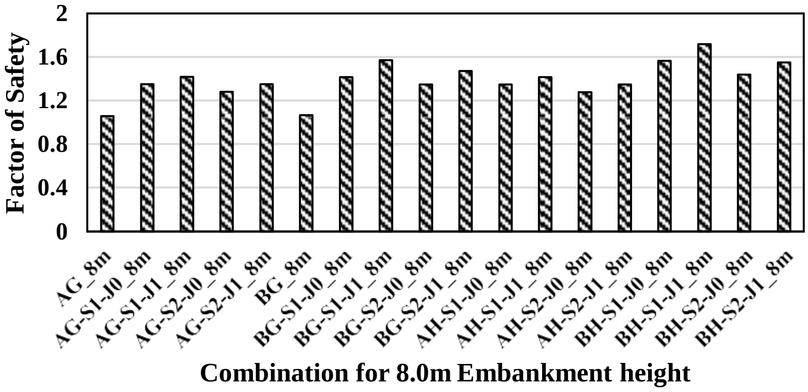

Figure 9: Factor of Safety with Ground Model B for different reinforcement and stone column spacing condition

From Figure 8 and Figure 9, it is clear that the gravel trench method and homogenization method predicts reasonably accurate safety factor for ground model A, stone column terminating in soft clay. While the maximum error between both the methods is 10.67%, for ground model B, stone column terminating in medium-dense sand.

4 Conclusion

In this study stability and deformation behavior of stone column supported geosynthetic reinforced embankment is analyzed with two different modeling methods and two different ground conditions. The effect of various parameters such as soil stratigraphy, stone column spacing and geogrid stiffness was examined. From the analysis the following conclusions can be drawn:

1. Basal reinforcement has noticeable influence on lateral soil deformation of the embankment and below the embankment ground for both stone columns

terminating in soft soil and medium dense sandy soil. The stability of the embankment is significantly influenced by uniaxial geogrid presence. For higher height embankment (h/Hs >0.57), resting on soft clay basal has a noticeable influence on base settlement, specifically for stone columns terminating in soft soil.

2. Stability, base settlement and lateral deformation significantly are affected more by stone columns spacing for stone columns terminating in soft soil rather than medium-dense sand.
3. Gravel trench method of stone column analysis has a similar output for base settlement and stability for stone column terminating in soft soil.
4. Lateral deformation is more significant for stone columns terminating in soft soil than in medium dense sand. In absence of basal reinforcement, while measuring lateral ground deformation, there is 4.5% & 8% variation for 6m and 8 m height respectively for ground model A with gravel trench method. Similarly, for Ground model B for 6m and 8m height, it is 3.7 & 6.5 and with gravel trench method. The maximum variation is observed at top of the stone columns for both ground models.
5. Homogenization method predicts a similar base settlement profile and factor of safety for stone columns terminating in soft soil when compared with gravel trench method. While there is a noticeable deviation in the condition when stone column terminates in medium-dense sand.

References

Abusharar, S. W., & Han, J. (2011). Two-dimensional deep-seated slope stability analysis of embankments over stone column-improved soft clay. *Engineering Geology*, *120*(1–4), 103–110. https://doi.org/10.1016/j.enggeo.2011.04.002

Ambily, A. P., & Gandhi, S. R. (2012). *Behavior of Stone Columns Based on Experimental and FEM Analysis*. https://doi.org/10.1061/ASCE1090-02412007133:4405

Bathurst, R. J., & Naftchali, F. M. (2021). Geosynthetic reinforcement stiffness for analytical and numerical modelling of reinforced soil structures. *Geotextiles and Geomembranes*, *49*(4), 921–940. https://doi.org/10.1016/j.geotexmem.2021.01.003

Deb, K., & Mohapatra, S. R. (2013). Analysis of stone column-supported geosynthetic-reinforced embankments. *Applied Mathematical Modelling*, *37*(5), 2943–2960. https://doi.org/10.1016/j.apm.2012.07.002

Gupta, R. M., Gajjar, H., & Shukla, J. (2022). Slope Stability Analysis of Stacker–Reclaimer Embankment Under the Influence of Adjacent Stockpile. *Lecture Notes in Civil Engineering*, *152*, 283–292. https://doi.org/10.1007/978-981-16-1831-4_26

Jayapal, J., & Rajagopal, K. (2020). Slope Stability Analysis of Embankment Resting on Granular Columns Using FEM. *Lecture Notes in Civil Engineering*, *85*, 311–326. https://doi.org/10.1007/978-981-15-6086-6_25

Murugesan, S., & Rajagopal, K. (2006). Geosynthetic-encased stone columns: Numerical evaluation. *Geotextiles and Geomembranes*, *24*(6), 349–358. https://doi.org/10.1016/j.geotexmem.2006.05.001

Rowe, R. K., & Li, A. L. (2002). *Geosynthetic-reinforced embankments over soft foundations*.

Yoo, C., & Kim, S. B. (2009). Numerical modeling of geosynthetic-encased stone column-reinforced ground. *Geosynthetics International*, *16*(3), 116–126. https://doi.org/10.1680/gein.2009.16.3.116

Zheng, G., Yu, X., Zhou, H., Wang, S., Zhao, J., He, X., & Yang, X. (2020). Stability analysis of stone column-supported and geosynthetic-reinforced embankments on soft ground. *Geotextiles and Geomembranes*, *48*(3), 349–356. https://doi.org/10.1016/j.geotexmem.2019.12.006