Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam
Visakhapatnam Chapter

Slope Stability Analysis of Stacker – Reclaimer Embankment Under The Influence of Adjacent Stock Pile

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Abstract. The present Case study emphasis on slope stability analysis of Stacker- Reclaimer (S-R) embankment due to adjacent iron ore Stockpile of 20 m height for the site situated in the South East Asia. Available geotechnical Investigation data suggest that subsoil profile is mainly consist of weak soft soil in form of silty clay to soft clay up to 15 to 18 m from the natural ground surface. For slope stability requirement of the proposed embankment for Stacker-Reclaimer foundation, factor of safety (FOS) was calculated without the considering the influence of adjacent Stockpile and was observed satisfactory. However, calculating global FOS with considering influence of adjacent Stockpile operation, stability requirement was not within the limit as deep-seated slope failure is observed under the action of iron or Stockpile load. In order to maintain the recommended factor of safety for interacting foundations, various ground improvement techniques were explored. Vibro Replacement stone columns were adopted as suitable ground improvement measures. Sequential filling of Stockpile in stages was adopted for monitoring variation in the factor of safety. Global factor of safety at each stage is calculated considering both the improved and unimproved ground conditions. Present paper highlights the geotechnical interaction of adjacent facility and explores the way forward to address them in design.

Keywords: Soft Soil; Stock pile; Stacker-Reclaimer (S-R); Vibro Replacement Stone Column; Stage construction

1 Introduction

Infrastructure sector is one of the fastest developing sectors in developing countries. Due to economic growth and progressive increase in population, readily available soil with reasonable shear strength and bearing capacity is scare. For the past few decades several ground improvement techniques has been very well explored and implemented (Ambily & Gandhi, 2007),(Christoulas 1997 ,.وآخ)The selection of any ground improvement technique is mainly governed by soil type, resource availability, its environmental impact and economic viability. Based on available previous study Ground improvement by bottom feed stone column explicitly for loose sandy silt / soft clay type soil is considered as one of most proven method (Dheerendra Babu ,.وآخ

2013). Over the period of time several analytical as well as empirical has been develop to understand the settlement as well as stability behavior of bottom feed stone column (H. J. Prieb, 1995),(McCabe 2009 ,.وآخ) .

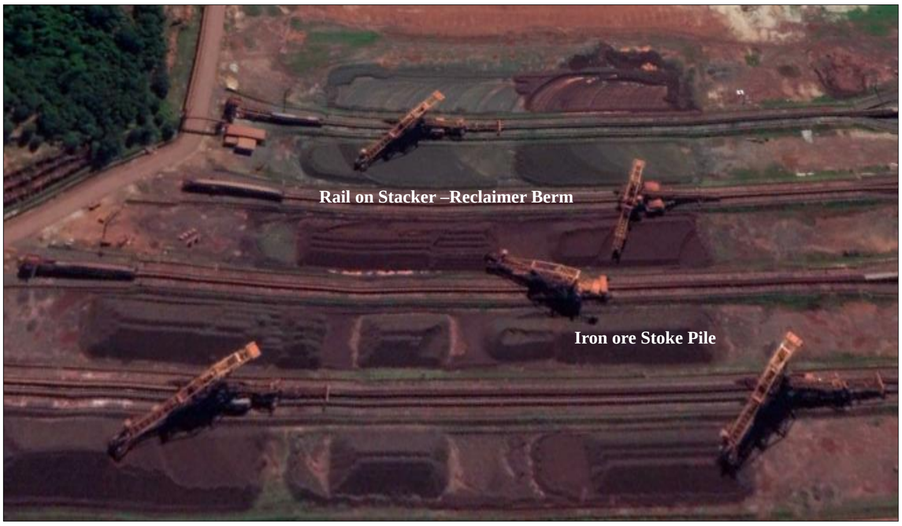


Fig. 1. Reference Site Picture with Iron ore Stockpile and Stacker Reclaimer berm Facility

Present study has been carried out in order to understand the influence of 20 m iron ore stockpile on stacker/reclaimer (S-R) berm. Refer figure-1 for site reference and arrangement of iron ore stoke pile with stacker reclaimer berm facility. (Shukla & Sengupta, 2019)

For the material handling work, stacker/reclaimer crane runs on the rails provided on the berm. To anticipate the vertical load from the stacker reclaimer facilities, pile foundation system has been provided. Moreover, several underground utilities such as fire pipes and drains were also passing underground the stacker reclaimer berm. Based on available soil data and preliminary calculations it was found that there may excessive displacement and instability occur if week soft soil strata was not modified.

Local stability of stacker/reclaimer (S-R) berm without influence of Stockpile was carried out and it was not of major concern. However, while calculating the stability considering the Stockpile influence, deep seated failure was observed beneath the (S-R) berm. Based on soil profile and previous ground improvement measure of the same site bottom feed vibro stone column is selected as the ground improvement technique for the stability of proposed stacker/ reclaimer berm. In the present case the height of stockpile is divided in to equal "h" m thick layer and influence of its sequential filling on adjacent Stacker/ reclaimer berm is studied. Stage construction methodology has been adopted for stability analysis. Stockpile was discretized into 8 stages (each of equal height).

Parametric study has been carried out by varying the friction angle and grid spacing of stone column to understand its influence on stability. For each stage of stockpile filling comparison is made between improved and unimproved ground condition. The results are summarized in various charts.

2 Ground characterization

The general ground profile was prepared based on available soil borehole detail data. From the soil description and standard penetration test (SPT) 'N' value it was concluded that the soil strata was majorly governed by interbedded layers of sandy silt and clayey silt type of soil. Moreover, from SPT value it can be classified as weak soil. The value of soil cohesion observed was less than 30 kPa for unimproved ground conditions.

The material model used for stacker / reclaimer berm, Stockpile and soil layer are Elasto-Plastic Mohr Column model. Stone column was modeled as a material with friction property only.

Berm soil is also modeled as cohesion less deposit. Moreover, for stockpile, which is an iron ore deposit only friction angle is estimated. The material property for the berm, Stockpile and stone column are considered as given in the table 2 below:

Table 1. Ground Characterization

Sr. No.	Soil Description	Depth (m)	Average SPT 'N' Value
1	Sandy clay	0-2	4
2	Silty sand	2-4	3
3	Soft clay	4-7.45	1
5	Gravelly sand	7.45-9.45	1
6	Sandy clay	9.45-11	1
7	Clayey sand	11-13	6
8	Sandy clay	13-16	4
9	Silty sand	16-23.45	7
10	Sandy silt	23.45-28.95	15
11	Hard sandy silt	28.95-34.4	50

Table 2. Material property used for Limit equilibrium analysis

Material Description	Bulk Density (γ), kN/m^3	Angle of Internal Friction (φ)	Cohesion (C), kPa
Fill layer	18	30	0
S-R berm	20	35	05
Stone column	18	40	0
Iron ore stock pile	28	40	0

2.1 2-Dimensional LEM model validation

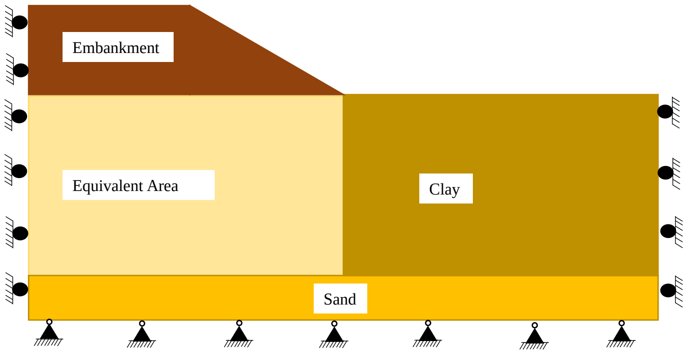
A two layer slope has been taken from literature (Abusharar and Han, 2011) and analyzed to validate the methodology adopted in using the GEO-SLOPE International Ltd (Slope/w) software. The parameter used for the stability analysis with respect to embankment fill and foundation material is given in Table 3. The Morgenstern-Price method have been chosen in Slope/w for the limit equilibrium analysis.

Table 3. Soil property used in validation model (Abusharar and Han, 2011)

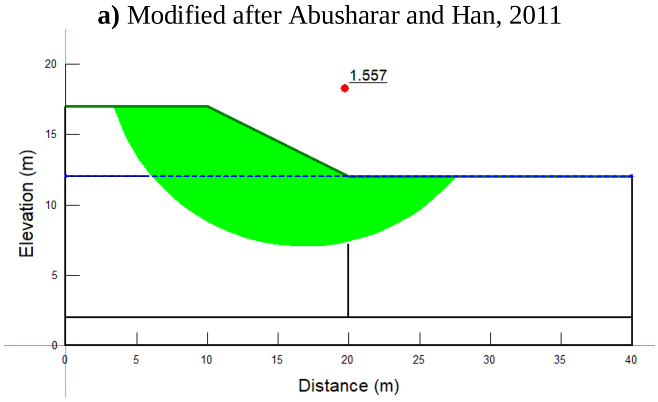
Material Parameter	Unit	Sand	Clay	Embankment fill	Stone column	Equivalent parameter
Saturated Unit Weight	kN/m^3	18	16	18	17	16.2
Cohesion	kPa	0	20	0	0	16
Friction angle	Degree	30	0	32	38	8.9

Comparison is made between finite difference method (FDM) and Limit Equilibrium method based on Itasca International Inc. and GEO-SLOPE International Ltd Software respectively. The location of critical slip surface observed by these two methods is also observed. Only factor of safety is discussed for validation purpose. The height of embankment is taken as 5.0 m. The slope of embankment with respect to horizontal is 26.56º (0.5V:1 H).

The model Dimensions and configuration adopted for validation are shown in figure 2(a). Figure 2(b) gives the factor of safety value obtain with LEM based analysis with GEOSLOPE software.



a) Modified after Abusharar and Han, 2011



b) Current LEM Model

Fig. 2 Model validation using Limit equilibrium approach a) Geometry used for model vali dation b) Present LEM model

The factor of safety value obtained was 1.557 for equivalent ground conditions which is very close to the reported FOS 1.6 (Abusharar and Han, 2011), which validates the methodology of analysis.

3 Numerical Modeling

In the present study the geotechnical design is mainly concerned with the stability of S-R berm under the influence of adjacent iron ore stockpile. 2-Dimensional Slope stability analysis is carried out with the help of GEOSLOPE software (GEO-SLOPE International Ltd). Limit equilibrium analysis based on the method of slices was selected to perform the stability check. Here also the Morgenstern-Price method have been chosen in Slope/w for the limit equilibrium analysis. The slope of S-R berm was considered as 35° with respect to ground surface

Among the various simplified geometric models such as unit cell, longitudinal gravel trench model, cylindrical gravel ring model, 3- Dimensional model etc. here homogenization method is selected for modeling. The Complex 3-Dimensional field problem is converted into the equivalent 2-D plain strain problem with homogenization or equivalent homogeneous soil model . In this method the stone column and soft soil is replaced by an equivalent homogeneous soil with improved shear strength parameters (Castro, 2017). The area treated with stone column is replaced by equivalent homogeneous soil. For conservative analysis the water table was assumed at the ground surface. In addition to this surcharge load with uniform intensity of 20 kPa was applied on the (S-R) berm.

The ratio of amount of soft soil replaced by stone column is called area replacement ratio (a_s). The area replacement ratio plays significant role in analyzing the stone column improve ground condition. By varying the area replacement ratio (a_s) and improved material parameter, various combinations can be analysis at design stage. The combinations of different stone column diameter, spacing and length can be made without making change in the geometry of the model. When the problem has complex geometry, this method is more suitable in order to simplify modeling with stone column. The weighted average of soil and stone column parameters taken according to area ratio (a_s). The equivalent soil parameters are computed as follows (Christoulas et al., 1997).

$$c_{eq} = c_c a_s + c_s (1 - a_s) \tag{1}$$

$$\varphi_{eq} = \tan^{-1}\left(a_s \tan\varphi_c + (1 - a_s)\tan\varphi_s\right) \tag{2}$$

$$\gamma_{eq} = \gamma_c a_s + \gamma_s (1 - a_s) \tag{3}$$

Here, a_s is area replacement ratio.

Area replacement ratio (a_s) was calculated for different grid spacing and friction angle of stone column, with constant column diameter as given in table 4. The material parameters are derived based on equation (1), (2) and (3). The square grid pattern was considered for further calculation.

It should be noted that physical phenomenon such as radial drainage towards the column, stress-concentration on soil and stone column cannot be reproduced by homogenization method. Though, after calibrating the parameters of the equivalent homogeneous soil, the overall response of the system on a large scale may be correctly predicted (Ng et al., 2014), (Castro, 2017).

To capture the trend of the stone column parameters (i.e. angle of internal friction, diameter, and grid spacing) following different cases were studied:

Table 4. Detail of various configuration explored

Case number	Series	Angle of internal friction (°)	Grid spacing (m)	Column diameter (m)
Case 1	A1	38	1.5	1.0
	B1	38	1.7	1.0
	C1	38	2	1.0
Case 2	A2	40	1.5	1.0
	B2	40	1.7	1.0
	C2	40	2	1.0
Case 3	A3	42	1.5	1.0
	B3	42	1.7	1.0
	C3	42	2	1.0

4 Result Analysis

The influence on the value of FOS corresponding the stage construction of stoke pile has been examined for (S-R) berm facility. Comparison is made between unimproved and improved ground condition considering the effect of varying stone column spacing and angle of internal friction of stone material. The diameter of column was kept constant and sequential filling of Stockpile was made. In case 1 the angle of internal friction was kept as 38° while the spacing of the stone column varies as 1.5, 1.7 and 2.0 m respectively (figure 3). Similarly, for case 2 with varying spacing of 1.5, 1.7 and 2.0 m, the column friction angle was kept as 40º (figure 4). And for case 3 with varying spacing of 1.5, 1.7 and 2.0 m, the friction angle was 42º (figure 5). The factor of safety for (S-R) berm was found 1.635 for unimproved ground condition. The same rages from 1.87 to 1.814 with stone column for improved ground condition for (S-R) berm facility. This analysis was made without taking in account the Stockpile influence.

Result of Effect of friction angle of stone column and varying column spacing on (S-R) Berm under the influence of Stockpile is as follows:

From the above results for unimproved ground condition it is to be noted that the berm is nearly stable up to the “2h”. However, with further increase in height of stacking from “3h” to “8h”, the (S-R) berm along with stockpile becomes unstable and lead to deep seated failure due to soft compressible soil. When analysis made considering ground improvement with stone column keeping friction angle of stone as 38º and column spacing of 1.5m the FOS observed ranges between 3.477 to 1.321 for Stage 1 to 8 respectively.

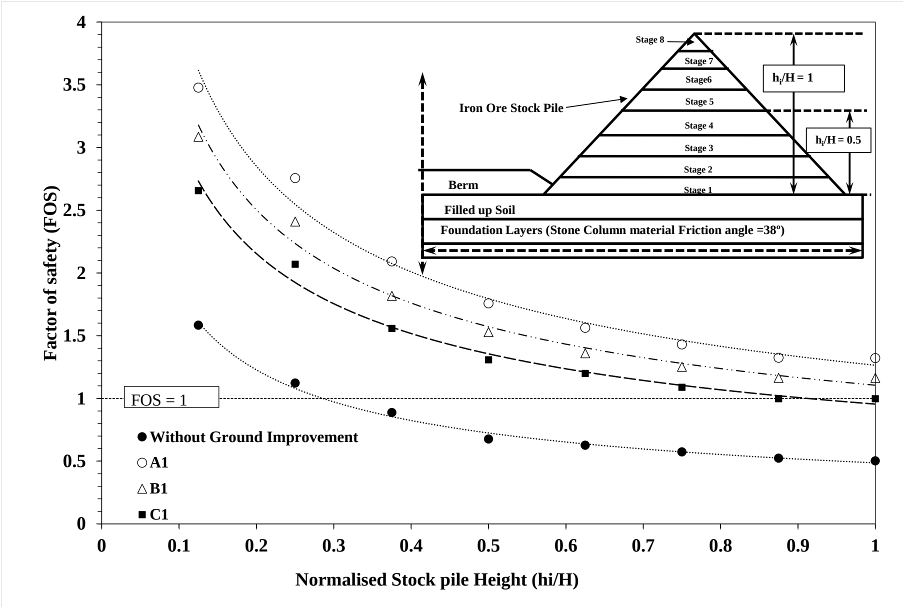


Fig. 3. Influence of Stockpile Height and Column spacing for stone column friction angle 38º

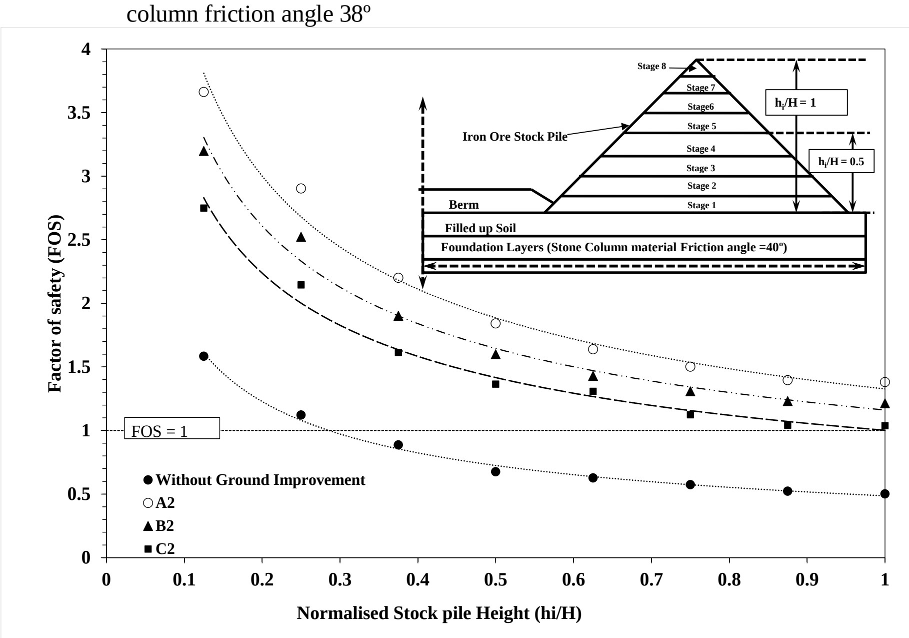


Fig. 4. Influence of Stockpile Height and Column spacing for stone column friction angle 40º

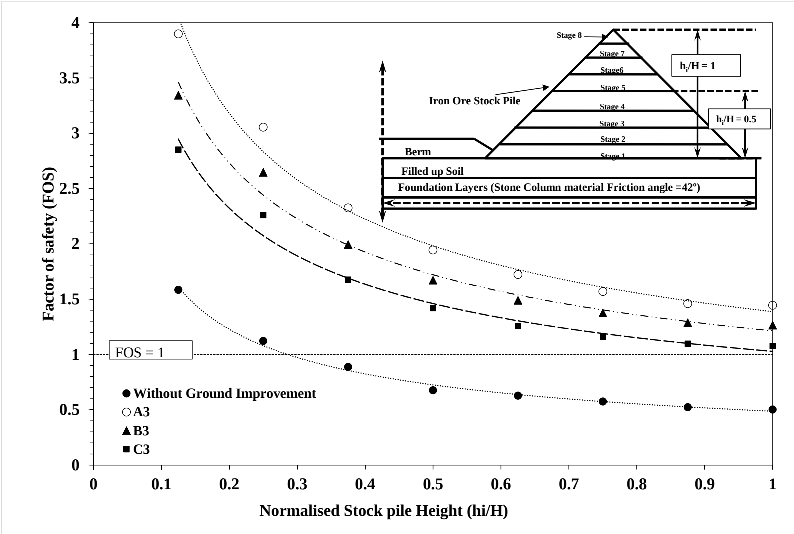


Fig. 5. Influence of Stockpile Height and Column spacing for stone column friction angle 42°

Similarly, for column spacing of 1.7m FOS observed was 3.086 to 1.164 and for 2.0m FOS observed was 2.656 and 0.998 for Stage 1 to 8.

The percentage variation in spacing of 22 % and 43 % results in percentage variation in FOS of 12 % to 24% respectively. Nearly 50 % variation is observed between area replacement ration and FOS. As by increasing the spacing the area replacement ration decreases which directly affect the stability of berm. The soil strength parameter gets improve with reduction in stone column spacing, as more amount of stone replaces the poor soil. Similar results were observed for stone friction angle of 40 and 42. Moreover it should be noted that as friction angle of stone material increases i.e. from 38 to 42, the factor of safety for similar spacing increases (Fig 3, 4 and 5). For Case C1 the FOS for stage "7h" and "8h" was found less than unity, while for similar stage FOS found more than unity with same spacing for Case C2 and C3. The increased friction angle of stone material dramatically increases the overall stability.

5 Conclusions

In this study it was observed that even though the (S-R) berm without any means of ground improvement was found stable, shows deep-seated failure with increase in the height of adjacent stacking. It is to be noted that in lieu of detailed analysis and modeling it would lead to the instability and fatal failure of the berm along with stock pile.

In order to optimize the spacing and minimize the cost parametric study plays vital role. Further stone column analysis with equivalent area approach saves considerable time in modeling and gives reasonably accurate results. It can be concluded that increase in friction angle of stone material leads to greater stability against deep seated failure. Moreover, as spacing of stone column increases, the area replacement ratio decreases leads to comparatively less improvement in shear strength parameter of equivalent area. This ultimately leads to decrease in factor of safety of the stone column improved ground. The higher area ratio results in increased factor of safety, which ultimately leads greater stability.

References

1. Abusharar, S.W., Han, J., 2011. Two-dimensional deep-seated slope stability analysis of embankments over stone column-improved soft clay. Engineering Geology 120, 103–110. https://doi.org/10.1016/j.enggeo.2011.04.002
2. Castro, J., 2017. Modeling stone columns. Materials 10. https://doi.org/10.3390/ma10070782
3. Christoulas, S., Giannaros, C., Tsiambaos, G., 1997. Stabilization of embankment foundations by using stone columns. Geotechnical and Geological Engineering 15, 247–258. https://doi.org/10.1007/bf00880828
4. Ng, K.S., Ann, S., Tan, H., 2014. Parametric study on the settlement improvement factor of stone column groups. ESTEEM Academic Journal 10, 55–65. https://doi.org/10.13140/2.1.5092.8328
5. 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
6. Ambily, A. P., & Gandhi, S. R. (2007). Behavior of stone columns based on experimental and FEM analysis. Journal of Geotechnical and Geoenvironmental Engineering, 133(4), 405–415. https://doi.org/10.1061/(ASCE)1090-0241(2007)133:4(405)
7. Castro, J. (2017). Groups of encased stone columns: Influence of column length and arrangement. Geotextiles and Geomembranes, 45(2), 68–80. https://doi.org/10.1016/j.geotexmem.2016.12.001
8. Christoulas, S., Giannaros, C., & Tsiambaos, G. (1997). Stabilization of embankment foundations by using stone columns. Geotechnical and Geological Engineering, 15(3), 247–258. https://doi.org/10.1007/bf00880828
9. Dheerendra Babu, M. R., Nayak, S., & Shivashankar, R. (2013). A Critical Review of Construction, Analysis and Behaviour of Stone Columns. Geotechnical and Geological Engineering, 31(1), 1–22. https://doi.org/10.1007/s10706-012-9555-9
10. H. J. Prieb. (1995). The design of vibro replacement. Ground Engineering, 28(10), 31–37. https://doi.org/10.1016/0148-9062(96)80092-1
11. McCabe, B. A., Nimmons, G. J., & Egan, D. (2009). A review of field performance of stone columns in soft soils. Proceedings of the Institution of Civil Engineers: Geotechnical Engineering, 162(6), 323–334. https://doi.org/10.1680/geng.2009.162.6.323
12. Shukla, J., & Sengupta, S. (2019). Geotechnical Challenges and Opportunities in Large Infrastructure Projects—Learning from Failures. December, 213–223. https://doi.org/10.1007/978-981-13-0505-4_19
13. Itasca Consulting Group, Inc., 2006. FLAC/Slope User's Guide, Version 5.0. 84p