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Soil Improvement Planning Combination of Preloading and Stone Column (Case Study) in Sidorukun District, Gresik, Jawa Timur

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ABSTRACT

The subgrade is the essential part of the construction process, such as access to factories, to develop industrial factory in areas to be developed, one of which in the Gresik area. Not all construction site has met the requirement. Hence, need soil improvement with a combination of preload and stone column. The soil parameters show the results of field and laboratory tests that the area has a small value NSPT with a thickness of the soft bottom layer up to a depth of 20 meters. This research is planned the initial height (Hinitial) to have stability analysis of un-reinforcement embankment, the diameter, and the distance from the stone column with the Xstab program. The results of the calculations carried out for the construction height of the embankment (Hfinal) 3.50 meters, then the first dam (HInitial) of 4.60 m is required. The tilt stabilization is obtained (MR = 168.7 tonm), wherein The Radius of the Slope area is 11.62 meters and the Safety Factor (SF = 0.881), where there is a possibility to slide. Planning preload with a stone column with a diameter of 1.00 meters needs to be combined, a distance of 1.50 meters installed in the subgrade.

Keywords: *Preloading; Safety factor; Soft soil; Stone Column; Subgrade*

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ABSTRAK

Tanah dasar merupakan bagian terpenting dalam proses pembangunan, seperti jalan akses menuju pabrik, pembangunan industri pabrik di daerah-daerah terus berkembang salah satunya di daerah Gresik. Pembangunan tersebut tidak semuanya dibangun di atas tanah yang memenuhi syarat, sehingga membutuhkan metode perbaikan tanah dasar, salah satunya metode yang digunakan yaitu kombinasi Preloading dan Stone Coloumn. Dari parameter tanah hasil pengujian di lapangan dan di laboratorium menunjukan bahwa area tersebut memiliki nilai N-SPT yang kecil dengan ketebalan lapisan tanah lunak sampai kedalaman 20 meter.Penulisan ini memiliki tujuan agar dapat merencanakan tinggi timbunan awal (H-Initial), analisa stabilitas tanah timbunan tanpa perkuatan Stone Coloumn dengan program bantu Xstabl serta merencanakan diameter dan jarak Stone Coloumn. Hasil dari perhitungan yang sudah dilakukan untuk tinggi rencana timbunan (H-Final) 3,50 meter, maka diperlukan timbunan awal (H-Initial) sebesar 4,60 meter, kemudian untuk stabilas lereng didapat momen penahan (MR= 168,7 ton meter), jari-jari bidang longsor sebesar 11,62 meter dan Angka Keamanan (SF = 0,881) dimana masih kemungkinan terjadi kelongsoran dikarena SF kurang dari 1 (satu). Sehingga Preloading yang direncanakan perlu dikombinasi dengan Stone Coloumn diamaeter 1,00 meter , jarak 1,50 meter yang dipasang pada tanah dasar.

Kata kunci: Angka Keamanan; *Preloading, Stone Coloumn*; Tanah dasar; Tanah Lunak

INTRODUCTION

The development of industrial factories in the regions continues to grow, one of which is in the Gresik area, East Java, but there are factory locations that are very far from public access.

Appropriate access is necessary to be provided. The access will be built on a subgrade in the form of soft soil, which greatly affects the various stages of planning, implementation, and maintenance. [1]

Soft soils generally have high water content and plasticity and low soil bearing capacity. Stockpiling on clay soil for road construction can fail because the clay's carrying capacity cannot accept the load from the embankment material [2]. Such a soil condition is a soil condition that is less stable to subsidence and landslides. If it is used as a subgrade, it is necessary to carry out soil improvement work. Soft soil improvement has various methods, one of the standard methods used to improve soft clay soil is preloading with the embankment load in the form of sand, gravel, or a mixture of both [3]. By being loaded with embankment before being used as subgrade, the soft soil will experience consolidation which will increase the carrying capacity. [4]

However, in terms of consolidation time, this technique is less effective. This can be used with a vertical drain to consolidate the soil according to the specified time. Bridge, rail, and road embankments, as well as fluid storage containers where settlement is higher, the stone column approach is more credible than pile in terms of low cast and time of construction as a substructure. The ground constructed with stone columns would have a high bearing capacity, low settlement downs, and free drainage. Loose sands and soft clays are ideal for this approach. [5]

In order to analyze slope stability, XSTABLE program was used to get the safety number, holding moment and radius of the landslide field. [6] To avoid sliding that occurs due to embankment work on the subgrade with low bearing capacity, reinforcement is carried out on the subgrade, namely by installing Stone Column [7]. So it is necessary to plan for soil improvement with a combination of preloading and stone coulomb in the Sidorukun district.

LITERATURE REVIEW

Preloading

In general, preloading or initial loading is a method of soil improvement with a soil compression process to provide vertical pressure before the planned permanent loading of the construction. Preloading uses embankment, the embankment load is designed with a certain height to match the amount of consolidation settlement to be achieved and the expected elevation height. The embankment height is generally 3 – 8 meters, with the settlement generally ranging from 0.3 – 2.0 meters [8]

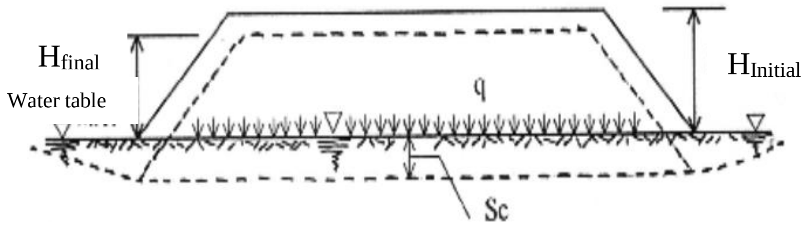

Figure 1. Preloading [9]

Preloading Planning

The preloading planning steps before the implementation stage are as follows :

1. Determine q value
2. Determine height of embankment as planned
3. *Settlement* calculation

For Normally Consolidated Soil (NC Soil) :

$$Sci = \left(\frac{Cci}{1+ei}\, log\frac{P'oi + \Delta pi}{P'oi}\right) Hi. \qquad (1)$$

For over-consolidated soil:

If $(P'oi + \Delta pi) \leq P'ci$, so consolidation value is:

$$Sci = \left(\frac{Cci}{1+ei}\, log\frac{P'oi + \Delta pi}{P'oi}\right) Hi \qquad (2)$$

If $P'ci < P'ei < (P'oi + \Delta pi)$, so consolidation value is:

$$Sci = \left(\frac{Csi}{1+ei} \log \frac{P'ci}{P'oi} + \frac{Cci}{1+ei} \log \frac{P'oi + \Delta pi}{P'ei}\right) Hi \quad (3)$$

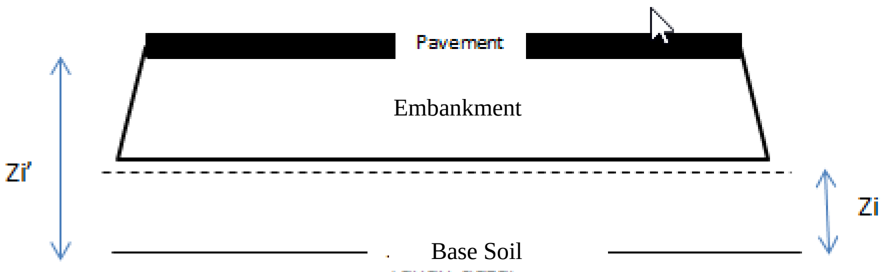

Figure 2. Base Soil Total Load

a. As the result of embankment load
Determined load of embankment (q)
$\Delta pi = 2 \times I \times q$ embankment
b. As the result of pavement load
$\Delta pi = \frac{\Delta P}{q} \times q$ pavement

4. Calculation of Initial Height and Final Height

The initial embankment height prior to implementation is not the same as the embankment height that will be determined in the design. To determine the design embankment height, what must be considered is the amount of compression that occurs in the original soil. To find the initial embankment height, use the following equation:

$$q = (H_{(initial)} - S_C)\gamma_{embankment} + S_C \times \gamma'_{timb} \quad (8)$$

$$q = (H_{(initial)} \times \gamma_{embankment}) - (S_C \times \gamma_{embankment}) + (S_C \times \gamma'_{embankment}) \quad (9)$$

$$H_{(initial)} = \frac{(q + (S_C \times \gamma_{timb}) + (S_C \times \gamma'_{timb}))}{\gamma_{embankment}} \quad (10)$$

$$H_{Final} = H_{(initial)} - S_C \quad (11)$$

If $\gamma_{sat} = \gamma_{embankment}$, So:

$$q = H_{(initial)} \cdot \gamma_{embankment} - S_C \cdot \gamma_w$$

and

$$H_{(initial)} = \frac{q + S_C \cdot \gamma_w}{\gamma_{timb}} \quad (12)$$

As for the final H calculation scheme, it can be seen in the image below.

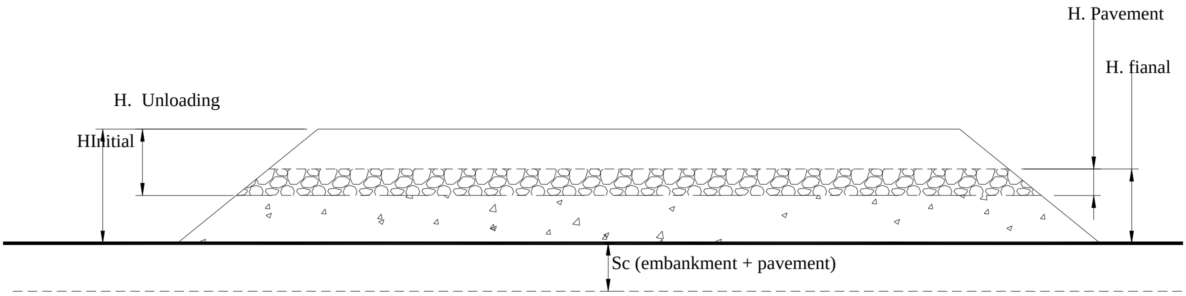

Figure 3: Determine H-$_{Final}$ dan H-$_{Initial}$ Planning

Embankment Slope Stability Analysis

Analyzing the stability of embankment slopes according to [10] was carried out by examining the safety factor of the planned embankment slopes, by comparing the shear stresses formed along the surface of the most critical crack plane with the shear strength of the soil. The safety factor can be defined as follows:

$$Fs = \frac{\tau f}{\tau d} \quad (13)$$

According to [11] also added, the strength of the soil that resists landslides consists of two main components, namely cohesion and soil shear angle, the equation is as follows:

$$\tau f = c + \sigma \tan \emptyset \quad (14)$$

Thus, the following equation can be formed:

$$\tau d = Cd + \sigma \tan \emptyset\, d \quad (15)$$

Embankment Slope Stability Analysis Using XSTABL

XSTABL program is a computer program written in FORTAN IV language, for solving general slope stability cases with two-dimensional balance methods. The calculation of the slope safety factor was carried out using the wedge method (adapted from the Modified Bishop Method) with a circular cylindrical slide plane. The specialty of XSTABL is that ten critical landslide areas can be determined from the input of hundreds of trials with a random number of landslide fields.

Stone Column

Stone column installation is one method of soil improvement. The primary function of the stone column installation is to increase the power A so that the soft soil can accept a greater load and the settlement that occurs will be reduced. In addition to increasing the bearing capacity of the soil, there are several other advantages according to [12] such as:

1. Decrease soil total settlement.
2. Shorten consolidation time
3. Decrease potential of *liquefaction*

In planning stone columns there are many things to consider, including:

1. The diameter of the stone column and the concept of unit cell, the diameter of the stone column (D) affects the replacement ratio area (as), depending on the soil being repaired, the magnitude of the surcharge load. The stone column installation pattern affects the shape of the unit cell cross-section. The stone column installation pattern is divided into 2 patterns, namely the equilateral triangle pattern and the square pattern. De = 1.05 s for the triangle pattern and De = 1.13 s
2. The length and distance of the stone column, which affects:
   a. Amount of replacement ratio
   b. Decreasing tension and settlement in the stone column dan surrounding soil
3. The method of stone column placement as follow:
   a. Vibro-Replacement (wet installation method)
   Favorable for soft soil which have high water content and low stability
   b. Vibro-Displacement (dry installation method)
4. Area replacement ratio (a_s), area is the ratio of the cross-sectional area of the stone column to the area of soft soil around it. Comparison as follows:
5. Tension concentration will cause:
   a. Inclining of shear tension in Stone Column
   b. Decreasing of settlement in soft soil surrounds the stone column.
   Stress concentration factor (n):

   $$n = \frac{\sigma s}{\sigma c} \quad (16)$$

   Value of n ranging at 4 s/d 5

   $$\sigma s = n\, \sigma / [1 + (n-1).\, a_s] = \mu s.\, \sigma \quad (17)$$

   $$\sigma c = \sigma / [1 + (n-1).\, a_s] = \mu c.\, \sigma \quad (18)$$
6. Control the bearing capacity of single stone column

$\sigma_3 = \sigma_{RO} + c \{1 + [\ Ln (Ec / (2c (1 + \nu))]\}$ (19)

a. Ultimate vertical tension (σ_1) *stone column* capacity :

$Kp = \sigma_1 / \sigma_3 = (1 + \sin \phi_s) / (1 - \sin \phi_s)$ (20)

$$\sigma_1 = q_{ult} = \left[\sigma_{RO} + c\left(1 + Ln \frac{Ec}{2c\,(1+\upsilon)}\right)\right]\left[\frac{1+\sin\phi_s}{1-\sin\phi_s}\right] \quad (21)$$

$q_{ult} = 1/2\ \gamma_c\, B\, N_\gamma + c\, N_c + D_f\,.\,\gamma_c\,.\,N_q$ (22)

7. Carrying capacity of stone columns group
   a. Horizontal passive tension

$\sigma_3 = 1/2\ \sigma_v\ Kp + 2c\ \sqrt{Kp}$ (23)

$\text{qult} = \ \sigma 3\ \text{Kp}_{kom} + \ + 2C_{avg}\sqrt{\text{Kp}_{kom}}$ (24)

$KP_{(kom)} = \tan \alpha^2\ (\ 45^0 + \frac{\phi_{avg}}{2})$ (25)

8. Push-Over Moment (M_{ov})

$M_{ov} = \frac{M_R}{SF}$ (26)

9. Determine additional moment

$\Delta M_R = S\ \times\ [(M_{ov}\ \times\ SF_{REN}) -\ M_R]$ (27)

10. Total force to stone column (ΣP)

$\Sigma P = \frac{\Delta M_R}{R}$ (28)

11. Calculation of the required number of stone columns, then all data is entered in a table to be checked for the ability of the stone column in order to make the use of the stone column economical.

METHOD

In planning for soil improvement, the data collection used is secondary data carried out by CV. Testana Engineering Inc [13] in the Sidorukun district, Gresik, East Java as shown in the Figure 4. Determine the soil parameters to be used by using statistical methods from the results of soil investigations carried out in the field and in the laboratory. Field investigations are in the form of boring tests and N-SPT data. Laboratory investigations to obtain soil parameters include liquid limit, plastic limit, moisture content, volume weight, void ratio, cohesion, shear angle, consolidation coefficient, and others. To find out the results of the calculations from this research, the data that has been obtained is processed by carrying out the stages that will be discussed in subsequent chapters. In this case, the results of data analysis can be concluded.

Figure 4. Site location captured by Google Earth (2019)

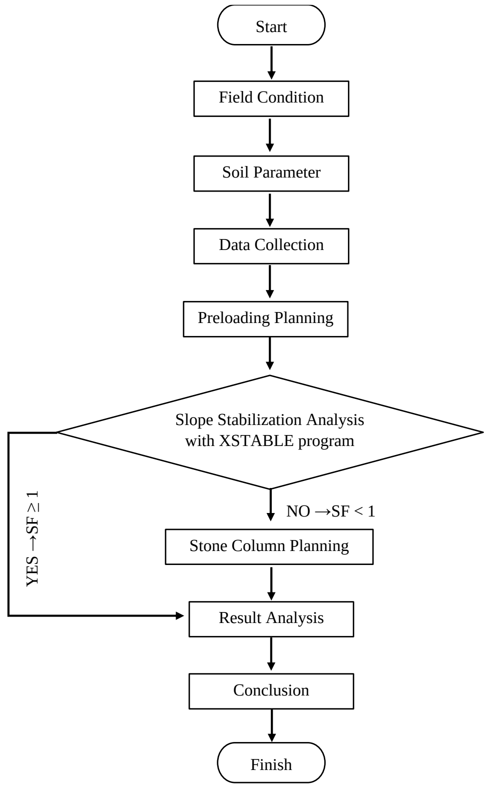

Figure 4. Workflow diagram

RESULT AND DISCUSSION

Data I Description

Table design in the text Table 1 Relationship between H-Initial, H-unloading, H-Final and Settlement for the consolidated soil layer to a depth of 20 meters.

Table 1. Relationship between H-Initial, H-Unloading, H-Final and Settlement

No.	Weight q (t/m^2)	Settlement Cause by embankment (m)	H-Initial (m)	Δq H-Unloading traffic (t/m^2)	H-Unloading traffic (m)	Thick of pavement (m)	Settlement Cause by pavement (m)	H-Final (m)	Total settlement (m)
	Desain	Calculation	((2+3) / 2.2)	Grafik	Calculation	Desain	Calculation	(4-3-8-6+7)	(3+8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	3	0.344	1.520	3.000	1.364	0.550	0.112	0.250	0.456
2	5	0.680	2.582	1.650	0.750	0.550	0.109	1.593	0.789
3	7	1.017	3.644	0.950	0.078	0.550	0.101	2.998	1.118
4	9	1.299	4.681	0.550	0.250	0.550	0.107	3.576	1.406
5	11	1.494	5.679	0.500	0.227	0.550	0.099	4.409	1.593

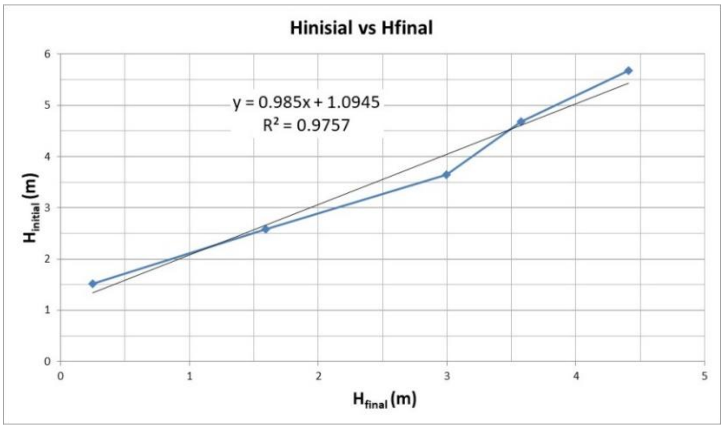

Figure 6. Relationship between H-Initial and H-Final

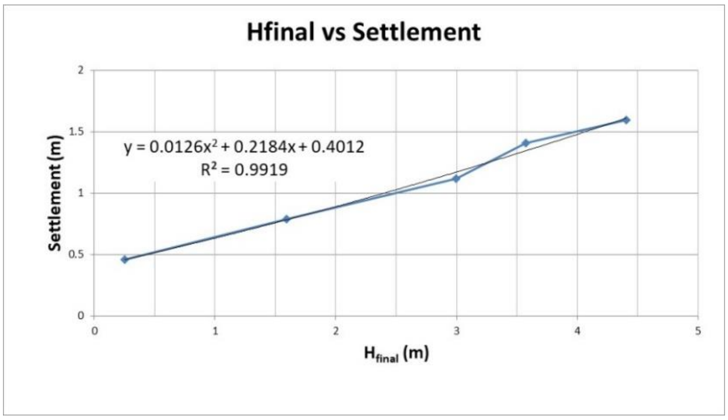

Figure 7. Relationship between H-Final and Settlement

In order to get the H-Final 3.50 m, the height of the H-Initial embankment must be 4.542 m rounded up to 4.6 m with a compression size (Sc) of 1.321 m. H final was estimated by an equation with linear regression by [14]

Modeling of landslide stability analysis using the XSTABL

Tabel 2. Output Dari Program XSTABL

	FOS (BISHOP) (m)	Circle Center x-coord (m)	Circle Center y-coord (m)	Radius	Initial x-coord (m)	Terminal x-coord (m)	Resisting Moment (kN-m)
1.	.881	16.54	27.28	11.62	15.00	27.33	1.687E+03
2.	.961	18.79	29.79	10.50	15.00	27.91	2.127E+03
3.	.962	17.12	32.41	12.82	13.89	27.29	1.939E+03
4.	.976	18.98	29.41	10.22	15.00	28.00	2.201E+03
5.	1.010	17.96	30.16	10.94	13.89	27.38	2.168E+03
6.	1.013	19.41	28.56	9.63	15.00	28.17	2.368E+03
7.	1.043	19.58	26.49	7.94	15.00	27.27	2.050E+03

8.	1.049	18.56	28.57	9.76	13.89	27.48	2.352E+03
9.	1.053	18.66	28.91	10.11	13.89	27.78	2.519E+03
10.	1.064	18.70	27.91	9.25	13.89	27.33	2.332E+03

seen in table 2 from the results of the XSTABL program calculation analysis of 100 landslide fields, 10 of which are the most critical and there are 4 that are still possible for landslides to occur due to SF < 1, so that the soil improvement method with Preloading requires a combination using Stone Column. to increase the bearing capacity subgrade.

Stone Column Planning

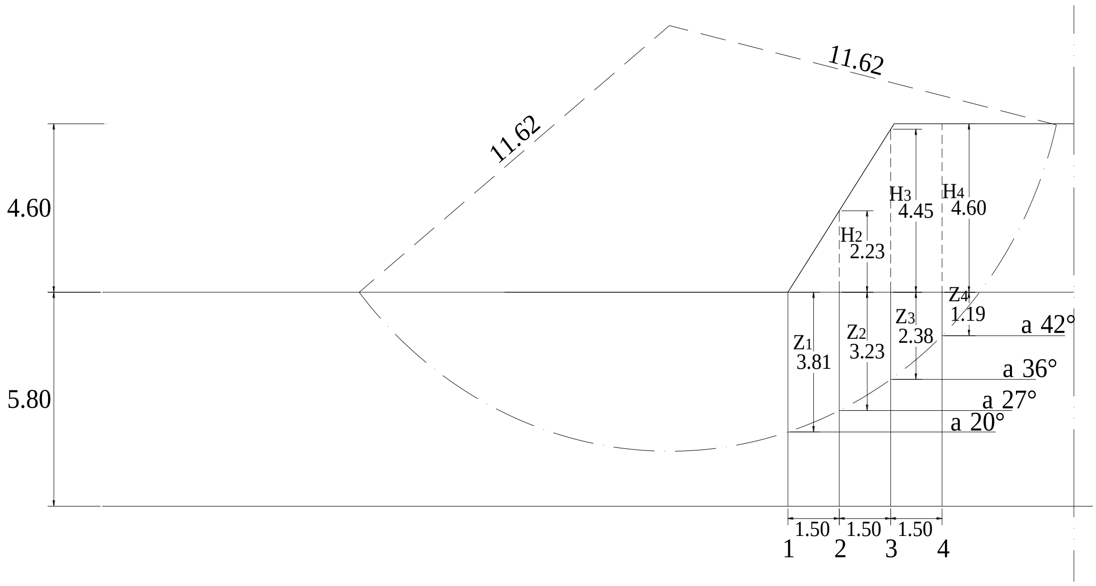

Figure 8. Stone column Plan cause by landslide field

Amount of Stone Coloumn Plan
Diameter of *Stone coloumn* (D) : 1,00 m
Distance of *Stone coloumn* (S) : 1,50 m
Area of *Stone coloumn* (A_S) : 0,785 m^2
Shear Angle of *Stone coloumn* ($\varnothing_{SC}$) : 42˚
Specific Gravity *Stone coloumn* (γ_{SC}) : 1,5 t/m^3
γ^1_{SC} : $\gamma sc - \gamma w$: 1,5 – 1,0 : 0,5 t/m^3
Specific Gravity of embankment ($\gamma_{embankment}$) : 2,2 t/m^3
Area Replacement Ratio (as) : 0,35 m^2
Tension Ratio *Stone coloumn* (μ_s) : 1,95
Then all the data is entered into a table for calculations:

No.	Distance Stone Column above slope area (Z1)	$W_1^1 = A_S * Z * \gamma^1 SC$	H	$W_2^1 = \mu_s * H * A_S * \gamma timb$	α(°)	cos α	$N^1 = (W_1 + W_2) * \cos \alpha$	$F = N^1 * Tan Ø_{SC}$	ΣF
1	3.81	1.495	0	0	20	0.939	1.404	1.264	
2	3.23	1.268	2.23	7.510	27	0.891	7.821	7.042	8.306
3	2.38	0.934	4.45	14.986	36	0.809	12.879	11.596	19.902
4	1.19	0.467	4.6	15.491	42	0.743	11.857	10.676	30.578

So **7,8 ton** ⟶ < **8,306 ton**

$\Sigma P < \Sigma F_{(SC\ 1-2)}$ ……………… Ok

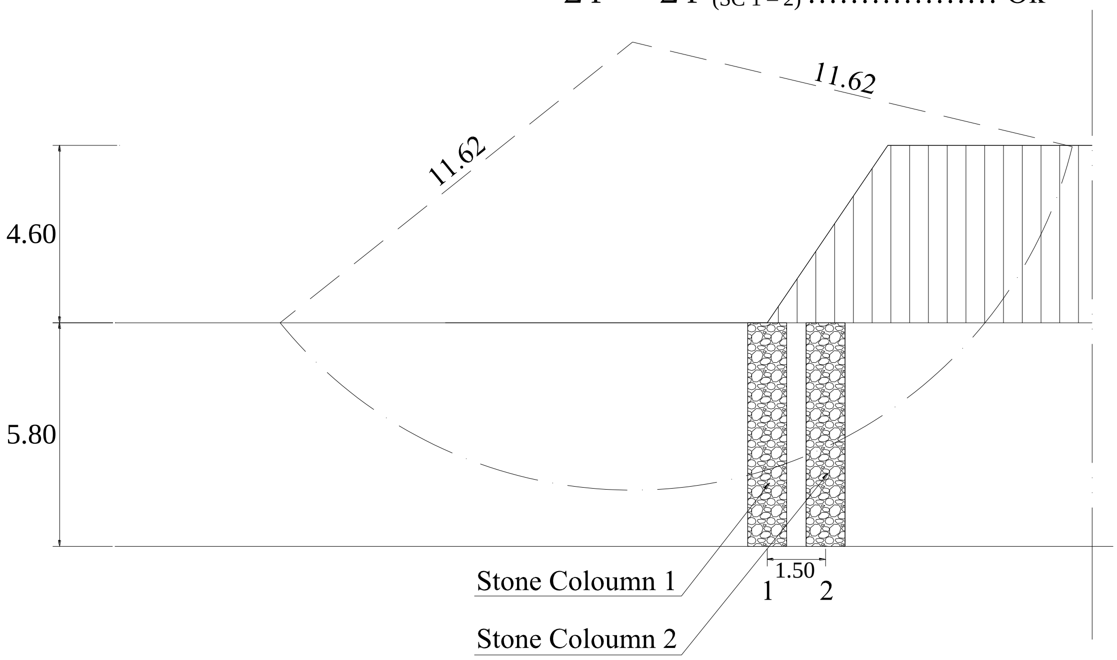

Figure 9. Necessity Stone Column

CONCLUSION

Based on the results of soil improvement planning using a combination of Preloading and Stone Column, have been achieved a plan height of 3.50 m for the embankment (H-Final), the initial embankment (H-Initial) required is 4.60 m. Based on the slope stability analysis of the XSTABL program before installing the stone column on the subgrade, it was found that an additional moment 168,7-ton m with Radius of slope area 11,62 m and safety Factor 0.881. In order to guarantee safety factor of stone column, the diameter 1.00 m is used with a distance of 1.5D which is 1.50 m.

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