EVALUATION OF BUND STABILITY USING GEOSTUDIO SOFTWARE WITH GROUND IMPROVEMENT METHOD USING SAND-KEY AT RECLAMATION WORK ON SOFT SOIL

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Abstract
The use of sand-key reclamation works in soft and very soft soils to increase the stability of the bund construction. Reclamation using the hydraulic fill method requires a stable embankment structure to withstand the potential for landslides from landfills, and in sea areas with very soft subgrade soils, with small undrained cohesion values causes the bund to be unstable and do not exceed the critical limit. The purpose of this study is to evaluate the improvement of soft soil in bund construction so that it is stable using GeoStudio. The Bund stability analysis results show that the value of the sand-key depth depends on the variation in the depth of the seabed. At a seabed depth of -6 m, there is a sand-key depth of 7 m, -5 m the sand-key depth of 10 m, -4 m thesand-key depth of 10 m, -3 m the sand-key depth is 5 m. The final safety number of 1.404,1.438,1,675, and 1.354 respectively.

***Keywords**: Reclamation, hydraulic fill, soft soil, bund, critical height, ground improvement, sand-key, safety factor*

INTRODUCTION

Substitute soil located under the construction of bund can be sand or sand-key. Sand-key has been used in the Tekong Island-Singapore reclamation project to build stable reclaimed land (Hoff, 2012). Land reclamation can be said as the process of creating new land by raising the elevation from the seabed (Hoff, 2012). According to Departemen Kelautan dan Perikanan, 2001:19, The expansion of the city is the main reason for reclamation, so that alternative coastal reclamations are carried out for various reasons, originally all activities were centered in the city so that a new space was needed to accommodate all activities which could not be facilitated in the city. Beaches that are oriented to ports, industry, tourism, or settlements with shallow coastal waters must be reclaimed so that they can be utilized (Huda, 2013).

One method of carrying out stockpiling in reclamation works is the hydraulic fill method. Hydraulic fill is a method of stockpiling soil by filling soil into the reclamation area which is constructed on each side of embankments or bund (Hoff, 2012). The embankment soil in the area where the embankment has been built must be stable and able to withstand soil pressure and the potential for slippage caused by the embankment soil (Hoff, 2012). A common method of hydraulic fill is using embankments or bunds. Because the shear strength value of soft soil is low and also has a low CBR value, one of the subgrade criteria for embankment soil needs to have a sufficient CBR value (Zaika & Suryo, 2019). In addition to stability problems, subsidence is also a problem that occurs in embankment on soft soil (Balasubramaniam et al., 2010). One of the methods used to construct stable embankments or bund is ground improvement with soil replacement (Hartlen et al., 1996).

Previous research that has been done on soft soil improvement by preloading and PVD is this study presents a numerical evaluation of the strength and stability of the soil enhanced by vacuum consolidation in combination with preloading embankments. The results showed the validity of soil improvement using vacuum consolidation with preloading embankments (Shibata et al., 2015), replacement by Lightweight Expanded Clay Aggregate (LECA), the results obtained showed that the decrease decreased with increasing thickness of the LECA replacement (Zukri et al., 2018), By pile, The evaluation is based on 2D and 3D finite element analysis and on the behavior of the calibrated soil in the failure test and the finnish railway embankment, the results of which are improved stability (Mansikkamäki & Länsivaara, 2013), by jet mixing piles, verified the effect of soft marine clay foundation reinforced by two new types of dry jet mixing piles and conventional piles based on the expressway project from Lianyungang in Jiangsu Province to Linyi in Shandong Province, The results show that it can shorten the time of dissipation of water pressure from the pores of the pile soil and further accelerate the stability of the consolidation of the roadbed to achieve fast and effective consolidation of the soft marine clay foundation (Xie et al., 2014).

MATERIALS AND METHODS

PT. Pertamina (Persero) plans to expand and develop land using the reclamation method covering an area of 400 hectares in the coastal waters of RU-IV Pertamina Balongan - West Java to support the need for a petrochemical refinery facility as a research location in Table 1 and Figure.1. Reclamation planning requires soil investigation by means of digging a hole (trial-pit), drilling, and direct testing (in-situ test), obtaining the technical properties of the soil, then used as consideration in analyzing soil stability and settlement.

Soil investigation tests are carried out in onshore and offshore areas, in the form of laboratory tests and field tests. From laboratory tests, soil data obtained in the form of compression index (Cc), Index Plasticity (IP) and void ratio (e), while field test data in the form of drilling using Standard Penetration Test (SPT).

For the properties of the clay, the N value from the SPT test (N-SPT) is used. Cohesion is defined as the soil resisting stress resulting from the attraction of soil molecules. The SI unit of cohesion is the kilo Pascal (kPa). According to Look (2007), Table 2 can be used to determine the type of clay based on the N-SPT value, or based on the cohesion/strength (C_u) value of the soil.

Meanwhile, the value of dry soil volume weight (γ_d) and saturated soil unit weight (γ_{sat}) can be determined using a soil density relationship table based on the soil description given by Look (2007) and shown in Table 3.

Table 1. Coordinates of soil data point in layout image

Location	*Coordinate*			
	UTM		*Degrees*	
	X	Y	South	East
A1	212910,87	9294305,51	6°22'40.23"S	108°24'17.66"
A2	212004,35	9295901,14	6°21'48.16"S	108°23'48.46"E
A3	214246,87	9295891,33	6°21'48.85"S	108°25'1.37"E
A4	214827,36	9295010,25	6°22'17.61"S	108°25'20.12"E
A5	214227,83	9294654,98	6°22'29.09"S	108°25'0.55"E
A6	213857,84	9294795,54	6°22'24.45"S	108°24'48.54"E

Figure 1. Petrochemical refinery development project land reclamation plan (Google Earth,2021)

Table 2. Coreltion of SPT test result with clay cohesion/and strength(C_u)

Material	Description	SPT-(blow/300 mm)	Strenght (kPa)
Clay	V. Soft	≤ 2	0 - 12
	Soft	2 - 5	12 - 25
	Firm	5 - 10	25 - 50
	Stiff	10 - 20	50 - 100
	V. Stiff	20 - 40	100 - 200
	Hard	≥ 40	> 200

Table 3. Relationship description of soil or rock with unit weight

Type	Soil decription	Unit weight range (kN/m²)	
		Dry	Saturated
Cohesionless	Soft sedimentary	12	18
	(chalk,shale,siltstone,coal		
Compacted	Hard sedimentary	14	19
Broken Rock	(Congglomerate, sanfstone)		
	Metamorphic	18	20
	Igneous	17	21
Cohesionless	Very loose	14	17
	Loose	15	18
Sand and gravel	Medium dense	17	20
	Dense	19	21
	Very dense	21	22
Cohesionless	Loose		
	Uniformly graded	14	17
	Well graded	16	19
Sand and gravel	Dense		
	Uniformly graded	18	20
	Well graded	19	21
Cohesive	Soft - organic	8	14
	Soft - non organic	12	15
	Stiff	16	18
	Hard	18	20

After the soil properties have been identified, it is continued to evaluate the stability of the bund, the number of safety, and the decrease of bunds in the embankment GeoStudio program.

First, according to Hartlen (1996) in planning an embankment work so that failure does not occur, it is necessary to make an initial estimate of the critical embankment height. According to Terzaghi (1956) in Hartlen (1996), the critical embankment height/Safe Embankment Height (Hs) can be calculated by Equation 1.

$$H_s = \frac{(N_c.\tau_{fu})}{(F.\gamma_e)} \qquad (1)$$

Where :

H_s = Critical embankment height (m)

N_c = Stability value ($N_c = 5.52$ for field circle failure)

τ_{fu} = Undrained shear strength of subsoil (kN/m^2)

F = Factor of safety

γ_e = Bulk weight of embankment (kN/m^3)

Second, carry out the step of calculating the stability of the bund against the safety factor, decreasing bunds so that the construction of the bund is stable by carrying out two calculation stages.

a) Construction stage 1

In the calculation of the construction phase 1 by piling up bund as high as + 2.00 m above sea level, including:

1. The fill height (H_e) must be less than the critical height (H_{cr}).
2. If $H_e < H_{cr}$ with SF > 1.3, you can proceed to the calculation phase of SF, settlement, strength gain, consolidation time, and the number of PVD, then continue with the construction phase 2, if $H_e < H_{cr}$

with SF < 1.3, soil improvement is carried out with the following steps c.

3. If He > Hcr, soil improvement is carried out with sand-key, sand-key depth is determined check and error determination of depth optimum sand-key with GeoStudio software for SF and manual with the ordinary method for consolidation settlement and strength gain.
4. If $H_e > H_{cr}$ and SF < 1.3, change the thickness of the soil improvement with a sand-key, then determine the sand-key depth again check and error determination of depth optimum sand-key with GeoStudio software until the optimum sand-key depth is selected with SF > 1.3, proceed as step b.

b) Construction stage 2

In the calculation of the construction stage1 by piling up bund as high as + 6.00 m above sea level, proceed with steps such as construction stage 1. Furthermore, the calculation of slope stability against the number of safety using the GeoStudio program and manually using the ordinary method in Equation 2 below (Das et al., 2002):

$$SF = \frac{\sum(c\ \Delta L_n + W_n \cos\cos\alpha_n\ \tan\tan\emptyset)}{\sum W_n \sin\sin\alpha_n} \qquad (2)$$

Where :

Fs = Factor of Safety

c_u = Cohesion undrained value (kN/m^2)

l = flat width (m)

W = Weight of each piece (kN)

α = The angle between the center of refraction and the sliding reference point(^{o})

φ = shear angle in soil (^{o})

According to Han (2015), soil subsidence occurs in soils that are loaded with static vertical loads. The total decrease consists of 3 components which are given in Equation 3.

$$S_t = S_i + S_c + S_s \qquad (3)$$

Where :

S_t = Total settlement total (m)

S_i = Immediate settlement (m)

S_c = Consolidation settlement (m)

S_s = secondary settlement (m)

RESULTS AND DISCUSSION

It is known that the bathymetric contour data that shows the depth of the seabed in the project layout has a depth variation ranging from 3m to 6 m (below water level). So that the reclamation embankment or bunds planning calculation will be carry out at each depth variation. This is expected that each seabed depth variation requires a different sand-key depth variation as well in Figure 2.

Soil Geotechnical Data

The process of stockpiling the embankment soil itself is based on the hydraulic fill method, namely by spraying the soil into the reclamation area, then using a soil excavator to form a bund. The specifications of the embankment soil, including embankment fill, bund and sand-key, are determined in advance using sand soil with γ_{sat} = 20 kN/m^3, γ_{dry} = 18 kN/m^3 and φ = 30^o. So that the cross section in each bunds has the same configuration. Cross action plan on reclamed area with various seabed's depth is shown in Figure 2.

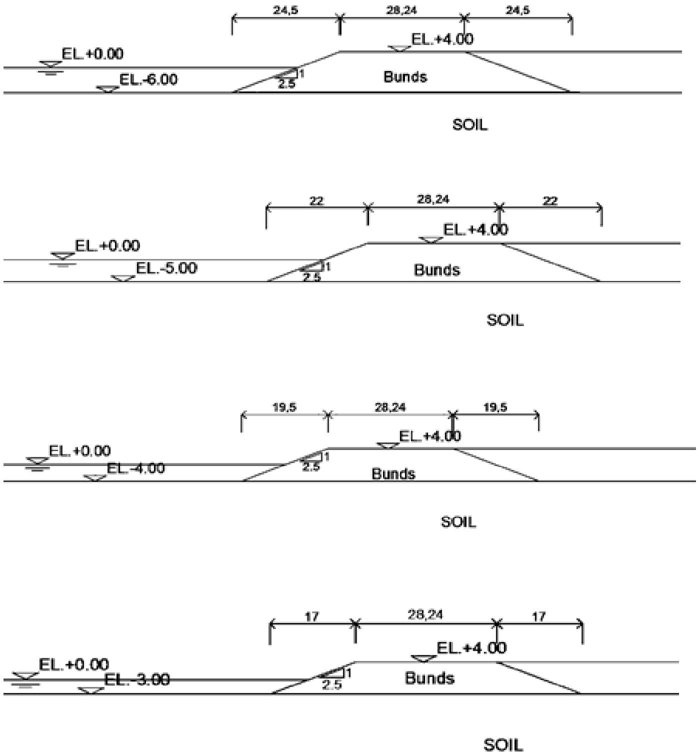


Figure 2. Cross section plan on reclaimed land with variations in seabed depth

Table 4. Offshore soil propertis recapitulation

Depth m	Layer	Soil type	average N-SPT	c_u kPa	ϕ deg	γ_{sat} kN/m^3	γ_d kN/m^3
0 - 5	Layer 1	Very soft clay	1.1	5.5	-	16	14
5 -10	Layer 2	Soft clay	3	15	-	16	14
10 -15	Layer 3	Soft clay	4.6	23	-	16	14
15 - 20	Layer 4	Firm clay	8.3	41.5	-	17	16
20 - 25	Layer 5	Very stiff clay	27.8	139	-	18	16
25 - 30	Layer 6	Very stiff clay	31.3	156.5	-	18	16
-	-	Sandkey; bunds; reclaim area	-	-	30	20	18

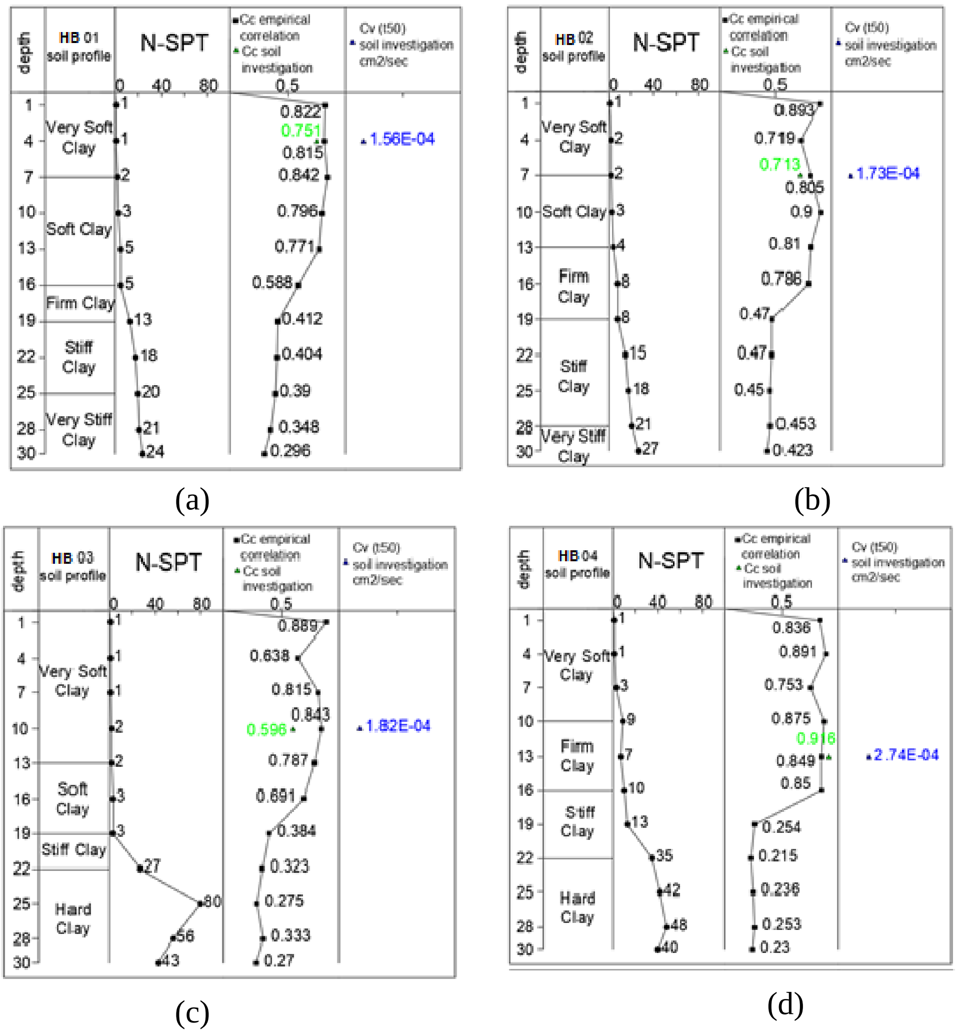
Table 4 shows the N-SPT test data in the offshore area, based on the description of the relationship between N-SPT with strength and unit weight according to Look (2007) in Table 2 and Table 3. While Table 5 is the result of data in the onshore area.

Table 5. Onshore soil properties recapitulaion

Depth m	*Average* C_c	Average(C_v) cm^2/sec	Average(Ip) (%)	Average e_0
0 - 5	0.830	$1.69.x.10^{-4}$	47.5	1.492
5 -10	0.840	$1.73.x.10^{-4}$	59.3	1.4
10 - 15	0.810	$1.82.x.10^{-4}$	62.3	2.28
15 - 20	0.555	$2.74.x.10^{-4}$	64.5	1.923
20 - 25	0.351			
25 - 30	0.322			

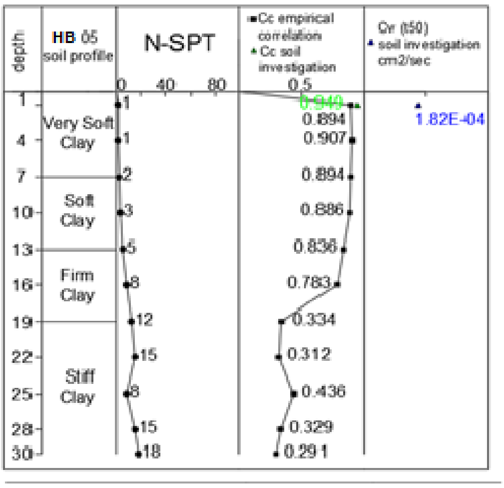
Soil Geotechnical Data Analysis

While the data from the results of soil investigations that have been carried out in the field and in the laboratory, both onshore and offshore. Soil investigation were carried out on drill samples taken at the site. Evaluation of slope stability required laboratory and field test data in Figure 3 and Figure 4 following.



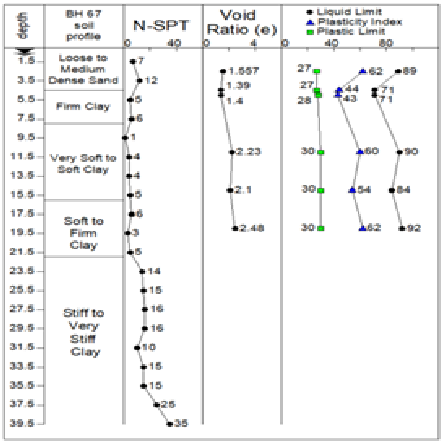
(a) (b)

(c) (d)

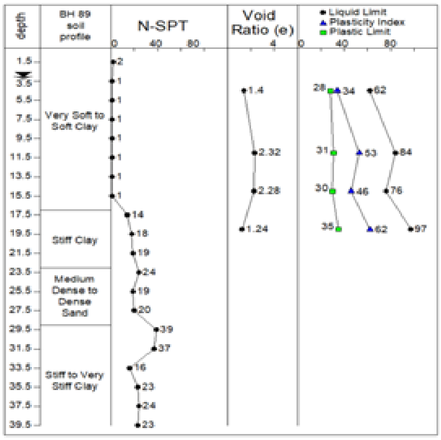


(e)

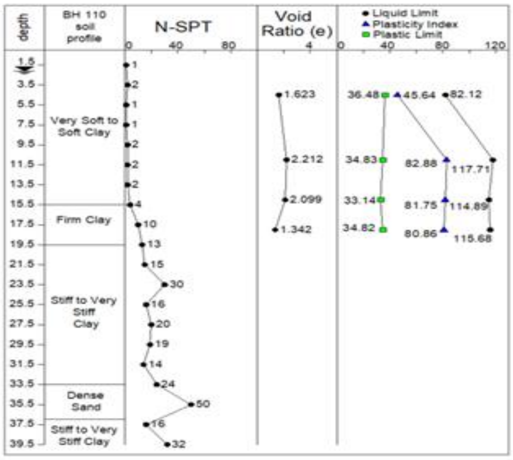
Figure 3. Borelog in the Balongan reclamation area on the offshore.
(a) BH 1, (b) BH 2, (c) BH 3, (d) BH 4, (e) BH 5



(a)



(b)



(c)

Figure 4. Borelog in the Balongan reclamation area on the onshore section.
(a) BH 67, (b) BH 89, (c) BH 110

If the seabed is at a depth of -6 m, the allowable height of the bund embankment so that it does not exceed the safe height value is 2.58 m or is located at an elevation of -3.42 m, where reclamation has a target elevation on the EL. +4.00. The elevation is still below sea level, which is very difficult to operate the project (needed for embankment height above sea level). To overcome very soft clay subsoil conditions, several options can be carried out, for example using soil improvement, namely by soil replacement under the bund using sand-key. Because the bund stockpile height did not meet the final embankment target height (target elevation at EL. +4.00, the reclamation and bund embankment was carried out using the stage construction method, and the initial assumption was that the landfill was in two stages. The first stage is stockpiling to an elevation of +2 m above sea level, and in the second stage, stockpiling is to an elevation of +4 m above sea level.

Calculation of sand-key (soil replacement) under the bund, where the height of the bund elevation at construction stage 1 is determined EL.+2.0m, then a review is carried out on several sand-key depths, namely 4,6,7,10 m. Calculation of sand-key stability check and error against the selected sand-key depth variation on a 6 m seabed in Table 6 and sand-key + bund at construction stage 2 in Table 7.

Calculation of Sand-key Stability Check and Error with GeoStudio and ordinary manual of 0.008, While the calculation of Check and Error Stability Sand-key + bund with GeoStudio and manual ordinary is 0.193. Similarly, the results of calculating the total decrease immediately due the accumulation of bunds in calculation stage 1 and calculation stage 2 in Table 8. The recapitulation of the evaluation results of slope stability and soil improvement with Sand-key materials for construction phase 1 and construction phase 2 includes safety factor, settlement and final elevation of the desired and stable bund, can be seen in Table 9 and Table 10.

Table 6. Check and error stability of sand-key depth variation at construction stage 1

Depth				Safety Factor	
Sea Bed	Sandkey	Safety Factor	Selected Sandkey	GeoSudio	Ordinary
6	4	1.118	7	1.603	1.611
	6	1.448			
	7	1.603			
	10	2.044			

Table 7. Check and error stability of sand-key depth variation at construction stage 2

Depth				Safety Factor	
Sea Bed	Sandkey	Safety Factor	Selected Sandkey	GeoSudio	Ordinary
6	7	1.603	7	1.404	1.597

Table 8. The result of total settlement and final elevation at construction stage 1 and construction stage 2

Depth		Settlement total		Fianl elevation	
Sea Bed	Sandkey	Construction stage1	Construction stage2	Construction stage1	Construction stage2
6	7	2,2581	1,8401	-0,2581	4,1599

Table 9. Recapitulation of sand-key head base on variation of seabed depth (construction stage 1)

Seabed	Fill Height from sandkey base	Safety Factor	Settlement	Initial Elevation	Final Elevation
(Elv)	(m)	(m)	(m)	(m)	(m)
6	7	1,603	2,2581	2	-0,2581
5	10	1,547	2,1612	2	-0,1612
4	10	1,464	2,3275	2	-0,3275
3	5	1,570	1,8354	2	0,1646

Table 10. Recapitulation of sand-key head base on variation of seabed depth (construction stage 1)

Seabed	Fill Height from sandkey base	Safety Factor	Settlement	Initial Elevation	Final Elevation
(Elv)	(m)	(m)	(m)	(m)	(m)
6	7	1,404	1,8401	6	4,1599
5	10	1,438	1,4463	6	4,5537
4	10	1,675	1,4148	6	4,5852
3	5	1,354	1,9645	6	4,0355

Seabed Relationship, Safety Factor, Settlement and final elevation.

The relationship between the selected seabed and san-key depths to the factors of safety, settlement, and final elevation at construction stage 1 and construction stage 2 in Figure 5, Figure 6 and Figure 7 below.

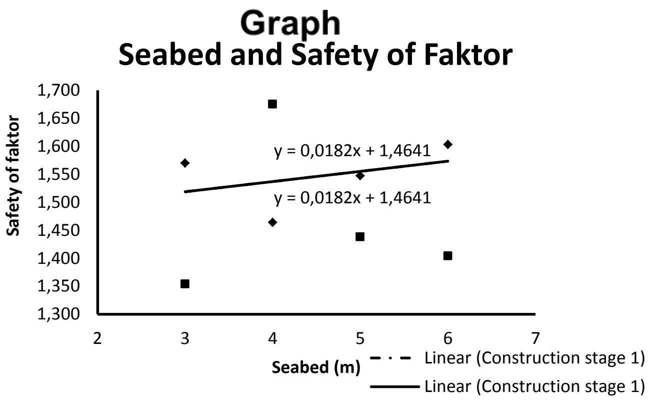


Figure 5. Seabed Relationship and safety factor

Based on Figure 5, shows that the deeper the seabed, the trend of the safety factor is increasing, both construction stage 1 and construction stage 2. Based on Figure 6, shows that the deeper the seabed, the trend of settlement is increasing in construction stage 1, and conversely the deeper the seabed, the trend of settlement is decreasing at construction stage 2. Based on Fig. 7, shows that the deeper the seabed, the trend of the final elevation on the bund, tends to decrease and its value is negative at construction stage 1, Conversely the deeper the seabed, the trend of final elevation, tends to increase in construction stage 2 according to the desired elevation with a value of + 4 m.

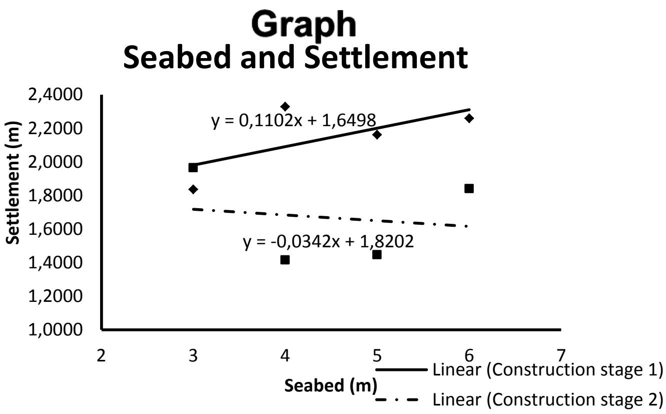


Figure 6. Seabed and settlement relationship

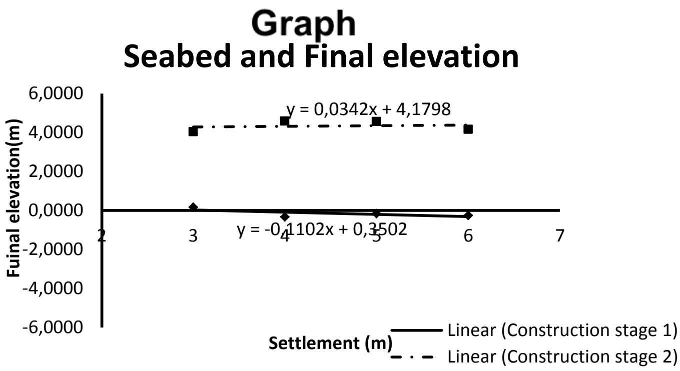


Figure 7. Seabed relationship and final elevation

CONCLUSION

The Bund stability analysis results show that the value of the sand-key depth depends on the variation in the depth of the seabed. At a seabed depth of -6 m, there is a sand-key depth of 7 m with a final safety number of 1.404, at a seabed depth of -5 m a sand-key depth of 10 m is obtained with a final safety number of 1.438, at a seabed depth of -4 m a sand-key depth of 10 m is obtained with a final safety number of 1.675 , at a seabed depth of -3 m, the sand-key depth is 5 m with the final safety number 1.354. From the result of analysis, it can be concluded that ground improvement using soil replacement with sand-key can make the construction of embankment or bund become stable in reclamation work at soft soil area.

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