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Behaviour Study of Abutment Foundation Pile on Lightweight Embankment Oprit (Case Study: Kali Otek Bridge – Lamongan North Ring Road Construction Package Section 2)

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ABSTRACT

The Kali Otek Bridge is in the Lamongan North Ring Road Development Package Section 2 with a bridge span length of 40.8m. The boring test results show that the subgrade is included in the very soft soil classification to a depth of >15 meters. The existing condition is a pond area that can be inundated with water reaching a height of 1 meter, thus affecting the occurrence of land subsidence and stability of the bridge abutment foundation pillars. The existence of embankment construction can also cause subsidence on the subgrade.

In this research, soil settlement and stability analysis of lightweight foam mortar embankment has been carried out by varying the percentage of the height of the existing embankment and the foam mortar. In addition, it also analyzes the effect of using lightweight embankment, both as a whole and its variations on the stability of bridge abutment foundation piles, both with and without Prefabricated Vertical Drain (PVD).

The analysis showed that the use of foam mortar reduced the subgrade settlement by 61.2% with a longer time of 18.5%. The smallest settlement and lateral deflection was at 100% foam mortar backfill variation with consolidation time of 190 days. The greater the percentage of foam mortar height, the smaller the settlement as the factor of safety increases. Thus, the use of foam mortar can be an alternative embankment for bridge oprites on soft soil.

Keywords : Oprites, foundation pile, abutment, foam mortar

INTRODUCTION

The Java Pantura Road (North Coast of Java) is one of the economic axes on the island of Java starting from Merak Port, Cilegon to Ketapang Port, Banyuwangi. Lamongan Regency as one of the East Java Pantura Lines is a busy route during Lebaran homecoming. The East Java-Bali National Road Implementation Center (BBPJN) as an extension of the Directorate General of Highways, Ministry of Public Works and Public Housing is carrying out road construction in order to unravel the density of traffic flow between cities and the East Java Pantura national road in Lamongan Regency through the Lamongan North Ring Road Development.

Figure 1. Layout of Lamongan North Ring Road Development Package
Source: BBPJN Jatim-Bali, 2024

The Lamongan North Ring Road Development Package is divided into Section 1 (STA 0+000 - STA 3+250) including the Kali Deket Bridge, and Section 2 (STA 3+250 - STA 6+765) including the Kali Otek Bridge and Kali Kandang Bridge. Currently both are in the process of implementation organized with a multi-year contract (MYC) system for 2023-2024 by BBPJN Jatim-Bali, especially in PPK 4.5 East Java Province. The location of the existing road construction is a pond area that is always flooded during the rainy season with a flood water level of 1 meter and in general, the soil conditions are very soft to a depth of between 16-24 m.

Kali Otek Bridge is one of the bridges to be built in the 40.8 meter on The Lamongan North Ring Road Section 2 Development package and is the object of current research. The location of this bridge is at STA 4 + 062 which uses a concrete spun pile foundation Ø 60 cm along 31 meters. Based on the results of boring tests at the research site, it is known that the soil type is very soft clay with N-SPT < 4 to a depth of more than 15 meters.

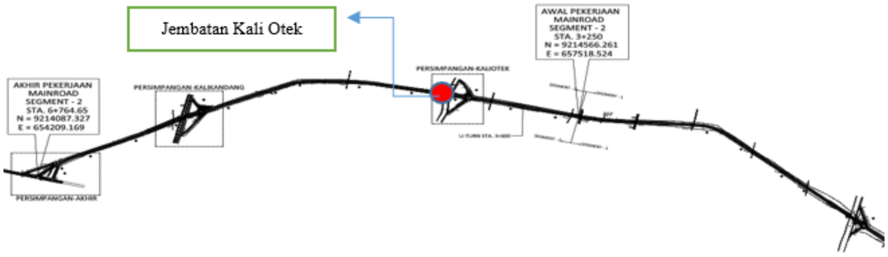

Figure 2. Layout of Kali Otek Bridge
Source: BBPJN Jatim-Bali, 2024

Considering the heavy traffic on the coastal road in Lamongan Regency and the fact that it will be diverted to the Lamongan North Ring Road, the use of the existing embankment planned for the oprit of the Kali Otek Bridge may affect the subsidence of the soil causing a difference in elevation of the bridge oprit. The difference in oprite elevation can cause inconvenience for road users. For this reason, the use of lightweight foam mortar backfill material can be an alternative because it has a smaller density than the existing backfill material used.

Table 1. Parameter Comparison of Backfill Soil and Foam Mortar

No.	Backfill Material	Parameter			
		Dencity (kg/m^3)	Cohession (kPa)	Shear Angle (°)	Compressive Strength (kPa)
1.	Backfill soil	1800	0,2	28 – 50$^{4)}$	-
2.	Foam Mortar	800$^{2)}$	0$^{3)}$	35 - 40$^{3)}$	800 (backfill), 2000 (top layer of foundation) $^{2)}$

Sources : $^{2)}$ SKh.2.7.21 Mortar Busa, Ditjen Bina Marga (2024)
$^{3)}$ Triwari, dkk (2017)
$^{4)}$ Burt G. Look (2007)

LITERATUR REVIEW

Soil Parameters Based on SPT Testing

SPT testing has been widely used as a correlation of soil volume weight (γ), relative density (D_r), internal friction angle (ϕ) and undrained compressive strength (qu) values. The correlation of soil parameters for cohesive soils is shown as follow:

Table 2. Parameter of Cohessive Soil

Cohessive Soil					
N (blows)	<4	4 - 6	6 - 15	16 - 25	>25
γ (kN/m3)	14 – 18	16 - 18	16 - 18	16 - 20	>20
qu (kPa)	<25	20 - 50	30 - 60	40 - 200	>100
consistency	very soft	soft	medium	stiff	hard

Source: J.E. Bowles, 1984 in Wahyudi, 2018

The estimated shear angle (ϕ) and soil consistency values for silt and clay dominant soils can be seen in the following table:

Table 3. Estimated Shear Angle (ϕ) and Soil Consistency Values for Silt and Clay Dominant Soils

Type	**Soil Description/State**	**Effective Cohession (kPa)**	**Friction angle (degress)**
Cohesive	Soft - organic	5 - 10	10 - 20
	Soft - organic	10 - 20	15 - 25
	Stiff	20 - 50	20 - 30
	Hard	50 - 100	25 - 30

Source: Burt G Look, 2007

Foam Mortar

According to the Interim Special Specification SKh-2.7.21 Year 2024, foam mortar lightweight material is a concrete-like material consisting of a mixture of sand, cement, water and foam liquid (foam agent), and serves as a substitute for soil fill with a planned dry density of 8 kN/m^3, This material can be used as fill for road construction which is intended to reduce the load of the embankment.

Table 4. Minimum Compressive Strength of Foam Mortar

Function	**Minimum Compressive Strength (14 days old)**	
	kPa	**kg/cm^2**
Foundation Layer	2000	20
Bottom Foundation Layer / Backfill	800	8

Source: SKh.2.7.21 Mortar Busa, Ditjen Bina Marga (2024)

The modulus of elasticity of foam mortar backfill can be calculated) formula based on ACI Committee (2014) as shown in the following equation:

$$Ec = 4700\sqrt{fc'} \quad \ldots (1)$$

where:
Fc’ = compressive strength of foam mortar (MPa)

Safety Factor

The constructed embankment must meet the specified stability requirements determined in terms of its factor of safety. Minimum factor of safety required for short-term conditions or during the implementation period of the embankment are shown in the following table:

Table 5. Minimum Safety Factor of Embankment Stability

Road Class	**Safety Factor**
I	1,4
II	1,4
III	1,3
IV	1,3

Source: PUPR, 2015

Settlement Requirement

The requirements for embankment settlement during the construction period and the rate of settlement after the construction period required by Pt T-10-2002-B in the Ministry of PUPR Guidelines (2015) are shown in the following table:

Table 6. Embankment Settlement Criteria

Road Class	**Required settlement during the construction period**	**Subsidence velocity after construction (mm/year)**
I	> 90%	< 20
II	> 85%	< 25
III	> 80%	< 30
IV	> 75%	< 30

Notes : S is the settlement during the implementation period
S_{tot} s the total expected settlement

Source: PUPR, 2015

Meanwhile, the settlement of embankment on soft soil after the construction period for national roads is required to be 100 mm based on the Manual Desain Perkerasan Jalan Direktorat Jenderal Bina Marga (2017).

RESEARCH METHOD

This research uses secondary data obtained from BBPJN East Java-Bali during internship activities. The secondary data obtained includes DED data, shop drawings, soil test data, settlement plate monitoring results, and others. This research aims to determine the effect of using lightweight foam mortar backfill on the abutment piles of the Kali Otek bridge by varying the thickness of foam mortar with existing backfill in the form of limestone in the field either using PVD or without PVD. The modeling of all variations used the Plaxis 2D program. The embankment variations that were modeled are as follows:

1. All foam mortar backfill (100% MB)
2. 25% limestone backfill + 75% foam mortar backfill (25% LS + 75% MB)
3. 50% limestone backfill + 50% foam mortar backfill (50% LS + 50% MB)
4. 75% limestone backfill + 25% foam mortar backfill (75% LS + 25% MB)
5. All existing/limestone backfill (100% LS)

DATA COLLECTION

In this study, to obtain soil parameters that will be used in analyzing the variation of embankment in the Plaxis 2D program, using the back analysis method so that the decline obtained is close to the decline that occurs in the field. After the N-SPT correction, there are four soil layers with consistency from top to bottom, namely soft, very soft and medium. In the medium consistency layer, it is divided into two parts because the soil is compressible only to a depth of 26 meters. For this reason, the parameters at the next depth up to 30 meters are slightly different even though they are still in the same soil consistency. After back-analyzing using Plaxis 2D through some trial and error, the subgrade parameters were obtained whose settlement is close to the real settlement in the field, as shown in the following table:

Table 7a. Parameter of Soil per Layer

Depth	**Thick of Layer**	**v**	**e0**	γ_{unsat}	γ_{sat}	**E**	**c'**	**ϕ'**	**Consistency of Soil**
(m)	**(m)**			**(kN/m^3)**	**(kN/m^3)**	**(kN/m^2)**	**(kN/m^2)**	□	
1	1	0,2	1,34	16,4	17	3000	22	17,3	*soft*
2	1	0,2	1,34	16,4	17	3000	22	17,3	*soft*
3	1	0,2	1,34	16,4	17	3000	22	17,3	*soft*
4	1	0,2	1,34	16,4	17	3000	22	17,3	*soft*
5	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
6	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
7	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
8	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
9	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
10	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
11	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
12	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
13	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
14	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
15	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
16	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
17	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
18	1	0,2	2,44	16	16	2050	15	13,3	*very soft*
19	1	0,2	1,34	17	17	6000	22	17,3	*medium*
20	1	0,2	1,34	17	17	6000	22	17,3	*medium*
21	1	0,2	1,34	17	17	6000	22	17,3	*medium*
22	1	0,2	1,34	17	17	6000	22	17,3	*medium*

Table 7b. Parameter of Soil per Layer

Depth	Thick of Layer	v	e0	γ_{unsat}	γ_{sat}	E	c'	ϕ'	Consistency of Soil
(m)	(m)			(kN/m^3)	(kN/m^3)	(kN/m^2)	(kN/m^2)	□	
23	1	0,2	1,34	17	17	6000	22	17,3	*medium*
24	1	0,2	1,34	17	17	6000	22	17,3	*medium*
25	1	0,2	1,34	17	17	6000	22	17,3	*medium*
26	1	0,2	1,34	17	17	6000	22	17,3	*medium*
27	1	0,31	0,9	17	17	7400	24	18	*medium*
28	1	0,31	0,9	17	17	7400	24	18	*medium*
29	1	0,31	0,9	17	17	7400	24	18	*medium*
30	1	0,31	0,9	17	17	7400	24	18	*medium*

Source: Processed by the Author

RESEARCH ANALYSIS

Parameter Determination using Back Analysis

In this research, the calculation of back analysis of parameters from the corrected N-SPT results to obtain parameters that are in accordance with the decline that occurred in the field. From the soil parameters obtained according to the corrected N-SPT, then inputted using the 2D Plaxis Program to determine the amount of decline in accordance with the decline that occurred in the field. If the settlement is obtained that is close to the real conditions in the field, then the parameters are used to analyze the stability of the abutment foundation using lightweight foam mortar backfill. The parameters obtained from the N-SPT correlation results as shown in the following table after the trial and error process will be used to analyze the settlement using Plaxis 2D.

Table 8. Recapitulation of Subgrade and Backfill Parameters

Depth (m)	Description	Soil Model on Plaxis	γ	γ sat	φ'	e	c’	E
			kN/m^3	kN/m^3	□		kN/m^2	kN/m^2
0 - 4	Silty clay soft (Layer 1)	Mohr Columb Undrained A	16,4	17	17,3	1,34	22	3000
4 - 18	Silty clay very soft (Layer 2)	Mohr Columb Undrained A	16	16	13,3	2,44	15	2050
18 - 26	Silty clay medium (Layer 3)	Mohr Columb Undrained A	17	17	17,3	1,4	22	6000
26 - 30	Silty clay medium (Layer 4)	Mohr Columb Undrained A	17	17	18	0,9	24	7400
	Backfill	Mohr Columb Drained	17,86	17,86	35	0,5	10	20000

Source: Processed by the Author

These parameters were modeled using the Mohr Columb soil model in the Plaxis 2D program by selecting the drained type for the embankment and undrained A for each subgrade layer as shown in Table 6. The depiction of embankment modeling is in accordance with the phasing of the embankment in the field as well as its geometrics. The results of the modeling obtained a settlement that is close to the field conditions of 1.519 m with a consolidation time of 214 days.

Determination of the Initial Height of the Embankment

The planned final height is 4.733 meters. In varying the percentage between existing embankment and foam mortar embankment, it is necessary to find the initial H to obtain the planned final height. For this reason, it is done by calculating the amount of initial H with different loads according to the variation in the height of the lightweight embankment using the formula equation:

$$\text{H initial} = \frac{q+(Sc*\gamma w)}{\gamma\ timbunan} \qquad \ldots (2)$$

Where :

q = embankment load ($\gamma_{\text{embankment}}$ x $h_{\text{embankment}}$)
Sc = amount of compression
γ_w = volume weight of water
$\gamma_{embk.}$ = volume weight of fill

By performing these calculations for all soil layers with variations in height of 2, 4, 6, and 8 meters, the initial H is obtained according to the combination of lightweight embankment as follows:

Table 9. H initial on Variation of Embankments

Variation of Embankment	H final (m)	H initial (m)	Limestone/LS (m)	Foam Mortar/MB (m)
100% MB	4,733	5,211	0,000	5,211
25% LS + 75% MB	4,733	5,393	1,348	4,045
50% LS + 50% MB	4,733	5,559	2,779	2,779
75% LS + 25% MB	4,733	5,622	4,216	1,405
100% LS	4,733	5,850	5,850	0,000

Source: Processed by the Author

Determination of the initial H in each variation of lightweight embankment is used to describe the height of each limestone embankment as existing embankment and foam mortar embankment in modeling using Plaxis 2D Program.

2D Plaxis Modeling in All Variation of Embankment

The height variation of the foam mortar embankment is in accordance with the initial H that has been obtained previously. This analysis also varies the use of PVD and without PVD to determine the decline that occurs in the embankment and its effect on the bridge pile foundation. The parameters of foam mortar and piles used can be seen in the following table:

Table 10. Parameter of Pile and Foam Mortar

Pile Properties - Elastic		Foam Mortar – Linear Elastic	
Diameter	0,6 m	γ unsat	8 kN/m^3
thickness	0,1 m	γ sat	8 kN/m^3
height	31 m	e	0,5
Spacing	2,25 m	E	1329361 kN/m^2
Fc’	52 MPa		
E	33892182 kN/m^2		
γ	25 kN/m^3		
P ijin	1275,3 kN		
M crack	245,25 kNm		

Source: Processed by the Author

In addition to the specified subgrade, embankment, foam mortar and pile parameter data, the depiction in the Plaxis 2D Program was adjusted to the geometry in the field. As for the variation without the use of PVD, the geometry is the same, but when analyzing in Plaxis, the pile material must be deactivated and the soil parameters changed from *khp* to *kx* because there is no effect of using PVD. The modeling image in Plaxis 2D is as follows:

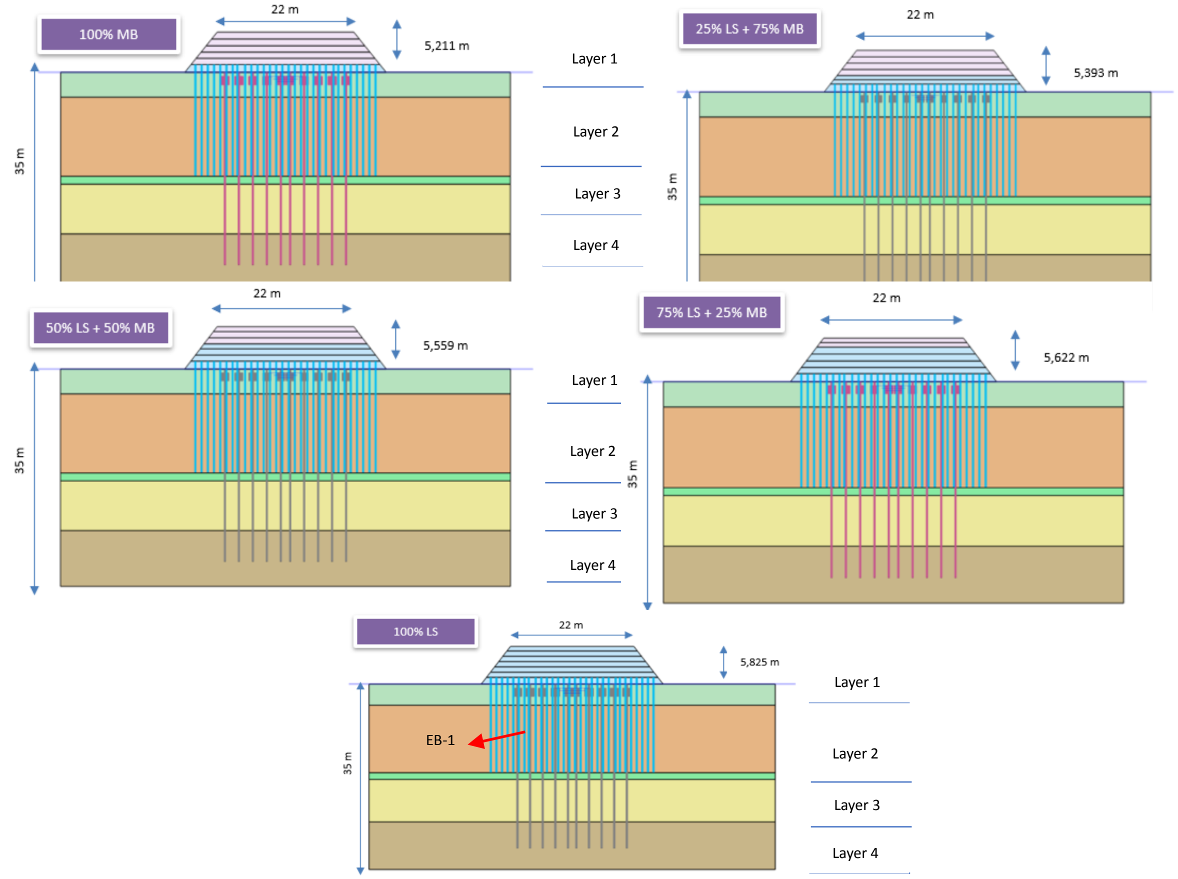

Figure 3. Geometry Modeling of All Variations (with PVD) in Plaxis 2D

Source: Processed by the Author

Then input is made to the 2D Plaxis Program application such as soil parameters, material properties, namely foam mortar material and pile material (piles) and other existing data to then proceed with running the program which later from the running results can be analyzed.

Table 11a. Deformation on All Variation of Embankment

Degree of Consolidation	With PVD									
	100%MB		25% LS + 75% MB		50% LS + 50% MB		75% LS + 25% MB		100%LS	
	S (m)	t (days)	S (m)	t (days)	S (m)	t (days)	S (m)	t (days)	S (m)	t (days)
U 10%	-0,408	34,89	-0,544	40,89	-0,694	42,11	-0,860	44,11	-1,067	46,90
U 20%	-0,416	39,60	-0,552	45,61	-0,708	48,39	-0,876	50,39	-1,087	53,18
U 30%	-0,423	45,10	-0,565	55,03	-0,714	51,54	-0,895	59,82	-1,095	56,33
U 40%	-0,430	51,39	-0,572	61,32	-0,728	60,97	-0,895	59,82	-1,115	65,76
U 50%	-0,435	57,67	-0,578	67,60	-0,735	67,25	-0,919	78,68	-1,127	72,05
U 60%	-0,446	76,52	-0,582	72,31	-0,747	79,83	-0,919	78,68	-1,137	78,34

Table 11b. Deformation on All Variation of Embankment

Degree of Consolidation	**With PVD**									
	100%MB		**25% LS + 75% MB**		**50% LS + 50% MB**		**75% LS + 25% MB**		**100%LS**	
	S (m)	**t (days)**	**S (m)**	**t (days)**	**S (m)**	**t (days)**	**S (m)**	**t (days)**	**S (m)**	**t (days)**
U 70%	-0,451	89,09	-0,590	84,88	-0,752	86,11	-0,932	91,26	-1,160	97,20
U 80%	-0,458	114,2	-0.599	103,74	-0,766	108,1	-0,949	116,4	-1,182	122,36
U 90%	-0,466	189,6	-0,609	141,44	-0,778	145,8	-0,963	154,1	-1,202	160,09
U 10%	-0,254	41,17	-0,340	47,18	-0,449	50,75	-0,578	51,18	-0,731	53,18
U 20%	-0,285	58,45	-0,392	72,31	-0,499	69,61	-0,641	70,04	-0,799	68,91
U 30%	-0,310	77,31	-0,413	84,88	-0,549	94,76	-0,701	95,19	-0,861	87,77
U 40%	-0,347	115,01	-0,445	110,02	-0,569	107,30	-0,764	132,90	-0,935	119,21
U 50%	-0,366	140,10	-0,470	135,16	-0,604	132,50	-0,798	158,05	-0,982	144,37
U 60%	-0,381	165,30	-0,492	160,30	-0,642	170,20	-0,825	183,20	-1,052	194,67
U 70%	-0,392	190,40	-0,516	198,00	-0,667	201,60	-0,849	208,34	-1,080	219,83
U 80%	-0,422	290,90	-0,538	245,14	-0,700	258,20	-0,893	271,21	-1,138	295,29
U 90%	-0,436	391,50	-0,563	345,69	-0,731	352,50	-0,934	371,79	-1,181	395,90

Source: Processed by the Author

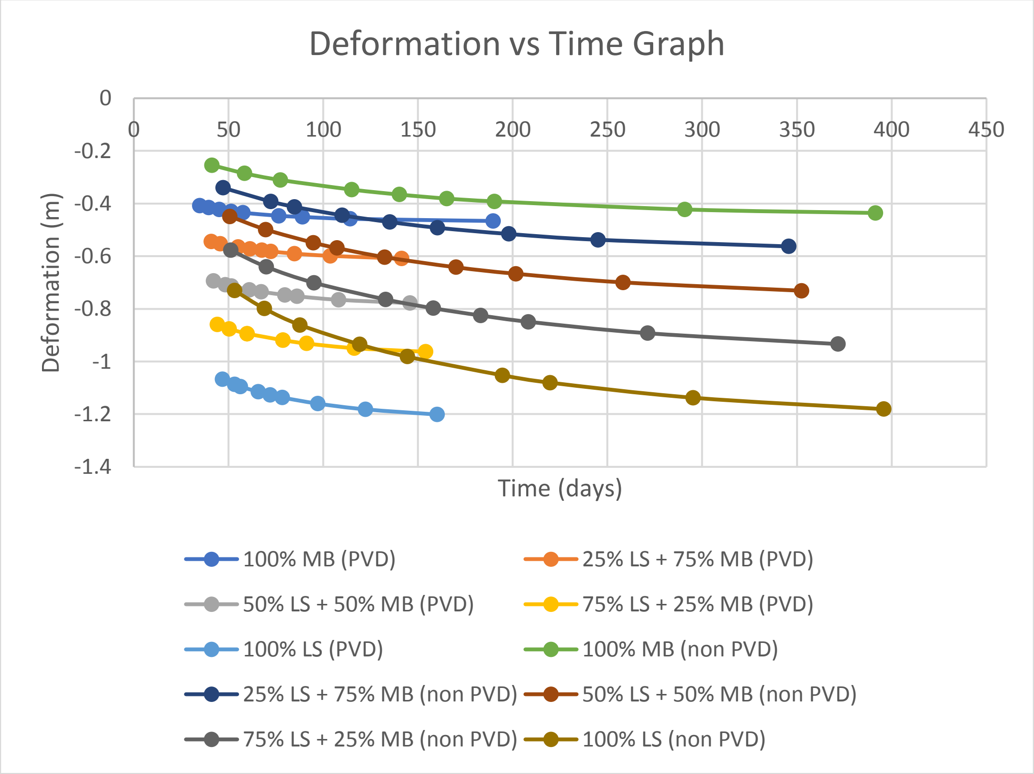

Figure 4. Deformation vs Time
Source: Processed by the Author

From Figure 4, it can be seen that the settlement of soil at each increase in the degree of consolidation has increased both with and without PVD. However, for the embankment variation without PVD the settlement value is smaller than that with PVD. This is because the pore water is trapped in the soil layer making it difficult to escape and takes longer than using PVDs. The figure also shows that the lighter the embankment or the greater the thickness of the foam mortar embankment, the smaller the settlement will be because the embankment load received by the subgrade is reduced.

Stability of Embankment

Table 3. Safety Factor in All Variation of Embankments

Variation of Embankment	Safety Factor	
	PVD	Non PVD
100% MB	3,659	3,490
25% LS-75% MB	2,479	2,318
50% LS-50% MB	1,917	1,757
75% LS-25% MB	1,630	1,469
100% LS	1,941	1,921

Source: Processed by the Author

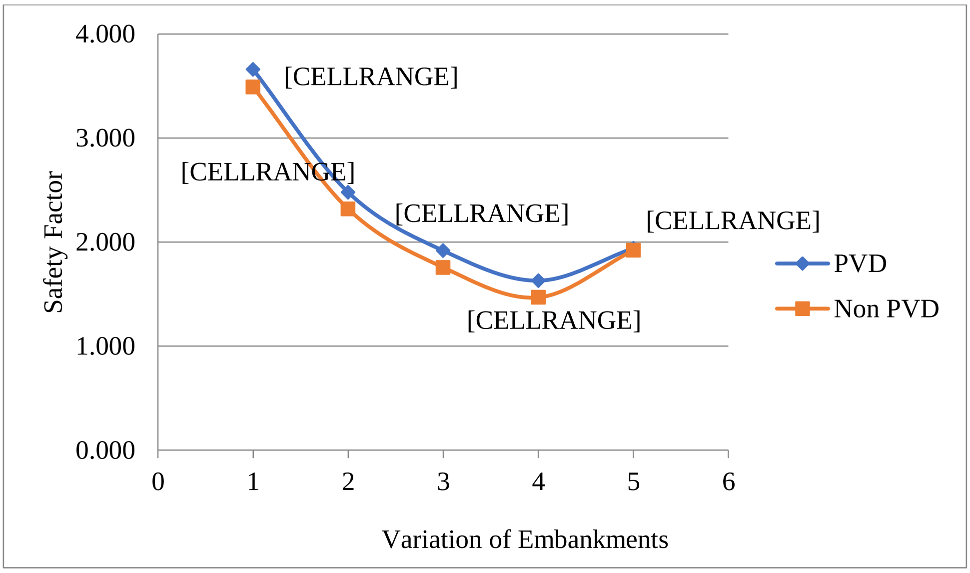

Figure 5. Safety Factor vs Variation Embankment Graph
Source: Processed by the Author

Based on Pd T-11-2005-B (2005) embankment stability requirements, for road class I the minimum factor of safety is 1.4. From the resulting factor of safety data, it can be concluded that all foam mortar embankment variations meet these requirements. The highest factor of safety value of all embankment variations with or without PVD is for 100% foam mortar embankment variation which is 3.659 with PVD and 3.490 for non PVD.

Hydrostatic Uplift

The existing condition before the Lamongan North Ring Road Development Package was carried out, was a pond / rice field where during the rainy season the flood water level reached 1 meter. For this reason, the bridge oprite embankment using lightweight foam mortar embankment needs to be analyzed for the uplift that occurs.

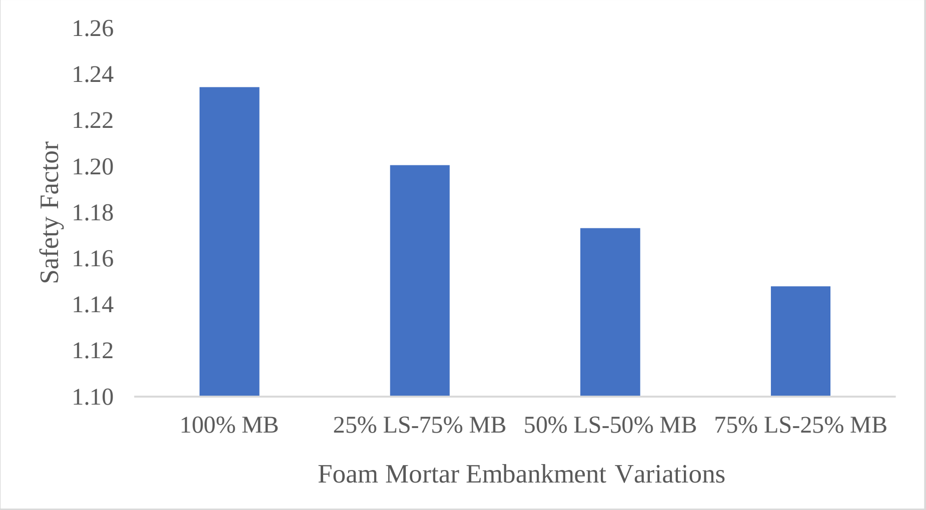

Figure 6. Graph of Safety Factor vs Uplift
Source: Processed by the Author

From the calculation results, it can be concluded that the use of the full foam mortar variation (100% MB) has met the requirements of the safety factor against uplift, which is at least 1.1. From the figure above, it can be seen that the thicker the foam mortar layer used, the greater the safety factor value. This can happen to anticipate the potential instability that exists in the variation of soil conditions.

Lateral Deflection of Piles

In the results of the Plaxis program analysis, the amount of lateral deflection of piles due to embankment loads both with and without using PVD can be seen. The pile under review is the EB-1 pile according to Figure 3, where the largest amount of lateral deflection is seen in each embankment variation. The results can be seen in the following table:

Table 4. Lateral Deflection in All Variation of Embankments

Variation of Embankments		**Lateral Deflection (m)**
PVD	100% MB	0,032
	25% LS + 75% MB	0,046
	50% LS + 50% MB	0,073
	75% LS + 25% MB	0,103
	100% LS	0,136
Non PVD	100% MB	0,035
	25% LS + 75% MB	0,050
	50% LS + 50% MB	0,080
	75% LS + 25% MB	0,128
	100% LS	0,194

Source: Processed by the Author

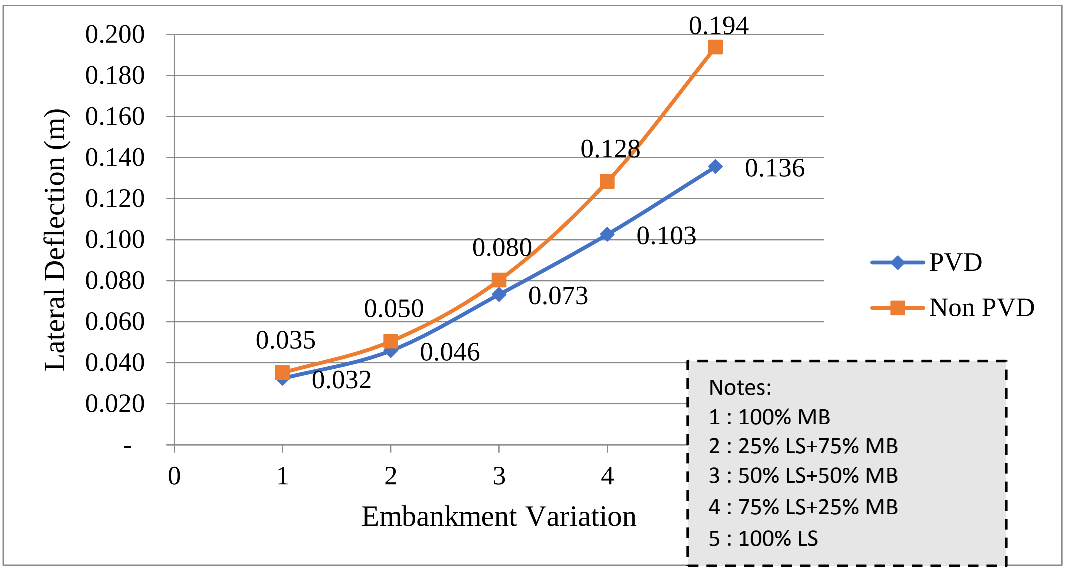

Figure 7. Lateral Deflection in All Variation of Embankments Graph
Source: Processed by the Author

Figure 7. shows that there is an increase in lateral deflection as the embankment load increases, both with and without PVD. This indicates that the thicker the foam mortar, the less lateral deflection will occur due to the light weight of the foam mortar material. The condition without PVD tends to experience a greater increase at the same variation. Without PVD, the subgrade has not yet consolidated so there is still a lot of pore water in the soil layer and when exposed to heavier loads it will easily experience lateral deflection.

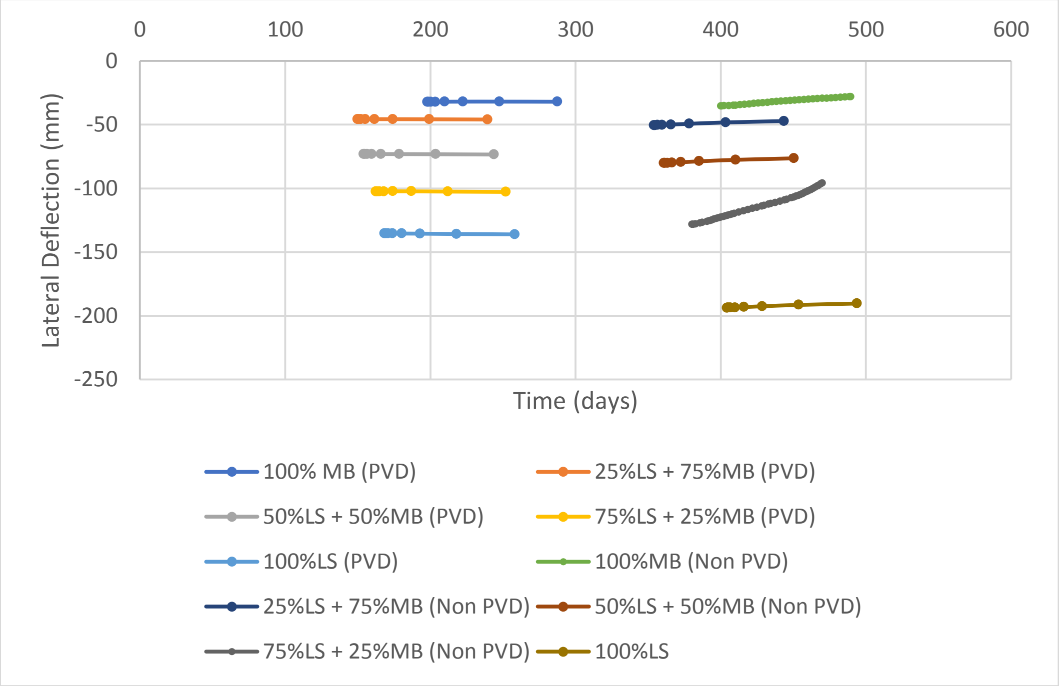

Figure 8. Lateral Deflection vs Time Graph
Source: Processed by the Author

Figure 8. shows that the lateral deflection of the pile that occurs in all variations of embankment using PVDs is smaller than without using PVDs. This can occur because the use of PVDs can accelerate the consolidation of soft soil, so that pore water in the soil can quickly escape and the soil becomes denser. Due to the denser soil condition, the lateral deflection is smaller, thus supporting better stability of the foundation piles when compared to without PVDs. The figure also shows that the higher percentage of foam mortar backfill (100% MB) also resulted in smaller lateral deflection of 0,032 meters with PVD and 0,035 meters without PVD. The time taken to achieve lateral deflection in the condition of using PVD is on average faster than without using PVD in all embankment variations because soil consolidation occurs faster, thus accelerating changes in soil properties that result in faster deflection of the pile.

Internal Forces of Pile

In pile foundations, the forces in the pile that occur due to light embankment loads are mainly influenced by the vertical load and how the pile interacts with the surrounding soil. Light embankment loads mean that the load applied to the soil is smaller, so the forces acting on the pile will also be relatively smaller. However, there are several factors that affect how these forces are distributed along the pile. The forces that occur in piles due to light embankment loads are in the form of axial forces, shear forces, and moment forces.

The use of PVDs accelerates soil consolidation and should improve soil stability, but there are several factors that can cause the force in the pile to be greater, including:

1. Rapid consolidation leads to greater ground settlement initially.
2. Uneven consolidation can lead to larger internal forces in the pile at certain points.
3. The speed at which loads are applied to more rapidly consolidated soils may temporarily cause larger internal force peaks.

However, once the consolidation process is complete and the soil stabilizes, the internal forces in the piles tend to decrease and become more controllable.

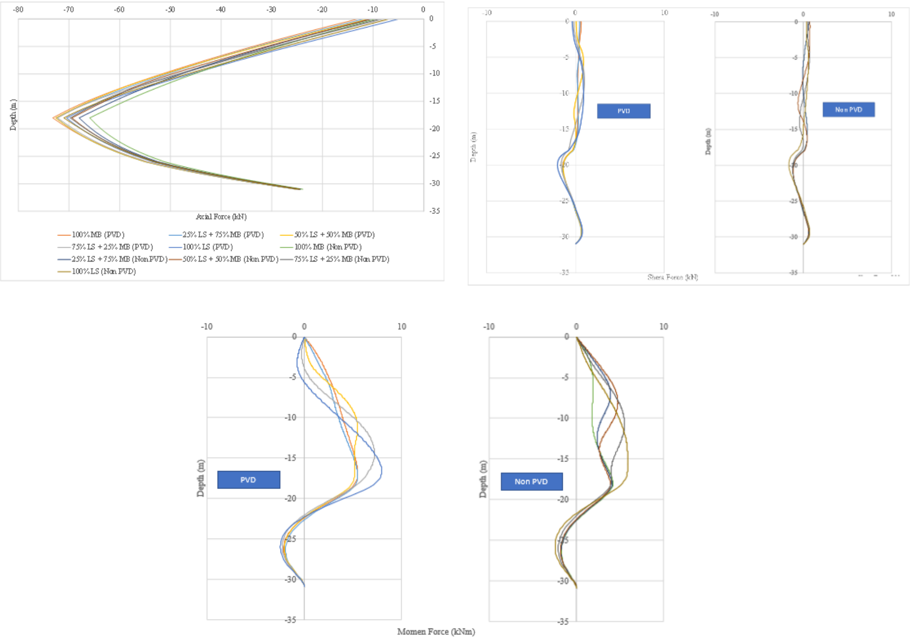

Figure 9. Internal Force on Pile
Source: Processed by the Author

CONCLUSIONS

Based on the results of the analysis that has been carried out, the following conclusions are obtained:

1. The settlement and stability of the embankment under full use of foam mortar and full use of existing embankment are as follows:
   a. The settlement of the 100% LS existing soil was 1.2 meters using PVD and 1.18 m without PVD. While the settlement of the 100% MB full foam mortar backfill is 0.466 m using PVD and 0.436 m without using PVD. Thus, the use of foam mortar material can reduce the settlement by 61.2% when using PVD and 63.1% when not using PVD.
   b. The factor of safety for the existing 100% LS soil is 1.94 with PVD and 1.92 without PVD. While the factor of safety at 100% MB is 3.659 with PVD and 3.490 without PVD. The use of lightweight foam mortar embankment can increase the stability of the embankment compared to the existing embankment. The thicker the foam mortar backfill layer, the factor of safety increases by 23.3% on average. This can be attributed to the smaller embankment load as the thickness of the foam mortar increases.
2. The lightweight embankment variation other than the variation in point 1, which experienced a decrease with a faster time and a smaller decrease was the 25% LS + 75% MB variation both in conditions with and without PVD. Whereas the most decreased with longer time and larger decrease is the variation of 75% LS + 25% MB. This shows that the thicker the foam mortar layer, the smaller the settlement and the faster the time due to the smaller density of the foam mortar material compared to the existing soil. The use of PVD can accelerate the consolidation time, so that the settlement is greater than without using PVD.
3. The effect of lightweight backfill on bridge abutment foundation piers in terms of:
   a. The lateral deflection of the pile on the embankment without PVD is greater than that using PVD in all variations of foam mortar embankment. This can occur because the use of PVD can accelerate the consolidation of soft soil, so that pore water in the soil can quickly escape and the soil becomes denser so that it can support the stability of the bridge foundation. The variation that produces the smallest lateral deflection with the fastest time is 100% MB backfill using PVD. The thicker the foam mortar backfill, the lateral deflection that occurs and the time will be faster due to the light density of the material.
   b. From the results of the internal force analysis that occurs according to the analysis, there is an uneven consolidation effect that causes the internal force in the condition using PVD to be greater than without using PVD.
   c. All variations of foam mortar backfill have met the requirements for factor of safety against uplift forces, with the largest variation of 100% MB producing a factor of safety of 1.23. The thicker the foam mortar backfill, the greater the factor of safety because the load on the subgrade is reduced.
4. The ground settlement in the consolidation process decreases as the degree of consolidation increases because most of the settlement occurs at the beginning of the consolidation process. The consolidation time to reach a higher degree of consolidation increases as the consolidation process becomes slower with time. The residual settlement after 10 years service life in the condition using PVD is only a little bit because it has decreased greatly during the initial consolidation process. The heavier the embankment, the less the residual settlement, which is 0.000261 mm in the 100% MB variation.

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