(e)ISSN 2656-8896 (p) 2656-890X
Jurnal Manajemen Aset Infrastruktur & Fasilitas – Vol. 7, No. 1, January 2025

Analysis of The Effect of Seismic Load on The Design Safety Factor of Foam Mortar with Bored Pile Landslide Location of Batas Pidie/Aceh Besar – Bts. Kota Sigli STA 0+560

Ichvan Danny Kurniawan[1,a], Trihanyndio Rendy Satrya[2,b], Ria Asih Aryani Soemitro[3,c], & Fikri Afzal[4,d]

[1]Magister Student, Civil Engineering Dept, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[2,3]Civil Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[3]National Road Implementation Agency of Aceh, Directorate General of Highways, Ministry of Public Works, Indonesia

Correspondent : [a]ichvandk@gmail.com, [b]trendysatrya@gmail.com, [c]soemitroraa@gmail.com & [d]fikri.afzal@pu.go.id

ABSTRACT

The Batas Pidie / Aceh Besar - Bts. Kota Sigli road section is a primary arterial road that has a very important role in connecting the capital city of Aceh Province with the capital city of North Sumatra Province. Landslide conditions that occur at the location of STA 0+560 can be caused by various factors, one of which is earthquakes. Aceh Province is a province with a high frequency of earthquakes. The design of foam mortar is simulated using the PLAXIS 2D auxiliary program to determine the stability of the slope against static load and seismic load. To determine the effect of seismic load on the safe number, the pseudostatic method of analysis and variation of seismic load with PGA of 0.4g, 0.45g, and 0.5g, 0.55g and 0.6g were used. From the results of the PLAXIS 2D modeling analysis on the reinforcement of slopes using foam mortar with a slope shows that the greater the seismic load PGA given, the value of the safe number will decrease, namely with a static load SF value of 1.932 (SF>1.5) and SF seismic load 0.4g of 1.285 (SF>1.1) to SF seismic load 0.6g of 1.121 (SF>1.1).

Keywords : slope, static load, seismic load, safety factor, foam mortar

INTRODUCTION

The Batas Pidie / Aceh Besar - Bts. Kota Sigli road section is a National Road that has a function as a Primary Arterial Road in Aceh Province which is under the working area of the National Road Implementation Agency of Aceh, Directorate General of Highways, Ministry of PUPR. As a primary arterial road, the Batas Pidie / Aceh Besar - Bts. Kota Sigli certainly has a very important role in connecting the capital of Aceh Province to the capital of North Sumatra Province so that if this road is cut off or experiencing interference, it will greatly impact the traffic flow on the section.

On January 25, there was a landslide on the Batas Pidie / Aceh Besar - Bts. Kota Sigli road section at the location STA 0+560. As a result of the incident, half of the road body collapsed and landslides on the road slope. There were no casualties due to the landslide but as a result of the landslide the traffic flow from Banda Aceh to North Sumatra Province and vice versa was disrupted as shown in the following picture:

Figure 1. Slope Condition After Landslide
Source: P2JN Aceh, 2023

There are several factors that can cause landslides on slopes, one of which is earthquake loading. Earthquake itself can affect the stability of the slope because it can increase the horizontal load. As is known, Aceh province is one of the provinces that is relatively active in experiencing earthquakes. In addition, based on the Indonesia Earthquake Hazard and Source Map for Bridges (Earthquake Map 2017), the location of the landslide on the Batas Pidie / Aceh Besar - Bts. Kota Sigli at the location STA 0+560 at 2% in 50 years has a range value at PGA 0.4 - 0.5g and 0.5 - 0.6g as shown in the following figure:

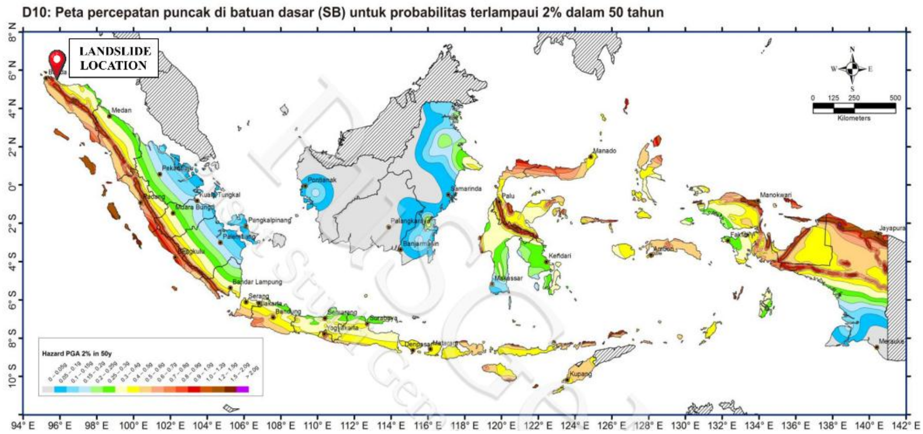

Figure 2. Map of Peak Acceleration in Bedrock (SB) for 2% Probability of Exceedance in 50 Years
Source: National Earthquake Study Center, 2017

To handle the landslide problem in the earthquake-prone area, an analysis of the proposed alternative handling of the landslide location of Batas Pidie / Aceh Besar - Bts. Kota Sigli STA 0+560 by using foam mortar with bored pile modeled with PLAXIS 2D in dry slope condition (S_r=0). In the analysis, the effect of pseudostatic seismic load on the safety factor is examined to determine whether the design of foam mortar with bored pile can be applied in the field.

LITERATUR REVIEW

Safety Factor (SF)

The slope safety number or safety factor (SF) is the ratio of the resisting force to the total collapsing force for a given collapse plane in a slope. It is a key concept in geotechnical engineering used to evaluate slope stability and ensure that the potential for collapse is minimized. Das (In Endah and Mochtar, 1993) defines the safety factor on a slope with the following equation:

$$SF = \frac{\tau_f}{\tau_d} \quad \text{... (1)}$$

Where:
SF = Safety Factor
τ_f = average shear strength of the soil
τ_d = average shear stress acting along the landslide plane

In SNI 8460:2017, it is determined for the safety factor of soil slopes and soil reinforcement structures against global stability both in static load conditions and seismic load conditions. In conditions on soil slopes at low uncertainty level conditions can use a static load safety factor of 1.25 (SF>1.5) and for static load landslide retaining structure buildings a safety factor of 1.5 (SF>1.5) is used and in seismic load conditions 1.1 (SF>1.1) is used.

Traffic Load

The traffic load used in this study refers to SNI 8460:2017 article 7.5.1.2 regarding traffic load. The article explains that the traffic load is added to the entire width of the road surface and the amount is determined based on the road class given in the following table:

Table 1. Traffic Loads for Stability Analysis (DPU, 2001) and Off-road Loads

Road Class	Traffic Load (kPa)	Off Road Load (*) (kPa)
I	15	10
II	12	10
III	12	10

Note: (*) Load from building houses around the slope
Source: National Standardization Agency, 2017

Seismic Load

The analysis used in PLAXIS modeling employs a pseudostatic modeling analysis using the PGA from the Peak Acceleration in Bedrock (SB) Map for a Probability of Exceedance of 2% in 50 Years. The following is the equation used to determine the peak acceleration at the ground surface based on the site classification (Yudianto, 2022):

$$PGA_m = F_{PGA} \text{ x PGA} \quad \text{... (2)}$$

Where:
PGAm : MCEG peak ground acceleration adjusted for the effect of site classification
PGA : Mapped peak ground acceleration
FPGA : Site coefficient

The following is the equation formula to obtain the horizontal seismic coefficient and vertical seismic coefficient used by Yudianto, 2022:

$$K_h = 0{,}5 \frac{a_d}{g} \quad \text{... (3)}$$

$$K_v = 0{,}5\, k_h \quad \text{... (4)}$$

Where:
a_d = corrected earthquake acceleration= PGA_M

Modified Mononabe-Okabe approach by considering soil cohesion. This approach uses the Anderson et al. (2008) equation in Yudianto (2022). This method assumes:

1. Vertical seismic coefficient (k_v) = 0

2. Horizontal seismic coefficient (k_h) = PGA adjusted to the condition of

Table 2. Site Classification (AASHTO, 2012)

Site Classification	$\overline{v_s}$ (m/s)	$\bar{\bar{N}}_{SPT}$	$\bar{S}_u$
SA (hard rock)	>1500	N/A	N/A
SB (bedrock)	750 – 1500	N/A	N/A
SC (hard, highly compacted soil and soft rock)	350 – 750	>50	≥100
SD (medium soil)	175 – 350	15 - 50	50 -100
SE (soft soil)	<175	<15	<50
	Or any soil profile containing more than 3 m with the following characteristics: 1. Plasticity Index (PI) > 20, 2. Water Content (w) ≥ 40%, 3. Undrained shear strength, $\bar{s}_u$ < 25 kPa		
SF (special soils, which require specific geotechnical investigations and site-specific response analysis)	Each soil layer profile has one or more of the following characteristics: - Prone to failure or collapse under seismic loads such as liquefaction, highly sensitive clays, weakly cemented soils - Very organic clay and/or peat (thickness, H > 3 m) - High plasticity clay (thickness, H > 7.5 m with Plasticity Index, PI > 75) - Soft/semi-firm clay layer with a thickness of H > 35 m with $\bar{s}_u$ < 50 kPa		

Source: National Standardization Agency, 2017

Table 3. Amplification Factor for PGA

Site Classification	PGA ≤ 0.1 $S_s \le 0.25$	PGA = 0.2 $S_s = 0.5$	PGA = 0.3 $S_s = 0.75$	PGA = 0.4 $S_s = 1.0$	PGA = 0.5 $S_s = 1.25$
Hard rock (SA)	0,8	0.8	0.8	0.8	0.8
Bedrock (SB)	1.0	1.0	1.0	1.0	1.0
Hard soil (SC)	1.2	1.2	1.1	1.0	1.0
Medium soil (SD)	1.6	1.4	1.2	1.1	1.0
Soft soil (SE)	2.5	1.7	1.2	0.9	0.9
Special soils (SF)	SS	SS	SS	SS	SS

Source: National Standardization Agency, 2017

RESEARCH METHOD

In the analysis, secondary data obtained from the National Road Planning and Supervision Unit of Aceh Province was used to model the slope based on soil stratigraphy to analyze the condition of the slope after the landslide. Furthermore, slope modeling using foam mortar reinforcement with bored pile was conducted using PLAXIS 2D application. In this analysis, static load variation and pseudostatic seismic load with PGA values of 0.4, 0.45, 0.5, 0.55 and 0.6 were used. Furthermore, from the analysis results, the effect of the seismic load on the safety factor and displacement at the 3 points under review is examined.

DATA COLLECTION

In the preparation of soil stratigraphy that will be used in data input in the PLAXIS 2D application, geotechnical data including N-SPT data and laboratory test data on undisturbed samples are needed. The following is the soil stratigraphic data that has been compiled based on the secondary data:

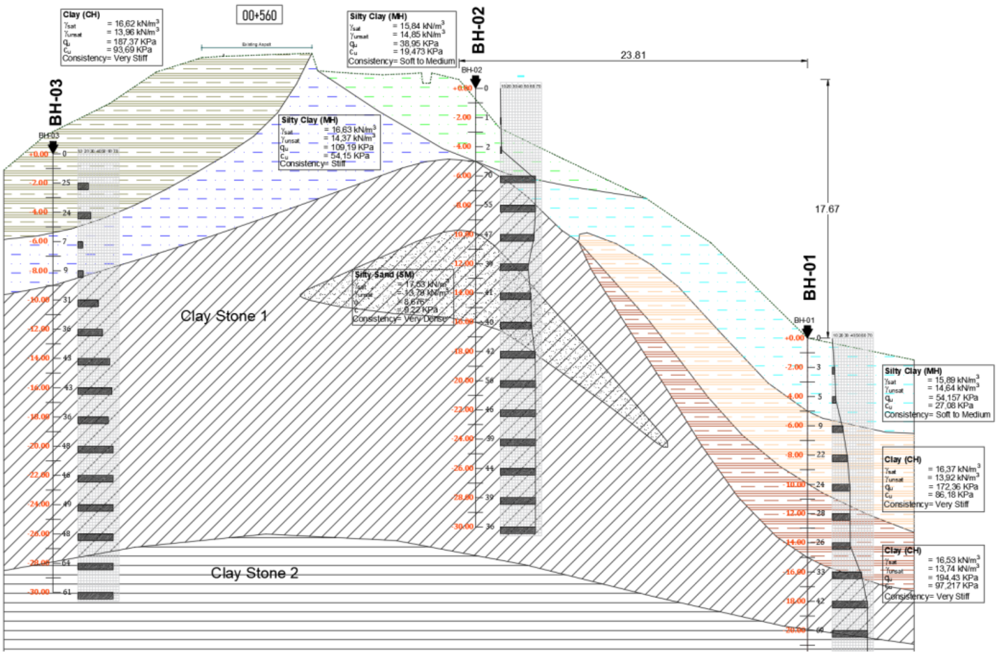

Figure 3. Landslide Site Soil Stratigraphy

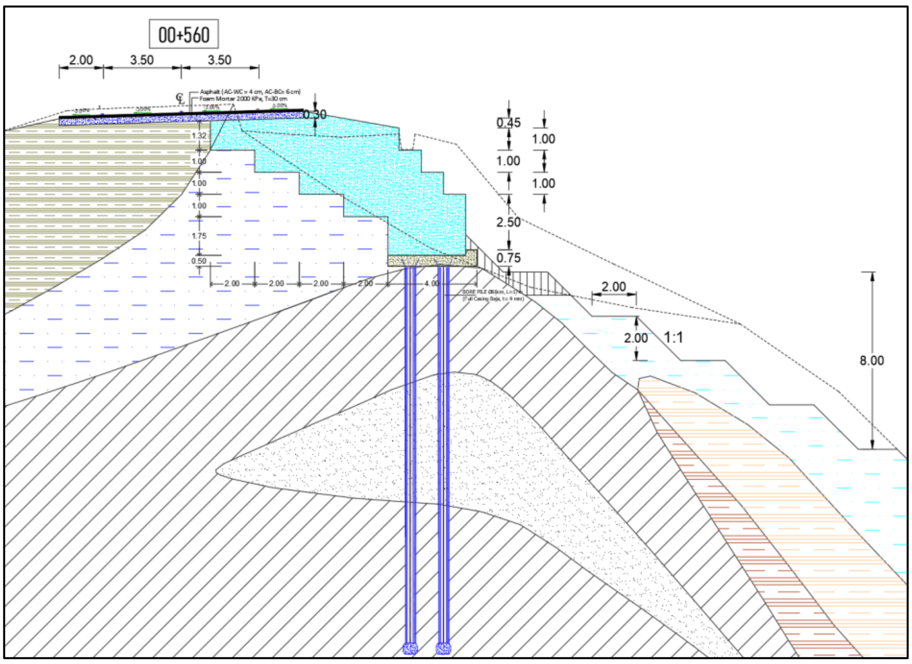

Figure 4. Foam Mortar Design with Bored Pile

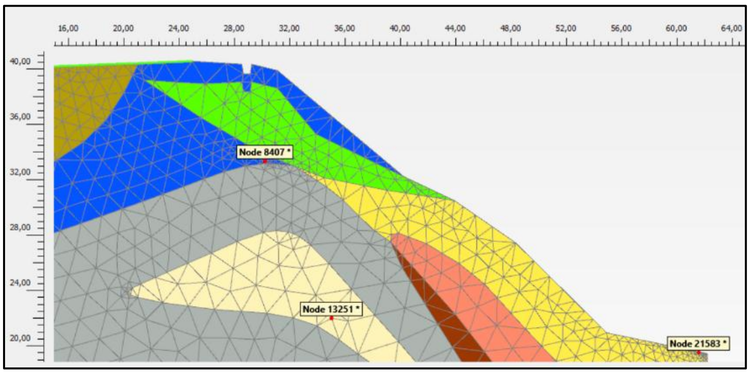

Figure 5. Location of displacement point under review

Table 4. Soil Properties (BH-01)

Parameter	Unit	Layer 1 Silty Clay	Layer 2 Clay	Layer 3 Clay	Layer 4 Clay Stone	Layer 5 Clay Stone
Soil Model		Hardening Soil	Hardening Soil	Hardening Soil	Hardening Soil	Hardening Soil
Drainage Type		Undrained	Undrained	Undrained	Undrained	Undrained
γ_{unsat}	kN/m^3	14.64	13.92	13.74	19.62	19.62
γ_{sat}	kN/m^3	15.89	16.37	16.53	22.16	22.16
e_{init}		1.65	1.51	1.45		
n_{init}		0.62	0.60	0.59		
E_{50}^{ref}	kN/m^2	16666.67	66666.67	66666.67	240000.00	2800000.00
E_{oed}^{ref}	kN/m^2	16666.67	66666.67	66666.67	240000.00	2800000.00
E_{ur}^{ref}	kN/m^2	50000.00	200000.00	200000.00	720000.00	8400000.00
s_u	kN/m^2	27.08	86.18	97.22	300.00	3500.00
v_{ur}		0.30	0.30	0.30	0.30	0.30

Table 5. Soil Properties (BH-02)

Parameter	Unit	Layer 1 Silty Clay	Layer 2 Silty Sand	Layer 4 Clay Stone	Layer 5 Clay Stone
Soil Model		Hardening Soil	Hardening Soil	Hardening Soil	Hardening Soil
Drainage Type		Undrained	Drained	Undrained	Undrained
γ_{unsat}	kN/m^3	14.85	13,79	19.62	19.62
γ_{sat}	kN/m^3	15.84	17.53	22.16	22.16
e_{init}		1.66	1.15		
n_{init}		0.62	0.54		
E_{50}^{ref}	kN/m^2	10000.00	53333.33	240000.00	2800000.00
E_{oed}^{ref}	kN/m^2	10000.00	53333.33	240000.00	2800000.00
E_{ur}^{ref}	kN/m^2	30000.00	160000.00	720000.00	8400000.00
S_u or c	kN/m^2	19.47	9.22	300.00	3500.00
φ	°		8.68		
v_{ur}		0.30	0.30	0.30	0.30

Table 6a. Soil Properties (BH-03)

Parameter	Unit	Layer 1 Clay	Layer 2 Silty Clay	Layer 3 Clay Stone	Layer 4 Clay Stone
Soil Model		Hardening Soil	Hardening Soil	Hardening Soil	Hardening Soil
Drainage Type		Undrained	Undrained	Undrained	Undrained

Table 7b. Soil Properties (BH-03)

Parameter	Unit	Layer 1 Clay	Layer 2 Silty Clay	Layer 3 Clay Stone	Layer 4 Clay Stone
Soil Model		Hardening Soil	Hardening Soil	Hardening Soil	Hardening Soil
Drainage Type		Undrained	Undrained	Undrained	Undrained
γ_{unsat}	kN/m^3	13.96	14.37	19.62	19.62
γ_{sat}	kN/m^3	16.62	16.33	19.62	19.62
e_{init}		1.41	1.48		
n_{init}		1.48	0.60		
E_{50}^{ref}	kN/m^2	66666.67	33333.33	240000.00	2800000.00
E_{oed}^{ref}	kN/m^2	66666.67	33333.33	240000.00	2800000.00
E_{ur}^{ref}	kN/m^2	200000.00	100000.00	720000.00	8400000.00
S_u	kN/m^2	93.69	54.59	300.00	3500.00
v_{ur}		0.30	0.30	0.30	0.30

Table 8. Foam Mortar Properties

Parameter	Unit	Foam Mortar 800 kPa	Foam Mortar 2000 kPa
Material Model		Linier Elastic	Linier Elastic
Drainage Type		Non-Porous	Non-Porous
γ	kN/m^3	8.00	8.00
E	kN/m^2	4203807.80	6646803.74
v_{ur}		0.15	0,15

Table 9. Bored Pile Properties

Parameter	Unit	*Bored Pile 1*	*Bored Pile 2*
		d= 60cm, L=17m	d= 60cm, L=17m
E	kN/m^2	38909429.50	38909429,50
γ	kN/m^3	24.53	24.53
Pile type		Predefined	Predefined
Predefined pile type		Massive circular pile	Massive circular pile
Diameter	m	0.60	0.60
$L_{spacing}$	m	2.00	2.00
Axial skin resistance		Multi-linier	Multi-linier
Lateral skin resistance		Multi-linier	Multi-linier
Base resistance (F max)	kN	1221.87	1321.23
F'c	MPa	30	30

Table 10. Pile cap and Asphalt Properties

Symbol	Unit	Pilecap f'c 30	Asphalt AC-WC s.d. AC-BC (t= 10cm)
Material type		Elastic	Elastic
γ	kN/m/m	12.26	2.28
Isotropic		yes	yes
EA_1	kN/m	13449282.68	500000.00
EI	kN/m^2/m	280193.39	416.67
$v_{(nu)}$		0.15	0.15

Table 11. Results of calculating the Pseudostatic Horizontal Coefficient (k_h)

PGA	FPGA	Multiplier Factor	K_h
0,40	1.1	0.5	0.22
0.45	1.05	0.5	0.24
0.50	1	0.5	0.25
0.55	1	0.5	0.28
0.60	1	0.5	0.30

RESEARCH ANALYSIS

Initial Conditions After the Landslide

In the preliminary analysis after the landslide, data from field and laboratory tests and the geometry of the slope after the landslide were used. The following are the results of the analysis of the safety factor of the slope after the landslide using PLAXIS 2D:

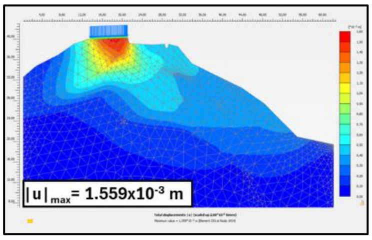

Figure 6. Total Resultant Displacement of Slope After Landslide Static Load

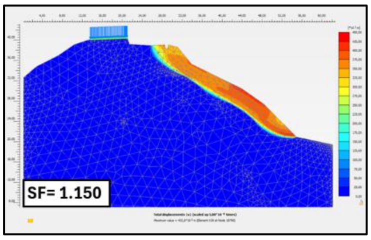

Figure 7. Safety Factor of Slope After Landslide Static Load

The analysis shows that the safety factor value is below the requirements with a safety factor value of 1.150 (SF<1.25) from the analysis results indicate that there is a potential for landslides on the slope surface area, so that additional reinforcement is needed. The analysis of the safety factor due to the seismic load of the slope cannot be done because the slope is in an unstable condition, so it cannot be done with PLAXIS 2D safety analysis.

Safety Factor Analysis of Foam Mortar Reinforcement with Bored Pile

At this stage, an analysis of foam mortar reinforcement with bored piles using PLAXIS 2D was carried out with a variation of static load (traffic load of 15 kPa) and pseudostatic seismic load PGA 0.4g - 0.6g which has been added to the traffic load (15 kPa). The following are the results of the safety factor analysis, and the total maximum resultant deformation obtained from PLAXIS 2D:

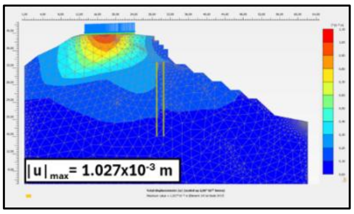

Figure 8. Resultant Maximum Displacement Static Load

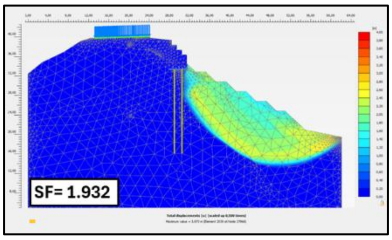

Figure 8. Safety Factor Static Load

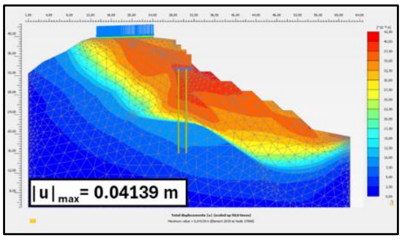

Figure 9. Resultant Maximum Displacement Seismic Load PGA 0.4g

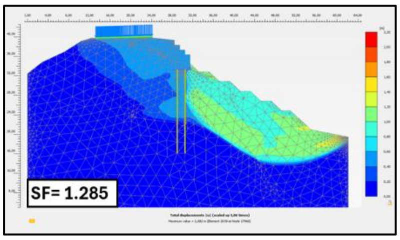

Figure 10. Safety Factor Seismic Load PGA 0.4g

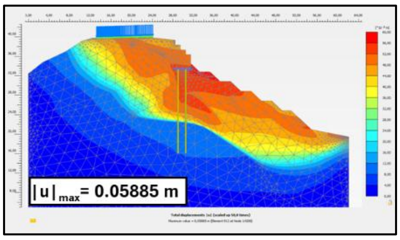

Figure 11. Resultant Maximum Displacement Seismic Load PGA 0.45g

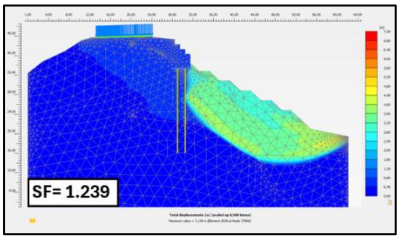

Figure 12. Safety Factor Seismic Load PGA 0.45g

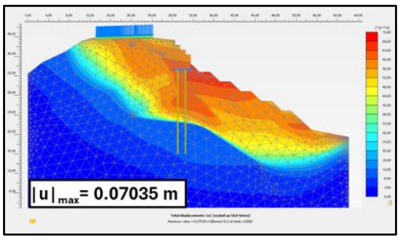

Figure 13. Resultant Maximum Displacement Seismic Load PGA 0.5g

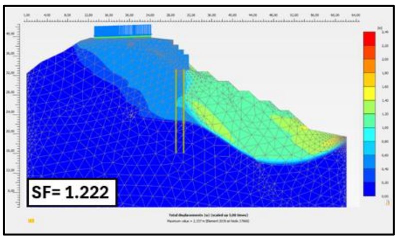

Figure 14. Safety Factor Seismic Load PGA 0.5g

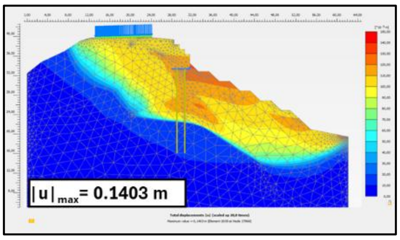

Figure 15. Resultant Maximum Displacement Seismic Load PGA 0.55g

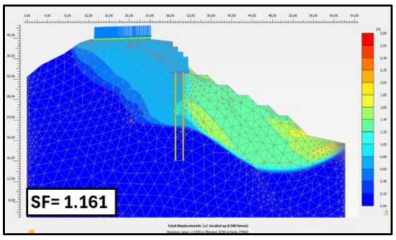

Figure 16. Safety Factor Seismic Load PGA 0.55g

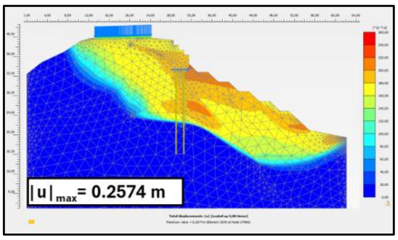

Figure 17. Resultant Maximum Displacement Seismic Load PGA 0.6g

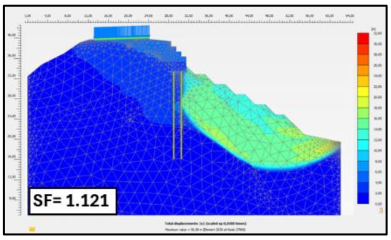

Figure 18. Safety Factor Seismic Load PGA 0.6g

The figure above shows that there is a difference in the position of the total maximum resultant displacement between static conditions (|u| maximum= 0.9354×10^{-3} m) and pseudostatic earthquake conditions (for example |u| maximum PGA 0.4 = 0.01475 m). The position of the maximum resultant displacement of the seismic load is at the edge of the middle slope while the static load is under the pavement. Different results are shown in the safety factor analysis. The PLAXIS 2D safety analysis figure shows the same pattern in both static and seismic load conditions. This shows that the weakest slope position on the slope reinforced with foam mortar and bored pile under both static and seismic load conditions is at the foot of the slope.

Table 12. Analysis Results Safety Factor (SF) and Total Resultant Displacement |u|

PGA	Foam Mortar with Bored Pile				
	Safety Factor (SF)	**Safety Factor Requirement**	**Resultant Displacement |u| Point 1 (m)**	**Resultant Displacement |u| Point 2 (m)**	**Resultant Displacement |u| Point 3 (m)**
Static	1.932	Satisfies (SF>1.5)	2.17E-04	1.01E-04	7.64E-06
0.40	1.285	Satisfies (SF>1.1)	3.80E-02	3.40E-02	3.90E-02
0.45	1.239	Satisfies (SF>1.1)	5.30E-02	4.80E-02	5.40E-02
0.50	1.222	Satisfies (SF>1.1)	6.30E-02	5.60E-02	6.40E-02
0.55	1.161	Satisfies (SF>1.1)	1.18E-01	1.07E-01	1.24E-01
0.60	1.121	Satisfies (SF>1.1)	1.96E-01	1.84E-01	2.15E-01

From the results of the analysis of alternative designs of foam mortar with bored pile, it shows that both under static load conditions and seismic loads the reinforced slopes are in a stable condition and meet the requirements for safety factor under static conditions (SF>1.5) and safety factor under seismic conditions (SF>1.1) as shown in Table 12. The following is a graph of the relationship between the PGA of the pseudostatic seismic load to the safety factor and the PGA of the pseudostatic seismic load to the total resultant displacement at point 1, point 2 and point 3 of the foam mortar with bored pile:

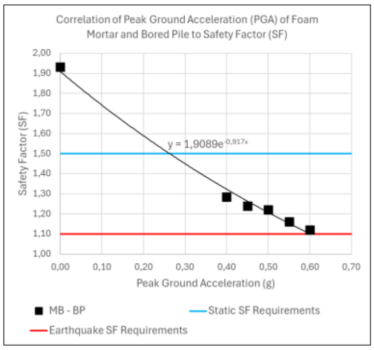

Figure 19. Correlation of PGA to Safety Factor

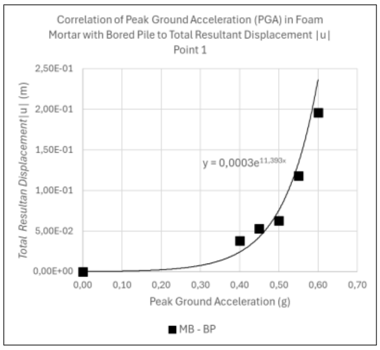

Figure 20. Correlation of PGA to Total Resultant Displacement |u| Point 1

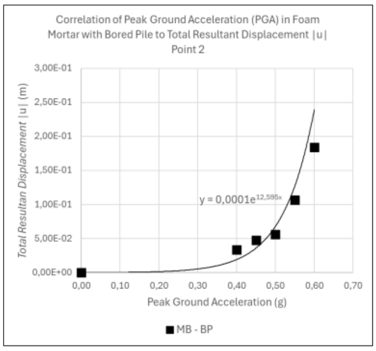

Figure 21. Correlation of PGA to Total Resultant Displacement |u| Point 2

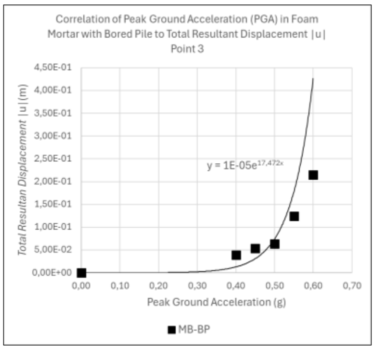

Figure 22. Correlation of PGA to Total Resultant Displacement |u| Point 3

From the graph of the relationship between the PGA of the pseudostatic seismic load and the safety factor of foam mortar with bored pile, it shows that the addition of the pseudostatic seismic load decreases the safety amount of the slope. The analysis shows that there is a decrease in the safety factor from a static load of 1.932 (SF>1.5) down to a PGA of 0.4g with a safety factor of 1.285 (SF>1.1) and still down to a PGA of 0.6g with a safety factor of 1.121 (SF>1.1). On the other hand, the graphs in **Error! Reference source not found.**, Figure 21 and Figure 22 show that as the PGA of the pseudostatic seismic increases, the total resultant displacement also increases. This indicates that the higher the PGA of a pseudostatic seismic, the lower the slope stability and the greater the slope movement. In addition, the results of the analysis show that review point 3 in seismic conditions always has a greater value than other points. In contrast to the static load conditions, point 1 has a higher value. This shows that the loading conditions affect the position of the displacement that occurs.

CONCLUSIONS

From the analysis of foam mortar with bored pile on the Batas Pidie / Aceh Besar - Bts. Kota Sigli road section STA 0+560 shows that both static conditions and pseudostatic seismic loads of 0.4g to 0.6g have a safety factor (SF) value above the requirements with a static SF value of 1.932 (SF>1.5) and SF pseudostatic seismic 0.4g of 1.285 (SF>1.1) to SF pseudostatic seismic 0.6g of 1.121 (SF>1.1). The results also show that the larger the PGA given, the lower the safety factor value and the higher the total resultant displacement.

REFERENCES

[1] Badan Standarisasi Nasional (2017). *SNI 8460:2017 Persyaratan perancangan geoteknik.* www.bsn.go.id. Jakarta.
[2] Bentley Advancing Infrastructure (2024). *Tutorial Manual 2D*. Bentleysystem.service-now.com/comuunity.

[3] Bentley Advancing Infrastructure (2024). *Material Models Manual 2D. Tutorial Manual 2D*. Bentleysystem.service-now.com/comuunity.

[4] Bentley Advancing Infrastructure (2024). *Scientific Manual 2D. Tutorial Manual 2D*. Bentleysystem.service-now.com/comuunity.

[5] Bowles, Joseph E. (1997). *Foundation Analysis and Design Fifth Edition.* Teh McGraw-Hill Companies,Inc. Singapore.

[6] Das, Braja (1995). *Mekanika Tanah (Prinsip-Prinsip Rekayasa Geoteknis) Jilid 1. Terjemahan Noor Endah Mochtar, Ir., M.Sc., Ph.D., dan Indra Surya B. Mochtar, Ir., M.Sc.*, Ph.D. Erlangga. Jakarta.

[7] Direktorat Jenderal Bina Marga (2024). *Spesifikasi Khusus: Material Ringan Mortar Busa SKh-2.7.21*. https://binamarga.pu.go.id/index.php/nspk. Jakarta.

[8] PT Virama Karya (2023). Penanggulangan Penurunan Badan Jalan pada Ruas Batas Pidie/Aceh Besar-Batas Kota Sigli Km 80+630 P2JN Aceh. *Laporan Akhir Project.* Banda Aceh.

[9] Pusat Studi Gempa Nasional (2017). *Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017*. Jakarta.

[10] Yudianto, A.M., Lastiasih, Y., Taufik, R. and Ismawanto, I. (2021). "Analisis Deformasi Lereng dengan Perkuatan Soil Nailing pada Proyek Pembangunan Jalan Baru Batas Kota Singaraja-Mengwitani". *Jurnal Aplikasi Teknik Sipil, Vol. 20, No. 1, Hal: 59 - 67. Surabaya.*