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Analysis Stability of Abutment on the Railway Bridge

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ABSTRACT

Railway bridge *Bangunan Hikmah* (BH 39) Pariaman (Padang– Pariaman Route) is a new bridge. This new bridge was built because the old one could not accommodate the load of the additional locomotive. The railway bridge consists of two parts: the upper structure and the substructure. The substructure consists of abutments and foundations. When the abutment accepts considerable lateral ground pressure, so the stability of the abutment will be disturbed. To resolve the problem, the need exists to study abutment reinforcement with geotextile or additional foundation pile to raise the stability abutments on the Railway bridge *Bangunan Hikmah* (BH 39) Pariaman. The result of the loading on the upper structure is obtained. The total vertical force acting on the abutment is 6111,624 kN, and the horizontal load is 2849,689 kN. Abutment stability analysis is carried out in 3 stages (without reinforcement, with reinforcement geotextiles, and with existence foundation pile (bored pile). The results of the analysis show value safety factor minimum without Reinforcement (SF) is 1,29; this shows that the abutment is unstable because the safety factor obtained is < 1.5, with reinforcement geotextile, the value of the safety factor minimum (SF) is 1,66, this indicates that the abutment is stable but still critical and the value of the safety factor (SF) minimum with bored pile foundations is 2,10. Installation of a bored pile foundation (pile group) at a depth of 10m shows a significant increase in the value of the safety factor. In the BH 39 Kurai Taji Pariaman railway bridge project, it is recommended to use a pile group foundation with a depth of 10 m.

1. Introduction

A railway bridge is a bridge that accommodates the load of rail traffic that crosses the floor surface of the bridge[1] [2]. The bridge consists of two parts: the upper structure and substructure. In many cases, the failure of the bridge structure is caused by the failure of the substructure; the substructure serves to transmit the load to the subgrade.

The substructure consists of foundations and abutments. The foundation functions to transmit the load to the subgrade. The abutment functions as a carrier for all live loads (wind, vehicles, etc.) and dead loads (girder loads, etc.) on the bridge [3] [4]. Abutments resist earth pressure from the backfill and transmit loads to the foundation [2] [5]. In planning, abutments must meet the stability requirements against overturning, sliding, and carrying capacity. Abutment stability must be taken into account against external and internal influences [6]. Unstable abutments often cause the failure of a bridge on the bridge [7], [3], [6].

To increase the stability of the abutment, the study of the abutment reinforcement is needed. In this study, geosynthetics and pile foundations are used as reinforcement. Geosynthetics is a factory material widely used in the field with various uses [8]. Geosynthetics are synthetic materials that, when combined with soil, can withstand the tensile forces generated by lateral earth pressure (reinforced soil) [9]. Geosynthetic reinforcement can reduce lateral soil movement on abutment walls. It will reduce vertical deformation by 1.3 times after traffic loads work compared to without geosynthetic reinforcement [10]. The load received by the abutment is transferred to the foundation. Thus, the foundation must be placed on a solid layer of soil. The combination of geosynthetics and the foundation will produce a higher stability value.

In this study, the type of geosynthetic used was the Woven which was installed on the heaped soil behind the abutment. The foundation used is a bored pile foundation. The results of this study focused on comparing the safety factor values of abutments using geosynthetics, bored pile foundations, and a combination of geosynthetics and bored pile foundations. Consultants can use these results as a consideration in terms of reinforcement abutments.

2. Materials and Methods

This paper uses secondary data; obtained from the Bangunan Hikmat (BH) 39 railway construction project. It is located in Kurai Taji Pariaman, West Sumatera. The abutment stability analysis was carried out for three conditions: without reinforcement, with geosynthetic reinforcement, and with a bored pile.

a) Data collection

The data consists of:

1) The bridge profiles and loading data on the bridge

In general, the bridge has length: 51.6 m; width: 4.9 m; height: 8.5 m; type of steel: BJ 55; breaking stress (fu): 550 MPa; stress yield (fy): 410 MPa, and modulus of elasticity of steel (E): 200,000 MPa. The detailed data shown in the Figure 1 and Table 1.

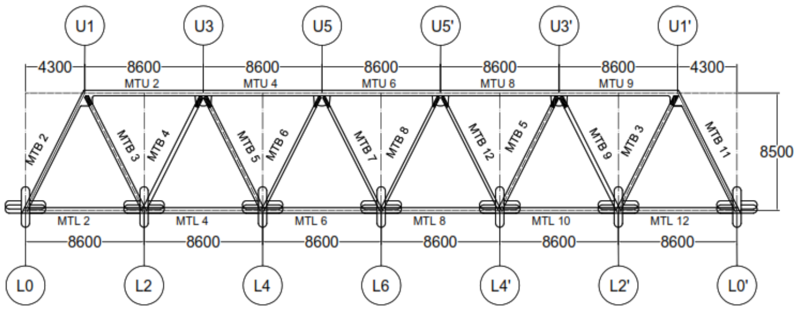

Figure 1. Longitudinal section of the bridge

Table 1. Dimensions of Steel Profiles on Bridges

No	Nama	Profile Type	*Section Index* (mm)	tw (mm)	tf (mm)
1	MTL	Tube	370 x 370	25	25
2	MTB 2	Tube	370 x 390	25	25
3	MTB 3	IWF	360 x 320	20	20
4	MTB 4	Tube	330 x 330	25	25
5	MTB 5	IWF	330 x 330	15	15

No	Nama	Profile Type	*Section Index* (mm)	tw (mm)	tf (mm)
6	MTB 6	Tube	330 x 260	10	10
7	MTB 7	Tube	330 x 260	10	10
8	MTB 8	Tube	330 x 260	10	10
9	MTB 12	Tube	330 x 260	10	10
10	MTB 5	IWF	330 x 310	10	10
11	MTB 9	Tube	330 x 330	25	25
12	MTB 3	IWF	360 x 320	15	15
13	MTB 11	Tube	370 x 380	20	20
14	Bracing on Joint Rails	Elbow Steel	100 x 100	10	10
15	Longitudinal girder	IWF	380 x 700	30	25
16	Transverse girder	IWF	380 x 950	30	25

While, loading obtained: vertical load: 6111.624 kN and horizontal load: 2849.689 kN.

2) Soil data (Borlog and Standard Penetration Test data)

The soil layer at a depth of 1m -10m is dominated by a layer of sandy silt (soft soil) with an N SPT value ranging from (3 - 7), while at a depth of 12 m - 20 m consisting of dense sand with an N SPT value ranged from (35 – 53) as shown in Table 2.

Table 2. N-SPT value and soil type

Depth (m)	Type of soil	N-SPT
0	Silty Sand, gravel	0
2	Silty Sand, gravel	7
4	A little sandy silt	4
6	A little sandy silt	4
8	A little sandy silt	3
10	Dense sand slightly silt	5
12	Dense sand slightly silt	35
14	Dense sand slightly silt	43
16	Dense sand slightly silt	45
18	Dense sand slightly silt	48
20	Dense sand slightly silt	53

Other soil parameters such as bulk density (γ), internal friction angle (γ), and soil cohesion (c) are obtained from the correlation of the N SPT values as shown in Table 3, and Table 4.

Table 3. Correlation of Soil Type to bulk density (γ)

Type of soil	γ sat (KN/m^3)	γ dry (KN/m^3)
Gravel	20 – 22	15 – 17
Sand	18 – 20	13 – 16
Silt	18 – 20	14 – 18
Clay	16 – 22	14 – 21

Whereas, the value of the soil internal friction angle is shown in Table 4.

Table 4. Correlation of N-SPT to friction angle (φ)

Depth (m)	N – SPT	Internal friction angle (φ)
12	35	37
14	43	39
16	45	40

b) ***Abutment Stability Analysis***

As previously stated, the abutment stability analysis was carried out for three conditions: without reinforcement, with geosynthetic reinforcement, and with a bored pile. An analysis was carried out for each condition using the Bishop, Fellenius, Petterson Spencer, Janbu, and Morgenstern methods by calculating the safety factor value.

1) Stability analysis of abutments without reinforcement [6]

- Stability of Sliding

$$SF = \frac{f.W}{\Sigma H} \geq 1.5 \quad (1)$$

Where:

SF : Factor of safety of sliding

f : coefficient of friction between concrete and soil

W : vertical load acting on the abutment

ΣH : total horizontal load

- Overturning Stability

Overturn control is then calculated by decomposing the equation as follows

$$SF_{guling} = \frac{\Sigma \text{Momen yang menahan}}{\Sigma \text{Momen Guling}} \geq 1.5 \quad (2)$$

- Stability of bearing capacity

$$SF_{bearing\ capacity} = \frac{q_{ult}}{q_{mak}} \geq 3 \quad (3)$$

Where:

SF : Factor of safety to bearing capacity

q_{ult} : maximum soil bearing capacity

q_{max} : maximum bearing capacity that occurs in the sole of the abutment due to the working load

2) Stability analysis of abutments with geosynthetic reinforcement.

The stability of abutments using reinforcement is reviewed for external stability and internal stability [11].[12]

a) External Stability

- Safety factor against sliding

$$SF = \frac{LH\gamma_1 tg\ \delta_b}{0{,}5\ H^2\gamma_2 Ka + qK_a} \geq 1{,}5\ (8) \quad (4)$$

Where:

L : width of the abutment

K_a : active earth pressure coefficient

H : backfill height

δ_b : angle of friction between the soil and the abutment materials

$\gamma 1$: unit weight of the soil in the reinforced zone

$\gamma 2$: the unit weight of the soil behind the structure

- Overturning safety factor

$$SF = \frac{\Sigma M_R}{\Sigma M_D} \geq 1.5 - 2 \quad (5)$$

Where:

ΣM_R : the amount of resisting moment

ΣM_D : overturning moment

- Safety factor for bearing capacity

$$SF = \frac{qu}{\sigma_V} \geq 3 \quad (6)$$

Where:

q_u : soil bearing capacity

σ_V: Vertical pressure at the base of the structure

b) Internal Stability

- Safety factor against breaking of reinforcement (SFr)

$$SF_r = \frac{T_a}{\Delta P_h} \geq 1,5 \quad (7)$$

Where:

T_a : Allowable tensile strength of reinforcement

ΔP_H: Horizontal force caused by soil and reinforcement = σ_h S_v

σ_h : Horizontal pressure due to the soil

S_v : Distance between reinforcement.

- Safety factor against Unplug of reinforcement (SFp)

The reinforcement must be long enough so that the soil in the active zone that will slide can be resisted by the frictional resistance of the reinforcement in the passive zone. The maximum force against the reinforcement per meter of width that can be generated from the friction between the soil and the reinforcement.

$$SF_p = \frac{2\mu\, F^* \sigma_V L_e}{\Delta P_h} \geq 1,5. \quad (8)$$

Where:

T_{max} : maximum frictional resistance between reinforcement

F^* : pullout resistance factor

L_e : The length of the reinforcement in the passive zone

3) Stability analysis of abutments with bored pile foundations

Bearing capacity of bored pile foundation consists of end bearing capacity and friction pile bearing capacity

$$Qu = Qb + Qs - Wp \quad (9)$$

Where:

Qu : bearing capacity of the pile,

Qb : end resistance of the pile

Qs : frictional resistance of the pile

Wp : weight of the pile

Safety factor (SF)

$$SF = Qu/Qall \quad (10)$$

Where, Qall is allowable pile bearing capacity.

3. Result and Discussion

a) Stability analysis of abutments without reinforcement

The dimensions of the abutment and the backfill behind the abutment: a) Height of abutment: 6.67 m; b) Width of abutment tread; 5.88 m. Backfill behind the abutment; a) Soil 1 (height): 3.34 m; b) Soil 2 (height): 3.33 m; c) Soil unit weight (γ): 18 kN/m^3, d) Shear angle (ϕ) : 26.50 °, e) Soil Cohesion: 12 kPa; f) Vertical Force: 6111.62 kN; g) Horizontal Force : 2849.689 kN; h) load (q): 7.2 kN, as shown in figure 2.

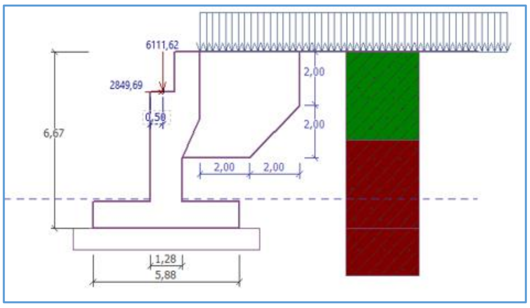

Figure 2. Cross section of Abutment

Stability analysis results of abutments against overturning were analyzed by several methods (Bishop, Fellenius, Spencer, Janbu, and Morgenstren-Price), the results of the analysis. Based on Table 5, the average safety factor of several is 1.5, and Fellenius is 1.29; this shows that the abutment is unstable because the safety factor obtained is < 1.5, so the abutment needs reinforcement.

Table 5. Safety Factor

Method	Safety Factor (SF)
Bishop	1,53
Felleniius/ Petterson	1,29
Spenser	1,54
Janbu	1,54
Morgenstern-Price	1,54

b) Stability analysis of abutments with geosynthetic reinforcement.

The geotextile used for embankment reinforcement is woven geotextile type 200/45, which has an ultimate strength of 200 kN/m. In this study, the number of geotextiles (reinforcement) used was: 4 pieces, the installation distance: was 1.33 m, and the length of the geotextile (reinforcement): was 10 m, as shown in figure 3.

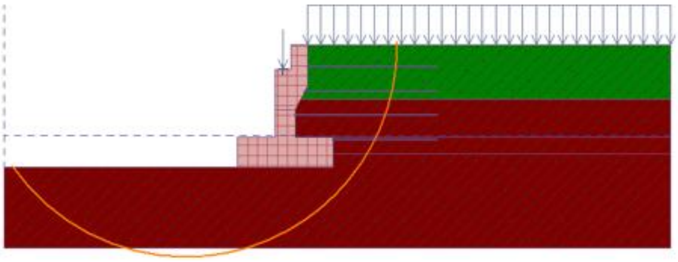

Figure 3. Results of abutment stability analysis

The results of the abutment stability analysis obtained the safety factor shown in Table 6. It shows that the safety factor increases with the geotextile, but the average safety factor value is still below 2; this indicates that the abutment is stable but still critical.

Table 6. safety factor of the abutment with reinforcement

Method	**Safety Factor (SF)**
Bishop	1,76
Felleniius/ Petterson	1,66
Spenser	1,77
Janbu	2,66
Morgenstern-Price	1,83

c) Stability analysis of abutments with bored pile foundations

The data used are: a) pile diameter: 0.8 m; b) unit weight of the pile (bored pile): 24 kN/m^3; c) length of the pile with variations: 8 m, and10 m . d) distance between piles: 1.6 m. According to Fig 6, Soil 3 is soil under the abutment consists of Silty Sand with the following soil parameters: a) Soil unit weight (γ): 14 kN/m^3; b) Internal friction angle (γ): 29°; c) Soil Cohesion (c): 12 kPa; d) Friction angle between concrete soil: 19°; e) Unit weight of saturated soil (γ_{sat}): 18 kN/m^3. Soil 4 consists of Silty and Little Sand with soil parameters: a) The unit weight of the soil (γ): 15 kN/m^3; b) The internal friction angle (φ): 26.50°; c) Adhesion between Soil and concrete: 12 kPa; d) Friction angle between concrete soil: 19°; e) Unit weight of saturated soil (γ_{sat}): 18 kN/m3. Soil 5 (Dense Sand Slightly Silt): a) Soil unit weight (γ): 18 kN/m^3; b) Internal friction angle (γ): 26.50°; c) Adhesion between Soil and concrete: 12 kPa; d) Friction angle between concrete soil: 17°; e) The unit weight of saturated soil (γ_{sat}): 18 kN/m^3.

The analysis used pile groups: a) Number of piles in x direction = 3, b) Number of piles in y direction = 3, c) Pile diameter = 0.8 m, d) Spacing between piles in x direction = 1.6 m, e) Spacing between piles direction y = 1.6 based on Figure 4, and 5

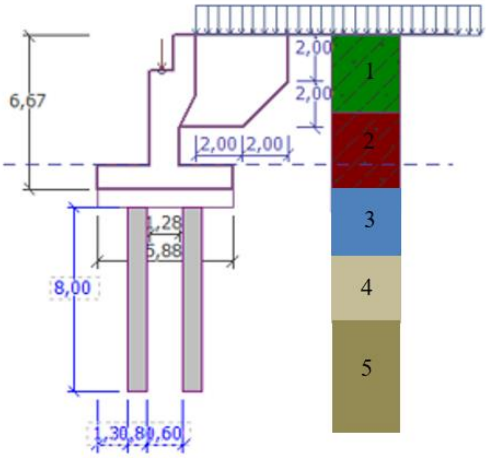

Figure 4. Bored Pile foundation cross section

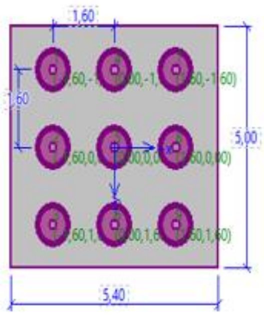

Figure 5. Bored Pile layout

Analyzing the stability of the abutments using bored piles (pile group) is reviewed with variations into the piles 8 m, and 10 m:

- Stability of abutments with a pile depth of 8 m

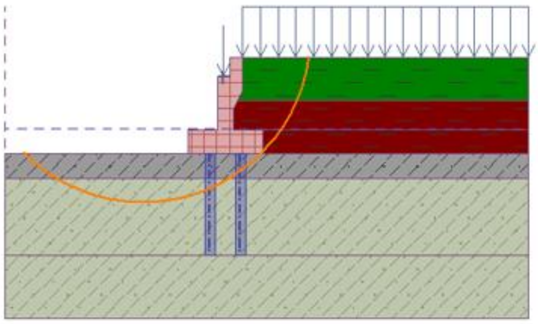

Figure 6. The cross section of the abutment with a bored pile depth of 8m.

Table 7. Factor of safety with bored pile at a depth of 8 m

Method	Safety Factor (SF)
Bishop	2,02
Felleniius/ Petterson	1,91
Spenser	3,87
Janbu	3,88
Morgenstern-Price	3,88

- Stability of abutments with bored pile depth of 10 m

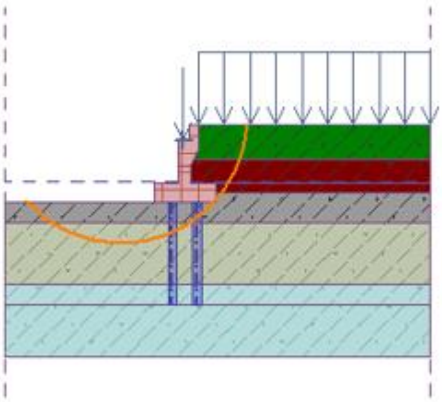

Figure 7. Slope Stability pile for 10 m

Table 8. Factor of safety with bored pile at a depth of 10 m

Methods	Factor of safety (SF)
Bishop	2,14
Felleniius/ Petterson	2,10
Spenser	5,08
Janbu	5,11
Morgenstern-Price	5,11

The results of the analysis of the stability of the abutment of the BH 39 Kurai Taji Pariaman railroad bridge from the several methods reviewed (Bishop, Fellenius, Petterson Spencer, Janbu and Morgenstern) are shown in Table 9. The results of the analysis show that the abutment's stability without reinforcement is less than 1.5. It indicates that the abutment is not safe. If the abutments are reinforced with Geosynthetics, the safety factor increases but is still in a critical condition. If using bored pile foundations with a depth of 8 m and 10 m, the safety factor increases significantly; the more the depth of the pile, the safety factor increases; this is due to the contribution of end resistance and friction resistance so that the bearing capacity increases, so the safety factor increases.

Table 9. Comparison of safety factor values (SF) of several methods

Metode	safety factor values (SF)			
	No Reinforcement	Geosintetik Reinforcement	Bor Pile	
			8 m	10 m
Bishop	1,53	1,76	2,02	2,14
Felleniius/ Petterson	1,29	1,66	1,91	2,10
Spenser	1,54	1,77	3,87	5,08
Janbu	1,54	2,66	3,88	5,11
Morgenstern-Price	1,54	1,83	3,88	5,11

4. Conclusions

The stability of the abutment is very dependent on the working load, the condition of the embankment soil, and the subgrade under the abutment. Installation of four geosynthetics on abutments with a distance between geosynthetics of 1.33 m has not significantly increased the safety factor. Installation of a bored pile foundation (pile group) at a depth of 10m shows a significant increase in the value of the safety factor. In the BH 39 Kurai Taji Pariaman railway bridge project, it is recommended to use a pile group foundation with a depth of 10 m as abutment reinforcement.

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