

Analysis of abutment safety factors against landslides on the Cipeundeuy bridge - Sukatani, Indonesia

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ABSTRACT

Bridges are connecting access between one region and another, and play an important role in transportation to facilitate community economic activities. The river bridge has very steep cliffs, and these cliffs often occur in landslides, therefore this study is very important to determine the safety of the bridge. This study aims to determine the safety of the bridge abutment structure which is the head of the bridge with the function of continuing the load on the bridge foundation. This analysis is limited to only calculating the stability and safety of bridge abutments with reinforced concrete structures. The analysis uses methods and formulas referring to Indonesian national standards, namely RSNI T-02-2005 regarding loading for bridges, RSNI T-12-2004 concerning concrete structure planning for bridges, SNI 03-2833-200X concerning earthquake resistance planning standards for bridges. The data used are drawing data and technical specifications used on the bridge, then the data is verified against planning consultants, project implementers, and observations at the location. The results of the analysis stated that the bridge abutment was declared safe from soil thrust and other forces, but did not have a good safety factor against shear forces. Landslides that occur can be resisted by the bridge abutments. This research is expected to be followed up by policymakers to repair bridges so that they are resistant to maximum shear forces, and provide safety signs from landslides to relieve public anxiety when crossing bridges, as well as provide reinforcement for the cliffs around the bridge.



KEYWORDS

Bridge
Landslide
Abutments
Stability
Safety factor



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1. Introduction

The bridge is one of the transportation access that has an important role in the economic, socio-cultural, environmental, political, defense and security fields, and is used for the greatest prosperity of the community [1]. The crossing of a long and large river becomes an obstacle in transportation to connect between regions or villages, therefore it needs connecting access, namely a bridge [2]. Internationally and in general, bridges have the same function, namely to connect one region to another [3]. Specifically, in the case study of this research, the bridge that was built was to connect Cipeundeuy village and Sukatani village, which are villages in the south Sukabumi area. As a regional link, the government built a bridge with a length of 40 m.

Bridges must be able to withstand loads such as wind loads, earthquake loads, traffic loads, and other loads on the bridge [4]. A bridge consists of 3 main parts, namely the foundation, substructure, and superstructure [5]. The most important part of a bridge is the foundation and substructure. The sub-building consists of the main structure in the form of the base of the bridge (abutment) [6]. Foundations and abutments have an important role in a bridge, namely transmitting all loads from the superstructure to the ground [7]. A river bridge with surrounding conditions in rice fields in general has a soft soil type and a lot of water, therefore it is necessary to analyze the safety factor of the bridge abutment which plays an important role in the connection of the bridge and the ground [8].

Increased rainfall causes landslides around the bridge which is the object of this research, causing concern for bridge users [9]. Bridge users are afraid that the bridge they are using will be hit by a

landslide and collapse, therefore it is necessary to ensure whether the bridge remains safe even though there has been a landslide around the bridge, so this research is very important and urgent.

This study aims to review and re-analyze to find out what loads work on the bridge abutment structure, the design load acting on the bridge, and the bridge abutment safe against soil thrust because the soil around the bridge has landslides. The results of this study can contribute to policy makers to repair bridges if the results of the analysis state that they are not safe, but if the results of the analysis state that the bridge abutments are safe, then this research greatly contributes to the community that the bridges used are safe, so as to eliminate the concerns and fears of people crossing the bridge.

2. Method

The steps taken in this study to solve the problems presented in the background, it is necessary to identify data needs. After knowing the data needed then determine the method of data collection. The data collection methods used in this study are observation, data processing, and literature, as well as field documentation. The data collection methods used in this study are observation, data processing, and literature, as well as field documentation [10]. While the literature data processing technique is a data collection technique by searching for literature related to the material under study [11]. In addition, field documentation needs to be done considering the need for visual data on various conditions and activities in the field, in order to support the previous literature.

The method used in the calculation for the analysis of the abutment structure in this case study is to use the formulas that have been determined based on the Indonesian National Standard, where the provisions of the Indonesian National Standard (SNI) refer to international provisions such as Allowable Stress Design (ASD), Load Resistant Factor Design (LRFD), ASCE 7-10 and more [12]. This analysis method uses the Indonesian National Standard (SNI) as follows:

- RSNI T-02-2005 for loading for bridge [13];
- RSNI T-12-2004 for the design of concrete structures for bridges [14]; and
- SNI 03-2833-2008 for earthquake resistance design standards for bridges [15].

2.1. Data Penelitian

This study using primary data and secondary data [16]. Primary data is data obtained from the results of direct observations and observations in the field as well as data obtained directly from bridge planning consultants and bridge project contractors. The primary data of this study consisted of a plan drawing of the Cipeundeuy - Sukatani bridge and soil data from the sondir test.

Secondary Data is supporting data used in the manufacture and preparation of research from existing literature [17]. This data cannot be used directly as a source but must go through a data processing process to be used. The secondary data used in this study are the design data for the 40 m span reinforced concrete bridge, loading data from RSNI T-02-2005 loading standards for bridges, safety factor data from SNI 03-1974-1990 for concrete compressive strength, SNI 03 -2491-2002 for split tensile strength of concrete, and SNI 03-2833-2008 for earthquake resistance planning standards for bridges.

2.2. Alur Penelitian

The flow of this research starts from identifying the problem, namely the concerns and fears of the bridge user community where there has been a landslide around the bridge. Next, formulate the right problem to describe the problem to be discussed, with the intention of providing answers to research problems.

Based on the problems that have been formulated then identify data needs, and continue with data collection. From the data collected then perform analysis, interpret the results of the analysis, make conclusions and provide recommendations. Briefly, the flow of this research is as described in Figure 1.

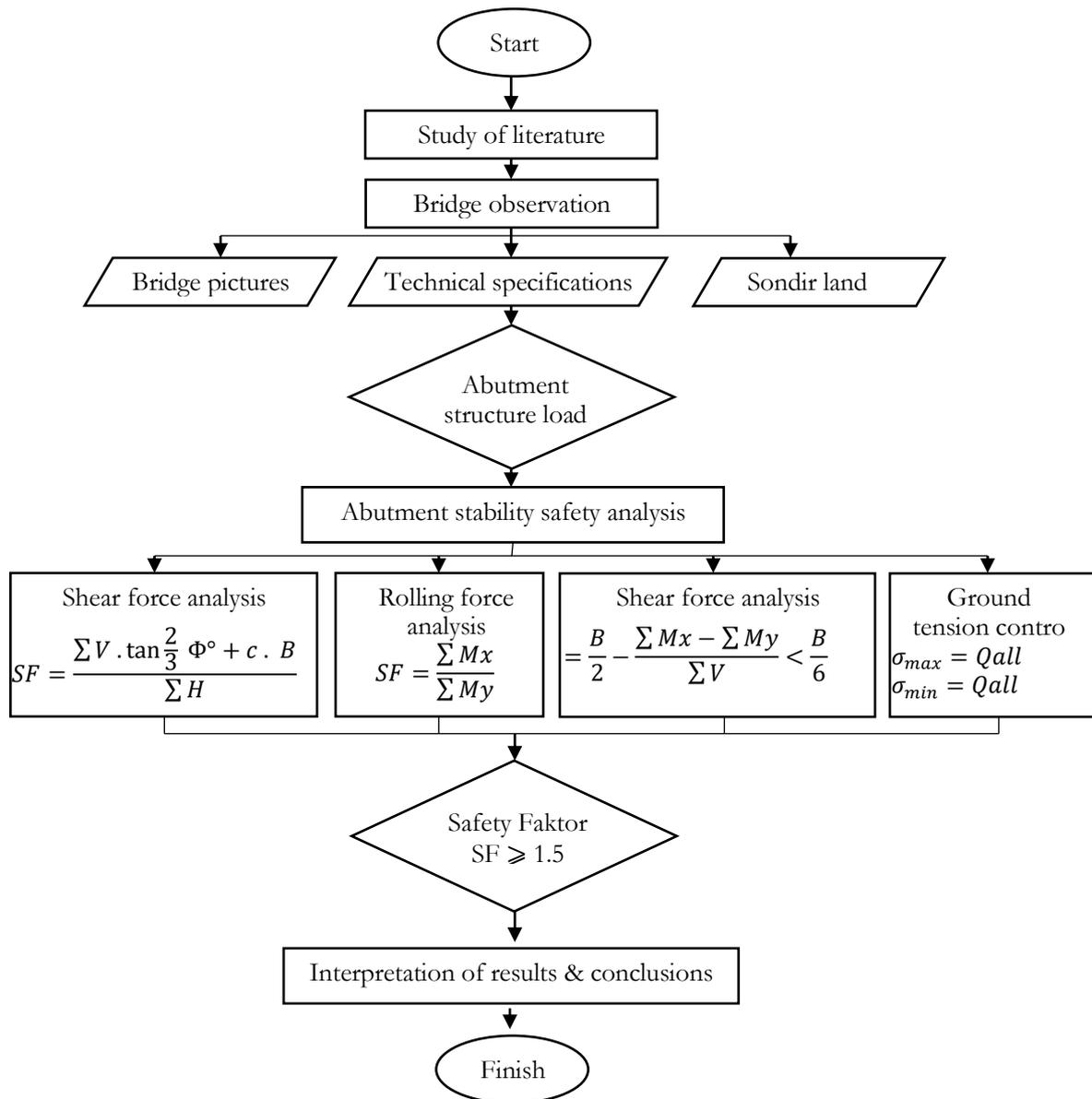


Fig. 1. Research Flow

3. Results and Discussion

3.1. Main Components of Bridge

The main components of the bridge consist of the bridge foundation, the substructure of the bridge, and the superstructure of the bridge. The bridge foundation functions to transmit the entire load of the bridge to the subgrade, with several systems, namely spread footing, caisson foundation, and pile foundation. The lower structure of the bridge functions to accept/bear the loads given by the superstructure and then distributes them to the foundation. The substructure consists of abutments, pier heads, pier bodies and bearings. The superstructure of the bridge serves to accommodate the loads generated by traffic and then distribute them to the lower building. The superstructure consists of plates, box girders, I girders, T girders, U girders, and railings. The main components of the bridge are as illustrated in Figure 2.

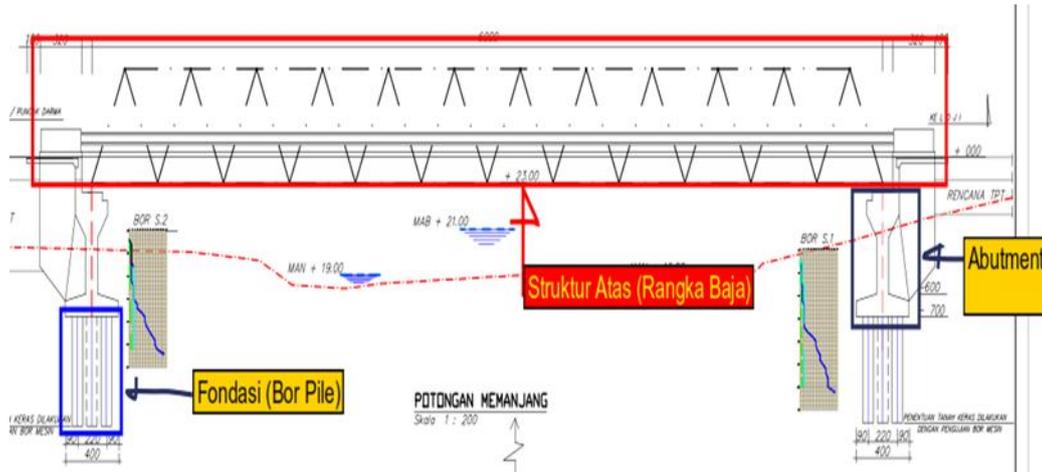


Fig. 2. Steel Frame Bridge Components

The main requirements of the foundation are, strong enough to withstand shear loads due to vertical and downward loads, can adjust to unstable soil movements (moving soil), resistance to the effects of weather changes, resistant to chemical influences, therefore the foundation must be strong, stable, safe so that it does not decrease, and does not break [18]. If there is a decrease or fracture of the foundation, there will be some visual changes, including damage to walls, cracks, cracked and corrugated floors, plates, and a decrease in the bridge.

3.2. Bridge Abutment Parts

In general, the abutment construction consists of several structural parts such as the base plate/support (Pile Cap), breast wall (wall), shoe holder, shoe placement (elastomeric bearing peat), parapet (back wall), wing (wing wall), as illustrated in Figure 3.

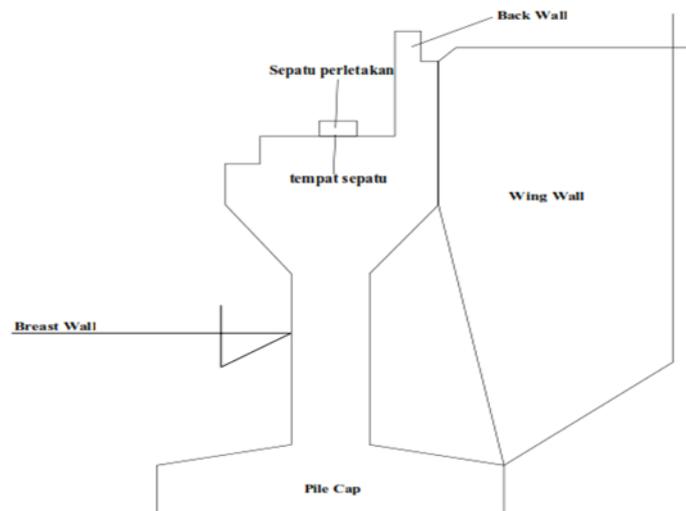


Fig. 3. Bridge Abutment Section

The base plate/pedestal (Pile Cap) consists of a front pedestal and a back pedestal, this base plate is also called a Footing Slab. When using a pile foundation, drill pile or well, this base plate serves to bind and unite the abutment and the pile or foundation. Breast Wall (Wall) which is also called a longitudinal wall, where this construction must be able to accept horizontal forces due to active earth pressure and passive earth pressure, earthquake forces, and all vertical forces acting [19]. Shoe Place is the construction of the placement of the longitudinal and transverse girders. Elastomeric Bearing Peat is a bearing that serves to reduce vibrations that occur in the girder due to loads and moving vehicles. The vibration is then transmitted to the abutment wall and then forwarded to the foundation [20]. Parapet (Back Wall), is a wall construction that functions as a barrier between the girder and the ground behind

the abutment. In addition, the parapet serves as a barrier to the girder so that it does not shift towards the back of the abutment. Wing (Wing Wall), serves to protect the back of the abutment from the working ground pressure [19].

3.3. Abutment Structure Analysis

3.3.1. Style on Abutment Structure

In the analysis of the abutment structure, the forces and loads that work are taken into account. Previously explained in advance the force acting on the abutment as shown in Figure 4.

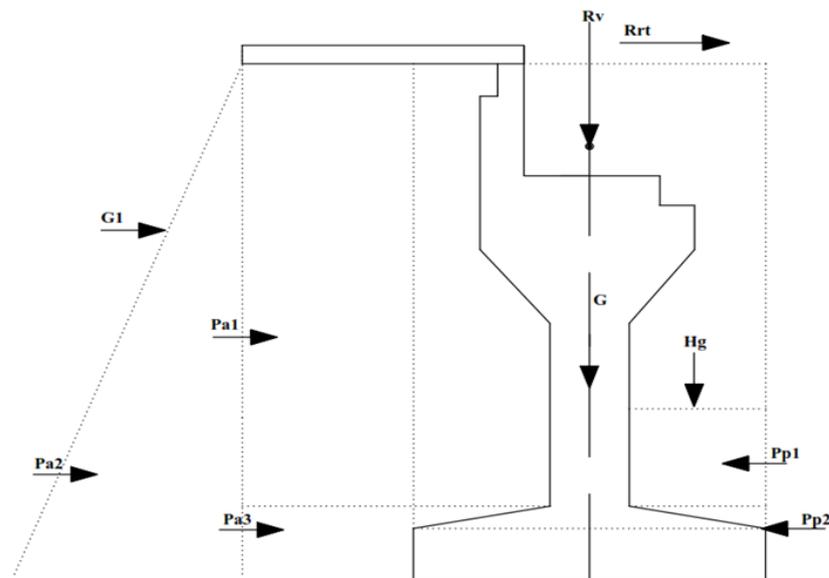


Fig. 4. Styles On Abutments

The various forces that occur in the abutment as illustrated in Figure 4 have the meaning as described in Table 1.

Table 1. Definition of the Style Symbol on the Abutment

Symbol	Definition
Rv	Compressive force due to load from above
Rrt	Force due to vehicle brakes and traction
G	Self weight abutment
G1	Earthquake force due to the upper building
Hg	Friction due to moving pedestal
Pa1, Pa2, Pa3	Active earth pressure behind the abutment
Pp1, Pp2	The passive compression force of the soil at the front of the abutment

3.3.2. Technical Specifications of Abutment Structure

After knowing the various forces that occur in the abutment, as a basis for analyzing the strength of the abutment, it is necessary to know the specification data of the abutment. The technical specifications of the abutments used in this research case study are as described in Table 2 and Table 3.

Table 2. Technical Specifications of Bridge Abutments and Upper Structure

1. Upper Structure		2. Bridge Abutments	
Description	Specification	Description	Specification
Construction Type	Reinforced concrete K350	Construction Type	Reinforced concrete K250
Length (L)	40.00 m	Height (H)	7.00m
Existing Width	11.00 m	Width (B)	4.00 m
Vehicle Lane Width (B)	7.00 m	Length (L)	11.00 m
Pavement Width (Wt)	1.00 m	Wingspan	3.00 m

Table 3. Technical Specifications of Bridge Foundation Abutments and Materials

3. Bridge Foundationn		4. Material Data	
Description	Specification	Description	Specification
Construction type	Drill pile Bor	Floor slab concrete quality	K – 350
Height (H)	7.00 m	Pavement concrete quality	K – 175
Diameter (D)	0.80 m	Quality of abutment concrete	K – 250
		Pile drill concrete quality	K – 250
		Density of reinforced concrete	2,50 t/m ³

3.3.3. Abutment Structure Load

The loads borne by the abutment structure consist of dead loads, live loads, wind loads, forces due to brakes and traction, frictional forces on moving supports, and earthquake forces [21]. Dead load is the load caused by the bridge component itself [22], and the dead load can be determined as presented in Table 4.

Table 4. Upper Structure Dead Load

N	Main Components of Bridge	Weight (tons)
1	Reinforced Concrete Slab	380
2	Sidewalk	135
3	Wave Steel Plate	27,68
4	Hotmix	47,04
5	Gusset Plate	21
6	Bolt	5,2
	Total	611,3

From the dead load of 611.3 tons, as described in Table 4, because the load is a total load while the load is distributed to both sides of the abutment, the load on one side of the abutment is 305.66 tons, by calculating using Equation 1 as follows:

$$R_{vd} = \frac{611,3}{2} = 305,66 \text{ tons} \quad (1)$$

R_{vd} is the compressive force due to the load from above or the compressive force due to the dead load of the components of the bridge structure itself.

The abutment will receive a live load, what is meant by a live load is a changing load such as the load caused by humans, passing vehicles, and other consequences that are not fixed but will burden the abutment from time to time. Live load is calculated and explained in Equation 2 as follows:

$$\text{Live Load } P_L = 12 \text{ ton}; q_L = 2,2 - \frac{1,1}{60} (60 - 30) = 1,65 \text{ tons/m} \quad (2).$$

Because the width of the traffic lane is 7 m, the compressive force due to living loads from above can be calculated in stages using Equation 3, Equation 4, Equation 5, Equation 6, and Equation 7 as follows:

$$\text{Shock Coefficient} = 1 + \frac{20}{50+L} = 1 + \frac{20}{50+60} = 1,18 \text{ tons} \quad (3).$$

$$R_{PL} = \frac{P}{2,75} \cdot k \cdot l = \frac{12}{2,75} \times 1,18 \times 7 = 36,04 \text{ tons/m} \quad (4).$$

$$R_{qL} = \frac{q}{2,75} \cdot L = \frac{1,65}{2,75} \times 60 = 36 \text{ tons/m} \quad (5).$$

$$R_{VL} = \frac{1}{2} (R_{qL} + R_{PL}) = \frac{1}{2} (36 + 36,04) = 36,02 \text{ tons/m} \quad (6).$$

$$\text{Then the total reaction } (R_v) = R_{vd} + R_{VL} = 305,66 + 36,02 = 341,68 \text{ tons} \quad (7).$$

Based on the results of the analysis, the abutment load consisting of compressive forces due to dead loads and live loads is 341.68 tons.

Then calculate the wind load using Equation 8 as follows:

$$R_{EW} = 0,0006 \cdot C_w \cdot (V_w)^2 \cdot A_b = 0,0006 \cdot 1,25 \cdot (35)^2 \cdot 300 = 26,96 \text{ tons} \quad (8)$$

Another load that needs to be calculated is the force due to brakes and traction. This load is calculated at 5% of the dead load (D) without a shock coefficient with a catch point of 0.25 m above the vehicle floor surface as calculated using Equation 9.

$$R_{rt} = \frac{5\%(R_{PL}+R_{qL})}{2} = \frac{5\%(36,04 + 36)}{2} = 1,81 \text{ tons} \quad (9).$$

The frictional force on the moving support is calculated using Equation 10 and the earthquake force can be calculated using Equation 11 as follows.

$$G_g = \text{Friction coefficient} \times R_{vd} \quad (10).$$

$$G_g = 0,25 \times 305,66 = 76,415 \text{ tons}$$

$$\text{Earthquake Style G1} = K \times R_{vd} = 0,07 \times 305,66 = 21,396 \text{ tons} \quad (11).$$

The next loading analysis needs to calculate the soil pressure including active and passive earth pressure, the reaction in the substructure under normal conditions, and conditions during an earthquake. Overall this load is calculated using the Indonesian National Standard (SNI) formulas as exemplified in Equation 1 - Equation 11 in the previous discussion.

The stability of the abutment is viewed from the external forces that work when normal, when the superstructure has not worked, and during an earthquake [23]. The external forces acting under normal conditions are summarized in Table 5.

Table 5. External Forces That Work When Normal

Style	V (tons)	H (tons)	Moment Arm		Mx= V x X Holding Moment (tm)	My= H x Y Rolling Moment (tm)
			X (m)	Y (m)		
Rv	341,68		2		683,36	
Wc	339,295		1,888		640,589	
Wt1	116,021		3,285		381,129	
Wt2	54,6461		0,741		40,493	
Rrt		1,494		7,25		10,8315
Gg		76,415		4,3		328,585
Pa1		34,348		3,5		120,218
Pa2		240,35		2,333		560,817
Total H		352,607				
Pp		145,54		0,9	130,986	
Tb		50		2,3	115	
Total V	851,642					
Total Mx					1991,557	
Total My						1020,451

In addition to the external forces that work when normal in the stability of the abutment as shown in Table 5, before the analysis is carried out, it is necessary to first display the forces acting when the upper structure is not working in Table 6.

Table 6. Styles That Work When The Upper Structure Hasn't Worked

Style	V (tons)	H (tons)	Moment Arm		Mx= V x X Holding Moment (tm)	My= H x Y Rolling Moment (tm)
			X (m)	Y (m)		
Wc	339,295		1,888		640,589	
Wt1	116,021		3,285		381,129	
Wt2	54,6461		0,741		40,493	
Pa1		34,348		3,5		120,218
Pa2		240,35		2,333		560,817
Total H		274,698				
Pp		145,54		0,9	130,986	
Tb		50		2,3	115	
Total V	509,962					
Total Mx					1308,197	

Total My

681,035

In the analysis of abutment stability, another force that needs to be known is the force acting during an earthquake. These styles are presented in Table 7.

Table 7. The Force That Works During an Earthquake

Style	V (tons)	H (tons)	Moment Arm		Mx= V x X Holding Moment (tm)	My= H x Y Rolling Moment (tm)
			X (m)	Y (m)		
Rv	341,68		2		683,36	
Wc	339,295		1,888		640,589	
Wt1	116,021		3,285		381,129	
Wt2	54,6461		0,741		40,493	
Rrt		1,494		7,25		10,8315
Gg		76,415		4,3		328,585
Pa1		34,348		3,5		120,218
Pa2		240,35		2,333		560,817
G1		21,396		7		149,772
G2		23,75		2,7		64,125
Total H		397,753				
Pp		145,54		0,9	130,986	
Tb		50		2,3	115	
Total V	851,642					
Total Mx					1991,557	
Total My						1234,348

3.3.4. Abutment Stability Security Analysis

After identifying the forces that occur in the abutment, it is necessary to calculate the stability of the base shear of the foundation, the stability of the eccentricity, the stability of the overturning of the foundation base, and the control of the soil stress at the base of the abutment under normal conditions and during an earthquake. The results of the abutment stability security analysis are as presented in Table 8.

Table 8. Abutment Structure Security Stability

N	Stability	Score	SF (Safety Factor)	Status
I <i>Normal Condition</i>				
1	Slide Style	0,363	$\geq 1,5$	Not safe
2	Roll Style	1,952	$\geq 1,5$	Secure
3	Eccentricity (e)	-1,138	$< B/6 = 0,67$	Secure
4	Maximum earth stress	4,255	$\leq Q_{all} = 187,40 \text{ tons/m}^2$	Secure
5	Minimum earth stress	0,842		
II <i>Earthquake Condition</i>				
1	Slide Style	0,322	$\geq 1,5$	Not safe
2	Roll Style	1,613	$\geq 1,5$	Secure
3	Eccentricity (e)	-0,887	$< B/6 = 0,67$	Secure
4	Maximum earth stress	3,879	$\leq Q_{all} = 187,40 \text{ tons/m}^2$	Secure
5	Minimum earth stress	1,218		

The results of the analysis show that the stability of the abutment structure under normal conditions and during an earthquake, can withstand overturning, eccentric, maximum earth stress, and minimum earth stress, as shown in Table 8, it is shown that the value of the stability of the abutment structure is greater than the safety factor determined based on the Indonesian National Standard (SNI). While the strength of the abutment structure under normal conditions and earthquake conditions in resisting shear forces, has a value smaller than the safety factor required by the Indonesian National Standard (SNI), so it can be stated that the abutment structure is not safe in resisting shear forces.

4. Conclusion

This study has conducted observations and reviewed the river bridge where there was a cliff slide around the bridge. Observation and review of the bridge to ensure the safety of the bridge from the danger of landslides. The results of the analysis state that the stability of the abutment structure under normal conditions and during an earthquake can withstand overturning, eccentric, maximum earth stress, and minimum earth stress. This means that the abutment structure is able to withstand soil thrust under minimum and maximum soil stress conditions, so it can be stated that the abutment is able to withstand soil pressure and is safe from landslides. The results of the structural analysis on shear forces can be declared less safe because the strength of the bridge structure to withstand shear forces is smaller than the required safety factor based on the provisions of Indonesian national standards. The results of this study can contribute to policymakers making bridge repairs so that the bridge structure is able to withstand maximum shear forces. This study also provides information to the bridge user community, that the bridge abutment structure can withstand landslides. Based on this information, it is hoped that it can eliminate public concerns and fears about the danger of landslides that can cause bridges to collapse. Furthermore, it is hoped that each bridge will strengthen the cliffs around the bridge so that landslides do not occur which causes concern and fear.

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