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Original Article

Alternative Design of Abutment Damage Management for Glendeng Bridge Tuban Regency

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Abstract

This study aims to reconstruct the damage to the bridge abutment that occurred in 2020. The bridge abutment was modeled based on its actual conditions, followed by simulations under various scenarios. The research methods included collecting secondary and primary data, as well as computational modeling. Secondary data collected consisted of bridge design drawings, soil data, and river water level data for specific time periods. The next step was to model the bridge structure using Plaxis software. The analysis results indicate that the collapse of the bridge abutment in 2020 was likely caused by floodwater infiltration into the soil, followed by a rapid decrease in floodwater levels. Slope stability analysis using PLAXIS software for the 2020 damage yielded a minimum safety factor (SFmin) of 1.184. After the flood subsided during the operational load stage (LWL), the SFmin indicated "Structural Failure." The failure was attributed to the infiltration process in the soil when the water reached the Low Water Level; flood-saturated soil became unstable as the water receded due to its transition to a saturated state. The 2021 reinforcement resulted in an SFmin of 1.097 during the bridge construction and embankment stages. The embankment load exceeded the capacity of the retaining wall, whose foundation was embedded in soft soil, leading to instability. To address the landslide in the 2021 reinforcement, a Contiguous Pile Wall was utilized, featuring a configuration of bored piles with a diameter of 1 m, a pile length of 30 m, concrete strength (f'c) of 30 MPa, and steel strength (fy) of 400 MPa. A single row of pile caps was included to support the retaining wall along the slip plane, consisting of a row of bored piles embedded as a Contiguous Pile Wall.The analysis results using Plaxis software showed that the safety factor (SF) increased to 1.551, with a total displacement of 0.069 m, which can be categorized as "Safe" according to the Indonesian National Standard (SNI) – 8460 of 2017 on Geotechnical Design.

Keywords: Slope Stability, Abutment Damage, Bridge Abutment.

1. Introduction

One of the basic infrastructure components of the transport network is roads and bridges. The bridge structure generally consists of two important parts, namely the superstructure and the substructure in the form of pillars and bridge abutments (Lutjito, 2016). The existence of buildings on the side of the riverbank, namely bridge pillars, is considered to be able to change the geometric or flow of the river so that it can affect the structure above it (Abdrabbo et al., 2024; Das & Sobhan, 2012; Isleem et al., 2022).

Glendeng Bridge was built in 1991 - 1992, located in Kalirejo Village, Bojonegoro Subdistrict and Simo Village, Soko Subdistrict, is one of the closest accesses connecting Tuban Regency and Bojonegoro Regency (Mushthofa, 2023). The bridge over the Bengawan Solo river has a length of 310 metres with a width of 7 metres. The superstructure is a type B steel frame with 5 (five) spans and the foundation structure uses steel piles.

The chronology of damage to the Glendeng Bridge on 3 November 2020 was an avalanche of retaining walls on the bridge approach road in the Tuban Regency area which was thought to be due to the scouring of the Bengawan Solo river, followed by the bridge pillars shifting and resulting in a decrease in the bridge superstructure (steel frame) (Baum et al., 2008). Existing picture of Glendeng Bridge when there is damage to the approach road on the Tuban Regency side when damage occurs (Departemen Permukiman dan Prasarana Wilayah, 2002; GEO-SLOPE, 2012). Based on data obtained from BBWS Bengawan Solo on 3 November 2020, the average water level of ± 4 m.

In 2021, the Tuban Regency Government carried out repair work after the damage that occurred in 2020 with design changes to the bridge approach road. The bridge abutment was set back 8 meters from the original abutment point to become part of the pillar. In February 2022 the Glendeng Bridge was reopened. However, at the end of 2022 the approach bridge pillars decreased, the new bridge abutments decreased by about 8 cm while the pillars decreased by an average of 35 cm. Through topographic measurements, conditions around the bridge approach abutments shifted the retaining wall about 19 cm to 46 cm and the pillar pile cap 16 cm to 20 cm which shifted towards the river (Zaein et al., 2023).

To avoid worse conditions, the Glendeng Bridge was closed again at the end of 2022. Based on the chronology of damage in 2020 and 2022, it is interesting to reconstruct what caused damage to the bridge abutment in 2020. Then it also needs to be checked what caused the decline in the Abutment and pillars after the 2022 repair. Based on these problems to find out the cause of abutment damage to the Glendeng Bridge, the purpose of this thesis research is to know the reconstruction of the existing conditions of the Glendeng Bridge due to the landslides that occurred. Knowing the reconstruction of conditions and causes of landslides in the 2021 reinforcement conditions. Obtaining effective and efficient alternatives for handling rehabilitation of bridge damage after reinforcement in 2021.

2. Methods

2.1. Data Collection

The data obtained is data obtained from the East Java Provincial Bina Marga Public Works Office and the Bengawan Solo BBWS. The data include the following:

a) Topographic Data
b) General Bridge Data
c) Bridge Progress Report Data
d) Topography Data
e) Water Level Elevation Data
f) Soil Data
g) Bridge Structure Drawing Data

2.2. Soil Characteristics

In the preparation of this research, soil data taken in the existing area of the Glendeng Bridge abutment is used.

2.3. Structure Modelling

Structural modelling aims to determine the internal forces that occur. Structural modelling to determine the stability of the slope when landslides occur by referring to the slope shift indicated by the safety factor number using the Plaxis auxiliary program (Bowles, 1996; Isleem et al., 2022; Plaxis, 2012).

2.3.1. Evaluation of Slope Stability Due to Slumping

The damage that occurred due to the landslide of the retaining wall of the Glendeng bridge approach road in 2020 was modelled to determine the cause of the landslide in order to obtain invesitations related to the damage that occurred. After the landslide in 2020, reinforcement was then built in 2021 in the form of Retaining Walls and Backfill and the approach Bridge but Sliding still occurred, this evaluation saw a shift by observing the development of FK values < 1.5 after the incident then the Tuban Regency Government carried out Bridge Rehabilitation in 2022 (Alonso & Pinyol, 2016; Pagoray, 2021).

The rehabilitation of the bridge cost a budget of 24 billion by demolishing the Approach Bridge and extending the bridge and planting a 48 m deep foundation, the addition of a cover on the abutment was also reinforced with shotcrate concrete for protection of the cover. From the evaluation results, the safety factor of the existing structure of the Glendeng Bridge Abutment will be obtained, where if $1.5 \leq SF \leq 2$, only repair or maintenance of the bridge structure is required. Meanwhile, if $SF < 1.5$, rehabilitation and additional reinforcement are required by building a new bridge structure.

2.3.2. Analysis of the Causes of Damage and Response Plan for the Rehabilitation of Glendeng Bridge Abutments

Strengthening or increasing the capacity of the structure will be planned if the safety factor (SF) of external stability and the ultimate moment that occurs $1.5 \leq SF \leq 2$. Strengthening the structure can be reviewed from several aspects that result in the structure not being strong. Rehabilitation planning for the bridge by planning a new bridge and protecting the abutments. If the safety factor ≥ 2 then only repairs are made to the structure. Bridge repairs can be in the form of returning elevations and strengthening the surrounding soil. However, if the safety factor < 1.5 then the structure must be rehabilitated by building a new bridge.

1) Handling of Bridge Damage Rehabilitation on Pillars

Handling bridge rehabilitation, especially damage to pillars, can be guided by the 2009 Technical Guidelines for Bridge Rehabilitation from the Directorate General of Highways, which outlines methods for addressing damage to the lower structure caused by pillar movement.

a. Check the amount of bridge head inclination angle that occurs and its direction.
b. Check the relationship between the bridge head and the foundation, whether the foundation is still in its original position or has tilted along with the bridge head.
c. If it is still in accordance with the design (originally), check whether there is a crack at the bottom of the bridge head (digging a little at the bottom of the abutment), if yes, it means that the slope occurs because the abutment relationship with the foundation is not strong enough), do a design analysis according to the existing tilt angle and make a conclusion whether the abutment can still be used or not.
d. If there is no crack, it means that the foundation is tilting with the whole abutment, analyse the design again to ensure that the slope of the foundation and abutment can still be tolerated or not.

2) Bridge Rehabilitation for Approach Roads

Handling bridge rehabilitation for approach roads, according to the 2009 Technical Guidelines for Bridge Rehabilitation of the Directorate General of Highways, involves the following steps:

a. Scour, addressing damage to the river approach road caused by missing parts can be done by:
- Mark the eroded parts.

- Make sure and measure the river upstream and downstream for at least 200 metres each.
- Check for changes in river flow or narrowing of the river's wetted profile.
- Design river flow control by placing gabion-type kribs or concrete piles.

3) Decrease

How to deal with damage to the river approach road due to subsidence can be done by :

a. Check the amount of embankment that has decreased.
b. Make a simple design, to determine what the embankment elevation should be, i.e. the embankment should have the same elevation as the bridge for at least 50 metres before entering the bridge.
c. Perform backfilling in accordance with applicable regulations.
d. Give pavement layers as required in the design.

2.3.3. General Requirements for Bridge Planning

The damage that occurs to the Glendeng Bridge Abutment can be categorised as severe so that it reduces the SF value <1.5 if this happens, it is necessary to rehabilitate the bridge. Based on the Guidelines for General Requirements for Bridge Planning in 2015, the Ministry of Public Works and Public Housing, the following things need to be considered when planning rehabilitation for a new bridge and protection of the lower building, namely:

1) General

The requirements for drains shall be determined by the competent authority after consultation with other parties concerned. The following factors should be considered.

a. Spans and vertical clearance need to be provided for river transport during normal flows or at specified flood water conditions including signs for river traffic where required.
b. The serviceability requirements of the bridge (wet track) as part of the road system, including the frequency and duration of bridge submergence due to flooding and the degree of community dependence on the road network.
c. The serviceability requirements of the land surrounding the bridge. Land use requirements will determine the flow clearance limitations during floods.
d. The serviceability requirements of the river bed, banks, and road embankments including the local effects of pillars and bridge heads. This will determine the permissible velocities, scour issues, and the degree of protection of the bridge from scour.
e. Requirements for the serviceability of the bridge to remain structurally sound under the effects of flooding. Consideration should also be given to the effect of debris carried during flooding on the bridge.
f. The strength and stability of the bridge structure so that it does not collapse due to the plan flood, including drifting objects.
g. Whether or not to build/install a structure that protects the bridge due to collisions on the lower building (fender or dolphin).

2) Pillar and Bridge Head Placement

The pillars must be planned such that :

a. Minimise interference with the passage of water;
b. avoid trapping drifting objects;
c. reduce obstacles to navigation; and
d. be laid parallel to the direction of flow of the river during plan flood conditions.

Slopes at the bridge head and underlying materials need to be checked for stability, protection against river erosion. The position and arrangement of pillars, and bridge heads are selected so as to:

a. minimise scour depth;

b. minimise downstream bank erosion;
c. compatible with pillars and bridge heads of neighbouring structures.

3) Solid Foundation with Protection

As much as possible, the foundation should be placed on rock or material that is not easily eroded. If the footings are laid on sand or erodible soil, the riverbed should be reinforced with reinforced concrete, or the footings protected with shoring or similar. Where the footings are on erodible material, the bottom of the footings shall not be higher than the lowest elevation in accordance with the Footings adjacent to streams shall not be placed higher than the stream bed unless :

a. The footing foundation stands on bedrock or rock fill; or
b. precautions are taken to prevent erosion of the material supporting the foundation.

Table 1. Minimum depth of tread foundation

Foundation Location	Minimum Depth (choose the one with the largest value)
Bridge Head, excluding arch structure	1.5 m below the average riverbed level
Pillars and arch bridge heads	2 m below the average riverbed level
	1.7 times the depth of total scouring below the average riverbed level
	0.5 m below the existing scour depth

Notes:

1) If there is a possibility of degradation or unnatural deepening of the riverbed, the minimum foundation depth must be increased to account for the expected deepening in the future.
2) For pillars and bridge heads made of gabions or timber frames, the minimum foundation depth can be reduced by 50%.

The penetration and strength of the pile structure, including sheet piles, should be sufficient to ensure stability against the worst conditions due to unnatural scouring, degradation and settlement. For retaining wall-type bridge heads resting on piles and in direct contact with watercourses, the base of the pile head should be done with a direct contact with water flow, the base of the pile head should be placed below the depth of possible scour, degradation, or unnatural deepening. Aprons may be used to protect pillars against scour at positions a minimum of 1.5 times the maximum width of the pillar or sole foundation in direct contact with the stream. The thickness of the apron should be 2 times the average size of the fill rock.

4) Engineering drawings of bridge abutment rehabilitation handling

The results of the conclusion of the bridge abutment damage evaluation calculation are outlined in the engineering drawings. So that the results of the research are in the form of pictures of Handling Damage Rehabilitation of Glendeng Bridge Abutments. To facilitate the depiction, the design of this structural development drawing uses AutoCAD software.

5) Handling Methods for Bridge Abutment Rehabilitation

This stage describes the rehabilitation implementation method including demolition to structural replacement that will be carried out in the field.

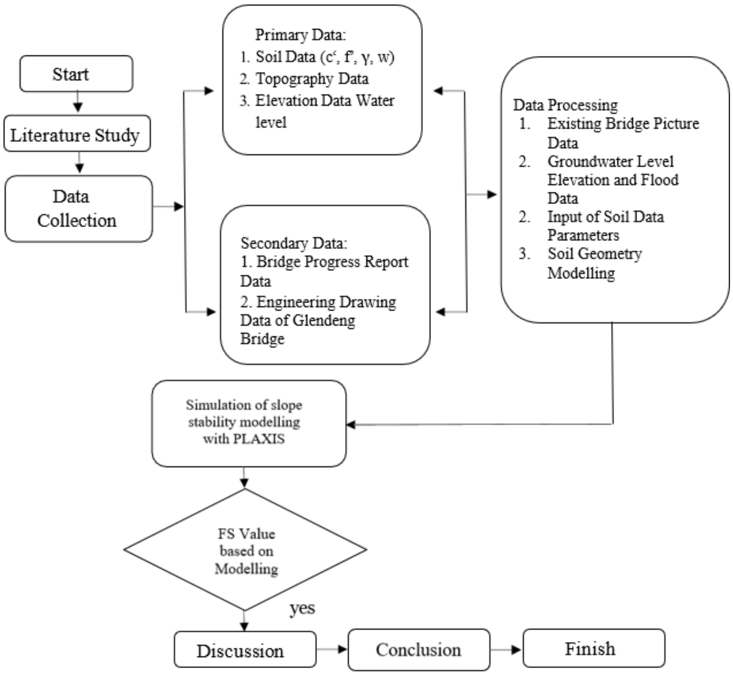
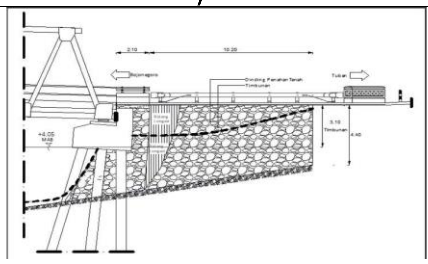


Figure 1. Research Flowchart

3. Results and Discussion

Based on the results of the safety factor analysis using Plaxis software, the results are obtained according to the chronology of the development of the Glendeng Bridge conditions.

Table 2. Results of Stability Analysis of Initial Conditions in 2020 (Before Flood)

Stability Analysis of Normal / Pre-Flood Conditions in 2020						
						
No.	Load Input	Condition	Water Level from the Top of the Bridge (m)	Safety Factor	Slope Stability SF > 1 to 1.5	Description
1.	Bridge Construction Stage	HWL	-2,8	1,443	< 1,5	Not Safe
2.	Operational Stage Expenses	HWL	-2,8	1,243	< 1,5	Not Safe
3.	Bridge Construction Stage	LWL	-5	1,347	< 1,5	Not Safe
4.	Operational Stage Expenses	LWL	-5	1,184	< 1,5	Not Safe

Based on the results of the above analysis, the value of SF = 1.443 is obtained in the analysis of the operational stage of the load with conditions when the flood water level (HWL) while in the operational stage of the load with normal water level conditions, the value of the safety factor decreases SF = 1.347 the increase in the SF value during flood conditions lies in the flood water elevation factor. The high water level elevation will increase the hydrosecurity pressure acting on the river cross section, thus increasing the magnitude of the resisting force element in resisting the driving force element in the form of soil mass from the river slope.

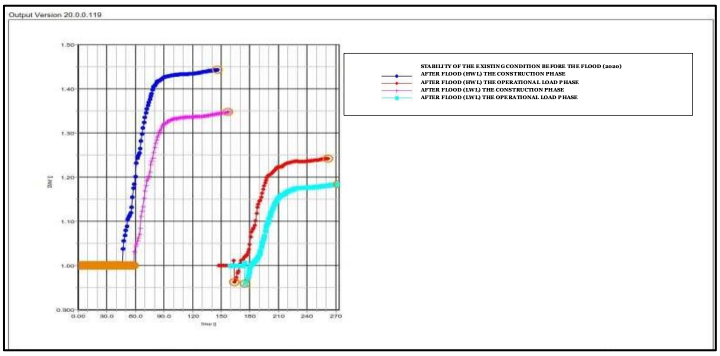


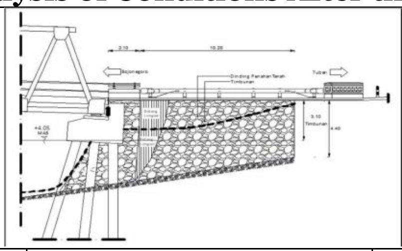
Figure 2. Graph of Factor of Safety Based on Stability Analysis of Existing Conditions Before the 2020 Flood

Based on the results of the analysis of the stability of the existing bridge structure before the flood at each stage, the safety factor value is obtained as follows:

1. Before the flood event (HWL) bridge construction stage, SF = 1.443
2. Before the flood event (HWL) load operational stage, SF = 1.243
3. Before the flood event (LWL) bridge construction stage, SF = 1.347
4. Before flood event (LWL) operational load stage, SF = 1.184

The comparison graph above is the result of the Plaxis software analysis at all stages of the pre-flood condition analysis or under normal conditions with the existing parameters showing that none of the stage conditions reach the SF = 1.5 value so that the existing conditions in 2020 already have a low SF value.

Table 3. Results of Stability Analysis of Conditions After Flooding in 2020 (After Flood)

Stability Analysis of Conditions After the 2020 Flood						
						
No.	Load Input	Condition	Water Level from the Top of the Bridge (m)	Safety Factor	Slope Stability SF > 1 to 1.5	Description
1.	Bridge Construction Stage	HWL	-2,8	1,218	< 1,5	Not Safe
2.	Operational Stage Expenses	HWL	-2,8	1,052	< 1,5	Not Safe
3.	Bridge Construction Stage	LWL	-5	1,134	< 1,5	Not Safe
4.	Operational Stage Expenses	Structure Failure Occurs				

Based on the results of the above analysis, the value of SF = 1.052 is obtained in the analysis of the operational stage of the load with conditions when the water level is flooded (HWL) while in the operational stage of the load with normal water level conditions, the structure experiences landslides when it is noted that landslides occur when the water level is normal, this is because there is a factor that is rapid drawdown so that it can affect the stability of the slope and surrounding structures. Rapid drawdown is a rapid decrease in water level elevation that affects the condition of slopes and nearby structures. This decrease can leave a saturation effect on the soil so that the soil parameters are assumed to decrease and overload the retaining wall structure, causing landslides.

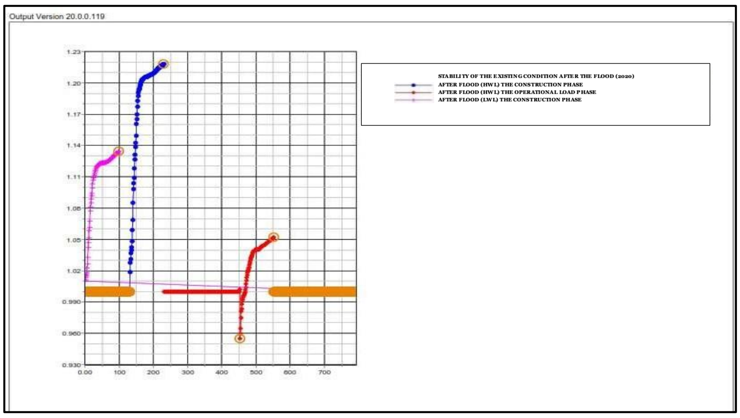


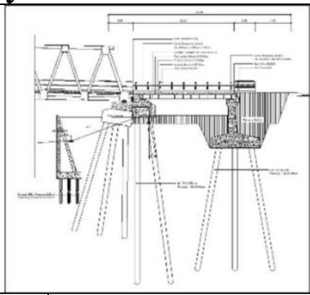
Figure 3. Graph of Factor of Safety Based on Stability Analysis of Existing Conditions After the 2020 Flood

Based on the results of the analysis of the stability of the existing bridge structure after flooding at each stage, the safety factor value is obtained as follows:

1) After the flood event (HWL) bridge construction stage, SF = 1.218
2) After the flood event (HWL) load operational stage, SF = 1.052
3) After flood event (LWL) bridge construction stage, SF = 1.134
4) After the flood event (LWL) load operational stage, structural failure occurs

The comparison graph above is the result of the Plaxis software analysis at all stages of the condition analysis after a flood or with the existing parameters showing the load stage experiencing landslides when the spring water is in the normal water level SF = - so that this existing condition correlates with the evaluation related to damage in 2020, namely the elevation of the flood water level affects the resistance force on slope stability. When the water level drops suddenly or rapid drawdown, landslides occur because the soil properties have changed to saturation due to the flooding that occurred.

Table 4. Stability Analysis Results of Reinforced Condition 2021

Stability Analysis of Reinforced Condition 2021						
						
No.	Load Input	Condition	Water Level from the Top of the Bridge (m)	Safety Factor	Slope Stability SF > 1 to 1.5	Description
1.	Bridge Construction Stage	LWL	-2,8	1,245	< 1,5	Not Safe
2.	Bridge and Embankment Construction Stage	LWL	-2,8	1,097	< 1,5	Not Safe
3.	Operational Stage Expenses	LWL	-2,8	1,101	< 1,5	Not Safe

Based on the results of data analysis before the 2020 flood, the value of SF = 1.243 was obtained at the operational stage of the load, while in 2021 in the retrofitting analysis, the value of SF = 1.245 was obtained. At the construction stage, the SF value continues to decrease with the addition of fill on the lower side of the bridge abutment so that SF = 1.097 is obtained. This causes a decrease in the side of the abutment so that the abutments and pillars of the approach bridge experience a decrease and elevation difference and require bridge rehabilitation to prevent sliding that occurs.

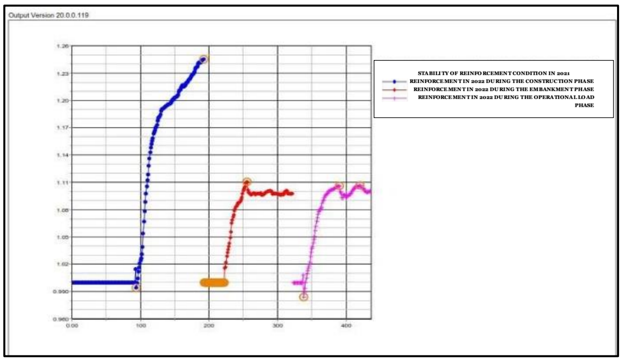


Figure 4. Safety Factor Graph Based on Stability Analysis of Reinforcement Condition 2021

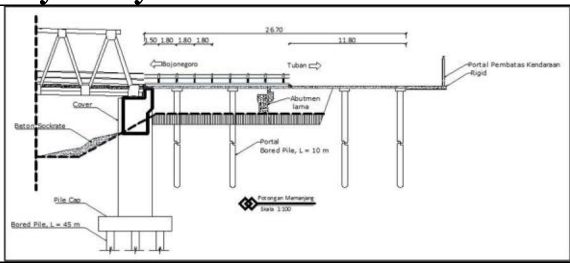
Based on the results of analyzing the stability of the bridge structure under reinforced conditions in 2021 at each stage, the safety factor value is obtained as follows:

1) Reinforcement 2021 Bridge construction stage, SF = 1.245
2) Reinforcement 2021 Bridge and embankment construction stage, SF = 1.097
3) 2021 Retrofitting Load operational stage, SF = 1.101

Based on the above graph at the existing construction stage in 2021, the SF value = 1.245 is obtained so that these results are still considered "Critical" because they are still <1.5

so that the existing conditions require handling related to the reinforcement that has been built.

Table 5. Stability Analysis Results of Reinforced Condition 2022

<table>
<tr><th colspan="7">Stability Analysis of Reinforced Condition 2022</th></tr>
<tr><td colspan="7"></td></tr>
<tr><td>No.</td><td>Load Input</td><td>Condition</td><td>Water Level from the Top of the Bridge (m)</td><td>Safety Factor</td><td>Slope Stability SF > 1 to 1.5</td><td>Description</td></tr>
<tr><td>1.</td><td>Bridge Construction Stage</td><td>LWL</td><td>-2,8</td><td>2,009</td><td>> 1,5</td><td>Safe</td></tr>
<tr><td>2.</td><td>Bridge and Embankment Construction Stage</td><td>LWL</td><td>-2,8</td><td>1,838</td><td>> 1,5</td><td>Safe</td></tr>
</table>

The results of the data analysis above show that the SF value at the operational stage of the reinforcement load in 2022 has decreased, the SF value = 1.838 is categorized as "Safe" according to (Bowles, 1984). However, in its implementation, this construction cost approximately 23 billion and had experienced obstacles until the work had to be completed until the beginning of 2024 due to these cost problems.

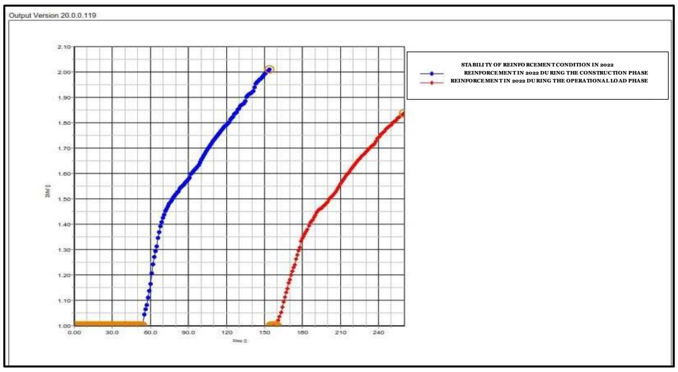


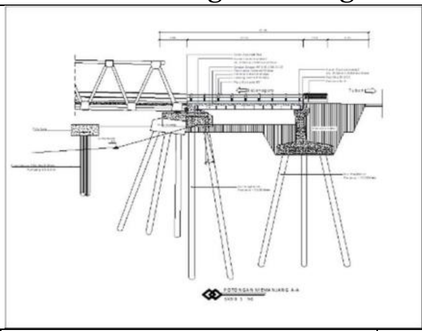
Figure 5. Graph of Factor of Safety Based on Stability Analysis of Reinforcement Condition 2022

Based on the results of analyzing the stability of the bridge structure under reinforced conditions in 2022 at each stage, the safety factor value is obtained as follows:

1) Reinforcement 2022 Bridge construction stage, SF = 2.009
2) Reinforcement 2022 Load operational stage, SF = 1.838

The graph of the analysis results obtained by the reinforcement built by the Tuban district government has increased FS = 2.009 even though the load operational stage analysis was carried out, the SF = 1.838 value proves that the reinforcement that has been built has succeeded in keeping the Glendeng Bridge structure safe even though the efficiency of workmanship and costs is still considered very large.

Table 6. Results of Analysis of Alternative Handling of Damage to Glendeng Bridge

Analysis of Alternative Handling of Damage to Glendeng Bridge					
					
No.	Load Input	Water Level from the Top of the Bridge (m)	Safety Factor	Slope Stability SF > 1 to 1.5	Description
1.	Bridge Construction Stage	-2,8	1,368	< 1,5	Not safe
2.	Reinforcement Construction Stage	-2,8	1,551	> 1,5	Safe

Based on the results of the analysis of the existing Plaxis software used in the analysis of this alternative treatment using the existing 2021 reinforcement which was damaged and resulted in a value of SF = 1.097 at the construction and embankment stages but the increase in the safety factor after bored pile was implanted as an alternative treatment was SF = 1.551 and the total dicplacement that occurred was 0.069 m, indicating that the reinforcement structure using Contiguous Bored Pile Wall can be categorized as "Safe / High" according to SNI - 8460 of 2017 concerning "Geotechnical Planning" this handling is also more economical only spending a budget of ± 3 billion Rupiah.

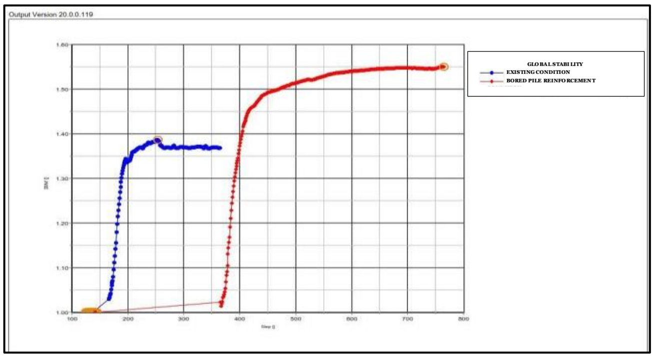


Figure 6. Graph of Safety Factor Based on Stability Analysis of Handling Alternatives

Based on the results of analyzing the stability of the bridge structure at each stage of construction, the safety factor value is obtained as follows:

1) Existing Bridge Construction Stage, SF = 1.368 < 1.50
2) Construction Stage of Strengthening the Bridge Structure, SF = 1.551> 1.50.

4. Conclusion

Based on the evaluation results and damage analysis calculations conducted at the Glendeng Bridge Abutment in Tuban Regency, the following conclusions were drawn: The reconstruction of the bridge abutment damage in 2020 revealed that the slope condition remained normal, with floodwater levels increasing compared to the normal water level analysis results. During the bridge construction phase, the safety factor (SF) was recorded at 1.443, while during the operational load phase, it was 1.243. Research findings indicated that slope stability was most significantly influenced by the elevation of the floodwater level. The highest safety factor occurred when the floodwater elevation increased, which added hydrostatic pressure to the river's cross-section. The infiltration process during floods caused soil saturation, increasing the load on the existing structure. Rapid drawdown of water levels around the bridge abutment also affected soil stability and nearby constructions.

It is planned to use a Contiguous Bored Pile Wall with a diameter of 1 meter, a pile length of 30 meters, and concrete quality (fc') of 30 MPa. To address the landslide, the Contiguous Pile Wall will consist of bored piles with the same diameter and concrete specifications, along with a pile cap to stabilize the retaining wall. After the installation of the bored piles, the safety factor increases to SF = 1.551, with a total displacement of 0.069 meters, indicating that the structure with the Contiguous Bored Pile Wall is "Safe/High," according to the SNI 8460:2017 standards on Geotechnical Design. Several suggestions for further research on the handling of damage to the Glendeng Bridge Abutment include evaluating alternative materials for bridge rehabilitation to optimize cost and efficiency in the budget planning process, ensuring a thorough understanding and study of any software program used in research and analysis to facilitate smoother implementation.

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