Analysis of Main Road Stability Due to The Effect of River Water Level Fluctuations and Rainfall (Case Study: Trengguli - Kudus Road Section)

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ABSTRACT

In Indonesia, many roads are built next to rivers due to several factors in terms of geography, topography, and function of the river. One of them is on the Trengguli - Kudus road where the road is flanked by two rivers. These road sections often experience damage in the form of cracks, potholes, and differential settlement. The existence of a river on the side of the road needs to be considered the possibility of the influence of changes in the river water level on the stability of the road. Rainfall also has a significant role in the stability of the main road considering that the rain that occurs is very intense, moreover, the road is already in cracked condition. This research was carried out numerically using the Plaxis program, with variations in river water level and rainfall adjusted to field conditions. The research results show that a rapid drawdown causes a significant decrease in the safety factor (SF=1.172). Even though the influence of rainfall is relatively small, it still reduces the safety factor (SF=1.152). The duration of the rapid drawdown only has a difference of <1.35%. However, the slope conditions are still within safe limits.

Keyword : asset management infrastructure, rapid drawdown, rainfall

INTRODUCTION

The Trengguli - Kudus road section is on the North Coast (Pantura) route, where this road is part of the arterial road that stretches along the north of Java Island from Merak to Banyuwangi with heavy traffic conditions that tend to be overloaded and is the main route. route. for logistics distribution on the island of Java, so that damage to the road can disrupt the economy, especially in the distribution of goods. Roads are a Public Works Infrastructure that must always be in good functional condition. This can be preserved if the infrastructure is well-planned, designed, constructed, operated, and maintained (Soemitro & Suprayitno, 2020). The Jalan Trengguli – Kudus section is flanked by two rivers, each of which functions as an irrigation and drainage canal. This road section often experiences damage in the form of cracks (both longitudinal and transverse cracks), potholes, and differential settlement (**Figure 1**).

Road maintenance is often carried out to repair this damage, starting from repairing the road pavement through asphalt overlays, replacing concrete pavement and foundation layers to repairing the subgrade. However, road damage always occurs and causes the life of the road to be less than the life of the construction plan. Therefore, it is necessary to find out the cause of the damage so that appropriate treatment can be carried out and it can last for the life of the construction. This is in line with the principles of Infrastructure Asset Management, which can be interpreted as the tasks that infrastructure managers need to undertake to maintain the functionality of the infrastructure. This is related to the current condition of the infrastructure, as explained in the study by Suprayitno & Soemitro (2018). Additionally, the basic quality of infrastructure is formulated as its performance in executing its functions (Suprayitno et al., 2020). The regulation applied to the river system from the upstream to downstream should consider the existing infrastructure, hence an appropriate asset management could be arranged (Maulana et al., 2019).

Figure 1. Road Damage on the Trengguli - Kudus Section KM 39+850

In 2021, the Road Pavement and Environment Center from the Ministry of Public Works and Public Housing has carried out a field survey which aims to see indications/suspected causes of road damage from visual observations so that further evaluation and action can be carried out regarding road repairs that will be carried out on the Trengguli – Kudus. The results of the field review are as follows:

1) Differential settlement occurs in the widening lane resulting in non-uniform bearing capacity so that when repeated loads occur, the concrete panels are not strong enough to withstand the load and cracks occur, while on the road shoulder because it uses flexible pavement and is not tied to the concrete pavement next to it, there is a decrease and shifting.
2) Poor compaction of the foundation layers and embankments resulting in poor bearing capacity stability and settlement at certain points resulting in voids under the pavement structure.
3) The use of poor embankment material or problematic subgrade (softsoil / expansive) which can result in shrinkage of the supporting layer, causing deformation in the form of subsidence or shifting in the lower layer of the pavement structure and affecting the condition of the layer above it.
4) The influence of water, whether seepage or high groundwater levels (or even the occurrence of tidal floods) which greatly influences the strength of the bearing capacity of the foundation layer of the pavement structure. The effect of this water flow can also result in erosion and voids in the layer material. Under the pavement structure, the next effect is a decrease and shift in the top layer as seen on the road shoulder, whereas on a

concrete slab, the effect of this shift and decrease results in the destruction of the concrete slab because it is not strong enough to withstand traffic loads.

5) A combination of the four mechanisms above.

Details of the results of the field review mentioned above are shown in **Figure 2**. The results of the field review are only conjectures that require further research. However, the results of the field review in points 1 to 3 are closely related to technical aspects which do not need to occur if the planning and implementation stages meet the standards set by the Directorate General of Highways. Likewise in point 4, where to prevent erosion slope protection can be added.

One of the things that needs to be paid attention to in point 4 is related to seepage, where this statement only discusses the carrying capacity and does not discuss stability in terms of it considering that the slope at that location has a steep and deep slope (especially in the Trengguli direction). Apart from that, the river along the Trengguli - Kudus section also has a river water level that changes and even dries up.

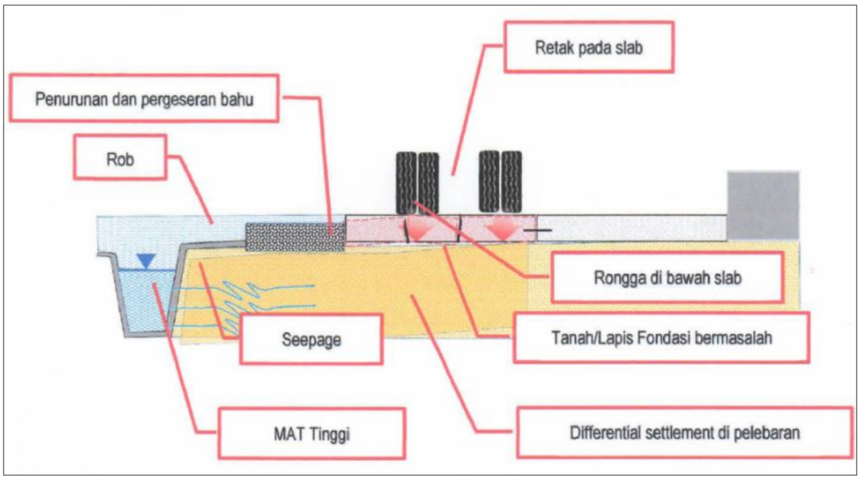


Figure 2. Damage Mechanism on the Trengguli - Kudus Road Section

The influence of river water level fluctuations needs to be taken into consideration in stability analysis, especially if there is a sudden drop in water level or rapid drawdown. The geometry shape and water level fluctuation induce embankment failure (Satrya et al., 2019). With large fluctuations in river water levels and a sudden decrease in river water levels, it can increase the pushing force of the soil due to the pressure of pore water remaining in the soil plus reduced resistance by river water, which can reduce the value of slope stability.

Pratama (2023) states that a sudden drop in water level in irrigation channels can decrease slope stability. The research results reveal that the most critical impact occurs when the irrigation canal suddenly recedes (water gates are closed), causing the water level in the irrigation channel to transition from normal elevation to dry conditions. In this situation, the soil on the slope has low permeability, allowing water to still be retained within the embankment of the road even though the water level in the irrigation canal has dropped.

Hamdhan & Pratiwi (2018) conducted research on cliffs around the river mouth, stating that the higher the water level position (during high tide conditions), the greater the safety factor value. This is caused by the addition of hydrostatic pressure from water that resists the force to slide. Conversely, the lower the water level position (during low tide conditions), the smaller the safety factor value due to a reduction in hydrostatic pressure. This study also examines the influence of soil permeability on slope safety factors, where soil with low permeability has a higher safety factor value.

In addition to the influence of water from the river, rainfall also has a significant impact on the stability of road embankments that have experienced cracking, considering the intense rainfall in the surrounding area (especially during the rainy season). Water can quickly penetrate the soil layers, and cracks can become filled with water. According to Ahmed et al. (2016), most earth slopes fail or become critical when the degree of saturation approaches 50% or more. Rainwater infiltration not only mechanically reduces the shear strength of slope materials but also chemically alters the mineral composition of the soil. Moreover, cracks that are filled with water can increase pore water pressure, affecting road stability. Besides pore water pressure, cracks can reduce the mechanical properties of the soil. The results of Hutagamissufardal et al.'s (2018) research indicate that the propagation of cracks in the soil significantly affects cohesion but does not influence the internal angle friction. The longer the presence of cracks in the soil, the lower the cohesion value of the soil.

The cracks appearing on the road surface (predominantly longitudinal cracks) are suspected to result from the instability of the slope, causing the main road to shift and deform. This movement can create cracks, and when exposed to rainwater, the cracks may widen and deepen, thus affecting stability. Therefore, an investigation is required to determine the soil conditions beneath these cracks without damaging the road pavement. One approach is to use geophysical methods such as electrical resistivity testing (Geoelectricity) and/or ground-penetrating radar (georadar).

Geoelectricity can identify soil layers that have experienced movement, allowing the determination of the sliding plane. Additionally, this testing can detect gaps that occur within the soil. Considering the heavy traffic flow and the impracticality of closing the road for an extended period, geoelectricity cannot be conducted across the road but rather along its length. For conditions across the road, georadar is assisted due to its quick execution. Georadar provides high-resolution images at shallow depths, offering a clear depiction of gaps or voids formed within the soil. Dalimunthe & Hamid (2018) conducted geoelectricity and georadar at a landslide location, indicating that the data from both methods complement each other. Geoelectricity provides a clearer image of soil layers, while georadar offers more detailed insights into anomalies occurring in shallow soil layers.

Given this situation, further research is necessary to investigate the stability conditions of the main road due to the influence of river water level fluctuations. This research aims to obtain stability values for the road, used as an approach to conditions where the road experiences deformation and the emergence of cracks in the main road, along with the subsequent impacts when rainwater intervenes in these cracks.

RESEARCH METHOD

This research is conducted to identify the stability of the main road due to the influence of river water level fluctuations and rainfall, which may be the potential causes of cracks and deformations. The study also aims to assess the potential impacts of these cracks when rainwater enters through them. The entire analysis is carried out using the Plaxis program based on the finite element method. This analysis will generate safety factor values.

Firstly, a back analysis is conducted to obtain a model in the Plaxis program that closely resembles the actual conditions in the field. There are several indicators used to determine a model that is suitable for the field, including:

1. The road remains stable or does not collapse during high water levels, low water levels, and rapid drawdown conditions, in other words, the safety factor (SF) > 1.
2. Deformations occur on the main road only on the slow lane side.
3. The occurrence of a sliding plane beneath the main road.

The model that meets the criteria is then subjected to stability analysis concerning the river water level. This analysis is conducted to observe the stability of the main road due to river water level fluctuations, considering influencing factors such as the river water level under two conditions. In the first condition, the simulation involves varying river water levels from the highest to the lowest positions, where the groundwater level follows the river water level. In the second condition, it simulates a sudden drop in water level (rapid drawdown), where the groundwater level is at the highest position, and the river water level is varied from the highest to the lowest positions.

Subsequently, the analysis is continued by introducing the influence of rainfall, where rainfall is simulated in areas of the road with and without cracks. In areas with cracks, infiltration is applied to the entire main road and slope. On roads without cracks, rainfall only affects the uncovered side of the road and the slope. Next, based on the data from geoelectricity and georadar, if cracks are observed, an analysis is conducted by modeling the gaps or voids in the soil and/or simulating by creating a thin weak layer with varying cohesion values.

Jiang et al. (2023) investigated the influence of crack depth and width on slope stability, where (1) Rainfall infiltration has a negative impact on the stability of the collapsing mass. Hydrostatic pressure formed by rainwater inside the cracks and the seepage force as it seeps out from the outer edge of the slope will generate thrust forces directed towards the free surface, increasing the overturning moment. (2) With increasing crack depth, the resistance of the soil behind the slope gradually decreases, reducing the restraining moment, and the hydrostatic pressure on the crack gradually increases, enhancing the overturning moment. (3) The width of the crack has a certain influence on slope stability, but its effect is not clear. as indicated by the results shown in **Figure 3**.

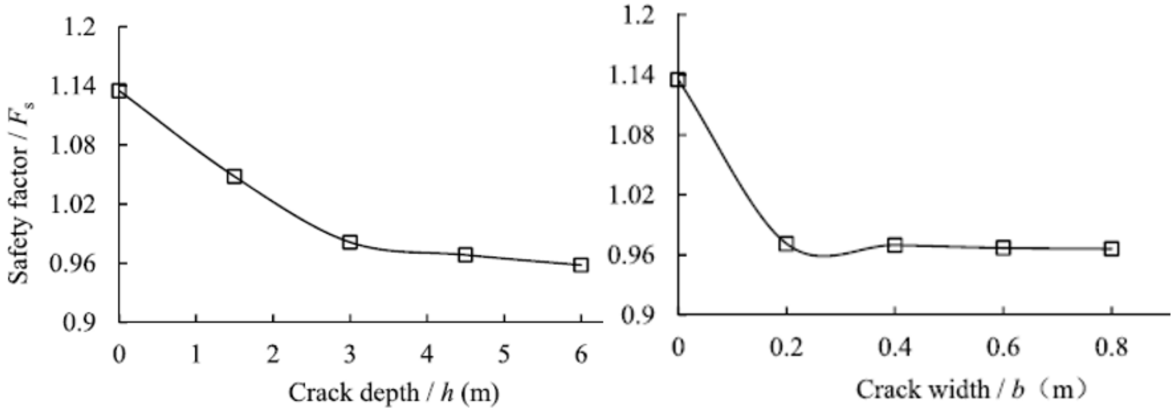


Figure 3. The Relationship Between Safety Factors and the Depth/Width of Cracks

Bentley Institute (2023) conducted a simulation introducing a thin weak layer in a soil layer. The analysis was performed using the undrained shear strength constant value of the soil (cu1) and five different undrained shear strength values for the thin layer (cu2) with cu2/cu1 ratios equal to 1, 0.8, 0.6, 0.4, and 0.2. Later, one of the ratios that led to the collapse resembling the thin weak layer would be selected. This experiment aligns with the research conducted by Hutagamissufardal et al. (2018).

DATA COLLECTION

In conducting the analysis for this research, input data is required, including the condition of the road structure, physical and mechanical properties of the soil, groundwater and river water levels, as well as rainfall. These data are obtained from secondary sources collected by government agencies and primary data collected by the researchers. The secondary data obtained include:

1) The soil investigation results were obtained from the National Road Planning and Supervision Unit (P2JN) of Central Java Province, Ministry of Public Works and Public Housing, through a geotechnical consultant. As for the soil layers based on the Standard Penetration Test (SPT) data according to their consistency and soil properties from laboratory testing with the simplified results, they are as follows:

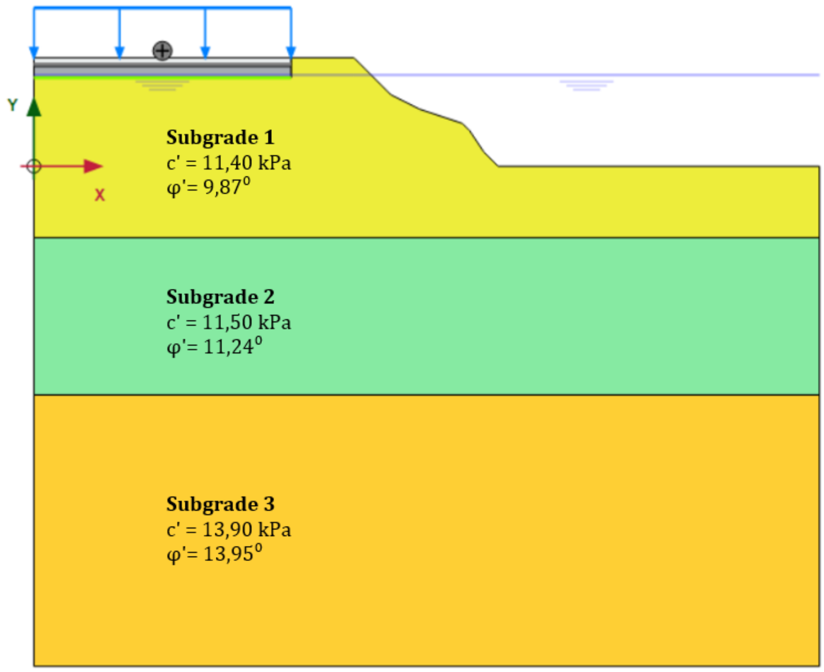


Figure 4. Soil Stratification

2) The results of the pit test evaluation related to the proposed design changes for the reconstruction of the Trengguli - Bts. Demak/Kudus road at KM 38 - 43 were conducted by the PPK 3.1 of Central Java Province, Ministry of Public Works and Public Housing. The results of the pit test can be seen in **Figure 5**.

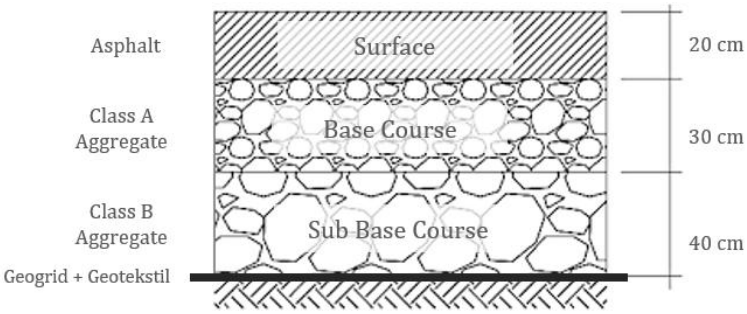


Figure 5. Road Pavement Structure at KM 39+850

3) The results of river discharge measurements were conducted by the PUSDATARU Management Unit of Wulan Region, Serang Lusi Juana Water Resources Management Office (BPSDA Seluna), Department of Public Works for Water Resources and Spatial Planning of Central Java Province. The discharge data available is only for the irrigation canal in the form of daily river discharge records for the year 2022. Due to the absence of discharge data for the drainage canal, the water level behavior is based on field

observations, utilizing the irrigation canal discharge data to observe the changes in river water levels over one year. The discharge data is then processed to derive the river water level, as depicted in **Figure 6**.

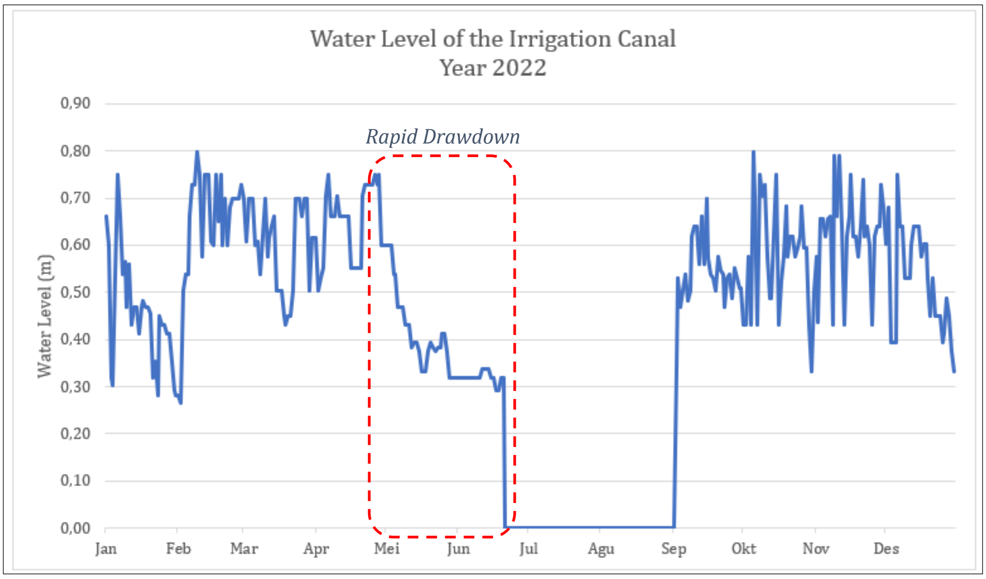


Figure 6. Water Level of the Irrigation Canal

4) The rainfall data for the last 10 years was collected by the Maritime Meteorological Station at Tanjung Emas, Meteorology, Climatology, and Geophysics Agency (BMKG). The rainfall data obtained consists of daily rainfall (without the duration of rainfall in hours) over 10 years. From the data, it is observed that the maximum daily rainfall in the last 10 years consistently occurs in February, with an average of 155 mm. This high rainfall coincides with the highest water levels. During the low-flow period between July and September, the maximum daily rainfall is recorded at 90 mm. Meanwhile, during rapid drawdown events, the maximum daily rainfall is only 68 mm (see **Table 1**).

Table 1. Maximum Daily Rainfall in the Last 10 Years

No.	Year	Maximum Daily Rainfall (mm/day)						
		Per Year		Per Month				
		Bulan	Curah Hujan	May	June	July	August	September
1	2013	February	135,00	42,00	49,00	43,00	44,00	0
2	2014	January	120,50	37,00	22,50	46,00	26,50	1,50
3	2015	February	119,40	38,50	54,00	1,70	11,90	0,00
4	2016	September	74,00	33,00	60,50	66,50	55,00	74,00
5	2017	October	99,50	40,00	34,40	10,20	1,50	21,00
6	2018	February	138,50	10,00	50,00	0,40	0,00	3,30
7	2019	February	92,70	37,00	0	1,30	5,00	48,00
8	2020	January	105,60	38,50	17,00	64,40	44,50	45,00
9	2021	February	155,00	47,20	45,40	3,50	90,00	89,10
10	2022	December	134,00	31,20	68,00	48,40	35,80	21,50
River Water Condition		High Water Level		*Rapid Drawdown*		Low Water Level		

Source : BMKG, 2023

Additionally, primary data collection was carried out, including slope geometry measurements and geophysical testing conducted by the researchers with assistance from the team at the Department of Geophysics Engineering, ITS (Institut Teknologi Sepuluh Nopember). The tests performed included Electrical Resistivity (Geoelectric) and Ground-Penetrating Radar (Georadar) tests.

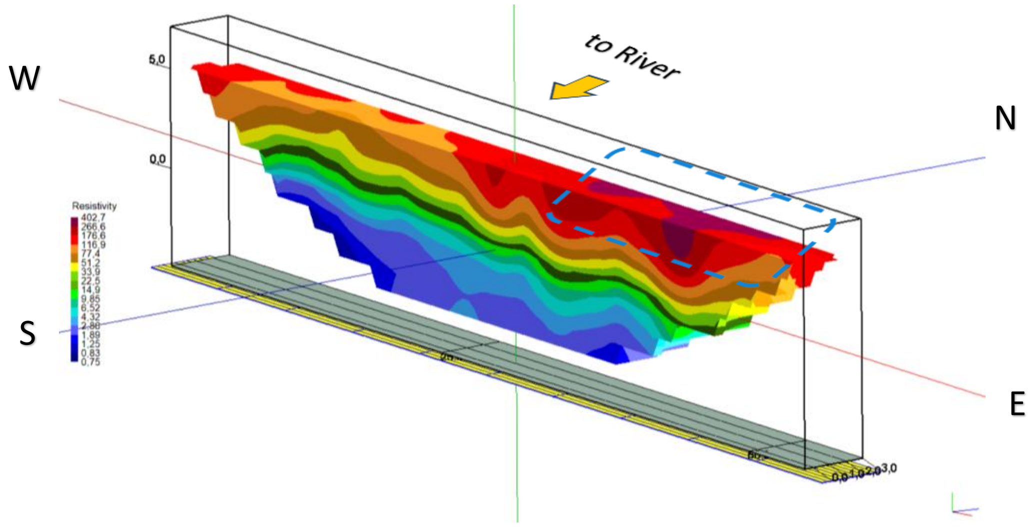


Figure 7. Results of 3D Geoelectricity

From the test results (**Figure 7**), it is evident that there is soil movement towards the river, indicating the shifting of material on the main road towards the slope. However, no cracks or fractures were found beneath the main road during the testing.

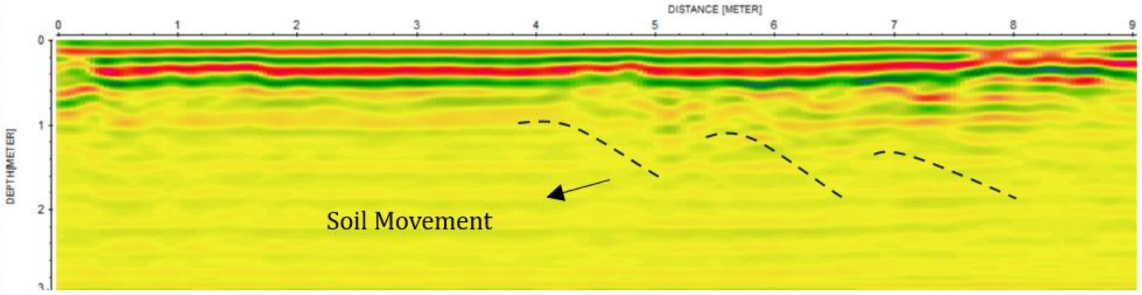


Figure 8. Cross-Sectional Road Radargram.

From the radargram (**Figure 8**), there is evidence of soil movement (half of the road lane) towards the river. However, similar to the geoelectric testing, there is no visible formation of cracks within the soil.

RESEARCH ANALYSIS

Back analysis is conducted by varying several conditions and values of soil parameters, including:

1) Soil Layers

The road structure consists of asphalt pavement (surface) with a thickness of 20 cm, upper base layer: Class A aggregate (Base) with a thickness of 30 cm, lower base layer: Class B aggregate (Sub Base) with a thickness of 40 cm, embankment with a thickness of 65 cm, and subgrade soil. The subgrade soil is divided into three layers with thicknesses of 5.6 m, 5.5 m, and 9.5 m, respectively. The thickness of the first

subgrade layer is not reduced by the embankment thickness. In the modeling, the asphalt pavement is not included but is still considered part of the load.
The model used in Plaxis for soil layers is differentiated only by the use of embankment material or not. This is done because there is no separator between the embankment material and the subgrade soil, which can lead to intermixing, considering that the subgrade soil is soft, and the embankment material is assumed not to exist. The modeling related to soil layers results in 2 variations of models.

2) Soil Model

The subgrade soil model uses the Mohr-Coulomb model because this model is very suitable for stability analysis. As asphalt is not modeled in this analysis, the load acting on the roadbed will be directly received by the foundation layer. Therefore, a soil model with stiffness is required, and the linear elastic hardening soil model is used. The modeling related to the soil model results in 2 variations of models.

3) Effective Cohesion (c')

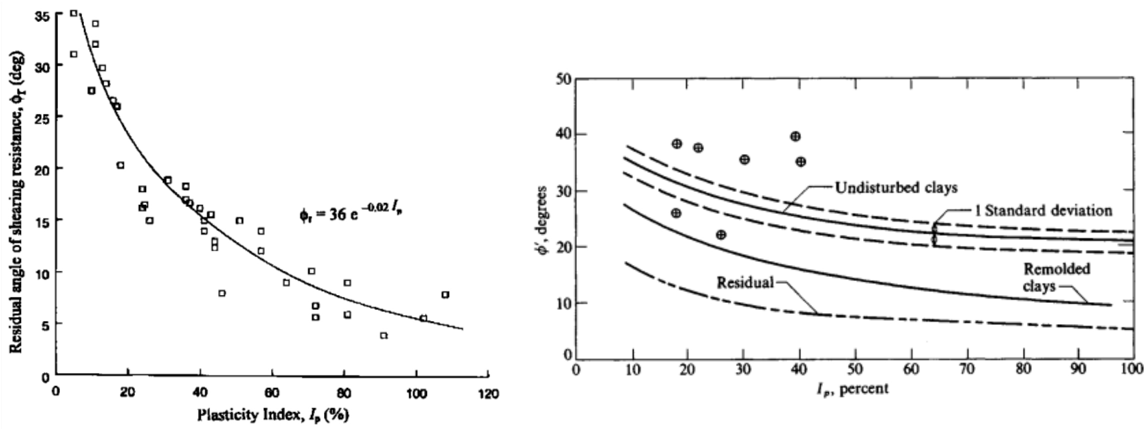
The effective cohesion value is based on the results of direct shear testing, direct shear testing corrections, and the correlation of cu values by Salgado (2008). The modeling related to the effective cohesion value results in 3 variations of values.

Stroud (1975) developed a correlation for clayey soils concerning the Standard Penetration Test (SPT) values that yield the undrained cohesion (c_u). This correlation was modified by Salgado (2008) due to adjustments made for the SPT energy ratio.

$$\frac{c_u}{P_a} = \alpha' N_{60} \qquad \ldots (1)$$

4) Effective Internal Angle Friction (φ')

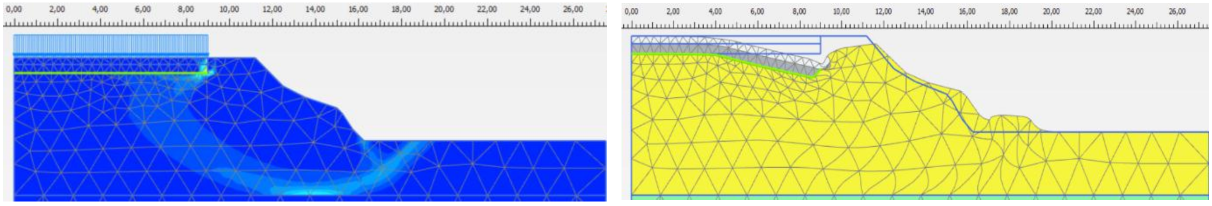
The effective internal friction angle is based on the assumption that the clay soil type has φ' = 0 and the correlation provided by Bovis (1978) and Bowles (1996). The modeling related to the effective internal friction angle results in 3 variations of values.



(a) Bovis (1978) (b) Bowles (1996)

Figure 9. The Correlation between the Internal Angle Friction With I_p value

From the four variations mentioned above, several slope stability models were obtained as shown in **Table 2**. The model that best meets the criteria is Model 4. The results of Model 4 align with the Georadar, where soil movement was detected at a crosswise distance of 4 - 9 m (**Figure 8**). Additionally, the deformations produced by the modeling correspond to those observed in the field (**Figure 10**). Consequently, this model can be employed for analyzing the influence of river water level fluctuations, with soil parameters inputted into the Plaxis program as outlined in **Table 3**.



(a) Sliding Plan (b) Deformation

Figure 10. Results of Plaxis Analysis "Model 4"

Table 2. Variations in Slope Stability Modelling

No	Modeling	Safety Factor				Deformation	Sliding Plan	Mechanical Properties	
		High WL	Low WL	Rapid 7 days	Rapid 30 days			c'	φ'
1	Model 1	Collapse	Collapse	Collapse	Collapse	Not Suitable	Not Suitable	Salgado (2008)	φ'=0
2	Model 2	1,188	Collapse	Collapse	Collapse	Not Suitable	Not Suitable	Salgado (2008)	Bowles (1996)
3	Model 3	1,933	1,589	1,276	1,277	Not Suitable	Not Suitable	Salgado (2008)	Bovis (1978)
4	Model 4	1,750	1,476	1,179	1,172	Suitable	Suitable	Direct Shear	Direct Shear
5	Model 5	1,793	1,504	1,207	1,201	Suitable	Suitable	Direct Shear Correction	Direct Shear Correction
6	Model 6	Collapse	Collapse	Collapse	Collapse	Not Suitable	Not Suitable	Salgado (2008)	φ'=0
7	Model 7	1,214	Collapse	Collapse	Collapse	Not Suitable	Not Suitable	Salgado (2008)	Bowles (1996)
8	Model 8	1,961	1,593	1,299	1,299	Not Suitable	Not Suitable	Salgado (2008)	Bovis (1978)
9	Model 9	1,833	1,476	1,220	1,220	Not Suitable	Not Suitable	Direct Shear	Direct Shear
10	Model 10	1,873	1,506	1,247	1,247	Not Suitable	Not Suitable	Direct Shear Correction	Direct Shear Correction
11	Model 11	Collapse	Collapse	Collapse	Collapse	Not Suitable	Not Suitable	Salgado (2008)	φ'=0
12	Model 12	1,241	Collapse	Collapse	Collapse	Not Suitable	Not Suitable	Salgado (2008)	Bowles (1996)
13	Model 13	1,976	1,624	1,292	1,293	Not Suitable	Not Suitable	Salgado (2008)	Bovis (1978)
14	Model 14	1,820	1,492	1,215	1,209	Not Suitable	Not Suitable	Direct Shear	Direct Shear
15	Model 15	1,86	1,523	1,239	1,236	Not Suitable	Not Suitable	Direct Shear Correction	Direct Shear Correction
16	Model 16	Collapse	Collapse	Collapse	Collapse	Not Suitable	Not Suitable	Salgado (2008)	φ'=0
17	Model 17	1,243	Collapse	Collapse	Collapse	Not Suitable	Not Suitable	Salgado (2008)	Bowles (1996)
18	Model 18	1,987	1,614	1,305	1,305	Not Suitable	Not Suitable	Salgado (2008)	Bovis (1978)
19	Model 19	1,845	1,484	1,224	1,224	Not Suitable	Not Suitable	Direct Shear	Direct Shear
20	Model 20	1886	1,514	1,251	1,253	Not Suitable	Not Suitable	Direct Shear Correction	Direct Shear Correction

Table 3. Input Soil Parameters Into The Plaxis Program

No.	**Soil Parameters**	**Symbol**	**Unit**	**Soil Layer**				
				Subgrade 1	**Subgrade 2**	**Subgrade 3**	**Subbase**	**Base**
1	Soil Type	-	-	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Hardening Soil	Hardening Soil
2	Drainage Type	-	-	Undrained A	Undrained A	Undrained A	Drained	Drained
3	Dry Unit Weight	γ_{unsat}	kN/m^3	12,77	10,48	8,35	20,00	20,00
4	Unit Weight of Soil	γ_{sat}	kN/m^3	17,85	16,49	15,28	22,00	22,00
5	Elastic Modulus	E	kN/m^2	11.634	15.101	19.050	150.000	150.000
6	Poisson's Ratio	ν	-	0,25	0,25	0,25	0,35	0,35
7	Cohesion	c'	kN/m^2	11,40	11,50	13,90	0	0
8	Internal Angle Friction	φ'	^{0}	9,87	11,24	13,95	37,00	37,00
9	Dilatancy angle	ψ	^{0}	0	0	0	7,00	7,00
10	Soil Classification	-	-	Fine	Fine	Fine	Coarse	Coarse
11	Particles $< 2\mu m$	–	%	89,60	72,44	90,06	10,00	10,00
12	Particles $2\mu m$ - $50\mu m$	–	%	6,88	13,76	6,59	13,00	13,00
13	Permeability	k	m/s	8,64E-06	8,64E-06	8,64E-06	8,64	8,64

From the analysis results (**Figure 11**), it is evident that the fluctuations in river water level significantly impact the slope stability factor. The safety factor (SF) initially at 1.751

(high water level) decreases to 1.476 during low water levels. However, the most critical condition occurs during the transition between these two states, specifically during the rapid drawdown of the river water level. The analysis of rapid drawdown reveals the lowest safety factor recorded at SF=1.172. This condition is crucial in identifying factors or causes of road damage at the research site, especially when the water level decreases abruptly.
Furthermore, the analysis indicates that the longer the rapid drawdown persists, the lower the safety factor becomes. However, this decrease is not highly significant, with a difference of only 1.35%, and the safety factor stabilizes after the 30th day. Despite a significant decrease in the safety factor during the rapid drawdown, the slope remains in a safe condition (SF>1), indicating that there is no landslide. This suggests that there are other factors contributing to the critical state of the slope. In this case, the rapid drawdown occurs on a weekly basis. This aligns with Craig's (1991) assertion that in soils with low permeability, the measured drawdown period on a weekly timescale can be considered "sudden" concerning dissipation time. Additionally, changes in pore water pressure can be assumed to occur under undrained conditions during this rapid drawdown period.

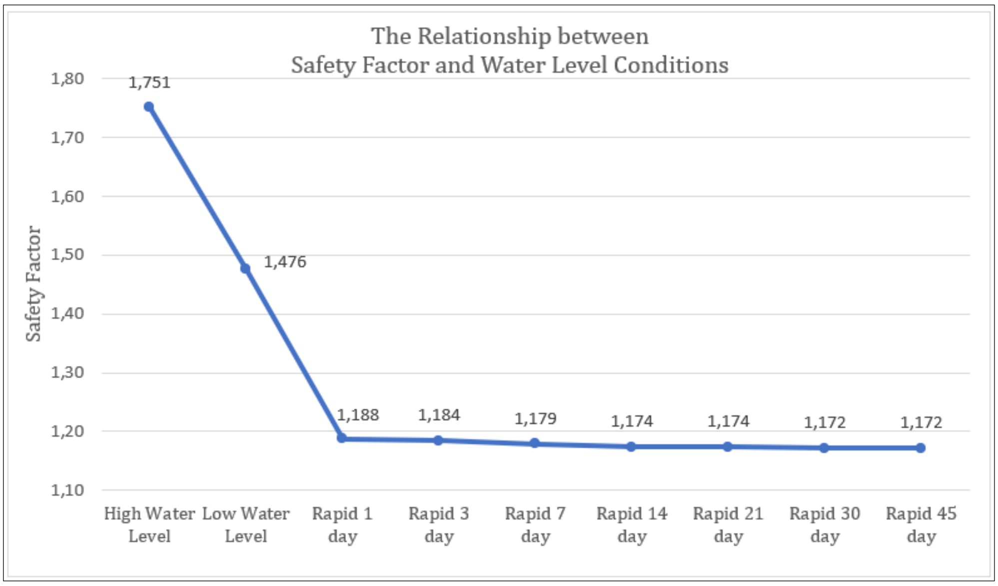
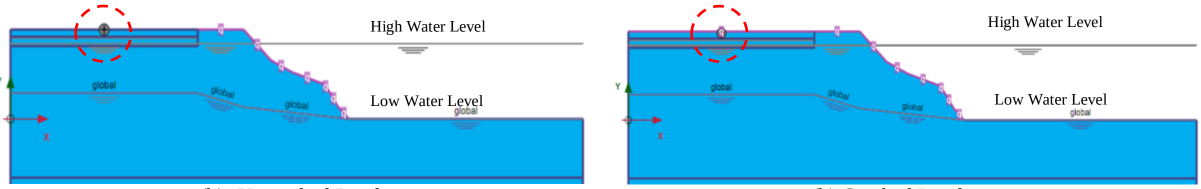


Figure 11. The Relationship of Stability between Safety Factor and Water Level Conditions

The stability analysis was initially conducted considering the influence of river water level fluctuations. Subsequently, the analysis was revisited by incorporating the effect of rainfall. The influence of rainfall applied according to the data in **Table 1** is implemented using the maximum rainfall during the occurrence of related water level conditions. Specifically, for rapid drawdown conditions with a duration of 3 to 45 days, the average rainfall during the rapid drawdown (in May and June) is utilized. As mentioned earlier, a variation in rainfall will be explored to observe the stability behavior of the road embankment. The chosen range of rainfall variations is based on the minimum to maximum rainfall values recorded over the past 10 years.

Two models were employed in this analysis. The first model assumes that the road does not have any cracks, preventing rainwater from infiltrating beneath the road embankment. In contrast, the second model considers the presence of cracks in the road, allowing water to penetrate through the road embankment (**Figure 12**).



(b) Uncracked Road (b) Cracked Road

Figure 12. Surface Affected by Rainwater

The analysis results indicate that the road with cracks has a lower safety factor compared to the road without cracks (**Figure 13**). This is due to the larger affected area by rainwater infiltration in the cracked road compared to the road without cracks. Similar to the influence of river water level fluctuations, rapid drawdown remains the determining condition with the lowest safety factor. Additionally, as the duration of rapid drawdown increases, the safety factor decreases. However, this decline is also not highly significant, with a difference of 2.12%, and the decrease in the safety factor stabilizes after the 21st day.

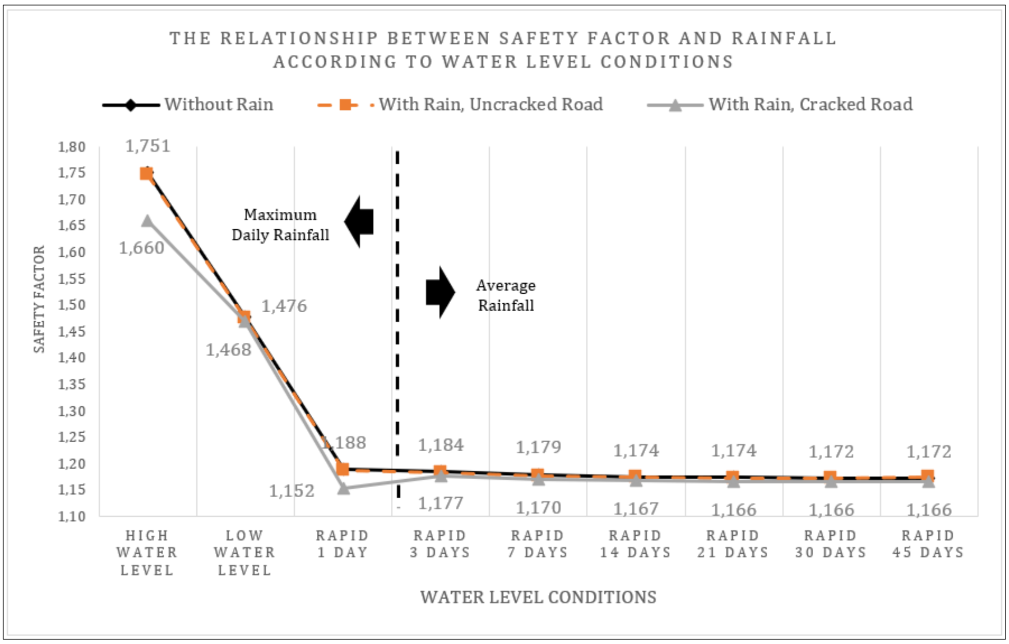
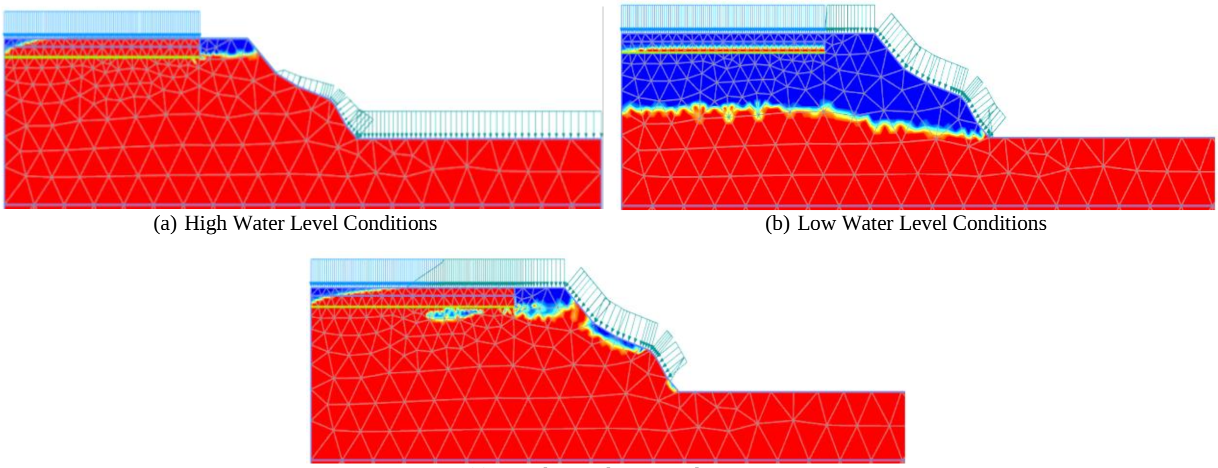


Figure 13. The Relationship between Safety Factor and Water Level Conditions with/without Rainfall Influence

From the analysis results, it is evident that the influence of rainfall is not highly significant in affecting the slope stability. The safety factor during high water levels, initially SF=1.751, decreases to SF=1.660 (a difference of 5.20%). During low water levels, SF changes from 1.476 to 1.468 (a difference of 0.54%), and during rapid drawdown, SF decreases from 1.188 to 1.152 (a difference of 3.03%). Among these three conditions, the high water level condition is the most affected by rainfall, showing the largest decrease in the safety factor. This is attributed to the soil conditions, which become nearly saturated, reducing shear stress across all soil layers (on the slip surface), and an additional load is imposed due to rainfall. However, despite the significant impact, this condition still maintains a high safety factor due to the resistance provided by the river water (**Figure 14**).



(a) High Water Level Conditions (b) Low Water Level Conditions

(c) Rapid Drawdown Conditions

Figure 14. Soil Moisture Content Due to Rainfall Influence

Despite a significant decrease in the safety factor during rapid drawdown with the influence of rainfall, the slope remains in a stable condition (SF>1), indicating that the rainfall does not render the slope critical. The combined influence of river water level fluctuations and rainfall results in each water level condition having a linear relationship with the decrease in the safety factor. This allows for the prediction of safety factors, as illustrated in **Figure 15**.

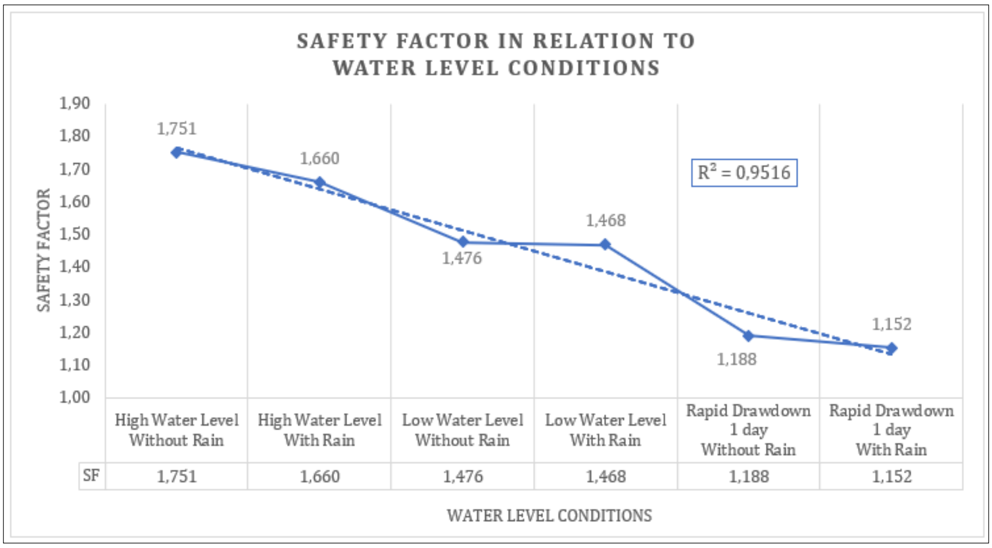


Figure 15. Reduction in Safety Factor Due to Water Level Conditions

The analysis also incorporates variations in rainfall. This is valuable in providing an overview of slope stability under different rainfall scenarios. Additionally, it's worth noting that the obtained maximum rainfall values may not fully represent the actual maximum rainfall, as data on maximum rainfall is often not fully recorded due to limitations in the measuring instruments' maximum capacity. From the analysis of the impact of rainfall variations (**Figure 16** and **Figure 17**), it can be concluded that rainfall has a limited effect on slope stability, and it is insufficient to make the slope conditions critical in the Trenggguli-Kudus section. This is evident from the small decrease in safety factors under each condition. The maximum daily rainfall has a maximum impact of 5.20% on stability, while the maximum average daily rainfall has a maximum impact of 2.12%.

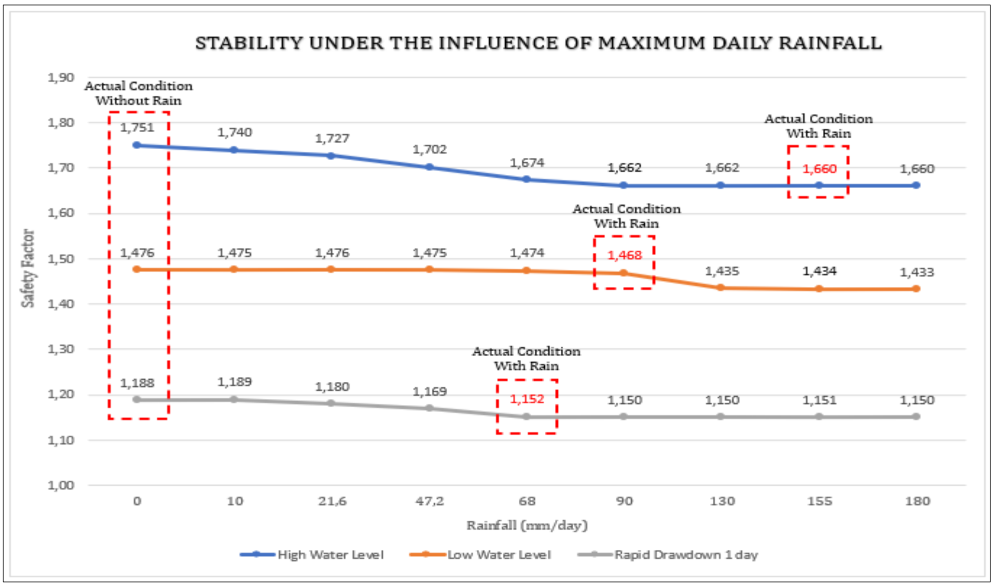


Figure 16. Stability under the Influence of Maximum Daily Rainfall

Figure 16 also demonstrates that, during high water level conditions, rainfall starts to exhibit less influence at a rainfall intensity of 90 mm/day. For low water level conditions, the impact diminishes at a rainfall intensity of 130 mm/day. Meanwhile, during rapid drawdown, the influence of rainfall becomes less pronounced at a rainfall intensity of 68 mm/day.

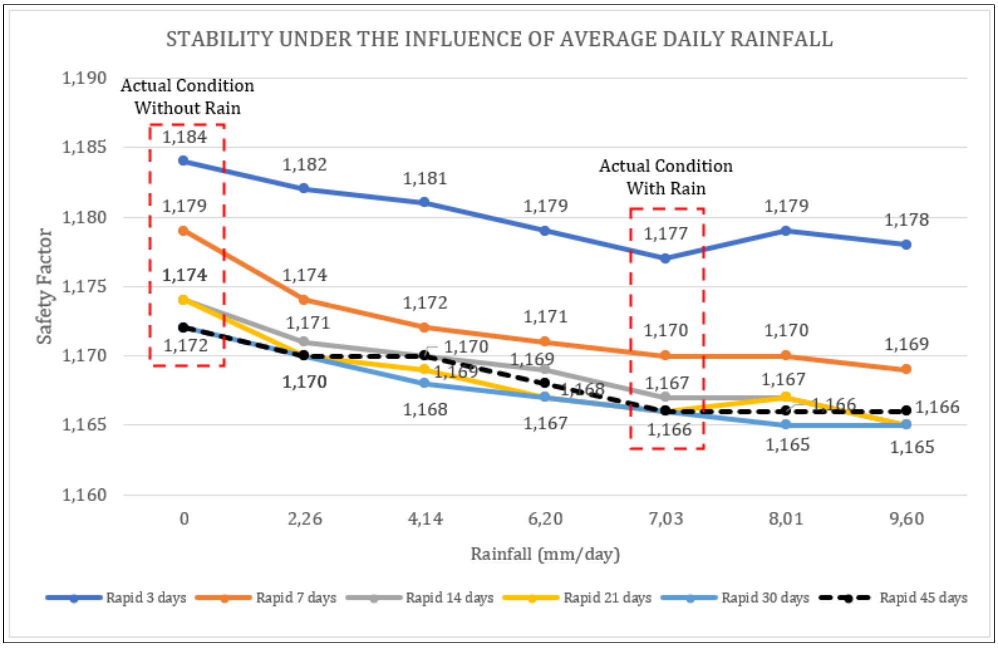


Figure 17. Stability under the Influence of Average Daily Rainfall

CONCLUSIONS

This paper assesses the stability of the road structure on the Trengguli – Kudus section concerning changes in safety factors due to fluctuations in river water levels and the influence of rainfall on the road surface, considering both cracked and non-cracked road conditions. Additionally, geophysical testing is conducted to obtain an understanding of the subgrade conditions beneath the road pavement caused by surface cracks.

Based on the calculation and testing results, it can be concluded that the stability of the road structure is significantly affected by fluctuations in river water levels. The safety factor, initially SF=1.751 (during high water levels), decreases to SF=1.476 (during low water levels). However, the most critical condition occurs during the transition between these two states, specifically during the rapid drawdown of the river water level. The analysis of rapid drawdown reveals the lowest safety factor, with a value of SF=1.172.

From the geophysical testing, it was found that the soil condition at the research site is experiencing movement towards the slope. This is evident from the geoelectric testing results, which show the composition of road materials emerging at the road's edge. However, this testing could not indicate the presence of sliding planes or cracks beneath the road due to technical issues that required altering the testing path and the testing not being conducted during the rainy season. On the other hand, the radargram results (from georadar testing) indicate significant deformation in the area near the slope. This is evident between the transverse distances of 4 to 9 meters, where changes in color and line shapes are observed. However, during this testing, no evidence of gaps or voids beneath these cracks was found. This is confirmed by the absence of intermittent lines on the radargram extending from the surface into the soil.

For the analysis of the impact of rainfall and its correlation with the results of geophysical testing, rainwater is simulated to enter the road surface through the cracks. From this analysis, it is evident that rainfall affects the maximum safety factor by 5.2%, and this reduction occurs during high water levels (which are not the determining conditions). The lowest safety factor occurs during rapid drawdown, SF=1.152 (with a difference of 1.71% from the influence of river water level fluctuations). Therefore, it can be concluded that the impact of rainfall has a minimal effect on the stability of the road structure.

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